USDA United States Department of Agriculture

Foundational Literature for Moving Native Plant Materials in Changing Climates

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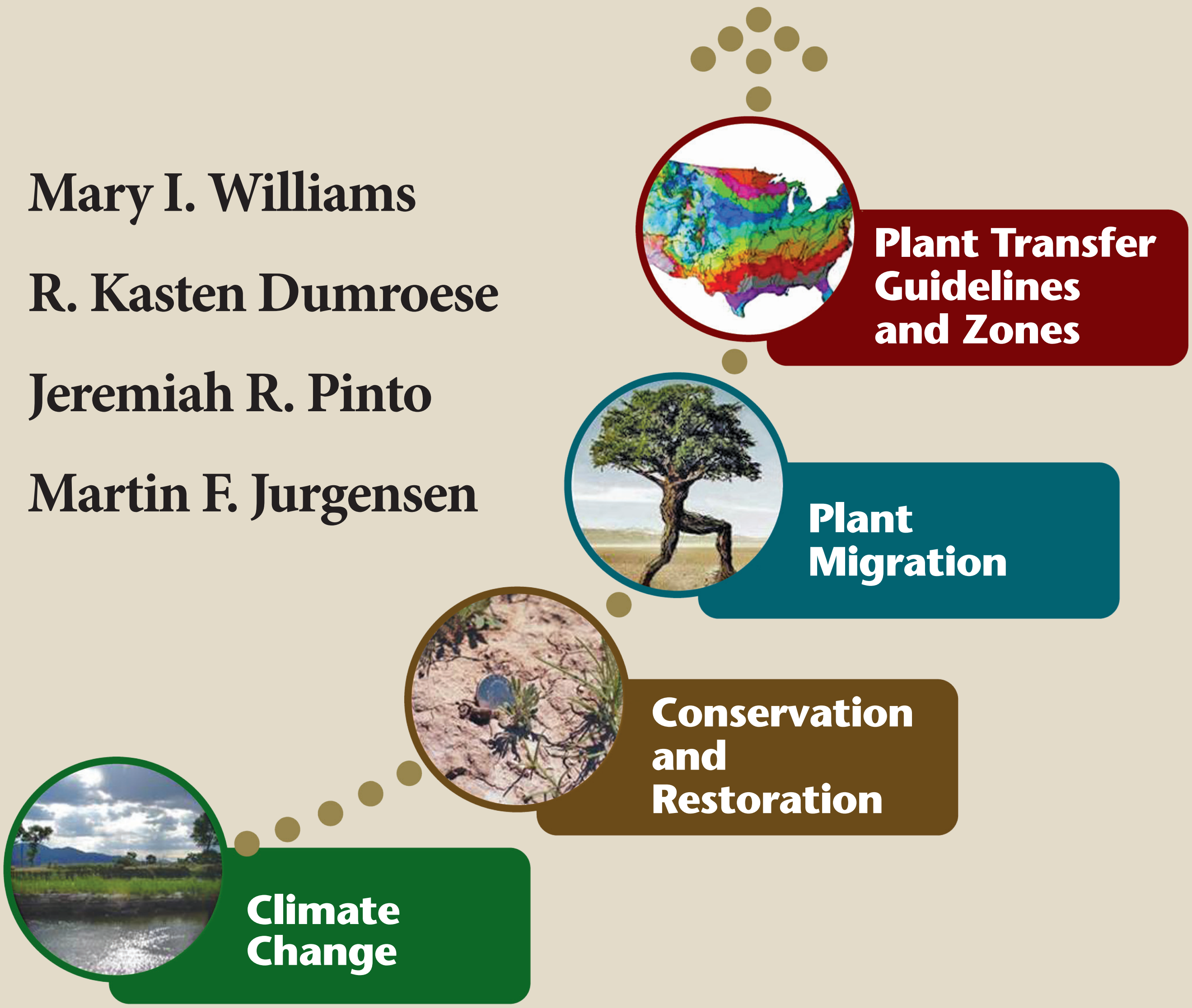

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Foundational Literature for Moving Native Plant Materials in Changing Climates

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ABSTRACT

Seed transfer guidelines and zones are used to manage the movement of plant materials, but by the end of the century many landscapes across the globe will have climates that are incompatible with current vegetation. The mismatch in rates between climate change and plant migration and adaptation will pose significant challenges for natural resource managers, especially when scientific information often lags behind the demand for management actions. We developed a bibliography to reflect the growing interest in assisted migration, the intentional movement of plant materials in response to climate change, and to provide a central foundation for collaboration in generating research questions, conducting studies, transferring and acquiring data, expanding studies to key species and geographic regions, and guiding native plant transfer in changing climates. The bibliography contains literature through 15 March 2015 on plant transfer guidelines as related to climate change, restoration and conservation, and adaptation strategies, such as assisted migration. References are arranged in four chapters: Climate Change, Conservation and Restoration, Migration, and Transfer Guidelines and Zones. Chapters are further divided into sections: General (editorials, reviews, summaries, surveys, and trends), Research (common garden studies, genecology research, provenance tests, range shifts), Strategies (adaptation options, decision support, frameworks, and policies) and Resources (manuals, models, tools, and websites).

Keywords: assisted colonization, assisted migration, bibliography, conservation, forestry, land management, managed relocation, restoration

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Cover images: Climate change and conservation and restoration, Mary I. Williams. Plant migration, UNK. Plant transfer guidelines and zones, USDA Forest Service.

Table of Contents

Introduction

In North America, tree populations are lagging behind their optimal climate niche (415). In other words, some forests are not keeping pace with contemporary changes in climate (540) and by the end of this century, many landscapes in the United States will have climates that are incompatible with current vegetation (497) and similar scenarios are possible for Europe (83). Climate projections indicate that trees must migrate more than 3,000 m per year to avoid maladaptation, extirpation, and/or extinction, a rate far exceeding their observed rates of less than 500 m per year (346; 383). The disparity in rates between climate change and plant migration and adaptation will pose significant challenges for natural resource managers, requiring them to consider a broad range of management options, including assisted migration, defined as the intentional movement of plant materials in response to climate change.

The practice of restricting native plant movement to environments similar to their source has a long history in natural resource management, especially in forestry (596; 851). General transfer guidelines developed by the U.S. Department of Agriculture (USDA) have since improved for most commercially important native tree species and a few other native plants, but seed transfer research will need to factor in climate change. Plant materials from current or static planting zones will be growing in unfavorable conditions by the end of this century. Managers may need to assist plant species in their migration to new locations. It is difficult, however, to stay up-to-date on the latest research, policies, and terminologies. To alleviate this challenge, we compiled a bibliography that is focused on climate change, migration, and native plant transfer guidelines. It provides a central location for native plant transfer research and reflects the growing interest in assisted migration. The bibliography is commensurate with several goals set by the USDA, the Forest Service, and the Rocky Mountain Research Station (Appendix A, this section), principally the acquisition of research to "ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change" (USDA 2014, http://www.usda.gov/documents/usda-strategic-plan-fy-2014-2018.pdf).

METHODOLOGY

To identify main features of the native plant transfer literature, we searched BioOne, Google Scholar, Science Citation Index, ScienceDirect, and Treesearch without date restrictions. We accessed these databases between 6 January 2012 and 15 March 2015 using 13 search terms in 252 unique search strings (fig. 1).

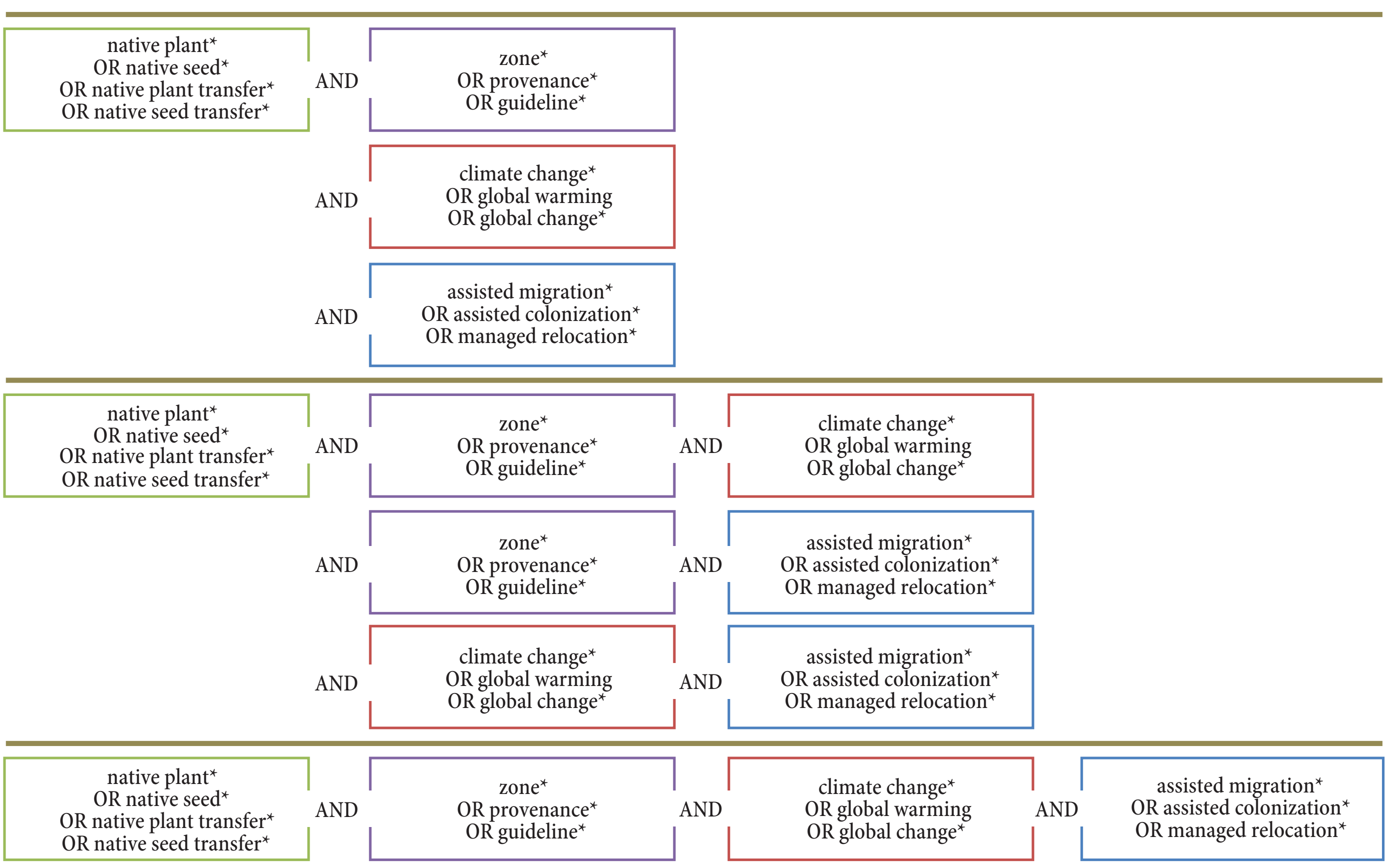
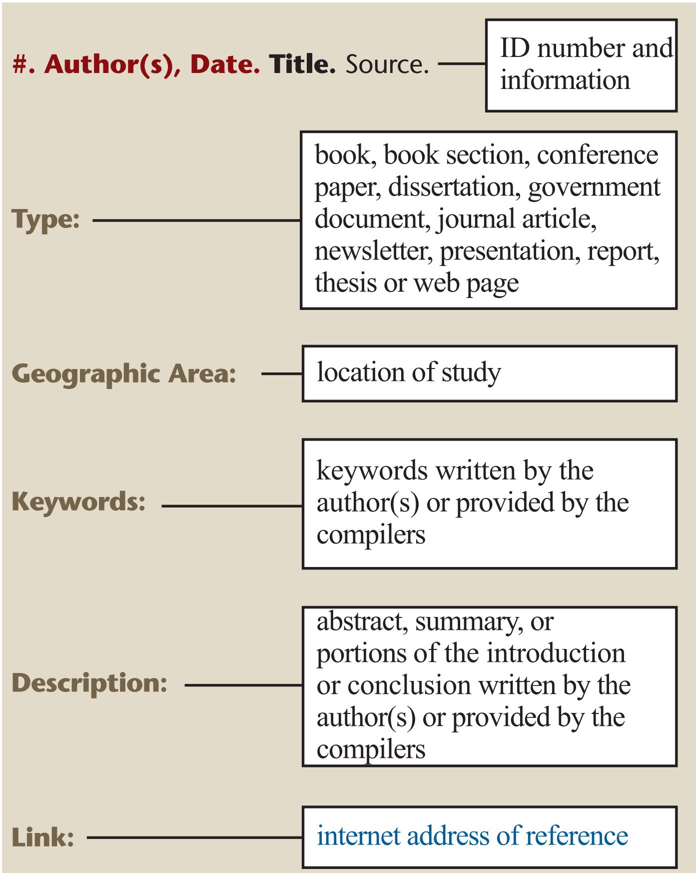


Figure 1. Search terms and strings used to locate references for the bibliography. Terms were searched in combinations using "AND" and "OR" statements. Asterisks indicate partial search words for which multiple derivations may be relevant, for example, plant, plants, and planting.

Figure 2. Each reference has a unique identification number and contains the following:



We focused on references from North America, but considered work having a global perspective and those providing novel approaches regardless of geographic location. The database and cross-reference searches produced 877 references, of which the main focus is on plant species and populations. We reviewed the author, title, publication, date, and full text as needed and organized each reference in EndNote. References are indexed by author(s) and include date, geographic area, keywords, abstract (summary), and URLs, if available (fig. 2). When keywords were not provided in the original reference, we, the compilers of this bibliography, added them. When an abstract was not written by the author(s) but an introduction or conclusion that could serve as an abstract (summary) was, the later was used and thusly noted. In some cases when no suitable summary was available, we generated one. Any portions (keywords or summary) added by the compilers are so noted. Most references are peer-reviewed articles from journals (>70%) and the remaining are government documents, books, reports, graduate theses, and grey literature, such as newsletters, websites, and presentations. This bibliography is not an inclusive list; we recognize that this is a current and evolving topic. It is our intent, however, as resources permit, for the online version of this bibliography to keep pace with the growing body of literature on the topic (http://www.rngr.net/publications/assisted-migration).

SCOPE

The bibliography contains literature that has bearing on native plant transfer and includes references about climate change (Chapter 1), conservation and restoration (Chapter 2), migration (Chapter 3), and transfer guidelines and zones (Chapter 4). It includes work from as early as 1922 by Göte Turesson (611; 784) who coined the term genecology—the study of species in relation to their environment—that provided a foundation for researchers to explore genetic × environmental relationships in plants and develop seed transfer guidelines for many tree species and populations (596). The primary focus is on native plants, but

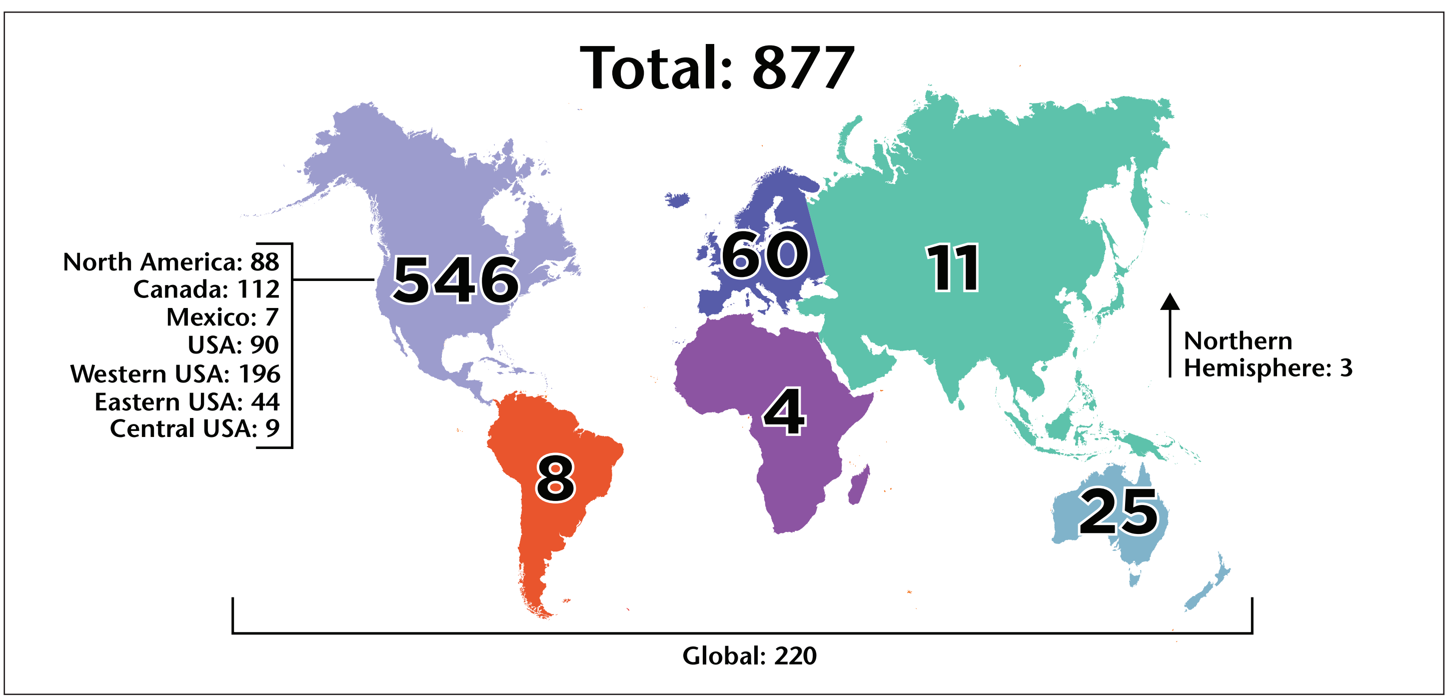


Figure 3. Geographic distribution of references included in this bibliography.

we include some references about other organisms, such as the well-cited article by Griffith and others (418) about animal translocations and articles by Parmesan and others on butterfly populations (483) and changes in plant and animal distributions due to climate change (102; 481; 482). Most references cover work from North America (62%) and a few are from Africa, Asia, Australia, Europe, and South America. Of the references from North America, 62% concern the U.S., 21% represent Canada, and a few (<2%) are from Mexico (fig. 3).

Chapters are divided into sections: **General** (editorials, reviews, summaries, surveys, and trends), **Research** (common garden studies, genecology research, provenance tests, and range shifts), **Strategies** (adaptation options, decision support, frameworks, and policies), and **Resources** (manuals, models, tools, and websites). References are alphabetized by author within each section. Users can search for topics and words of interest using the 'Find' and/or 'Advanced Search' tools in Adobe Reader (Ctrl+F, Edit > Find/Advanced Search, or right-click the document and choose 'Find' from the pop-up menu). In the succeeding paragraphs, we provide a brief overview of each chapter noting the more prominent references.

Chapter 1 includes references about climate-induced risks to plants such as drought (37) and insects (45), changes in phenology due to rising temperatures (102; 481), widespread tree mortality (108; 135), and maladaptation in tree populations (117). References also cover historical plant distributions (91; 92; 131) and novel ecosystems (73; 132). Government reports about climate change impacts and risks to forests are also included (16), as well as government policies or action plans (168; 171; 202; 876) and reviews and surveys of adaptation strategies (12; 21; 26; 121; 151). Modeling programs designed to help understand climate change impacts, such as the System for Assessing Vulnerability of Species (SAVS) (3; 206; 207), the Forest Tree Genetic Risk Assessment System (ForGRAS) (208; 211; 212), MaxENT for species habitat modeling (210), and BioSIM to forecast pest events (214) can be found in the Resources section of Chapter 1.

In **Chapter 2**, we provide references about growing native plants (328; 329), selecting the right plant material (223; 298), restoring ecosystems (323; 332; 337), producing and storing seed (240; 247; 272; 330), and conserving sensitive plant species, such as five-needle white pines (241; 283; 300; 319). We include theoretical references, such as those discussing paradigm shifts in natural resource conservation and restoration (219; 220; 228; 229; 292) and the value of genetic research and conservation in planning for climate change (226; 227; 233; 266; 291; 305; 322). Strategies and programs for seed storage (290; 325), native plant materials development (320; 321), and genomics (294; 307; 312) are also included in this chapter.

We list more than 240 references concerning both natural and human-assisted migration in **Chapter 3**. It includes studies about past vegetation (341; 427; 538), range shifts (423; 449; 483), migration rates (345; 365; 428; 453), migration capacity (421; 433; 501; 539; 540), evolutionary and adaptive responses (346; 384; 510), and model projections of future plant distributions (448; 497). Assisted migration is a controversial and popular topic in natural resource science and management laden with ethical, ecological, and political concerns (339; 340; 342; 355; 358; 359; 371; 475). In regards to assisted migration, we include reviews (354; 388; 466; 577), justifications (158; 363), policies (550; 555), decision frameworks (465; 549; 559), guidelines on implementation (416; 568), and strategies to facilitate migration, such as using species and population genetic information to guide movement (382; 446; 494; 558). References also address reintroduction (385; 419; 459), and assisted migration and transfer of species and populations in Canada (387; 454; 458; 525), the U.S. (341; 512; 514; 537), China (451), and Europe (381; 431).

Native plant transfer guidelines and zones are located in **Chapter 4**, beginning with references that discuss the development and importance of seed transfer guidelines in sustaining ecosystem services (302; 584; 588; 596; 597; 599; 611; 612; 613; 615; 784). Many (>185) references cover genetic × environmental variation in plant species and populations for tree improvement and reforestation (630; 635; 738; 744; 752; 838), and delineating transfer zones for future climates (507; 676; 687; 757; 799). We provide references on how to select appropriate seed sources and determine transfer zones (804; 806; 812; 813; 817; 821; 824), including seed zone mapping tools with climate forecasting (830; 845; 853; 854; 877). Seed transfer guidelines and zones including maps are located in the Resources section, and most guidelines are for tree species, such as Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) (633; 862), but there are provisional guidelines for native plants (834). Genetic studies and development of seed transfer guidelines for non-commercial plant species have increased over the last 15 years (623; 647; 652; 682; 693; 714; 759; 850; 865).

APPLICATION

Climate change poses a significant challenge for restoring, sustaining, and enhancing natural resources. Even in a time where information is easy to access and share, it is difficult to keep up-to-date of all the latest developments, especially with respect to climate change research, restoration practices, assisted migration, and genetic studies. This bibliography can provide a central foundation for scientists, land managers, and policymakers to generate research questions, conduct studies and literary syntheses, transfer and acquire data, identify knowledge gaps, and guide native plant transfer in a manner to curtail significant social, economic, and ecological losses associated with impacts from a rapidly changing climate. This research has transfered and will continue to transfer, current information to scientists, land managers, policymakers, and the general public about climate change and adaptive strategies pertaining to native plant species toward maintaining resilient, functional ecosystems across the landscape.

Appendix A

USDA, Forest Service, and Rocky Mountain Research Station strategic goals, elements, and research priorities with bulleted points showing how the bibliography supports this work.

USDA Strategic Plan, Goals 2014–2018

http://www.usda.gov/documents/usda-strategic-plan-fy-2014-2018.pdf

1 – Assist rural communities to create prosperity so they are self-sustaining, repopulating, and economically thriving

- Is a source of practical forestry and agricultural guidelines that can be used to improve and expand ecosystem services and products for rural economies
- Provides technical information to support current and future forestry and agricultural markets that are important to rural communities

2 – Ensure national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources

- Is a source of past and current ecological research that can be used to inform climate change adaptation strategies, such as assisted migration
- Includes research that can be used to evaluate forest, grassland, and shrubland health

U.S. Forest Service Strategic Plan, Goals 2015–2020

http://www.fs.fed.us/strategicplan/

1 – Sustain Our Nation's Forests and Grasslands

- Serves as an integration of work aimed at improving health and resilience of forests, grasslands, and shrublands
- Provides technical information, such as vulnerability assessment reports, that can be used to foster resilient and adaptive ecosystems to mitigate climate change
- Includes research on the conservation and restoration of native plant species, including species with economic value
- Includes methods, technologies, and strategies for addressing disturbance

2 – Deliver Benefits to the Public

- Provides information that can be used by the public to make decisions about managing forests, grasslands, and shrublands
- Is a source of technical information for maintaining and sustaining forestry and agricultural markets and public space
- Provides information that can be used to develop partnerships and educational material

3 – Apply Knowledge Globally

- Serves as a literary resource to identify needs and set priorities for forests, grasslands, and shrublands
- Exists as a public document and is available on the Internet
- Includes tools for evaluating management practices and provides appropriate information for decisionmakers

U.S. Forest Service Research and Development Research Topics

http://www.fs.fed.us/research/research-topics/

1 – Invasive Species

- Includes research that can be used to help reduce and minimize the introduction of invasive species in management options, such as assisted migration
- Contains literature about the impact of insects and plant pathogens on forests and wood products

2 – Inventory, Monitoring and Analysis

- Provides data, reports, maps, and other resources to land owners and managers, policy makers, researchers, practitioners, and other interest groups
- Includes research on the current status and trends of forests, grasslands, and shrublands, including threats and management options

3 – Outdoor Recreation

- Provides reports about forest systems and societal benefits
- Contains management options to sustain ecosystem services in a changing climate, such as assisted migration

4 – Resource Management and Use

- Provides research and technologies to help sustain the ecological and economical value of forests, grasslands, and shrublands
- Contains information that can be used by communities, land owners, and practitioners to maintain resources and plan for climate change

6 – Wildland Fire and Fuel

- Includes technical guidelines for restoring lands after wildfire and other disturbances
- Provides frameworks for selecting appropriate plant materials

7 – Wildlife and Fish

- Includes research about climate change impacts on wildlife and fish
- Contains several studies about animal translocations and assisted migration of animal species

U.S. Forest Service Global Change Research Strategy, Research Elements 2009–2019

http://www.fs.fed.us/climatechange/documents/global-change-strategy.pdf

1 – Research to enhance ecosystem sustainability

- Includes research on ecosystem health and sustainability, including assessments of climate change impacts on ecosystems
- Provides tools, applications, and technologies to improve management under a changing climate
- Includes genetic research that can be used to identify plant and seed sources for restoration and conservation
- Provides a way to synthesize information to enhance understanding of the changing relationships between climate and land disturbances

2 – Research to increase carbon sequestration

- Includes local, regional, and national policies and management actions for forests and wood products
- Provides studies that show how carbon pools may change under different climatic scenarios
- Is a source of guidelines and approaches that can help identify plant materials for sustaining and conserving carbon resources

3 – Research to provide decision support

- Contains tools and frameworks for managing forest, grassland, and shrubland resources in changing climates
- Provides information to increase our understanding of environmental needs by species and ecosystems
- Highlights Forest Service expertise along with other regional and international expertise about climate change and ecosystems

4 – Shared research needs—infrastructure, scientific collaboration, and science delivery

- Is a source of literature to help identify knowledge gaps, improve data coordination and sharing, and enhance climate change monitoring actions
- Shares interdisciplinary research
- Serves as a central location for literature about native plant transfer guidelines, climate change and assisted migration

Rocky Mountain Research Station Strategic Research Priorities 2014–2017

http://www.fs.fed.us/rmrs/docs/leadership-team/strategic-framework.pdf

1 – Disturbance Ecology

- Includes research that targets plant response to climate change and how to mitigate those responses
- Is a source of tools to assess, characterize, and model ecological effects of past, present, and future climate change on plant species
- Contains research to help understand the effects of land use and management actions on ecosystems, with special emphasis on native plant species

3 – Human-Landscape Interactions

- Includes management options and strategies to sustain ecosystem services in a changing climate
- Contains literature that explores social and economic drivers behind ecosystem change and services

4 – Inventory and Monitoring

- Includes several studies on plant adaptation and migration
- Contains new approaches and technologies for monitoring and analyzing ecosystems and landscapes, such as plant genomics

5 – Managing Resilient Landscapes

- Is a source of studies on plant genetic variation and gene flow
- Includes many resources for identifying, collecting, developing, testing, and producing native plant materials, including selection guidelines and transfer zones
- Contains species vulnerability assessments and tools for evaluating and predicting system resilience
- Is a source of management strategies that support conservation and restoration

6 – Species Endangerment

- Contains species vulnerability assessments and tools for evaluating and predicting species response to disturbance
- Includes species distribution models for threatened and endangered species
- Provides management options and strategies for species at risk of maladaptation or extinction, such as assisted migration or managed relocation
- Includes studies that use genetic approaches to conserve and restore endangered species

Climate Change

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

1. Anjozian LN. 2011. Checking the range for signs of climate change: in the past, present, and future. Albuquerque (NM): USDA Forest Service, Rocky Mountain Research Station, Grassland, Shrubland, and Desert Ecosystem Science Program. 8 p.

Type: Newsletter

Geographic Area: Western USA

Compilers' Keywords: grassland, shrubland, desert, RMRS, climate change, U.S. Forest Service, GSD Update

Introduction: Imagine you have access to a machine that can make particles move faster and faster until they approach the speed of light, and essentially travel through time. The machine might look like the Large Hadron Collider—the particle accelerator below ground in Switzerland—but instead of producing teeny, tiny, short-lived, exotic particles no one's ever seen before, it transports you, a person of ample curiosity, into the future. You disembark your time travel machine, look around, and though you believe you're in the same geography, things don't look quite the same. If you began your trip somewhere in the interior American West where familiar grasslands, shrublands, or deserts were found, you have reason to be perplexed. The ecosystems of the future world have changed. What does that future world look like? Scientists in the Grassland, Shrubland, and Desert Ecosystems Science Program (GSD)—a unit of the USDA Forest Service Rocky Mountain Research Station (RMRS)—are not waiting for the future to arrive to have a look—they are working on revealing the story to us now.

Link: http://www.treesearch.fs.fed.us/pubs/39154

2. Ayling R. 2012. A history of forests and climate change under the IPCC. The Forestry Chronicle 88:381-382.

Type: Journal

Geographic Area: Global

Compilers' Keywords: climate change, forest management, IPCC, migration, commentary

Introduction: The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by two United Nations agencies, the World Meteorological Organization and the UN's Environment Programme, to "assess the scientific, technical and socioeconomic information relevant for the risk of human-induced climate change." Its first assessment report in 1990 was the basis for the UN Framework Convention on Climate Change (UNFCCC). For more than twenty years the IPCC has remained the most important source of scientific, technical and socioeconomic information for the Convention. The relationship between the UNFCCC and the IPCC is regarded by the international community as a "model for interaction between science and decision makers."

3. Bagne KE, Finch DM. 2012. It works both ways: how scientists and managers join forces to conserve today's natural resources. Albuquerque (NM): USDA Forest Service, Grassland, Shrubland, and Desert Ecosystem Science Program. 7 p.

Type: Newsletter

Geographic Area: Western USA

Compilers' Keywords: native plant guidelines, conservation, management, GSD Update

Introduction: "Too many people fail to realize that real communication goes in both directions." Lee Iacocca spoke these wise words about the failings of business, but clearly there is a lesson here for management of natural resources as well. Scientists are doing research every day that improves our understanding of our valued resources. But work does not stop at simply conducting an experiment, it needs to include effective communication of results that are relevant to managers. Scientists listen closely to what managers have to say and design studies to address questions across the diverse array of issues that challenge management goals today. (Features article about native plant transfer guidelines.)

Link: http://www.treesearch.fs.fed.us/pubs/41330

4. Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F. 2012. Impacts of climate change on the future of biodiversity. Ecology Letters 15:365-377.

Type: Journal

Geographic Area: Global

Keywords: biodiversity, climate change, species extinctions

Abstract: Many studies in recent years have investigated the effects of climate change on the future of biodiversity. In this review, we first examine the different possible effects of climate change that can operate at individual, population, species, community, ecosystem and biome scales, notably showing that species can respond to climate change challenges by shifting their climatic niche along three non-exclusive axes: time (e.g. phenology), space (e.g. range) and self (e.g. physiology). Then, we present the principal specificities and caveats of the most common approaches used to estimate future biodiversity at global and sub-continental scales and we synthesize their results. Finally, we highlight several challenges for future research both in theoretical and applied realms. Overall, our review shows that current estimates are variable, depending on the method, taxonomic group, biodiversity loss metrics, spatial scales and time periods considered. Yet, the majority of models indicate alarming consequences for biodiversity, with the worst-case scenarios leading to extinction rates that would qualify as the sixth mass extinction in the history of the earth.

Link: http://www.ncbi.nlm.nih.gov/pubmed/22257223

5. Bierbaum R, Smith JB, Lee A, Blair M, Carter L, Chapin FS, Fleming P, Ruffo S, Stults M, McNeeley S, Wasley E, Verduzco L. 2012. A comprehensive review of climate adaptation in the United States: more than before, but less than needed. Mitigation and Adaptation Strategies for Global Change 18:361-406.

Type: Journal

Geographic Area: USA

Keywords: adaptation process, barriers, climate change, mainstreaming, multiple stressors, stakeholder participation, successes, case studies

Abstract: We reviewed existing and planned adaptation activities of federal, tribal, state, local governments and the private sector in the United States (U.S.) to understand what types of adaptation activities are underway across different sectors and scales throughout the country. Primary sources of review included material officially submitted for consideration in the upcoming 2013 U.S. National Climate Assessment and supplemental peer-reviewed and grey literature. Although substantial adaptation planning is occurring in various sectors, levels of government and the private sector, few measures have been implemented and even fewer have been evaluated. Most adaptation actions to date appear to be incremental changes, not the transformational changes that may be needed in certain cases to adapt to significant changes in climate. While there appear to be no one-size-fits-all adaptations, there are similarities in approaches across scales and sectors, including mainstreaming climate considerations into existing policies and plans, and pursuing no- and low-regrets strategies. Despite the positive momentum in recent years, barriers to implementation still impede action in all sectors and across scales. The most significant barriers include lack of funding, policy and institutional constraints and difficulty in anticipating climate change given the current state of information on change. However, the practice of adaptation can advance through learning by doing, stakeholder engagements (including "listening sessions") and sharing of best practices. Efforts to advance adaptation across the U.S. and globally will necessitate the reduction or elimination of barriers, the enhancement of information and best practice sharing mechanisms and the creation of comprehensive adaptation evaluation metrics.

Link: http://www.climateaccess.org/sites/default/files/Bierbaum%20et%20al_A%20comprehensive%20review%20of%20climate%20adaptation.pdf

6. Blaser J, Gregersen H. 2013. Forests in the next 300 years. Unasylva 64:61-73.

Type: Journal

Geographic Area: Global

Compilers' Keywords: climate change, range shifts, forest ecosystems

Introduction (2nd paragraph): At the global scale, the question of whether individual trees, such as those that survive to maturity is unimportant, but the overall fate of the forests of which they are a part is crucial. Forests and trees are a *renewable* resource, providing an enormous range of goods and ecosystem services. In the face of expected declines in the availability of *non-renewable* resources and massive environmental change, the fate of trees and forests in the next 200–300 years is of fundamental importance to humanity. Forests come and go, but in the last several hundred years there has been a dramatic decline. Nevertheless, there is potential to reverse this and to greatly increase the global forest resource. In this article, we consider the factors that will influence the fate of forests in the next 300 years, and predict a world that is more reliant than ever on its forests—and on its forest managers.

Link: https://www.eda.admin.ch/content/dam/deza/en/documents/Themes/resource_en_223023.pdf

7. Brown JH, Gibson AC. 1983. **Biogeography**. St. Louis (MO): C. V. Mosby. 643 p.

Type: Book

Geographic Area: Global

Compilers' Keywords: biodiversity, evolutionary processes, geography

Compilers' Summary: Biogeography (2nd edition) combines ecological and historical perspectives to show how contemporary environments, Earth history and evolutionary processes have shaped the distributions of species and the patterns of biodiversity. It illustrates general patterns and processes using examples from different groups of plants and animals from diverse habitats and geographic regions. Written primarily for use in undergraduate and graduate courses in plant and/or animal geography, the book serves as a general synthesis and reference as well.

8. Collins S, Larry E. 2007. **Caring for our natural assets: an ecosystem services perspective**. Portland (OR): USDA Forest Service, Pacific Northwest Region. General Technical Report PNW-GTR-733. 11 p.

Type: Government Document

Geographic Area: USA

Keywords: ecosystem services, ecosystem management, natural capital, climate change, human well-being

Abstract: Global attention to climate change has advanced an awareness of human impacts on the environment. Progressing more slowly is recognition of the critical link between forest ecosystems and human welfare. Forests provide a number of societal benefits or ecosystem services, such as water purification, climate and flood regulation, recreational opportunities and spiritual fulfillment. This paper examines an emerging perspective that describes ecosystems as natural assets that support human health and well-being. The perspective serves as both a conservation approach and an extension of ecosystem management, involving the connection of ecosystem services to the people who benefit, in some cases with an assigned market value. We argue that the emergence of an ecosystem services perspective is timely as public interest in the state of the environment increases and natural resource managers face the reality of rapid forest ecosystem change. Forest conservation that considers the supply and delivery of ecosystem services will enhance the health and resiliency of ecosystems, engage and serve a broader public and attract private investment and leadership in a common effort to safeguard natural systems.

Link: http://www.treesearch.fs.fed.us/pubs/31719

9. Dormann CF. 2007. **Promising the future? Global change projections of species distributions**. Basic and Applied Ecology 8:387-397.

Type: Journal

Geographic Area: Global

Keywords: climate change, conservation management, environmental change, extrapolation, prediction, spatial statistics, species distribution model

Abstract: Projections of species' distribution under global change (climatic and environmental) are of great scientific and societal relevance. They rely on a proper understanding of how environmental drivers determine species occurrence patterns. This understanding is usually derived from an analysis of the species' present distribution by statistical means (species distribution models). Projections based on species distribution models make several assumptions, (such as constancy of limiting factors, no evolutionary adaptation to drivers, global dispersal) some of which are ecologically untenable. Also, methodological issues muddy the waters (e.g. spatial autocorrelation, collinearity of drivers). Here, I review the main shortcomings of species distribution models and species distribution projections, identify limits to their use and open a perspective on how to overcome some current obstacles. As a consequence, I caution biogeographers against making projections lightheartedly and conservation ecologists and policy makers to be aware that there are several unresolved problems.

Link: http://www.biom.uni-freiburg.de/mitarbeiter/dormann/publications-dormann/Dormann2007BasicApplEcol.pdf

10. Easterling WE. 1996. **Adapting North American agriculture to climate change in review**. Agricultural and Forest Meteorology 80:1-53.

Type: Journal

Geographic Area: North America

Compilers' Keywords: climate change, agriculture, global warming, policy, genetic diversity, crop varieties, adaptation

Abstract: The adaptability of North American agriculture to climate change is assessed through a review of current literature. A baseline of North American agriculture without climate change suggests that farming faces serious challenges in the future (e.g. declining domestic demand, loss of comparative advantage, rising environmental costs). Climate change adjustments at the farm-level and in government policy, including international trade policy, are inventoried from the literature. The adaptive potential of agriculture is demonstrated historically with situations that are analogous to climate change, including the translocation of crops across natural climate gradients, the rapid introduction of new crops such as soybeans in the U.S. and canola in Canada and resource substitutions prompted by changes in prices of production inputs. A wide selection of modeling studies is reviewed, which in net, suggests several agronomic and economic adaptation strategies that are available to agriculture. Agronomic strategies include changes in crop varieties and species, timing of operations and land management including irrigation. Economic strategies include investment in new technologies, infrastructure and labor and shifts in international trade. Overall, such agronomic strategies were found to offset either partially or completely the loss of productivity caused by climate change. Economic adaptations were found to render the agricultural costs of climate change small by comparison with the overall expansion of agricultural production. New avenues of adaptive research are recommended including the formalization of the incorporation of adaptation strategies into modeling, linkage of adaptation to the terrestrial carbon cycle, anticipation of future technologies, attention to scaling from *in situ* modeling to the landscape scale, expansion of data sets and the measurement and modeling of unpriced costs. The final assessment is that climate change should not pose an insurmountable obstacle to North American agriculture. The portfolio of assets needed to adapt is large in terms of land, water, energy, genetic diversity, physical infrastructure and human resources, research capacity and information systems and political institutions and world trade—the research reviewed here gives ample evidence of the ability of agriculture to utilize such assets. In conclusion, the apparent efficiency with which North American agriculture may adapt to climate changes provides little inducement for diverting agricultural adaptation resources to efforts to slow or halt climate changes.

Link: http://www.climateknowledge.org/figures/Rood_Climate_Change_AOSS480_Documents/Easterling_North_American_Agriculture_AgricForMet_1996.pdf

11. Groffman PM, Kareiva P, Carter S, Grimm NB, Lawler JJ, Mack M, Matzek V, Tallis H. 2013. Ecosystems, biodiversity, and ecosystem services (Draft for public comment). Chapter 8. In: NCADAC Draft Climate Assessment Report. Washington (DC): U.S. Global Change Research Program. p 291-330.

Type: Government Document

Geographic Area: Global

Compilers' Keywords: climate change, ecosystems, biodiversity, ecosystem services, impacts, management, assessment

Introduction: Climate change affects the living world, including people, through changes in ecosystems, biodiversity and ecosystem services. Ecosystems entail all the living things in a particular area, as well as the non-living things with which they interact, such as air, soil, water and sunlight. Biodiversity refers to the variety of life, including the number of species, life forms, genetic types and habitats and biomes (which are characteristic groupings of plant and animal species found in a particular climate). Biodiversity and ecosystems produce a rich array of benefits that people depend on, including fisheries, drinking water, fertile soils for growing crops, climate regulation, inspiration and aesthetic and cultural values. These benefits are called "ecosystem services"—some of which, like food and fisheries, are more easily quantified than others, such as climate regulation or cultural values. Ecosystem services translate into jobs, economic growth, health and human well-being. Although ecosystems and ecosystem services are what we interact with every day, their linkage to climate change can be elusive because they are influenced by so many additional entangled factors. Ecosystem perturbations driven by climate change have direct human impacts, including reduced water supply and quality, the loss of iconic species and landscapes, distorted rhythms of nature and the potential for extreme events to overcome the regulating services of ecosystems. Even with these well-documented ecosystem impacts, it is often difficult to quantify human vulnerability that results from shifts in ecosystem processes and services. For example, although it is straightforward to predict how precipitation will change water flow; it is much harder to pinpoint which farms and cities will be at risk of running out of water, and even more difficult to say how people will be affected by the loss of a favorite fishing spot or a wildflower that no longer blooms in the spring. A better understanding of how everything from altered water flows to the loss of wildflowers matters to people may be key to managing ecosystems in a way that promotes resilience to climate change.

Link: http://ncadac.globalchange.gov/download/NCAJan11-2013-publicreviewdraft-chap8-ecosystems.pdf

12. Hajjar R, McGuigan E, Moshofsky M, Kozak RA. 2014. Opinions on strategies for forest adaptation to future climate conditions in western Canada: surveys of the general public and leaders of forest-dependent communities. Canadian Journal of Forest Research 44:1525-1533.

Type: Journal

Geographic Area: Western Canada

Keywords: assisted migration, biotechnology, public opinion, reforestation, climate change adaptation

Abstract: Two province-wide surveys of residents in Alberta and British Columbia were conducted to assess the acceptability of a range of reforestation strategies—many of which revolve around biotechnology—that could be used to aid western Canada's forests in adapting to future climate change. The opinions of leaders of forest-dependent communities were also sought to evaluate how well they align with those of the public at large. Results show that the views of the general public and community leaders correspond. There is a low acceptance for a "do nothing" strategy that allows climate change to run its course without any human intervention; high acceptance of replanting with local seeds; a decreasing acceptance of strategies that involve more manipulation such as breeding, using nonlocal seeds and moving seeds outside of a species' natural range; and a low acceptance of genetically engineered solutions. However, a high proportion of respondents changed their answers when told that a particular strategy would lead to either favourable or unfavourable outcomes related to socioeconomics of forest-dependent communities, forest aesthetics, pest, disease and fire outbreaks. We conclude that a meaningful and participatory dialogue on forest adaptation strategies in the face of climate change can only emerge if residents and other interested stakeholders have an adequate understanding of current forest management practices, proposed reforestation strategies, the role of technological interventions and the values and services for which western Canada's forests are to be managed.

Link: http://www.nrcresearchpress.com/doi/abs/10.1139/cjfr-2014-0142#.VTiDQZgcRLM

13. Harris JA, Hobbs RJ, Higgs E, Aronson J. 2006. **Ecological restoration and global climate change.** Restoration Ecology 14:170-176.

Type: Journal

Geographic Area: Global

Keywords: climate change, ecosystem change, ecosystem function, historical ecosystem, restoration goals

Abstract: There is an increasing consensus that global climate change occurs and that potential changes in climate are likely to have important regional consequences for biota and ecosystems. Ecological restoration, including (re)-afforestation and rehabilitation of degraded land, is included in the array of potential human responses to climate change. However, the implications of climate change for the broader practice of ecological restoration must be considered. In particular, the usefulness of historical ecosystem conditions as targets and references must be set against the likelihood that restoring these historic ecosystems is unlikely to be easy, or even possible, in the changed biophysical conditions of the future. We suggest that more consideration and debate needs to be directed at the implications of climate change for restoration practice.

Link: http://nctc.fws.gov/CSP/Resources/fwca/Climate%20Change/Ecological%20restoration%20and%20CC.pdf

14. Hodgkin T, Bordoni P. 2012. **Climate change and the conservation of plant genetic resources.** Journal of Crop Improvement 26:329-345.

Type: Journal

Geographic Area: Global

Keywords: plant genetic resources, conservation, *ex situ*, *in situ*, adaptation

Abstract: Over the next decades, agricultural production practices will change significantly and become more sustainable while they also respond to the need to contribute to reducing malnutrition and hunger and meeting the challenges of climate change. The enhanced use of agricultural biodiversity will play an essential role in this process, providing improved adaptability and resiliencies in agro-ecosystems. Plant genetic resources, a major component of agricultural biodiversity, play a key role in improving agricultural production and productivity. They are also essential to coping with climate change. As a result of climate change, increased efforts will be needed to conserve the diversity of crops and their wild relatives, and both *in situ* and *ex situ* conservation strategies will have to be adapted to meet changing environmental conditions and the need to secure biodiversity threatened by changing climate and altered production practices. Improved use of plant genetic resources will be essential, and this is likely to require increased national and international movements of resources to ensure that adapted germplasm is available to meet changing production environments. Greater emphasis will also need to be placed on evaluation for resistance to biotic and abiotic stresses and on properties such as adaptability, plasticity and resilience, which can help maintain productivity under changing environmental conditions.

15. Hopkins AD. 1938. **Bioclimatics: a science of life and climate relations.** Washington (DC): U.S. Government Printing Office. Miscellaneous Publication No. 280. 199 p.

Type: Government Document

Geographic Area: Global

Compilers' Keywords: climatic adaptation, Hopkin's law, seasonal variation, species distribution

Introduction: Bioclimatics is a science of relations between life, climate, seasons and geographic distribution. It deals with fundamental laws, principles, systems and methods of application in general research and economic practice, and has special reference to the major and minor effects of the major astronomic and terrestrial laws of causation, as represented by the variable phenomena of life, climate and seasons, relative to the geographic coordinates as expressed, measured and interpreted in units of time, temperature, and distance. The science differs from the other branches of biology, climatology, and geography in that it is based on the bioclimatic (and related) laws and principles, and in that it deals more specifically with fundamentals and methods of application relative to the phenomena of seasons, climates, and geographic distribution. It is not, therefore, a branch of any one of the major or minor sciences, but is intended to be supplementary to all in contributing information on fundamentals, and to serve a specific purpose.

Link:http://books.google.com/books?hl=en&lr&id=OpE9wLvCq8oC&oi=fnd&pg=PA1&dq=Bioclimatics:+A+science+of+life+and+climate+relations&ots=xoklNA0odR&sig=kwq_AHk28qk-7pDdQDLinbQtzYA#v=onepage&q=Bioclimatics%3A%20A%20science%20of%20life%20and%20climate%20relations&f=false

16. Intergovernmental Panel on Climate Change [IPCC]. 2014. **Summary for policymakers.** In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL, editors. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. New York (NY): Cambridge University Press. 32 p.

Type: Government Document

Geographic Area: Global

Compilers' Keywords: climate change, natural resources, human impacts, socioeconomic processes, land-use change, risks, vulnerability, exposure, hazards, decisionmaking

Introduction: Human interference with the climate system is occurring, and climate change poses risks for human and natural systems. The assessment of impacts, adaptation, and vulnerability in the Working Group II contribution to the IPCC's Fifth Assessment Report (WGII AR5) evaluates how patterns of risks and potential benefits are shifting due to climate change. It considers how impacts and risks related to climate change can be reduced and managed through adaptation and mitigation. The report assesses needs, options, opportunities, constraints, resilience, limits, and other aspects associated with adaptation. Climate change involves complex interactions and changing likelihoods of diverse impacts. A focus on risk, which is new in this report, supports decision making in the context of climate change and complements other elements of the report. People and societies may perceive or rank risks and potential benefits differently, given diverse values and goals. Compared to past WGII reports, the WGII AR5 assesses a substantially larger knowledge base of relevant scientific, technical, and socioeconomic literature. Increased literature has facilitated comprehensive assessment across a broader set of topics and sectors, with expanded coverage of human systems, adaptation, and the ocean. Section A of this summary characterizes observed impacts, vulnerability and exposure, and adaptive responses to date. Section B examines future risks and potential benefits. Section C considers principles for effective adaptation and the broader interactions among adaptation, mitigation, and sustainable development.

Link: https://ipcc-wg2.gov/AR5/images/uploads/WG2AR5_SPM_FINAL.pdf

17. Jansen E, Overpeck J, Briffa KR, Duplessy J-C, Joos F, Masson-Delmotte V, Olago D, Otto-Bliesner B, Peltier WR, Rahmstorf S, Ramesh R, Raynaud D, Rind D, Solomina O, Villalba R, Zhang D. 2007. **Palaeoclimate.** Chapter 6. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL, editors. Climate Change 2007: The Physical Science Basis. Cambridge, United Kingdom: Cambridge University Press. p 433-498.

Type: Book Section

Geographic Area: Global

Compilers' Keywords: climate change, migration, emissions scenarios, paleoecology, palaeoclimate, climate models, ice age, warming, greenhouse gases

Introduction: This chapter assesses palaeoclimatic data and knowledge of how the climate system changes over interannual to millennial time scales, and how well these variations can be simulated with climate models. Additional palaeoclimatic perspectives are included in other chapters. Palaeoclimate science has made significant advances since the 1970s, when a primary focus was on the origin of the ice ages, the possibility of an imminent future ice age, and the first explorations of the so-called Little Ice Age and Medieval Warm Period. Even in the first IPCC assessment (IPCC, 1990), many climatic variations prior to the instrumental record were not that well known or understood. Fifteen years later, understanding is much improved, more quantitative and better integrated with respect to observations and modelling. After a brief overview of palaeoclimatic methods, including their strengths and weaknesses, this chapter examines the palaeoclimatic record in chronological order, from oldest to youngest. This approach was selected because the climate system varies and changes over all time scales, and it is instructive to understand the contributions that lower-frequency patterns of climate change might make in influencing higher-frequency patterns of variability and change. In addition, an examination of how the climate system has responded to large changes in climate forcing in the past is useful in assessing how the same climate system might respond to the large anticipated forcing changes in the future.

18. Joyce LA, Running SW, Breshears DD, Dale VH, Malmsheimer RW, Sampson RN, Sohngen B, Woodall CW. 2013. **Forestry.** Chapter 7. In: NCADAC Draft Climate Assessment Report. Washington (DC): U.S. Global Change Research Program. p 263-289.

Type: Government Document

Geographic Area: Global

Compilers' Keywords: forest management, climate change, impacts, ecosystem services

Key Messages: Climate change is increasing the vulnerability of forests to ecosystem change and tree mortality through fire, insect infestations, drought, and disease outbreaks. Western U.S. forests are particularly vulnerable to increased wildfire and insect outbreaks; eastern forests have smaller disturbances but could be more sensitive to periodic drought. U.S. forests currently absorb about 13% of all carbon dioxide (CO_2) emitted by fossil fuel burning in the U.S. Climate change, combined with current societal trends regarding land use and forest management, is projected to reduce forest CO_2 uptake. Bioenergy is an emerging new market for wood; with higher wood prices, development of a market in salvaged wood from trees killed by drought, insects, and fire could help finance salvage and restoration activities and reduce U.S. fossil fuel consumption. However, the environmental and socioeconomic consequences of bioenergy production vary greatly with region and intensity of human management. The changing nature of private forestland ownership, globalization of forestry markets, emerging markets for bioenergy, and U.S. climate change policy will all influence forest management responses to climate change. However, development of and better access to practical and timely information for managers to consider in choosing adaptation and mitigation options will facilitate management of public and private forestland.

Link: http://ncadac.globalchange.gov/download/NCAJan11-2013-publicreviewdraft-chap7-forestry.pdf

19. Kaye TN. 2010. **What do we think? An international survey on restoration and climate change.** National Native Seed Conference: Native Plant Materials Development, Production, and Use for Habitat Restoration. Corvallis (OR): Institute for Applied Ecology. 37 p.

Type: Presentation

Geographic Area: USA

Compilers' Keywords: climate change, survey, restoration, paradigm, managers, opinion

Abstract: Climate change may be the defining challenge to the field of restoration ecology this century. How does the wider restoration community currently approach the challenges of habitat and species restoration, and how is this approach likely to shift if the climate changes locally and globally? Understanding how people conduct or support restoration is crucial to engaging in discussions that move our field forward in the face of changing environments. We conducted an international survey of over 1000 restoration practitioners and ecologists to gather information on their perspectives about these issues. We asked a series of twenty questions focused on the restoration process and obtaining organisms for restoration, climate change, and moving species in response to climate change. Survey results suggest that practitioners are somewhat split in their preferences around sources of organisms; 55% prefer native source material from close sources and 32% prefer them from similar habitats, not necessarily the closest source. A majority prefer organisms from a mix of populations (71%) compared to single sources (10%). Regarding genetic issues during captive production, practitioners ranked loss of genetic diversity above domestication selection or outbreeding depression. A strong majority (89%) of respondents were convinced that climate change is underway, and many (75%) believed that the practice of restoration should be modified to anticipate it. For example, the practice of setting restoration goals to match historic conditions may become infrequent or no longer used by many (65%) if climate changes. Many practitioners were cautious about moving species in response to climate change. For example, moving species beyond their historic range was unpopular (10% said 'yes' while 30% chose 'maybe') unless the species faces extinction. In contrast, moving species within their historic range but between watersheds was acceptable to many (56% said 'yes' and 22% said 'maybe'). Also, respondents were somewhat (42%) or very (55%) concerned that species moved in response to climate change could become invasive in a new area. These survey results suggest many commonalities among restorationists regarding the major issues they face while conducting restoration, obtaining organisms, and responding to climate change. In particular, there is widespread agreement that restoration should respond to shifting climates but exactly how to respond remains controversial.

Link: http://www.nativeseed.info/2010/presentations/Kaye%20-%20restoration%20and%20climate%20change.pdf

20. Kujala H, Burgman MA, Moilanen A. 2012. **Treatment of uncertainty in conservation under climate change.** Conservation Letters 6:73-85.

Type: Journal

Geographic Area: Global

Keywords: biodiversity, conservation planning, epistemic uncertainty, global warming, human decision uncertainty, linguistic uncertainty, uncertainty analysis

Abstract: Climate change is an important threat to biodiversity globally, but there are major uncertainties associated with its magnitude and ecological consequences. Here, we investigate how three major classes of uncertainty, linguistic uncertainty, epistemic uncertainty (uncertainty about facts), and human decision uncertainty, have been accounted for in scientific literature about climate change. Some sources of uncertainty are poorly characterized and epistemic uncertainty is much more commonly treated than linguistic or human decision uncertainty. Furthermore, we show that linguistic and human decision uncertainties are relatively better treated in the literature on sociopolitics or economics than in natural sciences, which often overlook communication between stakeholders and socioeconomic consequences. As uncertainty can significantly influence

implementation of conservation, we discuss uncertainties associated with some commonly proposed conservation adaptation actions to mitigate climate change. There may be major differences between strategies, with implications on how they should be viewed in conservation planning. We conclude that evaluating conservation strategies in terms of different types of uncertainty will facilitate communication between disciplines and stakeholders. While accounting for uncertainties in a quantitative manner is difficult and data demanding, even qualitative appreciation about the uncertainties inherent in conservation strategies can facilitate and improve decision making.

Link: https://tuhat.halvi.helsinki.fi/portal/files/26044830/Kujala_et_al_2013_CL.pdf

21. Lenart M, Jones C. 2014. Perceptions on climate change correlate with willingness to undertake some forestry adaptation and mitigation practices. Journal of Forestry 112:553-563.

Type: Journal

Geographic Area: USA

Keywords: climate change, adaptation, mitigation, climate records, forest management

Abstract: Results from a survey taken anonymously by 1,029 U.S. -based respondents in forest management and academia highlight how individuals' perceptions about climate change correlated with their willingness to consider management prescriptions for forest ecosystems. About two-thirds of respondents identified themselves as having a professional land management role, and most of the remainder specialized in research or education. In most cases, respondents' willingness to try specific adaptation or mitigation measures related to the degree to which they agreed that "climate change is occurring because of human activities that release greenhouse gases to the atmosphere." The survey results are considered with a focus on which proposed practices and types of climate information received the most acceptance or resistance. For instance, respondents across the spectrum of climate change perceptions supported efforts to thin overly dense forests and opposed options to sequester carbon by promoting the woody invasion of grasslands or ignoring biodiversity.

Link: http://www.ingentaconnect.com/content/saf/jof/2014/00000112/00000006/art00003

22. Littell J, Peterson D. 2009. Pacific Northwest forests and climate. Western Forester 54:1-24.

Type: Newsletter

Geographic Area: USA

Compilers' Keywords: climate change, forest ecosystems, genotypes, forest management, adaptation, diversity

Introduction: We already know from over a century of observations in Western forests that climate exerts strong influences on forest ecosystems. The obvious relationships—like severe drought and forest fires, or warmer decades and increased survival of seedlings at upper tree line—have been well studied. Other effects, such as the combined role of climate in insect life cycles and their tree hosts' vulnerability, are just beginning to be understood. So the idea that climate variability plays a role in forests is not new, nor is the idea that understanding that variability is critical for successful planning in forest management and forestry. But events like the 2002 Biscuit fire in Oregon, nearly 500,000 acres, or mountain pine beetle epidemics that impact entire watersheds synchronously over the West, give us pause.

Link: http://www.forestry.org/media/docs/westernforester/2009/jan09.pdf

23. Næss MW. 2013. Climate change, risk management and the end of Nomadic pastoralism. International Journal of Sustainable Development & World Ecology 20:123-133.

Type: Journal

Geographic Area: Tibet, Asia

Keywords: fragmentation, climate change, density dependence, risk, nomadic pastoralism, grazing patterns, Chang Tang, Tibetan Plateau, China

Abstract: Mobility has been argued to be the single factor explaining why some pastoralists do relatively well during extreme climatic events, while others do not, because mobility works by taking advantage of the spatial and temporal structure of resource failure by moving away from scarcity towards abundance. In spite of this, a common governmental management strategy is to resettle pastoral populations and thereby significantly reduce mobility. By revealing the underlying logic of mobility for Tibetan pastoralists, this paper questions official policy that aims at privatizing communally owned rangelands since it reduces pastoral flexibility and access to key resources. This is especially pertinent in the face of climate change. While little is known as to the specifics of how climate change will affect nomadic pastoralists, environmental variability is likely to increase. Consequently, policies resulting in decreased mobility may exacerbate the negative effects of climate change because of a positive feedback between climate and negative density dependence.

24. Nakicenovic N, Davidson O, Davis G, Grubler A, Kram T, Lebre La Rovere E, Metz B, Morita T, Pepper W, Pitcher H, Sankovski A, Shukla P, Swart R, Watson R, Zhou D. 2000. Summary for policy makers: emissions scenarios, a special report of Working Group III of the Intergovernmental Panel on Climate Change. PNNL-SA-39650. 27 p.

Type: Government Document

Geographic Area: Global

Compilers' Keywords: climate change, emissions scenarios, policy, IPCC

Preface: The Intergovernmental Panel on Climate Change (IPCC) was established jointly by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess periodically the science, impacts and socioeconomics of climate change and of adaptation and mitigation options. The IPCC provides, on request, scientific and technical advice to the Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) and its bodies. In response to a 1994 evaluation of the earlier IPCC IS92 emissions scenarios, the 1996 Plenary of the IPCC requested this Special Report on Emissions Scenarios (SRES) (see Appendix I for the Terms of Reference). This report was accepted by the Working Group III (WGIII) plenary session in March 2000. The long-term nature and uncertainty of climate change and its driving forces require scenarios that extend to the end of the 21st century. This Report describes the new scenarios and how they were developed.

Link: https://docs.google.com/a/mtu.edu/file/d/0B1gFp6Ioo3akcXQxMnNsWnRlSTA/edit?usp=drive_web&urp=http://www.ipcc.ch/publications_and_data/publicati&pli=1

25. Prescott C. 2012. Forests, climate change, and science: we need to do better. The Forestry Chronicle 88:371-372.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: editorial, climate change, forest, Canada

Introduction: To Canadian foresters, climate change is not a vague concept of something that might happen in the future. Canadian foresters are planting and managing forests that will be harvested or otherwise enjoyed decades in the future, so considering possible future climates is part of their day-to day work. It is therefore essential that Canadian foresters be provided with the best possible advice to help them plan and manage forests that are resilient in uncertain future climates.

26. Prescott C, Weese K. 2014. Crossing the divide: engaging scientists and policy-makers in adapting forest management to climate change in British Columbia. The Forestry Chronicle 90:89-95.

Type: Journal

Geographic Area: Western Canada

Keywords: science, policy development, forest management, climate change, interdisciplinary research, client-based research, best practices

Abstract: The Future Forest Ecosystems Scientific Council (FFESC) was created in 2008 following a one-time allocation of funding from the BC provincial government to support research that would inform adaptation of BC's current forest management policies to a changing climate. A key goal of the council was to maximize the utility of the research to inform provincial policy. The eight- step process that we developed to achieve this goal is described in this paper. In roughly chronological order, the eight steps were: determining the research needed to inform policy, connecting scientists and policy-makers, requiring interdisciplinary teams including both natural and social scientists and relevant stakeholders, assessing proposals for their value to inform policy, fostering scientific excellence, fostering ongoing communication between scientists and policy-makers, tailoring communication to policy-makers, and disseminating the policy relevant outcomes in a timely and targeted manner. Based on the FFESC experience, we suggest best practices for engaging policy-makers in research and scientists in policy development and adaptation.

Link: http://pubs.cif-ifc.org/doi/abs/10.5558/tfc2014-014

27. Regniere J, Bentz B. 2008. Mountain pine beetle and climate change. In: McManus K, Gottschalk KW, editors. Proceedings 19th USDA Interagency Research Forum on Invasive Species 2008. Newtown Square (PA): USDA Forest Service, Northern Research Station. General Technical Report NRS-P-36. p 63-64.

Type: Government Document

Geographic Area: Western North America

Compilers' Keywords: climate change, mountain pine beetle, management, forestry, invasive species, boreal forest

Abstract: The mountain pine beetle (MPB) (*Dendroctonus ponderosae*) is a native insect of pine forests in western North America. While it has a broad geographical distribution, it has been historically confined to the western side of the continent, in the U.S. by the distribution of its pine hosts and in the northern half of British Columbia in western Canada by the geoclimatic barrier of the Rockies. Since the early to mid-1990s, an outbreak of MPB has reached unprecedented levels in terms of acreages and numbers of pine trees, in particular lodgepole pine, killed throughout its range, most notably in Colorado and British Columbia. The MPB is also causing very high mortality among whitebark and limber pines at high elevations. Historical records from the past 100 years suggest these ecosystems have had pulses of MPB-caused mortality but not at levels currently being observed. Since 2006, MPB has extended its range into the Peace River area of north-central Alberta. Climate change may well be involved in this recent northeastward and upward range expansion. There is ample and mounting evidence of similar latitudinal and altitudinal shifts in insect distributions throughout the world, many convincingly Linked to climate change. The main concern at this time is the likelihood that this insect will continue spreading east into the pines of Canada's boreal forest, eventually reaching the eastern provinces and threatening the pines growing on the Atlantic side of the continent all the way into the Southern U.S. Because of this recent incursion at the gates of the Canadian boreal forest, MPB is being viewed as a potential invading species in eastern pine ecosystems. It could be viewed as an invader into the high-elevation whitebark pine ecosystems as well.

Link: http://www.treesearch.fs.fed.us/pubs/19347

28. Richardson DM. 2012. Conservation biogeography: what's hot and what's not? Diversity and Distributions 18:319-322.

Type: Journal

Geographic Area: Global

Compilers' Keywords: conservation, diversity, editorial, climate change, invasion biology, biogeography

Conclusion: Conservation biogeography is now well established as an exciting and important field in the cloud of subdisciplines associated with biogeography, ecology and environmental management. The challenges in biodiversity conservation are increasing rapidly, and innovative approaches and tools are urgently needed. I hope you will agree that Diversity and Distributions has carved an important niche for itself in the growing number of journals dealing with conservation.

29. Sample VA, Bixler RP, editors. 2013. Forest conservation and management in the Anthropocene: adaptation of science, policy, and practices. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-71. 494 p.

Type: Government Document

Geographic Area: Global

Compilers' Keywords: forest management, adaptation, climate change, conservation, restoration, forest ecosystems, Pinchot

Abstract: Climate change is but one aspect of the Anthropocene, a new epoch in which the effects of human activities have become the predominant force in the global biosphere. More than just an overlay on the traditional concerns of sustainable natural resource management, the uncertainties associated with these effects are creating a "no-analog future" in which much of the existing science relating to the functioning and response of forest ecosystems—which serves as the fundamental basis for current forest management practices and policies—must be reconsidered. In these collected papers, leading scientists, resource managers and policy specialists explore the implications of climate change and other manifestations of the Anthropocene on the management of wildlife habitat, biodiversity, water, and other resources, with particular attention to the effects of wildfire. Recommendations include the need for a supporting institutional, legal, and policy framework that is not just different but more dynamic, to facilitate resource management adaptation and preparedness in a period of accelerating environmental change.

Link: http://www.treesearch.fs.fed.us/pubs/46127

30. Sutherland WJ, Clout M, Cote IM, Daszak P, Depledge MH, Fellman L, Fleishman E, Garthwaite R, Gibbons DW, De Lurio J, Impey AJ, Lickorish F, Lindenmayer D, Madgwick J, Margerison C, Maynard T, Peck LS, Pretty J, Prior S, Redford KH, Scharlemann JP, Spalding M, Watkinson AR. 2010. A horizon scan of global conservation issues for 2010. Trends in Ecology and Evolution 25:1-7.

Type: Journal

Geographic Area: Global

Compilers' Keywords: aerosols, animals, atmosphere, charcoal, climate change, conservation, ecosystem, environmental pollution, forecasting, genetic engineering, oceans and seas, nitrogen, oxygen, seawater, telemetry, volcanic eruptions

Abstract: Horizon scanning identifies emerging issues in a given field sufficiently early to conduct research to inform policy and practice. Our group of horizon scanners, including academics and researchers, convened to identify fifteen nascent issues that could affect the conservation of biological diversity. These include the impacts of and potential human responses to climate change, novel biological and digital technologies, novel pollutants and invasive species. We expect to repeat this process and collation annually.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19939492

31. Swift K. 2010. Searching for sustainability in forest management: is good silviculture the key? Journal of Ecosystems and Management 12:7-9.

Type: Journal

Geographic Area: Western North America

Compilers' Keywords: climate change, forest management, Canada, United States, workshop

Introduction: I am pleased to summarize the first session from the 2010 Winter Southern Interior Silviculture Committee (SISCO) Workshop. As most are aware, the financial situation that a lot of us find ourselves in has affected our ability to attend many face-to-face events; however, although numbers were down, SISCO was able to deliver an informative one-and-a-half-day session that focused on climate change, sustainable forest management, and issues and concerns of small firms and operators. This article provides an update on the workshop's opening plenary session, titled "Climate Change—The Underlying Reality that Shapes Forest Planning and Management," and the latest science that can help inform decisions.

32. U.S. EPA. 2012. Climate change indicators in the United States. Washington (DC): United States Environmental Protection Agency. EPA 430-F-12-032. 4 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: indicators, global trends

Compilers' Summary: The Earth's climate is changing. Temperatures are rising, snow and rainfall patterns are shifting, and more extreme climate events—like heavy rainstorms and record high temperatures—are already affecting society and ecosystems. Scientists are confident that many of the observed changes in the climate can be Linked to the increase in greenhouse gases in the atmosphere, caused largely by people burning fossil fuels to generate electricity, heat and cool buildings, and power vehicles. The EPA is working with many other organizations to better understand the causes and effects of climate change. With help from these partners, the EPA has compiled a set of 26 indicators tracking signs of climate change. Most of these indicators focus on the United States, but some include global trends to provide context or a basis for comparison. These indicators represent a selected set of key climate change measurements, and are not an exhaustive group of all climate change indicators. The EPA's indicators are based on peer-reviewed data from various government agencies, academic institutions, and other organizations. EPA selected these indicators based on the quality of the data and other criteria.

Link: http://www.epa.gov/climatechange/science/indicators/

33. Walker BH, Steffen WL. 1991. The nature of global change. Chapter 1. In: Walker BH, Steffen WL, Canadell J, Ingram J, editors. The Terrestrial Biosphere and Global Change. Cambridge, United Kingdom: Cambridge University Press. p 1-18.

Type: Book Section

Geographic Area: Global

Compilers' Keywords: climate change, land cover, atmospheric composition, biodiversity, synthesis, terrestrial ecosystems

Introduction: Despite the growing prominence of global change as an environmental issue, the term 'global change' and the phenomena it encompasses are still widely misunderstood. Global change is often referred to as 'global warming' or 'climate change,' but there is much more to it than a change in climate and, in fact, climatic change is now and will continue to be for the next few decades one of the less important components of global change in terms of effects on the structure and functioning of terrestrial ecosystems. Other more immediate and more certain components are the direct human conversion and modification of terrestrial ecosystems, especially the accelerating loss of natural biological communities, and the alteration of the chemical composition of the atmosphere.

34. Walsh J, Wuebbles D, Hayhoe K, Kunkel K, Somerville R, Stephens G. 2013. Our changing climate. Chapter 2. In: NCADAC Draft Climate Assessment Report. Washington (DC): U.S. Global Change Research Program. p 25-103.

Type: Government Document

Geographic Area: Global

Compilers' Keywords: climate change, anthropogenic disturbance, precipitation, temperature, frost-free season, hurricanes, heat wave

Introduction: This chapter summarizes how climate is changing, why it is changing, and what is projected for the future. While the focus is on changes in the United States, the need to provide context requires a broader geographical perspective in some parts of the discussion. Additional geographic detail is presented in the regional chapters of this report. Since the previous national climate assessment was published in 2009, the climate has continued to change, with resulting effects on the U.S. The trends described in the 2009 report have continued, and our understanding of the data and ability to model the many facets of the climate system have increased substantially. Several noteworthy advances are mentioned in the chapter.

Link: http://ncadac.globalchange.gov/download/NCAJan11-2013-publicreviewdraft-chap2-climate.pdf

35. Welch D. 2005. What should protected areas managers do in the face of climate change? The George Wright Forum 22:75-93.

Type: Journal

Geographic Area: Canada

Compilers' Keywords: climate change, parks, adaptive management, public concern

Compilers' Summary: This paper describes the impact of past, current and future climate change and how managers should approach protecting land and adaptive management to promote sustainable and resilient habitats. The author uses examples from Parks Canada to illustrate why and when to adapt, how to adapt, what to do (i.e., goals and actions) and what not to do. Adapting to climate change and protecting natural areas required active involvement and collaboration among scientists, managers, the public and stakeholders.

Link: http://www.climateaccess.org/sites/default/files/Welch_What%20Should%20Protected%20Areas%20Managers%20Do.pdf

36. Woodward FI. 1987. **Climate and plant distribution.** London, United Kingdom: Cambridge University Press. 188 p.

Type: Book

Geographic Area: Global

Compilers' Keywords: climate change, plant distribution, range shifts, migration

Introduction: The central thesis for plant ecology is that climate exerts the dominant control on the distribution of the major vegetation types of the world. Within a vegetation type smaller-scale variations in distribution may be controlled by smaller-scale features of the environment such as soil types, human activity or topography. However, at all spatial scales the response of the plant to climate is a crucial feature in its presence. In view of the importance of climate in controlling distribution of plants it is surprising that this area of subject is not a popular one in plant ecology. Such questions as 'when' and 'how' does climate have its effect are clearly difficult to answer, perhaps explaining the limited acceptance as an area of study. I have set out to encourage an interest in climate and plant distribution by proposing different approaches to the subject. They are approaches which many not find general acceptance, but if they create interest and debate, which is my hope, then they will have been successful. I have drawn exclusively on vascular plants as examples of distribution types and responses. This reflects my interests and is not a comment on the ecology of non-vascular plants. Where possible, I have also avoided the use of the emotive terminologies, such as niche, strategy and adaptation; however I admit to the unavoidable use of competition, in spite of real problems in its measurements.

Link: http://books.google.com/books?hl=en&lr=&id=0Ld1h0MT3oIC&oi=fnd&pg=PR9&ots=QeJGze6gZK&sig=GtOVVnkmqLYEBXlzL_cjCWLDBBY#v=onepage&q&f=false

Climate Change

General (1–36)—editorials, opinions, reviews, trends, surveys, summaries

Research (37–135)—climate change impacts, projections, paleoecology

Strategies (136–205)—policies, adaptation options, frameworks, mitigations

Resources (206–214)—tools, websites, software

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

37. Allen CD, Macalady AK, Chenchouni H, Bachelet D, McDowell N, Vennetier M, Kitzberger T, Rigling A, Breshears DD, Hogg EH, Gonzalez P, Fensham R, Zhang Z, Castro J, Demidova N, Lim J-H, Allard G, Running SW, Semerci A, Cobb NS. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management 259:660-684.

Type: Journal

Geographic Area: Global

Keywords: climate change, drought effects, forest die-off, forest mortality, global patterns, tree mortality

Abstract: Greenhouse gas emissions have significantly altered global climate, and will continue to do so in the future. Increases in the frequency, duration, and/or severity of drought and heat stress associated with climate change could fundamentally alter the composition, structure, and biogeography of forests in many regions. Of particular concern are potential increases in tree mortality associated with climate induced physiological stress and interactions with other climate-mediated processes such as insect outbreaks and wildfire. Despite this risk, existing projections of tree mortality are based on models that lack functionally realistic mortality mechanisms, and there has been no attempt to track observations of climate-driven tree mortality globally. Here we present the first global assessment of recent tree mortality attributed to drought and heat stress. Although episodic mortality occurs in the absence of climate change, studies compiled here suggest that at least some of the world's forested ecosystems already may be responding to climate change and raise concern that forests may become increasingly vulnerable to higher background tree mortality rates and die-off in response to future warming and drought, even in environments that are not normally considered water-limited. This further suggests risks to ecosystem services, including the loss of sequestered forest carbon and associated atmospheric feedbacks. Our review also identifies key information gaps and scientific uncertainties that currently hinder our ability to predict tree mortality in response to climate change and emphasizes the need for a globally coordinated observation system. Overall, our review reveals the potential for amplified tree mortality due to drought and heat in forests worldwide.

Link: http://static.consbio.org/media/publications/files/Allen2010ForEcManGlobalForestDieback.pdf

38. Aubry C, Devine W, Shoal R, Bower AD, Miller J, Maggiulli N. 2011. Climate change and forest biodiversity: a vulnerability assessment and action plan for National Forests in Western Washington. Olympia (WA): USDA Forest Service. 310 p.

Type: Government Document

Geographic Area: Pacific Northwest USA

Compilers' Keywords: forest management, vulnerability assessment

Introduction: Climate change predictions for the Pacific Northwest include overall warming, increased winter precipitation, and decreased summer precipitation, resulting in warmer, wetter winters and warmer, drier summers. The extent and duration of the regional snowpack is projected to decrease, particularly at lower elevations. Seasonal stream flow patterns are likely to shift to earlier spring peak flows and lower summer flows, especially for snowmelt-dominated watersheds. There is a limited amount of information on climatic tolerance for many tree species and even less information on what complex interactions could result from ecosystem-wide exposure to a changing environment. The goals of this analysis are to conduct a climate change vulnerability assessment of forest tree species, assess the vulnerability of non-forested habitats to climate change, and propose practical management actions that will work under a variety of future climate scenarios and can be implemented by the national forests in western Washington in cooperation with other land managers.

Link: http://ecoshare.info/2011/05/09/climate-change-and-forest-biodiversity-a-vulnerability-assessment-and-action-plan-for-national-forests-in-western-washington/

39. Bakkenes M, Eickhout B, Alkemade R. 2006. Impacts of different climate stabilisation scenarios on plant species in Europe. Global Environmental Change 16:19-28.

Type: Journal

Geographic Area: Europe

Keywords: biodiversity, climate change, stabilisation profiles, integrated assessment, scenario analysis

Abstract: With the use of goals from the Convention on Biological Diversity we evaluated two climate stabilisation profiles on their merits for conservation of biodiversity, comparing them with a baseline profile. Focusing on plant ecosystems at the pan-European level, we concluded that although a maximum global-mean temperature increase of 21°C is likely to be met in a 550 ppmv CO_2-equivalent stabilisation profile, large areas of ecosystems in Europe will be affected. Most of the impacts manifest themselves in northern countries, with a high net increase of plant species, and in Mediterranean countries, with a decrease in the number of plant species and stable area. Other impacts are less robust, given the regional variation in climate results for different climate models.

40. Barnosky AD, Hadly EA, Bascompte J, Berlow EL, Brown JH, Fortelius M, Getz WM, Harte J, Hastings A, Marquet PA, Martinez ND, Mooers A, Roopnarine P, Vermeij G, Williams JW, Gillespie R, Kitzes J, Marshall C, Matzke N, Mindell DP, Revilla E, Smith AB. 2012. Approaching a state shift in Earth's biosphere. Nature 486:52-58.

Type: Journal

Geographic Area: Global

Compilers' Keywords: animals, climate change, ecosystem, environmental monitoring, forecasting, human activities, models

Abstract: Localized ecological systems are known to shift abruptly and irreversibly from one state to another when they are forced across critical thresholds. Here we review evidence that the global ecosystem as a whole can react in the same way and is approaching a planetary-scale critical transition as a result of human influence. The plausibility of a planetary-scale "tipping point" highlights the need to improve biological forecasting by detecting early warning signs of critical transitions on global as well as local scales, and by detecting feedbacks that promote such transitions. It is also necessary to address root causes of how humans are forcing biological changes.

Link: http://www.ncbi.nlm.nih.gov/pubmed/22678279

41. Beaulieu J, Rainville A. 2005. Adaptation to climate change: genetic variation is both a short- and a long-term solution. The Forestry Chronicle 81:704-709.

Type: Journal

Geographic Area: Eastern Canada

Keywords: climate change, white spruce, provenance test, transfer model, site index, adaptation, plantation, GIS

Abstract: We propose a methodology combining a biophysical site index model and a seed source transfer model based on both temperature and precipitation to estimate white spruce plantation yield under present and future global warming conditions. The biophysical site index model predicts dominant height at 25 years, which is further used to estimate plantation yield using yield tables. The transfer model shows that, on average, seed sources are best adapted to the temperature conditions where they presently grow, and give maximum yield under these conditions. However, this model also shows that transfer of seed sources to drier sites could improve plantation yield. To predict site index values under climate change conditions, values obtained from the biophysical site index model are corrected by a factor estimated using the seed source transfer model. Our simulation results predict that global warming should favor a slight increase in white spruce plantation yield in southern Quebec. However, one cannot expect to obtain similar yields from a seed source rapidly exposed to warmer conditions compared with a seed source that is presently growing under climatic conditions to which it has become adapted. It would take several generations

(adaptation lag) for a seed source to adapt to warmer conditions to which it has become adapted. We believe that the method we propose will be helpful in identifying the most productive seed source to be used at any given location in the province, and in revising seed source transfer rules.

Link: http://mrn.gouv.qc.ca/publications/forets/connaissances/recherche/Rainville-Andre/For-Chron-81-5-704-709.pdf

42. Beierkuhnlein C, Thiel D, Jentsch A, Willner E, Kreyling J. 2011. Ecotypes of European grass species respond differently to warming and extreme drought. Journal of Ecology 99:703-713.

Type: Journal

Geographic Area: Europe

Keywords: adaptation, climate change, climatic events, extreme weather, grassland, meadow, phenotypes, plant-climate interactions, provenances, within-species vulnerability

Abstract: Climate extremes are expected to increase in frequency and magnitude as a consequence of global warming. Managed permanent grasslands cover a large surface in Europe and contribute substantially to agricultural production. These managed plant communities are dominated by perennial clonal species. Their capacity to adapt to rapidly changing environmental conditions may be limited. We hypothesize that those plant populations that have already been exposed to conditions that are expected to occur due to future climate change, particularly conditions that would be "extreme" in the target area, are able to cope better with these conditions. For a common-garden experiment we selected ecotypes (provenances as supported by accessions in seed banks) of important European grass species: *Arrhenatherum elatius*, *Festuca pratensis*, *Holcus lanatus* and *Alopecurus pratensis*. Southern target locations of ecotypes (populations) were identified based on climate model projections for the local site in Northern Bavaria, Germany. In a controlled experiment, the plants were exposed to warming and extreme drought. Drought conditions (16–19 days, depending on the species) were imposed starting from the end of May in combination with and without an increase in the average temperature from May to September 2009 (+1.5 °K compared with control; +2.5 °K compared with ambient conditions outside of the experimental units). Ecotypes and drought manipulation had significant impacts on biomass production and tissue die-back. Significant interactions between ecotype and drought indicated a different drought tolerance of the ecotypes in some cases. The warming treatment yielded a less significant response. The local ecotype generally did not perform significantly worse than the presumably better-adapted southern ecotypes. The selection of ecotypes that are adapted to more extreme climatic conditions could be an option for maintaining future ecosystem functioning in temperate managed grasslands, as was indicated by the clear differences between ecotypes in our experiment. Based on our data, however, performance cannot be predicted from climatic origin. Therefore, we recommend enhancing the genetic variability within populations of species in general.

Link: http://www.researchgate.net/publication/224763331_Ecotypes_of_European_grass_species_respond_specifically_to_warming_and_extreme_drought/file/72e7e51a5c38a6cf72.pdf

43. Bell G, Gonzalez A. 2011. Adaptation and evolutionary rescue in metapopulations experiencing environmental deterioration. Science 332:1327-1330.

Type: Journal

Geographic Area: Global

Compilers' Keywords: climate change, physiological, biological evolution, models, directed molecular evolution, adaptation, Saccharomyces cerevisiae

Abstract: It is not known whether evolution will usually be rapid enough to allow a species to adapt and persist in a deteriorating environment. We tracked the eco-evolutionary dynamics of metapopulations with a laboratory model system of yeast exposed to salt stress. Metapopulations experienced environmental deterioration at three different rates and their component populations were either unconnected or connected by local dispersal or by global dispersal. We found that adaptation was favored by gradual deterioration and local dispersal. After further abrupt deterioration, the frequency of evolutionary rescue depended on both the prior rate of deterioration and the rate of dispersal. Adaptation was surprisingly frequent and rapid in small peripheral populations. Thus, evolutionary dynamics affect both the persistence and the range of a species after environmental deterioration.

Link: http://izt.ciens.ucv.ve/ecologia/Archivos/ECO_POB%202011/ECOPO2_2011/Bell%20y%20Gonzalez%202011.pdf

44. Bentz B, editor. 2009. Bark beetle outbreaks in western North America: causes and consequences. Snowbird (UT): University of Utah Press. 42 p.

Type: Conference Proceedings

Geographic Area: Western North America

Compilers' Keywords: climate change, forest impact, insect outbreaks, symposium

Compilers' Summary: Since 1990, native bark beetles have killed billions of trees across millions of acres of forest from Alaska to northern Mexico. Although bark beetle infestations are a regular force of natural change in forested ecosystems, several of the current outbreaks, which are occurring simultaneously across western North America, are the largest and most severe in recorded history.

Link: http://www.usu.edu/beetle/Symposium/SymposiumCover.pdf

45. Bentz BJ, Régnière J, Fettig CJ, Hansen EM, Hayes JL, Hicke JA, Kelsey RG, Negrón JF, Seybold SJ. 2010. **Climate change and bark beetles of the western United States and Canada: direct and indirect effects.** BioScience 60:602-613.

Type: Journal

Geographic Area: Western North America

Keywords: cold tolerance, mountain pine beetle, seasonality, spruce beetle, temperature

Abstract: Climatic changes are predicted to significantly affect the frequency and severity of disturbances that shape forest ecosystems. We provide a synthesis of climate change effects on native bark beetles, important mortality agents of conifers in western North America. Because of differences in temperature-dependent life-history strategies, including cold-induced mortality and developmental timing, responses to warming will differ among and within bark beetle species. The success of bark beetle populations will also be influenced indirectly by the effects of climate on community associates and host-tree vigor, although little information is available to quantify these relationships. We used available population models and climate forecasts to explore the responses of two eruptive bark beetle species. Based on projected warming, increases in thermal regimes conducive to population success are predicted for *Dendroctonus rufipennis* (Kirby) and *Dendroctonus ponderosae* Hopkins, although there is considerable spatial and temporal variability. These predictions from population models suggest a movement of temperature suitability to higher latitudes and elevations and identify regions with a high potential for bark beetle outbreaks and associated tree mortality in the coming century.

Link: http://www.fs.fed.us/wwetac/projects/PDFs/BioScience_CC_and_Bark_Beetles.pdf

46. Berry PM, Rounsevell MDA, Harrison PA, Audsley E. 2006. **Assessing the vulnerability of agricultural land use and species to climate change and the role of policy in facilitating adaptation.** Environmental Science & Policy 9:189-204.

Type: Journal

Geographic Area: Europe

Keywords: climate change, farmers, species, vulnerability, adaptation, policy

Abstract: The term vulnerability has been used in a variety of contexts, including climate change impact assessment. In this paper those issues relevant to climate change impacts on agriculture and species are discussed. Outputs from models are used to assess the vulnerability of farmers and species to climate and socio-economic change by estimating their sensitivity and capacity to adapt to external factors as a means of identifying what causes the differences in their vulnerability. The results showed that the vulnerability of both farmers and species is dependent on the scenario under consideration. In agriculture, it is the socio-economic scenarios that particularly lead to different patterns of intensification, extensification and abandonment. For species, vulnerability is more related to the climate change scenarios. In both cases, the adaptation options and potential were associated with the different socio-economic futures and policy intervention. The conceptual Linking of the two sectors shows that impacts in the agriculture sector and consequent adaptation could have a significant effect on the adaptation potential of species. This demonstrates the importance of cross-sectoral assessments of vulnerability and highlights the importance of sectoral integration in policy development and implementation.

Link: http://ethree.com/downloads/Climate%20Change%20Readings/International%20Climate%20Policy/Berry%20-%20Vulnerability%20Agr%20land%20%2B%20species%20climate%20change.pdf

47. Booth TH, Broadhurst LM, Pinkard E, Prober SM, Dillon SK, Bush D, Pinyopusarerk K, Doran JC, Ivkovich M, Young AG. 2015. **Native forests and climate change: lessons from eucalypts.** Forest Ecology and Management 347:18-29.

Type: Journal

Geographic Area: Australia

Keywords: vulnerability, adaptation, carbon dioxide, genomics, species distribution models, simulation models

Abstract: The purpose of this paper is to review studies relevant to potential climate change impacts on natural stands of eucalypts, with a view to identifying not only specific lessons for the management of native forests in Australia but also some general lessons relevant to native forests anywhere. More than 800 species of *Eucalyptus* are found naturally across Australia, as well as species such as *E. deglupta* and *E. urophylla* in countries north of Australia. Eucalypts provide a particularly interesting opportunity to examine the likely impacts of climate change, as many species have been widely evaluated in trials within and outside Australia, often under conditions that are warmer and sometimes drier than those found within their natural distributions. Results from these trials indicate the intrinsic ability of particular eucalypt species and provenances to tolerate conditions that are somewhat different from those experienced within their natural distributions. Eucalypts have particularly poor dispersal capabilities, so natural stands will be generally unable to track changing climatic conditions. Therefore, in the period to the end of the present century a key issue for each eucalypt species under climate change is whether its intrinsic adaptability will be sufficient to allow it to survive where it is currently located. Their ability to survive will be affected not only by climatic, but also atmospheric changes, which will affect important processes such as photosynthesis and water exchange. Again eucalypts provide a useful group for climate change studies as their commercial significance has led to various enhanced carbon dioxide experiments being carried out, as well as detailed genomic studies. This review considers eucalypts in relation to four main areas: (i) resources and characteristics (natural distributions and introduced distributions including their adaptability/plasticity), (ii) analysis tools (species distribution models and growth models), (iii) physiological factors (including temperature, drought and enhanced CO_2) and (iv) interactions with other species (including pests and diseases). Priorities for future research are identified. It is concluded that analyses that do not allow for the intrinsic climatic adaptability of tree species, as well as their particular dispersal capabilities, are unlikely to provide reliable predictions of climate change impacts.

Link: http://www.sciencedirect.com/science/article/pii/S0378112715001139

48. Bradley BA, Wilcove DS. 2009. When invasive plants disappear: transformative restoration possibilities in the western United States resulting from climate change. Restoration Ecology 17:715-721.

Type: Journal

Geographic Area: Western USA

Keywords: bioclimatic envelope modeling, *Bromus tectorum*, climate change, ecological niche, invasive species, restoration, species distribution

Abstract: Most ecologists believe that climate change poses a significant threat to the persistence of native species. However, in some areas climate change may reduce or eliminate nonnative invasive species, creating opportunities for restoration. If invasive species are no longer suited to novel climate conditions, the native communities that they replaced may not be viable either. If neither invasive nor native species are climatically viable, a type of "transformative" restoration will be required, involving the translocation of novel species that can survive and reproduce under new climate conditions. Here, we illustrate one approach for restoration planning by using bioclimatic envelope modeling to identify restoration opportunities in the western United States, where the invasive plant cheatgrass (*Bromus tectorum*) is no longer climatically viable under 2100 conditions projected by the Geophysical Fluid Dynamics Laboratory (GFDL2.1) coupled atmosphere-ocean general circulation model. We then select one example of a restoration target area and identify novel plant species that could become viable at the site in the wake of climate change. We do so by identifying the closest sites that currently have climate conditions similar to those projected at the restoration target area in 2100. This approach is a first step toward identifying appropriate species for transformative restoration.

Link: http://www.firescience.gov/projects/05-2-1-94/project/05-2-1-94_bradley_re_2009.pdf

49. Breshears DD, Cobb NS, Rich PM, Price KP, Allen CD, Balice RG, Romme WH, Kastens JH, Floyd ML, Belnap J, Anderson JJ, Myers OB, Meyer CW. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Science USA 102:15144-15148.

Type: Journal

Geographic Area: Southwestern USA

Keywords: tree mortality, vegetation dynamics, climate change impacts, woodlands, *Pinus edulis*

Abstract: Future drought is projected to occur under warmer temperature conditions as climate change progresses, referred to here as global-change-type drought, yet quantitative assessments of the triggers and potential extent of drought-induced vegetation die-off remain pivotal uncertainties in assessing climate-change impacts. Of particular concern is regional-scale mortality of overstory trees, which rapidly alters ecosystem type, associated ecosystem properties, and land surface conditions for decades. Here, we quantify regional-scale vegetation die-off across southwestern North American woodlands in 2002-2003 in response to drought and associated bark beetle infestations. At an intensively studied site within the region, we quantified that after 15 months of depleted soil water content, > 90% of the dominant, overstory tree species (*Pinus edulis*, a pinon) died. The die-off was reflected in changes in a remotely sensed index of vegetation greenness (Normalized Difference Vegetation Index), not only at the intensively studied site but also across the region, extending over 12,000 km^2 or more; aerial and field surveys confirmed the general extent of the die-off. Notably, the recent drought was warmer than the previous subcontinental drought of the 1950s. The limited, available observations suggest that die-off from the recent drought was more extensive than that from the previous drought, extending into wetter sites within the tree species' distribution. Our results quantify a trigger leading to rapid, drought-induced die-off of overstory woody plants at subcontinental scale and highlight the potential for such die-off to be more severe and extensive for future global-change-type drought under warmer conditions.

Link: http://www.ncbi.nlm.nih.gov/pubmed/16217022

50. Bucharová A, Brabec J, Münzbergová Z. 2012. Effect of land use and climate change on the future fate of populations of an endemic species in central Europe. Biological Conservation 145:39-47.

Type: Journal

Geographic Area: Central Europe

Keywords: conservation action plan, population viability analysis, grassland management, *Gentianella*, matrix model, extinction probability

Abstract: The identification of optimal management strategies for a given species is a major challenge of species conservation.

It becomes especially challenging when the environmental conditions are expected to change in the future, and the optimal management applied today may differ from the management that is optimal under the changed conditions (e.g. due to climate change). This study evaluates prospect of a rare plant species endemic to semi-natural grasslands in central Europe, *Gentianella praecox* subsp. *bohemica*. The number of populations of this species has declined rapidly in the last 60 years; currently, a conservation action plan has been established in the Czech Republic, where most populations of this species occur. This study uses periodic matrix models to compare different management regimes under different scenarios of climate change and to identify the optimal management in each case. Without management, populations of the species are not able to survive. Flowering individuals can occur for a long time after the cessation of management, but the extinction of the population is inevitable within several decades. Without management, even very large populations (1,000 flowering individuals) will go extinct in less than 50 years. Total extinction (including seed bank) will follow several years after observation of the last flowering plant. The most suitable management is mowing and disturbance (by harrowing), which is also the best method for restoration of threatened populations. Mowing is less suitable, but it is fully sufficient for large prospering populations. When managed, even small populations (10–15 flowering individuals) are able to survive. When management is applied, future climate change may have a relatively small impact on the probability of survival of the species. Climate change will, however, increase the extinction probability of very small populations.

51. Carnicer J, Coll M, Ninyerola M, Pons X, Sanchez G, Penuelas J. 2011. Widespread crown condition decline, food web disruption, and amplified tree mortality with increased climate change-type drought. Proceedings of the National Academy of Science USA 108:1474-1478.

Type: Journal

Geographic Area: Southern Europe

Keywords: extreme events, earth system feedbacks, ecological networks, global change, Mediterranean biome

Abstract: Climate change is progressively increasing severe drought events in the Northern Hemisphere, causing regional tree die-off events and contributing to the global reduction of the carbon sink efficiency of forests. There is a critical lack of integrated community-wide assessments of drought-induced responses in forests at the macroecological scale, including defoliation, mortality, and food web responses. Here we report a generalized increase in crown defoliation in southern European forests occurring during 1987–2007. Forest tree species have consistently and significantly altered their crown leaf structures, with increased percentages of defoliation in the drier parts of their distributions in response to increased water deficit. We assessed the demographic responses of trees associated with increased defoliation in southern European forests, specifically in the Iberian Peninsula region. We found that defoliation trends are paralleled by significant increases in tree mortality rates in drier areas that are related to tree density and temperature effects. Furthermore, we show that severe drought impacts are associated with sudden changes in insect and fungal defoliation dynamics, creating long-term disruptive effects of drought on food webs. Our results reveal a complex geographical mosaic of species-specific responses to climate change—driven drought pressures on the Iberian Peninsula, with an overwhelmingly predominant trend toward increased drought damage.

Link: http://www.pnas.org/content/108/4/1474.short

52. Chmura DJ, Anderson PD, Howe GT, Harrington CA, Halofsky JE, Peterson DL, Shaw DC, St. Clair JB. 2011. Forest responses to climate change in the northwestern United States: ecophysiological foundations for adaptive management. Forest Ecology and Management 261:1121-1142.

Type: Journal

Geographic Area: Northwestern USA

Keywords: adaptation, drought, fire, genetics, insects, silviculture

Abstract: Climate change resulting from increased concentrations of atmospheric carbon dioxide ([CO_2]) is expected to result in warmer temperatures and changed precipitation regimes during this century. In the northwestern US, these changes will likely decrease snowpack, cause earlier snowmelt, increase summer evapotranspiration, and increase the frequency and severity of droughts. Elevated [CO_2] and warmer temperatures may have positive effects on growth and productivity where there is adequate moisture or growth is currently limited by cold. However, the effects of climate change are generally expected to reduce growth and survival, predispose forests to disturbance by wildfire, insects, and disease; and ultimately change forest structure and composition at the landscape scale. Substantial warming will likely decrease winter chilling resulting in delayed bud burst, and adversely affect flowering and seed germination for some species. The extent of these effects will depend on the magnitude of climate change, the abilities of individual trees to acclimate, and for tree populations to adapt *in situ*, or to migrate to suitable habitats. These coping mechanisms may be insufficient to maintain optimal fitness of tree populations to rapidly changing climate. Physiological responses to climatic stresses are relatively well-understood at the organ or whole-plant scale but not at the stand or landscape scale. In particular, the interactive effects of multiple stressors are not well known. Genetic and silvicultural approaches to increase adaptive capacities and to decrease climate-related vulnerabilities of forests can be based on ecophysiological knowledge. Effective approaches to climate adaptation will likely include assisted migration of species and populations, and density management. Use of these approaches to increase forest resistance and resilience at the landscape scale requires a better understanding of species adaptations,

within-species genetic variation, and the mitigating effects of silvicultural treatments.

Link: http://www.treesearch.fs.fed.us/pubs/39611

53. Classen AT, Norby RJ, Campany CE, Sides KE, Weltzin JF. 2010. Climate change alters seedling emergence and establishment in an old-field ecosystem. PLoS ONE 5:e13476.

Type: Journal

Geographic Area: Eastern USA

Compilers' Keywords: atmosphere, carbon dioxide, tree growth and development

Abstract: Ecological succession drives large-scale changes in ecosystem composition over time, but the mechanisms whereby climatic change might alter succession remain unresolved. Here, we asked if the effects of atmospheric and climatic change would alter tree seedling emergence and establishment in an old-field ecosystem, recognizing that small shifts in rates of seedling emergence and establishment of different species may have long-term repercussions on the transition of fields to forests in the future. We introduced seeds from three early successional tree species into constructed old-field plant communities that had been subjected for 4 years to altered temperature, precipitation, and atmospheric CO_2 regimes in an experimental facility. Our experiment revealed that different combinations of atmospheric CO_2 concentration, air temperature, and soil moisture altered seedling emergence and establishment. Treatments directly and indirectly affected soil moisture, which was the best predictor of seedling establishment, though treatment effects differed among species. The observed impacts, coupled with variations in the timing of seed arrival, are demonstrated as predictors of seedling emergence and establishment in ecosystems under global change.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20976104

54. Coops NC, Waring RH, Schroeder TA. 2009. Combining a generic process-based productivity model and a statistical classification method to predict the presence and absence of tree species in the Pacific Northwest, USA. Ecological Modelling 220:1787-1796.

Type: Journal

Geographic Area: Pacific Northwest USA

Keywords: 3-PG model, regression-tree analysis, climate change, U.S. Forest Inventory and Analysis, Sitka spruce, ponderosa pine, western juniper, lodgepole pine, Douglas-fir, western hemlock

Abstract: Although long-lived tree species experience considerable environmental variation over their life spans, their geographical distributions reflect sensitivity mainly to mean monthly climatic conditions. We introduce an approach that incorporates a physiologically based growth model to illustrate how a half-dozen tree species differ in their responses to monthly variation in four climatic-related variables: water availability, deviations from an optimum temperature, atmospheric humidity deficits, and the frequency of frost. Rather than use climatic data directly to correlate with a species' distribution, we assess the relative constraints of each of the four variables as they affect predicted monthly photosynthesis for Douglas-fir, the most widely distributed species in the region. We apply an automated regression-tree analysis to create a suite of rules, which differentially rank the relative importance of the four climatic modifiers for each species, and provide a basis for predicting a species' presence or absence on 3,737 uniformly distributed U.S. Forest Services' Forest Inventory and Analysis (FIA) field survey plots. Results of this generalized rule-based approach were encouraging, with weighted accuracy, which combines the correct prediction of both presence and absence on FIA survey plots, averaging 87%. A wider sampling of climatic conditions throughout the full range of a species' distribution should improve the basis for creating rules and the possibility of predicting future shifts in the geographic distribution of species.

Link: http://www.fs.fed.us/rm/pubs_other/rmrs_2009_coops_n001.pdf

55. Cortini F, Comeau PG, Bokalo M. 2012. Trembling aspen competition and climate effects on white spruce growth in boreal mixtures of Western Canada. Forest Ecology and Management 277:67-73.

Type: Journal

Geographic Area: Western Canada

Keywords: conifer growth, mixedwood forests, climate, competition, white spruce, trembling aspen

Abstract: We investigated the combined effect of trembling aspen competition and climate on white spruce growth using data from a long term study with matching treatments spread across the boreal mixed wood forests of Alberta and Saskatchewan (Canada). Results indicate that competition (i.e., aspen basal area), initial size of the tree and mean annual temperature can account for 88% of the year to year variation in spruce volume growth for these six locations. Based on the model that we developed, spruce growth, in the absence of competition, is estimated to increase by up to 17% compared with an increase in mean annual temperature from 2 °C to 3.3 °C, while at high levels of competition (aspen basal area = 27 m^2/ha) spruce growth increases by only 8%. Moreover, effects of aspen on spruce growth increase more than proportionally as temperature increases. This outcome indicates that abundant aspen competition limits the spruce responses to rising temperature, presumably due to competition for light and potentially increased competition for soil resources. Results also show that competition and climate effects vary between locations, indicating that spruce growth is strongly influenced by local factors such as micro-climate, topography, and soil properties.

Link: http://www.researchgate.net/publication/225071346_Trembling_aspen_competition_and_climate_effects_on_white_spruce_growth_in_boreal_mixtures_of_Western_Canada/file/9fcfd4fc66733d4533.pdf

56. Crookston NL, Rehfeldt GE, Dixon GE, Weiskittel AR. 2010. Addressing climate change in the forest vegetation simulator to assess impacts on landscape forest dynamics. Forest Ecology and Management 260:1198-1211.

Type: Journal

Geographic Area: Western USA

Keywords: species–climate relationships, stand dynamic, species composition, genetic adaptation, general circulation model, climate change, carbon loads, site index, growth and yield

Abstract: To simulate stand-level impacts of climate change, predictors in the widely used Forest Vegetation Simulator (FVS) were adjusted to account for expected climate effects. This was accomplished by: (1) adding functions that Link mortality and regeneration of species to climate variables expressing climatic suitability, (2) constructing a function Linking site index to climate and using it to modify growth rates, and (3) adding functions accounting for changing growth rates due to climate-induced genetic responses. For three climatically diverse landscapes, simulations were used to explore the change in species composition and tree growth that should accompany climate change during the 21st century. The simulations illustrated the changes in forest composition that could accompany climate change. Projections were the most sensitive to mortality, as the loss of trees of a dominant species heavily influenced stand dynamics. While additional work is needed on fundamental plant–climate relationships, this work incorporates climatic effects into FVS to produce a new model called Climate–FVS. This model provides for managers a tool that allows climate change impacts to be incorporated in forest plans.

Link: http://www.treesearch.fs.fed.us/pubs/37335

57. Daniels AE, Morrison JF, Joyce LA, Crookston NL, Chen SC, McNulty SG. 2012. Climate projections FAQ. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-277WWW. 32 p.

Type: Government Document

Geographic Area: Western USA

Keywords: climate change, climate projections, downscaling, general circulation models, vulnerability assessment

Abstract: Climate scenarios offer one way to identify and examine the land management challenges posed by climate change. Selecting projections, however, requires careful consideration of the natural resources under study, and where and how they are sensitive to climate. Selection also depends on the robustness of different projections for the resources and geographic area of interest, and possibly on what climate projections are available for a region. Rather than a misguided attempt to identify the "most accurate" climate scenario, managers are strongly encouraged to explore variability through the use of multiple climate scenarios. Considering a range of possible future climates facilitates the identification of management strategies to help ensure resilience of natural resource systems across a broad set of potential conditions. Downscaling climate projections increases the spatial resolution of climate information and can make projections more relevant to natural resource managers by allowing decision-makers to better visualize what these different futures imply locally and regionally. The following series of questions describes key concepts that end-users of climate projection products should understand to appropriately interpret downscaled climate projections, including various sources of uncertainty. The selection used for each component of a downscaled climate projection has implications for interpreting the resulting climate scenario. Understanding the merits and limitations of the downscaling method employed is also important since downscaling approaches vary in their dependence on observed data availability, computational requirements, and in resultant uncertainty owed to biases of the method or the spatial scale of the downscaling.

Link: http://www.treesearch.fs.fed.us/pubs/40614

58. Davison JE, Coe S, Finch DM, Rowland EL, Friggens MM, Graumlich LJ. 2012. Bringing indices of species vulnerability to climate change into geographic space: an assessment across the Coronado National Forest. Biodiversity and Conservation 21:189-204.

Type: Journal

Geographic Area: Southwestern USA

Keywords: biodiversity, climate change adaptation, GIS, land use planning, species vulnerability assessments

Abstract: Indices that rate the vulnerability of species to climate change in a given area are increasingly used to inform conservation and climate change adaptation strategies. These species vulnerability indices (SVI) are not commonly associated with landscape features that may affect local-scale vulnerability. To do so would increase their utility by allowing managers to examine how the distributions of vulnerable species coincide with environmental features such as topography and land use, and to detect landscape-scale patterns of vulnerability across species. In this study we evaluated 15 animal species that had been scored with the USDA-Forest Service Rocky Mountain Research Station's system for assessing vulnerability of species to climate change. We applied the vulnerability scores to each species' respective habitat models in order to visualize the spatial patterns of cross-species vulnerability across the biologically diverse Coronado National Forest, and to identify the considerations of spatially referencing such indices. Across the study extent, cross-species vulnerability was higher in higher-elevation

woodlands and lower in desert scrub. The results of spatially referencing SVI scores may vary according to the species examined, the area of interest, the selection of habitat models, and the method by which cross-species vulnerability indices are created. We show that it is simple and constructive to bring species vulnerability indices into geographic space: landscape-scale patterns of vulnerability can be detected, and relevant ecological and socioeconomic contexts can be taken into account, allowing for more robust conservation and management strategies.

Link: http://www.fs.fed.us/rm/pubs_other/rmrs_2012_davison_j001.pdf

59. Dawson TP, Jackson ST, House JI, Prentice IC, Mace GM. 2011. Beyond predictions: biodiversity conservation in a changing climate. Science 332:53-58.

Type: Journal

Geographic Area: Global

Compilers' Keywords: conservation of natural resources, migration, review, vulnerability, paleoecology, framework

Abstract: Climate change is predicted to become a major threat to biodiversity in the 21st century, but accurate predictions and effective solutions have proved difficult to formulate. Alarming predictions have come from a rather narrow methodological base; but a new, integrated science of climate-change biodiversity assessment is emerging, based on multiple sources and approaches. Drawing on evidence from paleoecological observations, recent phenological and microevolutionary responses, experiments, and computational models, we review the insights that different approaches bring to anticipating and managing the biodiversity consequences of climate change, including the extent of species' natural resilience. We introduce a framework that uses information from different sources to identify vulnerability and to support the design of conservation responses. Although much of the information reviewed is on species, our framework and conclusions are also applicable to ecosystems, habitats, ecological communities, and genetic diversity, whether terrestrial, marine, or fresh water.

Link: http://www.ncbi.nlm.nih.gov/pubmed/21454781

60. Dodson EK, Root HT. 2013. Conifer regeneration following stand-replacing wildfire varies along an elevation gradient in a ponderosa pine forest, Oregon, USA. Forest Ecology and Management 302:163-170.

Type: Journal

Geographic Area: Oregon, USA

Keywords: resilience, environmental gradient, climate change-type drought, seedling establishment, natural regeneration

Abstract: Climate change is expected to increase disturbances such as stand-replacing wildfire in many ecosystems, which have the potential to drive rapid turnover in ecological communities. Ecosystem recovery, and therefore maintenance of critical structures and functions (resilience), is likely to vary across environmental gradients such as moisture availability, but has received little study. We examined conifer regeneration a decade following complete stand-replacing wildfire in dry coniferous forests spanning a 700 m elevation gradient where low elevation sites had relatively high moisture stress due to the combination of high temperature and low precipitation. Conifer regeneration varied strongly across the elevation gradient, with little tree regeneration at warm and dry low elevation sites. Logistic regression models predicted rapid increases in regeneration across the elevation gradient for both seedlings of all conifer species and ponderosa pine seedlings individually. This pattern was especially pronounced for well-established seedlings (≥ 38 cm in height). Graminoids dominated lower elevation sites following wildfire, which may have added to moisture stress for seedlings due to competition for water. These results suggest moisture stress can be a critical factor limiting conifer regeneration following stand-replacing wildfire in dry coniferous forests, with predicted increases in temperature and drought in the coming century likely to increase the importance of moisture stress. Strongly moisture limited forested sites may fail to regenerate for extended periods after stand-replacing disturbance, suggesting these sites are high priorities for management intervention where maintaining forests is a priority.

61. Dukes JS, Pontius J, Orwig D, Garnas JR, Rodgers ViL, Brazee N, Cooke B, Theoharides KA, Stange EE, Harrington R, Ehrenfeld J, Gurevitch J, Lerdau M, Stinson K, Wick R, Ayres M. 2009. Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: what can we predict? Canadian Journal of Forest Research 39:231-248.

Type: Journal

Geographic Area: Eastern North America

Compilers' Keywords: uncertainty, management, USA, Canada

Abstract: Climate models project that by 2100, the northeastern U.S. and eastern Canada will warm by approximately 3-5 °C with increased winter precipitation. These changes will affect trees directly and also indirectly through effects on "nuisance" species, such as insect pests, pathogens, and invasive plants. We review how basic ecological principles can be used to predict nuisance species' responses to climate change and how this is likely to impact northeastern forests. We then examine in detail the potential response of two pest species (hemlock woolly adelgid (*Adeleges tsugae* Annand) and forest tent caterpillar (*Malacosoma disstria* Hubner)); two pathogens (armillaria root rot (*Armillaria* spp.) and beech bark disease (*Cryptococcus fagisuga* Lind. + *Neonectria* spp.)); and two invasive plant species (glossy buckthorn (*Frangula alnus* Mill.) and oriental bittersweet (*Celastrus orbiculatus* Thunb.)). Several of these species are likely to have stronger or more widespread effects on forest composition and structure under the projected climate.

However, uncertainty pervades our predictions because we lack adequate data on the species and because some species depend on complex, incompletely understood, unstable relationships. While targeted research will increase our confidence in making predictions, some uncertainty will always persist. Therefore, we encourage policies that allow for this uncertainty by considering a wide range of possible scenarios.

Link: http://web.ics.purdue.edu/~jsdukes/DukesEtAl2009.pdf

62. Finch DM. 2012. Climate change in grasslands, shrublands, and deserts of the interior American West: a review and needs assessment. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-285. 139 p.

Type: Government Document

Geographic Area: Western USA

Keywords: climate change, grasslands, shrublands, deserts, assessment

Abstract: Recent research and species distribution modeling predict large changes in the distributions of species and vegetation types in the western interior of the United States in response to climate change. This volume reviews existing climate models that predict species and vegetation changes in the western United States, and it synthesizes knowledge about climate change impacts on the native fauna and flora of grasslands, shrublands and deserts of the interior American West. Species' responses will depend not only on their physiological tolerances but also on their phenology, establishment properties, biotic interactions, and capacity to evolve and migrate. The volume is divided into eight chapters that cover the topics of carbon mitigation and adaptation. Current and likely responses of species and habitats to climate change are examined in relation to taxonomic group and ecoregion and with regard to other disturbances. The volume ends with a review of management decision support needs and tools for assessing vulnerability of natural resources and conserving and restoring ecosystems that are or may be impacted by climate change.

Link: http://www.treesearch.fs.fed.us/pubs/41171

63. Franks SJ, Weis AE. 2008. A change in climate causes rapid evolution of multiple life-history traits and their interactions in an annual plant. Journal of Evolutionary Biology 21:1321-1334.

Type: Journal

Geographic Area: Southwestern USA

Keywords: *Brassica rapa*, common principal components analysis, developmental constraints, drought, global change, heterochrony, multivariate evolution, natural selection, phenology, resurrection paradigm

Abstract: Climate change is likely to spur rapid evolution, potentially altering integrated suites of life-history traits. We examined evolutionary change in multiple life history traits of the annual plant *Brassica rapa* collected before and after a recent 5-year drought in southern California. We used a direct approach to examining evolutionary change by comparing ancestors and descendants. Collections were made from two populations varying in average soil moisture levels, and lines propagated from the collected seeds were grown in a greenhouse and experimentally subjected to conditions simulating either drought (short growing season) or high precipitation (long growing season) years. Comparing ancestors and descendants, we found that the drought caused many changes in life history traits, including a shift to earlier flowering, longer duration of flowering, reduced peak flowering and greater skew of the flowering schedule. Descendants had thinner stems and fewer leaf nodes at the time of flowering than ancestors, indicating that the drought selected for plants that flowered at a smaller size and earlier ontogenetic stage rather than selecting for plants to develop more rapidly. Thus, there was no evidence for absolute developmental constraints to flowering time evolution. Common principal component analyses showed substantial differences in the matrix of trait covariances both between short and long growing season treatments and between populations. Although the covariances matrices were generally similar between ancestors and descendants, there was evidence for complex evolutionary changes in the relationships among the traits, and these changes depended on the population and treatment. These results show that a full appreciation of the impacts of global change on phenotypic evolution will entail an understanding of how changes in climatic conditions affect trait values and the structure of relationships among traits.

64. Grace J. 1987. Climate tolerance and the distribution of plants. New Phytologist 106:113-130.

Type: Journal

Geographic Area: Global

Keywords: plant distribution, tree line, life forms, temperature climatological variables

Summary: Boundaries to the distribution of life forms and species often coincide with isometric lines of climatological variables. Prominent examples of this phenomenon are the restriction of megaphanerophytes to areas where the mean temperature of the warmest month does not fall below about 10 °C, and the restriction of species within the British Isles to areas of specific summer or winter warmth. In the interpretation of these patterns, it is important to realize that the climate at plant surfaces may differ appreciably from that of the atmosphere as a whole, to an extent which depends on structural attributes of the vegetation. In particular, chamaephytes experience a much higher surface temperature than phanerophytes when comparisons are made in bright sunlight and this contributes to their success in mountains. Temperatures of flowers may similarly be elevated. In the British Isles, temperatures in the summer months may be

decisive in determining the success of many species, as physiological processes in C3-plants display near-linear relationships with temperatures in the range which prevails for most of the time. The life-cycle of native plants responds to environmental cues in such a way as to synchronize the development of the plant with the succession of seasons. When species are transplanted to different phytogeographical zones, as in forestry and horticulture, they frequently fail because of asynchrony.

Link: http://onlinelibrary.wiley.com/doi/10.1111/j.1469-8137.1987.tb04686.x/pdf

65. Grant GE, Tague CL, Allen CD. 2013. Watering the forest for the trees: an emerging priority for managing water in forest landscapes. Frontiers in Ecology and the Environment 11:314-321.

Type: Journal

Geographic Area: North America

Compilers' Keywords: forest management, hydrology, climate change, drought, water management, conservation

Abstract: Widespread threats to forests resulting from drought stress are prompting a re-evaluation of priorities for water management on forest lands. In contrast to the widely held view that forest management should emphasize providing water for downstream uses, we argue that maintaining forest health in the context of a changing climate may require focusing on the forests themselves and on strategies to reduce their vulnerability to increasing water stress. Management strategies would need to be tailored to specific landscapes but could include thinning, planting and selecting for drought-tolerant species, irrigating, and making more water available to plants for transpiration. Hydrologic modeling reveals that specific management actions could reduce tree mortality due to drought stress. Adopting water conservation for vegetation as a priority for managing water on forested lands would represent a fundamental change in perspective and potentially involve trade-offs with other downstream uses of water.

Link: http://www.fsl.orst.edu/wpg/pubs/13_Granteal_WFFT.pdf

66. Groffman PM, Rustad LE, Templer PH, Campbell JL, Christenson LM, Lany NK, Socci AM, Vadeboncoeur MA, Schaberg PG, Wilson GF, Driscoll CT, Fahey TJ, Fisk MC, Goodale CL, Green MB, Hamburg SP, Johnson CE, Mitchell MJ, Morse JL, Pardo LH, Rodenhouse NL. 2012. Long-term integrated studies show complex and surprising effects of climate change in the northern hardwood forest. BioScience 62:1056-1066.

Type: Journal

Geographic Area: Northeastern USA

Keywords: climate change, forests, long-term studies, northeastern United States, winter

Abstract: Evaluations of the local effects of global change are often confounded by the interactions of natural and anthropogenic factors that overshadow the effects of climate changes on ecosystems. Long-term watershed and natural elevation gradient studies at the Hubbard Brook Experimental Forest and in the surrounding region show surprising results demonstrating the effects of climate change on hydrologic variables (e.g., evapotranspiration, streamflow, soil moisture); the importance of changes in phenology on water, carbon, and nitrogen fluxes during critical seasonal transition periods; winter climate change effects on plant and animal community composition and ecosystem services; and the effects of anthropogenic disturbances and land-use history on plant community composition. These studies highlight the value of long-term integrated research for assessments of the subtle effects of changing climate on complex ecosystems.

Link: http://www.treesearch.fs.fed.us/pubs/42303

67. Guisan A, Thuiller W. 2005. Predicting species distribution: offering more than simple habitat models. Ecology Letters 8:993-1009.

Type: Journal

Geographic Area: Global

Keywords: dispersal, ecological niche theory, future projections, habitat suitability maps, population dynamics, prediction errors, predictive biogeography, spatial scales, species distribution models

Abstract: In the last two decades, interest in species distribution models (SDMs) of plants and animals has grown dramatically. Recent advances in SDMs allow us to potentially forecast anthropogenic effects on patterns of biodiversity at different spatial scales. However, some limitations still preclude the use of SDMs in many theoretical and practical applications. Here, we provide an overview of recent advances in this field, discuss the ecological principles and assumptions underpinning SDMs, and highlight critical limitations and decisions inherent in the construction and evaluation of SDMs. Particular emphasis is given to the use of SDMs for the assessment of climate change impacts and conservation management issues. We suggest new avenues for incorporating species migration, population dynamics, biotic interactions and community ecology into SDMs at multiple spatial scales. Addressing all these issues requires a better integration of SDMs with ecological theory.

Link: http://perceval.bio.nau.edu/downloads/grail/climate_seminar/section2/Guisan_and_Thuiller05.pdf

68. Hanson HC. 1958. Principles concerned in the formation and classification of communities. The Botanical Review 24:65-125.

Type: Journal

Geographic Area: Global

Compilers' Keywords: plant ecology, population, genetics

Summary: Characteristics of species that are important in the formation of plant groupings are classified as basic principles, as follows: Every species has certain relations to the physical environment: (a) essential requirements, (b) range of ecological amplitude, (c) capacity to utilize available resources. Every plant has relations with other organisms: (a) competition, (b) association of species, (c) reproduction and dispersal, (d) changes in relations because of grazing, mowing or other disturbance, (e) parasitism, (f) mutualism and commensalism. The ecological success of a species or a population depends upon its capacity to cope with its physical environment and associated organisms in relationships, such as those stated in these principles. Groupings of species in stands or communities are formed because of similarities and differences among them with regard to these principles and because of similarities and differences in habitats. The best descriptions are based upon analysis which reveals intrinsic characteristics of the stands. The more detailed and accurate the analysis, the more valuable is the description. Stands that show the greatest number of characteristics in common may be grouped into community types or abstract communities of various kinds. Precise similarity of stands in each kind of type is not essential. Various classifications of stands and community-types may be made, depending upon the purpose to be served. Some of the bases of classification are: similarities and differences in composition and structure, or in complexity of communities; relations to habitat, succession or geographic distribution; physiognomic appearance; and economic values. Each of these is discussed with examples.

69. Harel C, Holzapfel C, Sternberg M. 2011. Seed mass and dormancy of annual plant populations and communities decrease with aridity and rainfall predictability. Basic and Applied Ecology 12:674-684.

Type: Journal

Geographic Area: Israel, Middle East

Keywords: desert, germination strategies, Mediterranean, plant community, seed bank, seed size

Abstract: Several theoretical and empirical studies have examined the influence of environmental conditions on seed traits and germination strategies of annual species. A positive relationship between seed mass and dormancy has been described for annuals occupying climatically unpredictable ecosystems. Larger-seeded species tend to have higher seedling survival rates, while dormancy allows a bet-hedging strategy in unpredictable environments. Until now, these ideas have been addressed primarily for only one or a few focal species, without considering differences among populations and communities. The novelty of the present study lies in the population and community-level approach, where a comprehensive seed trait database including 158 annual species occurring along a gradient of rainfall variability and aridity in Israel was used to ask the following question: Does average seed mass and dormancy of annual populations and communities decrease with increasing aridity and rainfall unpredictability? Soil seed bank samples were collected at the end of the summer drought, before the onset of the rains, from four plant communities. Germination was tested under irrigated conditions during three consecutive germination seasons to determine the overall seed germinability in each soil sample. Seed mass was obtained from newly produced seeds collected at the study sites in late spring. The community level results showed that, in contrast to common theoretical knowledge, seed mass and dormancy of the dominant annual species decreased with increasing aridity and rainfall variability. Accordingly, a negative correlation was found between seed mass and seed germination fractions. The present study demonstrates that an analysis of seed traits along climatic gradients is significantly improved by approaches that target both population and community levels simultaneously. A critical evaluation sheds new light upon the selective pressures that act on seed ecology of annuals along a climatic gradient and facilitates formulation of more mechanistic hypotheses about factors governing critical seed traits.

Link: http://www.researchgate.net/publication/216466974_Seed_mass_and_dormancy_of_annual_plant_populations_and_communities_decreases_with_aridity_and_rainfall_predictability/file/9fcfd509bd306822a5.pdf

70. Haughian SR, Burton PJ, Taylor SW, Curry CL. 2012. Expected effects of climate change on forest disturbance regimes in British Columbia. BC Journal of Ecosystems and Management 13:1-24.

Type: Journal

Geographic Area: Western Canada

Keywords: disturbance ecology, ecoprovinces, forest pathogens, insect outbreaks, tree mortality, wildfire, wind damage

Abstract: In this article we summarize the changes to forest disturbance regimes and forest damage that are projected to emerge under a changing climate in British Columbia (BC). We focus on regionally-specific expectations so that land managers can take pro-active steps to avoid or adapt to future conditions. While some projections are based on extrapolations of recent multi decadal trends, most are based on global climate models (GCMs) that utilize a range of scenarios for possible atmospheric greenhouse gas emission trajectories over the next century. Regardless of the models or emission scenarios used, it is universally expected that BC will experience warmer air temperatures. Projections for precipitation are more variable, ranging from slight decreases in some regions to substantial increases in others, which have different effects on disturbance projections. Forest fires are expected to be more frequent and more intense in the southern half of the province and in the Taiga Plains, but less important in other portions of the

province. Forest insects and fungal pathogens are expected to more fully occupy the current range of their host tree species and expand ranges northward and to higher elevations along with their hosts. More frequent and more detrimental pest outbreaks are expected in some regions when several years of favourable weather align, which is more likely under current and projected climate trends. Wind damage, floods, and landslides can be expected to increase on terrain where they are already a risk factor. For many agents of tree mortality, an expansion or shifting of the seasonal window of activity is expected, but these changes vary among regions within BC. The prediction of future forest disturbance regimes is in its infancy, requiring a much more concerted effort in compiling both empirical and simulated data, but managers may wish to adjust plans accordingly where there is consensus among projections.

Link: http://www.jem.forrex.org/index.php/jem/article/viewArticle/152

71. Heikkinen RK, Luoto M, Araújo MB, Virkkala R, Thuiller W, Sykes MT. 2006. Methods and uncertainties in bioclimatic envelope modelling under climate change. Progress in Physical Geography 20:751-777.

Type: Journal

Geographic Area: Global

Keywords: bioclimatic model, climate change, land cover, model performance, modelling methods, niche properties, scale, species distribution model, species geography, uncertainty, validation

Abstract: Potential impacts of projected climate change on biodiversity are often assessed using single-species bioclimatic 'envelope' models. Such models are a special case of species distribution models in which the current geographical distribution of species is related to climatic variables so to enable projections of distributions under future climate change scenarios. This work reviews a number of critical methodological issues that may lead to uncertainty in predictions from bioclimatic modelling. Particular attention is paid to recent developments of bioclimatic modelling that address some of these issues as well as to the topics where more progress needs to be made. Developing and applying bioclimatic models in an informative way requires good understanding of a wide range of methodologies, including the choice of modelling technique, model validation, collinearity, autocorrelation, biased sampling of explanatory variables, scaling and impacts of nonclimatic factors. A key challenge for future research is integrating factors such as land cover, direct CO_2 effects, biotic interactions and dispersal mechanisms into species-climate models. We conclude that, although bioclimatic envelope models have a number of important advantages, they need to be applied only when users of models have a thorough understanding of their limitations and uncertainties.

Link: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.105.4455&rep=rep1&type=pdf

72. Hennon PE, D'Amore DV, Schaberg PG, Wittwer DT, Shanley CS. 2012. Shifting climate, altered niche, and a dynamic conservation strategy for yellow-cedar in the North Pacific Coastal Rainforest. BioScience 62:147-158.

Type: Journal

Geographic Area: Western Canada

Keywords: climate adaptation, forest decline, root cold tolerance, *Callitropsis nootkatensis*, *Chamaecyparis nootkatensis*

Abstract: The extensive mortality of yellow-cedar along more than 1,000 kilometers of the northern Pacific coast of North America serves as a leading example of climate effects on a forest tree species. In this article, we document our approaches to resolving the causes of tree death, which we explain as a cascade of interacting topographic, forest-structure, and microclimate factors that act on a unique vulnerability of yellow-cedar to fine-root freezing. The complex causes of tree mortality are reduced to two risk factors—snow depth and soil drainage—which are then used to model present and future cedar habitat suitability. We propose a dynamic, comprehensive conservation strategy for this valuable species on the basis of zones created by shifting climate, cedar's ecological niche, and observed risk factors. Research on yellow-cedar decline is offered as a template for understanding and adapting to climate change for other climate-forest issues.

Link: http://www.nrs.fs.fed.us/pubs/jrnl/2012/nrs_2012_hennon_001.pdf

73. Hobbs RJ, Higgs E, Harris JA. 2009. Novel ecosystems: implications for conservation and restoration. Trends in Ecology and Evolution 24:599-605.

Type: Journal

Geographic Area: Global

Compilers' Keywords: climate change, environmental monitoring, human activities, models, population density, ecosystem function, migration

Abstract: Many ecosystems are rapidly being transformed into new, non-historical configurations owing to a variety of local and global changes. We discuss how new systems can arise in the face of primarily biotic change (extinction and/or invasion), primarily abiotic change (e.g. land use or climate change) and a combination of both. Some changes will result in hybrid systems retaining some original characteristics as well as novel elements, whereas larger changes will result in novel systems, which comprise different species, interactions and functions. We suggest that these novel systems will require significant revision of conservation and restoration norms and practices away from the traditional place-based focus on existing or historical assemblages.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19683830

74. Holmes J, Lowe J, Wolff E, Srokosz M. 2011. Rapid climate change: lessons from the recent geological past. Global and Planetary Change 79:157-162.

Type: Journal

Geographic Area: Global

Keywords: rapid climate change, Late Quaternary, thermohaline circulation, meridional overturning circulation, 8.2 ka event, Termination I

Abstract: Rapid, or abrupt, climate change is regarded as a change in the climate system to a new state following the crossing of a threshold. It generally occurs at a rate exceeding that of the change in the underlying cause. Episodes of rapid climate change abound in the recent geological past (defined here as the interval between the last glacial maximum, dated to approximately 20,000 years ago, and the present). Rapid climate changes are known to have occurred over time periods equal to or even less than a human lifespan: moreover, their effects on the global system are sufficiently large to have had significant societal impacts. The potential for similar events to occur in the future provides an important impetus for investigating the nature and causes of rapid climate change. This paper provides a brief overview of rapid climate change and an introduction to this special issue, which presents results generated by the palaeoclimatic component of the UK Natural Environment Research Council's rapid climate change programme, called RAPID. The papers in the special issue employ palaeoclimatic proxy data-sets obtained from marine, ice core and terrestrial archives to reconstruct rapid climate change during the last glacial cycle, its subsequent termination and the ensuing Holocene interglacial; some papers also report new attempts to match the palaeoclimate data to hypothesised causes through numerical modelling. The results confirm the importance of freshwater forcing in triggering changes in Atlantic meridional overturning circulation (MOC) and the close Links between MOC and rapid climate change. While advancing our understanding of these Linkages, the RAPID research has highlighted the need for further research in order to elucidate more specific details of the mechanisms involved.

Link: http://www.see.ed.ac.uk/~shs/Climate%20change/Data%20sources/Rapid%20climate%20change%20NERC.pdf

75. Ibáñez B, Ibáñez I, Gómez-Aparicio L, Ruiz-Benito P, García LV, Marañón T, Thuiller W. 2014. Contrasting effects of climate change along life stages of a dominant tree species: the importance of soil-climate interactions. Diversity and Distributions 20:872-883.

Type: Journal

Geographic Area: Southern Spain

Keywords: Bayesian analysis, declining forest, demographic rates, establishment, forest inventory data, Mediterranean region

Abstract: For tree species, adult survival and seedling and sapling recruitment dynamics are the main processes that determine forest structure and composition. Thus, studying how these two life stages may be affected by climate change in the context of other abiotic and biotic variables is critical to understand future population trends. The aim of this study was to assess the sustainability of cork oak (*Quercus suber*) forests at the core of its distributional range under future climatic conditions. Using forest inventory data collected at two periods 10 years apart, we performed a comprehensive analysis to evaluate the role of different abiotic and biotic factors on adult survival and recruitment patterns. We found that both life stages were influenced by climatic conditions, but in different ways. Adult tree survival was negatively impacted by warmer spring temperatures, while recruitment was positively affected by warmer winter temperatures. Our results also revealed the importance of soil texture as a modulator of winter precipitation effects on adult survival. With higher winter precipitation, adult survival increased in sandy soils and decreased in clayish soils. Therefore, under predicted future climate scenarios of wetter winters and warmer temperatures, the presence of cork oaks is more likely to occur in sandy soils vs. clayish soils. Biotic conditions also affected these life stages. We found a negative effect of heterospecific but not conspecific trees on both adult survival and seedling recruitment. Overall, the sustainability of the studied forests will be highly dependent not only on future climatic trends, but also on their interaction with other key factors—soil properties in particular—that modulate the effects of climate on demographic rates.

Link: http://www.diverbos.com/wp-content/uploads/2014/07/Ibanez_2014_DD_wAppendix.pdf

76. Iverson LR, Matthews SN, Prasad AM, Peters MP, Yohe G. 2012. Development of risk matrices for evaluating climatic change responses of forested habitats. Climatic Change 114:231-243.

Type: Journal

Geographic Area: Eastern USA

Compilers' Keywords: extinction, migration, approach

Abstract: We present an approach to assess and compare risk from climate change among multiple species through a risk matrix, in which managers can quickly prioritize for species that need to have strategies developed, evaluated further, or watched. We base the matrix upon earlier work towards the National Climate Assessment for potential damage to infrastructures from climate change. Risk is defined here as the product of the likelihood of an event occurring and the consequences or impact of that event. In the context of species habitats, the likelihood component is related to the potential changes in suitable habitat modeled at various times during this century. Consequences

are related to the adaptability of the species to cope with the changes, especially the increasing intensity and/or frequency of disturbance events that are projected. We derived consequence scores from nine biological and 12 disturbance characteristics that were pulled from literature for each species. All data were generated from an atlas of climate change for 134 trees of the eastern United States. We show examples which depict a wide range of risk for tree species of northern Wisconsin, including species that may gain substantial habitat as well as lose substantial habitat, both of which will require the development of strategies to help the ecosystems adapt to such changes.

Link: http://www.nrs.fs.fed.us/pubs/jrnl/2012/nrs_2012_iverson_001.pdf

77. Jones EA, Reed DD, Desanker PV. 1994. Ecological implications of projected climate change scenarios in forest ecosystems of central North America. Agricultural and Forest Meteorology 72:31-46.

Type: Journal

Geographic Area: Central North America

Compilers' Keywords: climate change impacts, projections, commercial tree species, GCM, weather stations

Abstract: Climate change scenarios in central North America were projected for selected weather stations using a stochastic daily weather simulation model. The projections were conditioned on changes in seasonal temperature and precipitation as predicted by several global climate models. The impacts of these projected changes on temperate forest ecosystems were evaluated through projected changes in such variables as average annual temperature, average growing season temperature, and the ratio of potential evaporation to precipitation during July and August. Even the mildest climate change scenario examined indicated that ecologically significant changes could occur in the composition and productivity of these forests. The possibility also exists that climatically induced regional decline episodes for a number of important commercial species could occur in the northern temperate forests of central North America.

Link: http://www.webpages.uidaho.edu/nitrogen-gradient/Publications/Jones_1994_Agric_For_Metogy.pdf

78. Kallarackal J, Roby TJ. 2012. Responses of trees to elevated carbon dioxide and climate change. Biodiversity and Conservation 21:1327-1342.

Type: Journal

Geographic Area: Global

Keywords: trees, climate change, responses, carbon dioxide, temperature, growth, FACE

Abstract: The enhancement in photosynthesis at elevated concentration of carbon dioxide level than the ambient level existing in the atmosphere is widely known. However, many of the earlier studies were based on the instantaneous responses of plants grown in pots. The availability of field chambers for growing trees, and long-term exposure studies of tree species to elevated carbon dioxide, has changed much of our views on carbon dioxide acting as a fertiliser. Several tree species showed acclimation or even down-regulation of photosynthetic responses while a few of them showed higher photosynthesis and better growth responses. Whether elevated levels of carbon dioxide can serve as a fertilizer in a changed climate scenario still remains an unresolved question. Forest-Air-Carbon dioxide Enrichment (FACE) sites monitored at several locations have shown lately, that the acclimation or down regulation as reported in chamber studies is not as widespread as originally thought. FACE studies predict that there could be an increase of 23-28% productivity of trees at least till 2050. However, the increase in global temperature could also lead to increased respiration, and limitation of minerals in the soil could lead to reduced responses in growth. Elevated carbon dioxide induces partial closure of leaf stomata, which could lead to reduced transpiration and more economical use of water by the trees. Even if the carbon dioxide acts as a fertilizer, the responses are more pronounced only in young trees. And if there are variations in species responses to growth due to elevated carbon dioxide, only some species are going to dominate the natural vegetation. This will have serious implications on the biodiversity and the structure of the ecosystems. This paper reviews the research done on trees using elevated CO_2 and tries to draw conclusions based on different methods used for the study. It also discusses the possible functional variations in some tree species due to climate change.

79. Keenan TF, Hollinger DY, Bohrer G, Dragoni D, Munger JW, Schmid HP, Richardson AD. 2013. Increase in forest water-use efficiency as atmospheric carbon dioxide concentrations rise. Nature 499:324-327.

Type: Journal

Geographic Area: Northern Hemisphere

Compilers' Keywords: ecosystem, plant leaves, trees

Abstract: Terrestrial plants remove CO_2 from the atmosphere through photosynthesis, a process that is accompanied by the loss of water vapour from leaves. The ratio of water loss to carbon gain, or water-use efficiency, is a key characteristic of ecosystem function that is central to the global cycles of water, energy and carbon. Here we analyse direct, long-term measurements of whole-ecosystem carbon and water exchange. We find a substantial increase in water-use efficiency in temperate and boreal forests of the Northern Hemisphere over the past two decades. We systematically assess various competing hypotheses to explain this trend, and find that the observed increase is most consistent with a strong CO_2 fertilization effect. The results suggest a partial closure of stomata-small pores on the leaf surface that regulate gas exchange-to maintain a near-constant concentration of CO_2 inside the leaf even under continually increasing atmospheric CO_2 levels. The

observed increase in forest water-use efficiency is larger than that predicted by existing theory and 13 terrestrial biosphere models. The increase is associated with trends of increasing ecosystem-level photosynthesis and net carbon uptake, and decreasing evapotranspiration. Our findings suggest a shift in the carbon— and water—based economics of terrestrial vegetation, which may require a reassessment of the role of stomatal control in regulating interactions between forests and climate change, and a re-evaluation of coupled vegetation-climate models.

Link: http://www.ncbi.nlm.nih.gov/pubmed/23842499

80. Kramer K, Leinonen I, Loustau D. 2000. The importance of phenology for the evaluation of impact of climate change on growth of boreal, temperate and Mediterranean forests ecosystems: an overview. International Journal of Biometeorology 44:67-75.

Type: Journal

Geographic Area: Europe

Keywords: annual cycle, climate change scenarios, frost hardiness, growth, forest growth model, photosynthetic capacity, competition, water availability

Abstract: An overview is presented of the phenological models relevant for boreal coniferous, temperate-zone deciduous and Mediterranean coniferous forest ecosystems. The phenology of the boreal forests is mainly driven by temperature, affecting the timing of the start of the growing season and thereby its duration, and the level of frost hardiness and thereby the reduction of foliage area and photosynthetic capacity by severe frost events. The phenology of temperate-zone forests is also mainly driven by temperature. Since temperate-zone forests are mostly mixed-species deciduous forests, differences in phenological response may affect competition between tree species. The phenology of Mediterranean coniferous forests is mainly driven by water availability, affecting the development of leaf area, rather than the timing of phenological events. These phenological models were subsequently coupled to the process-based forest model FORGRO to evaluate the effect of different climate change scenarios on growth. The results indicate that the phenology of each of the forest types significantly affects the growth response to a given climate change scenario. The absolute responses presented in this study should, however, be used with caution as there are still uncertainties in the phenological models, the growth models, the parameter values obtained and the climate change scenarios used. Future research should attempt to reduce these uncertainties. It is recommended that phenological models that describe the mechanisms by which seasonality in climatic drivers affects the phenological aspects of trees should be developed and carefully tested. Only by using such models may we make an assessment of the impact of climate change on the functioning and productivity of different forest ecosystems.

Link: http://research.eeescience.utoledo.edu/lees/papers_pdf/Kramer_2000_IntJBiomet.pdf

81. Kreyling J. 2010. Winter climate change: a critical factor for temperate vegetation performance. Ecology 97:1939-1948.

Type: Journal

Geographic Area: Global

Keywords: climate change, frost, global warming, snow, temperate zone, winter ecology

Abstract: Winter ecological processes are important drivers of vegetation and ecosystem functioning in temperate ecosystems. There, winter conditions are subject to rapid climate change. The potential loss of a longer-lasting snow cover with implications to other plant-related climate parameters and overwintering strategies make the temperate zone particularly vulnerable to winter climate change. A formalized literature search in the ISI Web of Science shows that plant related research on the effects of winter climate change is generally underrepresented. Temperate regions in particular are rarely studied in this respect, although the few existing studies imply strong effects of winter climate change on species ranges, species compositions, phenology, or frost injury. The generally positive effect of warming on plant survival and production may be counteracted by effects such as an increased frost injury of roots and shoots, an increased insect pest risk, or a disrupted synchrony between plants and pollinators. Based on the literature study, gaps in current knowledge are discussed. Understanding the relative effects of interacting climate parameters, as well as a stronger consideration of short-term events and variability of climatic conditions is urgent. With respect to plant response, it would be particularly worthwhile to account for hidden players such as pathogens, pollinators, herbivores, or fungal partners in mycorrhization.

Link: ftp://norbif.uio.no/pub/outgoing/runeho/KR/Krey10Ecol91-1939.pdf

82. Li J, Wang MH, Ho YS. 2011. Trends in research on global climate change: a Science Citation Index Expanded-based analysis. Global and Planetary Change 77:13-20.

Type: Journal

Geographic Area: Global

Keywords: word cluster analysis, bibliometrics, climate change, research trend, model

Abstract: This study was conceived to evaluate the global scientific output of climate change research over the past 18 years and to assess the characteristics of the research patterns, tendencies, and methods in the papers. Data were based on the online version of Science Citation Index Expanded from 1992 to 2009. Articles referring to climate change were assessed by distribution of source countries, source institutes, paper titles, author keywords, KeyWords Plus, abstracts, and the most cited articles in these years. By synthetic analysis of the four kinds of keywords, it was concluded that the items "temperature," "environment," "precipitation," "greenhouse gas," "risk," and "biodiversity" will be the foci of climate change research in the 21st century, while "model," "monitoring," and "remote sensing" will continue to be the leading research methods. A novel method, "phylogeography," may have a strong application potential in the near future.

Link: http://trend.asia.edu.tw/Visitors/JF%20Li/Glo%20Pla%20Cha77,%2013.pdf

83. Lindner M, Maroschek M, Netherer S, Kremer A, Barbati A, Garcia-Gonzalo J, Seidl R, Delzon S, Corona P, Kolström M, Lexer MJ, Marchetti M. 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. Forest Ecology and Management 259:698-709.

Type: Journal

Geographic Area: Europe

Keywords: climate change impacts, adaptive capacity, forestry, vulnerability, regional differences

Abstract: This study compiles and summarizes the existing knowledge about observed and projected impacts of climate change on forests in Europe. Forests will have to adapt not only to changes in mean climate variables but also to increased variability with greater risk of extreme weather events, such as prolonged drought, storms and floods. Sensitivity, potential impacts, adaptive capacity, and vulnerability to climate change are reviewed for European forests. The most important potential impacts of climate change on forest goods and services are summarized for the Boreal, Temperate Oceanic, Temperate Continental, Mediterranean, and mountainous regions. Especially in northern and western Europe the increasing atmospheric CO_2 content and warmer temperatures are expected to result in positive effects on forest growth and wood production, at least in the short–medium term. On the other hand, increasing drought and disturbance risks will cause adverse effects. These negative impacts are very likely to outweigh positive trends in southern and eastern Europe. From west to east, the drought risk increases. In the Mediterranean regions productivity is expected to decline due to strongly increased droughts and fire risks. Adaptive capacity consists of the inherent adaptive capacity of trees and forest ecosystems and of socio-economic factors determining the capability to implement planned adaptation. The adaptive capacity in the forest sector is relatively large in the Boreal and the Temperate Oceanic regions, more constrained by socio-economic factors in the Temperate Continental, and most limited in the Mediterranean region where large forest areas are only extensively managed or unmanaged. Potential impacts and risks are best studied and understood with respect to wood production. It is clear that all other goods and services provided by European forests will also be impacted by climate change, but much less knowledge is available to quantify these impacts. Understanding of adaptive capacity and regional vulnerability to climate change in European forests is not well developed and requires more focused research efforts. An interdisciplinary research agenda integrated with monitoring networks and projection models is needed to provide information at all levels of decision making, from policy development to the management unit.

Link: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.466.7250&rep=rep1&type=pdf

84. Littell J, Peterson DL, Tjoelker M. 2008. Douglas-fir growth in mountain ecosystems: water limits tree growth from stand to region. Ecological Monographs 78:349-368.

Type: Journal

Geographic Area: Northwestern USA

Keywords: climate change, climate effects, dendrochronology, Douglas-fir, ecological amplitude, ecophysiology, limiting factors, niche, *Pseudotsuga menziesii*, tree growth, water balance deficit

Abstract: The purpose of this work is to understand the nature of growth–climate relationships for Douglas-fir (*Pseudotsuga menziesii*) across the climatic dimensions of its niche. We used a combination of biophysically informed sampling (to identify sample sites) and dendroclimatology (to identify growth–climate relationships) along a climate gradient in northwestern United States mountain ecosystems from the western Olympic Peninsula, Washington to the eastern Rocky Mountain Front, Montana. We used a multi-scale sampling strategy that accounted for continentality, physiography, and topography as non-climatic factors that could influence climate and alter tree growth. We developed a network of 124 Douglas-fir tree-ring chronologies and explored growth–climate correlations across the sampled gradients. We considered two different spatial scales of monthly and seasonal climate variables as potential controlling factors on tree growth. Annual radial growth in 60–65% of the plots across the region is significantly correlated with precipitation, drought, or water balance during the late summer prior to growth and the early summer the year of growth. In a few plots, growth is positively correlated with cool-season temperature or negatively correlated with snowpack. Water availability is therefore more commonly limiting to Douglas-fir growth than energy limitations on growing season length. The first principal component derived from the chronologies is significantly correlated with independent drought reconstructions. The sensitivity of Douglas-fir to summer water balance deficit (potential evapotranspiration minus actual evapotranspiration) indicates that increases in April to September temperature without increases in summer precipitation or soil moisture reserves are likely to cause decreases in growth over much of the sampled area, especially east of the Cascade crest. In contrast, Douglas-fir may exhibit growth

increases at some higher elevation sites where seasonal photosynthesis is currently limited by growing-season length or low growing-season temperature. Life-history processes such as establishment, growth, and mortality are precursors to changes in biogeography, and measurements of climate effects on those processes can provide early indications of climate-change effects on ecosystems.

Link: http://www.fs.fed.us/pnw/pubs/journals/pnw_2008_littell001.pdf

85. Littell J, Elsner MM, Mauger GS, Lutz E, Hamlet AF, Salathe E. 2011. **Regional climate and hydrologic change in the Northern U.S. Rockies and Pacific Northwest: internally consistent projections of future climate for resource management.** Seattle (WA): Climate Impacts Group, University of Washington. 109 p.

Type: Report

Geographic Area: Western USA

Compilers' Keywords: planning, natural resources, global climate model GCM, watershed

Rationale and Objectives: Planning for the effects of climate change on natural resources often requires detailed projections of future climate at scales consistent with the processes managers typically consider. While it is numerically possible to produce downscaled climate at very fine scales (< 5 km), both the absence of a sufficiently dense network of long term climate observations and the presence of local contingencies such as topography and land surface feedbacks from vegetation and snowpack make accurate estimation at these scales difficult and less tractable without very detailed local information. For such purposes as developing adaptation strategies, vulnerability assessments, climate impacts assessments, and specific resource modeling at landscape scales, downscaled projections can be developed that maximize translation of climatic information from the coarser scales of global climate models (GCMs) to more local scales. This project was designed to provide climate information that meets those needs and creates a basis for more detailed work or for a more comprehensive approach to downscaling and regional climate modeling. The goal of this project was to (1) develop consistent historical and future downscaled climate and hydrologic data and projections using the same methodology for several major river basins in the western United States (Columbia, upper Missouri, upper Colorado, and Great Basins) and (2) summarize that information in forms consistent with the needs of the funding agencies. This report describes where to get the information developed as well as the methods, results obtained, uses of and uncertainties associated with the data and projections.

Link: http://cses.washington.edu/picea/USFS/pub/Littell_etal_2010/Littell_etal._2011_Regional_Climatic_And_Hydrologic_Change_USFS_USFWS_JVA_17Apr11_reduced.pdf

86. Lloret F, Peñuelas J, Prieto P, Llorens L, Estiarte M. 2009. **Plant community changes induced by experimental climate change: seedling and adult species composition.** Perspectives in Plant Ecology, Evolution and Systematics 11:53-63.

Type: Journal

Geographic Area: Mediterranean

Keywords: climate change, drought, Mediterranean, seedling establishment, vegetation dynamics, warming

Abstract: Experimental manipulation of climate provides a powerful tool for studying plant community dynamics with respect to current climate change. We experimentally investigated the vegetation dynamics of a Mediterranean shrubland under directional climate change by manipulating rain and temperature at stand level throughout 7 years. We focused on seedling establishment in relation to the between-year variability of drought conditions. We also compared seedling dynamics to changes in the established adult vegetation to assess the coupling between both dynamics. We used multivariate techniques (principal response curves (PRC) and redundancy analysis (RDA)) to explore changes in the whole community, and Generalized Linear Model (GLZM) to analyze the influence of drought on the abundance and survival of the most abundant species. Drought treatment induced significant changes in the species composition of the seedlings, via a differential decrease in the seedling density of most species. No species was particularly favoured in terms of seedling abundance under water-deficit conditions. Warming only explained a low percentage of the variability in seedling species composition. The emergence of seedlings in control plots—which may be considered an estimation of the between-year variability in the conditions for seedling establishment—was a better predictor of seedling emergence in experimental plots than climate manipulation treatments. The PRC analysis of the adults showed dynamics that were different from those recorded for seedlings, and it also showed that drought treatment significantly explained species composition. This result is reinforced by the change in the relative abundance of seedling and adults of the more common species in the drought and warming treatments, supporting the hypothesis that climatic directional change heightens discrepancies between recruitment and the adult performance. The RDA analysis applied to species composition at the end of the experiment failed, however, to attain any statistical significance. The warming treatment did not produce any significant shifts in adult vegetation. In conclusion, directional climate change—particularly drier conditions in Mediterranean shrublands—would result in a change in the recruitment of the plant community. This change in seedling recruitment tends to be different from the dynamics of adults, suggesting that potential adult mortality would not be compensated by actual seedling recruitment, thus enhancing shifts in community composition.

87. Logan JA, Regniere J, Powell JA. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and the Environment 1:130-137.

Type: Journal

Geographic Area: North America

Compilers' Keywords: climate change, insect outbreaks, forest management, review

Abstract: Forest insects and pathogens are the most pervasive and important agents of disturbance in North American forests, affecting an area almost 50 times larger than fire and with an economic impact nearly five times as great. The same attributes that result in an insect herbivore being termed a "pest" predispose it to disruption by climate change, particularly global warming. Although many pest species have co-evolved relationships with forest hosts that may or may not be harmful over the long term, the effects on these relationships may have disastrous consequences. We consider both the data and models necessary to evaluate the impacts of climate change, as well as the assessments that have been made to date. The results indicate that all aspects of insect outbreak behavior will intensify as the climate warms. This reinforces the need for more detailed monitoring and evaluations as climatic events unfold. Luckily, we are well placed to make rapid progress, using software tools, databases, and the models that are already available.

Link: http://www.usu.edu/beetle/documents/Loganet.al.2003.pdf

88. Maherali H, DeLucia EH. 2000. Xylem conductivity and vulnerability to cavitation of ponderosa pine growing in contrasting climates. Tree Physiology 20:859-867.

Type: Journal

Geographic Area: Southwestern USA

Keywords: hydraulic conductivity, leaf/sapwood area ratio, temperature, vapor pressure deficit, xylem cavitation

Summary: We examined the effects of increased transpiration demand on xylem hydraulic conductivity and vulnerability to cavitation of mature ponderosa pine (*Pinus ponderosa* Laws.) by comparing trees growing in contrasting climates. Previous studies determined that trees growing in warm and dry sites (desert) had half the leaf/sapwood area ratio (AL/AS) and more than twice the transpiration rate of trees growing in cool and moist sites (montane). We predicted that high transpiration rates would be associated with increased specific hydraulic conductivity (KS) and increased resistance to xylem cavitation. Desert trees had 19% higher KS than montane trees, primarily because of larger tracheid lumen diameters. Predawn water potential and water potential differences between the soil and the shoot were similar for desert and montane trees, suggesting that differences in tracheid anatomy, and therefore KS, were caused primarily by temperature and evaporative demand, rather than soil drought. Vulnerability to xylem cavitation did not differ between desert and montane populations. A 50% loss in hydraulic conductivity occurred at water potentials between –2.61 and –2.65 MPa, and vulnerability to xylem cavitation did not vary with stem size. Minimum xylem tensions of desert and montane trees did not drop below –2.05 MPa. Foliage turgor loss point did not differ between climate groups and corresponded to mean minimum xylem tensions in the field. In addition to low AL/AS, high KS in desert trees may provide a way to increase tree hydraulic conductivity in response to high evaporative demand and prevent xylem tensions from reaching values that cause catastrophic cavitation. In ponderosa pine, the flexible responses of AL/AS and KS to climate may preclude the existence of significant intraspecific variation in the vulnerability of xylem to cavitation.

Link: http://classes.uleth.ca/201301/biol3460a/Lab%20Materials/Lab%20Presentation%20Project/Project%202/Maherali%20TreePhysiol%202000.pdf

89. Maherali H, Williams BL, Paige KN, DeLucia EH. 2002. Hydraulic differentiation of ponderosa pine populations along a climate gradient is not associated with ecotypic divergence. Functional Ecology 16:510-521.

Type: Journal

Geographic Area: Southwestern USA

Keywords: ecotypes, genetic variation, hydraulic architecture, microsatellites, phenotypic plasticity

Summary: *Pinus ponderosa* occurs in a range of contrasting environments in the western USA. Xeric populations typically have lower leaf : sapwood area ratio (AL/AS) and higher whole-tree leaf specific hydraulic conductance (KL) than mesic populations. These climate driven shifts in hydraulic architecture are considered adaptive because they maintain minimum leaf water potential above levels that cause xylem cavitation. Using a common garden study, we examined whether differences in biomass allocation and hydraulic architecture between *P. ponderosa* populations originating from isolated outcrops in the Great Basin desert and Sierran montane environments were caused by ecotypic differentiation or phenotypic plasticity. To determine if populations were genetically differentiated and if phenotypic and genetic differentiation coincided, we also characterized the genetic structure of these populations using DNA microsatellites. Phenotypic differentiation in growth, biomass allocation and hydraulic architecture was variable among populations in the common garden. There were no systematic differences between desert and montane climate groups that were consistent with adaptive expectations. Drought had no effect on the root : shoot and needle : stem ratio, but reduced seedling biomass accumulation, leaf area ratio, AL/AS and KL. Stem hydraulic conductance (KH) was strongly size dependent, and was lower in drought plants, primarily because of lower growth. Although microsatellites

were able to detect significant non-zero ($P < 0.001$) levels of differentiation between populations, these differences were small and were not correlated with geographic separation or climate group. Estimates of genetic differentiation among populations were low (< 5%), and almost all the genetic variation (> 95%) resided within populations, suggesting that gene flow was the dominant factor shaping genetic structure. These results indicate that biomass allocation and hydraulic differences between desert and montane populations are not the result of ecotypic differentiation. Significant drought effects on leaf : sapwood allocation and KL suggest that phenotypic differentiation between desert and montane climates could be the result of phenotypic plasticity.

Link: http://www.life.illinois.edu/delucia/FEC510.pdf

90. Michaelian M, Hogg EH, Hall RJ, Arsenault E. 2011. Massive mortality of aspen following severe drought along the southern edge of the Canadian boreal forest. Global Change Biology 17:2084-2094.

Type: Journal

Geographic Area: Canada

Keywords: aspen, boreal forest, climate change, dieback, drought, mortality, *Populus tremuloides*

Abstract: Drought-induced, regional-scale dieback of forests has emerged as a global concern that is expected to escalate under model projections of climate change. Since 2000, drought of unusual severity, extent, and duration has affected large areas of western North America, leading to regional scale dieback of forests in the southwestern US. We report on drought impacts on forests in a region farther north, encompassing the transition between boreal forest and prairie in western Canada. A central question is the significance of drought as an agent of large-scale tree mortality and its potential future impact on carbon cycling in this cold region. We used a combination of plot-based, meteorological, and remote sensing measures to map and quantify aboveground, dead biomass of trembling aspen (*Populus tremuloides* Michx.) across an 11.5 Mha survey area where drought was exceptionally severe during 2001–2002. Within this area, a satellite-based land cover map showed that aspen-dominated broadleaf forests occupied 2.3 Mha. Aerial surveys revealed extensive patches of severe mortality (> 55%) resembling the impacts of fire. Dead aboveground biomass was estimated at 45 Mt, representing 20% of the total aboveground biomass, based on a spatial interpolation of plot-based measurements. Spatial variation in percentage dead biomass showed a moderately strong correlation with drought severity. In the prairie-like, southern half of the study area where the drought was most severe, 35% of aspen biomass was dead, compared with an estimated 7% dead biomass in the absence of drought. Drought led to an estimated 29 Mt increase in dead biomass across the survey area, corresponding to 14 Mt of potential future carbon emissions following decomposition. Many recent, comparable episodes of drought-induced forest dieback have been reported from around the world, which points to an emerging need for multiscale monitoring approaches to quantify drought effects on woody biomass and carbon cycling across large areas.

Link: http://nofc.cfs.nrcan.gc.ca/bookstore_pdfs/31947.pdf

91. Millar CI, Woolfenden WB. 1999. Sierra Nevada forests: where did they come from? Where are they going? What does it mean? Transactions of the 64th North American Wildlife and Natural Resources Conference. p 206-236.

Type: Conference Paper

Geographic Area: Sierra Nevada, California, North America

Compilers' Keywords: Quaternary sciences, climate change, historic natural variability, vegetation distribution, land management

Introduction: The prospect of human-induced global warming has received center-stage attention from ecologists concerned about future ecosystems. While such effects deserve critical analysis, they are best understood in the context of natural climate change. Anthropogenic atmospheric effects are often discussed as if background climates were stable. Even in the recent past, however, climates have changed at similar rates and magnitudes to predicted anthropogenic changes, catalyzing significant natural changes in terrestrial ecosystems. With or without the complication of human effects, implications of climate change to conservation and management planning are great. Over the past twenty years, advances in Quaternary sciences have significantly improved our understanding of historic climate and its influence on biota and planetary systems. Although resource ecologists increasingly engage this research, much of relevance remains to be incorporated into the thinking of forest science and management. In this paper, we briefly review the nature of historic climate change, summarize conclusions relevant to ecosystems of the Sierra Nevada, California, and suggest implications for managing Sierran forest ecosystems.

Link: http://www.treesearch.fs.fed.us/pubs/24289

92. Millar CI, King JC, Westfall RD, Alden HA, Delany DL. 2006. Late Holocene forest dynamics, volcanism, and climate change at Whitewing Mountain and San Joaquin Ridge, Mono County, Sierra Nevada, CA, USA. Quaternary Research 66:273-287.

Type: Journal

Geographic Area: California, USA

Keywords: paleoecology, medieval climate, Late Holocene, climate change, Long Valley volcanism, Inyo Craters, forest history, palaeoclimatic modeling, tree-ring dating

Abstract: Deadwood tree stems scattered above treeline on tephra covered slopes of Whitewing Mtn (3051 m) and San Joaquin Ridge (3122 m) show evidence of being killed in an

eruption from adjacent Glass Creek Vent, Inyo Craters. Using tree-ring methods, we dated deadwood to AD 815–1350 and infer from death dates that the eruption occurred in late summer AD 1350. Based on wood anatomy, we identified deadwood species as *Pinus albicaulis, P. monticola, P. lambertiana, P. contorta, P. jeffreyi,* and *Tsuga mertensiana*. Only *P. albicaulis* grows at these elevations currently; *P. lambertiana* is not locally native. Using contemporary distributions of the species, we modeled paleoclimate during the time of sympatry to be significantly warmer (+3.2 °C annual minimum temperature) and slightly drier (–24 mm annual precipitation) than present, resembling values projected for California in the next 70–100 yr.

Link: http://www.treesearch.fs.fed.us/pubs/31776

93. Mondoni A, Rossi G, Orsenigo S, Probert RJ. 2012. **Climate warming could shift the timing of seed germination in alpine plants.** Annals of Botany 110:155-164.

Type: Journal

Geographic Area: Italy, Europe

Keywords: seed ecology, seed germination, climate change, adaptation, alpine plants

Abstract: Despite the considerable number of studies on the impacts of climate change on alpine plants, there have been few attempts to investigate its effect on regeneration. Recruitment from seeds is a key event in the life-history of plants, affecting their spread and evolution and seasonal changes in climate will inevitably affect recruitment success. Here, an investigation was made of how climate change will affect the timing and the level of germination in eight alpine species of the glacier foreland. Using a novel approach which considered the altitudinal variation of temperature as a surrogate for future climate scenarios, seeds were exposed to 12 different cycles of simulated seasonal temperatures in the laboratory, derived from measurements at the soil surface at the study site. Under present climatic conditions, germination occurred in spring, in all but one species, after seeds had experienced autumn and winter seasons. However, autumn warming resulted in a significant increase in germination in all but two species. In contrast, seed germination was less sensitive to changes in spring and/or winter temperatures, which affected only three species. Climate warming will lead to a shift from spring to autumn emergence but the extent of this change across species will be driven by seed dormancy status. Ungerminated seeds at the end of autumn will be exposed to shorter winter seasons and lower spring temperatures in a future, warmer climate, but these changes will only have a minor impact on germination. The extent to which climate change will be detrimental to regeneration from seed is less likely to be due to a significant negative effect on germination per se, but rather to seedling emergence in seasons that the species are not adapted to experience. Emergence in autumn could have major implications for species currently adapted to emerge in spring.

Link: http://www.ncbi.nlm.nih.gov/pubmed/22596094

94. Moritz C, Agudo R. 2013. **The future of species under climate change: resilience or decline?** Science 341:504-508.

Type: Journal

Geographic Area: Global

Compilers' Keywords: fossil record, range shifts, climate change

Abstract: As climates change across already stressed ecosystems, there is no doubt that species will be affected, but to what extent and which will be most vulnerable remain uncertain. The fossil record suggests that most species persisted through past climate change, whereas forecasts of future impacts predict large-scale range reduction and extinction. Many species have altered range limits and phenotypes through 20th-century climate change, but responses are highly variable. The proximate causes of species decline relative to resilience remain largely obscure; however, recent examples of climate-associated species decline can help guide current management in parallel with ongoing research.

Link: http://www.ncbi.nlm.nih.gov/pubmed/23908228

95. Myers P, Lundrigan BL, Hoffman SMG, Haraminac AP, Seto SH. 2009. **Climate-induced changes in the small mammal communities of the northern Great Lakes Region.** Global Change Biology 15:1434-1454.

Type: Journal

Geographic Area: Northern Great Lakes, USA

Keywords: climatic warming, *Didelphis virginiana, Glaucomys sabrinus, Glaucomys volans,* Great Lakes, Michigan, *Peromyscus leucopus, Peromyscus maniculatus gracilis, Tamias minimus, Tamias striatus*

Abstract: We use museum and other collection records to document large and extraordinarily rapid changes in the ranges and relative abundance of nine species of mammals in the northern Great Lakes region (white footed mice, woodland deer mice, southern red-backed voles, woodland jumping mice, eastern chipmunks, least chipmunks, southern flying squirrels, northern flying squirrels, common opossums). These species reach either the southern or the northern limit of their distributions in this region. Changes consistently reflect increases in species of primarily southern distribution (white-footed mice, eastern chipmunks, southern flying squirrels, common opossums) and declines by northern species (woodland deer mice, southern red-backed voles, woodland jumping mice, least chipmunks, northern flying squirrels). White-footed mice and southern flying squirrels have extended their ranges over 225 km since 1980, and at particularly well-studied sites in Michigan's Upper Peninsula, small mammal assemblages have shifted from numerical domination by

northern species to domination by southern species. Repeated resampling at some sites suggests that southern species are replacing northern ones rather than simply being added to the fauna. Observed changes are consistent with predictions from climatic warming but not with predictions based on recovery from logging or changes in human populations. Because of the abundance of these focal species (the eight rodent species make up 96.5% of capture records of all forest-dwelling rodents in the region and 70% of capture records of all forest-dwelling small mammals) and the dominating ecological roles they play, these changes substantially affect the composition and structure of forest communities. They also provide an unusually clear example of change that is likely to be the result of climatic warming in communities that are experienced by large numbers of people.

Link: http://www.fws.gov/uploadedFiles/Myers2009.pdf

96. Nicotra AB, Atkin OK, Bonser SP, Davidson AM, Finnegan EJ, Mathesius U, Poot P, Purugganan MD, Richards CL, Valladares F, van Kleunen M. 2010. **Plant phenotypic plasticity in a changing climate.** Trends in Plant Science 15:684-692.

Type: Journal

Geographic Area: Global

Compilers' Keywords: adaptation, climate change, flowers, plant physiological phenomena, plant genetics, seed physiology, review, tool

Abstract: Climate change is altering the availability of resources and the conditions that are crucial to plant performance. One way plants will respond to these changes is through environmentally induced shifts in phenotype (phenotypic plasticity). Understanding plastic responses is crucial for predicting and managing the effects of climate change on native species as well as crop plants. Here, we provide a toolbox with definitions of key theoretical elements and a synthesis of the current understanding of the molecular and genetic mechanisms underlying plasticity relevant to climate change. By bringing ecological, evolutionary, physiological and molecular perspectives together, we hope to provide clear directives for future research and stimulate cross-disciplinary dialogue on the relevance of phenotypic plasticity under climate change.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20970368

97. Nitschke CR, Innes JL. 2008. **A tree and climate assessment tool for modelling ecosystem response to climate change.** Ecological Modelling 210:263-277.

Type: Journal

Geographic Area: Western Canada

Keywords: climate change, regeneration, modelling, resilience, ecosystem, forest management, vulnerability, niche theory

Abstract: Understanding how vulnerable forest ecosystems are to climate change is a key requirement if sustainable forest management is to be achieved. Modelling the response of species in their regeneration niche to phenological and biophysical processes that are directly influenced by climate is one method for achieving this understanding. A model was developed to investigate species resilience and vulnerability to climate change within its fundamental regeneration niche. The utility of the developed model, tree and climate assessment (TACA), was tested within the interior Douglas-fir ecosystem in south central British Columbia. TACA modelled the current potential tree species composition of the ecosystem with high accuracy and modelled significant responses amongst tree species to climate change. The response of individual species suggests that the studied ecosystem could transition to a new ecosystem over the next 100 years. TACA showed that it can be an effective tool for identifying species resilience and vulnerability to changes in climate within the most sensitive stage of development, the regeneration phase. The TACA model was able to identify the degree of change in phenological and biophysical variables that control tree establishment, growth and persistence. The response to changes in one or more of these variables resulted in changes in the climatic suitability of the ecosystem for species and enabled a measure of vulnerability to be quantified. TACA could be useful to forest managers as a decision support tool for adaptation actions and by researchers interested in modelling stand dynamics under climate change.

Link: http://www4.nau.edu/direnet/publications/publications_n/files/Nitschke_CR_Innes_JL_A_tree_and_climate_assessment_tool.pdf

98. Niven DK, Butcher GS, Bancroft GT, Monahan WB, Langham G. 2009. **Birds and climate change: ecological disruption in motion.** New York (NY): National Audubon Society. 16 p.

Type: Report

Geographic Area: North America

Compilers' Keywords: wildlife, Audubon Society, biological indicators

Introduction: Each year for more than a century, dedicated volunteers have braved snow, wind, rain and ice to record the number and location of North American birds. The carefully organized and compiled observations of tens of thousands of Citizen Scientists participating in Audubon's annual Christmas Bird Count have grown to form the world's longest uninterrupted repository of bird population information. Analyses of its data have time after time revealed important trends, alerting America to perils and opportunities with implications far beyond avian well-being. Birds are well-known barometers of environmental health. Changes in their condition can warn of threats to habitats and natural systems critical to all life on Earth. Like canaries in a coal mine, they can alert us to danger.

And, if we heed their warnings, caring for the birds can help us protect ourselves and the future of the world we share. Amid mounting concerns over accelerating global climate change, Audubon looked to the birds to determine if and how these sensitive creatures might be responding to changes here in the continental US. Birders have long reported surprising sightings of species far north of expected ranges. But are the reports significant? If so, are they connected to documented changes in our climate? Analyses of four decades of Christmas Bird Count data provide some answers. The results confirm what bird lovers have long suspected. Findings summarized in the pages that follow offer a look at forty years of change, a peek at what the future likely holds in one part of our nation, and an urgent message of warning from the birds—a message we would be wise to heed.

Link: http://web4.audubon.org/news/pressroom/bacc/pdfs/birds%20and%20climate%20report.pdf

99. Ooi MKJ, Auld TD, Denham AJ. 2011. Projected soil temperature increase and seed dormancy response along an altitudinal gradient: implications for seed bank persistence under climate change. Plant and Soil 353:289-303.

Type: Journal

Geographic Area: Australia

Keywords: Fabaceae, fire, heat wave, local adaptation, maternal effects, physiological dormancy, seed ecology, legume

Abstract: Understanding the mechanistic effects of climate change on species key life-history stages is essential for predicting ecological responses. In fire-prone regions, long-term seed banks allow post-fire recovery and persistence of plant populations. For physically dormant species, seed bank longevity depends on the maintenance of dormancy which is controlled primarily by temperature. Successful inter-fire recruitment is rare and dormancy loss between fires produces a net loss to the seed bank. We assessed whether temperature increases related to climate change can affect seed dormancy and, potentially, seed bank longevity. We quantified the relationship between air temperatures and soil temperatures. Seeds of two shrub species, from four populations along an altitudinal gradient, were then exposed to a range of soil temperatures calculated to occur at the end of the 21st century, using projected mean and heat wave scenarios. Alterations to dormancy were assessed via germination. For every 1 °C increase in air temperature, associated soil temperature increased by 1.5 °C. Mean temperature increase had no effect on seed dormancy. However, future heat wave conditions produced soil temperatures that significantly increased dormancy loss. This impact was greatest in seeds from cooler, high elevation populations. Projected heat wave events produce conditions that provide a mechanism for seed bank compromise. Dormancy-breaking temperatures for each population were positively related to parental environment temperatures, indicating local adaptation. Whilst heat from fire may govern post-fire recruitment response, we suggest that parental climate is the key selective force determining dormancy-breaking threshold temperatures, ensuring inter-fire seed bank persistence.

100. Opdam P, Wascher D. 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biological Conservation 117:285-297.

Type: Journal

Geographic Area: Global

Keywords: climate change, habitat fragmentation, metapopulation dynamics, geographical range, habitat networks

Abstract: Climate change and habitat fragmentation are considered key pressures on biodiversity. In this paper we explore the potential synergetic effects between these factors. We argue that processes at two levels of spatial scale interact: the metapopulation level and the species range level. Current concepts of spatially dynamic metapopulations and species ranges are consistent, and integration improves our understanding of the interaction of landscape level and geographical range level processes. In landscape zones in which the degree of habitat fragmentation allows persistence, the shifting of ranges is inhibited, but not blocked. In areas where the spatial cohesion of the habitat is below the critical level of metapopulation persistence, the expansion of ranges will be blocked. An increased frequency of large-scale disturbances caused by extreme weather events will cause increasing gaps and an overall contraction of the distribution range, particularly in areas with relatively low levels of spatial cohesion. Taking into account the effects of climate change on metapopulations, habitat distribution and land use changes, future biodiversity research and conservation strategies are facing the challenge to re-orient their focus and scope by integrating spatially and conceptually more dynamic aspects at the landscape level.

Link: http://research.eeescience.utoledo.edu/lees/Teaching/EEES4760_07/Opdam.PDF

101. Oregon Forest Resources Institute. 2006. Forests, carbon and climate change: a synthesis of science findings. Portland (OR): Oregon Forest Resources Institute and Oregon State University. 192 p.

Type: Book

Geographic Area: Western USA

Compilers' Keywords: forest management, carbon dioxide, scale, strategies

Preface: The Oregon Forest Resources Institute (OFRI) commissioned this book, a synthesis of science findings on the relationships between forests, atmospheric carbon and climate change. While there is not scientific consensus about all the causes and implications of global climate change and the role of human activities, there is agreement that the relationships between forests and carbon, carbon and climate, and climate and forests are important and need to be better understood. It is also clear that Oregon is a forest-rich state, poised with opportunities for forests, forestry and forest product enterprises to contribute toward maintaining a livable climate.

Link: http://tongassmonitoring.com/pdf/Forests-Carbon-ClimateChange-2006.pdf#page=39

102. Parmesan C. 2007. Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Global Change Biology 13:1860-1872.

Type: Journal

Geographic Area: Northern Hemisphere

Keywords: animal, climate change, global warming, insect–plant interactions, latitude, meta-analysis, phenology, plant, temperature, trophic interactions

Abstract: New analyses are presented addressing the global impacts of recent climate change on phenology of plant and animal species. A meta-analysis spanning 203 species was conducted on published datasets from the northern hemisphere. Phenological response was examined with respect to two factors: distribution of species across latitudes and taxonomic affiliation or functional grouping of target species. Amphibians had a significantly stronger shift toward earlier breeding than all other taxonomic/functional groups, advancing more than twice as fast as trees, birds and butterflies. In turn, butterfly emergence or migratory arrival showed three times stronger advancement than the first flowering of herbs, perhaps portending increasing asynchrony in insect–plant interactions. Response was significantly stronger at higher latitudes where warming has been stronger, but latitude explained < 4% of the variation. Despite expectation, latitude was not yet an important predictor of climate change impacts on phenology. The only two previously published estimates of the magnitude of global response are quite different: 2.3 and 5.1 days decade^{-1} advancement. The scientific community has assumed this difference to be real and has attempted to explain it in terms of biologically relevant phenomena: specifically, differences in distribution of data across latitudes, taxa or time periods. Here, these and other possibilities are explored. All analyses indicate that the difference in estimated response is primarily due to differences between the studies in criteria for incorporating data. It is a clear and automatic consequence of the exclusion by one study of data on "stable" (nonresponsive) species. Once this is accounted for, the two studies support each other, generating similar conclusions despite analyzing substantially no overlapping datasets. Analyses here on a new expanded dataset estimate an overall spring advancement across the northern hemisphere of 2.8 days decade^{-1}. This is the first quantitative analysis showing that data-sampling methodologies significantly impact global (synthetic) estimates of magnitude of global warming response.

Link: http://www.discoverlife.org/pa/or/polistes/pr/2010nsf_macro/references/Parmesan2007.pdf

103. Polley HW, Briske DD, Morgan JA, Wolter K, Bailey DW, Brown JR. 2013. Climate change and North American rangelands: trends, projections, and implications. Rangeland Ecology & Management 66:493-511.

Type: Journal

Geographic Area: North America

Keywords: atmospheric CO_2, atmospheric warming, climate variability, greenhouse gases, livestock production, precipitation patterns

Abstract: The amplified "greenhouse effect" associated with increasing concentrations of greenhouse gases has increased atmospheric temperature by 1 °C since industrialization (around 1750), and it is anticipated to cause an additional 2 °C increase by mid-century. Increased biospheric warming is also projected to modify the amount and distribution of annual precipitation and increase the occurrence of both drought and heat waves. The ecological consequences of climate change will vary substantially among ecoregions because of regional differences in antecedent environmental conditions; the rate and magnitude of change in the primary climate change drivers, including elevated carbon dioxide (CO_2), warming and precipitation modification; and no additive effects among climate drivers. Elevated atmospheric CO_2 will directly stimulate plant growth and reduce negative effects of drying in a warmer climate by increasing plant water use efficiency; however, the CO_2 effect is mediated by environmental conditions, especially soil water availability. Warming and drying are anticipated to reduce soil water availability, net primary productivity, and other ecosystem processes in the southern Great Plains, the Southwest, and northern Mexico, but warmer and generally wetter conditions will likely enhance these processes in the northern Plains and southern Canada. The Northwest will warm considerably, but annual precipitation is projected to change little despite a large decrease in summer precipitation. Reduced winter snowpack and earlier snowmelt will affect hydrology and riparian systems in the Northwest. Specific consequences of climate change will be numerous and varied and include modifications to forage quantity and quality and livestock production systems, soil C content, fire regimes, livestock metabolism, and plant community composition and species distributions, including range contraction and expansion of invasive species. Recent trends and model projections indicate continued directional change and increasing variability in climate that will substantially affect the provision of ecosystem services on North American rangelands.

Link: http://www.climate-eval.org/sites/default/files/news/study%20on%20effects%20of%20climate%20change%20on%20north%20american%20rangelands.pdf

104. Ponce Campos GE, Moran MS, Huete A, Zhang Y, Bresloff C, Huxman TE, Eamus D, Bosch DD, Buda AR, Gunter SA, Scalley TH, Kitchen SG, McClaran MP, McNab WH, Montoya DS, Morgan JA, Peters DP, Sadler EJ, Seyfried MS, Starks PJ. 2013. Ecosystem resilience despite large-scale altered hydroclimatic conditions. Nature 494:349-352.

Type: Journal

Geographic Area: Global

Compilers' Keywords: climate change, drought, 20th century, 21st century, plants, Poaceae, rain, trees, water

Abstract: Climate change is predicted to increase both drought frequency and duration, and when coupled with substantial warming, will establish a new hydroclimatological model for many regions. Large-scale, warm droughts have recently occurred in North America, Africa, Europe, Amazonia and Australia, resulting in major effects on terrestrial ecosystems, carbon balance and food security. Here we compare the functional response of above-ground net primary production to contrasting hydroclimatic periods in the late twentieth century (1975–1998), and drier, warmer conditions in the early twenty-first century (2000–2009) in the Northern and Southern Hemispheres. We find a common ecosystem water-use efficiency (WUE(e): above-ground net primary production/evapotranspiration) across biomes ranging from grassland to forest that indicates an intrinsic system sensitivity to water availability across rainfall regimes, regardless of hydroclimatic conditions. We found higher WUE(e) in drier years that increased significantly with drought to a maximum WUE(e) across all biomes; and a minimum native state in wetter years that was common across hydroclimatic periods. This indicates biome-scale resilience to the interannual variability associated with the early twenty-first century drought—that is, the capacity to tolerate low, annual precipitation and to respond to subsequent periods of favourable water balance. These findings provide a conceptual model of ecosystem properties at the decadal scale applicable to the widespread altered hydroclimatic conditions that are predicted for later this century. Understanding the hydroclimatic threshold that will break down ecosystem resilience and alter maximum WUE(e) may allow us to predict land-surface consequences as large regions become more arid, starting with water-limited, low-productivity grasslands.

Link: http://www.ncbi.nlm.nih.gov/pubmed/23334410

105. Porter WP, Budaraju S, Stewart WE, Ramankutty N. 2000. Calculating climate effects on birds and mammals: impacts on biodiversity, conservation, population parameters, and global community structure. American Zoologist 10:597-630.

Type: Journal

Geographic Area: Global

Compilers' Keywords: climate change, endangered species, body size

Synopsis: This paper describes how climate variation in time and space can constrain community structure on a global scale. We explore body size scaling and the energetic consequences in terms of absorbed mass and energy and expended mass and energy. We explain how morphology, specific physiological properties, and temperature dependent behaviors are key variables that Link individual energetics to population dynamics and community structure. This paper describes an integrated basic principles model for mammal energetics and extends the model to bird energetics. The model additions include molar balance models for the lungs and gut. The gut model couples food ingested to respiratory gas exchanges and evaporative water loss from the respiratory system. We incorporate a novel thermoregulatory model that yields metabolic calculations as a function of temperature. The calculations mimic empirical data without regression. We explore the differences in the quality of insulation between hair and feathers with our porous media model for insulation. For mammals ranging in size from mice to elephants we show that calculated metabolic costs are in agreement with experimental data. We also demonstrate how we can do the same for birds ranging in size from hummingbirds to ostriches. We show the impact of changing posture and changing air temperatures on energetic costs for birds and mammals. We demonstrate how optimal body size that maximizes the potential for growth and reproduction changes with changing climatic conditions and with diet quality. Climate and diet may play important roles in constraining community structure (collection of functional types of different body sizes) at local and global scales. Thus, multiple functional types may coexist in a locality in part because of the temporal and spatial variation in climate and seasonal food variation. We illustrate how the models can be applied in a conservation and biodiversity context to a rare and endangered species of parrot, the Orange-bellied Parrot of Australia and Tasmania.

106. Pretzsch H, Biber P, Schutze G, Uhl E, Rotzer T. 2014. Forest stand growth dynamics in Central Europe have accelerated since 1870. Nature Communications 5:1-10.

Type: Journal

Geographic Area: Central Europe

Compilers' Keywords: climate change, tree growth, projections, forest management

Abstract: Forest ecosystems have been exposed to climate change for more than 100 years, whereas the consequences on forest growth remain elusive. Based on the oldest existing experimental forest plots in Central Europe, we show that, currently, the dominant tree species Norway spruce and European beech exhibit significantly faster tree growth (+32 to 77%), stand volume growth (+10 to 30%) and standing stock accumulation (+6 to 7%) than in 1960. Stands still follow similar general allometric rules, but proceed more rapidly through usual trajectories. As forest stands develop faster, tree numbers are currently 17-20% lower than in past same-aged stands. Self-thinning lines remain constant, while growth rates increase indicating the stock of resources have not changed, while growth velocity and turnover have altered. Statistical analyses of the experimental plots, and application of an ecophysiological model, suggest that mainly the rise in temperature and extended growing seasons contribute to increased growth acceleration, particularly on fertile sites.

Link: http://www.ncbi.nlm.nih.gov/pubmed/25216297

107. Pyke CR, Fischer DT. 2005. Selection of bioclimatically representative biological reserve systems under climate change. Biological Conservation 121:429-441.

Type: Journal

Geographic Area: California, USA

Keywords: systematic conservation planning, climate change, habitat loss, bioclimatic representation, integer linear-programming, vernal pools

Abstract: Biological reserves are intended to protect species, communities, and ecosystems in human-dominated landscapes. However, existing protected areas represent only relatively small, geographically biased samples of species and habitats. Climate change and habitat loss can exacerbate these biases and the net result is a small, skewed subset of historic environmental conditions. We developed a general model to improve the representation of environmental conditions across the range of at-risk species or any other elements targeted for conservation. We implemented the model as an integer linear-programming problem to select additional areas to complement existing reserves and create new portfolios that are bioclimatically representative across a range of climatic scenarios. We demonstrated the use of the model for a small dataset including two hydrologic variables across the range of five species of fairy shrimp (*Anostraca*) in the Central Valley ecoregion of California, USA under three climate scenarios. The bioclimatic representation model identified solutions that meet biodiversity representation goals and substantially improve bioclimatic representation at minimal additional cost in terms of total land selected for a conservation portfolio. Additional constraints rewarding bioclimatic representation under two conflicting climate scenarios resulted in only a small decrease in the performance of solutions with respect to current climate. We conclude that this model provides a general tool for improving bioclimatic representation, and results from the Central Valley case study suggest an encouraging, testable hypothesis that climatically robust bioclimatic representation can be achieved at negligible marginal costs.

Link: http://www.geog.ucsb.edu/~fischer/PykeFischer2005.pdf

108. Rehfeldt GE, Ferguson DE, Crookston NL. 2009. Aspen, climate, and sudden decline in western USA. Forest Ecology and Management 258:2353-2364.

Type: Journal

Geographic Area: Western USA

Keywords: bioclimate models, sudden aspen decline, global warming impacts, climate responses, climatic niche

Abstract: A bioclimate model predicting the presence or absence of aspen, *Populus tremuloides*, in western USA from climate variables was developed by using the Random Forests classification tree on Forest Inventory data from about 118, 000 permanent sample plots. A reasonably parsimonious model used eight predictors to describe aspen's climate profile. Classification errors averaged 4.5%, most of which were errors of commission. The model was driven primarily by three variables: an annual dryness index, the ratio of summer to annual precipitation, and an interaction of growing season precipitation with the summer–winter temperature differential. Projecting the contemporary climate profile into the future climate provided by three General Circulation Models and two scenarios (SRES A2 and either B1 or B2) suggested that the area occupied by the profile should diminish rapidly over the course of the century, 6–41% by the decade surrounding 2030, 40–75% for that surrounding 2060, and 46–94% for 2090. The relevance of the climate profile to understanding climate-based responses is illustrated by relating trends in climate to the recent incidence of sudden aspen dieback that has plagued portions of the aspen distribution. Of the eight variables in the profile, four reached extreme values during 2000–2003, the period immediately preceding the appearance of damage in aerial surveys.

Link: http://www.treesearch.fs.fed.us/pubs/33823

109. Rietkerk M, Dekker SC, de Ruiter PC, van de Koppel J. 2004. Self-organized patchiness and catastrophic shifts in ecosystems. Science 305:1926-1929.

Type: Journal

Geographic Area: Global

Compilers' Keywords: climate change, range shifts, ecosystem management

Abstract: Unexpected sudden catastrophic shifts may occur in ecosystems, with concomitant losses or gains of ecological and economic resources. Such shifts have been theoretically attributed to positive feedback and biostability of ecosystem states. However, verifications and predictive power with respect to catastrophic responses to a changing environment are lacking for spatially extensive ecosystems. This situation impedes management and recovery strategies for such ecosystems. Here, we review recent studies on various ecosystems that link self-organized patchiness to catastrophic shifts between ecosystem states.

Link: http://www.sciencemag.org/content/305/5692/1926.short

110. Robbirt KM, Davy AJ, Hutchings MJ, Roberts DL. 2011. Validation of biological collections as a source of phenological data for use in climate change studies: a case study with the orchid *Ophrys sphegodes*. Journal of Ecology 99:235-241.

Type: Journal

Geographic Area: Southern and Central Europe

Keywords: biological collections, climate change, flowering time, herbarium specimens, natural history collections, *Ophrys sphegodes*, Orchidaceae, phenology, spring, temperature

Summary: The scarcity of reliable long-term phenological data has severely hindered the study of the responses of species to climate change. Biological collections in herbaria and museums are potential sources of long term data for such study, but their use for this purpose needs independent validation. Here we report a rigorous test of the validity of using herbarium specimens for phenological studies, by comparing relationships between climate and time of peak flowering derived from herbarium records and from direct field-based observations, for the terrestrial orchid *Ophrys sphegodes*. We examined herbarium specimens of *O. sphegodes* collected between 1848 and 1958, and recorded peak flowering time directly in one population of *O. sphegodes* between 1975 and 2006. The response of flowering time to variation in mean spring temperature (March–May) was virtually identical in both sets of data, even though they covered different periods of time which differ in extent of anthropogenic temperature change. In both cases flowering was advanced by about 6 days per °C rise in average spring temperature. The proportion of variation in flowering time explained by spring temperature was lower in the herbarium record than in direct field observations. It is likely that some of the additional variation was due to geographical variation in collection site, as flowering was significantly earlier at more westerly sites, which have had warmer springs, over their range of 3.44° longitude. Predictions of peak flowering time based on the herbarium data corresponded closely with observed peak flowering times in the field, indicating that flowering response to temperature had not altered between the two separate periods over which the herbarium and field data were collected. These results provide the first direct validation of the use of herbarium collections to examine the relationships between phenology and climate when field-based observational data are not available.

Link: http://www.drdavidroberts.com/docs/Robbirt_etal_2011_Ophrys_Climate_Change.pdf

111. Savva Y, Denneler B, Koubaa A, Tremblay F, Bergeron Y, Tjoelker MG. 2007. Seed transfer and climate change effects on radial growth of jack pine populations in a common garden in Petawawa, Ontario, Canada. Forest Ecology and Management 242:636-647.

Type: Journal

Geographic Area: Ontario, Canada

Keywords: adaptation, climate change, GCM, *Pinus banksiana*, provenance, radial growth, transfer functions

Abstract: The effects of seed transfer and climate change on the width and basal area of tree rings were studied in 21 provenances of jack pine (*Pinus banksiana* Lamb.) grown in a common-garden plantation in Petawawa, Ontario, Canada. Seed-source origin significantly influences both mean tree-ring width and mean annual basal area increment over a 25-year growth period (1975-1999). Temperature and precipitation transfer functions were developed to predict width and basal area of tree rings of the jack pine populations. The best predictors of growth were the transfer distances of mean annual maximum daily temperature and annual precipitation between the plantation site and the seed origins. Radial growth of the jack pine populations was mainly related to temperature at seed origin and, to a lesser degree, to precipitation at seed origin. Extension of the transfer functions to three sets of independent data revealed signification correlations between estimated and predicted mean radial growth characteristics. Seed sources of jack pine originating from warmer and drier climates than that of the plantation site in Petawawa had slightly higher mean ring widths and basal areas than the local populations. The application of different climate change scenarios derived from general circulation models to the developed transfer functions indicated that radial growth of jack pine may decline only if significant climate changes occur, which might not happen before the mid-21st century. Both a higher radial growth of southern seed sources and potential negative effect of a significant temperature increase and precipitation decrease in future suggest restricting the northward transfer of southern seed sources to less than 1 degree latitude. However, provenance specific differences in survivorship, frost- and disease-resistance, and cone serotiny should also be taken into consideration.

112. Schoettle AW, Sniezko R, Burns KS. 2009. Sustaining *Pinus flexilis* ecosystems of the southern Rocky Mountains (USA) in the presence of *Cronartium ribicola* and *Dendroctonus ponderosae* in a changing climate. In: Noshad D, Noh Eun W, King J, Sniezko R, editors. Breeding and Genetic Resources of Five-Needle Pines. Seoul, Republic of South Korea: Korea Forest Research Institute. p 63-65.

Type: Conference Paper

Geographic Area: Northwestern USA

Compilers' Keywords: limber pine, genetic variation, forest management, forest health, pest management, forest regeneration

Abstract: Limber pine, *Pinus flexilis* James, is characterized by a patchy distribution that displays metapopulation dynamics and spans a broad latitudinal and elevational range in North America. In the southern Rocky Mountains, limber pine grows from below the forest-grassland ecotone up to the forest-alpine ecotone, from ~1600 m above sea level in the short grass steppe to > 3300 m at the continental divide. In this region, limber pine's altitudinal range is wider than any of its co-occurring tree species. Limber pine ecosystems serve a variety of important ecological roles, such as (1) occupying and stabilizing dry habitats, (2) defining ecosystem boundaries (treelines), (3) being among the first tree species to colonize a site after fire, (4) facilitating the establishment of late successional species and (5) providing diet and habitat for animals.

Link: http://www.treesearch.fs.fed.us/pubs/34716

113. Schueler S, Falk W, Koskela J, Lefevre F, Bozzano M, Hubert J, Kraigher H, Longauer R, Olrik DC. 2014. Vulnerability of dynamic genetic conservation units of forest trees in Europe to climate change. Global Change Biology 20:1498-1511.

Type: Journal

Geographic Area: Europe

Keywords: climate niche modelling, favourability function, forest genetic resources, gap analysis, genetic conservation unit, velocity of climate change

Abstract: A transnational network of genetic conservation units for forest trees was recently documented in Europe aiming at the conservation of evolutionary processes and the adaptive potential of natural or man-made tree populations. In this study, we quantified the vulnerability of individual conservation units and the whole network to climate change using climate favourability models and the estimated velocity of climate change. Compared to the overall climate niche of the analysed target species populations at the warm and dry end of the species niche are underrepresented in the network. However, by 2100, target species in 33-65% of conservation units, mostly located in southern Europe, will be at the limit or outside the species' current climatic niche as demonstrated by favourabilities below required model sensitivities of 95%. The highest average decrease in favourabilities throughout the network can be expected for coniferous trees although they are mainly occurring within units in mountainous landscapes for which we estimated lower velocities of change. Generally, the species-specific estimates of favourabilities showed only low correlations to the velocity of climate change in individual units, indicating that both vulnerability measures should be considered for climate risk analysis. The variation in favourabilities among target species within the same conservation units is expected to increase with climate change and will likely require a prioritization among co-occurring species. The present results suggest that there is a strong need to intensify monitoring efforts and to develop additional conservation measures for populations in the most vulnerable units. Also, our results call for continued transnational actions for genetic conservation of European forest trees, including the establishment of dynamic conservation populations outside the current species distribution ranges within European assisted migration schemes.

Link: http://www.ncbi.nlm.nih.gov/pubmed/24273066

114. Schwartz MW, Iverson LR, Prasad AM, Matthews SN, O'Connor RJ. 2006. Predicting extinctions as a result of climate change. Ecology 87:1611-1615.

Type: Journal

Geographic Area: North America

Keywords: climate and environmental models, climate change, distribution breadth, eastern United States, endemic, extinction, prediction uncertainty, regression tree, vulnerability

Abstract: Widespread extinction is a predicted ecological consequence of global warming. Extinction risk under climate change scenarios is a function of distribution breadth. Focusing on trees and birds of the eastern United States, we used joint climate and environment models to examine fit and climate change vulnerability as a function of distribution breadth. We found that extinction vulnerability increases with decreasing distribution size. We also found that model fit decreases with decreasing distribution size, resulting in high prediction uncertainty among narrowly distributed species. High prediction uncertainty creates a conservation dilemma in that excluding these species under predicts extinction risk and favors mistaken inaction on global warming. By contrast, including narrow endemics results in over-predicting extinction risk and promotes mistaken inaction on behalf of individual species prematurely considered doomed to extinction.

Link: http://kb.osu.edu/dspace/bitstream/handle/1811/49027/fac_IversonL_Ecology_2006_87_7.pdf?sequence=1

115. Seager R, Ting M, Held I, Kushnir Y, Lu J, Vecchi G, Huang HP, Harnik N, Leetmaa A, Lau NC, Li C, Velez J, Naik N. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. Science 316:1181-1184.

Type: Journal

Geographic Area: Southwestern USA

Compilers' Keywords: hydrology, climate change

Abstract: How anthropogenic climate change will affect hydroclimate in the arid regions of southwestern North America has implications for the allocation of water resources and the course of regional development. Here we show that there is a broad consensus among climate models that this region will dry in the 21st century and that the transition to a more arid

climate should already be under way. If these models are correct, the levels of aridity of the recent multiyear drought or the Dust Bowl and the 1950s droughts will become the new climatology of the American Southwest within a time frame of years to decades.

Link: http://www.ncbi.nlm.nih.gov/pubmed/17412920

116. Soolanayakanahally RY, Guy RD, Silim SN, Song M. 2012. Timing of photoperiodic competency causes phenological mismatch in balsam poplar (*Populus balsamifera* L.). Plant Cell and Environment 36:116-127.

Type: Journal

Geographic Area: Canada

Keywords: bud flush, bud set, climate change, growing season length, height growth cessation, latitude, phenology, photoperiod

Abstract: Plant phenology is expected to be sensitive to climate warming. In boreal trees, spring flush is primarily temperature driven, whereas height growth cessation and autumn leaf senescence are predominantly controlled by photoperiod. Cuttings of 525 genotypes from the full range of balsam poplar were planted into two common gardens (Vancouver and Indian Head, Canada) at similar latitudes, but with differing winter temperatures and growing seasons. There was clinal variation in spring and, particularly, summer and fall phenology. Bud flush and, despite milder climate, bud set and leaf drop were earlier at Vancouver than at Indian Head by 44, 28 and 7 d, respectively. Although newly flushed growth is insensitive to photoperiod, many genotypes at both sites became competent before the summer solstice. At Vancouver, high-latitude genotypes set dormant terminal buds in mid-spring. Most other genotypes grew until midsummer or set bud temporarily and then experienced a second flush. In both gardens and in a growth chamber experiment, earlier bud set was associated with reduced height growth and higher root/shoot ratios. Shoots attained competency approximately 5 weeks after flushing, which would normally prevent dormancy induction before the solstice, but may be insufficient if spring advances by more than a few weeks.

Link: http://www.ncbi.nlm.nih.gov/pubmed/22702736

117. St. Clair JB, Howe GT. 2007. Genetic maladaptation of coastal Douglas-fir seedlings to future climates. Global Change Biology 13:1441-1454.

Type: Journal

Geographic Area: Pacific Northwest USA

Keywords: climate change, forest trees, genecology, local adaptation, natural selection, precipitation, *Pseudotsuga menziesii*, quantitative traits, relative risk of maladaptation, temperature

Abstract: Climates are expected to warm considerably over the next century, resulting in expectations that plant populations will not be adapted to future climates. We estimated the risk of maladaptation of current populations of coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) to future climates as the proportion of no overlap between two normal distributions where the means and genetic variances of current and future populations are determined from genecological models derived from seedling common garden studies. The risk of maladaptation was large for most traits when compared with the risk associated with current transfers within seed zones, particularly for the more drastic climate change scenario. For example, the proportion of no overlap for a composite trait representing bud set, emergence, growth, and root : shoot ratio was as high as 0.90. We recommend augmenting within-population variation by mixing local populations with some proportion of populations from lower elevations and further south. Populations expected to be adapted to climates a century from now come from locations as far down in elevation as 450–1130 m and as far south in latitude as 1.8–4.9°.

118. Strzepek K, Yohe G, Neumann J, Boehlert B. 2010. Characterizing changes in drought risk for the United States from climate change. Environmental Research Letters 5:044012.

Type: Journal

Geographic Area: USA

Keywords: drought, climate change, drought severity indices, uncertainty

Abstract: The effect of climate change on the frequency and intensity of droughts across the contiguous United States over the next century is assessed by applying Standardized Precipitation Indices and the Palmer Drought Severity Index to the full suite of 22 Intergovernmental Panel on Climate Change General Circulation Models for three IPCC-SRES emissions scenarios (B1, A1B, and A2 from the Special Report on Emissions Scenarios (SRES) listed in order of their emissions through 2100 from high to low). The frequency of meteorological drought based on precipitation alone is projected to increase in some parts of the U.S., for example the southwestern states, and decrease in others. Hydrological drought frequencies based on precipitation and temperature are projected to increase across most of the country, however, with very substantial and almost universally experienced increases in drought risk by 2050. For both measures, the southwestern U.S. and the Rocky Mountain states are projected to experience the largest increases in drought frequency, but these areas may be able to exploit existing excess storage capacity. Drought frequencies and uncertainties in their projection tend to increase considerably over time and show a strong worsening trend along higher greenhouse gas emissions scenarios, suggesting substantial benefits for greenhouse gas emissions reductions.

Link: http://globalchange.mit.edu/files/document/MITJPSPGC_Reprint_2010-14.pdf

119. Swift K, Ran S. 2012. Successional responses to natural disturbance, forest management, and climate change in British Columbia's Forests. Journal of Ecosystems and Management 13:1-23.

Type: Journal

Geographic Area: Western Canada

Keywords: successional pathways, climate change, natural disturbance, fire, insects, diseases

Abstract: Natural and human-induced disturbance such as wildfire, insect and disease outbreak, windthrow, and forest harvesting are important drivers for forest renewal, post-disturbance stand structure, and ecosystem function. Each disturbance or combination of disturbances sets up a forest to proceed down a certain successional pathway in terms of structure and function. Using the context of Ecoprovinces and Ecosystem Types, successional pathways of a variety of ecosystems found in British Columbia are briefly described, and the ways in which forest management practices have affected those pathways are discussed. This Extension Note also describes how projected changes in temperature and precipitation may also affect these natural disturbance drivers. The information contained in this article is based on a larger synthesis report that is available in FORREX Series 28 and is designed to facilitate further conservation around building resistant and resilient forests for the future.

Link: http://www.jem.forrex.org/forrex/images/PDFs/JEM_VOL_13_NO_1.pdf#page=62

120. Tague C, Peng H. 2013. The sensitivity of forest water use to the timing of precipitation and snowmelt recharge in the California Sierra: implications for a warming climate. Journal of Geophysical Research: Biogeosciences 118:875-887.

Type: Journal

Geographic Area: California, USA

Compilers' Keywords: climate change, hydrologic change

Abstract: Forest responses to warming, in the absence of changes in vegetation structure, reflect the balance between the increased atmospheric demand for water and changes in water availability. This study uses a coupled hydroecologic model applied to a snow-dominated mountain watershed to demonstrate how complex topography and interannual variation in climate drivers combine to alter the balance between moisture availability and energy demand. We focus specifically on how often and under what conditions changes in the timing of soil water recharge as precipitation or snowmelt are a significant control on forest actual evapotranspiration (AET) in the Central California Sierra. We show that while interannual variation in precipitation is the dominant control on interannual variation in AET, how much of that recharge accumulates as a seasonal snowpack can act as a second-order control. This sensitivity of AET to snow accumulation and melt occurs across a substantial elevation range (1800–2700 m) and at both aggregate watershed and 90 m patch scales. Model results suggest that the variation in AET due to recharge timing is greatest for patches and years with moderate levels of precipitation or patches that receive substantial lateral moisture inputs. For a 3 °C warming scenario, the annual AET increases in some years due to warmer temperatures but decreases by as much as 40% in other years due to an earlier timing of snowmelt. These results help to clarify the conditions under which water availability for forests decreases and highlight scenarios that may lead to increased drought stress under a warming climate in snow-dominated mountain regions.

121. Tepe TL, Meretsky VJ. 2011. Forward-looking forest restoration under climate change—are U.S. nurseries ready? Restoration Ecology 19:295-298.

Type: Journal

Geographic Area: USA

Keywords: forest restoration, planning, restoration planting, state nurseries

Abstract: The pace of climate change suggests that restoration efforts once focused on past conditions should become more forward-looking. Suggestions for such restoration emphasize the use of a suite of species adapted to a range of possible future climates. In forest restoration, opportunities for forward-looking restoration may be limited by the availability of suitable stock from state and commercial nurseries. Presently, most state nurseries have stock potentially suited to warmer climates than currently exist in their states. However, these nurseries are generally not actively incorporating information about climate change into their stocking choices and some see clear obstacles to providing such stock, particularly uncertainty about the future climate, and the existence of seed zones and other policies designed to protect locally adapted species genetics. As restoration ecologists adapt their methods to incorporate climate change, state nurseries should be involved in those discussions and may be important partners in outreach.

122. Thomas CD, Hill JK, Anderson BJ, Bailey S, Beale CM, Bradbury RB, Bulman CR, Crick HQP, Eigenbrod F, Griffiths HM, Kunin WE, Oliver TH, Walmsley CA, Watts K, Worsfold NT, Yardley T. 2011. A framework for assessing threats and benefits to species responding to climate change. Methods in Ecology and Evolution 2:125-142.

Type: Journal

Geographic Area: Britain, Global

Keywords: biodiversity, climate envelope, distribution, global warming, IUCN, policy, risk assessment, species conservation

Summary: Current national and international frameworks for assessing threats to species have not been developed in the context of climate change, and are not framed in a way that recognizes new opportunities that arise from climate change. The framework presented here separates the threats and benefits of climate change for individual species. Threat is assessed by the level of climate-related decline within a species' recently occupied (e.g., pre-1970s) historical distribution, based on observed (e.g., repeat census) and/or projected changes (e.g., modelled bioclimate space). Benefits are assessed in terms of observed and/or projected increases outside the recently occupied historical range. Exacerbating factors (e.g., small population size, low dispersal capacity) that might increase levels of threat or limit expansion in response to climate change are taken into consideration within the framework. Protocols are also used to identify levels of confidence (and hence research and/or monitoring needs) in each species' assessment. Observed and projected changes are combined into single measures of expected decline and increase, together with associated measures of confidence. We weight risk classifications towards information that is most certain. Each species is then placed in one of six categories (high risk, medium risk, limited impact, equivalent risks & benefits, medium benefit, high benefit) reflecting whether climate change is expected (or has been observed) to cause net declines or increases in the region considered, based on the balance of benefits and threats. We illustrate the feasibility of using the framework by applying it to (i) all British butterflies ($N = 58$ species) and (ii) an additional sample of British species: 18 species of plants, bats, birds and beetles. Our framework assesses net declines and increases associated with climate change, for individual species. It could be applied at any scale (regional, continental or global distributions of species), and complements existing conservation assessment protocols such as red-listing. Using observed and projected population and/or range data, it is feasible to carry out systematic conservation status assessments that inform the development of monitoring, adaptation measures and conservation management planning for species that are responding to climate change.

Link: http://www.researchgate.net/publication/229977974_A_framework_for_assessing_threats_and_benefits_to_species_responding_to_climate_change/file/79e4150c83bfe76a17.pdf

123. Trenberth KE. 2011. Changes in precipitation with climate change. Climate Research 47:123-138.

Type: Journal

Geographic Area: Global

Keywords: climate change, precipitation, storms, drought, extremes, floods, geoengineering, climate models

Abstract: There is a direct influence of global warming on precipitation. Increased heating leads to greater evaporation and thus surface drying, thereby increasing the intensity and duration of drought. However, the water holding capacity of air increases by about 7% per 1 °C warming, which leads to increased water vapor in the atmosphere. Hence, storms, whether individual thunderstorms, extratropical rain or snow storms, or tropical cyclones, supplied with increased moisture, produce more intense precipitation events. Such events are observed to be widely occurring, even where total precipitation is decreasing: "it never rains but it pours!" This increases the risk of flooding. The atmospheric and surface energy budget plays a critical role in the hydrological cycle, and also in the slower rate of change that occurs in total precipitation than total column water vapor. With modest changes in winds, patterns of precipitation do not change much, but result in dry areas becoming drier (generally throughout the subtropics) and wet areas becoming wetter, especially in the mid- to high latitudes: the "rich get richer and the poor get poorer." This pattern is simulated by climate models and is projected to continue into the future. Because, with warming, more precipitation occurs as rain instead of snow and snow melts earlier, there is increased runoff and risk of flooding in early spring, but increased risk of drought in summer, especially over continental areas. However, with more precipitation per unit of upward motion in the atmosphere, i.e., "more bang for the buck," atmospheric circulation weakens, causing monsoons to falter. In the tropics and subtropics, precipitation patterns are dominated by shifts as sea surface temperatures change, with El Niño a good example. The volcanic eruption of Mount Pinatubo in 1991 led to an unprecedented drop in land precipitation and runoff, and to widespread drought, as precipitation shifted from land to oceans and evaporation faltered, providing lessons for possible geoengineering. Most models simulate precipitation that occurs prematurely and too often, and with insufficient intensity, resulting in recycling that is too large and a lifetime of moisture in the atmosphere that is too short, which affects runoff and soil moisture.

Link: http://envsci.rutgers.edu/~toine379/extremeprecip/papers/trenberth_2011.pdf

124. Vandersteen W. 2011. Detecting gene expression profiles associated with environmental stressors within an ecological context. Molecular Ecology 20:1322-1323.

Type: Journal

Geographic Area: Global

Keywords: adaptation, climate change, conservation biology, genomics/proteomics transcriptomics

Abstract: Prior to the development of any conservation strategies to mitigate deleterious impacts of environmental change and contamination, there must be a method to make meaningful predictions of the effect of environmental change on organisms. Assessment of relative transcriptomic expression patterns can provide a link between the environment and the physiological response of the organism by identifying genes that respond to environmental stressors; this information could also assist in teasing apart the molecular basis of toxicological

effects vs. physiological adaptation. Molecular responses to environmental stressors are probably not restricted to single or few genes, and therefore a more integrative approach is required to examine broad-scale patterns of transcriptomic response. To address this objective, Chapman et al. (2011) used machine learning tools to link the mechanisms of physiological response to environmental stress; although widely used in clinical applications, such as finding the genetic basis of diseases, ecological genomics applications of artificial neural networks are just beginning to emerge. Analyses such as these are important to help identify limitations on the adaptive capacity of organisms and to predict impacts of climate change, ocean acidification and anthropogenic contaminants on aquatic organisms.

125. Walther GR, Post E, Convey P, Menzel A, Parmesan C, Beebee TJC, Fromentin JM, Hoegh-Guldberg O, Bairlein F. 2002. Ecological responses to recent climate change. Nature 416:389-395.

Type: Journal

Geographic Area: Global

Compilers' Keywords: review, phenology, range shift

Abstract: There is now ample evidence of the ecological impacts of recent climate change, from polar terrestrial to tropical marine environments. The responses of both flora and fauna span an array of ecosystems and organizational hierarchies, from the species to the community levels. Despite continued uncertainty as to community and ecosystem trajectories under global change, our review exposes a coherent pattern of ecological change across systems. Although we are only at an early stage in the projected trends of global warming, ecological responses to recent climate change are already clearly visible.

Link: http://eebweb.arizona.edu/courses/Ecol206/Walther%20et%20al%20Nature%202002.pdf

126. Warren R, VanDerWal JJ, Price J, Welbergen JA, Atkinson I, Ramirez-Villegas J, Osborn TJ, Jarvis A, Shoo LP, Williams SE, Lowe J. 2013. Quantifying the benefit of early climate change mitigation in avoiding biodiversity loss. Nature Climate Change May:1-5.

Type: Journal

Geographic Area: Global

Compilers' Keywords: species distribution, habitat contractions, emission reductions, plants, animals

Abstract: Climate change is expected to have significant influences on terrestrial biodiversity at all system levels, including species-level reductions in range size and abundance, especially amongst endemic species. However, little is known about how mitigation of greenhouse gas emissions could reduce biodiversity impacts, particularly amongst common and widespread species. Our global analysis of future climatic range change of common and widespread species shows that without mitigation, 57 ± 6% of plants and 34 ± 7 of animals are likely to lose ≥ 50% of their present climatic range by the 2080s. With mitigation, however, losses are reduced by 60% if emissions peak in 2016 or 40% if emissions peak in 2030. Thus, our analyses indicate that without mitigation, large range contractions can be expected even amongst common and widespread species, amounting to a substantial global reduction in biodiversity and ecosystem services by the end of this century. Prompt and stringent mitigation, on the other hand, could substantially reduce range losses and buy up to four decades for climate change adaptation.

127. Warwell MV, Rehfeldt GE, Crookston NL. 2010. Modeling species' realized climatic niche space and predicting their response to global warming for several western forest species with small geographic distributions. In: Pye JM, Rauscher HM, Sands Y, Lee DC, Beatty JS, editors. Advances in threat assessment and their application to forest and rangeland management. Portland (OR): USDA Forest Service, Pacific Northwest and Southern Research Stations. General Technical Report PNW-GTR-802. p 171-182.

Type: Government Document

Geographic Area: Western North America

Keywords: bioclimatic models, climatic distributions, climatic niche, global warming, Random Forests, multiple-regression tree, response to climate change, narrow endemic

Abstract: The Random Forests multiple regression tree was used to develop an empirically based bioclimatic model of the presence absence of species occupying small geographic distributions in western North America. The species assessed were subalpine larch (*Larix lyallii*), smooth Arizona cypress (*Cupressus arizonica* ssp. *glabra*), Paiute cypress (syn. Piute cypress) (*Cupressus arizonica* ssp. *nevadensis*), and Macfarlane's four-o'clock (*Mirabilis macfarlanei*). Independent variables included 33 simple expressions of temperature and precipitation and their interactions. These climate variables were derived from a spline climate model for the western United States that provides point estimates (latitude, longitude, and altitude). Analyses used presence-absence data largely from the Forest Inventory and Analysis, USDA Forest Service database. Overall errors of classification ranged from 1.39 percent for Macfarlane's four-o'clock to 3.55 percent for smooth Arizona cypress. The mapped predictions of species occurrence using the estimated realized climatic niche space were more accurate than published range maps. The Hadley and Canadian general circulation models (scenario IS92a for 1 percent increase GGa/year) were then used to illustrate the potential response of the species' contemporary realized climatic niche space to climate change. Predictions were mapped at a 1-km^2 resolution. Concurrence between species' geographic

distribution and their contemporary realized climatic niche rapidly disassociates through the century. These models demonstrate the heightened risk for species occupying small geographic ranges of displacement into climatic disequilibrium from rapid climate change and provide tools to assist decision makers in mitigating the threat.

Link: http://www.treesearch.fs.fed.us/pubs/37041

128. Wasserman TN, Cushman SA, Shirk AS, Landguth EL, Littell JS. 2011. **Simulating the effects of climate change on population connectivity of American marten (*Martes americana*) in the northern Rocky Mountains, USA.** Landscape Ecology 27:211-225.

Type: Journal

Geographic Area: Northwestern USA

Keywords: habitat fragmentation, gene flow, climate change, American marten, *Martes americana*, connectivity, landscape genetics

Abstract: We utilize empirically derived estimates of landscape resistance to assess current landscape connectivity of American marten (*Martes americana*) in the northern Rocky Mountains, USA, and project how a warming climate may affect landscape resistance and population connectivity in the future. We evaluate the influences of five potential future temperature scenarios involving different degrees of warming. We use resistant kernel dispersal models to assess population connectivity based on full occupancy of suitable habitat in each of these hypothetical future resistance layers. We use the CDPOP model to simulate gene exchange among individual martens in each of these hypothetical future climates. We evaluate: (1) changes in the extent, connectivity and pattern of marten habitat, (2) changes in allelic richness and expected heterozygosity, and (3) changes in the range of significant positive genetic correlation within the northern Idaho marten population under each future scenario. We found that even moderate warming scenarios resulted in very large reductions in population connectivity. Calculation of genetic correlograms for each scenario indicates that climate driven changes in landscape connectivity results in decreasing range of genetic correlation, indicating more isolated and smaller genetic neighborhoods. These, in turn, resulted in substantial loss of allelic richness and reductions in expected heterozygosity. In the U.S. northern Rocky Mountains, climate change may extensively fragment marten populations to a degree that strongly reduces genetic diversity. Our results demonstrate that for species, such as the American marten, whose population connectivity is highly tied to climatic gradients, expected climate change can result in profound changes in the extent, pattern, connectivity and gene flow of populations.

Link: http://www.fs.fed.us/rm/pubs_other/rmrs_2012_wasserman_t002.pdf

129. Westerling AL, Turner MG, Smithwick EAH, Romme WH, Ryan MG. 2011. **Continued warming could transform Greater Yellowstone fire regimes by mid-21st century.** Proceedings of the National Academy of Science, Ecology, Environmental Sciences 108:13165-13170.

Type: Journal

Geographic Area: Montana, Wyoming, USA

Compilers' Keywords: climate change, wildfire regime

Abstract: Climate change is likely to alter wildfire regimes, but the magnitude and timing of potential climate-driven changes in regional fire regimes are not well understood. We considered how the occurrence, size, and spatial location of large fires might respond to climate projections in the Greater Yellowstone ecosystem (GYE) (Wyoming), a large wildland ecosystem dominated by conifer forests and characterized by infrequent, high-severity fire. We developed a suite of statistical models that related monthly climate data (1972–1999) to the occurrence and size of fires > 200 ha in the northern Rocky Mountains; these models were cross-validated and then used with downscaled (~12 km × 12 km) climate projections from three global climate models to predict fire occurrence and area burned in the GYE through 2099. All models predicted substantial increases in fire by midcentury, with fire rotation (the time to burn an area equal to the landscape area) reduced to < 30 y from the historical 100–300 y for most of the GYE. Years without large fires were common historically but are expected to become rare as annual area burned and the frequency of regionally synchronous fires increase. Our findings suggest a shift to novel fire–climate–vegetation relationships in Greater Yellowstone by midcentury because fire frequency and extent would be inconsistent with persistence of the current suite of conifer species. The predicted new fire regime would transform the flora, fauna, and ecosystem processes in this landscape and may indicate similar changes for other subalpine forests.

Link: http://www.greateryellowstone.org/uploads/GYE_and_Fire_Westerling_et_al__2011.pdf

130. White JW, Hoogenboom G, Kimball BA, Wall GW. 2011. **Methodologies for simulating impacts of climate change on crop production.** Field Crops Research 124:357-368.

Type: Journal

Geographic Area: Global

Keywords: adaptation, agricultural impacts, climate change, crop growth simulation, global warming, modeling

Abstract: Ecophysiological models are widely used to forecast potential impacts of climate change on future agricultural productivity and to examine options for adaptation by local stakeholders and policy makers. However, protocols followed in such assessments vary to such an extent that they constrain cross-study syntheses and increase the potential for bias in projected impacts. We reviewed 221 peer reviewed papers that used crop simulation models to examine diverse aspects of how climate change might affect agricultural systems. Six subject areas were examined: target crops and regions; the crop model(s) used and their characteristics; sources and application of data on CO_2 and climate; impact parameters evaluated; assessment of variability or risk; and adaptation strategies. Wheat, maize, soybean and rice were considered in approximately 170 papers. The USA (55 papers) and Europe (64 papers) were the dominant regions studied. The most frequent approach used to simulate response to CO_2 involved adjusting daily radiation use efficiency (RUE) and transpiration, precluding consideration of the interacting effects of CO_2, stomatal conductance and canopy temperature, which are expected to exacerbate effects of global warming. The assumed baseline CO_2 typically corresponded to conditions 10–30 years earlier than the date the paper was accepted, exaggerating the relative impacts of increased CO_2. Due in part to the diverse scenarios for increases in greenhouse gas emissions, assumed future CO_2 also varied greatly, further complicating comparisons among studies. Papers considering adaptation predominantly examined changes in planting dates and cultivars; only 20 papers tested different tillage practices or crop rotations. Risk was quantified in over half the papers, mainly in relation to variability in yield or effects of water deficits, but the limited consideration of other factors affecting risk beside climate change per se suggests that impacts of climate change were overestimated relative to background variability. A coordinated crop, climate and soil data resource would allow researchers to focus on underlying science. More extensive model intercomparison, facilitated by modular software, should strengthen the biological realism of predictions and clarify the limits of our ability to forecast agricultural impacts of climate change on crop production and associated food security as well as to evaluate potential for adaptation.

Link: http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1891&context=usdaarsfacpub&sei-redir=1&referer=http%3A%2F%2Fscholar.google.com%2Fscholar%3Fq%3DMethodologies%2Bfor%2Bsimulating%2Bimpacts%2Bof%2Bclimate%2Bchange%2Bon%2Bcrop%2Bproduction%26btnG%3D%26hl%3Den%26as_sdt%3D0%252C13#search=%22Methodologies%20simulating%20impacts%20climate%20change%20crop%20production%22

131. Whitlock C, Bartlein PJ. 1997. Vegetation and climate change in the northwest America during the past 125 kyr. Nature 388:57-61.

Type: Journal

Geographic Area: Western North America

Compilers' Keywords: migration, pollen record, glacial maximum, Cascade Range, past vegetation

Abstract: Vegetation records spanning the past 21 kyr in western North America display spatial patterns of change that reflect the influence of variations in the large-scale controls of climate. Among these controls are millennial-scale variations in the seasonal cycle of insolation and the size of the ice sheet, which affect regional climates directly through changes in temperature and net radiation, and indirectly by shifting atmospheric circulation. Longer vegetation records provide an opportunity to examine the regional response to different combinations of these large-scale controls, and whether non-climatic controls are important. But most of the longer North American records are of insufficient quality to allow a robust test, and the long European records are in regions where the vegetation response to climate is often difficult to separate from the response to ecological and anthropogenic controls. Here we present a 125-kyr record of vegetation and climate change for the forest/steppe border of the eastern Cascade Range, northwest America. Pollen data disclose alternations of forest and steppe that are consistent with variations in summer insolation and global ice volume, and vegetational transitions correlate well with the marine isotope stage boundaries. The close relationship between vegetation and climate beyond the Last Glacial Maximum provides evidence that climate variations are the primary cause of regional vegetation change on millennial timescales, and that non-climatic controls are secondary.

132. Williams JW, Jackson ST. 2007. Novel climates, no-analog communities, and ecological surprises. Frontiers in Ecology and the Environment 5:475-482.

Type: Journal

Geographic Area: North America

Compilers' Keywords: novel ecosystems, no-analogue plant associations, climate change, IPCC, modern analogs, greenhouse emissions

Abstract: No-analog communities (communities that are compositionally unlike any found today) occurred frequently in the past and will develop in the greenhouse world of the future. The well documented no-analog plant communities of late-glacial North America are closely Linked to "novel" climates also lacking modern analogs, characterized by high seasonality of temperature. In climate simulations for the Intergovernmental Panel on Climate Change A2 and B1 emission scenarios, novel climates arise by 2100 AD, primarily in tropical and subtropical regions. These future novel climates are warmer than any present climates globally, with spatially variable shifts in precipitation, and increase the risk of species reshuffling into future no-analog communities and other ecological surprises. Most ecological models are at least partially parameterized from modern observations and so may fail to accurately predict ecological responses to these novel climates. There is an urgent need to test the robustness of ecological models to climate conditions outside modern experience.

Link: http://training.fws.gov/EC/Resources/climate_change/lcc/nov_10/williams_and_jackson%20_2007_frontiers.pdf

133. Williams JW, Shuman BN, Webb TI. 2001.

Dissimilarity analyses of late-quaternary vegetation and climate in eastern North America. Ecology 82:3346-3362.

Type: Journal

Geographic Area: Eastern North America

Keywords: biomes, dissimilarity analysis, eastern North America, equilibrium vs. disequilibrium, hypotheses, no-analogue plant associations, paleoecology, paleoclimatology, pollen, Quaternary, vegetation

Abstract: Plant formations different from any extant today apparently were widespread in North America and Europe during the last deglaciation, produced by the independent biogeographic responses of plant taxa to climate change. Dissimilarity analyses of modern and fossil pollen samples in eastern North America show that the unique plant associations centered around the Great Lakes at 14,000 calendar years before present (yr BP), with high dissimilarities during 17,000–12,000 yr BP. The late-glacial fossil pollen assemblages are characterized by (1) high abundances of boreal conifers such as spruce and larch relative to their Holocene values, (2) high abundances of herbaceous types (sedge, sage, and ragweed), (3) high abundances of broad-leaved deciduous types (ash, hornbeam, poplar, hazel, and willow), and (4) the low abundance or absence of pine, alder, and birch. When the fossil pollen samples are assigned to biomes using the affinity core technique, the late Pleistocene pollen samples are assigned to mixed parkland, a biome that is not extant in North America today. The fastest vegetational changes occurred 13,000–11,000 yr BP, when the late Pleistocene vegetation reorganized into the Holocene biomes, which have persisted to today. Simulations by the Community Climate Model, version 1 (CCM1), suggest that late glacial climates were also unlike modern climates, featuring a "hypercontinental" mixture of colder-than-present winters, warmer than-present summers, and lower-than-present precipitation. Dissimilarity analyses of the pollen data and CCM1 simulations for 21,000, 16,000, 14,000, 11,000, and 6,000 yr BP show that (1) the temporal and spatial distribution of high dissimilarities in the vegetation (relative to present) coincide with dissimilarities in simulated climate, (2) the timing and spatial distribution of changes in the vegetation and simulated climate also agree, and (3) the largest climatic and vegetational changes follow the peak period of dissimilarity from present. Taken together, these three lines of evidence support the hypothesis that the no-analogue plant associations were in equilibrium with orbital- and millennial-scale climate change. Nonclimatic factors such as low atmospheric CO_2 concentrations and the presence of now-extinct megafauna species may have increased the openness of the Pleistocene vegetation, but by themselves cannot explain the observed mixture of boreal, temperate, and herbaceous taxa in the no-analogue pollen assemblages, nor can they explain the prevalence of no-analogue pollen samples during the late glacial period.

Link: http://www.cof.orst.edu/cof/teach/fs545/Readings/Williams,%20Shuman,%20Webb%202001.pdf

134. Wilsey CB, Lawler JJ, Maurer EP, McKenzie D, Townsend PA, Gwozdz R, Freund JA, Hagmann K, Hutten KM. 2013.

Tools for assessing climate impacts on fish and wildlife. Journal of Fish and Wildlife Management 4:220-241.

Type: Journal

Geographic Area: North America

Keywords: climate change, ecological modeling, hydrology, vegetation, fire

Abstract: Climate change is already affecting many fish and wildlife populations. Managing these populations requires an understanding of the nature, magnitude, and distribution of current and future climate impacts. Scientists and managers have at their disposal a wide array of models for projecting climate impacts that can be used to build such an understanding. Here, we provide a broad overview of the types of models available for forecasting the effects of climate change on key processes that affect fish and wildlife habitat (hydrology, fire, and vegetation), as well as on individual species distributions and populations. We present a framework for how climate-impacts modeling can be used to address management concerns, providing examples of model-based assessments of climate impacts on salmon populations in the Pacific Northwest, fire regimes in the boreal region of Canada, prairies and savannas in the Willamette Valley-Puget Sound Trough-Georgia Basin ecoregion, and marten populations in the northeastern United States and southeastern Canada. We also highlight some key limitations of these models and discuss how such limitations should be managed. We conclude with a general discussion of how these models can be integrated into fish and wildlife management.

135. Worrall JJ, Rehfeldt GE, Hamann A, Hogg EH, Marchetti SB, Michaelian M, Gray LK. 2013.

Recent declines of *Populus tremuloides* in North America linked to climate. Forest Ecology and Management 299:35-51.

Type: Journal

Geographic Area: North America

Keywords: decline, dieback, die-off, drought, climate envelope, climatic niche

Abstract: *Populus tremuloides* (trembling aspen) recently experienced extensive crown thinning, branch dieback, and mortality across North America. To investigate the role of climate, we developed a range wide bioclimate model that characterizes climatic factors controlling distribution of aspen.

We also examined indices of moisture stress, insect defoliation and other factors as potential causes of the decline. Historic climate records show that most decline regions experienced exceptionally severe drought preceding the recent episodes. The bioclimate model, driven primarily by maximum summer temperatures and April–September precipitation, shows that decline tended to occur in marginally suitable habitat, and that climatic suitability decreased markedly in the period leading up to decline in almost all decline regions. Other factors, notably multi-year defoliation by tent caterpillars (*Malacosoma* spp.) and stem damage by fungi and insects, also play a substantial role in decline episodes, and may amplify or prolong the impacts of moisture stress on aspen over large areas. Many severely affected stands have poor regeneration potential, raising concerns that increasing aridity could ultimately lead to widespread loss of aspen forest cover. The analysis indicates that exceptional droughts were a major cause of the decline episodes, especially in the drier regions, and that aspen is sensitive to drought in much of its range. Coupling the bioclimate model with climate projections suggests that we should expect substantial loss of suitable habitat within the current distribution, especially in the USA and Mexico.

Link: http://www.ualberta.ca/~ahamann/publications/pdfs/Worrall_et_al_2013.pdf

Climate Change

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

136. Alfaro RI, Fady B, Vendramin GG, Dawson IK, Fleming RA, Sáenz-Romero C, Lindig-Cisneros RA, Murdock T, Vinceti B, Navarro CM, Skrøppa T, Baldinelli G, El-Kassaby YA, Loo J. 2014. The role of forest genetic resources in responding to biotic and abiotic factors in the context of anthropogenic climate change. Forest Ecology and Management 333:76-87.

Type: Journal

Geographic Area: Global

Keywords: tree genetic variation, climate change, adaptation, natural disturbance

Abstract: The current distribution of forest genetic resources on Earth is the result of a combination of natural processes and human actions. Over time, tree populations have become adapted to their habitats including the local ecological disturbances they face. As the planet enters a phase of human-induced climate change of unprecedented speed and magnitude, however, previously locally-adapted populations are rendered less suitable for new conditions, and "natural" biotic and abiotic disturbances are taken outside their historic distribution, frequency and intensity ranges. Tree populations rely on phenotypic plasticity to survive in extant locations, on genetic adaptation to modify their local phenotypic optimum or on migration to new suitable environmental conditions. The rate of required change, however, may outpace the ability to respond, and tree species and populations may become locally extinct after specific, but as yet unknown and unquantified, tipping points are reached. Here, we review the importance of forest genetic resources as a source of evolutionary potential for adaptation to changes in climate and other ecological factors. We particularly consider climate-related responses in the context of Linkages to disturbances such as pests, diseases and fire, and associated feedback loops. The importance of management strategies to conserve evolutionary potential is emphasised and recommendations for policy-makers are provided.

Link: http://www.sciencedirect.com/science/article/pii/S037811271400231X

137. Anderson PD, Chmura DJ. 2009. Silvicultural approaches to maintain forest health and productivity under current and future climates. Western Forester 54:6-8.

Type: Newsletter

Geographic Area: Pacific Northwest USA

Compilers' Keywords: climate change, forest management

Introduction: Climate modeling based on a variety of scenarios for the Pacific Northwest suggests that over the next century temperatures may increase and that the abundance of summer precipitation may decline. Historically, climate changes at the century scale have been accompanied by adjustments in species population sizes and the composition of vegetation communities. Silvicultural practices may be employed to assist in forest adaptation to climate changes, principally by influencing stand structure and species composition throughout stand development. Forest managers might consider a primary silviculture objective over the next century of increasing forest vigor to increase both resistance and resilience to direct and indirect stresses arising from climate variation.

Link: http://www.fs.fed.us/pnw/pubs/journals/pnw_2009_anderson001.pdf

138. Bosselmann AS, Jacobsen JB, Kjaer ED, Thorsen BJ. 2008. **Climate change, uncertainty and the economic value of genetic diversity: a pilot study on methodologies.** Forest and Landscape Working Papers 31-2008:1-58.

Type: Journal

Geographic Area: Denmark, Europe

Compilers' Keywords: methods, forest management

Summary: The report is based on a limited empirical material, which stresses the need for qualified information from genetic research and tree improvement programmes as climate change is picking up speed and forest owners every day make decisions that will affect the stability, health and growth of forest many decades into the future. The decisions are made on information that was produced under a research and tree improvement paradigm focused on tree breeding for production under a known climate believed to be stable. Any new and improved information is greatly needed—even if it is not exact and only indicative. Therefore, existing clone and provenance trials in forest genetic research and tree improvement programmes should be systematically investigated across as large climate gradients as permitted by the location of the trials. Such analysis should be able to bring about at least indicative information on the genotype response to variation in the main climate and growth factors. Such information can subsequently be used in more thorough analyses along the steps outlined here, perhaps with a special focus on potential gains from mixing provenances on the same area. Tree improvement programmes should use the information produced to gradually adjust current recommendations concerning local and regional choices of planting material, and of course to adjust and diversify breeding strategies accordingly. In the long run, such research may go into more details along the lines discussed earlier. In particular, genetic research into sensitivity of different provenances and clones to potentially more frequent pest attacks, mild winters, etc. may be relevant. On a broader scale, ecological and economic research could aim to provide more information on the way forest ecosystem services and their value rely on the state and characteristics of the forest ecosystem and notably its stability. Such information will be needed for a reliable economic modelling of the consequences of climate change for the provision of such ecosystem services at landscape levels.

Link: http://curis.ku.dk/ws/files/20572936/wp31.pdf

139. Campbell EM, Saunders SC, Coates KD, Meidinger DV, MacKinnon A, O'Neill GA, MacKillop DJ, DeLong SC, Morgan DG. 2009. **Ecological resilience and complexity: a theoretical framework for understanding and managing British Columbia's forest ecosystem in a changing climate.** Victoria, British Columbia, Canada: BC Ministry of Forests and Range, Forest Science Program. Technical Report 055. 44 p.

Type: Government Document

Geographic Area: Western Canada

Compilers' Keywords: climate change, forest management, mitigation, ecosystem services, review

Summary: At global, regional, and local scales, forest managers are faced with unprecedented pressures to supply forest resources for human consumption while still maintaining a diverse array of other ecosystem services essential to human well-being. While this alone has posed major challenges to forest management, global climate change presents a new range of daunting challenges. The potential for major ecosystem changes as well as uncertainties about the degree and rate of climate change necessitates a major shift in thinking about forest management. Recent scientific literature proposes new approaches to forest management that focus on "managing for ecological resilience," with the idea that it provides a tenable framework for achieving sustainability goals when environments are changing and the future is uncertain. The concept of ecological resilience has been used to guide the management of ecosystems degraded by human land use activities, and managing for resilience is a commonly discussed approach for countering the negative impacts of climate change. This document summarizes the theoretical literature on ecological resilience and complexity, and describes how this evolving body of science can begin to guide the management of forest ecosystems in a changing climate. Ecological resilience describes the capacity of ecosystems to absorb disturbance without collapsing into a qualitatively different state. While research is still under way to develop a structured understanding of the mechanisms regulating ecological resilience, scientists propose that key ecological processes, operating across varying scales of time and space (e.g., seedling survivorship, forest succession, periodic natural disturbances, propagule dispersal that facilitates species range shifts), generate the complexity needed to maintain ecosystem resilience to environmental change. Maintaining and enhancing biological diversity across multiple scales may play an important role in preserving ecosystem services if it generates redundancy in the ecological processes that confer ecological resilience (i.e., conserves key ecosystem functions). Adapting forest management frameworks to climate change involves actions that minimize the risk of adverse climate-change impacts and capitalize on its benefits. Managing for resilience advocates diverse and novel actions that help cope with uncertainties about future forest conditions and reduce both societal and ecological vulnerabilities to climate change. While societal adaptations to climate change include the development of policies to encourage adaptation, modifying wood processing technologies, and revising expectations of resource use and conservation objectives, management to maintain ecological resilience involves deliberate, on-the-ground forest practices that maintain ecosystem complexity across multiple scales of time and space, and facilitate gradual ecosystem change in response to climate change. In this report, we present some examples of the kinds of on-the-ground actions that could be undertaken to begin the process of managing for ecological resilience to climate change. They include: facilitating tree species (and population) migration and range shifts; developing forest harvest, regeneration, and stand-tending activities that maintain or enhance ecosystem complexity and response diversity to environmental change, such as the forest structures generated by past disturbance regimes; planting broader mixes of trees across landscapes to help reset successional trajectories; promoting landscape connectivity; and retaining or restoring areas that may be buffered against climate change. Managing for ecological resilience is in its infancy and the technical details about how to implement this new approach to forest management will depend on ecosystem type and evolve as the science integrating resilience, complexity, and biodiversity evolves and more information about the impacts of climate change on ecosystems becomes available through field monitoring programs and quantitative modelling research. Resilience-based ecosystem management, especially when it takes into account changing climate conditions, represents a profound shift in the way the Ministry of Forests and Range will approach how forest ecosystems are managed, and poses challenges to many existing practices and policies in British Columbia. Involving a more diverse array of forest practices than traditional forest management approaches, it will require setting landscape-level management objectives for desired future forest conditions and making decisions regarding how to cope with unexpected and undesirable management outcomes. Transitioning to resilience-based ecosystem management also requires an understanding of complex ecological and social feedbacks, but an awareness of this, and an openness to work with complexity scientists, forest ecologists, climatologists, forest geneticists, and others can help to make this transition.

Link: http://www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr055.htm

140. Ciccarese L, Mattsson A, Pettenella D. 2012.

Ecosystem services from forest restoration: thinking ahead. New Forests 43:543-560.

Type: Journal

Geographic Area: Global

Keywords: ecosystem services, forest restoration, bioenergy, climate change, planting stock production, economics

Abstract: Global deforestation and forest degradation have led to massive loss of biodiversity and decline of ecosystem services. Against this prospect, it is important not only to protect, but also to restore forest ecosystems. The paper analyzes the current and future role of the restoration of forests and degraded lands starting with the definition of various techniques, scales and objectives of forest restoration. Three key motivations for and targets of forest restoration are then discussed: forest biodiversity protection, biomass production, climate change mitigation and adaptation. The paper also briefly discusses three tools of increasing relevance for supporting forest restoration policies: the development of forest nursery techniques and the improvement of quality of forest reproductive material, the use of standard and certification tools, and financing of restoration investments, including projects aimed at reducing emissions from deforestation and forest degradation. We conclude by making some final remarks on the future challenges of forest restoration policies.

141. Colombo S, Boysen B, Brosemer K, Foley A, Obenchain A. 2008.

Managing tree seed in an uncertain climate: conference summary. Ontario, Canada: Ontario Ministry of Natural Resources, Applied Research and Development Branch. Note Number 8. 8 p.

Type: Government Document

Geographic Area: Central Canada

Compilers' Keywords: forest, seed transfer, adaptive variation, forest genetic resources, forest management

Introduction: Canadian forests will experience greater increases in temperature than those growing further south. One set of projections for Ontario indicates that by the end of the century, average summer temperature will increase from 3 to 7 °C (southern and northern Ontario, respectively) and that winter temperatures will increase from up to 4 °C in the south to 10 °C in the north. Predictions of precipitation with climate change vary, but future precipitation may be insufficient to prevent large areas of Ontario forests from experiencing more frequent and intense drought. Such temperature and soil moisture changes would alter the ecological conditions in forests enough to affect how well trees are adapted to local climates. As a result, climate change presents many challenges to sustainable forest management in Canada. The long life of tree species and long rotation cycles mean that the effects of today's decisions can persist for a century or more. Given projections for Ontario's future climate, those who are concerned about forest ecology, management, and policy must be concerned about seed source deployment. Important questions include: 1. What if any changes do we make in how we distribute seed sources when planting? 2. When do we make changes? 3. Can we predict the effects of such changes? Out of concern for these issues, a conference entitled Managing Tree Seed in an Uncertain Climate was held on November 14-15, 2007, in Sault Ste. Marie, Ontario. The event was co-hosted by the Ontario Ministry of Natural Resources (through its climate change initiative) and Forest Genetics Ontario. This conference focused on managing tree seed in a rapidly changing climate, including seed movement (species and populations) and regulatory tools (guidelines/zones); the science behind identifying and predicting patterns of adaptive variation response to climate change (invited speakers' abstracts are shown in the appendix); the need to revise seed movement decision-making; and reforestation aspects of management planning under climate change. The goals of the conference were to: 1. Build awareness about climate change and its potential impacts on the deployment of forest genetic resources (e.g., seed transfer guidelines, seed source bulking, seed banking, and tree improvement strategies) 2. Initiate a dialogue among those concerned about impacts of climate change on forest genetic resources 3. Develop a roadmap of future actions promoting adaptation of forests to future climate.

Link: http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@climatechange/documents/document/276918.pdf

142. Conroy MJ, Runge MC, Nichols JD, Stodola KW, Cooper RJ. 2011. **Conservation in the face of climate change: the roles of alternative models, monitoring, and adaptation in confronting and reducing uncertainty.** Biological Conservation 144:1204-1213.

Type: Journal

Geographic Area: Eastern USA

Keywords: climate change, birds, prediction, monitoring, adaptive management

Abstract: The broad physical and biological principles behind climate change and its potential large scale ecological impacts on biota are fairly well understood, although likely responses of biotic communities at fine spatio-temporal scales are not, limiting the ability of conservation programs to respond effectively to climate change outside the range of human experience. Much of the climate debate has focused on attempts to resolve key uncertainties in a hypothesis-testing framework. However, conservation decisions cannot await resolution of these scientific issues and instead must proceed in the face of uncertainty. We suggest that conservation should precede in an adaptive management framework, in which decisions are guided by predictions under multiple, plausible hypotheses about climate impacts. Under this plan, monitoring is used to evaluate the response of the system to climate drivers, and management actions (perhaps experimental) are used to confront testable predictions with data, in turn providing feedback for future decision making. We illustrate these principles with the problem of mitigating the effects of climate change on terrestrial bird communities in the southern Appalachian Mountains, USA.

143. Driscoll DA, Felton A, Gibbons P, Felton AM, Munro NT, Lindenmayer DB. 2011. **Priorities in policy and management when existing biodiversity stressors interact with climate-change.** Climatic Change 111:533-557.

Type: Journal

Geographic Area: Global

Compilers' Keywords: environmental stressors

Abstract: There are three key drivers of the biodiversity crisis: 1) the well-known existing threats to biodiversity such as habitat loss, invasive pest species and resource exploitation; 2) direct effects of climate-change, such as on coastal and high elevation communities and coral reefs; and 3) the interaction between existing threats and climate-change. The third driver is set to accelerate the biodiversity crisis beyond the impacts of the first and second drivers in isolation. In this review we assess these interactions, and suggest the policy and management responses that are needed to minimise their impacts. Renewed management policy action that address known threats to biodiversity could substantially diminish the impacts of future climate change. An appropriate response to climate-change will include a reduction of land clearing, increased habitat restoration using indigenous species, a reduction in the number of exotic species transported between continents or between major regions of endemism, and a reduction in the unsustainable use of natural resources. Achieving these measures requires substantial reform of international, national and regional policy, and the development of new or more effective alliances between scientists, government agencies, non-government organisations and land managers. Furthermore, new management practices and policy are needed that consider shifts in the geographic range of species, and that are responsive to new information acquired from improved research and monitoring programs. The interactions of climate-change with existing threats to biodiversity have the potential to drive many species to extinction, but there is much that can be done now to reduce this risk.

144. Erickson VJ, Aubry C, Berrang PC, Blush T, Bower AD, Crane BS, DeSpain T, Gwaze D, Hamlin J, Horning ME, Johnson R, Mahalovich MF, Maldonado M, Sniezko R, St. Clair JB. 2012. **Genetic resource management and climate change: genetic options for adapting national forests to climate change.** Washington (DC): USDA Forest Service, Forest Management. 24 p.

Type: Government Document

Geographic Area: North America

Compilers' Keywords: genecology, planning, USFS, genetic options, review, guidelines

Summary: This report provides an overview of current climate change knowledge and potential implications for forest tree species, as well as goals, principles, and recommendations for enhancing forest resilience and resistance through a re-aligned "climate-smart" National Forest System (NFS) Genetic Resource Management Program. Although national forests may differ in terms of species and population vulnerability to climate change, as well as appropriate management response, our recommendations and adaptation options all follow three overarching principles: (1) genetically diverse and adapted seed and planting stock will provide the foundation for healthy forests and ecosystems in the future; (2) gene conservation is key to preserving vulnerable species and populations for the future; and (3) establishing and maintaining partnerships will be more important than ever. Implementation of the adaptation options will require new tools, practices, and refocused investments in NFS Genetic Resource Management activities, as well as a trained workforce, supporting plant production infrastructure, and strong support from research and management.

Link: http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5368468.pdf

145. Guariguata MR, Cornelius JP, Locatelli B, Forner C, Sánchez-Azofeifa GA. 2008. **Mitigation needs adaptation: tropical forestry and climate change.** Mitigation and Adaptation Strategies for Global Change 13:793-808.

Type: Journal

Geographic Area: Global

Keywords: climate change, adaptation, tropical forests, tropical tree plantations, natural forest management

Abstract: The relationship between tropical forests and global climate change has so far focused on mitigation, while much less emphasis has been placed on how management activities may help forest ecosystems adapt to this change. This paper discusses how tropical forestry practices can contribute to maintaining or enhancing the adaptive capacity of natural and planted forests to global climate change and considers challenges and opportunities for the integration of tropical forest management in broader climate change adaptation. In addition to the use of reduced impact logging to maintain ecosystem integrity, other approaches may be needed, such as fire prevention and management, as well as specific silvicultural options aimed at facilitating genetic adaptation. In the case of planted forests, the normally higher intensity of management (with respect to natural forest) offers additional opportunities for implementing adaptation measures, at both industrial and smallholder levels. Although the integration in forest management of measures aimed at enhancing adaptation to climate change may not involve substantial additional effort with respect to current practice, little action appears to have been taken to date. Tropical foresters and forest-dependent communities appear not to appreciate the risks posed by climate change and, for those who are aware of them, practical guidance on how to respond is largely non-existent. The extent to which forestry research and national policies will promote and adopt management practices in order to assist production forests adapt to climate change is currently uncertain. Mainstreaming adaptation into national development and planning programs may represent an initial step towards the incorporation of climate change considerations into tropical forestry.

Link: http://www.cifor.org/publications/pdf_files/articles/AGuariguata0801.pdf

146. Gunn JS, Hagan JM, Whitman AA. 2009. **Forestry adaptation and mitigation in a changing climate—a forest resource manager's guide for the northeastern United States.** Brunswick (ME): Natural Capital Initiative at Manomet. NCI-2009-1. 16 p.

Type: Report

Geographic Area: Northeastern USA

Compilers' Keywords: climate change, forest management, guidelines, silviculture, report, resilience

Summary: A coordinated response to reduce greenhouse gas emissions will not be adequate to prevent unprecedented climate change resulting from the elevated levels of carbon dioxide (CO_2) already in the atmosphere. Climate adaptation management strategies are essential if landowners and managers are going to have plans that help them achieve their objectives in the face of uncertainty (e.g., revenue, silviculture, retain third-party forest certification). Strategies are also needed if northeastern U.S. forests will continue to play a mitigating role in addressing greenhouse gas emissions. In this report, we lay out a framework for understanding potential impacts of climate change on forestry. This framework draws on a review of recommended actions from forest managers and scientists throughout Canada, the U.S., and Europe. We then present a toolbox of practices that forest managers in the northeastern U.S. might apply to reduce exposure to the immediate and long-term risk from climate change. The toolbox approach incorporates three broad strategies of Resistance, Resilience, and Response. A Resistance strategy is a set of short-term approaches to address immediate threats and focuses on minimizing the impacts of disturbance regimes that are exacerbated by climate change. Resilience can be seen both as a short-term and a long-term strategy. Resilience strategies address the capacity of a stand or community to recover from a disturbance and return to a reference or desired state. The primary purpose of a Response strategy is to facilitate the movement of species over time. This strategy encompasses the most costly practices and requires acceptance of a level of uncertainty that many landowners and managers will likely not choose.

Link: http://www.manomet.org/sites/default/files/publications_and_tools/Manomet_ForestryAdaptationtoCCReport%205-09.pdf

147. Halofsky JE, Peterson DL, Furniss MJ, Joyce LA, Millar CI, Neilson RP. 2011. Workshop approach for developing climate change adaptation strategies and actions for natural resource management agencies in the United States. Journal of Forestry 109:219-225.

Type: Journal

Geographic Area: USA

Keywords: climate change, adaptation, forest management

Abstract: Concrete ways to adapt to climate change are needed to help land-management agencies take steps to incorporate climate change into management and take advantage of opportunities to balance the negative effects of climate change. Because the development of adaptation tools and strategies is at an early stage, it is important that ideas and strategies are disseminated quickly to advance thinking and practice. Here, we offer an example of a successful workshop, focused on National Forests in the United States, which allowed quick dissemination of ideas and strategies for climate change adaptation in resource management through an interaction between scientists and managers. We share both the process used in the workshop and the outcome of facilitated dialogue at the workshop. By presenting concrete adaptation methods and showing the value of a focused scientist—manager dialogue, we hope to motivate the U.S. Forest Service and other natural resources agencies to emulate our approach and begin the process of adapting to climate change.

Link: http://www.treesearch.fs.fed.us/pubs/39144

148. Hannah L, Midgley GF, Miller G. 2002. Climate change-integrated conservation strategies. Global Ecology and Biogeography 11:485-495.

Type: Journal

Geographic Area: Global

Keywords: biodiversity, climate change, conservation, matrix management, modelling, protected areas, range shifts

Abstract: Conservation strategies currently include little consideration of climate change. Insights about the biotic impacts of climate change from biogeography and palaeoecology, therefore, have the potential to provide significant improvements in the effectiveness of conservation planning. We suggest a collaboration involving biogeography, ecology and applied conservation. The resulting Climate Change-integrated Conservation Strategies (CCS) apply available tools to respond to the conservation challenges posed by climate change. The focus of this analysis is global, with special reference to high biodiversity areas vulnerable to climate change, particularly tropical montane settings. Current tools from climatology, biogeography and ecology applicable to conservation planning in response to climate change are reviewed. Conservation challenges posed by climate change are summarized. CCS elements are elaborated that use available tools to respond to these challenges. Five elements of CCS are described: regional modelling, expanding protected areas; management of the matrix regional coordination; and transfer of resources. Regional modelling uses regional climate models, biotic response models and sensitivity analysis to identify climate change impacts on biodiversity at a regional scale appropriate for conservation planning. Expansion of protected areas management and systems within the planning region are based on modelling results. Management of the matrix between protected areas provides continuity for processes and species range shifts outside of parks. Regional coordination of park and off-park efforts allows harmonization of conservation goals across provincial and national boundaries. Finally, implementation of these CCS elements in the most biodiverse regions of the world will require technical and financial transfer of resources on a global scale. Collaboration across disciplines is necessary to plan conservation responses to climate change adequately. Biogeography and ecology provide insights into the effects of climate change on biodiversity that have not yet been fully integrated into conservation biology and applied conservation management. CCS provide a framework in which biogeographers, ecologists and conservation managers can collaborate to address this need. These planning exercises take place on a regional level, driven by regional climate models as well as general circulation models (GCMs), to ensure that regional climate drivers such as land use change and mesoscale topography are adequately represented. Sensitivity analysis can help address the substantial uncertainty inherent in projecting future climates and biodiversity response.

Link: http://www.cakex.org/sites/default/files/Climate%20change%20integrated%20conservation%20strategies_1.pdf

149. Hayward, GD, Flather, CH, Uloth, E, Safford, HD, Cleaves, DA. 2009. Managing fish and wildlife in the face of climate change: USDA Forest Service perspective. In: McCabe RE, Stockwell KA, editors. Transactions of the 74th North American Wildlife and Natural Resources Conference. Washington (DC): Wildlife Management Institute. p 98-109.

Type: Proceedings Paper

Geographic Area: North America

Compilers' Keywords: climate change, assisted migration, fish and wildlife management, IPCC, strategic framework, review, USFS

Introduction: This invited review explores progress that the research and management branches of the Forest Service have made addressing fish and wildlife management in the face of climate change. In this paper, we begin by providing an overview of the agency's research and management context. Key to this overview is the Forest Service Strategic Framework (U.S. Forest Service 2008a) for responding to climate change, which defines three broad categories of agency goals that guide the incorporation of climate change into natural resource management. Through a series of case studies we demonstrate progress the agency has made in each of those broad goal categories. We conclude by reviewing those features of the Forest Service that position it as an important partner in addressing climate change, and by highlighting some of the management, research, and policy opportunities that must be seized if fish and wildlife are to be successfully managed in the face of climate change.

Link: http://www.fs.fed.us/rm/human-dimensions/staff/flather/pubs/2009.Hayward.et.al.Trans.N.Am.Wildl.Nat.Res.Conf.pdf

150. Hebda RJ. 2008. Climate change, forests, and the forest nursery industry. In: Dumroese RK, Riley LE, editors. National Proceedings: Forest and Conservation Nursery Associations – 2007. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-57. p 81-82.

Type: Government Document

Geographic Area: Western North America

Keywords: ancient carbon, living carbon, mountain pine beetle, Dothistroma needle blight

Introduction: The devastating consequences of Hurricane Katrina demonstrate how ill-prepared people are when it comes to extreme weather events and potential changes in climate. The hurricane itself cannot be directly ascribed to climate change, but the likelihood of stronger hurricanes can be. The more energy the atmosphere has as it warms because of increasing concentrations of greenhouse gasses, the more energy it needs to shuffle around. Hurricanes are one way of doing just that. The potential risks from just such an event had been described in the region's major daily paper, yet the response to the hurricane seems to indicate that little action had been taken to get ready. The lessons of the event must be taken seriously by all sectors of society because climate change is a certainty, is now well underway, and will impact us all. The fourth series of reports issued in 2007 by the Intergovernmental Panel on Climate Change (IPCC IV), in what is a conservative account of climate change and its impacts, warns us clearly that major effects on forests must be expected. In northwestern North America, the climate has already changed and is continuing to change, and those changes are having serious impacts on regional forests. Furthermore, in one of the IPCC IV reports, Fischlin and others (2007) identify northwest North American forests as especially likely to be impacted by climate change. The devastating mountain pine beetle (*Dendroctonus ponderosae*) outbreak in the interior of British Columbia and adjacent regions has single-handedly altered the character of forests over a huge area in less than decade. Increases in Dothistroma needle blight on lodgepole pines (*Pinus contorta*) are also attributed to changes in climate. In the coastal temperate rainforests of British Columbia, western redcedars (*Thuja plicata*) are showing excessive autumn branchlet drop and top die-back, likely as a result of increased summer moisture deficits.

Link: http://www.treesearch.fs.fed.us/pubs/31835

151. Heller NE, Zavaleta ES. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation 142:14-32.

Type: Journal

Geographic Area: Global

Keywords: conservation, adaptation, reserve planning, landscape connectivity, resilience, global warming

Abstract: Climate change creates new challenges for biodiversity conservation. Species ranges and ecological dynamics are already responding to recent climate shifts, and current reserves will not continue to support all species they were designed to protect. These problems are exacerbated by other global changes. Scholarly articles recommending measures to adapt conservation to climate change have proliferated over the last 22 years. We systematically reviewed this literature to explore what potential solutions it has identified and what consensus and direction it provides to cope with climate change. Several consistent recommendations emerge for action at diverse spatial scales, requiring leadership by diverse actors. Broadly, adaptation requires improved regional institutional coordination, expanded spatial and temporal perspective, incorporation of climate change scenarios into all planning and action, and greater effort to address multiple threats and global change drivers simultaneously in ways that are responsive to and inclusive of human communities. However, in the case of many recommendations the how, by whom, and under what conditions they can be implemented is not specified. We synthesize recommendations with respect to three likely conservation pathways: regional planning; site-scale management; and modification of existing conservation plans. We identify major gaps, including the need for (1) more specific, operational examples of adaptation principles that are consistent with unavoidable uncertainty about the future; (2) a practical adaptation planning process to guide selection and integration of recommendations into existing policies and programs; and (3) greater integration of social science into an endeavor that, although dominated by ecology, increasingly recommends extension beyond reserves and into human occupied landscapes.

Link: http://people.ucsc.edu/~zavaleta/pubs/Heller%20and%20Zavaleta%202009_BiolCons09_climate.pdf

152. Jackson ST, Sax DF. 2010. Balancing biodiversity in a changing environment: extinction debt, immigration credit and species turnover. Trends in Ecology and Evolution 25:153-160.

Type: Journal

Geographic Area: Global

Compilers' Keywords: animals, climate change, humans, population dynamics, uncertainty, migration, framework

Abstract: Here, we outline a conceptual framework for biodiversity dynamics following environmental change. The model incorporates lags in extinction and immigration, which lead to extinction debt and immigration credit, respectively. Collectively, these concepts enable a balanced consideration of changes in biodiversity following climate change, habitat fragmentation and other forcing events. They also reveal transient phenomena, such as biodiversity surpluses and deficits, which have important ramifications for biological conservation and the preservation of ecosystem services. Predicting such transient dynamics poses a serious conservation challenge in a time of rapid environmental change.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19879014

153. Joyce LA, Briske DD, Brown JR, Polley HW, McCarl BA, Bailey DW. 2013. **Climate change and North American rangelands: assessment of mitigation and adaptation strategies.** Rangeland Ecology & Management 66:512-528.

Type: Journal

Geographic Area: North America

Keywords: carbon sequestration, land change science, social-ecological systems, social learning, sustainability, transformation

Abstract: Recent climatic trends and climate model projections indicate that climate change will modify rangeland ecosystem functions and the services and livelihoods that they provision. Recent history has demonstrated that climatic variability has a strong influence on both ecological and social components of rangeland systems and that these systems possess substantial capacity to adapt to climatic variability. Specific objectives of this synthesis are to: 1) evaluate options to mitigate greenhouse gas emissions and future climate change; 2) survey actions that individuals, enterprises, and social organizations can use to adapt to climate change; and 3) assess options for system transformation when adaptation is no longer sufficient to contend with climate change. Mitigation for carbon sequestration does not appear economically viable, given the small and highly variable carbon dioxide fluxes of rangeland ecosystems and the high transaction costs that would be incurred. In contrast, adaptation strategies are numerous and provide a means to manage risks associated with climate change. Adaptation strategies are diverse, including altered risk perception by individuals, greater flexibility of production enterprises, and modifications to social organizations that emphasize climatic variability, rather than consistency. Many adaptations represent "no regrets" actions because their implementation can be justified without emphasis on pending climate change. Adaptations specific to livestock production systems can include flexible herd management, alternative livestock breeds or species, innovative pest management, modified enterprise structures, and geographic relocation. Social-ecological systems in which adaptation is insufficient to counter the adverse consequences of climate change might undergo transformative change to produce alternative ecosystem services, production enterprises, and livelihoods. The rangeland profession is in a pivotal position to provide leadership on this global challenge because it represents the intersection of management and scientific knowledge, includes diverse stakeholders who derive their livelihoods from rangelands, and interacts with organizations responsible for rangeland stewardship.

Link: http://www.treesearch.fs.fed.us/pubs/44831

154. Joyce LA, Blate GM, McNulty SG, Millar CI, Moser S, Neilson RP, Peterson DL. 2009. **Managing for multiple resources under climate change: national forests**. Environmental Management 44:1022-1032.

Type: Journal

Geographic Area: USA

Keywords: resilience, resistance, anticipatory management, planning, assessments, adaptation

Abstract: This study explores potential adaptation approaches in planning and management that the United States Forest Service might adopt to help achieve its goals and objectives in the face of climate change. Availability of information, vulnerability of ecological and socio-economic systems, and uncertainties associated with climate change, as well as the interacting non-climatic changes, influence selection of the adaptation approach. Resource assessments are opportunities to develop strategic information that could be used to identify and link adaptation strategies across planning levels. Within a National Forest, planning must incorporate the opportunity to identify vulnerabilities to climate change as well as incorporate approaches that allow management adjustments as the effects of climate change become apparent. The nature of environmental variability, the inevitability of novelty and surprise, and the range of management objectives and situations across the National Forest System implies that no single approach will fit all situations. A toolbox of management options would include practices focused on forestalling climate change effects by building resistance and resilience into current ecosystems, and on managing for change by enabling plants, animals, and ecosystems to adapt to climate change. Better and more widespread implementation of already known practices that reduce the impact of existing stressors represents an important "no regrets" strategy. These management opportunities will require agency consideration of its adaptive capacity, and ways to overcome potential barriers to these adaptation options.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19588192

155. Joyce LA, Blate GM, Littell J, McNulty SG, Millar CI, Moser S, Neilson RP, O'Halloran KA, Peterson DL. 2008. Adaptation options for climate-sensitive ecosystems and resources. Chapter 3. In: Julius SH, West JM, editors. Adaptation Options for Climate-Sensitive Ecosystems and Resources. Washington (DC): U.S. Environmental Protection Agency. p 1-66.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: forest management, climate change, adaptive strategy, USFS, National Forest System

Summary: The National Forest System (NFS) is composed of 155 national forests (NFs) and 20 national grasslands (NGs), which encompass a wide range of ecosystems, harbor much of the nation's biodiversity, and provide myriad goods and services. The mission of the U.S. Forest Service (USFS), which manages the NFS, has broadened from water and timber to sustaining ecosystem health, diversity, and productivity to meet the needs of present and future generations. The evolution of this mission reflects changing societal values (e.g., increasing emphasis on recreation, aesthetics, and biodiversity conservation), a century of new laws, increasing involvement of the public and other agencies in NF management, and improved ecological understanding. Climate change will amplify the already difficult task of managing the NFS for multiple goals. This chapter offers potential adaptation approaches and management options that the USFS might adopt to help achieve its NF goals and objectives in the face of climate change.

Link: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=180143

156. Lankau R, Jørgensen PS, Harris DJ, Sih A. 2011. Incorporating evolutionary principles into environmental management and policy. Evolutionary Applications 4:315-325.

Type: Journal

Geographic Area: Global

Keywords: conservation biology, environmental management, evolution, gene flow, selection, variation

Abstract: As policymakers and managers work to mitigate the effects of rapid anthropogenic environmental changes, they need to consider organisms' responses. In light of recent evidence that evolution can be quite rapid, this now includes evolutionary responses. Evolutionary principles have a long history in conservation biology, and the necessary next step for the field is to consider ways in which conservation policy makers and managers can proactively manipulate evolutionary processes to achieve their goals. In this review, we aim to illustrate the potential conservation benefits of an increased understanding of evolutionary history and prescriptive manipulation of three basic evolutionary factors: selection, variation, and gene flow. For each, we review and propose ways that policy makers and managers can use evolutionary thinking to preserve threatened species, combat pest species, or reduce undesirable evolutionary changes. Such evolution-based management has potential to be a highly efficient and consistent way to create greater ecological resilience to widespread, rapid, and multifaceted environmental change.

Link: https://research.franklin.uga.edu/lankau/sites/research.franklin.uga.edu.lankau/files/Lankau%20et%20al.%202011.pdf

157. Leakey ADB, Ainsworth EA, Bernard SM, Markelz RJC, Ort DR, Placella SA, Rogers A, Smith MD, Sudderth EA, Weston DJ, Wullschleger SD, Yuan S. 2009. Gene expression profiling: opening the black box of plant ecosystem responses to global change. Global Change Biology 15:1201-1213.

Type: Journal

Geographic Area: Global

Keywords: elevated CO_2, genomic, microarray

Abstract: The use of genomic techniques to address ecological questions is emerging as the field of genomic ecology. Experimentation under environmentally realistic conditions to investigate the molecular response of plants to meaningful changes in growth conditions and ecological interactions is the defining feature of genomic ecology. Because the impact of global change factors on plant performance are mediated by direct effects at the molecular, biochemical, and physiological scales, gene expression analysis promises important advances in understanding factors that have previously been consigned to the "black box" of unknown mechanism. Various tools and approaches are available for assessing gene expression in model and nonmodel species as part of global change biology studies. Each approach has its own unique advantages and constraints. A first generation of genomic ecology studies in managed ecosystems and mesocosms have provided a testbed for the approach and have begun to reveal how the experimental design and data analysis of gene expression studies can be tailored for use in an ecological context.

Link: http://esd.lbl.gov/files/departments/ecology/publications/2009_GlobChangeBiol_Leakey_etal.pdf

158. Ledig FT, Kitzmiller JH. 1992. Genetic strategies for reforestation in the face of global climate change. Forest Ecology and Management 50:153-169.

Type: Journal

Geographic Area: Global

Compilers' Keywords: seed transfer, seed sources, local adaptation, forestry, assisted migration, translocation, uncertainty, review

Abstract: If global warming materializes as projected, natural or artificial regeneration of forests with local seed sources will become increasingly difficult. However, global warming is far from a certainty and predictions of its magnitude and timing vary at least twofold, In the face of such uncertainty, reforestation strategies should emphasize conservation, diversification, and broader deployment of species, seed sources, and families. Planting programs may have to deploy non-local seed sources, imported from further south or from lower elevations, which necessitates a system for conserving native gene pools in seed banks or clone banks. Planting a diverse array of species or seed sources is a hedge against the uncertainty inherent in current projections of warming. Most tree improvement programs already stress genetic diversity and deployment of multi-progeny mixes, but may better prepare for climate change by testing selections in an even wider set of environments than is now the case.

Link: http://www.treesearch.fs.fed.us/pubs/24275

159. Lemieux CJ, Scott DJ. 2011. Changing climate, challenging choices: identifying and evaluating climate change adaptation options for protected areas management in Ontario, Canada. Environmental Management 48:675-690.

Type: Journal

Geographic Area: Ontario, Canada

Keywords: climate change, parks, protected areas, adaptation, conservation, management, policy, Policy Delphi

Abstract: Climate change will pose increasingly significant challenges to managers of parks and other forms of protected areas around the world. Over the past two decades, numerous scientific publications have identified potential adaptations, but their suitability from legal, policy, financial, internal capacity, and other management perspectives has not been evaluated for any protected area agency or organization. In this study, a panel of protected area experts applied a Policy Delphi methodology to identify and evaluate climate change adaptation options across the primary management areas of a protected area agency in Canada. The panel identified and evaluated one hundred and sixty five (165) adaptation options for their perceived desirability and feasibility. While the results revealed a high level of agreement with respect to the desirability of adaptation options and a moderate level of capacity pertaining to policy formulation and management direction, a perception of low capacity for implementation in most other program areas was identified. A separate panel of senior park agency decision-makers used a multiple criterion decision-facilitation matrix to further evaluate the institutional feasibility of the 56 most desirable adaptation options identified by the initial expert panel and to prioritize them for consideration in a climate change action plan. Critically, only two of the 56 adaptation options evaluated by senior decision-makers were deemed definitely implementable, due largely to fiscal and internal capacity limitations. These challenges are common to protected area agencies in developed countries and pervade those in developing countries, revealing that limited adaptive capacity represents a substantive barrier to biodiversity conservation and other protected area management objectives in an era of rapid climate change.

Link: http://www.ncbi.nlm.nih.gov/pubmed/21850505

160. Lempriere TC, Bernier PY, Carroll AL, Flannigan MD, Gilsenan RP, McKenney DW, Hogg EH, Pedlar J, Blain D. 2008. The importance of forest sector adaptation to climate change. Edmonton, Alberta, Canada: Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre. NOR-X-416E. 78 p.

Type: Government Document

Geographic Area: Canada

Compilers' Keywords: forest management, insects, greenhouse emissions, IPCC

Abstract: This report summarizes current knowledge about recent changes in the climate of Canada's forests and projects further changes over this century based on scenarios of future global greenhouse gas emissions developed by the Intergovernmental Panel on Climate Change. Even with sustained reductions in global emissions the future climate is predicted to be quite different, meaning that adaptation will be essential. Impacts on the forest are already occurring and will be substantial in the future. The current upward trend in area burned annually is expected to continue. Forests will be prone to widespread stress induced by the changing climate, increasing the likelihood of pest outbreaks in the short to medium term. Recent outbreaks of several pests have exceeded in scope all previous known epidemics of these pests and are associated with the crossing of a climatic threshold. Invasion of the boreal forest by the mountain pine beetle, *Dendroctonus ponderosae* (Hopkins), appears likely, although the effect of this range expansion would likely be less severe than that observed recently in British Columbia, and outbreaks of the spruce budworm, *Choristoneura fumiferana* (Clemens), are predicted to be longer and more severe in the future. Future forest growth in response to climate change is expected to be variable; with growth reduction because of drought in parts of Canada's western forests perhaps the most dramatic short- to medium-term outcome, though modestly increased growth in the east is predicted. Such impacts have implications for the cost and characteristics of timber supply and climate change will also affect forestry operations, recreation opportunities, biodiversity, and carbon storage. Planning based on past approaches will need to be reconsidered. Current objectives for sustainable forest management may not be attainable in the future, although there may be some new opportunities. Climate change may produce public safety risks, significant economic and social dislocation in forest-dependent communities including Aboriginal

communities, and impacts on the competitiveness of companies as well as on the actions and policies of all levels of government. These effects can be reduced through early identification and implementation of actions to reduce vulnerabilities or take advantage of new opportunities. The key needs associated with adaptation in the forest sector include awareness building and debate, improved knowledge and information, vulnerability assessments, planning frameworks and tools, and enhanced coordination and cooperation among governments and other forest sector participants. Meeting the challenge of adaptation will require sustained effort for many years.

Link: http://publications.gc.ca/collections/collection_2009/nrcan/Fo133-1-416E.pdf

161. Lindenmayer DB, Steffen WL, Burbidge AA, Hughes L, Kitching RL, Musgrave W, Stafford Smith M, Werner PA. 2010. **Conservation strategies in response to rapid climate change: Australia as a case study.** Biological Conservation 143:1587-1593.

Type: Journal

Geographic Area: Australia

Keywords: climate change, biodiversity conservation, Australia, climate responses, existing biodiversity stressors

Abstract: As in all parts of the globe, rapid climate change in Australia will have significant negative impacts on biodiversity. It also will interact with pre-existing stressors such as native vegetation clearing, altered natural disturbance regimes and invasive species—all of which already have major negative effects on biota in Australia. Strategies to reduce climate change impacts on Australian biodiversity include a mixture of mitigation and adaptation actions (sensu Millar et al. 2007) such as: (1) significantly reducing greenhouse gas emissions, (2) ensuring bio-diverse carbon capture, (3) better tackling pre-existing stressors on biodiversity, (4) better preparing for the effects of major natural disturbances, (5) significantly improving off-reserve conservation efforts including fostering appropriate connectivity, and (6) enhancing the existing reserve system by making it more comprehensive, adequate and representative. The first strategy above demands a global response otherwise major mitigation attempts in Australia that are not paralleled elsewhere around the world will have little effect on climate change and, in turn, contribute little to enhanced biodiversity conservation. Strategies 2–6 demand multi-scaled responses, particularly at a regional level, given the major regional differences in direct climate change impacts and their interactions with pre-existing regional stressors. Well-developed multi-scaled conservation plans to implement these strategies currently do not exist, nor do appropriate institutional arrangements and capacities. Institutional reforms are urgently needed in Australia to develop the land management, monitoring and regional response capabilities required to conserve biodiversity on a continent already significantly modified.

162. Maness TC. 2009. Forest management and climate change mitigation: good policy requires careful thought. Journal of Forestry 107:119-124.

Type: Journal

Geographic Area: USA

Keywords: climate change mitigation, forest management, forest policy

Abstract: Many people believe that forest management and the production of forest products can be important tools in a climate change mitigation strategy. This article critically examines how forest management can contribute to climate change mitigation in the global context, and it examines four major issues that must be considered before developing a strategy that would achieve real contributions. The article argues that protection of the carbon stock in the existing natural forest should be the central management objective related to carbon. Second should be the development of a widely accepted standard for calculating forestry offsets to drive future private investment on private forests. The article concludes with some recommendations for policy setting.

163. Manter DK, Reeser PW, Stone JK. 2005. A climate-based model for predicting geographic variation in Swiss needle cast severity in the Oregon Coast Range. Phytopathology 95:1256-1265.

Type: Journal

Geographic Area: Oregon, USA

Keywords: climate change, Douglas-fir, epidemiology, fungal pathogen, modeling

Abstract: Since the early 1990s, Swiss needle cast disease caused by *Phaeocryptopus gaeumannii* has been increasing in Douglas-fir plantations in the Oregon Coast Range. Considerable variation in disease severity across the affected area often has been noted. We investigated the influence of site microclimate on fungal colonization as a basis for this variation with a combination of seedling inoculation and field studies. Development of *P. gaeumannii* ascocarps on inoculated seedlings subjected to mist, irrigation, and shading treatments was followed for 10 months. Contrary to expectations, numbers of ascocarps on foliage were negatively correlated with shade and mist and positively correlated with temperature. Numbers of ascocarps on foliage, site temperature, and leaf wetness were monitored over 5 years at nine field sites in the Oregon Coast Range. Factors most highly correlated with ascocarp abundance were winter mean daily temperature and spring cumulative leaf wetness. Predictive models for disease severity on the basis of these correlations were tested against disease and climate data measured at field sites during 2003–2004. A temperature-based disease prediction model was developed in combination with geographical information systems (GIS)-linked climate databases to estimate disease levels across a portion of the Oregon Coast Range. This model can be used for hypothesis testing and as a decision support tool for forest managers.

Link: http://www.ncbi.nlm.nih.gov/pubmed/18943355

164. Mawdsley JR, O'Malley R, Ojima DS. 2009. A review of climate-change adaptation strategies for wildlife management and biodiversity conservation. Conservation Biology 23:1080-1089.

Type: Journal

Geographic Area: Global

Keywords: adaptation, biodiversity, climate change, conservation, management, restoration, wildlife

Abstract: The scientific literature contains numerous descriptions of observed and potential effects of global climate change on species and ecosystems. In response to anticipated effects of climate change, conservation organizations and government agencies are developing "adaptation strategies" to facilitate the adjustment of human society and ecological systems to altered climate regimes. We reviewed the literature and climate-change adaptation plans that have been developed in United States, Canada, England, Mexico, and South Africa and found 16 general adaptation strategies that relate directly to the conservation of biological diversity. These strategies can be grouped into four broad categories: land and water protection and management; direct species management; monitoring and planning; and law and policy. Tools for implementing these strategies are similar or identical to those already in use by conservationists worldwide (land and water conservation, ecological restoration, agrienvironment schemes, species translocation, captive propagation, monitoring, natural resource planning, and legislation/regulation). Although our review indicates natural resource managers already have many tools that can be used to address climate-change effects, managers will likely need to apply these tools in novel and innovative ways to meet the unprecedented challenges posed by climate change.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19549219

165. Millar CI, Stephenson NL, Stephens SL. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications 17:2145-2151.

Type: Journal

Geographic Area: USA

Keywords: carbon sequestration, climate change, desired conditions, ecosystem management, facilitated conservation, forest management, historical variability, resilience, resistance, wildfire

Abstract: We offer a conceptual framework for managing forested ecosystems under an assumption that future environments will be different from present but that we cannot be certain about the specifics of change. We encourage flexible approaches that promote reversible and incremental steps, and that favor ongoing learning and capacity to modify direction as situations change. We suggest that no single solution fits all future challenges, especially in the context of changing climates, and that the best strategy is to mix different approaches for different situations. Resources managers will be challenged to integrate adaptation strategies (actions that help ecosystems accommodate changes adaptively) and mitigation strategies (actions that enable ecosystems to reduce anthropogenic influences on global climate) into overall plans. Adaptive strategies include resistance options (forestall impacts and protect highly valued resources), resilience options (improve the capacity of ecosystems to return to desired conditions after disturbance), and response options (facilitate transition of ecosystems from current to new conditions). Mitigation strategies include options to sequester carbon and reduce overall greenhouse gas emissions. Priority-setting approaches (e.g., triage), appropriate for rapidly changing conditions and for situations where needs are greater than available capacity to respond, will become increasingly important in the future.

Link: http://www.treesearch.fs.fed.us/pubs/31774

166. Munang R, Rivington M, Takle ES, Mackey B, Thiaw I, Liu J. 2010. Climate information and capacity needs for ecosystem management under a changing climate. Procedia Environmental Sciences 1:206-227.

Type: Journal

Geographic Area: Global

Keywords: ecosystem management, climate information, adaptation, ecosystem services, decision making

Abstract: The paper demonstrates the need to integrate across information types (i.e., weather, climate, socio-economic, policy and ecology) to better inform those involved in decision-making for ecosystem management. The provision of climate information and an understanding of ecosystem responses to climate change and variability urgently need to underpin any planning for the future. Integrating climatic information into risk assessment frameworks and adaptation planning is essential as it will enable better informed decision making in planning to ensure the adequate provision of ecosystem services (water, food, air quality, shelter etc.) and appropriate adaptation and mitigation strategies for the well being of both people and nature. A substantial mindset shift to fully recognize the fundamental role of ecosystems as life-supporting systems is urgently needed. The value given to ecosystems and the magnitude of effort to manage them has to be based on this mere fact and indeed, it should be an integral part of any climate change agreement.

167. Nagel L. 2013. Developing adaptive silvicultural strategies in the context of climate change. In: Forestry and Natural Resources Webinar Portal. USDA Forest Service. 91 p.

Type: Presentation

Geographic Area: USA

Compilers' Keywords: silviculture, adaptive strategy, forest management

Abstract: Climate change is a pervasive driver of ecosystem change and uncertainty regarding future conditions, and represents a significant threat to many critical ecosystem functions. The uncertain nature of climate change adds an additional dimension to developing sustainable management plans, including the development of silviculture prescriptions. Forest managers need conceptual tools to incorporate adaptation into management approaches. This process begins with reframing objectives and the notion of desired future conditions, which can be especially important where restoration treatments are a priority. Decision-making processes built on principles of adaptive management can help managers assess potential climate-related challenges to their goals and objectives, evaluate the feasibility of existing objectives in the context of climate change, diagnose the need for climate change adaptation efforts, prescribe appropriate treatments, and use monitoring efforts to evaluate treatment effectiveness and gauge the need to adjust management over time. A common emerging adaptation theme is to manage ecosystems for resistance and resilience, which can often be achieved by maintaining and enhancing complexity. A case study using northern hardwoods of the Great Lakes region, an extensive and economically important forest type that has undergone significant change and homogenization as a result of past land-use, will be discussed in the context of these tools. Additionally, an adaptive silviculture project will be highlighted that is building science-management partnerships to guide managers through the process of developing site-specific, objectives-driven climate change adaptation treatments. This project will simultaneously establish a framework for a long-term study of responses to several common climate change adaptation options in a variety of forest types across the United States.

Link: http://www.forestrywebinars.net/webinars/developing-adaptive-silvicultural-strategies-in-the-context-of-climate-change

168. National Fish, Wildlife, and Plants Climate Adaption Partnership. 2012. National fish, wildlife and plants climate adaptation strategy. Washington (DC): Fish and Wildlife agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and U.S. Fish and Wildlife Service. 120 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: climate change, translocation, management planning

Summary: The Strategy is the first joint effort of three levels of government (federal, state, and tribal) that have primary authority and responsibility for the living resources of the United States to identify what must be done to help these resources become more resilient, adapt to, and survive a warming climate. It is designed to inspire and enable natural resource managers, legislators, and other decision makers to take effective steps towards climate change adaptation over the next five to ten years. Federal, state, and tribal governments and conservation partners are encouraged to read the Strategy in its entirety to identify intersections between the document and their mission areas and activities. The Strategy is guided by nine principles. These principles include collaborating across all levels of government, working with non-government entities such as private landowners and other sectors like agriculture and energy, and engaging the public. It is also important to use the best available science—and to identify where science and management capabilities must be improved or enhanced. When adaptation steps are taken, it is crucial to carefully monitor actual outcomes in order to adjust future actions to make them more effective, an iterative process called adaptive management. We must also link efforts within the U.S. with efforts internationally to build resilience and adaptation for species that migrate and depend on areas beyond U.S. borders. Finally, given the size and urgency of the challenge, we must begin acting now.

Link: http://www.wildlifeadaptationstrategy.gov/strategy.php

169. Nitschke CR, Innes JL. 2008. Integrating climate change into forest management in South-Central British Columbia: an assessment of landscape vulnerability and development of a climate-smart framework. Forest Ecology and Management 256:313-327.

Type: Journal

Geographic Area: Western Canada

Keywords: climate change, vulnerability, risk, forest management, triad zoning, modelling, fire, biodiversity, resilience, ecosystem, mountain pine beetle

Abstract: The achievement of sustainable forest management requires the incorporation of risk and uncertainty into long-term planning. Climatic change will have significant impacts on natural disturbances, species and ecosystems, particularly on landscapes influenced by forest management. Understanding where vulnerabilities lie is important in managing the risks associated directly or indirectly with climatic change. The vulnerability of landscapes to natural disturbances, the resilience of ecosystems and distribution of species are all important components that need to be considered when undertaking forest planning, but climatic change is rarely factored into such planning. In this study, the vulnerability of fire potential, fire regimes, ecosystems and species to climatic change was modelled for a 145,000 ha landscape in the south-central interior of British Columbia, Canada. The results from

these analyses were used to guide forest zoning, using the triad zoning framework, and for the development of a "climate smart" management framework. The use of climate-smart management is advocated as a decision-making framework for managing forested landscapes based on an understanding of landscape vulnerability to future climatic change. From this understanding, the maintenance of ecosystem health and vitality could be achieved.

Link: http://madsg.com/wp-content/uploads/2013/04/1-s2.0-S037811270800368X-main.pdf

170. Northern Institute of Applied Climate Science [NIACS]. 2009. Climate change response framework. (URL accessed 25 November 2015)

Type: Web Page

Geographic Area: USA

Compilers' Keywords: approach, forest management, forest trees, USFS

About: Resource managers face the immense challenge of integrating the inherent uncertainties of a changing climate into a wide variety of management decisions. These decisions occur along geographic scales, from several acres to millions of acres, and time scales, from immediate actions to long-term planning. Adaptation means taking action to enhance the ability of ecosystems to thrive in future conditions, but there is not a single answer for how to best adapt to climate change. Adaptation responses will vary by region based upon the magnitude of expected climate impacts, resilience of ecosystems, values and resources of local communities, and many other factors that demand unique responses to local conditions. The Climate Change Response Framework is a highly collaborative approach to helping land managers understand the potential effects of climate change on forest ecosystems and integrating climate change considerations into management. Since 2009, the Framework projects have worked to bridge the gap between scientific research on climate change impacts and on-the-ground management. The Framework stretches across the boundaries of partners to invite participation of forestlands owned and managed by private individuals, forest industry, tribes, state, local, and federal agencies. The Framework was initiated with a joint commitment of the U.S. Forest Service Northern Research Station and the Eastern Region to work closely together in addressing the challenges of climate change. The hallmark of the Framework, however, is the high level of cross-boundary cooperation among forest owners, considered essential to coping with an issue that spans borders, disciplines, and perspectives. There are currently three ecoregional Framework Projects that encompass 133 million acres in eight states, including 11 National Forests.

Link: http://www.climateframework.org/

171. Obama B. 2013. The President's climate action plan. Washington (DC): Executive Office of the President. 21 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: climate change, natural resources

Introduction: Climate change represents one of our greatest challenges of our time, but it is a challenge uniquely suited to America's strengths. What follows is a blueprint for steady, responsible national and international action to slow the effects of climate change so we leave a cleaner, more stable environment for future generations. It highlights progress already set in motion by the Obama Administration to advance these goals and sets forth new steps to achieve them.

Link: http://www.whitehouse.gov/share/climate-action-plan

172. Ogden AE, Innes J. 2007. Incorporating climate change adaptation considerations into forest management planning in the boreal forest. International Forestry Review 9:713-733.

Type: Journal

Geographic Area: Canada

Keywords: climate change, adaptation, boreal forest, Montréal Process, forest management plans

Abstract: Climate change will pose increasing challenges to forest managers working to achieve sustainable forest management in the boreal forest. To date, discussions around when, where and how to consider adaptation in forest management plans for the boreal forest have been limited. As a starting point, specific objectives for climate change adaptation need to be articulated, which we consider to be synonymous with the criteria for conservation and sustainable management of boreal forests as defined by the Montréal Process. Secondly, because forest management plans are hierarchal—there are higher level strategic plans and lower level operational plans—it is important to distinguish at which planning level adaptation options are most appropriately considered. The purpose of this paper is to put forward a range of alternative adaptation options that forest managers working in the boreal zone could consider during the development of strategic and operational forest management plans in order to achieve sustainability as defined by the Montréal Process.

173. Oliver M. 2012. Adaptation: planning for climate change and its effects on Federal Lands. Portland (OR): USDA Forest Service, Pacific Northwest Research Station. Issue 148. 6 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: adaptation strategy, forest management, USFS

Summary: National forest managers are charged with tackling the effects of climate change on the natural resources under their care. The Forest Service National Roadmap for Responding to Climate Change and the Climate Change Performance Scorecard require managers to make significant progress in addressing climate change by 2015. To help land managers meet this challenge, Forest Service scientists conducted three case studies on national forests and adjacent national parks and documented a wide range of scientific issues and solutions. They summarized the scientific foundation for climate change adaptation and made the information accessible to land managers by creating a climate change adaptation guidebook and web portal. Case study teams discovered that collaboration among scientists and land managers is crucial to adaptation planning, as are management plans targeted to the particular ecosystem conditions and management priorities of each region. Many current management practices are consistent with climate change adaptation goals. Because timely implementation is critical, strategies are in development at the national level to speed the implementation of science-based climate change adaptation processes in national forests throughout the country.

Link: http://www.treesearch.fs.fed.us/pubs/42317

174. Olwell P. 2010. National native plant materials development program: ensuring options in a changing climate. National Native Seed Conference: Native Plant Materials Development, Production and Use in Habitat Restoration. Corvallis (OR): Institute for Applied Ecology. 40 p.

Type: Presentation

Geographic Area: USA

Compilers' Keywords: seeds of success, seed storage, migration, BLM

Abstract: Following record breaking wildfire seasons of 1999 and 2000, Congress directed the Bureau of Land Management (BLM) to develop and implement a program for site appropriate native plant materials. The NPMDP is coordinating organizations around the country to collect, curate and conserve plant diversity before it is lost. With the assistance of more than 500 partners, BLM is leading the interagency Native Plant Materials Development Program (NPMDP) to ensure the quality and quantity of genetically appropriate native plant materials are available commercially for restoring native plant communities across the American landscape. Developing a crop from native wild species begins with seed collection. Seeds of Success (SOS) is the native seed collection phase of the NPMDP. SOS makes the primary collection of common native species that are needed for restoration after fire, weed eradication, energy development, or for use in climate adaptation strategies. Almost 100 teams are collecting nation-wide to add to the more than 9,500 collections which collectively form the Seeds of Success National Collection. Climate change is altering native plant communities at a greater rate than previously anticipated and the effects on native plant communities could be extensive. To avoid the threat of habitats dominated by monocultures of invasive species, we may need to move and establish native plant materials to more northern latitudes if plant communities cannot adapt to climate change. Developing native plant materials and having native seed stored in long-term conservation storage and available on the market for restoration will provide federal agencies with some of the most important tools to help address threats to natural systems posed by destructive events such as wildfires, invasive species, and climate change.

Link: http://nativeseed.info/2010/presentations/Olwell.pdf

175. Peterson D, Millar CI, Joyce LA, Furniss MJ, Halofsky JE, Neilson RP, Morelli TL. 2011. Responding to climate change in national forests: a guidebook for developing adaptation options. Portland (OR): USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-855. 109 p.

Type: Government Document

Geographic Area: USA

Keywords: adaptation, climate change, national forests, national parks, science-management partnership, vulnerability assessment

Abstract: This guidebook contains science-based principles, processes, and tools necessary to assist with developing adaptation options for national forest lands. The adaptation process is based on partnerships between local resource managers and scientists who work collaboratively to understand potential climate change effects, identify important resource issues, and develop management options that can capitalize on new opportunities and reduce deleterious effects. Because management objectives and sensitivity of resources to climate change differ among national forests, appropriate processes and tools for developing adaptation options may also differ. Regardless of specific processes and tools, the following steps are recommended: (1) become aware of basic climate change science and integrate that understanding with knowledge of local resource conditions and issues (review), (2) evaluate sensitivity of specific natural resources to climate change (rank), (3) develop and implement strategic and tactical options for adapting resources to climate change (resolve), and (4) monitor the effectiveness of adaptation options (observe) and adjust management as needed. Results of recent case studies on adaptation in national forests and national parks can facilitate integration of climate change in resource management and planning and make the adaptation process more efficient. Adaptation to climate change will be successful only if it can be fully implemented in established planning processes and other operational aspects of national forest management.

Link: http://www.treesearch.fs.fed.us/pubs/39884

176. Pojar J. 2010. **A new climate for conservation: nature, carbon and climate change in British Columbia.** British Columbia, Canada: Working Group on Biodiversity, Forests and Climate. 100 p.

Type: Report

Geographic Area: Western Canada

Compilers' Keywords: strategy, carbon management

Introduction: A New Climate for Conservation: Nature, Carbon and Climate Change in British Columbia explores the role of nature conservation in a climate action strategy for ecological adaptation (Part 1) and ecological mitigation (Part 2), with the key recommendation to develop a comprehensive and integrated Nature Conservation and Climate Action Strategy for the Province of British Columbia (Part 3): Part 1 presents available science on current climate-change projections, and present and future impacts of climate change to ecosystems, species, genotypes, and the processes Linking them. The review focuses primarily on forested systems, and also addresses non-forest and aquatic systems. Ecosystem resilience and adaptation options, in relation to climate change, are outlined. Current thinking in conservation science is then summarised in light of external pressures. B.C.'s existing conservation planning and forestry management are reviewed in terms of their ability to respond to the challenges of climate change. Part 2 summarises literature on natural capital, ecosystem services and the role of ecosystems in climate change mitigation. Variations in carbon sequestration and storage in different ecosystems are discussed and research gaps in forest carbon dynamics are identified. Current opportunities for an offset market through carbon activities such as avoided degradation, ecological restoration and improved forest management are also explored, in light of recent pilot projects in B.C. Part 3 integrates the findings from Part 1 and Part 2 in a central recommendation—to develop a comprehensive and integrated provincial Nature Conservation and Climate Action Strategy. To be efficient, this strategy must combine nature conservation and carbon/climate management planning. To be effective, it must embrace the fundamental role of conserving natural ecosystems for adaptation and mitigation of climate change and for nature's many other ecosystem services, which underpin sustainable options for current and future generations.

Link: http://www.borealbirds.org/resources/report-pojar-bcconservation.pdf

177. Pressey RL, Cabeza M, Watts ME, Cowling RM, Wilson KA. 2007. **Conservation planning in a changing world.** Trends in Ecology and Evolution 22:583-592.

Type: Journal

Geographic Area: Global

Compilers' Keywords: animals, biodiversity, humans, social change

Abstract: Conservation planning is the process of locating, configuring, implementing and maintaining areas that are managed to promote the persistence of biodiversity and other natural values. Conservation planning is inherently spatial. The science behind it has solved important spatial problems and increasingly influenced practice. To be effective, however, conservation planning must deal better with two types of change. First, biodiversity is not static in time or space but generated and maintained by natural processes. Second, humans are altering the planet in diverse ways at ever faster rates.

Link: http://www.ncbi.nlm.nih.gov/pubmed/17981360

178. Rowland EL, Davison JE, Graumlich LJ. 2011. **Approaches to evaluating climate change impacts on species: a guide to initiating the adaptation planning process.** Environmental Management 47:322-337.

Type: Journal

Geographic Area: Global

Keywords: climate change, vulnerability assessments, management, species, adaptation planning

Abstract: Assessing the impact of climate change on species and associated management objectives is a critical initial step for engaging in the adaptation planning process. Multiple approaches are available. While all possess limitations to their application associated with the uncertainties inherent in the data and models that inform their results, conducting and incorporating impact assessments into the adaptation planning process at least provides some basis for making resource management decisions that are becoming inevitable in the face of rapidly changing climate. Here we provide a non-exhaustive review of long-standing (e.g., species distribution models) and newly developed (e.g., vulnerability indices) methods used to anticipate the response to climate change of individual species as a guide for managers grappling with how to begin the climate change adaptation process. We address the limitations (e.g., uncertainties in climate change projections) associated with these methods, and other considerations for matching appropriate assessment approaches with the management questions and goals. Thorough consideration of the objectives, scope, scale, time frame and available resources for a climate impact assessment allows for informed method selection. With many data sets and tools available on-line, the capacity to undertake and/or benefit from existing species impact assessments is accessible to those engaged in resource management. With some understanding of potential impacts, even if limited, adaptation planning begins to move toward the development of management strategies and targeted actions that may help to sustain functioning ecosystems and their associated services into the future.

Link: http://www.ncbi.nlm.nih.gov/pubmed/21259061

179. Schmidtling RC. 1994. Use of provenance tests to predict response to climatic change: Loblolly pine and Norway spruce. Tree Physiology 14:805-817.

Type: Journal

Geographic Area: Southeastern USA

Keywords: genetic response, growth, height growth, seed source, temperature, tree response

Summary: Provenance tests are often used to determine genetic responses of seed sources to transfer to different climates. This study was undertaken to determine whether provenance tests can be used to predict tree response to rapid climate changes *in situ*. Data from provenance tests of loblolly pines (*Pinus taeda* L.), Norway spruce (*Picea abies* L. Karst) and other southern pines (subsect. AUSTRALES Loud.) were interpreted using regression models to relate growth to temperature variables. Results of different plantings were combined by expressing growth as a percent deviation from the "local" source, and expressing temperature at the source as a deviation from that of the planting site. The results of the loblolly pine and Norway spruce models predicted a loss of about 5 to 10% in height growth below that expected for a genetically adapted seed source, if the average yearly temperature increases by 4 °C.

Link: http://treephys.oxfordjournals.org/content/14/7-8-9/805.full.pdf

180. Schmitz OJ, Lawler JJ, Beier P, Groves C, Knight G, Boyce DA, Bulluck J, Johnston KM, Klein ML, Muller K, Pierce DJ, Singleton WR, Strittholt JR, Theobald DM, Trombulak SC, Trainor A. 2015. Conserving biodiversity: practical guidance about climate change adaptation approaches in support of land-use planning. Natural Areas Journal 35:190-203.

Type: Journal

Geographic Area: USA

Keywords: biodiversity, climate adaptation, conservation planning, land use planning

Abstract: As species' geographic ranges and ecosystem functions are altered in response to climate change, there is a need to integrate biodiversity conservation approaches that promote natural adaptation into land use planning. Successful conservation will need to embrace multiple climate adaptation approaches, but to date they have not been conveyed in an integrated way to help support immediate conservation planning and action in the face of inherent spatial uncertainty about future conditions. Instead, these multiple approaches are often conveyed as competing or contradictory alternatives, when in fact, they are complementary. We present a framework that synthesizes six promising spatially explicit adaptation approaches for conserving biodiversity. We provide guidance on implementing these adaptation approaches and include case studies that highlight how biodiversity conservation can be used in planning. We conclude with general guidance on choosing appropriate climate adaptation approaches to amend for conservation planning.

Link: http://www.bioone.org/doi/abs/10.3375/043.035.0120

181. Schwartz MW. 2012. Using niche models with climate projections to inform conservation management decisions. Biological Conservation 155:149-156.

Type: Journal

Geographic Area: Global

Keywords: species distribution model, niche model, climate change, resource management, adaptive management, decision theory, extinction, natural resource management

Abstract: Conservation science strives to inform management decisions. Applying niche models in concert with future climate projections to project species vulnerability to extinction, range size loss, or distribution shifts has emerged as a potentially useful tool for informing resource management decisions. Making climate change niche modeling useful to conservation decisions requires centering studies on the types of decisions that are made regarding the focal taxa of a niche model study. Recent recommendations for climate adaptation strategies suggest four types of decision makers: policy, habitat protection, habitat management, species management. Targeting research to questions relevant for management decisions will increase utility of a niche model study. Constraints to the accuracy and precision of niche models to project potential future distributions are well recognized. How to incorporate these uncertainties into management decision-making remains a challenge. Refining estimates and making sound management recommendations is critical because species that are generally modeled to be the most vulnerable to climate change (i.e., narrow endemics), are also the most vulnerable to bad decisions based on uncertain models. I review uncertainties of niche models to assert that there is an inherent bias for models to overestimate climate-driven vulnerability to extirpation. Explicit recognition of this bias leads to a decision framework that accommodates unbalanced uncertainty. Namely, niche models may be more useful for identifying conservation opportunities identifying newly available habitats under changing climate than they are for asserting where current habitat will no longer exist under future climate states.

182. Seabrook L, McAlpine CA, Bowen ME. 2011. Restore, repair or reinvent: options for sustainable landscapes in a changing climate. Landscape and Urban Planning 100:407-410.

Type: Journal

Geographic Area: Global

Keywords: restoration, novel ecosystems, landscape change, ecosystem function

Abstract: Globally, land use and land cover changes to provide resources for human society have led to loss of biodiversity and declines in ecosystem services. Climate change will compound these impacts. Ecological restoration can reverse environmental degradation and is starting to restore ecological services, as well as help mitigate climate change. Although this may be an anathema to some, we must systematically assess and proactively redesign and manage the landscapes we inhabit so they can continue to provide ecosystem services essential for all species, including humans. We define three restoration pathways based largely on existing land use and the degree of modification: restoration for areas of natural ecosystems; repair for production landscapes; and reinvention for urban areas. Challenges and research priorities include understanding: the effects of mean climate change and climate extremes on species' distribution and ecosystem composition; how restoration can be used for carbon sequestration; the effects of proximate and endogenous drivers on landscape change; how to better bio-design landscapes for multiple functions; integration of different scales of restoration planning and design; and the establishment of long-term monitoring and adaptive management.

183. Seavy NE, Gardali T, Golet GH, Griggs FT, Howell CA, Kelsey R, Small SL, Viers JH, Weigand JF. 2009. **Why climate change makes riparian restoration more important than ever: recommendations for practice and research.** Ecological Restoration 27:330-338.

Type: Journal

Geographic Area: California, USA

Keywords: California, climate change, genetics, hydrology, restoration, riparian

Abstract: Over the next century, climate change will dramatically alter natural resource management. Specifically, historical reference conditions may no longer serve as benchmarks for restoration, which may foster a "why bother?" attitude toward ecological restoration. We review the potential role for riparian restoration to prepare ecological systems for the threats posed by climate change. Riparian ecosystems are naturally resilient, provide linear habitat connectivity, link aquatic and terrestrial ecosystems, and create thermal refugia for wildlife: all characteristics that can contribute to ecological adaptation to climate change. Because riparian systems and the projected impacts of climate change are highly variable geographically, there is a pressing need to develop a place-based understanding of climate change threats to riparian ecosystems. Restoration practitioners should consider how they can modify practices to enhance the resilience of riparian ecosystems to climate change. Such modifications may include accelerating the restoration of private lands, participating in water management decisions, and putting the emerging field of restoration genetics into practice.

Link: http://riverpartners.org/documents/press_releases/PressRelease_20090831.pdf

184. Sgrò CM, Lowe AJ, Hoffmann AA. 2011. **Building evolutionary resilience for conserving biodiversity under climate change.** Evolutionary Applications 4:326-337.

Type: Journal

Geographic Area: Global

Keywords: adaptive potential, biodiversity, climate change, conservation, evolution, evolutionary resilience, genetic diversity

Abstract: Evolution occurs rapidly and is an ongoing process in our environments. Evolutionary principles need to be built into conservation efforts, particularly given the stressful conditions organisms are increasingly likely to experience because of climate change and ongoing habitat fragmentation. The concept of evolutionary resilience is a way of emphasizing evolutionary processes in conservation and landscape planning. From an evolutionary perspective, landscapes need to allow *in situ* selection and capture high levels of genetic variation essential for responding to the direct and indirect effects of climate change. We summarize ideas that need to be considered in planning for evolutionary resilience and suggest how they might be incorporated into policy and management to ensure that resilience is maintained in the face of environmental degradation.

Link: http://www.trend.org.au/sites/default/files/Sgro_Lowe_Hoffman_2011.pdf

185. Shoo LP, Hoffmann AA, Garnett ST, Pressey RL, Williams YM, Taylor M, Falconi L, Yates CJ, Scott JK, Alagador D, Williams SE. 2013. **Making decisions to conserve species under climate change.** Climatic Change 119:239-246.

Type: Journal

Geographic Area: Global

Compilers' Keywords: biodiversity, decision framework, assisted colonization

Abstract: Severe impacts on biodiversity are predicted to arise from climate change. These impacts may not be adequately addressed by conventional approaches to conservation. As a result, additional management actions are now being considered. However, there is currently limited guidance to help decision makers choose which set of actions (and in what order) is most appropriate for species that are considered to be vulnerable. Here, we provide a decision framework for the full complement of actions aimed at conserving species under climate change from ongoing conservation in existing refugia through various forms of mobility enhancement to *ex situ* conservation

outside the natural environment. We explicitly recognize that allocation of conservation resources toward particular actions may be governed by factors such as the likelihood of success, cost and likely co-benefits to non-target species in addition to perceived vulnerability of individual species. As such, we use expert judgment of probable tradeoffs in resource allocation to inform the sequential evaluation of proposed management interventions.

186. Sjølie HK, Latta GS, Solberg B. 2013. Potentials and costs of climate change mitigation in the Norwegian forest sector: does choice of policy matter? Canadian Journal of Forest Research 43:589-598.

Type: Journal

Geographic Area: Norway, Europe

Compilers' Keywords: forest management, greenhouse gases, emissions

Abstract: Forests are important contributors to the global carbon cycle and mitigate climate change through carbon sequestration and the supply of wood that substitutes for fossil fuels and greenhouse gas (GHG)-intensive building materials. However, current climate policies only partially credit forest carbon sequestration and bioenergy policies are handled independently of forestry. Using Norway as a case study, we analyze two sets of simulated carbon tax/subsidy policies, one crediting forest carbon sequestration while maintaining predetermined harvest levels and utilization of wood, and another targeting GHG fluxes in the entire forest industrial sector allowing harvest levels and wood markets to change in response to the policy. Results indicate that GHG emission reduction potentials differ substantially between the two policies, being several times higher for the latter than the former policy at a given carbon price. This suggests that (i) previous research efforts in Europe have not captured the full mitigation potential as they have not included adaptations in the harvest level and the wood market and (ii) climate policies should target GHG fluxes in the entire sector to utilize its potential contribution for mitigating climate change.

187. Smale M, Hanson J. 2010. Assessing the impact of CGIAR investments in germplasm collection, conservation, characterization and evaluation: the scope of the literature. Consultative Group on International Agricultural Research. 37 p.

Type: Report

Geographic Area: Global

Compilers' Keywords: germplasm, literature review, Consultative Group on International Agricultural Research

Introduction: The terms of reference for the study to which this paper contributes state that while the impact of CGIAR research in crop germplasm improvement and integrated pest management is well documented, there remain critical gaps in the portfolio of evidence. One of these concerns the impacts of germplasm collection, conservation, characterization and evaluation and the availability of evidence to determine impacts. Compared to literature about the impacts of CGIAR crop breeding programs, the body of published literature about the costs and benefits of gene bank collections and the services they provide is both small and narrow in the value components measured. The more theoretical work in this literature has also been of limited relevance to the problems and constraints faced by gene bank managers and system-wide bank system. Some of the gray literature produced by experts associated closely with the CGIAR gene banks has been more useful from an operational standpoint, but cannot yet be generalized across crops and collections because of important differences among the cost and benefits of conserving various crops due to their characteristics, bank location, and divergent operational approaches.

Link: http://impact.cgiar.org/sites/default/files/images/Smale-Hansen2011.pdf

188. Solomon AM, Birdsey R, Joyce L, Hayes J. 2009. Forest Service global change research strategy, 2009-2010. Washington (DC): USDA Forest Service, Research and Development. FS-917a. 20 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: climate change, adaptive strategy, framework, research and development, forest management, USFS

Summary: In keeping with the research goals of the U.S. Climate Change Science Program, the Research and Development agenda of the Forest Service, USDA helps define climate change policy and develop best management practices for forests (both rural and urban) and grasslands. These actions are taken to sustain ecosystem health, adjust management for ecosystem services ("adaptation"), and increase carbon sequestration ("mitigation"), all under changing climate conditions. The fundamental research focus of the Forest Service Global Change Research Strategy is to increase understanding of forest, woodland, and grassland ecosystems so that they can be managed in a way that sustains and provides ecosystem services for future generations.

Link: http://www.treesearch.fs.fed.us/pubs/41132

189. Spittlehouse DL. 2005. Integrating climate change adaptation into forest management. The Forestry Chronicle 81:691-695.

Type: Journal

Geographic Area: Canada

Keywords: climate change, impacts, adaptation, vulnerability, forests, ecosystems, risk management

Abstract: Future climate change will affect society's ability to use forest resources. We take account of climate in forest management and this will help us adapt to the effects of climate change on forests. However, society will have to adjust to how forests adapt by changing expectations for the use of forest resources because management can only influence the timing and direction of forest adaptation at selected locations. There will be benefits as well as loses and an important component of adaptation will be balancing values. Adaptation options to respond to impacts on the timber supply in Canada for the next 50 to 100 years are limited mainly to forest protection and wood utilisation because these forests are already in the ground. Adaptation through reforestation will focus on commercial tree species. It is important to start developing adaptation strategies now. These include assessing forest vulnerability to climate change, revising expectations of forest use, determining research and educational needs, development of forest policies to facilitate adaptation, and determining when to implement responses. Government agencies should take the lead in creating an environment to foster adaptation in forestry and in developing the necessary information required to respond.

190. Spittlehouse DL, Stewart RB. 2003. Adaptation to climate change in forest management. BC Journal of Ecosystems and Management 4:1-11.

Type: Journal

Geographic Area: North America

Keywords: climate change, sustainable forest management, adaptation

Abstract: Adaptation in forestry is sustainable forest management that includes a climate change focus. Climate change over the next 100 years is expected to have significant impacts on forest ecosystems. The forestry community needs to evaluate the long-term effects of climate change on forests and determine what the community might do now and in the future to respond to this threat. Management can influence the timing and direction of forest adaptation at selected locations, but in many situations society will have to adjust to however forests adapt. Adapting to climate change in the face of the uncertain timing of impacts means we must have a suite of readily available options. A high priority will be coping with and adapting to forest disturbance while maintaining the genetic diversity and resilience of forest ecosystems. A framework for facilitating adaptation in forestry is discussed and a review of adaptive actions presented.

Link: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.170.1072&rep=rep1&type=pdf

191. St. Clair JB, Howe GT. 2009. Genetic options for adapting forests to climate change. Western Forester 54:9-11.

Type: Newsletter

Geographic Area: North America

Compilers' Keywords: restoration, forest genetics, local seed sources, management options

Introduction: Concerns over impacts of climate change on forest productivity and health, and questions about appropriate management responses, led to the formation of the Taskforce on Adapting Forests to Climate Change. An accompanying article discussed silvicultural approaches to deal with climate change. This article discusses genetic options including management actions that could be taken to influence the natural or human selection of genotypes, movement of genotypes across the landscape and conservation of genetic diversity.

Link: http://www.treesearch.fs.fed.us/pubs/34501

192. St. Clair JB, Howe GT. 2011. Strategies for conserving forest genetic resources in the face of climate change. Turkish Journal of Botany 35:403-409.

Type: Journal

Geographic Area: North America

Keywords: climate change, genetic conservation, adaptation

Abstract: Conservation of genetic diversity is important for continued evolution of populations to new environments, as well as continued availability of traits of interest in genetic improvement programs. Rapidly changing climates present new threats to the conservation of forest genetic resources. We can no longer assume that in situ reserves will continue to preserve existing genetic diversity. Management of reserves should become more active. In some reserves, existing genetic diversity should be preserved by creating stands that are more resistant to threats using silvicultural treatments such as thinning and prescribed burning. In other reserves, natural selection and adaptation to changed environments should be promoted by increasing within population genetic diversity and promoting gene flow. This may be done by locating reserves in areas of high environmental heterogeneity, minimizing fragmentation, and using assisted colonization to increase genetic diversity by establishing populations adapted to future climates within or adjacent to reserves. Threats to native stands from climate change and other interacting threats should bring a renewed importance to ex situ collections, particularly for rare and disjunct populations and those at the warmer and drier edges of a species range. Assisted colonization to move threatened populations to new environments must be considered as an additional conservation measure.

Link: http://www.treesearch.fs.fed.us/pubs/39973

193. St. Clair JB, Howe GT, Erickson VJ. 2010. Responding to climate change: genetic options. USDA Forest Service Genetic Resource Management Climate Change Workshop. Corvallis, OR. 70 p.

Type: Presentation

Geographic Area: Western USA

Compilers' Keywords: Douglas-fir, *Pseudotsuga menziesii*, provenance test, seed transfer guidelines, seed transfer zones

Introduction: When considering ecosystem and management responses to climate change, it is important to consider genetics of adaptation and genetic variation in adaptive traits. There are three considerations: 1. Plants are genetically adapted to their local climates. The climatic tolerances of populations are considerably lower than the tolerances of the species as a whole. Populations, not species, are the important biological unit of interest. 2. Evolutionary adaptation will determine what happens to plant populations given climate change. 3. Management of genetic variation may positively influence how plants respond and adapt to climate change.

Link: http://www.fs.fed.us/wwetac/projects/erickson.html

194. Steenberg JWN, Duinker PN, Van Damme L, Zielke K. 2011. Indicators of sustainable forest management in a changing climate. Ottawa, Ontario, Canada: Canadian Council of Forest Ministers. 51 p.

Type: Government Document

Geographic Area: Canada

Compilers' Keywords: climate change, Ontario, sustainability

Summary: The theme of sustainability is now woven throughout Canadian forest management and policy. Indeed, Canada was an early adopter of sustainability in forestry, largely through a series of initiatives led by the Canadian Council of Forest Ministers' (CCFM). One such initiative was development and application of a national suite of criteria and indicators of sustainable forest management (C&I-SFM). With appropriate data associated with each of the chosen indicators, the C&I-SFM serve up a comprehensive picture of forest and forest-sector progress on the road called sustainable development. For almost two decades, C&I-SFM have been applied at a wide range of levels, from international to national to provincial to local. The national set for Canada has been revised once (2003), and a second revision is likely imminent. In the meantime, the CCFM, in its 2008 vision for Canada's forests, stated that all initiatives related to SFM must consider the implications of a changing climate. In the context of a revision to the C&I-SFM, the question becomes this: what are the implications of a changing climate for the ongoing robustness and utility of Canada's national C&I-SFM? This report attempts to address that question. The approach consisted of devising a systematic set of questions, in other words, an evaluation protocol, to put to each indicator. Some questions pertained to the indicator's relationships with other indicators in the set, some to the expected influences of climate change on the entity represented by the indicator, and finally some that would help us understand the indicator's ongoing relevance to SFM under a changing climate. The research team consisted of experienced forestry professionals and researchers who applied their collective professional judgment, as informed by a thorough canvassing of relevant literature, in answering the questions and developing recommendations for each of the indicators. The preliminary findings, and indeed the entire report, were peer-reviewed by experts from across Canada. Forty-six indicators were examined using the evaluation protocol. The findings are summarized in the main report and detailed in a companion report. The evaluated indicators were assigned to one of three general outcomes. Twelve indicators were considered to be entirely independent of climate change, meaning that climate change is not expected to affect the phenomena represented by these indicators. The utility and robustness of all the remaining 34 indicators was considered to be influenced by a changing climate. For 23 of these, the team recommends no change to the indicator (unmodified category), and for 11 of them, changes are recommended. Initially it was thought that a potential outcome of the evaluation could be outright abandonment of an indicator in the event that the team found its ongoing utility to be seriously eroded by climate change. However, none of the indicators was found in this situation. Finally, he study identified six new indicators that could help provide a climate-change lens for monitoring and managing forests sustainably in Canada. These are: a) Connectivity of protected areas; b) Proportion of tenured forest area with seed transfer guidelines that account for climate change; c) Average, minimum, and maximum temperature d) Area of Crown forest with assisted migration initiatives; e) Rate and form of precipitation; and f) Carbon emissions avoided through product substitution The study concludes with a set of recommendations that should help improve the overall utility of the C&I-SFM, especially in the context of a changing climate. These recommendations address: (a) moving from predominantly retrospective analysis using C&I-SFM to a balance of retrospective and prospective analysis; (b) Linking C&I-SFM much more strongly and directly into forest management and policy processes; (c) undertaking analytical work using a framework of complex adaptive systems; (d) making explicit consideration of climate change in all forest management and policy decisions; and (e) sector-wide collaboration in ongoing improvement to and application of the C&I-SFM. The report concludes by reminding readers that C&I-SFM are a necessary element of the SFM enterprise. Progress is nigh impossible without using them. Confidence in such progress is indeed impossible without them. It is clear that climate change will affect the entire forest sector, sometimes in insidious ways, sometimes in abrupt and obvious ways, and sometimes even in helpful ways. Considering the complex manner in which climate change will interact with other human influences on forests and the sector, incisive cumulative effects assessment will become

increasingly important. Rigorous application of C&I-SFM will help develop the insight needed to assess the real prospects for SFM in Canada under a changing climate.

Link: http://www.for.gov.bc.ca/ftp/hfp/external/!publish/web/ffesc/reports/CI-SFM-ClimateChange_FinalReport_111017.pdf

195. Strange N, Thorsen BJ, Bladt J, Wilson KA, Rahbek C. 2011. Conservation policies and planning under climate change. Biological Conservation 144:2968-2977.

Type: Journal

Geographic Area: Global

Keywords: climate change, dynamic, policy, reserve selection, uncertainty

Abstract: Biodiversity conservation policies focus on securing the survival of species and habitats according to their current distribution. This basic premise may be inappropriate for halting biodiversity decline under the dynamic changes caused by climate change. This study explores a dynamic spatial conservation prioritization problem where climate change gradually changes the future habitat suitability of a site's current species. This has implications for survival probability, as well as for species that potentially immigrate to the site. The problem is explored using a set of heuristics for both of two policy objectives focusing on (1) the protection on current (native) species, and (2) all species, including immigrating species. The trade-offs between the protection of native species versus all species is illustrated. The study shows that the development of prediction models of future species distributions as the basis of decision rules can be crucial for ensuring the effectiveness of conservation plans. Finally, it is discussed how more adaptive strategies, that allow for the redirection of resources from protected sites to privately-owned sites, may increase the effectiveness of the conservation networks. Climate change induced shifts in the suitability of habitats for species may increase the value of such adaptive strategies, the benefit decreasing with increasing migration probabilities and species distribution dynamics.

196. Thorpe J. 2012. Adaptation to climate change in management of prairie grasslands. Saskatoon, Saskatchewan, Canada: Saskatchewan Research Council. SRC Publication No. 12855-1E12. 45 p.

Type: Report

Geographic Area: Canada

Compilers' Keywords: migration, Saskatchewan

Summary: Options for adaptation to climate change in management of prairie grasslands were examined as part of Terrestrial Ecosystems component of the Prairies Regional Adaptation Collaborative (PRAC). Adaptation options were structured according to the "three Rs": Create resistance to change (short-term adaptation), Promote resilience to change (medium-term adaptation), Enable ecosystems to respond to change (long-term adaptation) In grazing management, most of the adaptations that have been discussed are based on short-term resistance to drought or other extreme events. These include reducing cattle herds, finding alternative grazing, increased feeding, and addressing stockwater shortages. Medium-term adaptations aimed at increasing the resilience of grazing operations include moderate to conservative stocking rates, maintaining litter cover, more flexible herd structure, and improving water supply systems. Long-term response options in grazing management include grassland monitoring, revision of range management standards, changes in grazing and land use strategies, and increases in management flexibility. In biodiversity conservation, most of the adaptations that have been discussed are medium- to long-term resilience and response strategies. These include incorporating climate change into conservation plans, increasing protected areas, mitigating other threats to biodiversity such as exotic invasion, and improving information on climate change. The strategies most focused on long-term response aim at facilitating the northward movement of species to adjust to the warmer climate. There are two broad approaches, with advantages and disadvantages in different situations: increasing landscape connectivity, and assisted migration of selected species. Existing government programs that directly or indirectly address climate change in grassland management are reviewed. It is recommended that government agencies use the list of adaptation options provided here to review their current policies and programs, with the aim of identifying those that could be modified or expanded to better address climate change. Options that are not addressed by any current policies should be the focus of new policy development.

Link: http://www.cakex.org/sites/default/files/documents/12855-1E12%20Adaptation%20to%20ClimateChange%20in%20Grassland%20Management.pdf

197. Toth FL, Mwandosya M. 2001. Decision-making frameworks. Chapter 10. In: Metz B, Davidson O, Swart R, Pan J, editors. Climate Change 2001: Mitigation. Cambridge (MS): Cambridge University Press. p 601-688.

Type: Book Section

Geographic Area: Global

Compilers' Keywords: climate change, IPCC, mitigation, management, review

Summary: This chapter is a review of decision-making framework as applied to climate change mitigation. By taking into account the broader perspective of sustainable development the portfolio of mitigation policies is enhanced. A central issue in linking development and climate concerns is technological transfer that could help less-developed countries speed-up

their development and control GHG emissions at relatively low costs. Opportunities are ample, but barriers are significant also.

198. Turra A, Croquer A, Carranza A, Mansilla A, Areces AJ, Werlinger C, Martinez-Bayon C, Nassar CA, Plastino E, Schwindt E, Scarabino F, Chow F, Figueroa FL, Berchez F, Hall-Spencer JM, Soto LA, Buckeridge MS, Copertino MS, de Szechy MT, Ghilardi-Lopes NP, Horta P, Coutinho R, Fraschetti S, Leao ZM. 2013. Global environmental changes: setting priorities for Latin American coastal habitats. Global Change Biology 19:1965-1969.

Type: Journal

Geographic Area: Central and South America

Keywords: benthic ecology, climate impacts, habitat mapping, long-term monitoring, marine biodiversity

Abstract: As the effects of the Global Climate Changes on the coastal regions of Central and South Americas advance, there is proportionally little research being made to understand such impacts. This commentary puts forward a series of propositions of strategies to improve performance of Central and South American science and policy making in order to cope with the future impacts of the Global Climate Changes in their coastal habitats.

Link: http://www.ncbi.nlm.nih.gov/pubmed/23504820

199. U.S. Climate Change Science Program 2008. Preliminary review of adaptation options for climate-sensitive ecosystems and resources. Washington (DC): U.S. Environmental Protection Agency. Synthesis and Assessment Product 4.4. 873 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: climate change, adaptation strategy, EPA, sensitive plants and animals

Summary: Climate variables are key determinants of geographic distributions and biophysical characteristics of ecosystems, communities, and species. Climate change is therefore having profound effects on species attributes, ecological interactions, and ecosystem processes. Because changes in the climate system will continue into the future regardless of emissions mitigation, strategies for protecting climate sensitive ecosystems through management will be increasingly important. While there will always be uncertainties associated with the future path of climate change, the response of ecosystems to climate impacts, and the effects of management, it is both possible and essential for adaptation to proceed using the best available science. This report provides a preliminary review of adaptation options for climate-sensitive ecosystems and resources in the United States. The term "adaptation" in this document refers to adjustments in human social systems (e.g., management) in response to climate stimuli and their effects. Since management always occurs in the context of desired ecosystem conditions or natural resource management goals, it is instructive to examine particular goals and processes used by different organizations to fulfill their objectives. Such an examination allows for discussion of specific adaptation options as well as potential barriers and opportunities for implementation. Using this approach, this report presents a series of chapters on the following selected management systems: National Forests, National Parks, National Wildlife Refuges, Wild and Scenic Rivers, National Estuaries, and Marine Protected Areas. The information drawn from across these chapters is then analyzed to develop the key synthetic messages presented below.

Link: http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=180143

200. USDA FS. 2007. USDA Forest Service strategic plan FY 2007-2012. Washington (DC): USDA Forest Service. FS-880. 38 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: planning, forest management, climate change

Introduction: Managing the natural resources of the Nation's forests and grasslands requires the complex integration of resource assessments, management actions, and cooperative partnerships. United States population growth and expanding urban centers have created a greater demand for goods, services, and amenities from the Nation's private and public forests and grasslands. Given such changes, this section addresses core principles and issues central to delivering the Forest Service's mission. Increasingly diverse urban populations are losing their awareness and knowledge of the natural systems on which they depend. The Forest Service, USDA, must connect with and educate these citizens to expand their understanding of the Links between people, the way they live, and the natural settings within which they live. With increasingly urbanized landscapes, emergency response—including fighting wildland fires—becomes more complex and challenging. Along with our partners, the Forest Service is committed to maintaining and fielding a safe, effective response organization that can be mobilized for managing wildland fires or other national emergencies. We are jointly committed to reducing the loss of life and property and maintaining landscape values. Together, we will invest in the personnel, training, and equipment and provide leadership commensurate with those responsibilities.

Link: http://www.fs.fed.us/publications/strategic/fs-sp-fy07-12.pdf

201. USDA FS. 2008. Forest service strategic framework for responding to climate change. Washington (DC): USDA Forest Service. Version 1.0. 21 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: management, forest resources, ecosystem services

Introduction: The Nation's forests and grasslands provide clean water, scenic beauty, biodiversity, outdoor recreation, natural resource-based jobs, forest products, renewable energy and carbon sequestration. Climate change is one of the greatest challenges to sustainable management of forests and grasslands and to human well-being that we have ever faced, because rates of change will likely exceed many ecosystems' capabilities to naturally adapt. Without fully integrating consideration of climate change impacts into planning and actions, the Forest Service can no longer fulfill its mission. The Forest Service has a unique opportunity and responsibility to sustain forests and grasslands in the United States and internationally. This responsibility includes: 1) stewardship of 193 million acres of national forests and grasslands, 2) partnerships with States, Tribes, and private landowners for assisting communities and owners of 430 million acres of private and Tribal forests, and with other federal agencies, 3) international cooperation, 4) research and development to provide science and management tools. These responsibilities make it imperative that we understand and be able to respond to the effects of climate change on the Nation's forest and grassland resources. This document provides a strategic framework for the Forest Service to guide current and future actions to meet the challenge of climate change. It incorporates the actions included in Chief Gail Kimbell's letter to the National Leadership Council of February 15, 2008.

Link: http://www.fs.fed.us/climatechange/message.shtml

202. USDA FS. 2010. Forest Service global change research strategy, 2009-2019 implementation plan. Washington (DC): USDA Forest Service, Research and Development. FS-948. 72 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: climate change, forest management, assisted migration, USFS, mitigation

Summary: In keeping with the research goals of the U.S. Global Change Research Program, the climate change strategy of the USDA and the climate change framework of the Forest Service, this Forest Service Global Change Research Strategy, 2009-2019 Implementation Plan (hereafter called the Research Plan), was written by Forest Service Research and Development to help to define climate change policy and support best management practices for forests and woodlands (both rural and urban), grasslands, and their associated aquatic ecosystems (riparian systems, lakes, streams). The actions the Research Plan identifies will provide the scientific basis to sustain ecosystem health, adjust management for ecosystem services ("adaptation") and increase carbon sequestration ("mitigation"), all under changing climate conditions. The fundamental research focus of the Research Plan is to increase scientists' understanding of forest, woodland, and grassland ecosystems so that land managers can manage them in a way that sustains and provides ecosystem services for future generations.

Link: http://www.fs.fed.us/research/climate-change/

203. Valatin G. 2012. Additionality and climate change mitigation by the UK forest sector. Forestry 85:445-462.

Type: Journal

Geographic Area: United Kingdom

Compilers' Keywords: forest management, carbon accounting

Summary: Although widely considered to be a core aspect of quality assurance of climate change mitigation activities, additionality remains a source of much controversy in relation to carbon accounting and carbon markets. This article illuminates the multi-faceted nature of the concept and develops a taxonomy of different forms. It provides an overview of how additionality is currently applied in relation to both compliance and voluntary carbon markets, including tests used and underlying evidence base requirements. This draws upon and updates an earlier review commissioned to help inform development of a Woodland Carbon Code designed to underpin climate change mitigation activities in the UK by the forest sector. Sources of uncertainty and trade-offs in practical application of the concept are highlighted, and potential perverse incentives explored.

204. Wiens JA, Bachelet D. 2010. Matching the multiple scales of conservation with the multiple scales of climate change. Conservation Biology 24:51-62.

Type: Journal

Geographic Area: Global

Keywords: climate models, climate change, conservation planning, downscaling, scale, short-grass prairie, The Nature Conservancy

Abstract: To anticipate the rapidly changing world resulting from global climate change, the projections of climate models must be incorporated into conservation. This requires that the scales of conservation be aligned with the scales of climate-change projections. We considered how conservation has incorporated spatial scale into protecting biodiversity, how the projections of climate-change models vary with scale, and how the two do or do not align. Conservation planners use information about past and current ecological conditions at multiple scales to identify conservation targets and threats and guide conservation actions. Projections of climate change are also made at multiple scales, from global and regional circulation models to projections downscaled to local scales. These downscaled projections carry with them the uncertainties associated with the broad-scale models from which they are derived; thus, their high resolution may be more apparent than real. Conservation at regional or global scales is about establishing priorities and influencing policy. At these scales, the coarseness and uncertainties of global and regional climate models may be less important than what they reveal about possible futures. At the ecoregional scale, the uncertainties associated with downscaling climate models become more critical because the distributions of conservation targets on which plans are founded may shift under future climates. At a local scale, variations in topography and land cover influence local climate, often overriding the projections of broad-scale climate models and increasing uncertainty. Despite the uncertainties, ecologists and conservationists must work with climate-change modelers to focus on the most likely projections. The future will be different from the past and full of surprises; judicious use of model projections at appropriate scales may help us prepare.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20121841

205. Williams SE, Shoo LP, Isaac JL, Hoffman AA, Langham G. 2008. Towards an integrated framework for assessing the vulnerability of species to climate change. PLoS Biology 6:2621-2626.

Type: Journal

Geographic Area: Global

Compilers' Keywords: species sensitivity, biodiversity conservation, tools, adaptive capacity

Introduction: We believe that progress in vulnerability assessment relating to climate change could be hastened if a unified framework was available to coordinate the activities of disparate research disciplines. Specifically, what is needed is a complete working framework for assessing the vulnerability of species that explicitly links the various components of biotic vulnerability; the regional and local factors determining exposure to climatic change; the potential for both evolutionary and ecological responses, resilience, and active management to mediate the final realised impacts; and the potential for feedback effects. Such a framework would be invaluable as it would integrate and guide thought, research programmes, and policy in the biodiversity/climate change arena and allow significant gaps in knowledge to be clearly identified. To this end, we present a conceptual framework that addresses these challenges.

Link: http://www.nccarf.edu.au/userfiles/williams_shoo_etal2008_towards%20integrated%20framework.pdf

Climate Change

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

206. Bagne KE, Friggens MM, Finch DM. 2011. A system for assessing vulnerability of species (SAVS) to climate change. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-257. 28 p.

Type: Government Document

Geographic Area: USA

Keywords: climate change, vulnerability, vertebrate species, conservation, resource management

Abstract: Sustained conservation of species requires integration of future climate change effects, but few tools exist to assist managers. The System for Assessing Vulnerability of Species (SAVS) identifies the relative vulnerability or resilience of vertebrate species to climate change. Designed for managers, the SAVS is an easily applied tool that uses a questionnaire of 22 predictive criteria to create vulnerability scores. The user scores species' attributes relating to potential vulnerability or resilience associated with projections for their region. Six scores are produced: an overall score denoting level of vulnerability or resilience, four categorical scores (habitat, physiology, phenology, and biotic interactions) indicating source of vulnerability, and an uncertainty score, which reflects user confidence in the predicted response. The SAVS provides a framework for integrating new information into the climate change assessment process.

Link: http://www.treesearch.fs.fed.us/pubs/37850

207. Bagne KE, Friggens MM, Finch DM. 2011. SAVS: a system for assessing vulnerability of species. Albuquerque (NM): USDA Forest Service, Rocky Mountain Research Station. (URL accessed 07 November 2015)

Type: Web Page

Geographic Area: USA

Compilers' Keywords: decision support system, terrestrial vertebrates, resource management, climate change, tool, USFS

Compilers' Summary: The Rocky Mountain Research Station (USFS) has developed a System for Assessing Vulnerability of Species (SAVS) that quantifies the relative impact of expected climate change effects for terrestrial vertebrate species. The SAVS uses 22 criteria related to expected response or vulnerability of species in a questionnaire to provide a framework for assessing vulnerability to climate change. The questionnaire is completed using information gathered from published materials, personal knowledge, or expert consultation. The SAVS Climate Change Tool focuses solely on the effects of climate change for terrestrial vertebrate species. This tool aids managers by identifying specific traits and issues related to individual species vulnerabilities. Scores generated by completing a questionnaire are meant to be used to inform management planning. A comprehensive discussion of the development and application of this tool will be available from the RMRS General Technical Report [A System for Assessing Vulnerability of Species (SAVS) to Climate Change]. Information regarding specific criteria for each question are provided as information pop-ups with the scoring template. Users may also find it helpful to review assessments conducted for species in New Mexico and Arizona and legacy project briefs for Fort Huachuca, AZ and Barry M Goldwater Range, AZ.

Link: http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/

208. Devine W, Aubry C, Miller J, Potter KM, Bower AD. 2012. **Climate change and forest trees in the Pacific Northwest: guide to vulnerability assessment methodology.** Olympia (WA): USDA Forest Service, Pacific Northwest Region. 49 p.

Type: Government Document

Geographic Area: Pacific Northwest USA

Compilers' Keywords: tool, forest management, tree species, risk assessment, model, USFS, ForGRAS

Introduction: This guide provides a step-by-step description of the methodology used to apply the Forest Tree Genetic Risk Assessment System (ForGRAS) to the tree species of the Pacific Northwest in a recent climate change vulnerability assessment. We describe our modified version of the ForGRAS model, and we review the model's basic principles and operation. We also discuss further adjustments to the model that managers may find useful if applying it to other regions or to fit other objectives. Chapter 2 of this guide describes the overall methodology of the vulnerability assessment; chapters 3 through 7 describe each of the five risk factors that we selected for the Pacific Northwest vulnerability assessment. Appendices provide step-by-step procedures used to prepare the model input data.

Link: http://www.treesearch.fs.fed.us/pubs/44236

209. Morelli TL, Yeh S, Smith NM, Hennessy MB, Millar CI. 2012. **Climate project screening tool: an aid for climate change adaptation.** Albany (CA): USDA Forest Service, Pacific Southwest Research Station. Research Paper PSW-RP-263. 29 p.

Type: Government Document

Geographic Area: Western USA

Keywords: climate change, adaptation, land management, mitigation, Sierra Nevada

Abstract: To address the impacts of climate change, land managers need techniques for incorporating adaptation into ongoing or impending projects. We present a new tool, the Climate Project Screening Tool (CPST), for integrating climate change considerations into project planning as well as for developing concrete adaptation options for land managers. We designed CPST as part of the Westwide Climate Initiative project, which seeks to develop adaptation options for addressing climate change through science/management partnerships. The CPST lists projected climate trends for the target region and questions to be considered when designing projects in different resource areas. The objective is to explore options for ameliorating the effects of climate on resource management projects. To pilot the CPST, we interviewed 13 staff members and line officers of the U.S. Forest Service and Bureau of Land Management in the Sierra Nevada region of California. We found that a major value of the CPST was the process—with the activity of conducting the questionnaire being as important as the answers received from the staff. The CPST also serves as a priority-setting tool, allowing managers to consider effects of different actions. Finally, the CPST helps to reduce uncertainty by identifying the range of impacts that both climatic changes and management actions may have on resources. The CPST could also be modified to devise mitigation options for resource managers.

Link: http://www.treesearch.fs.fed.us/pubs/40319

210. Phillips NC, Anderson RP, Schapire RE. 2006. **MaxEnt software for species habitat modeling.** (URL accessed 07 November 2015).

Type: Web Page

Geographic Area: Global

Compilers' Keywords: MaxEnt, climate change, software, decision support tool, climate projections, modeling, species distribution

Compilers' Summary: MaxEnt is a program for modelling species distributions from presence-only species records. The software has been used to estimate species distributions under climate change scenarios, in an effort to evaluate management options such as assisted migration (see Vitt et al. 2010).

Link: http://www.cs.princeton.edu/~schapire/maxent/

211. Potter KM, Crane BS. 2010. **Forest tree genetic risk assessment systems: a tool for conservation decision-making in changing times.** Atlanta (GA): USDA Forest Service.

Type: Computer Program

Geographic Area: USA

Compilers' Keywords: user guide, climate change, tool, ForGRAS, sensitivity, forest management

Overview: Changing climate conditions and increasing pest and pathogen infestations will increase the likelihood that forest trees could experience population-level extirpation or species-level extinction during the next century. Funds, however, will be limited for management and gene conservation efforts to preserve forest tree genetic diversity.

The Forest Tree Genetic Risk Assessment System provides a framework for users to rank the relative risk of genetic degradation for multiple forest tree species. We have applied this framework for the species-rich forests of the southern Appalachian Mountains of the southeastern United States. Species differ in their physiological tolerances, life history strategies, probabilities of population extinctions and colonizations, and dispersal abilities; these individualistic traits likely underlie the high variability in strength of climate response across wild species, even among those subjected to similar climatic trends. In the face of these changes, an important goal will be to safeguard existing adaptedness and create conducive conditions for future evolution, with a focus on the conservation of variability in adaptive traits. In the absence of good information about the genetic composition of species, or even an understanding of the relevant adaptive traits, several researchers have suggested using ecological and life-history traits to rank the predisposition of species to climate change and other threats, for conservation planning, for the evaluation of species' genetic resources, and for the early detection of vulnerability. The Forest Tree Genetic Risk Assessment System gives each species a rating for risk factors relating to (1) its intrinsic attributes, such as population structure, fecundity and seed dispersal mechanism, that may increase its vulnerability in the face of change, and (2) the external threats to its genetic integrity, including changing climate and insect and disease threats. Species may be additionally rated for a set of conservation modifiers, such as listed status and endemism. The factor index values are weighted and summed to give risk ratings for the species within a given region, which are ranked according to their overall susceptibility to genetic degradation. This system has the advantage of accounting for the interactions among threats that may result in the most severe impacts associated with climate change. Only by considering extinction as a synergistic process of external threats and intrinsic biological traits will it be possible to make predictions of risk that approximate reality for most species, and therefore to increase the likelihood that conservation efforts will be effective. Additionally, the flexibility of the Forest Tree Genetic Risk Assessment System allows for its application at multiple scales and across any area for which the relevant data exist for the species of interest.

Link: http://www.forestthreats.org/research/projects/project-summaries/genetic-risk-assessment-system

212. Potter KM, Crane BS. 2010. Forest tree genetic risk assessment system (ForGRAS). North Carolina State University and USDA Forest Service. (URL accessed 07 November 2015)

Type: Web Page

Geographic Area: USA

Compilers' Keywords: decision support system, online tool, genetic adaptation, genetic degradation, forest management, Pacific Northwest, Southeastern United States, tree species, climate change

Summary: A variety of threats, most importantly climate change and insect and disease infestation, will increase the risk that forest trees could experience population-level or species-level extinction. Species, however, differ in important traits such as life-history strategies and population dynamics, which could drive widely varying responses to potential threats. Determining how to prioritize species for management and conservation activities in the face of these threats will pose a particular challenge in species-rich regions. To address this challenge, a cooperating scientist with the Southern Research Station's Eastern Forest Environmental Threat Assessment Center has developed a framework that allows managers to assess the relative risk of genetic degradation to forest trees affected by multiple threats. This assessment framework serves as a tool for planning management activities and conservation efforts, for evaluating species' genetic resources, and for detecting vulnerabilities. It has the advantage of accounting for multiple threats that may result in the most severe genetic impacts. Only by considering population-level extirpation as a synergistic process of external threats and intrinsic biological traits will we be able to make predictions of risk that approximate reality for most species. Known as the Forest Tree Genetic Risk Assessment System (ForGRAS), the framework has been used by the Forest Service Southern and Pacific Northwest Regions to identify species at risk as a step towards developing management plans. The flexibility of this approach allows for its application at multiple scales and across any area for which data exist on the population dynamics and distribution of the species of interest.

Link: http://www.forestthreats.org/research/projects/project-summaries/genetic-risk-assessment-system

213. Prasad AM, Iverson LR, Matthews S, Peters M. 2007. A climate change atlas for 134 forest tree species of the eastern United States [database]. Delaware (OH): USDA Forest Service, Northern Research Station. (URL accessed 07 November 2015)

Type: Web Page

Geographic Area: Eastern USA

Compilers' Keywords: sensitivity analysis, models, GCM, decision support system, forest management

Summary: We assess the current status (2000) and potential future status (2100) following climate change, of 134 tree species in the eastern United States (east of 100th meridian). We use U.S. Forest Service inventory data with 38 environmental variables to generate models of current suitable habitat for each species. We then change the climate according to three General Circulation Model (GCM) climate models (HADCM3, PCM & GFDL—see 3-GCMs for details) and two emissions scenarios (A1FI (Hi) = little conservation efforts to mitigate CO_2 emissions, B1 (Lo) = significant conservation effort), and model the potential future species habitats. These two emissions scenarios bracket most of the emission futures as outlined by the Intergovernmental Panel on Climate Change's (IPCC) evaluation of emission scenarios (Nakicenovic et al. 2000), and end the 21st century at roughly double (550 ppm-B1) and triple (970 ppm-A1fi) the pre-industrial levels of CO_2.

Link: http://www.nrs.fs.fed.us/atlas/tree

214. Regniere J, Saint-Amant R. 2008. BioSIM 9 - user's manual. Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre. Information Report LAU-X-134. 76 p.

Type: Government Document

Geographic Area: Canada

Compilers' Keywords: software, simulation model, pest management, forecasting, climate change, seasonal biology

Introduction: BioSIM is a software tool designed to assist in the application of temperature-driven simulation models in pest management. It can also be used as a tool in the development and analysis of such models for the purposes of scientific investigation. However, BioSIM's main purpose is to generate forecasts of features or "events" in the seasonal biology of pests or their host plants. Forecasts are made by simulation models provided by the system and are based on regional air temperature and precipitation interpolated from nearby weather stations, adjusted for elevation and location differentials with regional gradients.

Link: http://www.publications.gc.ca/collections/collection_2008/nrcan/Fo113-3-134E.pdf

Conservation and Restoration

General (215–232)—reviews, surveys, summaries, theory, foundations, paradigms

Research (233–285)—propagation, outplanting, invasion

Strategies (286–326)—frameworks, approach, decision support

Resources (327–338)—native plant materials, guidelines, handbooks

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

215. Arthur W. 1987. The niche in competition and evolution. New York (NY): John Wiley and Sons. 175 p.

Type: Book

Geographic Area: Global

Compilers' Keywords: population ecology, plant community ecology

Summary: Using the concept of the niche (and multiple-niche) this book attempts to synthesize two widely-investigated topics: polymorphism and between-species competition; the author's view being that multiple-niche coexistence and multiple-niche polymorphism together represent a common means of coexistence of competitors. Experimental detail and fieldwork are frequently cited in order to create a common point of reference for both population ecologists and geneticists. Concluding chapters discuss other important principles and hypotheses in evolution which are related to the niche concept.

216. Breukers A, van Asseldonk M, Bremmer J, Beekman V. 2012. Understanding growers' decisions to manage invasive pathogens at the farm level. Phytopathology 102:609-619.

Type: Journal

Geographic Area: Global

Compilers' Keywords: risk management, nursery practices, climate change, invasive species, pests, disease control and management

Abstract: Globalization causes plant production systems to be increasingly threatened by invasive pests and pathogens. Much research is devoted to support management of these risks. Yet, the role of growers' perceptions and behavior in risk management has remained insufficiently analyzed. This article aims to fill this gap by addressing risk management of invasive pathogens from a sociopsychological perspective. An analytical framework based on the Theory of Planned Behavior was used to explain growers' decisions on voluntary risk management measures. Survey information from 303 Dutch horticultural growers was statistically analyzed, including regression and cluster analysis. It appeared that growers were generally willing to apply risk management measures, and that poor risk management was mainly due to perceived barriers, such as high costs and doubts regarding efficacy of management measures. The management measures applied varied considerably among growers, depending on production sector and farm-specific circumstances.

Growers' risk perception was found to play a role in their risk management, although the causal relation remained unclear. These results underscore the need to apply a holistic perspective to farm level management of invasive pathogen risk, considering the entire package of management measures and accounting for sector- and farm-specific circumstances. Moreover, they demonstrate that invasive pathogen risk management can benefit from a multidisciplinary approach that incorporates growers' perceptions and behavior.

Link: http://www.ncbi.nlm.nih.gov/pubmed/22397409

217. Burton PJ, Macdonald SE. 2011. The restorative imperative: challenges, objectives and approaches to restoring naturalness in forests. Silva Fennica 45:843-863.

Type: Journal

Geographic Area: Global

Keywords: afforestation, disturbance regime, ecological restoration, forest rehabilitation, native species, reclamation

Abstract: Many of the world's forests are not primeval; forest restoration aims to reverse alterations caused by human use. Forest restoration (including reforestation and forest rehabilitation) is widely researched and practiced around the globe. A review of recent literature reveals some common themes concerning forest restoration motivations and methods. In some parts of the world, forest restoration aims mainly to re-establish trees required for timber or fuel wood; such work emphasizes the propagation, establishment and growth of trees, and equates with the traditional discipline of silviculture. Elsewhere, a recent focus on biocentric values adopts the goal of supporting full complements of indigenous trees and other species. Such ecosystem based restoration approaches consider natural templates and a wide array of attributes and processes, but there remains an emphasis on trees and plant species composition. Efforts to restore natural processes such as nutrient cycling, succession, and natural disturbances seem limited, except for the use of fire, which has seen widespread adoption in some regions. The inherent challenges in restoring "naturalness" include high temporal and spatial heterogeneity in forest conditions and natural disturbances, the long history of human influence on forests in many regions of the world, and uncertainty about future climate and disturbance regimes. Although fixed templates may be inappropriate, we still have a reasonably clear idea of the incremental steps required to make forests more natural. Because most locations can support many alternative configurations of natural vegetation, the restoration of forest naturalness necessarily involves the setting of priorities and strategic directions in the context of human values and objectives, as informed by our best understanding of ecosystem structure and function now and in the future.

Link: http://www.silvafennica.fi/pdf/article74.pdf

218. Campbell FT, Schlarbaum SE. 2014. Fading forests III: American forests, what choice will we make? Arlington (VA): The Nature Conservancy. 167 p.

Type: Report

Geographic Area: USA

Compilers' Keywords: forest management, invasive species, pest management, restoration, invasive pathogens, policy

Preamble (4th paragraph): Fading Forests III is the last publication of a trilogy on pests, policy, and forest health that we began over 20 years ago. This publication, however, is not intended to be a requiem. Instead, we hope that Fading Forests III will be received as a call to greater effort, focused on a limited agenda of actions that can ensure our forests' future.

Link: http://www.nature.org/ourinitiatives/habitats/forests/fading-forests-3-complete-report.pdf

219. Choi YD. 2007. Restoration ecology to the future: a call for new paradigm. Restoration Ecology 15:351-353.

Type: Journal

Geographic Area: Global

Keywords: ecology, future, paradigm, rehabilitation, restoration, sustainability

Abstract: The discipline of restoration ecology has grown remarkably in the past decades, providing new ideas and opportunities for conserving biological diversity, managing ecosystems, and testing ecological theories. On the other side, its past-oriented, static, and idealistic approach has been criticized for subjectivity in determining restoration goals, inapplicability to dynamic ecosystems, and inability for restoring certain irreversible losses. Moreover, unpredictable sustainability of the restored ecosystems, which were modeled after its historical fidelity, adds our skepticism under the changing environment. This paper calls for a new paradigm of ecological restoration to the future. A future-oriented restoration should (1) establish the ecosystems that are able to sustain in the future, not the past, environment; (2) have multiple alternative goals and trajectories for unpredictable endpoints; (3) focus on rehabilitation of ecosystem functions rather than recomposition of species or cosmetics of landscape surface; and (4) acknowledge its identity as a "value-laden" applied science within economically and socially acceptable framework. Applicability of ecological theories to restoration practice is also discussed in this paper.

Link: http://www.globalrestorationnetwork.org/uploads/files/LiteratureAttachments/564_restoration-ecology-to-the-future—a-call-for-a-new-paradigm.pdf

220. Handel SN. 2011. Past, present, future. Ecological Restoration 29:203-205.

Type: Journal

Geographic Area: Global

Compilers' Keywords: restoration, climate change, editorial

Closing Remarks: Importance of restoration ecology must enlarge and quicken if we are going to keep pace with environmental change and deliver the ecological services upon which we all depend. We can only hope that this journal is carried through.

Link: http://er.uwpress.org/content/29/3/203.full.pdf

221. Jones TA. 2009. Conservation biology and plant breeding: special considerations for the development of native plant materials for use in restoration. Ecological Restoration 27:8-11.

Type: Journal

Geographic Area: USA

Compilers' Keywords: nursery, genetic diversity, evolution, practices

Introduction: The development of native plant materials for restoration demands that close attention be paid to the expectations of the specialized customer base of ecological restorationists. Restoration practitioners' expectations are often built on assumptions and values reflective of the relatively new discipline of conservation biology. Unlike most scientific disciplines, conservation biology is unashamedly value driven. Its basic thrust is that we must maintain natural patterns of genetic diversity at many levels and thus preserve options for future evolution.

Link: http://sfc.smallfarmcentral.com/dynamic_content/uploadfiles/152/jones-conservation%20biology.pdf

222. Jones TA, Young SA. 2005. Native seeds in commerce: more frequently asked questions. Native Plants Journal 6:286-293.

Type: Journal

Geographic Area: Global

Keywords: seed prices, release, cultivar, pre-variety germplasm, genetic shift, pure live seed, seed certification, variety, germplasm, plant variety protection

Abstract: To make intelligent choices in the marketplace, customers should have a working understanding of 1) the diversity of products that are available in the seed trade; 2) how they move in the market; 3) how they are regulated for purity and germination; 4) how they are certified to assure genetic identity; and 5) how they are legally protected as intellectual property. Options for seed certification have greatly increased over the last several years. Two complementary certification mechanisms are currently being used to deliver native plant materials, one facilitating the traditional cultivars and the other directed toward the novel pre-variety germplasms. Both accommodate natural and genetically manipulated plant materials.

223. Landis TD. 2011. The target plant concept—a history and brief overview. In: Riley LE, Haase DL, Pinto JR, editors. Forest and Conservation Nursery Associations—2010. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-65. p 61-66.

Type: Government Document

Geographic Area: Global

Keywords: nursery, reforestation, restoration, seedling, native plant

Abstract: The target plant concept originated with morphological classification of conifer nursery stock in the 1930s, and the concept was enhanced through physiological research and seedling testing towards the end of the century. Morphological grading standards such as shoot height, stem diameter, and root mass are the most common use of the target plant concept, and some physiological grading standards are also being operationally implemented by nursery workers and seedling users. Since 2000, the concept has been expanded to include all types of plant materials, including seeds, cuttings, or wildlings, as well as traditional nursery stock. Because these native plant materials are being outplanted on harsh, severely disturbed sites, this more comprehensive native plant materials concept also involves environmental conditions on the project site.

Link: http://www.treesearch.fs.fed.us/pubs/40170

224. Norton DA, Forbes A. 2013. Can exotic pine trees assist in restoration? Applied Vegetation Science 16:169-170.

Type: Journal

Geographic Area: Chile

Compilers' Keywords: conservation, exotic species, regeneration

Abstract: Invasive exotic woody species, including conifers escaped from plantations, are usually regarded as serious threats to native biodiversity. Becerra & Montenegro (Applied Vegetation Science, 16, 2013, 2) present an interesting example of invasive *Pinus radiata* facilitating native woody regeneration in semi-arid central Chile. However, the positive value of invasive conifers for restoration and conservation will not necessarily apply in all situations.

Link: http://onlinelibrary.wiley.com/doi/10.1111/avsc.12014/full

225. Oliet JA, Jacobs DF. 2012. Restoring forests: advances in techniques and theory. New Forests 2012:1-7.

Type: Journal

Geographic Area: Mediterranean

Compilers' Keywords: genetics, disturbance, climate change, ecological function, review

Introduction: Much of the past science of forest regeneration emphasized reforestation following timber harvest for industrial purposes. In recent decades, a pronounced evolution has occurred whereby the focal point of many of today's forest regeneration scientists has shifted prominently toward restoration of harsh, degraded environments. Forest restoration is a highly complex process that requires consistent shifts to adapt to emerging circumstances. This is a special issue of 27 review articles covering a wide range of diverse issues in forest restoration.

Link: http://www.researchgate.net/publication/236148435_Restoring_forests_advances_in_techniques_and_theory/file/e0b4951665abeca599.pdf

226. Rajora OP, Mosseler A. 2001. **Challenges and opportunities for conservation of forest genetic resources.** Euphytica 118:197-212.

Type: Journal

Geographic Area: Canada

Keywords: adaptive traits, gene and genetic resource conservation, genetic and ecological restoration, genetic diversity and population genetic parameters, minimum viable population size, molecular markers, sustainable forest management

Abstract: Increased use of forest resources and a shrinking forestland base threaten the sustainability of forest genetic resources and highlight the importance of conservation and sustainable management of these resources. As forest trees are normally the keystone species of forest ecosystems, their continued existence is essential for many floral and faunal associations of these ecosystems. Major concepts, challenges and opportunities for conservation of forest genetic resources are briefly discussed in this paper. The major challenges include population decline and population structure changes due to forest removal and conversion of forest land to other uses, forest fragmentation, forestry practices, climate change, disease conditions, introduced pests, atmospheric pollution, and introgressive hybridization. Developing scientifically sound conservation strategies, maintaining minimum viable population sizes, and deployment of genetically engineered organisms represent other important challenges in conservation. The usefulness of various biochemical and molecular genetic markers, adaptive traits, and genetic diversity measures for developing conservation strategies for *in situ* and *ex situ* genetic resource conservation are also discussed. Major opportunities for conservation of forest genetic resources include: use of molecular genetic markers and adaptive traits for developing conservation strategies; *in situ* conservation through natural reserves, protected areas, and sustainable forest management practices; *ex situ* conservation through germplasm banks, common garden archives, seed banks, DNA banks, and tissue culture and cryopreservation; incorporation of disease, pest, and stress tolerance traits through genetic transformation; plantation forestry; and ecological restoration of rare or declining tree species and populations. Forest genetic resource conservation and resource use should be considered complementary rather than contradictory to each other.

227. Ratnam W, Rajora OP, Finkeldey R, Aravanopoulos F, Bouvet J-M, Vaillancourt RE, Kanashiro M, Fady B, Tomita M, Vinson C. 2014. **Genetic effects of forest management practices: global synthesis and perspectives.** Forest Ecology and Management 333:52-65.

Type: Journal

Geographic Area: Global

Keywords: forest management practices, timber production, genetic diversity, population structure, mating system, temperate, boreal and tropical forests

Abstract: Understanding the genetic impacts of forest management practices is crucial for conservation and management of forest genetic resources. Forest management practices based on selective and clear cut systems followed by natural or artificial regeneration can impact population structure and mating patterns, thus gene flow and genetic diversity. Survival and productivity of both tree and non-tree species can be compromised or, possibly, enhanced. The extent of genetic impacts depends on the management system applied, stand structure as well as species' distribution, demography, biological attributes and ecology. The impact of management practices is reviewed and synthesized for temperate, boreal and tropical forests based on experimental and simulation studies. In addition, the effects of genetically improved planting materials and establishment of large scale plantations on natural forests are examined. Recommendations are made for genetically sustainable forest management practices.

Link: http://www.sciencedirect.com/science/article/pii/S0378112714003697

228. Simberloff D. 1980. **A succession of paradigms in ecology: essentialism to materialism and probabilism.** Synthese 43:3-39.

Type: Journal

Geographic Area: Global

Compilers' Keywords: evolution, genetics, Darwin, review, foundational ecology

Compilers' Summary: In this essay, Simberloff discusses the major paradigms in ecology beginning with the materialistic revolution in evolution and genetics and ending with the ecosystem paradigm. Ecology's first paradigm that plant community is a superorganism (circa 1905 by Clements) was challenged by several ecologists, because succession does not always lead to the same climax. Simberloff claims that Clements' superorganism is not obsolete, however, but has transformed into a belief that the study of ecosystems should be approached in a holistic manner. Much of the information provided by Simberloff has shaped the way we study, conserve and restore ecosystems.

229. Stanturf JA, Palik BJ, Dumroese RK. 2014. Contemporary forest restoration: a review emphasizing function. Forest Ecology and Management 331:292-323.

Type: Journal

Geographic Area: Global

Keywords: reconstruction, rehabilitation, reclamation, replacement, ecological restoration, forest landscape restoration

Abstract: The forest restoration challenge (globally 2 billion ha) and the prospect of changing climate with increasing frequency of extreme events argues for approaching restoration from a functional and landscape perspective. Because the practice of restoration utilizes many techniques common to silviculture, no clear line separates ordinary forestry practices from restoration. The distinction may be that extraordinary activities are required in the face of degraded, damaged, or destroyed ecosystems. Restoration is driven by the desire to increase sustainability of ecosystems and their services and restoration is likely to have multiple goals arising from the motivations of those involved. The process of setting restoration objectives translates vague goals into feasible, measurable targets and ultimately actions on the ground. Our objective for this review is to synthesize the science underpinning contemporary approaches to forest restoration practice. We focus on methods and present them within a coherent terminology of four restoration strategies: rehabilitation, reconstruction, reclamation, and replacement. While not a consensus terminology, these terms have a logical foundation. Rehabilitation restores desired species composition, structure, or processes to a degraded ecosystem. Reconstruction restores native plant communities on land recently in other resource uses, such as agriculture. Reclamation restores severely degraded land generally devoid of vegetation, often the result of resource extraction, such as mining. Replacement of species (or their locally-adapted genotypes) with new species (or new genotypes) is a response to climate change. Restoration methods are presented as available tools; because adding vegetation is an effective restoration technique, the discussion of methods begins with a description of available plant materials. We then discuss altering composition under different initial overstory conditions, including deployment methods depending upon whether or not an overstory is present, how much of the landscape will be restored, and the complexity of the planting design. We present some major approaches for altering structure in degraded forest stands, and describe approaches for restoration of two key ecosystem processes, fire and flooding. Although we consider stand-level designs, what we describe is mostly scalable to the landscape-level. No restoration project is undertaken in a social vacuum; even stand-level restoration occurs within a system of governance that regulates relationships among key agents. Gathering information and understanding the social dimensions of a restoration project is as necessary as understanding the biophysical dimensions. Social considerations can trump biophysical factors.

Link: http://www.treesearch.fs.fed.us/pubs/46976

230. Stanturf JA, Palik BJ, Williams MI, Dumroese RK, Madsen P. 2014. Forest restoration paradigms. Journal of Sustainable Forestry 33:S161-S194.

Type: Journal

Geographic Area: Global

Keywords: reconstruction, rehabilitation, reclamation, novel ecosystems, intervention ecology

Abstract: An estimated 2 billion ha of forests are degraded globally and global change suggests even greater need for forest restoration. Four forest restoration paradigms are identified and discussed: revegetation, ecological restoration, functional restoration, and forest landscape restoration. Restoration is examined in terms of a degraded starting point and an ending point of an idealized natural forest. Global change, climate variability, biotechnology, and synthetic biology pose significant challenges to current restoration paradigms, underscoring the importance of clearly defined goals focused on functional ecosystems. Public debate is needed on acceptable goals; one role for science is to inform and help frame the debate and describe feasibility and probable consequences.

Link: http://www.treesearch.fs.fed.us/pubs/45775

231. Watrud E, Zensen F, Darbyshire R. 2012. Laws affecting reforestation on USDA Forest Service lands. Tree Planters' Notes 55:39-42.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: USFS, policy, restoration, management, national forests, silviculture

Abstract: Many laws affect reforestation practices on U.S. Department of Agriculture (USDA), Forest Service lands. This article summarizes several acts that have had important influences on Federal reforestation. In particular, we delve into The Knutson-Vandenberg Act of 1930 and the National Forest Management Act of 1976, which have had the largest effect on reforestation of the national forests.

Link: http://www.rngr.net/publications/tpn/55-2/laws-affecting-reforestation-on-usda-forest-service-lands/at_download/file

232. Watt AS. 1947. Pattern and process in the plant community. Journal of Ecology 35:1-22.

Type: Journal

Geographic Area: Global

Compilers' Keywords: ecology, patch dynamics, structure

Introduction: The plant community may be described from two points of view, for diagnosis and classification, and as a working mechanism. My primary concern is with the second of these. But in as much as the two aspects are not mutually exclusive, a contribution to our understanding of how a community is put together, and how it works, may contain something of value in description for diagnosis. It is now half a century since the study of ecology was injected with the dynamic concept, yet in the vast output of literature stimulated by it there is no record of an attempt to apply dynamic principles to the elucidation of the plant community itself and to formulate laws according to which it maintains and regenerates itself. Pavillard's assessment of the dynamic behaviour of species comes very near it, but is essentially concerned with the 'influence (direct or indirect) of the species on the natural evolution of plant communities. As things are, the current descriptions of plant communities provide information of some, but not critical, value to an understanding of them; how the individuals and the species are put together, what determines their relative proportions and their spatial and temporal relations to each other, are for the most part unknown. It is true that certain recent statistical work is stretching out towards that end, but the application of statistical technique, the formulation of laws and their expression in mathematical terms, will be facilitated if an acceptable qualitative statement of the nature of the relations between the components of the community is first presented. Such a statement is now made based on the study of seven communities in greater or less detail, for data of the kind required are seldom recorded. The ultimate parts of the community are the individual plants, but a description of it in terms of the characters of these units and their spatial relations to each other is impracticable at the individual level. It is, however, feasible in terms of the aggregates of individuals and of species which form different kinds of patches; these patches form a mosaic and together constitute the community. Recognition of the patch is fundamental to an understanding of structure as analysed here. In the subsequent analysis evidence is adduced to show that the patches (or phases, as I am calling them) are dynamically related to each other. Out of this arises that orderly change which accounts for the persistence of the pattern in the plant community. But there are also departures from this inherent tendency to orderliness caused by fortuitous obstacles to the normal time sequence. At any given time, therefore, structure is the result of causes which make for order and those that tend to upset it. Both sets of causes must be appreciated. In describing the seven communities I propose in the first examples to emphasize those features which make for orderliness, in the later to content myself with little more than passing reference to these and to dwell specifically upon departures from it; in all examples to bring out special points for the illustration of which particular communities are well suited or for which data happen to be available. For the present the field of inquiry is limited to the plant community, divorced from its context in the sere; all reference to relics from its antecedents and to invaders from the next state is omitted. I am assuming essential uniformity in the fundamental factors of the habitat and essential stability of the community over a reasonable period of time.

Link: http://faculty.washington.edu/edford/Watt_1947.pdf

Conservation and Restoration

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Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

233. Allendorf FW, Hohenlohe PA, Luikart G. 2010. Genomics and the future of conservation genetics. Nature Reviews Genetics 11:697-709.

Type: Journal

Geographic Area: Global

Compilers' Keywords: adaptation, physiological, animals, biodiversity, forecasting, genetic variation, population genetics, review

Abstract: We will soon have complete genome sequences from thousands of species, as well as from many individuals within species. This coming explosion of information will transform our understanding of the amount, distribution and functional significance of genetic variation in natural populations. Now is a crucial time to explore the potential implications of this information revolution for conservation genetics and to recognize limitations in applying genomic tools to conservation issues. We identify and discuss those problems for which genomics will be most valuable for curbing the accelerating worldwide loss of biodiversity. We also provide guidance on which genomics tools and approaches will be most appropriate to use for different aspects of conservation.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20847747

234. Aubry C, Shoal R, Erickson VJ. 2005. Grass cultivars: their origins, development, and use on national forests and grasslands in the Pacific Northwest. Portland (OR): USDA Forest Service. 55 p.

Type: Government Document

Geographic Area: Pacific Northwest USA

Compilers' Keywords: restoration, plant materials

Abstract: Grass cultivars are a distinct subset of a species, often intentionally bred to behave uniformly and predictably when grown in an environment to which the species is adapted. A cultivar, also called a variety or a release, is given a unique trade name chosen by the breeder. These single-word names—such as "Arlington," "Bromar" or "Secar"—most often relate to the place of origin, species name, cultivar characteristics, or an individual involved in the process. Grass cultivars have been used in large quantities, often without an assessment of the consequences. Since grass cultivars vary in their origins, development history, and effects on native plant populations, it is important to know more than the brand name and the species name when considering a seed source for revegetation. Although a cultivar has been developed for particular uses or appears to be adapted to a wide range of conditions, the material may not necessarily be suitable or optimal for all situations. Use of such material may have long-term and possibly irreversible genetic and ecological effects. Therefore it is essential to have a thorough understanding of plant material genetic origins, biological attributes, and level of compatibility with management objectives. In this paper we address the origins, and development of grass cultivars that have been used on national forests and grasslands in the Pacific Northwest. The genetic and ecological consequences of their use are discussed as well as recommendations for selection of plant materials for restoration projects.

Link: http://www.fs.fed.us/wildflowers/nativeplantmaterials/documents/cultivars_maindoc_040405_appendices.pdf

235. Bailey DW, Tabini RA, Waldron BL, Libbin JD, Al-Khalidi K, Alqadi A, Oun MA, Jensen KB. 2010. **Potential of *Kochia prostrata* and perennial grasses for rangeland restoration in Jordan.** Rangeland Ecology & Management 63:707-711.

Type: Journal

Geographic Area: Jordan, Middle East

Keywords: alternate forage sources, crested wheatgrass, forage kochia, Middle East, Russian wildrye, Siberian wheatgrass

Abstract: Six varieties of forage kochia (*Kochia prostrata* [L.] Schrad.), two Atriplex shrubs native to North America, and four drought tolerant perennial grass varieties were seeded and evaluated under arid rangeland conditions in Jordan. Varieties were seeded in December 2007 and evaluated in 2008 and 2009 at two sites. Conditions were dry with Qurain receiving 110 mm and 73 mm and Tal Rimah receiving 58 mm and 43 mm of annual precipitation during the winters of 2007/2008 and 2008/2009, respectively. Plants were more abundant and taller ($P < 0.001$) at Qurain than Tal Rimah in 2008. Forage kochia frequency was 48% and 30% in 2008 at Qurain and Tal Rimah, respectively. However, no seeded plants were observed at Tal Rimah in 2009, suggesting that 58 mm and 43 mm of annual precipitation are insufficient to allow plants to persist over multiple years. At the wetter site, forage kochia abundance in 2009 was similar ($P = 0.90$) to that observed in 2008 and plant height increased ($P < 0.001$) from 2008 (14.4 cm ± 1.1 SE) to 2009 (38.4 cm ± 1.1 SE). Sahro-select and Otavny-select were the most abundant forage kochia varieties ($P = 0.05$), suggesting that these experimental lines could be more adapted to the environmental conditions of Jordan than the commercially available cultivar Immigrant. Frequency of perennial grass varieties declined ($P < 0.001$) at Qurain from 82% ± 4 SE to 39% ± 4 SE between 2008 and 2009, respectively. Among grasses, Siberian wheatgrass had better stands than crested wheatgrass, with Russian wildrye being intermediate. Based on this study, forage kochia appears to have great potential for establishing palatable perennial shrubs in arid rangeland conditions in Jordan if annual precipitation is at least 70 mm. Arid-adapted perennial grass varieties might also be useful in rangeland restoration if annual precipitation is over 100 mm.

236. Benayas JMR, Newton AC, Diaz A, Bullock JM. 2009. **Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis**. Science 325:1121-1124.

Type: Journal

Geographic Area: Global

Compilers' Keywords: assessment, reference ecosystems, tropical biomes, environmental degradation, restoration success

Abstract: Ecological restoration is widely used to reverse the environmental degradation caused by human activities. However, the effectiveness of restoration actions in increasing provision of both biodiversity and ecosystem services has not been evaluated systematically. A meta-analysis of 89 restoration assessments in a wide range of ecosystem types across the globe indicates that ecological restoration increased provision of biodiversity and ecosystem services by 44 and 25%, respectively. However, values of both remained lower in restored versus intact reference ecosystems. Increases in biodiversity and ecosystem service measures after restoration were positively correlated. Results indicate that restoration actions focused on enhancing biodiversity should support increased provision of ecosystem services, particularly in tropical terrestrial biomes.

Link: http://www.sciencemag.org/content/325/5944/1121.short

237. Bhattarai K, Bushman BS, Johnson DA, Carman JG. 2011. **Searls prairie clover (*Dalea searlsiae*) for rangeland revegetation: phenotypic and genetic evaluations.** Crop Science 51:716-727.

Type: Journal

Geographic Area: Western USA

Compilers' Keywords: legume, rangeland restoration, genetic diversity, phenology, forb, common garden

Abstract: Few North American legumes are available for use in rangeland revegetation in the western USA, but Searls prairie clover [*Dalea searlsiae* (A. Gray) Barneby] is one that holds promise. Commercial scale seed production of this species could address the issues of unreliable seed availability and high seed costs associated with its wildland seed collection. To evaluate its utility for revegetation, we collected Searls prairie clover at 20 locations across Utah and Nevada. Amplified fragment length polymorphisms (AFLP) and morphological and phenotypic traits (measured in common-garden plots) were used to clarify the role of evolutionary forces responsible for its genetic structure. Collections were evaluated for dry-matter yield, inflorescence weight, number of inflorescences, plant height, foliage diameter, flowering date, acid-detergent fiber, neutral-detergent fiber, and crude protein at two

common-garden locations in northern Utah. Collections from southern Utah and eastern Nevada exhibited high phenotypic values, whereas collections from western Nevada and northwestern Utah had low phenotypic values. Collections from northwestern Utah were genetically differentiated from those of southern Utah and Nevada via AFLP markers. Strong isolation by distance between collections suggests that genetic drift and gene flow are important factors in determining population structure in Searls prairie clover.

Link: http://www.fs.fed.us/rm/boise/research/shrub/Links/2011papers/bhattaraietall2011.pdf

238. Bhattarai K, Johnson DA, Jones TA, Connors KJ, Gardner DR. 2008. Physiological and morphological characterization of basalt milkvetch (*Astragalus filipes*): basis for plant improvement. Rangeland Ecology & Management 61:444-455.

Type: Journal

Geographic Area: Western USA

Keywords: *Astragalus filipes*, restoration, revegetation, sagebrush steppe, western United States

Abstract: *Astragalus filipes* Torr. ex A. Gray (basalt milkvetch or threadstalk milkvetch) is a legume that is widely distributed in western North America and holds promise for revegetation and restoration programs in the western United States. Seed of 67 accessions was collected in 2003 from Utah, Nevada, Idaho, Oregon, California, and Washington. Field-collected forage samples from these accessions had non-detectable or low levels of selenium, swainsonine, and nitrotoxins. Accessions were evaluated at Providence and Millville in northern Utah in 2005 and 2006. At Providence accessions from north-central Oregon exhibited comparatively high biomass yield in summer and fall during both years. Basalt milkvetch accessions with low biomass generally had high crude protein concentration. Acid-detergent fiber and neutral-detergent fiber were positively correlated with biomass yield ($r = 0.42$, $P = 0.0001$; $r = 0.57$, $P = 0.0001$, respectively). At Millville accessions from north central Oregon exhibited comparatively high biomass and seed yield. Seed weight per 100 seeds varied among basalt milkvetch accessions in both years at Millville. Plants at Millville treated with imadicloprid insecticide had greater seed yields than nontreated plants in 2006, but not in 2005. When averaged across sites and years, a high correlation between number of stems and biomass ($r = 0.82$, $P = 0.0001$) indicated that number of stems is a reliable predictor of high biomass and seed yield. Principal component analysis of seven consolidated plant traits identified two principal components that accounted for 60% and 15% of the variation among accessions. The first principal component was negatively correlated with elevation ($r = 20.71$, $P = 0.01$) and positively correlated with latitude ($r = 0.46$, $P = 0.01$). The second principal component was positively correlated with elevation ($r = 0.36$, $P = 0.01$) and negatively correlated with latitude ($r = 20.47$, $P = 0.01$). These results are beneficial in identifying basalt milkvetch accessions that hold promise for plant improvement efforts.

239. Bockelmann AC, Wels T, Bakker JP. 2011. Seed origin determines the range expansion of the clonal grass *Elymus athericus*. Basic and Applied Ecology 12:496-504.

Type: Journal

Geographic Area: Europe

Keywords: invasion, seedling, herbivory, competition, habitat adaptation, salt marsh

Abstract: The recent invasion of clonal grasses to novel habitats poses a threat to biodiversity in various habitats. *Elymus athericus*, a clonal grass of north-western European salt marshes, is currently increasing in abundance and invading new habitats. In this study, we analyzed controlling factors for seedling establishment of *E. athericus* in frequently flooded low marsh habitats. Here, biotic and abiotic conditions are very different from the conditions of the parental sites with established populations higher up in the marsh. Hence, we hypothesized that seedling establishment at the expanding low marsh edge would depend on the parental origin (either through maternal effects or heritable local adaptation). We further hypothesized that seedling origin interacts with biotic factors such as herbivory and competition as well as with abiotic factors like inundation frequency. We tested the dependence of seedling survival, growth and vegetative reproduction on these factors in a factorial transplant experiment on Schiermonnikoog. Survival was high, with 77% of the planted seedling surviving until the end of the experiment. Biotic factors had a much stronger effect on seedling growth and mortality than parental origin and were independent of inundation. However, parental origin strongly interacted with herbivory and competition, with seedlings performing better under the conditions that resembled their parental site. We conclude that seedlings of *E. athericus*, a species that was previously thought to occur only in mid- to high marsh elevation, can establish at a frequently inundated low-marsh sites. Long term survival and further invasion will primarily depend on biotic factors in interaction with seed origin. Our results suggest that next to herbivory, limitation of seeds adapted to colonizing conditions is likely to slow down range expansion.

240. Bonner FT. 1990. Storage of seeds: potential and limitations for germplasm conservation. Forest Ecology and Management 35:35-43.

Type: Journal

Geographic Area: Global

Compilers' Keywords: seed germination, forestry, recalcitrant seeds, orthodox seeds, seed collection

Abstract: Objectives of seed storage are primarily either short-term for forestry operations, or long-term for germplasm conservation. Seeds can be grouped into four classes of storage characteristics: 'true orthodox' seeds can be stored for long periods at seed moisture contents of 5-10% and sub-freezing temperatures; 'sub-orthodox' seeds can be stored under the same conditions, but for shorter periods due to high lipid content or thin seed coats; 'temperate recalcitrant' seeds cannot be dried at all, but can be stored for 3-5 years at near-freezing temperatures; and 'tropical recalcitrant' seeds also cannot be dried, and they are killed by temperatures below 10-15 °C. Cryogenic storage in liquid nitrogen at –196 °C holds promise, but needs more research. Some genetic damage may occur during seed storage, but the extent and effect of this damage has yet to be determined. Seed storage, by both conventional and cryogenic technologies, offers a relatively cheap method of conserving a broad range of germplasm. It will likely play an essential, complementary role, in germplasm conservation as temporary conservation until *ex-situ* stands are established, and as a safety measure against disastrous losses for limited numbers of seedlots. To fulfill the conservation roles, seed storage life must exceed the natural interval between germination and seed production for the next generation. Most true orthodox and many sub-orthodox seeds offer no problem, but neither recalcitrant seed class can meet this criterion with present technology. However, even short gains in viability retention of recalcitrant species can be useful (e.g., in transporting seed collections from remote areas to nurseries or laboratories).

241. Bower AD, McLane SC, Eckert A, Jorgensen S, Schoettle AW, Aitken SN. 2011. Conservation genetics of high elevation five-needle white pines. In: Keane RE, Tomback DF, Murray MP, Smith CM, editors. High Five Symposium. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-63. p 98-117.

Type: Government Document

Geographic Area: Western North America

Compilers' Keywords: *Pinus*, restoration, genetic diversity, white pine blister rust, forest management

Abstract: Conservation genetics examines the biophysical factors influencing genetic processes and uses that information to conserve and maintain the evolutionary potential of species and populations. Here we review published and unpublished literature on the conservation genetics of seven North American high-elevation five-needle pines. Although these species are widely distributed across much of western North America, many face considerable conservation challenges: they are not valued for timber, yet they have high ecological value; they are susceptible to the introduced disease white pine blister rust (caused by the fungus *Cronartium ribicola*) and endemic-turned-epidemic pests; and some are affected by habitat fragmentation and successional replacement by other species. Potential range shifts resulting from global climate change pose additional threats to these high-elevation species, as suitable climates may no longer exist on the mountains where they grow. The combined impacts of these threats have necessitated active management and conservation activities. While several high-elevation five-needle pines have been well studied, large information gaps exist regarding the genetic diversity and population structure of others. This information is crucial for the development of conservation management strategies. In this report, information on genetic diversity, population structure, and strategies for gene conservation is presented and information gaps identified for North America's high-elevation five-needle pines.

Link: http://www.treesearch.fs.fed.us/pubs/38207

242. Bowles ML, Betz RF, DeMauro MM. 1993. Propagation of rare plants from historic seed collections: implications for species restoration and herbarium management. Restoration Ecology 1:101-106.

Type: Journal

Geographic Area: Central USA

Compilers' Keywords: milkweed, milkvetch, germination, rare plants, *Asclepias lanuginosa, Astragalus neglectus, Asclepias meadii, Astragalus tennesseensis*, seed viability, seed storage

Abstract: Herbaria are potentially important repositories of living seeds that could be useful for recovery of rare plant species. To examine this capacity, we tested seed germination of rare milkweed (*Asclepias*) and milkvetch (*Astragalus*) species representing different collection dates and different herbaria. These groups have contrasting seed characteristics, with greater potential for longevity in the nonpermeable hard-coated milkvetch seeds. Twelve-year-old *Asclepias lanuginosa* seeds failed to germinate. However, we achieved 45% germination from three-year-old *Asclepias meadii* seeds, but germination dropped to 0% after ages of four to five years. *Astragalus neglectus* seeds germinated from 97-, 48-, and 28-year-old herbarium specimens, and *Astragalus tennesseensis* seeds germinated from a four-year-old collection. Seedlings produced from these experiments were incorporated into *ex situ* garden populations for recovery or restoration of rare species populations. Different herbarium pest control techniques may have significant bearing on the viability of seeds stored on herbarium specimens. Microwaving can cause precipitous loss of seed viability, while deep-freezing appears to allow some seeds to remain viable. Potentially live seeds of rare species should be stored under conditions that enhance their long-term viability.

243. Burton PJ, Burton CM. 2002. Promoting genetic diversity in the production of large quantities of native plant seed. Restoration Ecology 20:117-123.

Type: Journal

Geographic Area: Western Canada

Keywords: restoration, seed production, genotype

Introduction: To address the lack of commercial quantities of native plant seed, we embarked on a 5-year research program to collect, propagate and screen common native grasses, sedges, legumes, and other forbs for use in the northern interior of British Columbia. Starting out with very little knowledge about the ecology, range, or breeding systems of candidate plant species, the challenge was to produce large quantities of seed at prices below that of wild-collected seed, while maintaining a high level of genetic diversity in this plant material. How could we benefit from concentrated production of single, identified native plant species in cultivated fields, without fully "domesticating" these species?

244. Cripps CL, Antibus RK. 2011. Native ectomycorrhizal fungi of limber and whitebark pine: necessary for forest sustainability? In: Keane RE, Tomback DF, Murray MP, Smith CM, editors. High Five Symposium. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-63. p 37-44.

Type: Government Document

Geographic Area: Western USA

Compilers' Keywords: white pine blister rust, mountain pine beetle, forest sustainability, Rocky Mountains, *Pinus flexilis*, *Pinus albicaulis*

Abstract: Ectomycorrhizal fungi are an important component of northern coniferous forests, including those of *Pinus flexilis* (limber pine) and *P. albicaulis* (whitebark pine) which are being decimated by white pine blister rust and mountain pine beetles. Ectomycorrhizal fungi are known to promote seedling establishment, tree health, and may play a role in forest sustainability. The goal of this research is to discover the native ectomycorrhizal fungi associated with these two pines in the Rocky Mountain region. Here we report 32 species of ectomycorrhizal fungi associated with whitebark pine, 26 with limber pine, with an overlap of 14 species (primarily suilloids). The ectomycorrhizal fungi can be grouped into 1. generalists, 2. western conifer associates, 3. calcareous species (limber pine) and 4. specialists for five-needle pine or stone pines (primarily suilloids). Some of the *Suillus* species occur with stone pines globally, suggesting a long co-evolutionary history and important ecological roles. Their association with limber pines is newly reported. These five-needle pine specialists could confer a competitive advantage over spruce and fir when present. A preliminary study of the physiology of the suilloid fungi reveals intra- and inter-specific variation in pH/preference/tolerance *in vitro*. Strains with limber pines from calcareous sites exhibit a broader pH tolerance than those found with whitebark pine which is restricted to high elevations. It is hoped that these efforts contribute to an understanding of the native ectomycorrhizal fungi with whitebark and limber pine and provide information useful towards sustaining these tree species, including strain selection for inoculation of nursery seedlings.

Link: http://www.treesearch.fs.fed.us/pubs/38191

245. De Steven D, Sharitz RR, Singer JH, Barton CD. 2006. Testing a passive revegetation approach for restoring coastal plain depression wetlands. Restoration Ecology 14:452-460.

Type: Journal

Geographic Area: Southeastern USA

Keywords: Carolina bays, depression wetlands, drought effects, isolated wetlands, revegetation, seed banks, wetland restoration

Abstract: Restoration of coastal plain depressions, a biologically significant and threatened wetland type of the southeastern United States, has received little systematic research. Within the context of an experimental project designed to evaluate several restoration approaches, we tested whether successful revegetation can be achieved by passive methods (recruitment from seed banks or seed dispersal) that allow for wetland "self-design" in response to hydrologic recovery. For 16 forested depressions that historically had been drained and altered, drainage ditches were plugged to reestablish natural ponding regimes, and the successional forest was harvested to open the sites and promote establishment of emergent wetland vegetation. We sampled seed bank and vegetation composition 1 year before restoration and monitored vegetation response for 3 years after. Following forest removal and ditch plugging, the restored wetlands quickly developed a dense cover of herbaceous plant species, of which roughly half were wetland species. Seed banks were a major source of wetland species for early revegetation. However, hydrologic recovery was slowed by a prolonged drought, which allowed nonwetland plant species to establish from seed banks and dispersal or to regrow after site harvest. Some nonwetland species were later suppressed by ponded conditions in the third year, but resprouting woody plants persisted and could alter the future trajectory of revegetation. Some characteristic wetland species were largely absent in the restored sites, indicating that passive methods may not fully replicate the composition of reference systems. Passive revegetation was partially successful, but regional droughts present inherent challenges to restoring depression wetlands whose hydrologic regimes are strongly controlled by rainfall variability.

Link: http://www.srs.fs.usda.gov/pubs/ja/ja_desteven005.pdf

246. Dey DC, Jacobs D, McNabb K, Miller G, Baldwin V, Foster G. 2008. Artificial regeneration of major oak (*Quercus*) species in the eastern United States—a review of the literature. Forest Science 54:77.

Type: Journal

Geographic Area: Eastern USA

Keywords: reforestation, afforestation, planting seedlings, competition control, direct seeding, regeneration success, *Quercus*, oak, silviculture, animal damage

Abstract: Although natural regeneration is often the best method for establishing new oak (*Quercus* spp.) stands, there are increasingly more situations in which high potential for oak regeneration failure dictates the use of artificial regeneration including direct seeding and planting seedlings. Additionally, afforestation planting programs frequently incorporate oak species. Artificial regeneration of oak stands is challenging for numerous reasons. In this article we synthesize the current state of knowledge regarding growing and planting the major oak species in the eastern United States, point out critical research gaps, and provide some general rowing, planting, and stand tending guidelines and recommendations. Adequate site preparation, careful planting of healthy, genetically adapted seed or seedlings of high morphological and physiological quality, and subsequent control of competing vegetation and browse damage are necessary actions to assure regeneration success. Oak seedling survival in the early years after planting or seeding is a poor indicator of regeneration success. Successful regeneration may be defined as having a desired proportion of the oak planting stock reach dominant/codominant status in the stand. The costs of all activities required to produce a successful oak tree in the future stand should be considered in economic comparison of alternative prescriptions for oak regeneration.

Link: http://www.treesearch.fs.fed.us/pubs/14223

247. Dunne RA, Dunne CG. 2002. Potential for expanded production of native rangeland seeds in western North America. Native Plants Journal 3:34-37.

Type: Journal

Geographic Area: Western North America

Keywords: seed collection, market price, seed increase, field production, federal agencies

Abstract: As producers of native plant seeds, we contacted similar businesses, asked them questions about expanding their cultivated production of native plant seeds, and incorporated their responses with our observations to provide a "seed producers' opinion" on what is limiting native plant seed production in the western U.S. and Canada. Here, we report the results of this survey and discuss common problems associated with wildland seed production from public lands and subsequent sale to the federal government.

Link: http://www.nativeplantnetwork.org/Content/Articles/3-1NPJ34-37.PDF

248. Ferrero-Serrano Á, Hild AL, Mealor BA. 2011. Can invasive species enhance competitive ability and restoration potential in native grass populations? Restoration Ecology 19:545-551.

Type: Journal

Geographic Area: Intermountain West USA

Keywords: *Cirsium arvense*, contemporary evolution, exotic, invasion, genetic differentiation, *Hesperostipa comata*, *Sporobolus airoides*

Abstract: Native plant individuals often persist within communities dominated by exotics but the influence of this exposure on native populations is poorly understood. Selection for traits contributing to competitive ability may lead to native plant populations that are more tolerant of the presence of exotic invaders. In this way, long-term coexistence with an exotic may confer competitive advantages to remnant (experienced) native populations and be potentially beneficial to restoration. In past studies we have documented genetic differentiation within native grass populations exposed to the exotic invader Russian knapweed (*Acroptilon repens*). Here, we examine populations of a cool-season grass, needle-and-thread (*Hesperostipa comata* [Trin. & Rupr.]) and a warm season, alkali sacaton (*Sporobolus airoides* [Torr.]) collected from Russian knapweed-invaded sites and adjacent noninvaded sites to assess their relative competitive ability against a novel exotic neighbor, Canada thistle (*Cirsium arvense*). Experienced *S. airoides* (from within *A. repens* invasions) appear to better tolerate (accumulate biomass, leaf nitrogen content, and to initiate new tillers) the presence of a novel competitor (*C. arvense*). Experienced and inexperienced *H. comata* genets differ in their response to the presence of *C. arvense*. Relative neighbor effects of native grasses on *C. arvense* were generally greater from experienced grasses. The ability to compete with novel neighbors may be driven by general competitive traits rather than species-specific coevolutionary trajectories. Irrespective of competitive mechanisms, the conservation of native species populations within weed invasions may provide an important restoration tool by retaining unique components of native gene pools selected by competitive interactions with exotics.

Link: http://weedcontrolfreaks.com/wp-content/uploads/2013/03/Fererro-Serrano-2009.pdf

249. Fiske J, Tappeiner JC. 2005. An overview of key silvicultural information for ponderosa pine. In: Ritchie MW, Maguire DA, Youngblood A, editors. Ponderosa Pine: Issues, Trends, and Management. Albany (CA): USDA Forest Service, Pacific Southwest Research Station. General Technical Report PSW-GTR-198. p 33-47.

Type: Government Document

Geographic Area: Western USA

Compilers' Keywords: *Pinus ponderosa*, review, reforestation, timber stand development, stand growth, forest management

Abstract: This paper provides a selected list of classical references for the important silvicultural findings for ponderosa

pine, and categorizes some of the key current literature, as well as some of the older, lesser known but important literature. The paper also provides some history of scientific developments, and sources of further information.

Link: http://www.treesearch.fs.fed.us/pubs/27255

250. Fu Y, Thompson D, Willms W, Mackay M. 2005. Long-term grazing effects on genetic variability in mountain rough fescue. Rangeland Ecology & Management 58:637-642.

Type: Journal

Geographic Area: Western Canada

Keywords: native grass, *Festuca campestris*, cattle grazing, genetic diversity, AFLP

Abstract: *Festuca campestris* Rydb. (mountain rough fescue) is a dominant grass species in the montane grasslands of western Canada. Little is known about the genetic diversity of this plant and the effects of long-term grazing on the genetics of populations. The amplified fragment length polymorphism (AFLP) technique was applied to compare the genetic diversity of fescue plants at adjacent grazed and protected areas for 3 populations spread across a longitudinal range: Stavely in the foothills, Milroy in the Rocky Mountain trench, and Goose Lake on the interior plateau. Five AFLP primer pairs were used to screen the tiller samples of about 39 plants in each grazed (or ungrazed) area, and 139 polymorphic AFLP bands were scored for each individual sample. These scored bands had frequencies ranging from 0.03 to 0.98 with an average of 0.56. About 81% of the total AFLP variation resided within the populations. The Goose Lake population had the lowest level of AFLP variation, but genetically was the most distinct. Four AFLP bands were possibly associated with chromosomal segments significant for grazing resistance. Comparisons of AFLP variation between grazing and nongrazing samples revealed variable and relatively small impacts of the long-term grazing on the genetic diversity of the grazed populations. The AFLP variation of grazed samples was 1.5% lower at Goose Lake, 2.2% higher at Milroy, and not different at Stavely. If developing diverse germplasm for rangeland seeding is desired, one should sample across geographic space rather than combining materials with and without historical grazing pressure.

251. Funda T, Lstibürek M, Klápště J, El-Kassaby YA. 2012. Optimization of genetic gain and diversity in seed orchard crops considering variation in seed germination. Scandinavian Journal of Forest Research 27:787-793.

Type: Journal

Geographic Area: Western Canada

Keywords: seed orchard, germination capacity, optimization, genetic gain, genetic diversity

Abstract: Balancing genetic gain and diversity in seed orchard crops is of a major regeneration importance. Here we extend our earlier work on the development of an optimization protocol that maximizes crops' genetic gain at any predefined diversity level, considering parental reproductive output, coancestry, and inbreeding, by incorporating variation in seed germination as an input. Variation in seed germination capacity substantially affected seedlots' genetic diversity by either under- or overestimating their effective population size; however, genetic gains were robust and their differences were negligible. The contrasting results of gain and diversity support the inclusion of the germination capacity, when available, in the optimization protocol.

252. Glass S. 1989. The role of soil seed banks in restoration and management. Restoration and Management 7:24-29.

Type: Journal

Geographic Area: Global

Compilers' Keywords: ecological conservation, seed longevity, species composition

Introduction: The role of seed banks (the reserves of viable seeds in the soil) is increasingly being viewed as important in understanding population and community dynamics and in planning and interpreting a broad range of conservation activities including ecological preservation, management and restoration.

Link: http://er.uwpress.org/content/7/1/24.full.pdf

253. Johnson GR, Berrang PC. 2007. Seed shatter dates of antelope bitterbrush in Oregon. Rangeland Ecology & Management 60:99-103.

Type: Journal

Geographic Area: Oregon, USA

Keywords: Purshia tridentata, seed collection, seed maturation

Abstract: Seed shatter dates for antelope bitterbrush (*Purshia tridentata* [Pursh] DC) were estimated from collections at 192 sites in Oregon and surrounding states. Shatter date was strongly correlated to elevation ($r = 0.74$) and an equation that included elevation, latitude, longitude, and longitude squared explained 79% of the variation in seed shatter dates. In general, earlier shatter dates were associated with more southerly latitudes, easterly longitudes, and lower elevations. Examination of climatic data confirmed the expectation that earlier shatter dates were associated with warmer sites. This information can assist those needing to schedule seed collection activities at multiple locations.

254. King JN, Hunt RS. 2004. Five needle pines in British Columbia, Canada: past, present, future. In: Sniezko R, Samman S, Schlarbaum SE, Kriebel HB, editors. IUFRO Working Party 2.02.15. Fort Collins (CO): USDA Forest

Service, Rocky Mountain Research Station. Proceedings RMRS-P-32. p 12-19.

Type: Government Document

Geographic Area: Western Canada

Keywords: genetic resistance, western white pine, whitebark pine, limber pine

Abstract: In British Columbia (BC), Canada, we have been involved with white pine and blister rust since the rust's discovery on imported infected pines through the port of Vancouver in 1910. Just after the rust's introduction, the USDA Forest Service established monitoring plots and species trials in BC, but these were abandoned when the rust became well established in the USA. Resistance research began again in 1946 with a collection of western white pine (*Pinus monticola* Dougl. ex D. Don) seed that was sent to Ontario for testing. In about 1950 grafted plus trees were inoculated in a disease garden, but this work was also abandoned in 1960 when it was demonstrated that seedlings from such selections could be susceptible. Parent tree selection and seedling inoculation of open-pollinated families of western white pine began again in earnest in 1987. From this material we have the basis of a breeding and seed orchard program based on partial resistance mechanisms. An F1 generation is being produced for future research. Additionally, we are considering single gene resistance traits, such as major gene resistance (MGR), which can be pyramided onto the partial resistance of our breeding population. Efforts, particularly for conservation interests, are also being started for whitebark pine (*P. albicaulis* Engel.).

Link: http://www.fs.fed.us/rm/pubs/rmrs_p032/rmrs_p032_012_019.pdf

255. Krakowski J, El-Kassaby YA. 2003. **Effects of stratification and simulated aging on germination of Douglas-fir seed from a clonal seed orchard.** Forest Genetics 10:65-70.

Type: Journal

Geographic Area: Western Canada

Keywords: *Pseudotsuga menziesii*, germination parameters, stratification, aging

Abstract: Seed from 15 Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) clones were germinated in a factorial design with two pre-treatments (unstratified and stratified) and seven simulated aging periods (0, 2, 4, 7, 10, 12 and 14 days). Simulated aging consisted of high temperature (40 °C) and humidity (100 % RH) exposure, which simulates physiological stresses and consequent deterioration in long term storage. Seed deteriorated as aging treatments lengthened; no germination occurred after 12 days. Germination parameters (capacity, peak value, speed, completeness) were calculated, and pre-treatment and aging effects evaluated using a mixed model analysis of variance. Germination completeness and speed were higher after two days of aging for stratified seed, whereas only peak value increased for unstratified seed. After four days aging, all parameters decreased. Two days of aging enhanced germination capacity of unstratified seed by 15%, but stratified seed was still 13% higher. Douglas-fir seed should be stratified before germination, but unstratified seed can be exposed to 40 °C and 100% humidity for two days to augment seedling stock during the growing season. *Ex situ* Douglas-fir genetic resource conservation, as well as more adequate representation of planted genotypes across the landscape, can benefit from two days of aging, which would ensure slowly-germinating genotypes are represented in the population.

Link: http://www.researchgate.net/publication/228479582_Effects_of_stratification_and_simulated_aging_on_germination_of_Douglas-fir_seed_from_a_clonal_seed_orchard/file/d912f51015315cf10e.pdf

256. Kramer AT, Zorn-Arnold B, Havens K. 2010.

Assessing botanical capacity to address grand challenges in the United States. Chicago (IL): Chicago Botanic Garden. 64 p.

Type: Report

Geographic Area: USA

Compilers' Keywords: workshop, report, human capacity, management, workforce, survey

Preface: Plants are central to the future of scientific discovery, human well-being, and the sustainable use and preservation of the nation's resources. The botanical community in the United States plays a mission-critical role in researching, conserving, and sustainably managing our plant diversity and resources. Botanical expertise is required to address current and future grand challenges and issues, including climate change mitigation, land management and wildlife habitat restoration, understanding the provision of ecosystem services, management and control of invasive species, and the conservation and recovery of rare species. Despite the fundamental role botanical capacity plays in tackling each of these issues, this report outlines where botanical capacity, particularly human capacity, is lacking across all sectors (government, academic, and private). In the United States over the past two decades, the botanical community has experienced significant changes in the demands placed upon it and the resources available to it. Since the early 1990s a series of published and anecdotal reports have outlined declining botanical capacity in many facets of this sector. This includes declines in human resources like botanical training and expertise, financial and management level support for research, education and application, and the loss of infrastructure such as herbaria. The nation's science and land management agenda is suffering as a result. Government agencies are losing botanical capacity as staff botanists retire and positions are not refilled, either because positions are eliminated, replaced by individuals without equivalent botanical training, or because there is an inability to find appropriately qualified new candidates to fill them. Botanical education and training likewise appears to be on the decline, with many botany departments at universities being subsumed into more general or interdisciplinary departments, and subsequently losing resident expertise as professors retire and are replaced by individuals without botanical expertise. Organizations in the private sector (e.g., botanic gardens and other non-profit conservation organizations, as well as for-profit businesses and self-employed individuals) are filling these widening gaps in capacity, providing botanical training, expertise, application, and infrastructure where it otherwise would not exist. Though there are ongoing concerns about funding and program sustainability, organizations in the private sector are poised to do more with additional resources and the right partnerships. Prior to this project, it was unclear exactly where the most critical gaps existed and which sector was most capable of filling them in both the short and long-term. Funding from the National Fish and Wildlife Foundation was awarded to the Chicago Botanic Garden to carry out a one year project to assess the nation's current and future botanical capacity to conduct research in the plant sciences, to educate the public, train the next generation of plant scientists, and to conserve and manage the nation's native plant species and habitat. In conducting this assessment, we utilized all background information available relating to botanical capacity (education, training, research, application, and infrastructure) in the United States. We conducted literature searches and obtained documents on plant science education, research, and application. With this information, and in consultation with members of an established Advisory Board and other individuals in the botanical community, we developed and conducted a series of seven on-line surveys. This included surveys for individuals involved in plant science research, education, or natural resource management at 1) federal government agencies; 2) state heritage programs; 3) other regional, state, county or city government agencies; 4) non-profit organizations; 5) self-employed and for-profit companies; 6) graduate school (master's and doctoral graduate students); and 7) academia (faculty and administrators). Surveys focused primarily but not exclusively on the humanly components of botanical capacity, and were open and publicly available for 8 weeks during the summer of 2009, with requests for participation sent via print and electronic means (e.g., the Botanical Society of America's Plant Science Bulletin, Facebook, websites, email, and through plant science, conservation, ecology and related list serves). We registered more than 1,500 survey respondents representing all 50 states, an indication that this topic is important and of interest throughout the United States. Survey results were an important source of information for this report, as the last time a survey was carried out that specifically targeted the botanical community in the United States was in 1989. Most surveys have been focused on a single sector (primarily the research/training components of the academic sector). To our knowledge, this is the first time multiple sectors of the botanical community (e.g., the entire pipeline from education and training to research, application, and employment) in the United States have been surveyed simultaneously.

Link: http://www.bgci.org/usa/bcap

257. Krasowski MJ, Owens JN. 2000. Morphological and physiological attributes of root systems and seedling growth in three different *Picea glauca* reforestation stock. Canadian Journal of Botany 30:1669-1681.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: root characteristics, planting stock, forest, white spruce

Abstract: The relationship between certain morphological characteristics of white spruce (*Picea glauca* (Moench) Voss) planting stock (STK) and post-planting seedling performance was evaluated. Root system size at planting, its expansion, and its capacity to conduct water during the first post-planting weeks were determined. These characteristics were related to the performance of STK planted on two forest sites and measured for three growing seasons and to the performance of seedlings grown in large wooden boxes buried in the soil outdoors for one growing season (grown without competition from other vegetation). The compared STK were (i) polystyroblock grown, (ii) polystyroblock grown with chemical root pruning, and (iii) peat-board grown with mechanical root pruning. After three growing seasons on forest sites, seedlings with mechanically pruned roots grew more above ground than did seedlings from polystyroblock containers. This difference in seedling growth performance was even more significant for seedlings grown in wooden boxes. Of these, the mechanically pruned seedlings grew more not only above the ground but they also produced larger root systems by the end of the first growing season. This was despite the initially significantly smaller root systems of mechanically pruned seedlings, compared with the other two STK. Early (5–7 weeks after planting) post planting root expansion patterns in the three STK were significantly different, with the roots of mechanically pruned seedlings growing less than the roots in the other two STK. In spite of this, pressure-probe measured hydraulic conductivity and water flux through root systems increased during the first post-planting weeks in mechanically pruned seedlings while declining or changing little in the other two STK. It was concluded that root system size at planting and its early postplanting expansion did not relate well to the root system hydraulic properties or to the post-planting seedling growth performance.

258. Kujawski J, Ogle D. 2005. Not your grandpa's cultivars: the new conservation releases. Native Plants Journal 6:49-51.

Type: Journal

Geographic Area: USA

Keywords: pre-varietal, tested, selected, source identified, germplasm, restoration

Abstract: Three new types of conservation plant releases are now available from USDA Plant Materials Centers as less thoroughly tested but still useful alternatives to traditional cultivars. These "pre-varietal" releases include "tested," "selected," and "source-identified" plant material and have distinct labeling. They help meet strong customer demand for native plant material that is available more quickly than it takes to develop and test a cultivar for a particular conservation use.

Link: http://npj.uwpress.org/content/6/1/49.short

259. Lambert JK. 2008. Willamette Valley prairie restoration: the Native Seed Network and *Sidalcea* [Thesis]. Corvallis (OR): Oregon State University. 95 p.

Type: Thesis

Geographic Area: Oregon, USA

Compilers' Keywords: applied science, conservation biology, native seed network, population genetics

Abstract: My internship was conducted with the Native Seed Network program within the Institute for Applied Ecology, a non-profit organization located in Corvallis, whose focus is education, applied research and active restoration and of native ecosystems. My internship goals were to increase my experience in applied restoration ecology and conservation biology with the emphasis on native plant communities in particular the endangered prairie communities of the Willamette Valley. These goals were met through my tenure with the Native Seed Network's native seed collection and increase program during the 2007 field season. This work provided me strong experience with a process necessary for genetically conservative restoration and provided the NSN with a willing intern to complete their goals for 2007. Additional work I accomplished included a morphometric analysis of the native Willamette Valley prairie forb *Sidalcea campestris* which served as one constituent towards resolving the general ambiguity of this focal species for prairie restoration. Included in this analysis is a presentation and my interpretation of an initial molecular phylogenetic analysis on a selection of *S. campestris* accessions by Liston and deFeniks (unpublished) that may aid in the future resolution of *S. campestris* and other congeners in the Willamette Valley. The purpose of the morphological research was not mastery of population genetics or statistics but an exercise in concentration and achievement towards a more integrated and advanced application of taxonomic work oriented towards preserving biological diversity. This entire report completes the written requirement for the Professional Science Masters degree in Applied Systematic through the Botany and Plant Pathology Department at Oregon State University.

Link: http://scholarsarchive.library.oregonstate.edu/xmlui/bitstream/handle/1957/13792/Joshua.Lambert.2008.BPP-PSM.pdf?sequence=1

260. Leif JW, Durling JC, Burgdorf DW. 2011. Comparison of seed germination techniques for common elderberry (*Sambucus nigra* L. ssp. *canadensis*). Native Plants Journal 12:132-135.

Type: Journal

Geographic Area: USA

Keywords: American black elderberry, stratification, scarification, sulfuric acid, Caprifoliaceae

Abstract: Soaking common elderberry seeds (*Sambucus nigra* L. ssp. *canadensis* (L.) R. Bolli [Caprifoliaceae]) in sulfuric acid followed by a 60-d stratification, or subjecting common elderberry seeds to a 60-d warm, moist treatment followed by a 90-d stratification, significantly increased seed germination of accession 9084126 common elderberry seeds. Stratification alone was less effective in promoting germination than was acid scarification followed by stratification or warm, moist treatment followed by stratification. Germination of common elderberry seeds soaked in hot water was not significantly different from the control treatment.

Link: http://www.plant-materials.nrcs.usda.gov/pubs/mipmcrj10583.pdf

261. Loch DS, Boyce KG. 2003. Balancing public and private sector roles in an effective seed supply system. Field Crops Research 84:105-122.

Type: Journal

Geographic Area: Global

Keywords: seed supply systems, public sector, private sector, seed quality, intellectual property

Abstract: A seed supply system can be defined in general terms as that combination of components, processes and their organisation, along with the interactions and support involved in the production and marketing of seeds of one or more species to a particular user–client grouping in an ongoing way. Seed supply systems come in a variety of forms, and operate at a range of levels (national, regional and local) and with different plant materials used for different purposes. In all cases, however, the public and the private sectors have complementary roles in ensuring that there is an effective seed supply system, which can meet consumer needs in terms of the range of plant materials available and the quantities and quality of seed required at an affordable price. Nationally, it is the government that sets the policy framework within which seed supply systems must operate, and also provides some supporting infrastructure. The private sector then is responsible for the timely and cost-effective production and delivery of seed to end users/clients within the policy framework that has been set by government. The balance in terms of public–private sector roles and responsibilities differs from place to place and changes over time. This paper discusses the factors that help shape what is an effective seed supply system under a

particular set of circumstances, but one that may not necessarily be as effective in other countries/regions or with a different product mix. It also considers the forces that lead to a gradual evolution of the system over time and to recent and more radical changes in major developed countries. The latter shift has been brought about by the commercial opportunities presented by genetic engineering and legal protection of the intellectual property (IP) in new plant varieties, coupled with a shift in government policy towards deregulation of the economy (and so greater industry self-regulation in areas like quality assurance). These factors have led to far-reaching structural changes in relation to commercial seed production and delivery in the developed world over the past decade. The recent changes in seed supply arrangements were focused initially on high volume arable food crops in the larger developed economies of North America and western Europe. However, they are now gradually moving through to lower volume seed markets and to smaller, less developed economies where they will have different implications for the development of effective country specific seed supply policies.

Link: http://startinternational.org/library/archive/files/public-private-seed-sector_d371f58830.pdf

262. Losey JE, Vaughan M. 2006. **The economic value of ecological services provided by insects.** BioScience 56:311-323.

Type: Journal

Geographic Area: USA

Keywords: ecological services, economic value, conservation, biodiversity, environmental policy

Abstract: In this article we focus on the vital ecological services provided by insects. We restrict our focus to services provided by “wild” insects; we do not include services from domesticated or mass-reared insect species. The four insect services for which we provide value estimates—dung burial, pest control, pollination, and wildlife nutrition—were chosen not because of their importance but because of the availability of data and an algorithm for their estimation. We base our estimations of the value of each service on projections of losses that would accrue if insects were not functioning at their current level. We estimate the annual value of these ecological services provided in the United States to be at least $57 billion, an amount that justifies greater investment in the conservation of these services.

Link: http://xerces.org/wp-content/uploads/2008/09/economic_value_insects.pdf

263. Matlaga D, Karoly K. 2004. **Long-term grazing effects on genetic variation in Idaho fescue.** Rangeland Ecology & Management 57:275-279.

Type: Journal

Geographic Area: Oregon, USA

Keywords: cattle grazing, Inter-Simple Sequence Repeat markers, *Festuca idahoensis*, Monte Carlo procedure

Abstract: The effect of cattle grazing on the genetic structure of native grass populations has received little attention. We investigated the effect of cattle grazing on genetic variation in Idaho fescue (*Festuca idahoensis* Elmer) using ISSR (inter simple sequence repeat) DNA markers. The ISSR markers are hypervariable and are generally interpreted as being selectively neutral. Idaho fescue tillers were sampled from inside (N = 31) and outside (N = 34) a 64-year-old cattle exclosure in southeastern Oregon. We extracted DNA and used 2 ISSR primers to determine the genotypes for grazed and ungrazed plants at 60 variable loci. No statistically significant differences were observed between grazed and ungrazed samples for percent polymorphic loci (grazed = 85%; ungrazed = 80%), mean expected heterozygosity (grazed = 0.1393; ungrazed = 0.1365), or for a measure of loci dissimilarity (grazed = 0.506; ungrazed = 0.536). We also found that the ungrazed individuals sampled inside the exclosure were not significantly genetically differentiated from the grazed individuals sampled outside the exclosure (Gst = 0.0008 averaged across all loci). Our results differ from past studies that found demographic and physiological differences between Idaho fescue inside and outside of grazing exclosures at the same site. Our results mirror those of other researchers who have also failed to detect genetic differences at marker loci in response to grazing. We propose that either the mechanisms that must be present to cause changes in neutral genetic variation are not affected by cattle grazing for Idaho fescue at this site, or that any effects of grazing on neutral genetic variation were overwhelmed by gene flow between the grazed and ungrazed samples.

Link: https://journals.uair.arizona.edu/index.php/jrm/article/download/12431/11710

264. Mealor BA, Hild AL. 2006. **Potential selection in native grass populations by exotic invasion.** Molecular Ecology 15:2291-2300.

Type: Journal

Geographic Area: USA

Keywords: AFLP, genetic differentiation, genomics, invasive species, native grasses, selection

Abstract: Ecological impacts of invasive plant species are well documented, but the genetic response of native species to invasive dominance has been often overlooked. Invasive plants can drastically alter site conditions where they reach dominance, potentially exerting novel selective pressures on persistent native plant populations. Do native plant populations in old exotic invasions show evidence of selection when compared to conspecific populations in adjacent, noninvaded areas? We employ amplified fragment length polymorphism (AFLP) analysis to screen a large number of loci from two native grass species (*Hesperostipa comata* (Trin. & Rupr.) Barkworth and *Sporobolus airoides* Torr.) that occur in old infestations of the invasive forb *Acroptilon repens*. We then compare observed locus by locus FST values with distributions of FST estimated from simulation models under expectation of neutrality. We also compare the proportion of loci possibly linked to selection and those not linked to selection which exhibit parallel trends in divergence between two community types (invaded, noninvaded). Few loci (*H. comata*, 2.6%; *S. airoides*, 8.7%) in the two native grasses may be linked to genes under the influence of selection. Also, loci linked to selection showed a greater portion of parallel trends in divergence than neutral loci. Genetic similarities between community types were less than genetic similarity within community types suggesting differentiation in response to community alteration. These results indicate that a small portion of scored AFLP loci may be linked to genes undergoing selection tied to community dominance by an invasive species. We propose that native plants in communities dominated by exotic invasives may be undergoing natural selection.

Link: http://www.ncbi.nlm.nih.gov/pubmed/16780441

265. Mealor BA, Hild AL, Shaw NL. 2004. Native plant community composition and genetic diversity associated with long-term weed invasions. Western North American Naturalist 64:503-513.

Type: Journal

Geographic Area: USA

Keywords: native grasses, invasive plants, diversity, ISSR, *Acroptilon repens*, *Cardaria draba*, *Achnatherum hymenoides*, *Hesperostipa comata*, *Sporobolus airoides*, *Poa secunda*

Abstract: Many studies have assessed genetic changes in exotic plant species in their native and introduced ranges, but none have focused on genetic variation in native plant species in response to exotic invasion. We examine characteristics of native plant communities within and outside old (>25 year) invasions of *Acroptilon repens* (Russian knapweed) and *Cardaria draba* (hoary cress). We also document genetic variability of 4 native grass populations (*Hesperostipa comata* [needle and thread], *Achnatherum hymenoides* [Indian ricegrass], *Sporobolus airoides* [alkali sacaton], and *Poa secunda* [Sandberg bluegrass]) from 2 areas: adjacent to and within weed invasions. Native plant species richness and diversity did not differ between invaded and noninvaded areas. Inter-simple sequence repeat (ISSR) analysis of individual native perennial grasses of each of the 4 species suggests that populations exposed to long-term coexistence with exotics may differ from adjacent noninvaded populations. We suggest that future research efforts should focus on intraspecific diversity of native plant species to identify possible candidates for restoration following weed control.

Link: http://www.treesearch.fs.fed.us/pubs/40785

266. Merritt DJ, Dixon KW. 2011. Restoration seed banks—a matter of scale. Science 332:424-425.

Type: Journal

Geographic Area: Global

Compilers' Keywords: conservation, long-term management, provenances, seed collection

Compilers' Summary: Comment on the current state of restoration in relation to seed banks and scale. The authors preface the article with the fact that seed banks do not have enough seed for large-scale restoration projects. Seed banks must shift from being "stamp-collections" of species to collections that can provide tons of seeds and the expertise to improve restoration efforts. Further, in the seed bank system, seed source, availability, or management and use of seeds are rarely considered in collections. The lack of information about each seed lot can lead to storage and planting failures. Some needs are seed farming of native species, seed technology for effective use and site delivery, genetic analysis tools to address provenances in seed farming, refinement of seed collection and utilization strategies, and transfer of knowledge on collecting, using and storing seeds.

Link: http://www.esalq.usp.br/lcb/lerf/divulgacao/recomendados/artigos/merritt2011.pdf

267. Miller RS. 1967. Pattern and process in competition. Advances in Ecological Research 4:1-74.

Type: Journal

Geographic Area: Global

Compilers' Keywords: plant populations, spatial distribution, coexistence, species diversity

Summary: This chapter discusses the development of competition theory, which has traditionally included three stages: inferences drawn from observation of natural populations, construction of mathematical models, and laboratory experiments designed to test elements of competitive interactions in controlled environments. Interference to any activity either directly or indirectly limits a competitor's access to a necessary resource or requirement. Different types of evidence are assigned for competition in nature. Principal categories are mutually exclusive spatial distributions without supporting evidence of a competitive interaction, observed or inferred ecological displacement in sympatric populations, and induced changes in distribution pattern. A considerable amount of ambiguity exists in interpretations of the results of interspecies competition. It is necessary to distinguish between maximum exploitation of the available resources by one species, and equitable utilization of the resources and possible coexistence in a mixed species system. The chapter suggests two major sources of species diversity. When competition is primarily through exploitation and the system is under strong environmental control, it is likely that fluctuations in factors affecting reproduction and survival will continually alter the outcome of the competitive interaction, allowing coexistence of mixed species populations

Link: http://www.sciencedirect.com/science/article/pii/S0065250408603190

268. Monsen SB, Shaw NL. 2001. Development and use of plant resources for western wildlands. In: McArthur ED, Fairbanks DJ, editors. Shrubland Ecosystem Genetics and Biodiversity. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-21. p 47-61.

Type: Government Document

Geographic Area: Western USA

Compilers' Keywords: native plant materials, biodiversity, restoration, native seed, review

Abstract: Concern for declines in big game habitat throughout the West and the pioneering work of revegetation researchers in the mid twentieth century led to increased use of native shrubs, grasses, and forbs for revegetation, and the 1975 establishment of the USDA Forest Service, Shrub Sciences Laboratory in Provo, Utah. During this period revegetation objectives shifted from an emphasis on production of commodities to conservation of biodiversity and ecosystem functions. Plant resource development altered from an agronomic approach focusing on plant improvement to one that incorporates ecological, genetic, and practical considerations. Although many problems remain, research, technological advances, efforts to stabilize the native seed industry, and improved seed testing and certification procedures are increasing our options for revegetating disturbed lands.

Link: http://www.treesearch.fs.fed.us/pubs/40780

269. Mortlock W. 2000. Local seed for revegetation: where will all that seed come from? Ecological Management and Restoration 1:93-101.

Type: Journal

Geographic Area: Australia

Compilers' Keywords: seed collection, large-scale demand, local adaptation

Abstract: Broad-scale revegetation requires large quantities of locally indigenous seed, but there are worrying signs that current demand for local seed may already be outstripping supply in some areas of Australia. Could integrated solutions include better regional cooperation for seed collection as well as the creation of seed production areas?

270. Muir JP, Taylor J, Interrante SM. 2005. Herbage and seed from Texan native perennial herbaceous legumes. Rangeland Ecology & Management 58:643-651.

Type: Journal

Geographic Area: Texas, USA

Keywords: herbage nutritive value, yield, wildlife, revegetation, rangeland

Abstract: Native seed mixes for rangeland seeding, prairie restoration, or cultivated pasture can benefit from a greater variety of forbs that more closely reflect the original vegetation of the southern Great Plains. Fifteen native, perennial herbaceous legumes were collected in central Texas and evaluated for herbage production, mineral content, and fiber concentration of established plants in research plots over 2 years. Downy milk-pea (*Galactia volubilis* [L.] Britton) was productive, regardless of rainfall, whereas prairie acacia (*Acacia angustissima* [Mill.] Kuntze var. *hirta* [Nutt.] B.L. Rob.) and Illinois bundle-flower (*Desmanthus illinoensis* [Michx.] MacMill. Ex. B.L. Rob. & Fernald) out-yielded others in year 3 when rainfall was the greatest. Herbage crude protein averaged approximately 100 g/kg for bush-clovers (*Lespedeza* spp.) compared to bundle-flowers (*Desmanthus* spp.), which exceeded 200 g/kg; the latter also was high in herbage phosphorus. Herbage neutral detergent fiber ranged from 300 to more than 500 g/kg, acid detergent fiber ranged from 140 to 360 g/kg, and acid detergent lignin ranged from 36 to 140 g/kg, a wide range from which to select if animal nutrition is a primary criterion. Seed production was evaluated within a subset of 8 entries submitted to periodic herbage removal or left intact throughout the season. Three bundle-flowers yielded the greatest mass and seed number, but were negatively affected by harvest, unlike prairie acacia. Herbage and seed characteristics indicate there are promising perennial herbaceous legumes in the southern Great Plains that can be included in native seed mixes.

271. Page MJ, Baxter GS, Lisle AT. 2006. Evaluating the adequacy of sampling germinable soil seed banks in semi-arid systems. Journal of Arid Environments 64:323-341.

Type: Journal

Geographic Area: Australia

Keywords: soil seed banks, species richness estimates, sample size, sampling strategy, seed distribution, semi-arid, first-order jackknife

Abstract: Quantification of soil seed is an important tool for understanding vegetation dynamics. However, determining adequate sample sizes and sampling regimes is problematic. The literature reports highly variable sample sizes and regimes without any generally applicable standards appearing to emerge. This problem is exaggerated by the heterogeneous and patchy nature of arid and semi-arid environments. Species accumulation curves are commonly used in floristic sampling to plan sampling effort and to evaluate its adequacy. However, the precision of the sample cannot be quantified and it is difficult to determine the number of species missed. We suggest an alternate approach in which a species richness estimator is compared to the actual number of species found. When applied to data collected in a semi-arid region of South-West Queensland, this method gave a good indication of sampling adequacy at large sample sizes. We suggest that this post hoc comparison of the predicted species richness (with coefficient of variation) to the actual number of species found would be useful in all studies reporting seed bank composition. This would allow the reader to evaluate the adequacy of the sampling effort, when judged against the research aims. We also investigated the deployment of sampling effort by examining structured subsets of our data. The results suggest that sampling effort may be optimized by taking fewer samples per transect in any one site, but selecting more transects and sites.

272. Peppin DL, Fulé PZ, Lynn JC, Mottek-Lucas AL, Hull Sieg C. 2010. Market perceptions and opportunities for native plant production on the southern Colorado plateau. Restoration Ecology 18:113-124.

Type: Journal

Geographic Area: Southwestern USA

Keywords: local genotype, market perception differences, native plant market, native plant policy, web-based survey

Abstract: Increases in revegetation activities have created a large demand for locally adapted native plant materials (NPM) in the southwestern United States. Currently, there is a minimal supply of local genotypes to meet this demand. We investigated the potential for the initiation of a native plant market in the southern Colorado Plateau. Through a literature search, interviews, and site visits, we identified existing native plant markets outside of the region as useful models to help initiate a regional market. We used web based surveys to identify and analyze current and future NPM needs and concerns. Survey results indicate that management policy strongly drives decisions regarding the use and purchase of NPM. From a demand perspective, lack of availability and cost of NPM has kept purchasing minimal, despite policy changes favoring the use of natives. For suppliers, further development of NPM is limited by inconsistent and unreliable demand and lack of production knowledge. The knowledge and tools necessary to initiate an NPM market are available, but inadequate funding sources and insufficient information sharing hinder its development. Communication among producers, land managers, buyers, and researchers, as well as partnerships with local growers, appear to be vital to initiating a functional market.

Link: http://www.fs.fed.us/rm/pubs_other/rmrs_2010_peppin_d001.pdf

273. Peppin DL, Fulé PZ, Hull Sieg C, Beyers JL, Hunter ME, Robichaude PR. 2011. Recent trends in post-wildfire seeding in western U.S. forests: costs and seed mixes. International Journal of Wildland Fire 20:702-708.

Type: Journal

Geographic Area: Western USA

Keywords: annual cereal grains, Burned Area Emergency Response, native plant species

Abstract: Broadcast seeding is one of the most commonly used post fire rehabilitation treatments to establish ground cover for erosion control and mitigation of non-native plant species invasions. Little quantitative information is available on overall trends of post-fire seeding expenditures and seed mixes used over time in forested ecosystems in the western USA. We reviewed scientific articles, government publications and unpublished documents as well as USDA Forest Service Burned Area Reports to determine trends in post-fire seeding in forested ecosystems over time. Of 1164 USDA Forest Service Burned Area Reports, 380 contained information on seeding treatments conducted in forested ecosystems. A review of 40 papers and 67 Burned Area Reports reporting species seeded between 1970 and 2007 revealed a trend of increasing use of native species, annual cereal grains and sterile-grass hybrids, with natives dominating seed mixes. According to 380 Burned Area Reports with data on costs and area seeded, total post-fire seeding expenditures have increased substantially, averaging U.S. $3.3 million per year spent on post-fire emergency seeding treatments in forested ecosystems that involved the Forest Service during the period 2000 to 2007—an increase of 192% compared with the average spent during the previous 30 years. The percentage of the total burned area seeded averaged 21% in the 1970s, compared with only 4% between 2000 and 2007.

Link: http://www.fs.fed.us/rm/pubs_other/rmrs_2011_peppin_d001.pdf

274. Pitman WD. 2009. Establishment and survival of native legumes on upland sites in Louisiana. Native Plants Journal 10:241-250.

Type: Journal

Geographic Area: Louisiana, USA

Keywords: renovation, *Centrosem virginianum*, *Mimosa strigillosa*, *Neptunia lutea*, *Rhynchosia latifolia*, *Strophostyles umbellata*, *Tephrosia virginiana*

Abstract: Field evaluations of perennial native legumes (Fabaceae) from Louisiana pineland ecosystems revealed differing colonization abilities among species under natural recolonization of disturbed sites. Initial establishment and growth of transplanted seedlings of 5 different species were good in an early field evaluation. In a subsequent evaluation initiated with scarified seeds, poor establishment of herbaceous mimosa (*Mimosa strigillosa* Torr. & A. Gray) indicated that populations of this species may be limited by lack of competitiveness of emerging seedlings. Virginia tephrosia (*Tephrosia virginiana* (L.) Pers.) produced vigorous upright seedling growth with population expansion in only one year of these evaluations. Initial establishment of prairie snoutbean (*Rhynchosia latifolia* Nutt. ex Torr. & A. Gray) was limited by inadequate rainfall in some instances, but under favorable conditions this species was superior in seed production and population expansion. Individual plants of these species were rather short-lived with long-term population survival dependent on seed production and seedling recruitment. Seed germination of these legumes was limited by hard seedcoats. Physical scarification readily overcame this limitation for all species evaluated. *Rhynchosia latifolia* appears to have potential value for use in reclamation and revegetation plantings because of potential for seed production and establishment of persistent populations under favorable conditions. *Mimosa strigillosa* has potential to provide superior ground cover and sustainable populations, but limited establishment from seeds indicates that selection from expanded germplasm collections for seedling vigor may be particularly important for successful use of this species.

275. Ray-Mukherjee J, Jones TA, Adler PB, Monaco TA. 2011. **Immature seedling growth of two North American native perennial bunchgrasses and the invasive grass *Bromus tectorum*.** Rangeland Ecology & Management 64:358-365.

Type: Journal

Geographic Area: Intermountain West USA

Keywords: absolute growth rate, bluebunch wheatgrass, relative growth rate, Snake River wheatgrass, specific leaf area, specific root length

Abstract: *Pseudoroegneria spicata* (Pursh) A. Love and *Elymus wawawaiensis* J. Carlson & Barkworth are two native perennial grasses widely used for restoration in the Intermountain West. However, the rapid establishment and spread of *Bromus tectorum* L., an invasive annual grass, has led to a decline in the abundance of native perennial grasses. Proliferation of *B. tectorum* has been attributed to its early germination, superior cold-temperature growth, profuse root production, and high specific leaf area (SLA). To enhance restoration success, we compared *B. tectorum* to commercially available plant materials of two perennial rangeland bunchgrasses, *P. spicata* (cv. Whitmar, cv. Goldar, and Anatone Germplasm) and *E. wawawaiensis* (cv. Secar), for germination, seedling morphological traits, and growth rates at the immature seedling stage. We monitored germination and immature seedling growth in a growth chamber in two separate experiments, one under low (5/10 °C) and the other under high (15/20 °C) day/night temperatures. Compared to the average of the two perennials, *B. tectorum* was 93% (77%) greater at high (and low) temperature for root:shoot length ratio, but only 14% (14%) greater for root:shoot biomass ratio and 12% (19%) lower for SLA. This suggests that *B. tectorum*'s substantial investment in surface area of roots, rather than in shoot length, root biomass, or leaf area, may be responsible for the annual's success at the early seedling stage. Compared to *E. wawawaiensis*, *P. spicata* averaged 65% (41%) higher shoot biomass, 39% (88%) higher root biomass, and 70% (10%) higher absolute growth rate, but 25% (15%) lower SLA and 15% (36%) lower specific root length (SRL) at high (and low) temperatures, respectively. Although *P. spicata*'s greater productivity may initially make for better seedling establishment than *E. wawawaiensis*, it may also prove disadvantageous in competitive or highly resource limited environments where high SLA or SRL could be an advantage.

Link: http://www.researchgate.net/publication/231186284_Immature_Seedling_Growth_of_Two_North_American_Native_Perennial_Bunchgrasses_and_the_Invasive_Grass_Bromus_tectorum/file/d912f5065c1749dd03.pdf

276. Rowe CLJ, Leger EA. 2011. **Competitive seedlings and inherited traits: a test of rapid evolution of *Elymus multisetus* (big squirreltail) in response to cheatgrass invasion.** Evolutionary Applications 4:485-498.

Type: Journal

Geographic Area: California, Nevada, USA

Keywords: adaptation, competition, contemporary evolution, ecological genetics, invasive species, natural selection, restoration

Abstract: Widespread invasion by *Bromus tectorum* (cheatgrass) in the Intermountain West has drastically altered native plant communities. We investigated whether (big squirreltail) is evolving in response to invasion and what traits contribute to increased performance. Seedlings from invaded areas exhibited significantly greater tolerance to *B. tectorum* competition and a greater ability to suppress *B. tectorum* biomass than seedlings from adjacent uninvaded areas. To identify potentially adaptive traits, we examined which phenological and phenotypic traits were correlated with seedling performance within the uninvaded area, determined their genetic variation by measuring sibling resemblance, and asked whether trait distribution had shifted in invaded areas. Increased tolerance to competition was correlated with early seedling root to shoot ratio, root fork number, and fine root length. Root forks differed among families, but none of these traits differed significantly across invasion status. Additionally, we surveyed more broadly for traits that varied between invaded and uninvaded areas. *Elymus multisetus* plants collected from invaded areas were smaller, allocated more biomass to roots, and produced a higher percentage of fine roots than plants from uninvaded areas. The ability of native populations to evolve in response to invasion has significant implications for the management and restoration of *B. tectorum*-invaded communities.

Link: http://naes.agnt.unr.edu/PMS/Pubs/548_2011_03.pdf

277. Samnegård U, Persson AS, Smith HG. 2011. **Gardens benefit bees and enhance pollination in intensively managed farmland.** Biological Conservation 144:2602-2606.

Type: Journal

Geographic Area: Sweden, Europe

Keywords: *Apoidea*, *Bombus*, *Campanula*, pollinator, seed set, agriculture, landscape

Abstract: The recent loss of pollinating insects and out-crossing plants in agricultural landscapes has raised concern for the maintenance of ecosystem services. Wild bees have been shown to benefit from garden habitats in urban and suburban areas. We investigated the effects of distance from garden habitats on wild bees and seed set of a native out crossing plant *Campanula persicifolia*, in intensively managed agricultural landscapes in southern Sweden. Bee abundance and species richness, as well as plant seed set, were higher closer to gardens (<15 m) than further away (>140 m). This highlights private gardens as a landscape wide resource for pollinators but also the lack of sufficient pollination of wild plants in contemporary agricultural landscapes.

278. Shaukat SS, Siddiqui IA. 2004. Spatial pattern analysis of seeds of an arable soil seed bank and its relationship with above-ground vegetation in an arid region. Journal of Arid Environments 57:311-327.

Type: Journal

Geographic Area: Pakistan, Southern Asia

Keywords: spatial pattern, seed bank, weeds, vegetation, dispersal

Abstract: The composition and spatial pattern of weeds was analysed in an arable-soil seed bank after the harvest of wheat. Four hundred cores were collected from a 10x10m grid in April 1999. Three indices of pattern detection (variance/mean ratio, Lloyd's index of mean crowding, and Morisita's index of aggregation) and Moran's I statistic of spatial autocorrelation were computed. The above-ground vegetation of the corresponding area was sampled by 100 randomly placed quadrats in March and September 1999 and variance/mean ratio of all the species was calculated. The seed bank of the field was dominated by annuals including *Convovulus arvensis*, *Amaranthus viridis*, *Anagallis arvensis*, *Chenopodium album* and *Conyza canadensis*. In all 27 species were recorded from the seed bank. For most of the species with a mean higher than 0.05 per core, the seed pattern (with two exceptions) was aggregated as indicated by various indices of pattern detection. Among the common species, only *Amaranthus viridis* exhibited a random pattern. Aggregated pattern of seeds was generally due to seeds settling in the neighbourhood of the mother plant and the clumped distribution of plant species in the overlying vegetation. Suggestions have been made regarding the improvement of the precision of the soil seed bank sample, in view of the aggregated distribution of seeds in soil. Seed bank showed considerable qualitative similarity with the above-ground vegetation, which is presumably the consequence of recurrent disturbances in the arable field.

279. Smith FS, Lloyd-Reilley J, Ocumpaugh WR. 2010. South Texas Natives: a collaborative regional effort to meet restoration needs in south Texas. Native Plants Journal 11:252-268.

Type: Journal

Geographic Area: Texas, USA

Keywords: USDA NRCS Plant Materials Program, restoration, revegetation, Rio Grande Plains, Sand Plains, Gulf Prairies and Marshes

Abstract: South Texas Natives (STN) is an initiative started in 2001 to develop and promote native plants for the restoration and reclamation of public and private lands in south Texas. At the urging of concerned conservationists and private landowners, STN has developed commercially viable sources of native seed and conducted research to discover effective restoration strategies that can be used by private landowners and government agencies to restore native plant communities. STN grew out of a strong partnership among the USDA Natural Resources Conservation Service E "Kika" de la Garza Plant Materials Center, Texas AgriLife Research, Rio Farms Inc, Caesar Kleberg Wildlife Research Institute, and private landowners of south Texas. Plant development efforts center on the release of commercially viable, multiple origin germplasms selected with an awareness of the commercial requirements for production but grounded in genetic and ecosystem function parameters. In addition to plant development efforts, extensive restoration and revegetation research is conducted by STN to develop usable methodology and much-needed guidelines for restoration in south Texas. Current restoration research emphasis centers on providing techniques for the diversification of areas dominated by invasive exotic grasses.

280. Sniezko R, Kegley A, Danchok R, Long S. 2007. Variation in resistance to white pine blister rust among 43 whitebark pine families from Oregon and Washington - Early results and implications for conservation. In: Goheen EM, Sniezko R, editors. Whitebark Pine: A Pacific Coast Perspective. Portland (OR): USDA Forest Service, Pacific Northwest Region. R6-NR-FHP-2007-01. p 82-97.

Type: Government Document

Geographic Area: Pacific Northwest USA

Compilers' Keywords: resistance, seed collection, inoculation, pest management, *Cronartium ribicola*

Abstract: All nine North American species of white pines are susceptible to the introduced, invasive pathogen *Cronartium ribicola*, the cause of white pine blister rust. Whitebark pine is considered one of the most susceptible species. Genetic resistance is considered a cornerstone for survival to this pathogen. Fortunately, all of the native species of white pines have some level of resistance. Evaluation of resistance in Oregon and Washington families of whitebark pine has only recently begun; currently over 150 seedlots collected from individual parent trees are in resistance testing. This report summarizes differences in responses among 43 seedling families and one bulked seedlot through two years after artificial inoculation with blister rust. Initial infection after inoculation of three-year-old seedlings was very high in the first set of trials; 100% of the seedlings developed needle lesions in the two trials reported in this paper. There were large differences among families in several traits, including percentage of trees with stem symptoms and survival two years after inoculation. The level of resistance present in some families and the frequency of resistance among the 43 families reported here is encouraging. A possible geographic trend in resistance is also noted. It is recommended that at least a subset of families be field planted to validate resistance ratings from this short-term screening. The collection and use of seed from putative resistance parent trees identified through this testing would be a good starting point for restoration efforts.

Link: http://www.fs.fed.us/r6/dorena/documents/publications/pub308.pdf

281. Teste FP, Lieffers VJ, Landhausser SM. 2011. **Seed release in serotinous lodgepole pine forests after mountain pine beetle outbreak.** Ecological Applications 21:150-162.

Type: Journal

Geographic Area: Western Canada

Keywords: biotic disturbance, cone burial, cone opening, *Dendroctonus ponderosae*, ground-foraging vertebrates, mountain pine beetle, natural regeneration, *Pinus contorta* var. *latifolia*, Rocky Mountain lodgepole pine, seed banks, serotiny (canopy seed storage), *Tamiasciurus hudsonicus*

Abstract: There are concerns that large-scale stand mortality due to mountain pine beetle (MPB) could greatly reduce natural regeneration of serotinous Rocky Mountain (RM) lodgepole pine (*Pinus contorta* var. *latifolia*) because the closed cones are held in place without the fire cue for cone opening. We selected 20 stands (five stands each of live [control], 3 years since MPB [3-yr-MPB], 6 years since MPB [6-yr MPB], and 9 years since MPB [9-yr-MPB] mortality) in north central British Columbia, Canada. The goal was to determine partial loss of serotiny due to fall of crown-stored cones via breakage of branches and *in situ* opening of canopy cones throughout the 2008 and 2009 growing seasons. We also quantified seed release by the opening of forest-floor cones, loss of seed from rodent predation, and cone burial. Trees killed by MPB three years earlier dropped; 3.5 times more cones via branch breakage compared to live stands. After six years, MPB-killed stands had released 45% of their canopy seed bank through cone opening, cone fall due to breakage, and squirrel predation. Further losses of canopy seed banks are expected with time since we found 9-yr-MPB stands had 38% more open canopy cones. This was countered by the development of a modest forest floor seed bank (6% of the original canopy seed bank) from burial of cones; this seed bank may be ecologically important if a fire or anthropogenic disturbance exposes these cones. If adequate levels of regeneration are to occur, disturbances to create seedbeds must occur shortly after tree mortality, before the seed banks are lost. Our findings also suggest that the sustained seed rain (over at least nine years) after MPB outbreak may be beneficial for population growth of ground-foraging vertebrates. Our study adds insight to the seed ecology of serotinous pines under a potentially continental-wide insect outbreak, threatening vast forests adapted to regeneration after fire.

Link: http://digitalcommons.usu.edu/barkbeetles/232/

282. Thompson PA. 1976. **Factors involved in the selection of plant resources for conservation as seed in gene banks.** Biological Conservation 10:159-167.

Type: Journal

Geographic Area: Global

Compilers' Keywords: seed bank, seed conservation, plant conservation genetics, cold storage, review

Abstract: The preservation of seed in cold stores provides a convenient and effective method of conserving many species of plants. The ease with which collections of some species may be kept in this way poses the danger that it may be applied uncritically to populations or taxa to which it is less suited. The paper briefly reviews the major factors which contribute to the success of collections for a seed bank and derives criteria from them which may be used as a means of evaluating proposals for seed conservation by this means. The method can also be used to identify possible problems or to estimate relative expenditures of time and other resources which would be involved in making collections or looking after banked seed.

283. Tomback DF, Achuff P, Schoettle AW, Schwandt JW, Mastrogiuseppe RJ. 2011. **The magnificent high-elevation five-needle white pines: ecological roles and future outlook.** In: Keane RE, Tomback DF, Murray MP, Smith CM, editors. The Future of High-Elevation, Five-Needle White Pines in Western North America: Proceedings of the High Five Symposium. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-63. p 2-28.

Type: Government Document

Geographic Area: Western USA

Compilers' Keywords: mountain pine beetle, white pine blister rust, review, threats

Abstract: The High Five symposium is devoted to exchanging information about a small group of pines with little commercial

value but great importance to the ecology of high-mountain ecosystems of the West. These High Five pines include the subalpine and treeline species—whitebark (*Pinus albicaulis*), Rocky Mountain bristlecone (*P. aristata*), Great Basin bristlecone (*P. longaeva*), and foxtail (*P. balfouriana*)—the montane to subalpine pine, southwestern white (*P. strobiformis*), and the lower treeline to upper treeline pine, limber (*P. flexilis*). Here, we discuss the taxonomy, distribution, ecology, and Native American use of these pines, as well as current threats and conservation status. Traditional classification places the bristlecones and foxtail pine together in Subsection Balfourianae, limber and southwestern white pine in Subsection Strobi, and whitebark pine in Subsection Cembrae. Whitebark pine has the largest range and most northerly occurrence. The distribution of limber pine is also large, with a wide elevational range. Southwestern white pine occurs from the southwestern U.S. through northern Mexico; foxtail pine is found in two widely-separated regions in California; and, Rocky Mountain bristlecone pine occurs in northern Arizona and the southern Rocky Mountains. Great Basin bristlecone pine is restricted to the high desert ranges of eastern California, Utah, and Nevada. The High Five pines vary successionally and geographically from minor to major forest and treeline components. As a group, they are also moderately to strongly shade intolerant, and dependent on disturbance, particularly fire, on productive sites for forest renewal. The high elevation pines tolerate cold, arid sites with poor soils. On exposed sites with infrequent disturbance, these trees can live for 1,000 to 4,500 years, depending on the species. Thus, these pines together comprise geographically extensive and ecologically diverse forest habitat types. Whitebark, limber and southwestern white pine produce large, wingless seeds that are eaten by a diversity of wildlife. Clark's nutcrackers (*Nucifraga columbiana*) are important seed dispersers for whitebark and limber pine, for southwestern white pine in its northern range, and to a lesser extent for the bristlecone pines. Furthermore, the High Five pines provide important ecosystem services directly benefiting humans, including the use of the seeds and other parts of pines as food and medicines by Native Americans, the regulation of downstream flow and the prevention of soil erosion by treeline forests, and the aesthetic and spiritual values often associated with high elevation forests. The future survival of the High Five pines is threatened by the exotic blister rust pathogen *Cronartium ribicola*, current mountain pine beetle (*Dendroctonus ponderosae*) outbreaks, successional replacement from fire suppression, and climate change. Whitebark pine has been assigned special status in Washington and British Columbia, and endangered status along with limber pine in Alberta. A petition to list whitebark pine as an endangered or threatened species is currently being evaluated by the U.S. Fish and Wildlife Service. In Canada, whitebark pine has been assessed federally as Endangered and is expected to be legally listed soon under the Species at Risk Act.

Link: http://www.treesearch.fs.fed.us/pubs/38188

284. Vance NC. 2010. Evaluation of native plant seeds and seeding in the East-Side Central Cascades Ponderosa Pine Zone. Portland (OR): USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-823. 85 p.

Type: Government Document

Geographic Area: Pacific Northwest USA

Keywords: postfire rehabilitation, native forb, native grass, *Pinus ponderosa/Purshia tridentate/Festuca idahoensis* plant association, seeds, seedlings east-side central Oregon Cascades

Abstract: In dry, open coniferous forests of the montane West, stand-replacing wildfires and land use activities alter the composition and abundance of native grasses and forbs by degrading the habitat and accelerating the invasion of exotic annuals. On these lands, native forbs and grasses delayed or prevented from recovery by natural processes may require intervention through supplementary seeding. However, effective seeding of native plants requires that their seed traits and the potential outcome of the seeding be better understood. This study evaluated seeds and seedlings of 13 native forbs and 5 grasses common in the dry *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* plant communities east of the Oregon Cascades crest and their potential for establishment in a landscape altered by past grazing and a recent, stand-replacing wildfire. Their potential for germination and establishment was examined in the laboratory and in 20 test plots located within the burned boundary of a 2002 wildfire. Seed collection, handling, testing, and sowing procedures are described. Data on seedling emergence, height, second-year survival and cover are presented in tables and figures. Onsite emergence and early growth data helped to reveal cause of early mortality related to biological and site conditions, including invasive competition, and differences in early growth and site occupancy. The study supports the efficacy of using multiple and functionally diverse species in a seeding program. Additional information on each of the 18 species is included in an appendix.

Link: http://www.treesearch.fs.fed.us/pubs/36921

285. Walters C, Wheeler LM, Grotenhuis JM. 2005. Longevity of seeds stored in a genebank: species characteristics. Seed Science Research 15:1-20.

Type: Journal

Geographic Area: USA, Global

Keywords: storage, viability, longevity, conservation, genebank, Avrami, composition, evolution, genetic diversity, seed

Abstract: Seeds of different species are believed to have characteristic shelf lives, although data confirming this are scarce, and a mechanistic understanding of why this should be remains elusive. We have quantified storage performance of c. 42,000 seed accessions, representing 276 species, within the USDA National Plant Germplasm System (NPGS) collection, as well as a smaller experiment of 207 cultivars from 42 species. Accessions from the NPGS collection were harvested between 1934 and 1975, and had relatively high initial germination percentages that decreased at a variable rate during storage at both 5 and -18 °C. Germination time courses, which represent the average performance of the species, were fitted to Avrami kinetics, to calculate the time at which germination characteristically declined to 50% (P50). These P50 values correlated with other longevity surveys reported in the literature for seeds stored under controlled conditions, but there was no correlation among these studies and seed persistence observed in the classic buried seed experiment by Duvel. Some plant families had characteristically short-lived (e.g., Apiaceae and Brassicaceae) or long-lived (e.g., Malvaceae and Chenopodiaceae) seeds. Also, seeds from species that originated from particular localities had characteristically short (e.g., Europe) or long (e.g., South Asia and Australia) shelf lives. However, there appeared to be no correlation between longevity and dry matter reserves, soluble carbohydrates and parameters relating to soil persistence or resource allocation. Although data from this survey support the hypothesis that some species tend to survive longer than others in a genebank environment, there is little information on the attributes of the seed that affect its storage performance.

Conservation and Restoration

General (215–232)—reviews, surveys, summaries, theory, foundations, paradigms

Research (233–285)—propagation, outplanting, invasion

Strategies (286–326)—frameworks, approach, decision support

Resources (327–338)—native plant materials, guidelines, handbooks

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

286. Aubry CA, Rochefort R. 2007. Whitebark pine in the Pacific Northwest: what's next? In: Goheen EM, Sniezko R, editors. Whitebark Pine: A Pacific Coast Perspective. Portland (OR): USDA Forest Service, Pacific Northwest Region. R6-NR-FHP-2007-01. p 64-70.

Type: Government Document

Geographic Area: Pacific Northwest USA

Compilers' Keywords: conservation, decision framework, forest management, *Pinus albicaulis*, restoration

Abstract: Conservation and restoration of whitebark pine are two important challenges facing us in the immediate future. We will present our approach for a whitebark pine conservation strategy which will focus on Federal lands in Oregon, Washington and California. This management plan will identify the actions needed to reduce the threats to the continued existence of whitebark pine throughout the planning area. Following the completion of the strategy, we will develop a land manager's guide for restoration and managing whitebark pine. This manual will describe site assessments, provide a decision-making guide for setting stand level prioritization, and explain restoration techniques. In our presentation we will review these restoration techniques and discuss the challenges of their application to the highly variable whitebark pine stands in the Pacific Northwest.

Link: http://prdp2fs.ess.usda.gov/Internet/FSE_DOCUMENTS/fsbdev2_026093.pdf

287. Booth DT, Jones TA. 2001. Plants for ecological restoration: a foundation and philosophy for the future. Native Plants Journal 2:12-20.

Type: Journal

Geographic Area: Global

Keywords: gene pool, evolution, reclamation, conservation, restoration gene pool concept

Abstract: Today's conservation concerns range from rare plant preservation to landscapes threatened by alien annuals. Effective action follows effective decision-making based on appropriately framed questions. We present the restoration gene pool (RGP) concept as a framework for choosing plant materials based on the priorities of the species, plant communities, systems, and landscapes threatened. We couch our discussion in an acknowledgment of 65 y of national plant materials progress that has evolved with society's priorities and has maintained a high degree of cooperation among participating entities. The plant materials program and its cooperators have contributed the bulk of the material and technology now used in ecosystem restoration and are foundation for meeting conservation challenges of the future. Using a discussion of the genetics of native plant materials and 2 conservation challenges, we illustrate how the RGP concept can be used to select plant materials based on their ability to meet priority concerns.

Link: http://afrsweb.usda.gov/SP2UserFiles/Place/54281000/pdfs/tj40.pdf

288. Burton CM, Burton PJ, Hebda R, Turner NJ. 2006. **Determining the optimal sowing density for a mixture of native plants used to revegetate degraded ecosystems.** Restoration Ecology 14:379-390.

Type: Journal

Geographic Area: Western Canada

Keywords: cover production, degraded soils, ecological restoration, fertilization, seeding densities, soil rehabilitation

Abstract: No standardized, objective methodology exists for optimizing seeding rates when establishing herbaceous plant cover for pastures, hay fields, ecological restoration, or other revegetation activities. Seeding densities, fertilizer use, season of seeding, and the interaction of these treatments were tested using native plants on degraded sites in northern British Columbia, Canada. A mixture of 20% *Achillea millefolium,* 20% *Carex aenea*, 20% *Elymus glaucus*, 20% *Festuca occidentalis*, 16% *Geum macrophyllum*, and 4% *Lupinus polyphyllus* seed was applied at 0, 375, 750, 1,500, 3,000, and 6,000 pure live seed (PLS) per m^2 in 2.5 x 2.5-m rototilled test plots, established in the fall and spring, with and without fertilizer. There was no significant difference in plant cover of sown species between fall seeding and spring seeding, and few treatment interactions were identified in the first 2 years after sowing. There was no significant difference in cover between seed densities of 3,000 and 6,000 PLS/m^2 in the first year, nor among 1,500, 3,000, and 6,000 PLS/m^2 treatments in the second year. Seed densities as low as 375 PLS/m^2 produced year 2 plant cover equivalent to that observed at 3,000 PLS/m^2 in year 1. Plots sown to seed densities less than or equal to 750 PLS/m^2 generally exhibited an increase (infilling) in plant density from year 1 to year 2, whereas plots sown to seed densities greater than or equal to 1,500 PLS/m^2 generally exhibited a decrease (density-dependent mortality) in plant density. These results imply a most efficient sowing density between 750 and 1,500 PLS/m^2 (corresponding to 190–301 established plants m^{-2} after two growing seasons). It is suggested that net changes in plant populations observed over a range of sowing densities are a robust and objective means of determining optimal sowing densities for the establishment of herbaceous perennials.

Link: http://www.researchgate.net/publication/229671456_Determining_the_Optimal_Sowing_Density_for_a_Mixture_of_Native_Plants_Used_to_Revegetate_Degraded_Ecosystems/file/32bfe5140b3b283e0d.pdf

289. Davies KW, Boyd CS, Beck JL, Bates JD, Svegcar TJ, Gregg MA. 2011. **Saving the sagebrush sea: an ecosystem conservation plan for big sagebrush plant communities.** Biological Conservation 144:2573-2584.

Type: Journal

Geographic Area: Western USA

Keywords: annual grasses, conservation easements, development, ecosystem management, mitigation, restoration, woodland encroachment

Abstract: Vegetation change and anthropogenic development are altering ecosystems and decreasing biodiversity. Successful management of ecosystems threatened by multiple stressors requires development of ecosystem conservation plans rather than single species plans. We selected the big sagebrush (*Artemisia tridentata* Nutt.) ecosystem to demonstrate this approach. The area occupied by the sagebrush ecosystem is declining and becoming increasingly fragmented at an alarming rate because of conifer encroachment, exotic annual grass invasion, and anthropogenic development. This is causing rangewide declines and localized extirpations of sagebrush associated fauna and flora. To develop an ecosystem conservation plan, a synthesis of existing knowledge is needed to prioritize and direct management and research. Based on the synthesis, we concluded that efforts to restore higher elevation conifer-encroached, sagebrush communities were frequently successful, while restoration of exotic annual grass-invaded, lower elevation, sagebrush communities often failed. Overcoming exotic annual grass invasion is challenging and needs additional research to improve the probability of restoration and identify areas where success would be more probable. Management of fire regimes will be paramount to conserving sagebrush communities, as infrequent fires facilitate conifer encroachment and too frequent fires promote exotic annual grasses. Anthropogenic development needs to be mitigated and reduced to protect sagebrush communities and this probably includes more conservation easements and other incentives to landowners to not develop their properties. Threats to the sustainability of sagebrush ecosystem are daunting, but a coordinated ecosystem conservation plan that focuses on applying successful practices and research to overcome limitations to conservation is most likely to yield success.

Link: http://oregonstate.edu/dept/eoarc/sites/default/files/publication/702.pdf

290. Engelmann F. 2012. **Germplasm collection, storage, and conservation.** Chapter 17. In: Altman A, Michael-Hasegawa P, editors. Plant Biotechnology and Agriculture: Prospects for the 21st century. London, United Kingdom: Academic Press. p 255-267.

Type: Book Section

Geographic Area: Global

Compilers' Keywords: biodiversity, *ex situ*, *in situ*, *in vitro,* cryopreservation, orthodox seeds, recalcitrant seeds, seed banking, climate change, genetic loss, gene conservation

Introduction: Two basic conservation strategies, *in situ* and *ex situ*, each composed of various techniques, are employed for conservation of plant biodiversity. Until recently, most conservation efforts, apart from work on forest genetic resources, have concentrated on *ex situ* conservation, particularly seed genebanks. In the 1950s and 1960s, major advances in plant breeding brought about the Green Revolution, which resulted in the wide-scale adoption of high-yielding varieties and genetically uniform cultivars of staple crops, particularly wheat and rice. Consequently, global concern about the loss of genetic diversity in these crops increased, as farmers abandoned their locally adapted landraces and traditional varieties and replaced them with improved, yet genetically uniform, modern ones. In response to this concern, research groups started to assemble germplasm collections of the major crop species within their respective mandates. It is in this context that the IBPBR (Biodiversity International) was established in 1974 to coordinate the global effort to systematically collect and conserve the world's threatened plant genetic diversity.

291. Falk DA, Knapp EE, Guerrant EO Jr. 2001. An introduction to restoration genetics. Tucson (AZ): Society for Ecological Restoration. 33 p.

Type: Report

Geographic Area: Global

Compilers' Keywords: climate change, diversity, review, guide, ecological restoration, policy, adaptation, uncertainty

Introduction: All living organisms carry a genetic blueprint. This is so regardless of whether they are plants, animals, or fungi, whether they are short- or long-lived, and whether they reproduce sexually or clonally. Therefore, to the extent that restoration deals with living organisms, genetics are part of the picture. Although the basic principles underlying restoration genetics may be familiar, to date surprisingly little attention has been devoted to genetic considerations in restoration practice. The purpose of this Restoration Science and Policy Paper is to outline some considerations that restoration designers and managers should be aware of, and to identify more detailed resources that may be useful in practice.

Link: http://www.ser.org/docs/default-document-library/ser_restoration_genetics.pdf

292. Falk DA, Palmer MA, Zedler JB. 2006. Foundations of restoration ecology. Washington (DC): Island Press. 379 p.

Type: Book

Geographic Area: Global

Compilers' Keywords: ecological function, approaches, climate change, paleoecology, framework

Introduction: This book is meant to provide a scientific framework for restoration ecology that can be used to inform ecological restoration as well as stimulate advances in our understanding of nature. As you read, bear in mind that the implementation of ecological restoration is not only escalating at an astounding rate, but also that it remains the most ecologically viable and aesthetically appealing remedy for mending Earth's ever increasing number and scale of degraded ecosystems.

Link: http://xa.yimg.com/kq/groups/22969879/472658511/name/Foundations+of+Restoration+Ecology.pdf#page=328

293. Ford-Lloyd BV, Jackson MT. 1991. Biotechnology and methods of conservation of plant genetic resources. Journal of Biotechnology 17:247-256.

Type: Journal

Geographic Area: Global

Keywords: genetic diversity, germplasm, conservation, genebank, cryopreservation

Introduction: The loss of biological diversity is of major environmental concern at the present time. Whether this relates to the destruction of the tropical rain forests, for instance, or the threat which faces natural ecosystems as climates change due to global warming, it is important that in order to survive and continue to evolve, plant and animal species must contain an ample reservoir of genetic diversity. One aspect of this process is the continuing loss of genetic diversity in the crops upon which world agriculture is based. Scientists throughout the world are rightly engaged in developing better and higher yielding cultivars of crop plants to be used on increasingly larger scales. But this involves the replacement of the generally variable, lower yielding, locally adapted strains grown in traditional farming systems, by the products of modern agriculture. Nowadays every major crop has a relatively narrow genetic base, and so under such situations, diversity in farming systems is replaced by genetic uniformity. However, in order to be able to respond to the various stresses that threaten modern agriculture, plant breeders are dependent upon the availability of a pool of diverse genetic material. The significance of genetic uniformity can be highlighted by several crop examples, one of historical importance and two others of more recent times. The history of the potato in Europe illustrates the necessity for utilizing genetic resources to broaden the genetic base of crop plants. The narrow genetic base of the potato crop was recognised during the last century following the devastating epidemics of late blight disease, caused by *Phytophthora infestans*, in the 1840s in Ireland. Massive destruction of the corn crop came about in the United States in 1970 with the southern corn leaf blight epidemic (caused by the fungus *Helmmthosportum maydls*). Modern plant breeding had led to the use of a cytoplasmic gene which conferred susceptibility to a particular race of this fungal pathogen. A more recent, but less publicised case of genetic vulnerability was caused not by plant disease, but by cold weather. By 1972 in the Soviet Union the wheat variety 'Bezostaja' was grown on almost 15 million hectares. It had been moved beyond its original area of cultivation into the Ukraine during a period of relatively mild winters. Then in 1972 a very severe winter occurred, causing losses of millions of tons of winter wheat (Fischbeck, 1981). In relation to this example, we can ask whether global warming will lead to similar crop losses in the future (Jackson and Ford-Lloyd, 1990). Plant genetic resources (germplasm) is a term used to describe the total genetic diversity of cultivated species and their wild relatives, much of which may be of value to breeders. Although commercial and obsolete varieties, breeders' lines and induced or natural mutations may be included under this term, it is much more usual to describe plant genetic resources as landraces or primitive forms, weed races which are closely related to the cultivated species, and related wild species. Landraces are populations of crops, often collected from remote areas, where the new, highly bred cultivars have not been introduced. They are highly diverse genetically, and have often been grown as mixtures of species, as well as diverse populations of one species. Such materials are closely allied genetically to modern varieties and are extremely important genetic resources, and as such have received top priority for conservation.

294. Graudal L, Aravanopoulos F, Bennadji Z, Changtragoon S, Fady B, Kjær ED, Loo J, Ramamonjisoa L, Vendramin GG. 2014. Global to local genetic diversity indicators of evolutionary potential in tree species within and outside forests. Forest Ecology and Management 333:35-51.

Type: Journal

Geographic Area: Global

Keywords: types of indicators, genetic and demographic verifiers, the genecological approach, diversity-productivity-knowledge management

Abstract: There is a general trend of biodiversity loss at global, regional, national and local levels. To monitor this trend, international policy processes have created a wealth of indicators over the last two decades. However, genetic diversity indicators are regrettably absent from comprehensive bio-monitoring schemes. Here, we provide a review and an assessment of the different attempts made to provide such indicators for tree genetic diversity from the global level down to the level of the management unit. So far, no generally accepted indicators have been provided as international standards, nor tested for their possible use in practice. We suggest that indicators for monitoring genetic diversity and dynamics should be based on ecological and demographic surrogates of adaptive diversity as well as genetic markers capable of identifying genetic erosion and gene flow. A comparison of past and present genecological distributions (patterns of genetic variation of key adaptive traits in the ecological space) of selected species is a realistic way of assessing the trend of intra-specific variation, and thus provides a state indicator of tree genetic diversity also able to reflect possible pressures threatening genetic diversity. Revealing benefits of genetic diversity related to ecosystem services is complex, but current trends in plantation performance offer the possibility of an indicator of benefit. Response indicators are generally much easier to define, because recognition and even quantification of, e.g., research, education, breeding, conservation, and regulation actions and programs are relatively straightforward. Only state indicators can reveal genetic patterns and processes, which are fundamental for maintaining genetic diversity. Indirect indicators of pressure, benefit, or response should therefore not be used independently of state indicators. A coherent set of indicators covering diversity–productivity–knowledge–management based on the genecological approach is proposed for application on appropriate groups of tree species in the wild and in cultivation worldwide. These indicators realistically reflect the state, trends and potentials of the world's tree genetic resources to support sustainable growth. The state of the genetic diversity will be based on trends in species population distribution and diversity patterns for selected species. The productivity of the genetic resource of trees in current use will reflect the possible potential of mobilizing the resource further. Trends in knowledge will underpin the potential capacity for development of the resource and current management of the genetic resource itself will reveal how well we are actually doing and where improvements are required.

Link: http://www.sciencedirect.com/science/article/pii/S0378112714002825

295. Hargrove WM, Hoffman FM. 2005. Potential of multivariate quantitative methods for delineation and visualization of ecoregions. Environmental Management 34:S39-S60.

Type: Journal

Geographic Area: USA

Compilers' Keywords: clustering, climate change, ecotone, environmental envelope, niche, preserve design, time series

Abstract: Multivariate clustering based on fine spatial resolution maps of elevation, temperature, precipitation, soil characteristics, and solar inputs has been used at several specified levels of division to produce a spectrum of quantitative ecoregion maps for the conterminous United States. The coarse ecoregion divisions accurately capture intuitively-understood regional environmental differences, whereas the finer divisions highlight local condition gradients, ecotones, and clines. Such statistically generated ecoregions can be produced based on user-selected continuous variables, allowing customized regions to be delineated for any specific problem. By creating

an objective ecoregion classification, the ecoregion concept is removed from the limitations of human subjectivity, making possible a new array of ecologically useful derivative products. A red–green–blue visualization based on principal components analysis of ecoregion centroids indicates with color the relative combination of environmental conditions found within each ecoregion. Multiple geographic areas can be classified into a single common set of quantitative ecoregions to provide a basis for comparison, or maps of a single area through time can be classified to portray climatic or environmental changes geographically in terms of current conditions. Quantified representativeness can characterize borders between ecoregions as gradual, sharp, or of changing character along their length. Similarity of any ecoregion to all other ecoregions can be quantified and displayed as a "representativeness" map. The representativeness of an existing spatial array of sample locations or study sites can be mapped relative to a set of quantitative ecoregions, suggesting locations for additional samples or sites. In addition, the shape of Hutchinsonian niches in environment space can be defined if a multivariate range map of species occurrence is available.

Link: http://www.researchgate.net/publication/7856972_Potential_of_multivariate_quantitative_methods_for_delineation_and_visualization_of_ecoregions/file/d912f508063c35b761.pdf

296. Havens K, Vitt P, Maunder M, Guerrant EO Jr, Dixon KW. 2006. ***Ex situ* plant conservation and beyond.** BioScience 56:525-531.

Type: Journal

Geographic Area: USA

Keywords: botanic garden, performance indicators, conservation strategies

Abstract: In recent years, the mission of many botanic gardens and arboreta has expanded from a traditional focus on developing a horticultural collection to one that includes taking a proactive role in plant conservation. To use their limited resources more effectively, many gardens are seeking ways to quantify their contributions to conservation efforts, both as a self-assessment tool to improve their effectiveness and as a way to give an explicit accounting of activities to donors and funding agencies. We suggest many ways gardens can measure the success of their conservation programs, and present results from a survey conducted to assess current conservation activities at botanic gardens.

Link: http://www.researchgate.net/publication/232691529_Ex_Situ_Plant_Conservation_and_Beyond/file/5046351a4cde1f01e9.pdf

297. Jones TA. 2003. The restoration gene pool concept: beyond the native versus non-native debate. Restoration Ecology 11:281-290.

Type: Journal

Geographic Area: Global

Keywords: genetic adaptation, genetic identity, metapopulation, multiple-origin polycross

Abstract: Restoration practitioners have long been faced with a dichotomous choice of native versus introduced plant material confounded by a general lack of consensus concerning what constitutes being native. The "restoration gene pool" concept assigns plant materials to one of four restoration gene pools (primary to quaternary) in order of declining genetic correspondence to the target population. Adaptation is decoupled from genetic identity because they often do not correspond, particularly if ecosystem function of the disturbed site has been altered. Because use of plant material with highest genetic identity, that is, the primary restoration gene pool, may not be ultimately successful, material of higher order pools may be substituted. This decision can be made individually for each plant species in the restored plant community in the scientific context that ecosystem management demands. The restoration gene pool concept provides a place for cultivars of native species and noninvasive introduced plant material when use of native-site material is not feasible. The use of metapopulation polycrosses or composites and multiple-origin polycrosses or composites is encouraged as appropriate. The restoration gene pool concept can be implemented as a hierarchical decision-support tool within the larger context of planning seedings.

Link: http://www.fs.fed.us/rm/boise/research/shrub/Links/2003papers/jones2003.pdf

298. Jones TA, Johnson DA. 1998. Integrating genetic concepts into planning rangeland seedings. Journal of Range Management 51:594-606.

Type: Journal

Geographic Area: USA

Keywords: genetic integrity, genetic pollution, introgression, natural selection, plant materials, polyploidy, rangeland weeds, succession

Abstract: Choice of plant materials is a fundamental component of any rangeland rehabilitation, reclamation, or restoration project. We describe here an integrated approach for such decision-making. This approach considers site potential, desired landscape, seeding objectives, conflicting land use philosophies, appropriate plant materials, weed invasion, community seral status, and economic limitations. Technical limitations are considered in generating a plan that has the greatest potential for success. Determining whether native-site plant material is best depends on objectives, heterogeneity of the site's environment, uniqueness of the site, plant population size, and biotic or abiotic site disturbance. Fixation of alien genes into a population is referred to both as introgression, which may ensure maintenance of genetic variation critical for adaptation

to a changing environment, and as genetic pollution, with the potential for swamping native cross-pollinating annual or short-lived perennial gene pools. Precautionary procedures during seed increase minimize genetic shift, which may be reversible, but genetic drift could result in permanent loss of desirable genes. A variety of germplasm classes, ranging from site-specific to widely adapted and varying in degrees of heterozygosity and heterogeneity should be considered. Material originating from multiple sites may increase the opportunity for natural selection. An understanding of the magnitude and nature of a species' genetic variation, its relationship to ecological adaptation, and its interaction with other ecosystem components contribute to informed decision-making. Though often unavailable, experience is the best guide for predicting performance of materials on non-native sites.

Link: http://afrsweb.usda.gov/SP2UserFiles/Place/54281000/pdfs/tj33.pdf

299. Jones TA, Monaco TA. 2007. **A restoration practitioner's guide to the restoration gene pool concept.** Ecological Restoration 25:12-19.

Type: Journal

Geographic Area: USA

Keywords: plant materials, genetic identity, metapopulation, ecoregion, restoration gene pool concept, ecological restoration

Abstract: Choosing plant materials for each desired species is often one of the most difficult steps in developing a restoration plan. The Restoration Gene Pool concept was developed to clarify the options available to the ecological restoration practitioner in terms of plant materials. We present a decision-making flowchart incorporating the issues delineated in the Restoration Gene Pool concept. We intend to provide practitioners with a framework to make objective and defensible plant materials choices in keeping with the objectives and philosophy of the restoration project. The flowchart consists of a series of boxes with single or multiple statements to be judged as true or false. The statements deal with issues such as genetic identity, plant metapopulation, functional guild, ecoregion, invasive weed presence, site soil and climate, endangered species presence, commercial seed availability, seed contracting potential, and availability of material bred for improved stress tolerance. Implementing the flowchart is a straightforward way to apply the Restoration Gene Pool concept to a particular project, but we encourage each practitioner to personalize the flowchart to make it as practical as possible for the situations that she or he most often encounters.

Link: http://www.fs.fed.us/rm/pubs_other/rmrs_2007_jones_t001.pdf

300. Keane RE, Schoettle AW. 2011. **Strategies, tools, and challenges for sustaining and restoring high elevation five-needle white pine forests in western North America.** In: Keane RE, Tomback DF, Murray MP, Smith CM, editors. High Five Symposium. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-63. p 276-294.

Type: Government Document

Geographic Area: Western North America

Compilers' Keywords: conference paper, white pine forests, mountain pine beetle, *Dendroctonus* spp., conservation, keystone species, restoration, strategies

Abstract: Many ecologically important, five-needle white pine forests that historically dominated the high elevation landscapes of western North America are now being heavily impacted by mountain pine beetle (*Dendroctonus* spp.) outbreaks, the exotic disease white pine blister rust (WPBR), and altered high elevation fire regimes. Management intervention using specially designed strategic treatments will be needed to conserve these keystone species. The goal of this intervention is to promote self-sustaining five-needle white pine ecosystems that have both resilience to disturbances and genetic resistance to white pine blister rust. Many tools and methods are available for land managers. In this paper we outline important steps for implementation of restoration treatments in declining high elevation white pine stands and discuss a number of proactive treatments in threatened ecosystems to mitigate adverse impacts of rust, beetles, and lack of fire. These steps for restoration include (1) create a strategy for restoration across multiple scales, (2) develop materials and techniques for conducting restoration treatments, such as seed collections and rust resistance assessments of the genetic material, (3) prioritize stands or landscapes by integrating the strategy with other management issues, administrative barriers, climate change mitigation, and other local concerns, (4) implement silvicultural cuttings and prescribed fire according to landscape and stand level strategies, (5) conduct activities and assessments to enhance and ensure restoration treatments are effective including planting rust-resistant pine seedlings and protecting valuable seed-sources, and finally (6) monitor treated landscape and stands for effects and adjust and modify future treatment designs accordingly. Examples from whitebark pine ecosystems in the northern Rocky Mountains will be presented to demonstrate this process. For those high elevation white pine ecosystems that are threatened by white pine blister rust or mountain pine beetle, there are actions that can be taken proactively to gain necessary information to evaluate risk and prepared landscapes for invasion to mitigate future impacts. The proactive strategy includes: (1) educate and engage the public and managers to shift from crisis management to management for resiliency, (2) conserve genetic diversity from native populations before they are impacted by WPBR or other stresses, (3) conduct research on patterns, processes and responses of native ecosystems to provide process level understanding of ecosystem behavior and (4) develop and conduct appropriate management activities to increase the resiliency of high elevation five-needle pine ecosystems to prepare them for change. Whether it is restoring impacted landscapes or interventions to mitigate the development of impacts on threatened landscapes, there are two important factors that will govern the success of these species even with comprehensive and effective rangewide strategies: (1) the magnitude of resources available over time to conduct restoration efforts, and (2) the commitment of natural resource agencies to conduct restoration activities over the long term, most likely for many decades to centuries.

Link: http://www.treesearch.fs.fed.us/pubs/38240

301. MacKinnon A, Meidinger DV, Klinka K. 1992. **Use of the biogeoclimatic ecosystem classification in British Columbia.** The Forestry Chronicle 68:100-120.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: silviculture, land management, land classification

Abstract: Biogeoclimatic ecosystem classification (BEC) is a hierarchical system that organizes ecosystems at three levels of integration - local, regional, and chronological. The system is used by silviculturists and range, recreation and wildlife managers in British Columbia. Based on the study of both vegetation and sites, the system reveals ecological potentialities and limitations of particular sites, and combined with the accumulation and widespread dissemination of ecological knowledge provides an ideal framework for integrated resource management. The ways in which the BEC system is adapted for, and used by, resource managers are described and demonstrated. Ongoing activities, including classification of seral ecosystems, quantification of soil moisture and nutrient regimes, identification of relationships between forest productivity and site quality, and provincial correlation of the six regional classifications, are outlined.

302. Mahalovich MF. 1995. **The role of genetics in improving forest health.** In: Eskew LG, editors. 1995 National Silviculture Workshop: Forest Health through Silviculture. Fort Collins (CO): USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-GTR-267. p 200-207.

Type: Government Document

Geographic Area: Northwestern USA

Compilers' Keywords: forest management, seed transfer, guidelines

Abstract: An often ignored tool to improve forest health is the application of genetics. Tree improvement programs in the Inland West utilize genetic principles to develop-seed transfer guidelines to avoid the problems associated with off-site plantings and to improve characteristics in conifers related to forest health. PC-based expert systems have been developed to aid in seed transfer in ponderosa pine and Douglas-fir. Genetic gains in adaptation, and insect and disease resistance, continue to be made in western white pine, western larch, ponderosa pine, Douglas-fir, and lodgepole pine. While progress has been made in the white pine blister rust program, restoring western white pine to Inland Northwest forests requires a continued commitment to selective breeding. Other insect and disease problems should also receive strong consideration in selective breeding programs, to prevent erosion of existing genetic resistance, and when warranted, to sustain and enhance this resistance.

Link: http://www.treesearch.fs.fed.us/pubs/23502

303. McArthur ED, Young SA. 1999. **Development of native seed supplies to support restoration of piñon-juniper sites.** In: Monsen SB, Stevens R, editors. Ecology and Management of Piñon-Juniper Communities within the Interior West. Ogden (UT): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-9. p 327-330.

Type: Government Document

Geographic Area: Western USA

Compilers' Keywords: woodlands, piñon-juniper, land management, survey, native plant materials

Abstract: Use of native plants for restoration and rehabilitation of disturbed or manipulated piñon-juniper communities is increasing in response to desires of land managers and society in general. Seeds of native plants are becoming more available, but estimates and surveys show there is still more demand than available supply. Field grown seeds and warehousing do anticipate demand but are only partial solutions to the native plant seed shortage. Exotic, developed plant materials, especially Triticeae grasses and legumes, remain important resources for rehabilitation plantings. Private industry seed collectors, growers, and developers will be responsive to plant materials needs of land managers. Seed genetic identity and quality can be better assured through the seed certification process whether the seed is wildland collected or field grown.

Link: http://www.fs.fed.us/rm/pubs/rmrs_p009/rmrs_p009_327_330.pdf

304. McMahon G, Gregonis SM, Waltman SW, Omernik JM, Thorson TD, Freeouf JA, Rorick AH, Keys JE. 2001. **Developing a spatial framework of common ecological regions for the conterminous US.** Environmental Management 28:293-316.

Type: Journal

Geographic Area: USA

Keywords: ecological region, spatial framework, ecologically oriented management, land resources, ecosystem management

Abstract: In 1996, nine federal agencies with mandates to inventory and manage the nation's land, water, and biological resources signed a memorandum of understanding entitled

"Developing a Spatial Framework of Ecological Units of the United States." This spatial framework is the basis for interagency coordination and collaboration in the development of ecosystem management strategies. One of the objectives in this memorandum is the development of a map of common ecological regions for the conterminous United States. The regions defined in the spatial framework will be areas within which biotic, abiotic, terrestrial, and aquatic capacities and potentials are similar. The agencies agreed to begin by exploring areas of agreement and disagreement in three federal natural-resource spatial frameworks—Major Land Resource Areas of the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service, National Hierarchy of Ecological Units of the USDA Forest Service, and Level III Ecoregions of the U.S. Environmental Protection Agency. The explicit intention is that the framework will foster an ecological understanding of the landscape, rather than an understanding based on a single resource, single discipline, or single agency perspective. This paper describes the origin, capabilities, and limitations of three major federal agency frameworks and suggests why a common ecological framework is desirable. The scientific and programmatic benefits of common ecological regions are described, and a proposed process for development of the common framework is presented.

305. Meyer SE. 1999. Genecological considerations in grassland restoration using wild-collected seed sources. In: Buchanan-Smith JG, Bailey LD, McCaughey P, editors. Proceedings of the 18th International Grassland Congress. Calgary, Alberta: Association Management Center. p 299-304.

Type: Conference Paper

Geographic Area: Western USA

Keywords: disturbed land reclamation, ecological restoration, genetic variation, propagation, seed transfer guidelines

Abstract: Choice of species and seed sources to use in the revegetation of drastically disturbed lands depends on intended post-reclamation land use. When the intent is to return the land to predisturbance native plant cover and composition, the process can be termed ecological restoration. Seed sources for species used in restoration are usually wildland populations. Genecology deals with the ecological or adaptive significance of genetic variation within and among populations of plants. In contrast with plant breeding or biotechnological approaches, in restoration this knowledge is used to safeguard the genetic composition of source populations, restored populations, and populations adjacent to restored areas. Particular attention is paid to adequate sampling of source populations and to the maintenance of within-population genetic diversity through seed increase or nursery propagation phases. The goal is to initiate processes that will lead to the reestablishment of native ecosystems with diversity, resilience, and capacity for continued evolution, nor to try to create static, idealized predisturbance vegetation.

Link: http://www.internationalgrasslands.org/files/igc/publications/1997/iii-299.pdf

306. Millar CI. 2014. Historic variability: informing restoration strategies, not prescribing targets. Journal of Sustainable Forestry 33:S28-S42.

Type: Journal

Geographic Area: North America

Keywords: climate change, ecological restoration, ecosystem management, forest management, historical ecology, historic range of variability

Abstract: The concept of historic range of variability (HRV) is briefly evaluated within the context of its application in ecosystem management over the past two decades. Despite caveats to the contrary, an implicit assumption continues to emerge of climatic stationarity, and, by corollary, that pre-settlement centuries provide an appropriate reference period. This is examined from the perspective of historic climate change and ecosystem response. As a means of developing reference prescriptions and management targets, HRV is generally inappropriate, although if historic periods are used for reconstruction that have coarse resemblance to present or projected future climates, such as the Medieval Climate Anomaly or middle Holocene rather than the pre-settlement centuries, these might be defensible. In cases of reclamation of severely degraded ecosystems, HRV prescriptions developed from analogous climate periods could provide coarse guides. In most situations, however, historic reconstructions are best used to improve understanding of ecological response to a wide range of forcing factors, and thereby to inform (rather than prescribe) management strategies. Such historically informed approaches are likely more effective than an HRV approach under future changing climate regimes for managing and restoring ecosystem function and for assisting transitions to new ecosystem states.

Link: http://www.treesearch.fs.fed.us/pubs/47361

307. Neale DB, Kremer A. 2011. Forest tree genomics: growing resources and applications. Nature 12:111-122.

Type: Journal

Geographic Area: Global

Compilers' Keywords: genomics, climate change

Abstract: Over the past two decades, research in forest tree genomics has lagged behind that of model and agricultural systems. However, genomic research in forest trees is poised to enter into an important and productive phase owing to the advent of next-generation sequencing technologies, the enormous genetic diversity in forest trees and the need to mitigate the effects of climate change. Research on long-lived woody perennials is extending our molecular knowledge of complex life histories and adaptations to the environment—enriching a field that has traditionally drawn biological inference from a few short-lived herbaceous species.

Link: http://www.ncbi.nlm.nih.gov/pubmed/21245829

308. Nuismer SL, Gandon S. 2008. Moving beyond common-garden and transplant designs: insight into the causes of local adaptation in species interactions. The American Naturalist 171:658-668.

Type: Journal

Geographic Area: Global

Keywords: coevolution, gene flow, geographic mosaic, host-parasite, Red Queen

Abstract: Theoretical and empirical studies of local adaptation in species interactions have increased greatly over the past decade, yielding new insights into the conditions that favor local adaptation or maladaptation. Generalizing the results of these studies is difficult, however, because of the different experimental designs that have been used to infer local adaptation. Particularly challenging is comparing results across empirical studies conducted in a common laboratory or garden environment with results of those conducted using transplants in natural environments. Here we develop simple and easily interpretable mathematical expressions for the quantities measured by these two different types of studies. Our results reveal that common-garden designs measure only a single component of local adaptation-the spatial covariance between the genotype frequencies of the interacting species-and thus provide only a partial description of local adaptation. In contrast, reciprocal-transplant designs incorporate additional terms that measure the contribution of spatial variability in the ecological environment. Consequently, the two types of studies should yield identical results only when local adaptation is caused by spatial variability in the genotype frequencies of the interacting species alone. In order to unify these disparate approaches, we develop a new methodology that can be used to estimate the individual components of local adaptation. When implemented in an appropriate experimental system, this partitioning allows the examination of fundamental questions such as the relative proportion of local adaptation attributable to interactions between species or to the abiotic environment.

Link: http://www.ncbi.nlm.nih.gov/pubmed/18419564

309. Opdam P, Steingröver E, van Rooij S. 2006. Ecological networks: a spatial concept for multi-actor planning of sustainable landscapes. Landscape and Urban Planning 75:322-332.

Type: Journal

Geographic Area: Global

Keywords: ecological networks, landscape planning, stakeholder decision-making, biodiversity, sustainable development

Abstract: In this paper, we propose the ecological network concept as a suitable basis for inserting biodiversity conservation into sustainable landscape development. For landscapes to be ecologically sustainable, the landscape structure should support those ecological processes required for the landscape to deliver biodiversity services for present and future generations. We first show that in multifunctional, human dominated landscapes, biodiversity conservation needs a coherent large-scale spatial structure of ecosystems. Theory and empirical knowledge of ecological networks provides a framework for the design of such structures. Secondly, ecological networks can bridge the paradox between reserve conservation (fixing nature in space and time) and development, which implies change. This is because ecological networks can change structure without losing their conservation potential. Thirdly, ecological networks facilitate stakeholder decision-making on feasible biodiversity goals. They help to focus on an effective spatial scale. We conclude that extending the ecological network concept with multifunctional indicators is a promising step towards sustainable landscape development and stakeholder decision-making.

310. Perry N. 2010. The ecological importance of species and the Noah's Ark problem. Ecological Economics 69:478-485.

Type: Journal

Geographic Area: Global

Keywords: ecological importance, ecosystem process, functional diversity, biodiversity, endangered species conservation

Abstract: Using the Noah's Ark problem—the problem of efficiently allocating limited funds to conserve biodiversity - the standard economic approach to endangered species conservation constructs a human-centered biodiversity by favoring species directly valuable to humans. I analyze this approach and draw on the functional ecology literature to offer an alternative emphasizing the role species play in their ecosystems. The aim is to create a working ecosystem on the Ark rather than a collection of charismatic and distinct species. To do so, I construct a new measure of a species' ecological importance and an ecological objective appropriate for cost-effective resource allocation. The ecological approach fundamentally changes the notion of species-value from a direct value based on a species' appearance or taxonomic difference to an indirect value based on a species' ecological role in its ecosystem. In the process, 'populations' of species become the fundamental unit of biodiversity rather than 'species,' and biotic processes also possess value. When compared to the economic approach, the ecological approach prioritizes different species for the Ark and achieves superior economic outcomes in all but the mythical Noah's Ark scenario where interactions are non-existent. The analysis challenges the approach of U.S. endangered species legislation and I call for a reformulation based on endangered ecological interactions.

311. Pojar J, Klinka K, Meidinger DV. 1987. Biogeoclimatic ecosystem classification in British Columbia. Forest Ecology and Management 22:119-154.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: land classification, land management, forest management

Abstract: Biogeoclimatic ecosystem classification is a system of ecological classification widely used in British Columbia. The system has been expanded by the B.C. Forest Service from the pioneering work of V.J. Krajina and his students. The recognized units result from a synthesis of vegetation, climate, and soil data. The approach to classification is hierarchical with three interrelated levels of integration. The multiple-category, local and regional levels involve vegetation and site; a chronological level deals with vegetation dynamics. Taxa of any level and category can be integrated according to their interpretive value for management. Vegetation units are defined and arranged into a floristic hierarchy based on the plant association, using traditional Braun-Blanquet methods modified to suit regional conditions. Where possible, zonal (climatic climax) plant associations are identified, thus defining biogeoclimatic subzones, which are divided into variants and aggregated into zones, regions, and formations. Plant associations are transformed into site associations environmentally characterized classes of ecosystems with similar biotic potential. Site associations are then subdivided into series and types, using biogeoclimatic and edaphic characteristics as differentiae. Examples of classification at local and regional levels are provided, as are examples of management applications. Biogeoclimatic ecosystem classification is a unique approach that draws on several of the European (including Russian) and North American schools of vegetation and land classification, and has similarities with the Cajander forest type, Barnes land type, Daubenmire habitat type, and Hills site type approaches. The classification provides a powerful integrative and predictive tool, with proven practical value for forest managers.

312. Renn SC, Siemens DH. 2010. Ecological genomics—changing perspectives on Darwin's basic concerns. Molecular Ecology 19:3025-3030.

Type: Journal

Geographic Area: Global

Keywords: adaptation, gene duplication, gene expression, gene phylogeny, genetic variation, genomics, speciation

Abstract: Ecological Genomics is an interdisciplinary field that seeks to understand the genetic and physiological basis of species interactions for evolutionary inferences. At the 7th annual Ecological Genomics Symposium, November 13–15, 2009, members of the Ecological Genomics program at Kansas State University invited 13 speakers and 56 poster presentations.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20618901

313. Richardson BA, Ekramoddoulah AKM, Liu JJ, Kim M-S, Klopfenstein NB. 2010. Current and future molecular approaches to investigate the white pine blister rust pathosystem. Forest Pathology 40:314-331.

Type: Journal

Geographic Area: Western USA

Compilers' Keywords: *Pinus,* genetic variation

Abstract: Molecular genetics is proving to be especially useful for addressing a wide variety of research and management questions on the white pine blister rust pathosystem. White pine blister rust, caused by *Cronartium ribicola*, is an ideal model for studying biogeography, genetics, and evolution because: (1) it involves an introduced pathogen; (2) it includes multiple primary and alternate hosts occurring in large, relatively undisturbed ecosystems; (3) some hosts exhibit endemic resistance; and (4) the disease interaction is long enduring. Molecular techniques are used to investigate population genetics, phylogenetics, hybrids, and proteomics in white pine (*Pinus*, subgenus *Strobus*) and blister rust (*Cronartium*) and the genetics of resistance and virulence in the blister rust pathosystem. These techniques include genetic markers, mapping, microarrays, sequencing, association genetics, genomics, and genecology. Molecular genetics contributes to gene conservation, breeding for resistance, and ecosystem management.

Link: http://www.treesearch.fs.fed.us/pubs/36219

314. Riggs LA. 1990. Conserving genetic resources onsite in forest ecosystems. Forest Ecology and Management 35:45-68.

Type: Journal

Geographic Area: California, USA

Compilers' Keywords: *in situ*, forest management, decision framework, genetic diversity, Douglas-fir, *Pseudotsuga menziesii*, ecosystem services, genetic conservation

Abstract: Genetic diversity and its structure (its organization in space and time) are the critical raw materials from which many other aspects of diversity are derived. These genetic resources represent information about unique and successful relationships among genes and between gene complexes and environments. Only a fraction of this information has been mined through research. The balance, and the genetic materials themselves, are most effectively conserved for future use by on-site (*in-situ*) preservation, management, or restoration of populations, communities and entire landscapes. While we have far to go on the road to understanding biodiversity, research progressing in an array of disciplines offers ample justification to maintain evolved patterns and processes that underlie biodiversity, mediate the efficiency of ecosystem 'services', and influence the availability of genetic raw material

for bioresource development, restoration, and use. As biotechnologies advance, we will appreciate more fully the true costs of constructing genetic moieties into fully functional organisms, and maintaining populations of these under controlled conditions or combining them in self-perpetuating systems. Intact populations and ecosystems will be ever more valuable sources of the genetic resources and contextual information required for this enterprise. Three elements are required to realize the values of biodiversity: genetic materials; environments; and information about the functional relationships of the first two. Effective conservation involves uniting these elements. Thorough review of historical, scientific, socioeconomic, and practical information about particular elements of biodiversity is necessary to assess the constraints on and opportunities for conservation activities. The California Gene Resources Program activities from 1980 to 1983 are examples of this kind of undertaking. Computerized information systems can assist managers and researchers in uniting these elements and facilitating both conservation of, and access to, genetic resources. The California Forest Genetic Sources Catalog, a microcomputer database application developed by GENREC for the Wildland Resources Center, is one such application. Well-constructed databases coupled with knowledge-based decision aids will become indispensable as *in situ* preserves and managed areas are integrated with *ex-situ* collections and research findings into effective genetic-resource conservation systems.

315. Satterthwaite W, Holl K, Hayes G, Barber A. 2007. Seed banks in plant conservation: case study of Santa Cruz tarplant restoration. Biological Conservation 135:57-66.

Type: Journal

Geographic Area: California, USA

Keywords: dormancy, population viability, coastal prairie, reintroduction macradenia

Abstract: Although conservation and restoration practitioners have focused on maximizing aboveground population size and seed set of rare plants, a clear understanding of seed bank dynamics is crucial to managing these species. Santa Cruz tarplant (*Holocarpha macradenia*) is a threatened annual forb restricted to coastal prairie habitats in central California. *Holocarpha* produces disk achenes germinating within a year of production and ray achenes forming a persistent seed bank. We constructed both deterministic and stochastic demographic models for a restored *Holocarpha* population, using demographic rates measured separately for unmanipulated plants and plants growing in plots where vegetation was clipped. The deterministic models indicated that regardless of germination from the seed bank, the population would decline without clipping or similar treatments that enhance survival and reproductive output. Deterministic models showed only a slight positive effect of increased ray seed germination rates on population growth, which would need to be balanced against a potential loss of buffering against environmental variation as the dormant seed bank was reduced. Our stochastic simulations suggested that extinction risk for *Holocarpha* populations would be minimized by intermediate levels of ray seed germination. Thus, managers should focus on improving the performance of aboveground plants before considering actions to stimulate germination, since the former will yield a greater increase in deterministic population growth and not sacrifice any buffering effect of the seed bank. This case study emphasizes the importance of considering dormant seeds and seed banks in designing successful restoration and management strategies for plant species at risk of extinction.

Link: http://www.elkhornsloughctp.org/uploads/files/1168483236Satterthwaite%202007%20Seed%20Banks.pdf

316. Schoettle AW. 2004. Developing proactive management options to sustain bristlecone and limber pine ecosystems in the presence of a non-native pathogen. In: Shepperd WD, Eskew LG, editors. Silviculture in Special Places: Proceedings of the National Silviculture Workshop. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-34. p 146-155.

Type: Government Document

Geographic Area: Northwestern USA

Compilers' Keywords: white pine blister rust, strategy, Rocky Mountain, *Pinus strobus*, *Pinus flexilis*, *Pinus aristata*

Abstract: Limber pine and Rocky Mountain bristlecone pine are currently threatened by the non-native pathogen white pine blister rust (WPBR). Limber pine is experiencing mortality in the northern Rocky Mountains and the infection front continues to move southward. The first report of WPBR on Rocky Mountain bristlecone pine was made in 2003, at a site that is more than 220 miles away from the former infection front. No mortality has been observed in this recently infected area but the species is highly susceptible. There are no ecological reasons to suspect that WPBR on bristlecone and the southern distribution of limber pine will not expand over time. Learning from experiences in impacted ecosystems will facilitate the development of proactive measures to mitigate impacts in these southern populations in the future. If no action is taken, and the pathogen takes its course, we risk losses of aesthetic landscapes; impacts to ecosystem boundaries, successional pathways, and watershed processes; and shifts from forested to treeless sites at some landscape positions. This paper introduces an interdisciplinary approach to developing proactive management options for limber and bristlecone pines in the southern Rocky Mountains. Managers, researchers, operational professionals and interested public groups will have to work together and share their knowledge and perspectives to sustain these ecosystems for future generations.

Link: http://www.treesearch.fs.fed.us/pubs/7221

317. Schoettle AW, Sniezko RA. 2007. Proactive intervention to sustain high-elevation pine ecosystems threatened by white pine blister rust. Journal of Forest Research 12:327-336.

Type: Journal

Geographic Area: Western North America

Keywords: evolution of resistance, exotic pathogen, *Pinus aristata*, *Pinus albicaulis*, *Pinus flexilis*

Abstract: Only recently have efforts begun to address how management might prepare currently healthy forests to affect the outcome of invasion by established nonnative pests. *Cronartium ribicola*, the fungus that causes the disease white pine blister rust (WPBR), is among the introductions into North America where containment and eradication have failed; the disease continues to spread. Ecosystem function is impaired by high rust-caused mortality in mature five-needle white pine forests. This paper evaluates five proactive management options to mitigate the development of impacts caused by white pine blister rust in threatened remote high-elevation five-needle pine ecosystems of western North America. They are: reducing pest populations; managing forest composition; improving host vigor; introducing resistant stock with artificial regeneration; and diversifying age class structure to affect the natural selection process for resistance. Proactive intervention to manage and facilitate evolutionary change in the host species may sustain host populations and ecosystem function during pathogen naturalization.

Link: http://www.treesearch.fs.fed.us/pubs/29500

318. Schoettle AW, Sniezko R, Burns KS, Freeman F. 2007. Preparing the landscape for invasion—early intervention approaches for threatened high elevation white pine ecosystems. In: Goheen EM, Sniezko RA, editors. Whitebark Pine: A Pacific Coast Perspective. Portland (OR): USDA Forest Service, Pacific Northwest Region. R6-NR-FHP-2007-01. p 72-75.

Type: Government Document

Geographic Area: Northwestern USA

Compilers' Keywords: whitebark pine, *Pinus albicaulis*, white pine blister rust, regeneration, forest management, pest management

Introduction: White pine blister rust is now a permanent resident of North America. The disease continued to cause tree mortality and impact ecosystems in many areas. However, not all high elevation white pine ecosystems have been invaded; the pathogen is still spreading within the distributions of the whitebark, limber, foxtail, Rocky Mountain bristlecone pine and has yet to infect Great Basin bristlecone pines. While the heavily impacted areas are in need of immediate management to restore ecosystem function, management of the threatened areas to position them to avoid development of severe impacts upon invasion is also an immediate need—as the disease intensifies, time is running out.

Link: http://www.treesearch.fs.fed.us/pubs/29501

319. Schoettle AW, Goodrich BA, Klutsch JG, Burns KS, Costello S, Sniezko R, Connor J. 2011. The proactive strategy for sustaining five-needle pine populations: an example of its implementation in the Southern Rocky Mountains. In: Keane RE, Tomback DF, Murray MP, Smith CM, editors. High Five Symposium. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-63. p 323-334.

Type: Government Document

Geographic Area: Northwestern USA

Compilers' Keywords: *Cronartium ribicola*, white pine blister rust, mountain pine beetle, *Dendroctonus ponderosae*, climate change, limber pine, management, genetic diversity, seed collection

Abstract: The imminent invasion of the non-native fungus, *Cronartium ribicola* J.C. Fisch., that causes white pine blister rust (WPBR) and the current mountain pine beetle (*Dendroctonus ponderosae* Hopkins, MPB) epidemic in northern Colorado limber pine forests will severely affect the forest regeneration cycle necessary for functioning ecosystems. The slow growth and maturity of limber pine enables trees to persist on the landscape for centuries, but without sufficient regeneration opportunities these traits will inevitably hinder the ability of limber pine to adapt to novel stresses such as WPBR or climate change. The current MPB outbreak will result in the death of many mature limber pines, including many with genetic resistance to WPBR. It will be decades until advanced regeneration develops into seed-producing mature trees in much of this region. This development will be limited further by WPBR which rapidly kills susceptible young trees. Efforts to sustain limber pine and Rocky Mountain bristlecone pine in the southern Rockies were initiated in 2001. The Northern Colorado Limber Pine Conservation Program, described here, is an example of the Proactive Strategy being implemented at a local scale. The program is a cooperative partnership between the USFS Rocky Mountain Research Station, Rocky Mountain National Park (RMNP), USFS Forest Health Management, and several Ranger Districts on the Arapaho-Roosevelt National Forest. It is designed to 1) conserve limber pine genetic diversity and 2) collect needed data to assist land managers in making informed decisions for preparation of a management plan intended to sustain resilient limber pine ecosystems in northern Colorado. The cooperative effort aims to provide immediate protection of limber pine from MPB, facilitate seed collections for WPBR resistance tests, and store and use seed for conservation, research and restoration. Seedlings are being screened for WPBR resistance

to determine frequencies of resistance across the landscape among populations and to identify resistant seed trees for future seed collections. The seedling tests will also estimate population differentiation along the elevation gradient to refine seed transfer guidelines. Surveys of forest health, biotic damage, rust incidence, and trends in advanced regeneration will help project persistence of these populations after passage of the MPB epidemic. These data will provide a basis for evaluations of proactive management options on a site specific basis before northern Colorado ecosystems are impaired by WPBR; this should shorten the time frame to return to functioning ecosystems. Focusing management on proactively maintaining genetic diversity and a functional regeneration cycle will promote sustained adaptive capacity and ecosystems resilience to novel stresses such as WPBR and climate change.

Link: http://www.treesearch.fs.fed.us/pubs/38244

320. Shaw NL, Youtie B, Olwell P. 2011. Building bridges between agencies, researchers, farmers and non-governmental organizations to create collaborative native seed programs. In: Proceedings 7th European Conference on Ecological Restoration. Avignon, France: Society for Ecological Restoration. p 1-4.

Type: Conference Paper

Geographic Area: Western USA

Keywords: climate change, disturbance by fire, invasive species, native plant programs

Abstract: The Native Plant Materials Development Program was authorized by the U.S. Department of the Interior and Related Agencies Appropriations Act of FY2001 to provide support for development of native plant materials required for restoration of disturbed public lands in the U.S.A. The Washington, DC, Office of the USDI Bureau of Land Management has provided national leadership for this program by developing partnerships with more than 250 public and private entities, a national program for collecting germplasm for *ex situ* conservation and for seed increase for restoration uses, and by initiating state and regional level native plant materials programs. Regional programs such as the Great Basin Native Plant Selection and Increase Project aim to fulfill long-term plant material needs by providing genetically diverse, regionally appropriate seed sources and fostering the research required to produce seeds of new restoration species in agricultural settings. The Deschutes Basin Native Plant Seedbank, a non-profit organization, has provided valuable leadership by functioning as a buyer's cooperatives to provide affordable local seed for public and private partners in areas with a mosaic of land ownerships. At all levels, native plant materials development programs rely heavily upon cooperation among land managers, researchers, non-governmental organizations, and the private sector seed industry.

Link: http://www.treesearch.fs.fed.us/pubs/39211

321. Shaw NL, Lambert SM, DeBolt AM, Pellant M. 2005. Increasing native forb seed supplies for the Great Basin. In: Dumroese RK, Riley LE, Landis TD, editors. Forest and Conservation Nursery Associations—2004. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-35. p 94-102.

Type: Government Document

Geographic Area: Great Basin USA

Keywords: native forbs, plant materials, seed production, seeding, rangelands

Abstract: Over the last 150 years, excessive grazing, annual weed invasions, increased wildfire frequency, and other human disturbances have negatively impacted native plant communities of the Great Basin. Native plant materials and appropriate planting strategies are needed to recreate diverse communities in areas requiring active restoration. Although native forbs are critical components of most plant communities, available seed supplies remain low. A cooperative research project being conducted by the USDI Bureau of Land Management Great Basin Restoration Initiative, the USDA Forest Service Rocky Mountain Research Station, and collaborators includes efforts to develop 20 native forbs as revegetation species. Research needs include selection of seed sources and development of seed production and wildland seeding technology for each species. Initial seed increase of new seed sources and maintenance of seed supplies will require production at a range of scales, likely creating new marketing niches for the native seed and nursery industries.

Link: http://www.treesearch.fs.fed.us/pubs/20897

322. St. Clair JB, Lipow S, Vance-Borland K, Johnson R. 2007. Conservation of forest genetic resources in the United States. In: Loo JA, Simpson JD, editors. Proceedings of the 13th Meeting of the Canadian Tree Improvement Association: Canada's Forests-Enhancing Productivity, Protection and Conservation. New Brunswick, Canada. p 16-24.

Type: Conference Paper

Geographic Area: USA

Compilers' Keywords: genetic variation, forest management, gene conservation, gap analysis, tree improvement

Abstract: Conservation of genetic diversity is recognized as an important requirement of sustainable forest management. Gene conservation activities include *in situ* conservation of native stands in reserves and *ex situ* conservation in seed banks, genetic tests, seed and breeding orchards, and other plantations of known identity. We present an example from Oregon and Washington of a GIS-based "gap analysis" approach to determine the spatial distribution of protected *in situ* genetic resources. GIS coverages showing detailed

distributions of eight tree species stratified into presumably unique genetic units using seed zones or ecoregions were overlaid with coverages of reserves to determine the locations of protected populations as Well as gaps in protection. The gap analysis indicated that most species appear to have sufficient genetic resources conserved in *in situ* reserves. This approach may be valuable elsewhere, particularly in the eastern United States where fewer large reserves exist. Of particular note, for *ex situ* conservation, is a recent agreement between the USDA Forest Service National Seed Laboratory and the USDA Agricultural Research Service National Center for Genetic Resources Preservation to provide long-term storage of seed collections of valuable plant germplasm in their facility in Ft. Collins, Colorado. Protection from disease and insects is another important component of gene conservation.

Link: http://www.treesearch.fs.fed.us/pubs/29348

323. Stanley AG, Kaye TN, Dunwiddle PW. 2008.

Regional strategies for restoring invaded prairies: observations from a multisite, collaborative research project. Native Plants Journal 9:247-254.

Type: Journal

Geographic Area: Pacific Northwest USA

Keywords: grassland restoration, prairie, herbicide, restoration methods, seed addition, native diversity, invasive species

Abstract: Invasive plants, especially nonnative perennial grasses, pose one of the most critical threats to protected prairies and oak woodlands in the Pacific Northwest. Our current knowledge regarding the effectiveness of weed control methods, especially in sites that retain a significant component of native vegetation, is largely anecdotal or based on results from a few site-specific studies. The Nature Conservancy jointly with the Institute for Applied Ecology and its partners have initiated a large-scale, long-term, interdisciplinary, and collaborative project to: 1) evaluate and improve strategies for controlling the abundance of invasive nonnative herbaceous weeds while maintaining or enhancing the abundance and diversity of native plant species; and 2) develop an approach to generalize results so they can be applied by land managers engaged in prairie stewardship throughout the region. This project combines simultaneous small-scale replicated experiments with large-scale unreplicated experiments at 11 sites in Washington, Oregon, and British Columbia. Experimental treatments, begun in 2005, include combinations of spring and fall mowing, burning, a grass-specific herbicide (sethoxydim), a broad-spectrum herbicide (glyphosate), and seeding of native species. Our preliminary observations show sethoxydim applications effectively reduce exotic perennial grasses. Combining sethoxydim with other treatments had added benefits: fall burning reduced thatch and moss cover, glyphosate application 1 to 2 wk after burning reduced broadleaf weeds, and seed addition increased native diversity.

Link: http://www.researchgate.net/publication/228743458_Regional_strategies_for_restoring_invaded_prairies_observations_from_a_multi-site_collaborative_research_project/file/9fcfd5059e6ca4a2cd.pdf

324. Thomas E, Jalonen R, Loo J, Boshier D, Gallo L, Cavers S, Bordács S, Smith P, Bozzano M. 2014.

Genetic considerations in ecosystem restoration using native tree species. Forest Ecology and Management 333:66-75.

Type: Journal

Geographic Area: Global

Keywords: ecosystem restoration, genetic diversity, native tree species, seed selection, measures of success, tree nursery

Abstract: Rehabilitation and restoration of forest ecosystems are in growing demand to tackle climate change, biodiversity loss and desertification—major environmental problems of our time. Interest in restoration of ecosystems is increasingly translated into strong political commitment to large-scale tree planting projects. Along with this new impetus and the enormous scale of planned projects come both opportunities and risks: opportunities to significantly increase the use of native species, and risks of failure associated with the use of inadequate or mismatched reproductive material, which though it may provide forest cover in the short term, will not likely establish a self-sustaining ecosystem. The value of using native tree species in ecosystem restoration is receiving growing recognition both among restoration practitioners and policy makers. However, insufficient attention has been given to genetic variation within and among native tree species, their life histories and the consequences of their interactions with each other and with their environment. Also restoration practitioners have often neglected to build in safeguards against the anticipated effects of anthropogenic climate change. Measurement of restoration success has tended to be assessments of hectares covered or seedling survival in a short timeframe, neither of which is an indicator of ecosystem establishment in the long term. In this article, we review current practices in ecosystem restoration using native tree species, with a particular focus on genetic considerations. Our discussion is organised across three themes: (i) species selection and the sourcing of forest reproductive material; (ii) increasing resilience by fostering natural selection, ecological connectivity and species associations; and (iii) measuring the success of restoration activities. We present a number of practical recommendations for researchers, policymakers and restoration practitioners to increase the potential for successful interventions. We recommend the development and adoption of decision-support tools for: (i) collecting and propagating germplasm in a way that ensures a broad genetic base of restored tree

populations, including planning the sourcing of propagation material of desired species well before the intended planting time; (ii) matching species and provenances to restoration sites based on current and future site conditions, predicted or known patterns of variation in adaptive traits and availability of seed sources; and (iii) landscape-level planning in restoration projects.

Link: http://www.sciencedirect.com/science/article/pii/S0378112714004356

325. van Slageren W. 2003. The Millennium Seed Bank: building partnerships in arid regions for the conservation of wild species. Journal of Arid Environments 54:195-201.

Type: Journal

Geographic Area: United Kingdom, Global

Keywords: seed bank, conservation, ex-situ, drylands, benefit-sharing, conventions, research, education

Abstract: The Millennium Seed Bank Project is a large, international conservation project. Most of the project will focus—in collaboration with many dryland countries—on the much-neglected need for conservation of wild species in the (semi-) arid regions of the world. Its principal aim is to help safeguard 24,000 species of dryland plants—10% of the world's flora—against extinction. A second aim is, equally through ex-situ conservation, to secure the future of almost all of the U.K.'s native flowering plants. For the project, a new building has been constructed at Wakehurst Place in Sussex, part of the Royal Botanic Gardens, Kew. After opening in late 2000, it will house the Seed Bank and be a world resource for seed conservation, research and education.

Link: http://www.cbd.int/doc/articles/2003/A-00155.pdf

326. Zhou S, Sauve RJ. 2006. Genetic fingerprinting of goldenseal using AFLP markers. Native Plants Journal 7:73-77.

Type: Journal

Geographic Area: Southeastern USA

Keywords: genetic diversity, molecular marker, plant DNA profile

Abstract: Goldenseal (*Hydrastis canadensis* L. [Ranunculaceae]) could be considered a worthy ornamental plant for a forest-like garden setting, however, its primary use is medicinal. Research described in this paper demonstrates that AFLP analysis can be used to determine the genetic relationships between accessions of a plant species collected from different regions. The genetic relationships of 9 goldenseal accessions collected in 3 neighboring states, Tennessee, Georgia, and Florida, were determined. A cluster analysis from AFLP data showed that the 2 Tennessee accessions were very closely related to each other with a high bootstrap value of 93%. The 4 Georgia accessions were more diversified with a bootstrap value ranging from 38% to 63%. Among the 3 Florida accessions, genetic relatedness was very low. One Florida accession was closely related to the 2 Tennessee accessions (96%), one with the Georgia accessions (88%), and the other was distant to all accessions. The molecular marker technique developed for determining the genetic relationship and the genetic diversity between accessions could be used by plant breeders for the selection of parental material.

Conservation and Restoration

General (215–232)—reviews, surveys, summaries, theory, foundations, paradigms

Research (233–285)—propagation, outplanting, invasion

Strategies (286–326)—frameworks, approach, decision support

Resources (327–338)—native plant materials, guidelines, handbooks

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

327. Bonner FT, Karrfalt RP. 2008. The woody plant seed manual. Washington (DC): USDA Forest Service. Agriculture Handbook 727. 1223 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: seed storage, seed collection, germination, handbook, propagation, outplanting

Introduction: The first comprehensive handbook on the seeds of trees and shrubs produced by the USDA Forest Service was USDA Misc. Pub. 654, *Woody-Plant Seed Manual*. The manuscript was ready for publication in 1941, but World War II delayed publication until 1948. The boom in tree planting in the 1950s and 1960s created a large demand for seeds and exposed the gaps in our knowledge concerning production and quality of seeds of woody plants in general. Realization of this condition led to the revision and considerable expansion of the manual, resulting in publication of USDA Agric. Handbk. 450, Seeds of *Woody Plants in the United States*, in 1974. Seed data were presented for about 800 species, varieties, and subspecies in 188 genera, considerable more than the 420 species and 140 genera in the 1948 edition. The 1974 Handbook proved to be very popular both in this country and abroad, leading to five printings and translations in several other languages. More than a quarter-century after its publication, however, numerous advances in tree seed technology have dictated that a new revision is needed; the result is the current volume.

Link: http://www.treesearch.fs.fed.us/pubs/32626

328. Dumroese RK, Owston P. 2003. A user's guide to nursery stock types. Western Forester 4-5.

Type: Newsletter

Geographic Area: USA

Compilers' Keywords: nursery practices, user guide, forest management, seedlings, trees, container

Introduction: Foresters must consider many factors when selecting nursery stock types for their planting projects. Forest nurseries can now produce a vast array of stock types to meet any challenge in the field—these target seedlings can be defined for particular sites. It is important that foresters work with a nursery that is known from experience or reputation to provide a consistently good product at a reasonable price. Foresters and nurseries must foster open and effective communication to continually improve stock type quality. To facilitate communication between nurseries and foresters, a system of naming stock types developed and those stock type descriptions fall into three broad categories: bareroot, container and "plug plus."

Link: http://www.treesearch.fs.fed.us/pubs/32849

329. Dumroese RK, Landis TD, Luna T. 2012. Raising native plants in nurseries: basic concepts. Fort Collins (CO): USDA Forest Service Rocky Mountain Research Station. General Technical Report RMRS-GTR-274. 92 p.

Type: Government Document

Geographic Area: North America

Compilers' Keywords: nursery practices, propagation, greenhouse, seed, container nursery, bareroot nursery, guidelines

Abstract: Growing native plants can be fun, challenging, and rewarding. This booklet, particularly the first chapter that introduces important concepts, is for the novice who wants to start growing native plants as a hobby; however, it can also be helpful to someone with a bit more experience who is wondering about starting a nursery. The second chapter provides basic information about collecting, processing, storing, and treating seeds. Chapter three focuses on using seeds to grow plants in the field or in containers using simple but effective techniques. For those native plants that reproduce poorly from seeds, the fourth chapter describes how to start native plants from cuttings. The final chapter provides valuable information on how to successfully move native plants from the nursery and establish them in their final planting location. Several appendices expand on what has been presented in the chapters, with more details and specific information about growing a variety of native plants.

Link: http://www.treesearch.fs.fed.us/pubs/40753

330. Jaramillo S, Baena M. 2007. *Ex situ* conservation of plant genetic resources. Cali, Columbia: International Plant Genetic Resources Institute. 229 p.

Type: Book

Geographic Area: Global

Compilers' Keywords: Latin America, Spain, training module, guide

Forward: Plant genetic resources form the basis on which humankind subsists. They provide basic needs and help solve problems such as hunger and poverty. However, they are being lost, mainly through inappropriate use and destruction of habitat. Given their vital importance, we must conserve them for the benefit of both present and future generations. Plant genetic resources can be conserved within or outside their natural habitats, or by combining the two alternatives. Outside their natural habitats, plant genetic resources are conserved in germplasm collections and genebanks, going through different stages and procedures that require trained staff. To help train personnel in managing genebanks, Bioversity International has developed this teaching manual as part of a collaborative project with Spain to promote the training and research of plant genetic resources in Latin America. The text trains users in the fundamental aspects of *ex situ* conservation of plant genetic resources, that is, from collecting to germplasm use. It explains principles and describes the procedures needed for effective *ex situ* conservation. It also includes bibliographic references and examples that illustrate how to move from theory to practice. By developing and making this material available to users, Biodiversity International hopes to significantly contribute to the training of technicians in plant genetic resources, thereby making them more efficient in *ex situ* conservation and germplasm use.

331. McCaughey W, Scott GL, Izlar KL. 2009. Whitebark pine planting guidelines. Western Journal of Applied Forestry 24:163-166.

Type: Journal

Geographic Area: Northern USA

Keywords: *Pinus albicaulis*, reforestation, tree-planting, seedlings, plantations

Abstract: This article incorporates new information into previous whitebark pine guidelines for planting prescriptions. Earlier 2006 guidelines were developed based on review of general literature, research studies, field observations, and standard U.S. Forest Service survival surveys of high-elevation whitebark pine plantations. A recent study of biotic and abiotic factors affecting survival in whitebark pine plantations was conducted to determine survival rates over time and over a wide range of geographic locations. In these revised guidelines, we recommend reducing or avoiding overstory and understory competition, avoiding swales or frost pockets, providing shade and wind protection, protecting seedlings from heavy snow loads and soil movement, providing adequate growing space, avoiding sites with lodgepole or mixing with other tree species, and avoiding planting next to snags.

Link: http://www.fs.fed.us/rm/pubs_other/rmrs_2009_mccaughey_w001.pdf

332. Monsen SB, Stevens R, Shaw NL. 2004. Grasses. Chapter 18. In: Monsen SB, Stevens R, Shaw NL, editors. Restoring Western Ranges and Wildlands. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-136. p 295-424.

Type: Government Document

Geographic Area: Western USA

Compilers' Keywords: plant ecology, native plant material, wildlife habitat, restoration

Introduction: Grasses are adapted to a wide range of edaphic and climatic conditions and are found in nearly all plant communities. In the Western United States, grasses are seeded on disturbances to provide forage, wildlife habitat, and watershed stability. A number of introduced grass species proved well-suited to Western rangelands and received extensive use in early reseeding efforts. Use of these and other introductions continued over time, but by the late 1900s, greater emphasis was being placed on the use of native grasses.

Link: http://www.treesearch.fs.fed.us/pubs/31963

333. Monsen SB, Stevens R, Shaw NL. 2004. **Restoring western ranges and wildlands.** Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-136. p 699-884.

Type: Government Document

Geographic Area: Western USA

Keywords: rehabilitation, revegetation, plant ecology, seed, plant communities, wildlife habitat, invasive species, equipment, plant materials, native plants

Abstract: This work, in three volumes, provides background on philosophy, processes, plant materials selection, site preparation, and seed and seeding equipment for revegetating disturbed rangelands, emphasizing use of native species. The 29 chapters include guidelines for planning, conducting, and managing, and contain a compilation of rangeland revegetation research conducted over the last several decades to aid practitioners in reestablishing healthy communities and curbing the spread of invasive species. Volume 3 contains chapters 24-29 plus appendices and index.

Link: http://www.treesearch.fs.fed.us/pubs/7379

334. Pendleton RL, Kitchen SG, McArthur ED, Mudge JE. 2008. **The 'Appar' flax release: origin, distinguishing characteristics, and use; and a native alternative.** Native Plants Journal 9:18-24.

Type: Journal

Geographic Area: North America, Europe

Keywords: heterostyly, distyly, native plant material, revegetation, xeriscaping, *Linum lewisii, Linum perenne,* Linaceae, native germplasm

Abstract: This article summarizes information on the taxonomy of 'Appar', a perennial blue flax cultivar (*Linum perenne* L. [Linaceae]), and characteristics that distinguish it from native Lewis flax (*Linum lewisii* Pursh [Linaceae]). 'Appar' apparently originated as a European flax that escaped from garden cultivation. Randomly amplified polymorphic DNA (RAPD) analysis places 'Appar' with other collections of European Linum perenne and separates it from native North American collections of Lewis flax. Morphologically, 'Appar' differs from Lewis flax in having an intense blue petal color, shorter internodes, leaves that point upward along the stem, and multiple slender stems suffused with red near the base. The heterostylous reproductive system, which it shares with its European cousins, keeps 'Appar' reproductively isolated from native populations of Lewis flax. All available data indicate that 'Appar' is not invasive and does not pose a threat to native flax populations. Ease of establishment, seed production, and showiness of the abundant flowers recommend 'Appar' for use in xeriscape plantings. Alternatively, the recent germplasm release of Lewis flax, 'Maple Grove', also establishes readily from seed and can be effectively used when objectives dictate the exclusive use of native germplasms.

Link: http://www.treesearch.fs.fed.us/pubs/30681

335. Proctor J, Haas W. 2007. **Guidelines for revegetation for the Medicine Bow-Routt National Forests and Thunder Basin National Grassland.** 69 p.

Type: Report

Geographic Area: Intermountain West USA

Compilers' Keywords: restoration, handbook

Compilers' Summary: This is a revegetation handbook for the Medicine Bow-Routt National Forests and Thunder Basin National Grassland that cover approximately 2.9 million acres in north central Colorado and central and northeastern Wyoming. It covers guidelines for mountain ranges, grasslands and riparian systems.

336. Scott GL, McCaughey WW. 2006. **Whitebark pine guidelines for planting prescriptions.** In: Riley LE, Dumroese RK, Landis TD, editors. National Proceedings: Forest and Conservation Nursery Associations—2005. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-43. p 84-90.

Type: Government Document

Geographic Area: Western USA

Keywords: whitebark pine, *Pinus albicaulis*, reforestation, tree planting, pocket gophers, white pine blister rust, mountain pine beetle, cones, seeds, fire suppression

Abstract: This paper reviews general literature, research studies, field observations, and standard Forest Service survival surveys of high-elevation whitebark pine plantations and presents a set of guidelines for outplanting prescriptions. When planting whitebark pine, the recommendations are: 1) reduce overstory competition; 2) reduce understory vegetation, especially grasses and sedges; 3) avoid outplanting in swales or frost pocket areas; 4) provide shade protection; 5) plant where there is protection from heavy snow loading; and 6) provide adequate growing space.

Link: http://www.treesearch.fs.fed.us/pubs/26661

337. Society for Ecological Restoration Ecological Restoration International Science and Policy Working Group. 2004. **The SER international primer on ecological restoration.** Tucson (AZ): Society for Ecological Restoration International. 15 p.

Type: Report

Geographic Area: Global

Compilers' Keywords: planning, manual, guidelines

Introduction: Ecological restoration is an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability. Frequently, the ecosystem that requires restoration has been degraded, damaged, transformed or entirely destroyed as the direct or indirect result of human activities. In some cases, these impacts to ecosystems have been caused or aggravated by natural agencies such as wildfire, floods, storms, or volcanic eruption, to the point at which the ecosystem cannot recover its predisturbance state or its historic developmental trajectory. This document is a primer on ecological restoration.

Link: http://www.ser.org/resources/resources-detail-view/ser-international-primer-on-ecological-restoration

338. USDA RNGR. 2014. National Nursery and Seed Directory. (URL accessed 29 November 2015)

Type: Web Page

Geographic Area: USA

Compilers' Keywords: native plants, directory, plant materials

Summary: This is a directory of nurseries and farms that produce native plant materials. It is maintained by the USDA Forest Service, Reforestation, Nurseries, and Genetics Resources (RNGR) team in collaboration with the University of Georgia, Southern Regional Extension Forestry (SREF). SREF verifies one-third of the directory annually. The RNGR website (http://www.rngr.net), also holds a vast amount of information about growing native plants. One of the most important differences between native plant materials and ornamental nursery stock is that natives are usually outplanted in relatively harsh environments generally without any subsequent care.

Link: http://www.rngr.net/resources/directory

Migration

Each reference contains the following:

#. Author(s), Date. Title. Source. — ID number and information

Type: — book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page

Geographic Area: — location of study

Keywords: — keywords written by the author(s) or provided by the compilers

Description: — abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers

Link: — internet address of reference

339. Albrecht GA, Brooke C, Bennett DH, Garnett ST. 2012. The ethics of assisted colonization in the age of anthropogenic climate change. Journal of Agricultural and Environmental Ethics 26:827-845.

Type: Journal

Geographic Area: Global

Keywords: ethics, climate change, assisted colonization, managed relocation, mitigation, adaptation, intrinsic value, instrumental value, sentience, environmental ethics, sustainability ethics, review

Abstract: This paper examines an issue that is becoming increasingly relevant as the pressures of a warming planet, changing climate and changing ecosystems ramp up. The broad context for the paper is the intragenerational, intergenerational, and interspecies equity implications of changing the climate and the value orientations of adapting to such change. In addition, the need to stabilize the planetary climate by urgent mitigation of change factors is a foundational ethical assumption. In order to avoid further animal and plant extinctions, or at the very least, their increased vulnerability to becoming rare and endangered; the systematic assisted colonization of "at risk" species is being seriously considered by scientists and managers of biodiversity. The more practical aspects of assisted colonization have been covered in the conservation biology literature; however, the ethical implications of such actions have not been extensively examined. Our discussion of the value issues, using a novel case study approach, will rectify the limited ethical analysis of the issue of assisted colonization of species in the face of climate change pressures.

340. Aubin I, Garbe CM, Colombo S, Drever CR, McKenney DW, Messier C, Pedlar J, Sander MA, Venier L, Wellstead AM, Winder R, Witten E, Ste-Marie C. 2011. Why we disagree about assisted migration: ethical implications of a key debate regarding the future of Canada's forests. The Forestry Chronicle 87:755-765.

Type: Journal

Geographic Area: Canada

Keywords: assisted colonization, climate change, environmental ethics, forest management, species conservation

Abstract: Assisted migration has been proposed as one tool to reduce some of the negative ecological consequences of climate change. The idea is to move species to locations that could better suit them climatically in the future. Although human mediated movements are not a recent phenomenon, assisted migration has lately been the source of debate, in particular within conservation biology circles. In this paper, we outline the major perspectives that help define differing views on assisted migration and shed some light on the ethical roots of the debate in the context of Canadian forests. We emphasize that there are many different forms of assisted migration, each responding to different (often unstated) objectives and involving unique risks and benefits, thus making the debate more nuanced than often portrayed. We point out certain seeming contradictions whereby the same argument may be used to both support and oppose assisted migration. The current debate on assisted migration primarily focuses on ecological risks and benefits; however, numerous uncertainties reduce our capacity to quantitatively assess these outcomes. In fact, much of the debate can be traced back to fundamental perspectives on nature, particularly to the ethical question of whether to deliberately manage natural systems or allow them to adapt on their own. To facilitate discussion, we suggest that the focus should move towards a clearer identification of values and objectives for assisted migration.

341. Barlow C. 2011. Paleoecology and the assisted migration debate: why a deep-time perspective is vital. (URL accessed 15 May 2015)

Type: Web Page

Geographic Area: Florida, USA

Compilers' Keywords: *Torreya taxifolia*, climate change, species extinctions

Background and Abstract: In the six years since the assisted migration (assisted colonization) debate was launched as a pro and con "Forum" in the Winter 2004/2005 issue of Wild Earth journal, the paleoecological perspective has been almost entirely missing from both the academic papers and the media reports on this vital conservation issue. The original PRO-assistance essay by Connie Barlow and (the late) Paul S. Martin was titled "Bring *Torreya taxifolia* North—Now". The original ANTI-assistance essay by Mark Schwartz was titled "Conservationists Should Not Move *Torreya taxifolia*". The intent of this skeletal essay is to demonstrate, by using the example of "poster plant" *Torreya taxifolia*, why the assisted migration debate must broaden to encompass a deep-time, paleoecological perspective. Since the beginning of the debate, the major advocates in favor of assisted migration for *Torreya taxifolia* have argued that paleoecological reasoning is exceedingly strong in favor of assisting the migration of this highly endangered conifer tree northward from the panhandle of Florida to the southern Appalachians. Notably, there is no dispute that the highly restricted endemic range of *Torreya taxifolia* in Florida (along the east shore of the Apalachicola River) served as one of the primary "pocket refuges" for America's rich Appalachian flora during the peak of the last glacial advance c. 18,000 years ago. It is therefore reasonable to suggest that *Torreya taxifolia* be looked upon as a "glacial relict" that, for one reason or another, failed to make the return trip north when the present interglacial began some 13,000 years ago. It is also plausible to posit that the reason this particular species failed to make the return journey north is that, in contrast to previous interglacial episodes, newly arrived humans obstructed northward migration by overhunting the conifer's obligate seed dispersal partners (squirrels and possibly now-extinct tortoises) in the narrow riverine corridor that contains soils rich enough to support the maturation of this yew-like tree.

Link: http://www.torreyaguardians.org/assisted-migration.html

342. Camacho AE. 2010. Assisted migration: redefining nature and natural resource law under climate change. Irvine (CA): University of California School of Law. Legal Studies Research Paper Series No. 2009-37. 86 p.

Type: Report

Geographic Area: USA

Compilers' Keywords: land management, resource management, uncertainty, endangered species, economic value conservation, ethics, review

Summary: To avoid extinctions and other harms to ecological health from escalating climatic change, scientists, resource managers, and activists are considering and even engaging in "assisted migration" - the intentional movement of an organism to an area in which its species has never existed. This article explores the profound implications of climate change for American natural resource management through the lens of this controversial adaptation strategy. It details arguments regarding the scientific viability and legality of assisted migration under the thicket of laws that govern natural resources in the United States. The article asserts, however, that the fundamental tensions raised by this strategy are ethical: to protect endangered species or conserve native biota; to manage ecological systems actively or leave nature wild and uncontrolled; and to preserve resources or manage them to promote their fitness under future conditions. The article explains why contemporary natural resource law's fidelity to historic baselines, protecting preexisting biota, and shielding nature from human activity is increasingly untenable, particularly in light of climate change. Active, anticipatory strategies such as assisted migration may not only be permissible but even necessary to avert substantial irreversible harm to ecological systems. Scientists and resource managers should focus on developing scientific data to aid analyses of the risks and benefits of assisted migration in particular circumstances. To help develop such data while minimizing ecological harm, the article proposes provisionally limiting experimental translocations to situations where translocation is technically and economically feasible, and where the species is endangered, ecologically valuable, and compatible with the proposed site. More broadly, assisted migration illustrates how the institutions and goals of natural resource law must be changed to better reflect a dynamic, integrated world. Climate changes forces a radical reconsideration of the aims, foci, and standards of natural resource management. Accordingly, the crucial project of natural resource law must be improving governance by cultivating agency accounting and learning to better manage uncertainty, promoting opportunities for interjurisdictional collaboration, and fostering public information and deliberation over the tradeoffs of strategies like assisted migration and the resource values that matter.

343. Camacho A. 2013. The law and ethics of assisted migration. In: Assisted Migration: A Primer for Reforestation and Restoration Decision Makers; Portland, OR. 42 p.

Type: Presentation

Geographic Area: Global

Compilers' Keywords: policies, EPA, Endangered Species Act, natural resource management

Abstract: To avoid extinctions and other harms to ecological health from escalating climatic change, scientists, resource managers, and activists are considering and even engaging in "assisted migration" – the intentional movement of an organism to an area in which its species has never existed. This article explores the profound implications of climate change for American natural resource management through the lens of this controversial adaptation strategy. It details arguments regarding the scientific viability and legality of assisted migration under the thicket of laws that govern natural resources in the United States. The article asserts, however, that the fundamental tensions raised by the strategy are ethical: to protect endangered species or conserve native biota; to manage ecological systems actively or leave nature wild and uncontrolled; and to preserve resources or manage them to promote their fitness under future conditions. The article explains why contemporary natural resource law's fidelity to historic baselines, protecting preexisting biota, and shielding nature from human activity is increasingly untenable, particularly in light of climate change. Active, anticipatory strategies such as assisted migration may not only be permissible but even necessary to avert substantial irreversible harm to ecological systems. Scientists and resource managers should focus on developing scientific data to aid analyses of the risks and benefits of assisted migration in particular circumstances. To help develop such data while minimizing ecological harm, the article proposes provisionally limiting experimental translocations to situation where translocation is technically and economically feasible, and where the species is endangered, ecologically valuable, and compatible with the proposed site.

Link: http://www.rngr.net/resources/assisted-migration

344. Crespi BJ. 2000. The evolution of maladaptation. Heredity 84:623-629.

Type: Journal

Geographic Area: Global

Keywords: adaptation, adaptive peaks, evolution, maladaptation

Abstract: This review contains a description of a research program for the study of maladaptation, defined here in terms of deviation from adaptive peaks. Maladaptation has many genetic causes, including mutation, inbreeding, drift, gene flow, heterozygote advantage and pleiotropy. Degrees of maladaptation are determined by genetic architecture and the relationship between the rates of selective, environmental change and the nature and extent of genetic responses to selection. The empirical analysis of maladaptation requires: (1) recognition of putative maladaptation, using methods from phylogenetics, teleonomy, development and genetics, followed by an assessment of the nature and degree of deviation from adaptation, using studies of natural selection and teleonomy; (2) determination of the causes of the deviation, using analyses of genetics, development, or other methods. Conditions for unambiguously identifying maladaptation are considerably more stringent than those for demonstrating adaptation and remarkably few studies have clearly identified and characterized maladaptive traits. A thorough understanding of the nature of phenotypic variation will never be achieved without an analysis of the scope and usual causes of maladaptation.

Link: http://www.sfu.ca/biology/courses/bisc441/Course_Materials/Readings/9-(Lect6)Crespi2000.pdf

345. Davis MB. 1990. Climate change and the survival of forest species. Chapter 6. In: Woodwell GM, editor. The Earth in Transition: Patterns and Processes of Biotic Impoverishment. Cambridge, United Kingdom: Cambridge University. p 99-110.

Type: Book Section

Geographic Area: Global

Compilers' Keywords: pollen, migration, paleoecology, trees, *Tsuga canadensis*

Introduction: The fossil record provides many examples of changes in geographical distributions of plants in response to changing climate. These examples provide a basis for predicting response to future climate. The accumulation of greenhouse gases in the atmosphere will soon cause climatic warming. With CO_2 doubling, global temperatures are expected to rise 3 degrees ± 1.5 °C degrees. If emission of greenhouse gases continues to increase at the present rates, global warming will average 0.3 °C per decade for the next century. Can the flora adjust easily? Or will climatic change cause extinction? The survival of many taxa through a series of glacial-interglacial cycles during the Pleistocene suggests that most plant species in the temperate zone have been able to disperse to keep pace with climatic changes in the past. Temperate zone trees survived the last glacial maximum as small populations in refugia in southeastern United States. As the ice sheets melted and the climate warmed at the end of the glacial interval, these plants were able to disperse northward hundreds of kilometers to occupy their present-day range. Future greenhouse warming, however, differs from climatic changes in the past: the rate of change will be at least one order of magnitude more rapid. Examples from the most recent time of relatively rapid change exist—the warming just at the end of the last glacial interval in northwestern Europe fossils from warmth-requiring species of water plants and beetles are found earlier than the oldest fossils from trees. This suggests that the climate became warm enough for trees several centuries before trees began to grow on the local landscape. Dispersal of tree seeds was insufficient to track the change in temperature, or development of soils was not rapid enough to provide appropriate habitats for trees.

346. Davis MB, Shaw RG. 2001. Range shifts and adaptive responses to Quaternary climate change. Science 292:673-679.

Type: Journal

Geographic Area: Global

Compilers' Keywords: vegetation change, latitude shifts, elevation shifts, migration, extinction, tree

Abstract: Tree taxa shifted latitude or elevation range in response to changes in Quaternary climate. Because many modern trees display adaptive differentiation in relation to latitude or elevation, it is likely that ancient trees were also so differentiated, with environmental sensitivities of populations throughout the range evolving in conjunction with migrations. Rapid climate changes challenge this process by imposing stronger selection and by distancing populations from environments to which they are adapted. The unprecedented rates of climate changes anticipated to occur in the future, coupled with land use changes that impede gene flow, can be expected to disrupt the interplay of adaptation and migration, likely affecting productivity and threatening the persistence of many species.

Link: http://web.clas.ufl.edu/users/mbinford/GEOXXXX_Biogeography/LiteratureForLinks/Davis_and_Shaw_2001_range_shifts_climate_adaption_Science.pdf

347. Fazey I, Fischer J. 2009. Assisted colonization is a techno-fix. Trends in Ecology and Evolution 24:475.

Type: Journal

Geographic Area: Global

Compilers' Keywords: animals, conservation, assisted migration, ecosystem, biological extinction, biological models, risk assessment

Introduction: In this letter, authors agree with the tenet of the argument of Ricciardi and Simberloff (2009) that the attention and credibility given to such schemes is worrying and that it might send an overly optimistic message about assisted colonization to policymakers and the public. Here we propose three important additional considerations which lend further support to the view that widespread implementation of assisted colonization will be inappropriate, especially when the broader social-ecological context of threatened species conservation is taken into account.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19577323

348. Hannah L. 2008. Protected areas and climate change. Annals of the New York Academy of Sciences 1134:201-212.

Type: Journal

Geographic Area: Global

Keywords: protected areas, climate change, biodiversity, reserves, connectivity, corridors, assisted migration

Abstract: The study of protected areas and climate change has now spanned two decades. Pioneering work in the late 1980s recognized the potential implications of shifting species range boundaries for static protected areas. Many early recommendations for protected area design were general, emphasizing larger protected areas, buffer zones, and connectivity between reserves. There were limited practical tests of these suggestions. Development of modeling and conservation planning methods in the 1990s allowed more rigorous testing of concepts of reserve and connectivity function in a changing climate. These studies have shown decreasing species representation in existing reserves due to climate change, and the ability of new protected areas to help slow loss of representation in mid-century scenarios. Connectivity on protected area periphery seems more effective than corridors linking protected areas. However, corridors serving other purposes, such as large carnivore movement, may be useful for accommodating species range shifts as well. Assisted migration and *ex situ* management strategies to complement protected areas are being explored. Finally, in scenarios of the latter half of the century, protected areas and connectivity become increasingly expensive and decreasingly effective, indicating the importance of reducing human-induced climate change.

349. Hewitt N, Klenk N, Smith AL, Bazely DR, Yan N, Wood S, MacLellan JI, Lipsig-Mumme C, Henriques I. 2011. Taking stock of the assisted migration debate. Biological Conservation 144:2560-2572.

Type: Journal

Geographic Area: Global

Keywords: assisted migration, assisted colonization, managed relocation, climate change adaptation, debate

Abstract: Assisted migration was proposed several decades ago as a means of addressing the impacts of climate change on species populations. While its risks and benefits have been debated, and suggestions for planning and management given, there is little consensus within the academic literature over whether to adopt it as a policy. We evaluated the main features of the assisted migration literature including the study methods, taxonomic groups, geographic regions and disciplines involved. We further assessed the debate about the use of assisted migration, the main barriers to consensus, and the range of recommendations put forth in the literature for policy, planning or implementation. Commentaries and secondary literature reviews were as prevalent as first-hand scientific research and attention focused on a global rather than regional level. There was little evidence of knowledge transfer outside of the natural sciences, despite the obvious policy relevance. Scholarly debate on this topic has intensified during the last 3 years. We present a conceptual framework for evaluating arguments in the debate, distinguishing among the direct risks and benefits to species, ecosystems and society on the one hand, and other arguments regarding scientific justification, evidence-base and feasibility on the other. We also identify recommendations with potential to advance the debate, including careful evaluation of risks, benefits and trade-offs, involvement of relevant stakeholders and consideration of the complementarity among assisted migration and less risk tolerant strategies. We conclude, however, that none of these will solve the fundamental, often values-based, challenges in the debate. Solutions are likely to be complex, context-dependent and multi-faceted, emerging from further research, discussion and experience.

Link: http://www.researchgate.net/publication/232361203_Taking_stock_of_the_assisted_migration_debate/file/79e41512f9fdb8e5a8.pdf

350. Hunter ML, Jr. 2007. Climate change and moving species: furthering the debate on assisted colonization. Conservation Biology 21:1356-1358.

Type: Journal

Geographic Area: Global

Compilers' Keywords: animals, conservation, biological extinction, greenhouse effect, population dynamics, assisted migration

Introduction: With global climate change looming large in the public psyche, the recent paper by McLachlan et al. (2007) and its popular accompaniment (Fox 2007) are timely indeed. Of course some conservation biologists will not wish to think about the prospect of actively moving species that are threatened with extinction by climate change. For them this would be almost analogous to handing out placebos in the midst of an epidemic and worse yet, these placebos may have serious unintended consequences if translocated species become invasive. They will probably argue that we should focus almost exclusively on two central roles for conservation biology: (1) facilitating natural range shifts by redoubling efforts to maintain or restore large scale connectivity and (2) working with our fellow environmental professionals to avoid carbon-management solutions that will have unacceptable consequences for biodiversity (e.g., by directing biofuel production away from sites that would involve the conversion of native vegetation into fuel farms. These two roles will be very demanding, but I believe we should allocate a small portion of our attention to the issue of assisted colonization. McLachlan et al. propose framing the debate around two considerations—perception of risk and confidence in ecological understanding—that can be construed to generate an axis or continuum from scientists who would strongly support assisted colonization to those who would oppose it. I think it is useful to advance this exercise by considering three issues that can also be construed as continua: species that are more or less acceptable to translocate, sites that are more or less acceptable for receiving translocations, and projects that are more or less acceptable because of their socioeconomic ramifications and feasibility. I have used the term assisted colonization in contrast to assisted migration used by McLachlan et al. because many animal ecologists reserve the word migration for the seasonal, round-trip movements of animals and because the real goal of translocation goes beyond assisting dispersal to assuring successful colonization, a step that will often require extended husbandry.

Link: http://www.ncbi.nlm.nih.gov/pubmed/17883502

351. Iverson LR, Peters MP, Matthews S, Prasad AM. 2013. An overview of some concepts, potentials, issues, and realities of assisted migration for climate change adaptation in forests. In: Browning J, Palacios P, editors. Proceedings of the 60th Annual Western International Forest Disease Work Conference. Tahoe City (CA): USDA Forest Service, Northern Research Station. p 25-34.

Type: Government Document

Geographic Area: Global

Compilers' Keywords: assisted migration, climate change, land management

Abstract: The climate has always been changing, but the rapid rate of climate change, as projected by the IPCC (2007) will likely place unique stresses on plant communities. In addition, anthropogenic barriers (e.g., fragmented land use) present a significant modern constraint that will limit the ability of species migration in responses to a changing climate. As such, managers are faced with four options that lay along a continuum when managing species in the face of climate change: (1) They can do nothing, and therefore allow existing landscapes to change without active intervention, accepting unknown or risky outcomes; (2) They can rely on passive resource management strategies to allow accommodation, such as Linking existing preserves with corridors; (3) They can actively manage landscapes to preserve them as they are, thus create refuges. Such habitat management would include actions like preventing invasions, installing irrigation, and regulating biotic interactions; or (4) They can actively manage landscapes to convert them into something deemed more compatible with projected climatic conditions. This last example of management would include assisted migration. The specific risks and benefits of each of these actions will depend upon the magnitude of climate

pressure, the context of the ecosystem and its landscape, and the goals of human decisions. This paper describes some options on how to decide among the above choices, introduces assisted migration, and describes the possible ramifications associated with it. We then present one research approach to assist in locating and evaluating potential applications of assisted migration.

Link: http://www.treesearch.fs.fed.us/pubs/45280

352. Johnson R. 2010. Seed movement and climate change from a Forest Service perspective. In: National Native Seed Conference: Native Plant Materials Development, Production, and Use for Habitat Restoration. Corvallis (OR): Institute for Applied Ecology. 39 p.

Type: Presentation

Geographic Area: USA

Compilers' Keywords: forest genetics, forest management, seedlot selection tool

Abstract: The USDA Forest Service (USFS) Native plant restoration policy calls for use of "genetically appropriate" native plant material on USFS lands. This is typically accomplished by delineating seed zones to restrict seed movement to ensure locally-adapted plant material is used in restoration / reforestation / rehabilitation efforts. Given that the climate is changing more rapidly than any time in the recent past, our starting point of "local is best" may not be the optimal option given that local climates have changed over the last few decades and even more change is forecasted in the future. While the USFS policy has not changed, USFS Regional Geneticists, along with USFS researchers, came together for a 3-day workshop to discuss seed movement options in light of climate change (a paper is forthcoming). The workshop centered on forest trees, not smaller native plants. Discussions acknowledged that climate has already changed in the last few decades (surface temperature has warmed about 1 °F) and that certain forest tree species have migrated in some places. Both genetic theory and species migration models suggest that climate change will impact species differently. The impact of climate change on a species will be function of lifespan, mating system, dispersal capabilities, habitat specialization, genetic variation, population size, pest/pathogen interactions, etc. Key points coming out of the meeting included: (1) The importance of deploying genetically diverse populations in our restoration efforts. (2) Local sources still appear to be appropriate choices at present, but including additional sources from adjacent seed zones could provide the variation needed for the future. (3) At least one region is moving seed up one elevation or "north" one cold hardiness band. (4) We will take minimal risks over large scales and larger risks at smaller scales (i.e., only do assisted migration studies over large distances on experimental scales). (5) The need for gene conservation programs is increasing in light of climate change. (6) For most species, we have no genetic data (common garden /provenance trials) to assist with making seed movement guidelines and research is needed.

Link: http://nativeseed.info/2010/session/climate.html#kaye

353. Keim B. 2008. Last-ditch resort: move polar bears to Antarctica? Wired 17 July 2008. (URL accessed 25 November 2015)

Type: Article

Geographic Area: Global

Compilers' Keywords: migration, conservation, extinctions

Introduction: It may seem like a preposterous question. But polar bears are just the tip of the "assisted colonization" iceberg. Other possibilities: moving African big game to the American Great Plains, or airlifting endangered species from one mountaintop to another as climate zones shrink. Once dismissed as wrongheaded and dangerous, assisted colonization—rescuing vanishing species by moving them someplace new—is now being discussed by serious conservationists. And no wonder: Caught between climate change and human pressure, species are going extinct 100 times faster than at any point in human history. And some scientists say that figure is too conservative. The real extinction rate, they say, is a full 1,000 times higher than normal. The last time such annihilation took place was during the time of the dinosaurs. And though many conservationists say that saving species by transplanting them is foolish, others say there's no choice.

Link: http://www.wired.com/science/planetearth/news/2008/07/species_relocation?currentPage=all

354. Koskela J, Vinceti B, Dvorak W, Bush D, Dawson IK, Loo J, Kjaer ED, Navarro C, Padolina C, Bordács S, Jamnadass R, Graudal L, Ramamonjisoa L. 2014. Utilization and transfer of forest genetic resources: a global review. Forest Ecology and Management 333:22-34.

Type: Journal

Geographic Area: Global

Keywords: reproductive material, plantations, introduced species, access and benefit sharing, Nagoya Protocol

Abstract: Over the last 200 years, genetic resources of forest trees have been increasingly transferred, within and outside of species' native distribution ranges, for forestry and for research and development (R&D). Transferred germplasm has been deployed to grow trees for numerous purposes, ranging from the production of wood and non-wood products to the provision of ecosystem services such as the restoration of forests for biodiversity conservation. The oldest form of R&D, provenance trials, revealed early on that seed origin has a major influence on the performance of planted trees. International provenance trials have been essential for selecting seed sources for reforestation and for improving tree germplasm through breeding. Many tree breeding programmes were initiated in the 1950s,

but as one round of testing and selection typically takes decades, the most advanced of them are only in their third cycle. Recent advances in forest genomics have increased the understanding of the genetic basis of different traits, but it is unlikely that molecular marker-assisted approaches will quickly replace traditional tree breeding methods. Furthermore, provenance trials and progeny tests are still needed to complement new research approaches. Currently, seed of boreal and temperate trees for reforestation purposes are largely obtained from improved sources. The situation is similar for fast growing tropical and subtropical trees grown in plantations, but in the case of tropical hardwoods and many agroforestry trees, only limited tested or improved seed sources are available. Transfers of tree germplasm involve some risks of spreading pests and diseases, of introducing invasive tree species and of polluting the genetic make-up of already present tree populations. Many of these risks have been underestimated in the past, but they are now better understood and managed. Relatively few tree species used for forestry have become invasive, and the risk of spreading pests and diseases while transferring seed is considerably lower than when moving live plants. The implementation of the Nagoya Protocol on access to genetic resources and benefit sharing (ABS) may significantly change current transfer practices in the forestry sector by increasing transaction costs and the time needed to lawfully obtain forest genetic resources for R&D purposes. Many countries are likely to struggle to establish a well-functioning ABS regulatory system, slowing down the process of obtaining the necessary documentation for exchange. This is unfortunate, as climate change, outbreaks of pests and diseases, and continual pressure to support productivity, increase the need for transferring tree germplasm and accelerating R&D.

Link: http://www.bioversityinternational.org/uploads/tx_news/Utilization_and_transfer_of_forest_genetic_resources_a_global_review_1869.pdf

355. Lawler JJ, Olden JD. 2011. **Reframing the debate over assisted colonization.** Frontiers in Ecology and the Environment 9:569-574.

Type: Journal

Geographic Area: Global

Compilers' Keywords: migration, climate change, landscape connectivity, managed relocation, framework, guidelines

Abstract: Assisted colonization—also known as managed relocation or assisted migration—is one way of facilitating range shifts for species that are restricted in their ability to move in response to climate or other environmental changes. Over the past decade, a healthy debate has evolved in the scientific community over the costs and benefits of assisted colonization as a climate-adaptation strategy. This discussion has focused largely on the specific risks and benefits of intentionally moving species, and has led to the development of multiple frameworks and numerous recommendations for weighing and evaluating these factors. Here, we argue that this debate is, in part, misguided, and that a more productive discussion would result if the issue were reframed in light of (1) the goals of assisted colonization, (2) the realities of projected climate impacts, and (3) the use of complementary adaptation strategies, such as enhancing landscape connectivity.

Link: http://depts.washington.edu/oldenlab/wordpress/wp-content/uploads/2013/03/FrontiersEcoEnv_2011.pdf

356. McLachlan JS, Hellmann JJ, Schwartz MW. 2007. **A framework for debate of assisted migration in an era of climate change.** Conservation Biology 21:297-302.

Type: Journal

Geographic Area: Global

Compilers' Keywords: conservation, demography, ecosystem, biological extinction, genetic variation, greenhouse effect, biological models, population dynamics, policy, framework

Introduction: Assisted migration is contentious issue that places different conservation objectives at odds with one another. This element of debate, together with the growing risk of biodiversity loss under climate change, means the now is the time for the conservation community to consider assisted migration. Our intent here is to highlight the problem caused by a lack of a scientifically based policy on assisted migration, suggest a spectrum of policy options, and outline a framework for moving toward a consensus on this emerging conservation dilemma.

Link: http://www.ncbi.nlm.nih.gov/pubmed/17391179

357. Millar CI. 2013. **The role of assisted migration in climate adaptation planning: when and where to employ it?** In: Assisted Migration: A Primer for Reforestation and Restoration Decision Makers; Portland, OR. 42 p.

Type: Presentation

Geographic Area: Global

Compilers' Keywords: assisted migration, climate change, natural migration, decision making, resistance, resilience, response, realignment, spatial scales, temporal scales, paleoclimate

Abstract: In the face of changing climates, either historic or contemporary, species respond by adapting, moving, or dying (going extinct or populations extirpating). Assisted migration commonly has been discussed in the context of genetic adaptation. As background to addressing the questions of "When and where to employ assisted migration?" I briefly review as well the ways in which species have moved in response to historic climate change. This begins with an overview of principles regarding natural climate change that are relevant to decision-making for contemporary climate adaptation. In an historic context, climates: 1) have been changing continually;

2) express at multiple and nested scales, including interannual, decadal, centennial, and millennial; 3) are driven by mostly independent mechanisms at each scale; and 4) cumulatively result in climate changes that have been novel, gradual and directional, episodic and quasi-reversible, and chaotic. At long time scales and in response to large climate changes, species have migrated (shifted ranges) long distances (e.g., hundreds of kilometers) in regions of low relief or across large elevation gradients (e.g., 1000 m) in mountainous environments. Species responded individualistically based on life-history characteristics and inherent climate envelopes. As a result, community compositions (species diversity) were transient, emerging as novel assemblages of species associated together at any one time and place. In response to shorter time-scale and smaller magnitude climate changes, species responded less often with biogeographic range contractions or expansions and more through changes in demography, species dominance relationships, density and vigor, and disturbance regimes. Lessons that emerge for climate adaptation focus on working with, not against, these inherent adaptive responses of species in the face of climate change. That change has been constant, hoever, does not imply that "anything goes." I review lessons learned from natural climate responses for implications to concepts of native range, neo-native distributions, community resilience, novel climates and non-analog associations, "red queen" responses, the role of climatic refugia in maintenance of diversity, and pace of change following disturbance. With this background, I turn to issues regarding decision—making for assisted migration: when and where to employ it in the face of contemporary climate change. Institutional context influences these factors, whether goals are primarily for ecosystem services (production of goods and services) or ecosystem management (species protection and recovery). First principles apply, including: do no harm, don't fix what isn't broken, learn as you go; leave intact escape routes; and weigh risk and urgency into decisions. Scale also affects decisions regarding "When?" in climate adaptation: actions justifiably made for the short term or small spatial scale are likely different from those focused on long-term investments and benefits. In regard to "Where?" considerations are important for both the source (donor) and destination locations. In the former, genetic concerns often are paramount, but ecological issues such as co-factors of disease or insect transmission, history of the population, and vigor of propagules (seed or ramet stock) are equally important. Factors to consider at the destination locations include concerns for both the target species (how well it will thrive) and the receiving ecosystem (how it is affected). Effects to weight include invasiveness, genetic contamination, allelo-chemical and soil-nutrient alterations, phenology, community interactions and species displacement, and influences on disturbance regimes. I review these considerations relative to the four fundamental options for climate adaptation planning: resistance, resilience, response, and realignment (restoration), and provide illustrative examples for each. In conclusion I comment on policy and regulatory opportunities and constraints relative to implementing assisted migration.

Link: http://www.rngr.net/resources/assisted-migration

358. Minteer BA, Collins JP. 2010. Move it or lose it? The ecological ethics of relocating species under climate change. Ecological Applications 20:1801-1804.

Type: Journal

Geographic Area: Global

Keywords: climate change, ecological policy, ethics, managed relocation, species conservation

Abstract: Managed relocation (also known as assisted colonization, assisted migration) is one of the more controversial proposals to emerge in the ecological community in recent years. A conservation strategy involving the translocation of species to novel ecosystems in anticipation of range shifts forced by climate change, managed relocation (MR) has divided many ecologists and conservationists, mostly because of concerns about the potential invasion risk of the relocated species in their new environments. While this is indeed an important consideration in any evaluation of MR, moving species across the landscape in response to predicted climate shifts also raises a number of larger and important ethical and policy challenges that need to be addressed. These include evaluating the implications of a more aggressive approach to species conservation, assessing MR as a broader ecological policy and philosophy that departs from longstanding scientific and management goals focused on preserving ecological integrity, and considering MR within a more comprehensive ethical and policy response to climate change. Given the complexity and novelty of many of the issues at stake in the MR debate, a more dynamic and pragmatic approach to ethical analysis and debate is needed to help ecologists, conservationists, and environmental decision makers come to grips with MR and the emerging ethical challenges of ecological policy and management under global environmental change.

Link: http://cirge.stanford.edu/Minter_managedrelocation_ethics_2010.pdf

359. Odenbaugh J. 2013. Assisted migration and invasive species: exploring an ethical dilemma. In: Assisted Migration: A Primer for Reforestation and Restoration Decision Makers; Portland, OR. 22 p.

Type: Presentation

Geographic Area: Global

Compilers' Keywords: ecological morality, species extinctions, climate change, exotic species

Abstract: According to many, we are subject to two duties. First, it is morally wrong for human to cause a species to go extinct. Second, it is morally wrong to introduce a species into an area in which it is not native. Unfortunately, human-induced climate change will cause species to go extinct unless we relocate those species to areas outside their native range. Thus, we are either causing species to go extinct or creating exotic species both of which are morally wrong. In this talk, I consider ways of dealing with the environmental dilemma.

Link: http://www.rngr.net/resources/assisted-migration

360. Park A, Talbot C. 2012. Assisted migration: uncertainty, risk and opportunity. The Forestry Chronicle 88:412-419.

Type: Journal

Geographic Area: Canada

Keywords: assisted migration, managed relocation, climate change scenarios, uncertainty, ecophysiology, epigenetics

Abstract: The recent Forestry Chronicle special section on the subject of Assisted Migration (AM) did a great service to the Canadian forestry community by summarizing the risks, opportunities and ecological aspects of this forest management strategy. In this paper, we expand on some aspects of AM that were discussed in the special section, as well as discussing additional dimensions of AM that should be considered and debated. We expand on the theme of scientific uncertainties around future warming, emphasizing the full extent of uncertainty in estimates of climate sensitivity. We also expand upon and summarize a number of recent ecophysiological results that have implications for the adaptation and acclimation of trees to climate change. We also discuss opportunities for innovative forest management, the influence of economic trends on the future of the Canadian forest industry, and limitations on public knowledge of climate change, all of which are factors that will influence the feasibility of AM schemes in the future.

361. Pedlar J, McKenney DW, Aubin I, Beardmore T, Beaulieu J, Iverson LR, O'Neill GA, Winder RS, Ste-Marie C. 2012. Placing forestry in the assisted migration debate. BioScience 62:835-842.

Type: Journal

Geographic Area: North America

Keywords: assisted migration, climate change, forestry, conservation, trees

Abstract: Assisted migration (AM) is often presented as a strategy to save species that are imminently threatened by rapid climate change. This conception of AM, which has generated considerable controversy, typically proposes the movement of narrowly distributed, threatened species to suitable sites beyond their current range limits. However, existing North American forestry operations present an opportunity to practice AM on a larger scale, across millions of hectares, with a focus on moving populations of widely distributed, nonthreatened tree species within their current range limits. Despite these differences (and many others detailed herein), these two conceptions of AM have not been clearly distinguished in the literature, which has added confusion to recent dialogue and debate. Here, we aim to facilitate clearer communication on this ftopic by detailing this distinction and encouraging a more nuanced view of AM.

362. Peters RL. 1992. Conservation of biological diversity in the face of climate change. Chapter 2. In: Peters RL, Lovejoy TE, editors. Global warming and biological diversity. New Haven (CT): Yale University Press. p 15-31.

Type: Book Section

Geographic Area: Global

Compilers' Keywords: climate change, range shifts, conservation, guidelines

Introduction: We can infer how the biota might respond to climate change by observing present and past distributions of plants and animals, which are largely determined by temperature and moisture patterns. For example, one race of dwarf birch (*Betula nana*) can grow only where the temperature never exceeds 22 °C, suggesting that it would disappear from those areas where global warming causes temperatures to exceed 22 °C. Recent historical observations of changes in range and species dominance, such as the gradual replacement spruce (*Picea rubens*) by deciduous species during the past 180 years in the eastern United States, can also suggest future responses. Insight into long-term responses to large climatic changes can be gleaned from studies of fossil distributions of, particularly, pollen and small mammals. Such observations tell us that plants and animals are very sensitive to climate. Their ranges move when the climate patterns change—species die out in areas where they were once found and colonize new areas where the climate becomes newly suitable.

363. Peters RL, Darling JDS. 1985. The greenhouse-effect and nature reserves. BioScience 35:707-717.

Type: Journal

Geographic Area: Global

Compilers' Keywords: assisted migration, climate change, biodiversity, global warming, conservation, review, species extinctions

Introduction: Current human development and population trends suggest to all but the very optimistic that by the next century most other surviving terrestrial species may well be relegated to small patches of their original habitat, patches isolated by vast areas of human-dominated urban and agricultural lands. Without heroic measures of habitat conservation and intelligent management, hundreds of thousands of plant and animal species could become extinct by the end of this century, with more to follow in the next. In this paper, we will identify problems caused by climate change that affect biological communities, examine the particular difficulties faced by species in biological reserves, and suggest management options. Although we recognize that dealing with short-term extinction threats alone will strain the resources of conservationists, we feel that the possible negative effects of global warming could be so severe that conservation plans should be amended to reflect knowledge of climatic effects as soon as it becomes available. Decisions about the siting and design of reserves and assumptions about how much management will be needed in the future must reflect the increased demands, both economic and biological, of global warming.

364. Ricciardi A, Simberloff D. 2009. Assisted colonization is not a viable conservation strategy. Trends in Ecology and Evolution 24:248-253.

Type: Journal

Geographic Area: Global

Compilers' Keywords: animals, conservation, ecosystem, biological extinction, human activities, biological models, plants, assisted migration, management

Abstract: A potential conservation strategy increasingly discussed by conservation biologists is the translocation of species to favorable habitat beyond their native range to protect them from human-induced threats, such as climate change. Even if preceded by careful risk assessment, such action is likely to produce myriad unintended and unpredictable consequences. Accurate risk assessment is impeded by contingency: the impacts of introduced species vary over time and space under the influence of local environmental variables, interspecific interactions and evolutionary change. Some impacts, such as native species extinctions, are large and irrevocable. Here we argue that conservation biologists have not yet developed a sufficient understanding of the impacts of introduced species to make informed decisions regarding species translocations.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19324453

365. Roberts L. 1989. How fast can trees migrate? Science 243:735-737.

Type: Journal

Geographic Area: USA

Compilers' Keywords: research news, tree migration, climate change, forest management, review, rates

Introduction: The forests in the south will go first. Seedlings will wither, the understory plants will be replaced. And over the next century or so, many now-abundant trees will go extinct across much of the United States. Such are the predictions of Margaret Davis, one of handful of ecologists looking at the effects of the much discussed greenhouse warming on North American forests. As Davis and others who make these predictions readily admit, they are riddled with uncertainties. Data are scarce and have been cobbled together from fossil records, theoretical models, and experiments in controlled environments. Few long-term field studies have been done. The critical question to Davis and a colleague, Catherine Zabinski, is how quickly trees can migrate, for the fate of numerous species in North America will depend on whether they can shift north to cooler climates when their current range becomes uninhabitable.

366. Safford HD, Hellmann JJ, McLachlan JM, Sax DF, Schwartz MW. 2009. Managed relocation of species: Noah's Ark or Pandora's Box? Eos 90:1.

Type: Journal

Geographic Area: Global

Compilers' Keywords: assisted migration, species conservation

Introduction: "Managed relocation" (MR; also called "assisted migration" or "assisted colonization") is the human-aided movement of species adversity affected by global change where these species cannot move themselves. Goals of MR include, but are not limited to, conservation of biodiversity, reduction of extinction risk, enhancement of evolutionary potential, and maintenance or augmentation of ecosystem services. Recently there has been much talk, in the scientific literature as well as in the press, about the costs and benefits of MR. As a conservation strategy, MR has promise, but it could also have serious collateral costs. For example, MR may succeed in rescuing a given species from extinction, but it may also introduce a species into habitat where it becomes invasive, causing ecosystem disruptions or extinctions of other taxa. A working group met in August 2008, in conjunction with the annual meeting of the ESA, to develop a framework for understanding the degree to which MR could achieve its objectives, the risks that it might incur, and strategies that could be used to implement it.

367. Sandler R. 2010. The value of species and the ethical foundations of assisted colonization. Conservation Biology 24:424-431.

Type: Journal

Geographic Area: Global

Keywords: assisted colonization, biodiversity, ecosystem management, value of species

Abstract: Discourse around assisted colonization focuses on the ecological risks, costs, and uncertainties associated with the practice, as well as on its technical feasibility and alternative approaches to it. Nevertheless, the ethical underpinnings of the case for assisted colonization are claims about the value of species. A complete discussion of assisted colonization needs to include assessment of these claims. For each type of value that species are thought to possess it is necessary to determine whether it is plausible that species possess the type of value and, if so, to what extent their possessing it justifies assisted

colonization. I conducted such an assessment for each of the predominant types of value ascribed to species: ecological, instrumental (including option value), existence, and intrinsic value (including interest-based, objective, and value-dependent intrinsic value). The vast majority of species, including several that have been proposed as candidates for assisted colonization, have much less value than is often presumed. Moreover, with respect to some types of value, assisted colonization would not fully preserve the value of the target species even if it were to keep the target species in existence. Therefore, the case for assisted colonization is significantly weaker and more qualified than its advocates often suppose. There may be exceptional species for which assisted colonization is well justified—and for this reason, case-by-case assessment is necessary—but in general the burden of justification generated by the ecological risks associated with assisted colonization is not met by the value potentially preserved by assisted colonization. This suggests that assisted colonization ought to have, at most, a very minor role in the portfolio of ecosystem management practices, even as it pertains to species conservation under conditions of rapid climate change.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19878237

368. Sax DF, Smith KF, Thompson AR. 2009. Managed relocation: a nuanced evaluation is needed. Trends in Ecology and Evolution 24:472.

Type: Journal

Geographic Area: Global

Compilers' Keywords: assisted migration, climate change

Introduction: Managed relocation (aka 'assisted colonization' and 'assisted migration') aims to save species from the effects of climate change by purposefully transporting them to areas where they have not previously occurred, but where they are expected to survive as temperatures increase. In a recent Opinion article in TREE, Ricciardi and Simberloff suggest that 'assisted colonization is tantamount to ecological roulette and should probably be rejected as a sound conservation strategy by the precautionary principle.' We disagree for three primary reasons. First, the precautionary principle is not a stand-alone reason to rule out managed relocation. Second, we know more about the impacts of species invasions than Ricciardi and Simberloff suggest, particularly with respect to species extinction. Third, because extinctions are permanent and irreversible, using managed relocation to reduce extinctions at the cost of changing the composition and functioning of ecosystems is a tradeoff that some managers might be willing to make. Ultimately, the risk of species extinctions from climate changes is too large to summarily discount managed relocation without first carefully evaluating its benefits and dangers in a nuanced way.

Link: http://www.brown.edu/Research/Sax_Research_Lab/Documents/PDFs/reply%20to%20managed%20relocation.pdf

369. Schlaepfer MA, Helenbrook WD, Searing KB, Shoemaker KT. 2009. Assisted colonization: evaluating contrasting management actions (and values) in the face of uncertainty. Trends in Ecology and Evolution 24:421-422.

Type: Journal

Geographic Area: Global

Compilers' Keywords: assisted migration, conservation, debate

Introduction: In their recent opinion article in Trends in Ecology & Evolution, Ricciardi and Simberloff argue that assisted colonization is not an appropriate management option because the impacts of introduced species are too difficult to predict, and can have harmful consequences for recipient ecosystems, including the extinction of native species. Invoking the precautionary principle, the authors argue that alternative conservation tactics must be pursued, even for species faced with extinction in their native range. We concur with the authors that there are risks associated with introducing species outside of their current range. However, we disagree that these risks are so great that assisted colonization should not be considered among possible management options.

Link: http://noss.cos.ucf.edu/papers/Schlaepfer%20et%20al%202009%20and%20Sax%20et%20al%202009.pdf

370. Schwartz MW. 1994. Conflicting goals for conserving biodiversity: issues of scale and value. Natural Areas Journal 14:213-216.

Type: Journal

Geographic Area: Global

Compilers' Keywords: review, conservation, translocation, assisted migration

Abstract: Differing conservation values create a multiplicity of goals toward which conservation activities are directed. Multiple and differing goals also are inherent in conservation at differing spatial and temporal scales. In many cases these different goals result in management actions that are complementary and that simultaneously benefit many species and habitats. In contrast, there are instances in which conservation for one set of values, or at one spatial scale, suggests a management action that would violate other conservation goals. I define the goals and value systems used to support biological conservation and present three cases where differing conservation objectives conflict. Specifically, I address how (1) a proposed translocation of an endangered species outside its historic range, to prevent its extinction, would violate the historic integrity of the recipient community; (2) the use of fire, to maintain plant community composition in grasslands, may threaten native insect biodiversity; and (3) assisting the process of long-distance seed dispersal, to aid plant-range shifts disrupted by anthropogenic climate warming, would violate the integrity of recipient plant communities. While examples of conflicting goals are not hard to describe, they are hard to resolve and pose challenges to conservation biology that are not adequately addressed at the present time. Increased use of goal-setting would improve our ability to explicitly measure the success of conservation projects. Failure to set priorities and goals in conservation management implies a misplaced faith in the balance of nature.

371. Schwartz MW, Hellmann JJ, McLachlan JM, Sax DF, Borevitz JO, Brennan J, Camacho AE, Ceballos G, Clark JR, Doremus H, Early R, Etterson JR, Fielder D, Gill JL, Gonzalez P, Green N, Hannah L, Jamieson DW, Javeline D, Minteer BA, Odenbaugh J, Polasky S, Richardson DM, Root TL, Safford HD, Sala O, Schneider SH, Thompson AR, Williams JW, Vellend M, Vitt P, Zellmer S. 2012. Managed relocation: integrating the scientific, regulatory, and ethical challenges. BioScience 62:732-743.

Type: Journal

Geographic Area: Global

Keywords: ethics, policy, law, conservation, translocation

Abstract: Managed relocation is defined as the movement of species, populations, or genotypes to places outside the areas of their historical distributions to maintain biological diversity or ecosystem functioning with changing climate. It has been claimed that a major extinction event is under way and that climate change is increasing its severity. Projections indicating that climate change may drive substantial losses of biodiversity have compelled some scientists to suggest that traditional management strategies are insufficient. The managed relocation of species is a controversial management response to climate change. The published literature has emphasized biological concerns over difficult ethical, legal, and policy issues. Furthermore, ongoing managed relocation actions lack scientific and societal engagement. Our interdisciplinary team considered ethics, law, policy, ecology, and natural resources management in order to identify the key issues of managed relocation relevant for developing sound policies that support decisions for resource management. We recommend that government agencies develop and adopt best practices for managed relocation.

372. Seddon PJ. 2010. From reintroduction to assisted colonization: moving along the conservation translocation spectrum. Restoration Ecology 18:796-802.

Type: Journal

Geographic Area: Global

Keywords: ecological engineering, novel ecosystems, population restoration, species introductions

Abstract: Translocation, the intentional movement of living organisms from one area to another is increasingly being used as a conservation tool to overcome barriers to dispersal. A dichotomy exists for conservation-oriented translocations: on one hand, there are those that release plants or animals into known historic ranges and on the other hand, there are releases outside historic distributions. Misuse of or attempts to redefine established terms and a proliferation of variants of new terms such as assisted colonization confuse and hamper communication. The aim of this opinion article is to describe and define a conservation translocation spectrum, from species reintroductions to assisted colonization, and beyond, and in so doing provide a standard framework and terminology for discussing translocation options. I suggest that we are moving along this spectrum, away from the dictates of historical species distribution records, toward the inclusion of more risky interventions that will be required to respond to habitat shifts due to anthropogenic impacts. To some extent rapid climate change changes everything, including how we should view introductions versus reintroductions. We need to seriously consider adding other approaches to our conservation toolbox. Assisted colonization will start us along this path, acknowledging as it does the accelerated rate of habitat change and the problems of attempting to preserve dynamic systems. The next step along the conservation translocation spectrum may be for reintroduction biology and restoration ecology to more comprehensively join forces on carefully selected projects to use species introductions to create novel ecosystems through active ecological community construction.

373. Shirey PD, Lamberti GA. 2010. Assisted colonization under the U.S. Endangered Species Act. Conservation Letters 3:45-52.

Type: Journal

Geographic Area: USA

Keywords: assisted colonization, assisted migration, climate change, endangered species act, endangered species policy, experimental population provision, managed relocation, Mitchell's satyr butterfly, *Neonympha mitchellii mitchellii*, translocation

Abstract: Assisted colonization could help prevent the extinction of threatened and endangered species by intentionally moving a species to a region where it has not occurred in the recent past, but should survive under future climate scenarios. Where species are naturally localized and confined to patchy habitats, assisted colonization might be the only means for population dispersal across human landscape barriers such as urban and agriculture areas. The major risk associated with assisted colonization is introducing ecologically harmful species. Previous policy papers have described management options for deciding when to move a species to mitigate for climate change. We build on this previous work by examining management options and policy solutions for assisted colonization under the U.S. Endangered Species Act (ESA). On its surface, the ESA statutory language appears to provide the legal framework for allowing assisted colonization, as the U.S. Congress gave the U.S. Fish and Wildlife Service (USFWS) broad discretion to manage populations of endangered species. However, current USFWS regulations are an impediment to assisted colonization for many endangered animal species, whereas regulations do not necessarily restrict assisted colonization of endangered plants. Because this discrepancy, we recommend a review of the regulatory language governing movements of endangered species.

Link: http://dev.cakex.org/sites/default/files/Assisted%20colonization%20under%20the%20U.S.%20Endangered%20Species%20Act.pdf

374. Sollenberger D, Vitt P, Yates E. 2010. Climate change, seeding banking and assisted migration - the long shadows of humanity. In: National Native Seed Conference: Native Plant Materials Development, Production, and Use in Habitat Restoration. Corvallis (OR): Institute for Applied Ecology. 33 p.

Type: Presentation

Geographic Area: USA

Compilers' Keywords: MaxEnt, *Cirsium pitcheri*, *Andropogon gerardii*, seed collection

Abstract: Rapid climate change has the potential to alter the climatic regime of many plant species globally. Plant species will respond variously via phenotypic plasticity, evolutionary adaptation, migration, or extinction. Using Species Distribution Model to predict how the bioclimatic envelopes for individual species might shift can provide insight into conservation strategies, including seed banking. When fragmentation limits the migration potential or when natural migration rates are outstripped by the pace of climate change, some propose purposeful, human-mediated migration (assisted migration or manage relocation) as a solution. We present a strategy to collect and bank seeds of plant species at risk of extinction in the face of rapid climate change to ensure that emerging habitats are as species-diverse as possible.

Link: http://nativeseed.info/2010/presentations/Vitt.pdf

375. Ste-Marie C, Nelson EA, Dabros A, Bonneau M. 2011. Assisted migration: introduction to a multifaceted concept. The Forestry Chronicle 87:724-730.

Type: Journal

Geographic Area: Canada

Keywords: assisted migration, Canada's forests, climate change, forest management, adaptation, species migration

Abstract: The idea that humans can assist nature by purposely moving species to suitable habitats to fill the gap between their migration capability and the expected rate of climate change is being increasingly contemplated and debated as an adaptive management option. The interest in assisted migration, both in the scientific community and society at large, is growing rapidly and is starting to be translated into action in Canada. However, the concept is in its infancy; clear terminology has not yet been established and assisted migration still encompasses a broad range of practices. This introductory paper for the special issue of The Forestry Chronicle on the subject of assisted migration describes increasing interest in the subject and its complexity. It also provides an overview of the potential scale of assisted migration, proposes a terminology, and briefly introduces the following papers. Overall, the five papers aim to present a comprehensive state of the scientific and operational knowledge and the debate on assisted migration in the context of Canada's forests.

376. Stone R. 2010. Home, home outside the range? Science 329:1592-1594.

Type: Journal

Geographic Area: Global

Compilers' Keywords: assisted migration, climate change, conservation, assisted colonization, butterfly, Orchidaceae

Compilers' Summary: One of the earlier popular press articles about moving species to new places in response to climate change. In China, orchids will be impacted by an increase in temperature, such that some scientists are considering assisted colonization to save species. But other scientists fear that movements may cause more harm than good. The article discusses both sides of the debate.

Link: http://plantecology.syr.edu/conbio/readings/Stone2010.pdf

377. Thomas CD. 2011. Translocation of species, climate change, and the end of trying to recreate past ecological communities. Trends in Ecology Evolution 26:216-221.

Type: Journal

Geographic Area: Global

Compilers' Keywords: biota, conservation, environment, conservation, environment, extinction, review

Abstract: Many of the species at greatest risk of extinction from anthropogenic climate change are narrow endemics that face insurmountable dispersal barriers. In this review, I argue that the only viable option to maintain populations of these species in the wild is to translocate them to other locations where the climate is suitable. Risks of extinction to native species in destination areas are small, provided that translocations take place within the same broad geographic region and that the destinations lack local endemics. Biological communities in these areas are in the process of receiving many hundreds of other immigrant species as a result of climate change; ensuring that some of the 'new' inhabitants are climate-endangered species could reduce the net rate of extinction.

Link: http://www.ncbi.nlm.nih.gov/pubmed/21411178

378. Watts A. 2014. Assisted migration: growing forests adapted to the future. The Forestry Source 19:1, 3.

Type: Newsletter

Geographic Area: North America

Compilers' Keywords: forest management, silviculture, Assisted Migration Adaptation Trial, Society of American Foresters

Introduction: Of the management strategies available to create resilient, productive forests in a changing climate, assisted migration is one strategy that is prompting much discussion in the forestry community. Assisted migration is viewed as a proactive strategy because many tree species do not have the ability to adapt or migrate naturally at the same rate as the climate is expected to change. This mismatch between trees and their environment could result in forests that are less productive and unhealthy.

379. Williams MI, Dumroese RK. 2013. Growing assisted migration: synthesis of a climate change adaptation strategy. In: Haase DL, Pinto JR, Wilkinson KM, editors. National Proceedings: Forest and Conservation Nursery Associations—2012. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-69. p 90-96.

Type: Government Document

Geographic Area: North America

Keywords: climate change, decision framework, implementation, managed relocation, native plant transfer guidelines, seed transfer zones

Abstract: Assisted migration may be necessary as a climate change adaptation strategy for native plant species that are less adaptive or mobile. Moving plants has been practiced a long time in human history, but movement of species in response to climate change is a new context. First proposed in 1985, assisted migration has gained attention since 2007 as a strategy to prevent species extinction, minimize economic loss, and sustain ecosystem services. We present a synthesis of proposed assisted migration guidelines and provide resources for nurseries, landowners, and researchers.

Link: http://www.treesearch.fs.fed.us/pubs/45634

380. Williams MI, Dumroese RK. 2014. Planning the future's forests with assisted migration. In: Sample VA, Bixler RP, editors. Forest Conservation and Management in the Anthropocene: Adaptation of Science, Policy, and Practices. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-71. p 133-144.

Type: Government Document

Geographic Area: Global

Keywords: assisted migration, strategies, review, forest management

Abstract: Studies show that changes in climate may exceed plant adaptation and migration. The mismatch in rates between climate change and plant adaptation and migration will pose significant challenges for practitioners that select, grow, and outplant native tree species. Native tree species and populations that are planted today must meet the climatic challenges that they will face during this century. Anticipated shifts in climate call for the revision of ethical, legal, political, and economical paradigms, as well as changes in the guidelines for growing and outplanting trees to maximize survival and curtail maladaptation. Growing trees that survive may be more important than growing perfectly shaped trees and may require selection of adapted genetic material and/or movement of plant populations (for example, assisted migration). We review and explore assisted migration as an adaptation strategy, present some working examples, and provide resources for consultation.

Link: http://www.treesearch.fs.fed.us/pubs/46582

Migration

General (339–380)—debates, reviews, trends, surveys, summaries

Research (381–540)—migration studies, range shifts, reintroductions

Strategies (541–580)—adaptation options, frameworks, decision support

Resources (581–582)—tools, websites, software

Each reference contains the following:

#. Author(s), Date. Title. Source. — ID number and information

Type: — book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page

Geographic Area: — location of study

Keywords: — keywords written by the author(s) or provided by the compilers

Description: — abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers

Link: — internet address of reference

381. Ager A, Nordh NE, Ledin S, Ostry M, Carlson M, Ronnberg-Wastljung A. 1990. International transfer of *Alnus*, *Populus*, and *Salix* germplasm: early test results. Biomass 22:49-62.

Type: Journal

Geographic Area: Canada, USA, Sweden

Keywords: biomass, alders, poplars, willows, energy forestry, tree improvement

Abstract: The interim results of a genetic testing program established within the International Energy Agency (lEA) Forestry Energy Agreement are reported. The 'Joint Evaluation Activity' was initiated to evaluate *Alnus*, *Populus* and *Salix* germplasm collected by lEA projects and national programs. The project was designed to compare the growth rates of selected genetic materials under a variety of growing environments, and identify germplasm with potential for biomass cultivation. The project was also designed to examine the limitations of long-distance international transfer of alder, poplar, and willow clones/provenances ~ species among national biomass programs. Four field tests were established, each containing selected clones and provenances of alder poplar and willow. Three-year growth data are reported here that identify genetic materials with superior growth potential in one or more of the test environments. They also identify the maximum climatic tolerance of several previously untested species/provenances. The results can be used to guide the selection of materials for future exchanges among the national programs participating in the study.

382. Aitken SN, Whitlock MC. 2013. Assisted gene flow to facilitate local adaptation to climate change. Annual Review of Ecology, Evolution, and Systematics 44:367-388.

Type: Journal

Geographic Area: Global

Keywords: assisted migration, evolutionary rescue, genetic rescue, outbreeding depression, phenotypic plasticity, seed transfer, ecological restoration, reforestation, facilitated adaptation

Abstract: Assisted gene flow (AGF) between populations has the potential to mitigate maladaptation due to climate change. However, AGF may cause outbreeding depression (especially if source and recipient populations have been long isolated) and may disrupt local adaptation to nonclimatic factors. Selection should eliminate extrinsic outbreeding depression due to adaptive differences in large populations, and simulations suggest that, within a few generations, evolution should resolve mild intrinsic outbreeding depression due to epistasis.

To weigh the risks of AGF against those of maladaptation due to climate change, we need to know the species' extent of local adaptation to climate and other environmental factors, as well as its pattern of gene flow. AGF should be a powerful tool for managing foundation and resource-producing species with large populations and broad ranges that show signs of historical adaptation to local climatic conditions.

Link: http://www.annualreviews.org/doi/abs/10.1146/annurev-ecolsys-110512-135747

383. Aitken SN, Yeaman S, Holliday JA, Wang T, Curtis-McLane S. 2008. Adaptation, migration or extirpation: climate change outcomes for tree populations. Evolutionary Applications 1:95-111.

Type: Journal

Geographic Area: Global

Keywords: conifer, ecological genetics, forest, gene flow, genomics, population, selection, species distribution models

Abstract: Species distribution models predict a wholesale redistribution of trees in the next century, yet migratory responses necessary to spatially track climates far exceed maximum post-glacial rates. The extent to which populations will adapt will depend upon phenotypic variation, strength of selection, fecundity, interspecific competition, and biotic interactions. Populations of temperate and boreal trees show moderate to strong clines in phenology and growth along temperature gradients, indicating substantial local adaptation. Traits involved in local adaptation appear to be the product of small effects of many genes, and the resulting genotypic redundancy combined with high fecundity may facilitate rapid local adaptation despite high gene flow. Gene flow with preadapted alleles from warmer climates may promote adaptation and migration at the leading edge, while populations at the rear will likely face extirpation. Widespread species with large populations and high fecundity are likely to persist and adapt, but will likely suffer adaptation lag for a few generations. As all tree species will be suffering lags, interspecific competition may weaken, facilitating persistence under suboptimal conditions. Species with small populations, fragmented ranges, low fecundity, or suffering declines due to introduced insects or diseases should be candidates for facilitated migration.

Link: http://www3.botany.ubc.ca/rieseberglab/plantevol/Aitken_et_al_2008.pdf

384. Alberto FJ, Aitken SN, Alia R, Gonzalez-Martinez SC, Hanninen H, Kremer A, Lefevre F, Lenormand T, Yeaman S, Whetten R, Savolainen O. 2013. Potential for evolutionary responses to climate change—evidence from tree populations. Global Change Biology 19:1645-1661.

Type: Journal

Geographic Area: Northern Hemisphere

Keywords: adaptive traits, conifers, local adaptation, natural selection, phenotypic plasticity, provenance trial, quantitative genetics

Abstract: Evolutionary responses are required for tree populations to be able to track climate change. Results of 250 years of common garden experiments show that most forest trees have evolved local adaptation, as evidenced by the adaptive differentiation of populations in quantitative traits, reflecting environmental conditions of population origins. On the basis of the patterns of quantitative variation for 19 adaptation-related traits studied in 59 tree species (mostly temperate and boreal species from the Northern Hemisphere), we found that genetic differentiation between populations and clinal variation along environmental gradients were very common (respectively, 90% and 78% of cases). Thus, responding to climate change will likely require that the quantitative traits of populations again match their environments. We examine what kind of information is needed for evaluating the potential to respond, and what information is already available. We review the genetic models related to selection responses, and what is known currently about the genetic basis of the traits. We address special problems to be found at the range margins, and highlight the need for more modeling to understand specific issues at southern and northern margins. We need new common garden experiments for less known species. For extensively studied species, new experiments are needed outside the current ranges. Improving genomic information will allow better prediction of responses. Competitive and other interactions within species and interactions between species deserve more consideration. Despite the long generation times, the strong background in quantitative genetics and growing genomic resources make forest trees useful species for climate change research. The greatest adaptive response is expected when populations are large, have high genetic variability, selection is strong, and there is ecological opportunity for establishment of better adapted genotypes.

Link: http://www.ncbi.nlm.nih.gov/pubmed/23505261

385. Albrecht MA, Guerrant EO Jr, Maschinski J, Kennedy KL. 2011. A long-term view of rare plant reintroduction. Biological Conservation 144:2557-2558.

Type: Journal

Geographic Area: Global

Compilers' Keywords: rare plant conservation, literature review

Introduction: Drawing on a literature review and survey questionnaires, Godefroid et al. (2011) explore how demographic, genetic, and ecological factors influence success rates in plant reintroductions and present valuable recommendations to improve plant reintroduction success. But we are concerned that the generally dismal picture they paint may erroneously be viewed by conservation practitioners, land managers, and policy makers as being broadly representative of reintroduction in general, causing hesitation or even dismissing reintroduction as a beneficial conservation tool.

386. Anderson AS, Reside AE, VanDerWal JJ, Shoo LP, Pearson RG, Williams SE. 2012. **Immigrants and refugees: the importance of dispersal in mediating biotic attrition under climate change.** Global Change Biology 18:2126-2134.

Type: Journal

Geographic Area: Australia

Keywords: climate change, global warming, MAXENT, montane tropics, ornithology, range shift

Abstract: Montane tropical rainforests are critically important areas for global bird diversity, but are projected to be highly vulnerable to contemporary climate change. Upslope shifts of lowland species may partially offset declines in upland species but also result in a process of lowland biotic attrition. This latter process is contingent on the absence of species adapted to novel warm climates, and isolation from pools of potential colonizers. In the Australian Wet Tropics, species distribution modelling has forecast critical declines in suitable environmental areas for upland endemic birds, raising the question of the future role of both natural and assisted dispersal in species survival, but information is lacking for important neighbouring rainforest regions. Here we use expanded geographic coverage of data to model the realized distributions of 120 bird species found in north-eastern Australian rainforest, including species from potential source locations in the north and recipient locations in the south. We reaffirm previous conclusions as to the high vulnerability of this fauna to global warming, and extend the list of species whose suitable environmental area is projected to decrease. However, we find that expansion of suitable area for some species currently restricted to northern rainforests has the potential to offset biotic attrition in lowland forest of the Australian Wet Tropics. By examining contrasting dispersal scenarios, we show that responses to climate change in this region may critically depend on dispersal limitation, as climate change shifts the suitable environmental envelopes of many species south into currently unsuitable habitats. For lowland and northern species, future change in vegetation connectivity across contemporary habitat barriers is likely to be an important mediator of climate change impacts. In contrast, upland species are projected to become increasingly isolated and restricted. Their survival is likely to be more dependent on the viability of assisted migration, and the emergence and persistence of suitable environments at recipient locations.

387. BC Ministry of Forests. 2009. **Assisted migration adaptation trial.** British Columbia, Canada: BC Ministry of Forests, Land and Natural Resource Operations. (URL accessed 29 November 2015)

Type: Web Page

Geographic Area: Western North America

Compilers' Keywords: forest management, climate change

Summary: Approximately 200 million seedlings are planted in BC each year. When those trees are harvested 60-80 years after they are planted, the climate could be 3-4 degrees warmer than when the seedlings were planted, exposing the trees to maladaptation and health risks. Consequently, Ministry of Forests, Land and Natural Resource Operations researchers have initiated a large, long-term climate change research study—the Assisted Migration Adaptation Trial (AMAT)—to better understand tree species' climate tolerances. Seeds from 15 species growing in BC and neighboring U.S. states were planted between 2009 and 2012 at 48 reforestation sites from northern California to southern Yukon. Their growth and health will be monitored, and related to the climate of the plantations, enabling researchers to identify the seed sources most likely to be best adapted to current and future climates. The information will be used to revise BC's species and seed source selection guidelines, helping to ensure maximum health and productivity of BC's planted forests well into the future.

Link: http://www.for.gov.bc.ca/hre/forgen/interior/AMAT.htm

388. Beardmore T, Winder R. 2011. **Review of science-based assessments of species vulnerability: contributions to decision-making for assisted migration.** The Forestry Chronicle 87:745-754.

Type: Journal

Geographic Area: Canada

Keywords: climate change, forest species, vulnerability assessments

Abstract: Assessing climate change impacts on forest species can significantly assist forest management planning. Recently, many tools have been developed for assessing species-specific vulnerability to climate change. These tools are question-based assessments that consider multiple criteria for individual species; the criteria are related to exposure and sensitivity to climate change. The following tools are discussed in relation to their use in Canada: (1) the NatureServe Climate Change Vulnerability Index; (2) the System for Assessing Vulnerability of Species to Climate Change (SAVS); (3) the Forest Tree Genetic Risk Assessment; (4) the Index for Predicting Tree Species Vulnerability; (5) ecological standards developed for the assisted migration of *Torreya taxifolia*; and (6) the Seeds of Success Program. These tools can all be applied to different forest species and they vary in such areas as their species-specific evaluation criteria, means for addressing uncertainty, and the integration of climate change models.

389. Beckage B, Osborne B, Gavin DG, Pucko C, Siccama T, Perkins T. 2008. A rapid upward shift of a forest ecotone during 40 years of warming in the Green Mountains of Vermont. Proceedings of the National Academy of Sciences USA 105:4197-4202.

Type: Journal

Geographic Area: Northeastern USA

Keywords: climate change, range shifts

Abstract: Detecting latitudinal range shifts of forest trees in response to recent climate change is difficult because of slow demographic rates and limited dispersal but may be facilitated by spatially compressed climatic zones along elevation gradients in montane environments. We resurveyed forest plots established in 1964 along elevation transects in the Green Mountains (Vermont) to examine whether a shift had occurred in the location of the northern hardwood-boreal forest ecotone (NBE) from 1964 to 2004. We found a 19% increase in dominance of northern hardwoods from 70% in 1964 to 89% in 2004 in the lower half of the NBE. This shift was driven by a decrease (up to 76%) in boreal and increase (up to 16%) in northern hardwood basal area within the lower portions of the ecotone. We used aerial photographs and satellite imagery to estimate a 91- to 119-m upslope shift in the upper limits of the NBE from 1962 to 2005. The upward shift is consistent with regional climatic change during the same period; interpolating climate data to the NBE showed a 1.1 °C increase in annual temperature, which would predict a 208-m upslope movement of the ecotone, along with a 34% increase in precipitation. The rapid upward movement of the NBE indicates little inertia to climatically induced range shifts in montane forests; the upslope shift may have been accelerated by high turnover in canopy trees that provided opportunities for ingrowth of lower elevation species. Our results indicate that high-elevation forests may be jeopardized by climate change sooner than anticipated.

Link: http://www.ncbi.nlm.nih.gov/pubmed/18334647

390. Becker U, Dostal P, Jorritsma-Wienk LD, Matthies D. 2008. The spatial scale of adaptive population differentiation in a wide-spread, well-dispersed plant species. Oikos 117:1865-1873.

Type: Journal

Geographic Area: Europe

Compilers' Keywords: adaptation, *Hypochoeris radicata*, reciprocal transplant, genetic variation, gene flow

Abstract: Adaptation to the specific conditions at different sites may contribute strongly to the wide distribution of a plant species. However, little is known about the scale at which such adaptation occurs in common species. We studied population differentiation, plasticity and local adaptation of the short-lived perennial *Hypochoeris radicata*, a widespread and common plant whose seeds are well dispersed. We reciprocally transplanted seedlings among several populations of different size within and among three European regions (in the northwest Czech Republic, central Germany and the central Netherlands) and studied several fitness-related traits over two growing seasons. The region in which the reciprocal transplant experiment was carried out had no influence on the performance of seedlings, indicating that there were no differences in overall habitat quality. In contrast, the site within region, and the plot within site strongly influenced mean plant performance. Plants from different populations of origin differed in their performance, indicating genetic variation among populations, but performance strongly depended on the specific combination of population of origin and transplant site. Plants that grew at their home site produced on average almost twice the number of seeds per transplant (a multiplicative fitness measure) than foreign plants originating from other sites. Survival, rosette size and multiplicative fitness all decreased with increasing distance from the home site to the transplant site. The size of the population of origin did not influence overall plant performance or the strength of local adaptation. In conclusion, our results indicate that the common and widespread H. radicata consists of locally adapted genotypes within its European range at a relatively small scale. Thus a large potential for gene flow by seeds and a high density of populations do not appear to be sufficient to prevent population differentiation by selection.

391. Bennie J, Hodgson JA, Lawson CR, Holloway CT, Roy DB, Brereton T, Thomas CD, Wilson RJ. 2013. Range expansion through fragmented landscapes under a variable climate. Ecology Letters 16:921-929.

Type: Journal

Geographic Area: United Kingdom

Keywords: climate variability, colonization, environmental threshold model, extinction, habitat networks, mechanistic model, metapopulation dynamics, microrefugia, species distribution

Abstract: Ecological responses to climate change may depend on complex patterns of variability in weather and local microclimate that overlay global increases in mean temperature. Here, we show that high-resolution temporal and spatial variability in temperature drives the dynamics of range expansion for an exemplar species, the butterfly *Hesperia comma*. Using fine-resolution (5 m) models of vegetation surface microclimate, we estimate the thermal suitability of 906 habitat patches at the species' range margin for 27 years. Population and metapopulation models that incorporate this dynamic microclimate surface improve predictions of observed annual changes to population density and patch occupancy dynamics during the species' range expansion from 1982 to 2009. Our findings reveal how fine-scale, short-term environmental variability drives rates and patterns of range expansion through spatially localized, intermittent episodes of expansion and

contraction. Incorporating dynamic microclimates can thus improve models of species range shifts at spatial and temporal scales relevant to conservation interventions.

Link: http://www.ncbi.nlm.nih.gov/pubmed/23701124

392. Bennuah SY, Wang T, Aitken SN. 2004.

Genetic analysis of the *Picea sitchensis* x *glauca* introgression zone in British Columbia. Forest Ecology and Management 197:65-77.

Type: Journal

Geographic Area: Western Canada

Keywords: Sitka spruce, white spruce, introgression zone, hybrid index, STS markers, allozymes, geographic pattern

Abstract: A genetic analysis of the introgression zone between Sitka spruce (*Picea sitchensis*) and white spruce (*P. glauca*) in northwestern British Columbia was conducted to (1) quantify the contributions of parental species to introgressed populations; (2) characterize genetic patterns of variation across the introgression zone; and (3) address practical issues of gene resource management in this region. Seeds were sampled and seedlings grown from 57 putative hybrid parent trees from 16 locations across the introgression zone. Foliage samples were also obtained for allopatric Sitka and white spruce reference populations. Based on allele frequencies for sequence-tagged-site (STS) molecular markers, a hybrid index was developed that reflects the relative contribution of Sitka spruce to hybrid populations (0 = white spruce, 1 = Sitka spruce). Mean STS hybrid index estimates ranged from 0.46 to 0.95 for locations within the zone of introgression. Significant differences in hybrid index were observed among sampling locations. Hybrid indices decreased from the coast to the interior within the introgression zone in spite of large among family variation within locations. Variation among locations in hybrid index was better explained by geographic variables than by climatic or ecological variables. Physical drainage distance along river valleys to the nearest marine inlet explained 78% of the variation in STS hybrid index. Concordant clines were obtained when the same analytical techniques were applied to published allozyme frequencies for seedlots originating from a wider geographic area across the introgression zone. Allozyme hybrid index estimates ranged from 0.01 to 0.98. The relatively steep cline observed in hybrid index across the maritime/continental climate ecotone is best managed by limiting longitudinal seed transfer for reforestation in this region.

393. Biere A, Verhoeven KJF. 2008.

Local adaptation and the consequences of being dislocated for coevolved enemies. New Phytologist 180:265-268.

Type: Journal

Geographic Area: Global

Compilers' Keywords: assisted migration, translocation, maladaptation, commentary, *Laccaria*, editorial

Introduction: Plants are being moved across the globe at an increasing rate both within and outside their current distributional range. Research in the past few decades has focused intensely on invasive exotic plant species that are moved outside their distributional range. Such invaders can have dramatic impacts on indigenous communities through altered biotic interactions with competitors, mutualists, and antagonists. But likewise, translocation within the distributional range exposes nonnative plant genotypes to interactions with nonlocal coevolved competitors, mutualists, and antagonists. A major concern in restoration ecology is that translocation of seeds from foreign seed sources introduces plant genotypes that are maladapted to local conditions and subsequently hybridize with locally adapted conspecifics, decreasing mean population fitness. Interestingly, while local adaptation of plants to their abiotic environment is well documented, warranting the concern, studies of plant local adaptation to their biotic environment have shown less unequivocal results, ranging from local adaptation to local maladaptation for interactions with antagonists. A large reciprocal transplant field study by Cremieux et al. reported in this issue of New Phytologist, offers a prime example of the diversity of outcomes of altered biotic interactions that we can observe following translocation of plants within their current distributional range even within a single community. In one plant species, local plant genotypes were more resistant to the local demes of specialist antagonist than nonlocal plant genotypes, suggesting plant local adaptation to important aspects of the biotic environment. However, in another plant species, the reverse pattern was observed. The take-home message from this study is a teeth-grinder for restoration ecologists: it is hard to make a general prediction as to whether foreign seed provenances pose a risk of introducing alleles causing low biotic resistance in the restoration area or not.

394. Bodin J, Badeau V, Bruno E, Cluzeau C, Moisselin J-M, Walther GR, Dupouey J-L. 2013.

Shifts of forest species along an elevational gradient in Southeast France: climate change or stand maturation? Journal of Vegetation Science 24:269-283.

Type: Journal

Geographic Area: Southeast France

Keywords: elevation, forest dynamics, forest inventory, land-use change, long-term monitoring, mountains of Southeast France, niche, modelling, plant species shift

Abstract: Recent vegetation changes in mountain areas are often explained by climate warming. However, effects of land-use changes, such as recolonization of abandoned pastures by forest, are difficult to separate from those of climate change. Even within forest belts, changes in stand structure due to forest management and stand maturation could confound the

climate signal. Here, we evaluate the direction and rate of plant species elevation shifts in mountain forests, considering the role of stand dynamics. We compared floristic data from the French National Forest Inventory collected in the 1980s and 1990s. They provided a large-scale (30,985 plots) and representative sample of vegetation between 0 and 2500 m a.s.l. Species response curves along the elevation and exposure gradients were fitted with a logistic regression model. In order to assess the effect of changes in successional stages of the forest stands, we compared plant species shifts in the whole set of stands with those solely in closed stands. A total of 62 species shifted downward, whereas 113 shifted upward, resulting in a significant upward mean shift of 17.9 m. Upward shifting species were preferentially woody and heliophilous, suggesting a role for forest closure and maturation in the observed changes. Excluding all open forest stages from analyses, the upward trend became weaker (-3.0 m) and was not significant. Forests of the study area have undergone closure and maturation, more strongly at lower altitudes than at higher ones, producing an apparent shift of species. In the mountain relief of Southeast France, changes in the successional stages of stands appear as the main cause of the apparent upslope movement of forest species. Since a similar trend of forest maturation exists in large areas throughout Europe, forest dynamics should be better taken into account among the causes of vegetation changes before inferring any climate change effect.

Link: http://onlinelibrary.wiley.com/doi/10.1111/j.1654-1103.2012.01456.x/full

395. Box EO, Crumpacker DW, Hardin ED. 1999.

Predicted effects of climate change on distribution of ecologically important native tree and shrub species in Florida. Climatic Change 41:213-248.

Type: Journal

Geographic Area: Florida, USA

Compilers' Keywords: climatic envelope model, temperate species, tropical species

Abstract: A previously developed plant species-climatic envelope model was evaluated further and used to predict effects of hypothesized climatic change on the potential distribution of 124 native woody plant species in Florida, U.S.A. Twelve scenarios were investigated. These included mean annual temperature increases of 1 °C or 2 °C, achieved either by equal 1 °C or 2 °C increases on a monthly basis throughout the year, or by disproportionately larger seasonal increases in winter and smaller ones in summer. The various temperature increases were then combined with each of several precipitation changes, ranging from +10% to –20%, to produce the final set of scenarios. More detailed analysis involving six of the scenarios and a subset of 28 representative, ecologically important species suggested that (1) large decreases in the Florida range of many temperate species would result if 1 °C warming occurs predominantly in winter or with a 20% decrease in annual precipitation, or (2) if 2 °C warming occurs, with or without decrease in annual precipitation, and regardless of whether there is a uniform monthly warming pattern or one that is higher in winter than in summer. Available information concerning other factors that might also affect climatic-change responses suggests that these large predicted impacts on temperate Florida species may be underestimates. Subtropical Florida species will tend to move north and inland with warming but extensive human assistance may be needed, if they are to realize their newly expanded, potential natural ranges.

396. Bradley BA, Blumenthal DM, Early R, Grosholz ED, Lawler JJ, Miller LP, Sorte CJB, D'Antonio CM, Diez JM, Dukes JS, Ibanez I, Olden JD. 2012.

Global change, global trade, and the next wave of plant invasions. Frontiers in Ecology and the Environment 10:20-28.

Type: Journal

Geographic Area: North America

Compilers' Keywords: non-native plants, climate change, horticulture trade, drought-tolerance, migration, review

Abstract: Many non-native plants in the U.S. have become problematic invaders of native and managed ecosystems, but a new generation of invasive species may be at our doorstep. Here, we review trends in the horticultural trade and invasion patterns of previously introduced species and show that novel species introductions from emerging horticultural trade partners are likely to rapidly increase invasion risk. At the same time, climate change and water restrictions are increasing demand for new types of species adapted to warm and dry environments. This confluence of forces could expose the U.S. to a range of new invasive species, including many from tropical and semiarid Africa as well as the Middle East. Risk assessment strategies have proven successful elsewhere at identifying and preventing invasions, although some modifications are needed to address emerging threats. Now is the time to implement horticulture import screening measures to prevent this new wave of plant invasions.

Link: http://web.ics.purdue.edu/~jsdukes/BradleyEtAl2012.pdf

397. Brooker RW, Travis JM, Clark EJ, Dytham C. 2007.

Modelling species' range shifts in a changing climate: the impacts of biotic interactions, dispersal distance and the rate of climate change. Journal of Theoretical Biology 245:59-65.

Type: Journal

Geographic Area: Global

Keywords: climate change, biodiversity, range shifting, biotic interactions, dispersal, modelling

Abstract: There is an urgent need for accurate prediction of climate change impacts on species ranges. Current reliance on

bioclimatic envelope approaches ignores important biological processes such as interactions and dispersal. Although much debated, it is unclear how such processes might influence range shifting. Using individual-based modelling we show that interspecific interactions and dispersal ability interact with the rate of climate change to determine range-shifting dynamics in a simulated community with two growth forms—mutualists and competitors. Interactions determine spatial arrangements of species prior to the onset of rapid climate change. These lead to space-occupancy effects that limit the rate of expansion of the fast-growing competitors but which can be overcome by increased long-distance dispersal. As the rate of climate change increases, lower levels of long-distance dispersal can drive the mutualists to extinction, demonstrating the potential for subtle process balances, non-linear dynamics and abrupt changes from species coexistence to species loss during climate change.

Link: http://www.ncbi.nlm.nih.gov/pubmed/17087974

398. Burke MB, Lobell DB, Guarino L. 2009. Shifts in African crop climates by 2050, and the implications for crop improvement and genetic resources conservation. Global Environmental Change 19:317-325.

Type: Journal

Geographic Area: Africa

Keywords: maize, Africa, genetic resources, climate change, adaptation, sorghum, millet

Abstract: Increased understanding of the substantial threat climate change poses to agriculture has not been met with a similarly improved understanding of how best to respond. Here we examine likely shifts in crop climates in Sub-Saharan Africa under climate change to 2050, and explore the implications for agricultural adaptation, with particular focus on identifying priorities in crop breeding and the conservation of crop genetic resources. We find that for three of Africa's primary cereal crops—maize, millet, and sorghum—expected changes in growing season temperature are considerable and dwarf changes projected for precipitation, with the warmest recent temperatures on average cooler than almost 9 out of 10 expected observations by 2050. For the "novel" crop climates currently unrepresented in each country but likely extant there in 2050, we identify current analogs across the continent. The majority of African countries will have novel climates over at least half of their current crop area by 2050. Of these countries, 75% will have novel climates with analogs in the current climate of at least five other countries, suggesting that international movement of germplasm will be necessary for adaptation. A more troubling set of countries—largely the hotter Sahelian countries—will have climates with few analogs for any crop. Finally, we identify countries, such as Sudan, Cameroon, and Nigeria, whose current crop areas are analogs to many future climates but that are poorly represented in major genebanks—promising locations in which to focus future genetic resource conservation efforts.

Link: http://www.stanford.edu/~mburke/papers/burke%20et%20al%20GEC%202009.pdf

399. Burrows MT, Schoeman DS, Richardson AJ, Molinos JG, Hoffmann A, Buckley LB, Moore PJ, Brown CJ, Bruno JF, Duarte CM, Halpern BS, Hoegh-Guldberg O, Kappel CV, Kiessling W, O'Connor MI, Pandolfi JM, Parmesan C, Sydeman WJ, Ferrier S, Williams KJ, Poloczanska ES. 2014. Geographical limits to species-range shifts are suggested by climate velocity. Nature 507:492-495.

Type: Journal

Geographic Area: Global

Compilers' Keywords: migration, biodiversity, climate change, climate niche, species distributions, modelling, trajectories

Abstract: The reorganization of patterns of species diversity driven by anthropogenic climate change, and the consequences for humans, are not yet fully understood or appreciated. Nevertheless, changes in climate conditions are useful for predicting shifts in species distributions at global and local scales. Here we use the velocity of climate change to derive spatial trajectories for climatic niches from 1960 to 2009 (ref. 7) and from 2006 to 2100, and use the properties of these trajectories to infer changes in species distributions. Coastlines act as barriers and locally cooler areas act as attractors for trajectories, creating source and sink areas for local climatic conditions. Climate source areas indicate where locally novel conditions are not connected to areas where similar climates previously occurred, and are thereby inaccessible to climate migrants tracking isotherms: 16% of global surface area for 1960 to 2009, and 34% of ocean for the 'business as usual' climate scenario (representative concentration pathway (RCP) 8.5) representing continued use of fossil fuels without mitigation. Climate sink areas are where climate conditions locally disappear, potentially blocking the movement of climate migrants. Sink areas comprise 1.0% of ocean area and 3.6% of land and are prevalent on coasts and high ground. Using this approach to infer shifts in species distributions gives global and regional maps of the expected direction and rate of shifts of climate migrants, and suggests areas of potential loss of species richness.

Link: http://www.ncbi.nlm.nih.gov/pubmed/24509712

400. Byrne M, Stone L, Millar MA. 2011. Assessing genetic risk in revegetation. Journal of Applied Ecology 48:1365-1373.

Type: Journal

Geographic Area: Global

Keywords: gene flow, genetic change, hybridisation, outbreeding depression, pollen dispersal, risk assessment

Abstract: Revegetation can provide major environmental benefits in degraded landscapes, but there is also potential for negative impacts from genetic change in local native populations. Broad areas of revegetation may provide a large source of foreign genes in landscapes where small remnant native populations act as a sink. Genetic change from hybridisation can threaten population persistence and contribute to species extinction through genetic assimilation or demographic swamping. Implementation of revegtation within a risk management framework allows identification of risk factors, analysis and evaluation of risk to inform decision-making and management to minimize and mitigate the risk. Informed analysis and evaluation of genetic risk is important in revegetation because it will be difficult to control or reverse the impacts in natural ecosystems and they are often not expressed until the second generation or later. A risk assessment protocol is presented based on evaluation of factors that influence the likelihood and consequences of adverse genetic change from revegetation arising through pollen dispersal. The assessment is applicable to a broad ranges of revegetation activities and contributes to the development of informed decision-making processes in implementation of revegetation systems and land use practices that protect and enhance biodiversity in degraded landscapes. Implementation of revegetation programmes within a risk management framework will help to ensure that significant environmental benefits are captured with minimal concomitant negative impacts on the surrounding biodiversity. A genetic risk protocol provides a tool for evaluation of potential adverse genetic impacts on native populations from revegetation and can be implemented in conjunction with weed risk assessment. Risk assessment as an integral part of evaluation of environmental impact for large-scale revegetation programmes will contribute to the development of informed decision-making processes in the implementation of revegetation systems, and ultimately, it will aid in the development of land uses that protect and enhance biodiversity in degraded landscapes.

401. Chuine I. 2010. Why does phenology drive species distribution? Philosophical Transactions of the Royal Society B: Biological Sciences 365:3149-3160.

Type: Journal

Geographic Area: Global

Keywords: fitness, adaptation, niche, species distribution

Abstract: Despite the numerous studies which have been conducted during the past decade on species ranges and their relationship to the environment, our understanding of how environmental conditions shape species distribution is still far from complete. Yet, some process-based species distribution models have been able to simulate plants and insects distribution at a global scale. These models strongly rely on the completion of the annual cycle of the species and therefore on their accomplished phenology. In particular, they have shown that the northern limit of species' ranges appears to be caused mainly by the inability to undergo full fruit maturation, while the southern limit appears to be caused by the inability to flower or unfold leaves owing to a lack of chilling temperatures that are necessary to break bud dormancy. I discuss here why phenology is a key adaptive trait in shaping species distribution using mostly examples from plant species, which have been the most documented. After discussing how phenology is involved in fitness and why it is an adaptive trait susceptible to evolve quickly in changing climate conditions, I describe how phenology is related to fitness in species distribution process-based models and discuss the fate of species under climate change scenarios using model projections and experimental or field studies from the literature.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20819809

402. Corlett RT, Westcott DA. 2013. Will plant movements keep up with climate change? Trends in Ecology and Evolution 28:482-488.

Type: Journal

Geographic Area: Global

Compilers' Keywords: review, migration, velocity, tracking

Abstract: In the face of anthropogenic climate change, species must acclimate, adapt, move, or die. Although some species are moving already, their ability to keep up with the faster changes expected in the future is unclear. 'Migration lag' is a particular concern with plants, because it could threaten both biodiversity and carbon storage. Plant movements are not realistically represented in models currently used to predict future vegetation and carbon-cycle feedbacks, so there is an urgent need to understand how much of a problem failure to track climate change is likely to be. Therefore, in this review, we compare how fast plants need to move with how fast they can move; that is, the velocity of climate change with the velocity of plant movement.

Link: http://www.ncbi.nlm.nih.gov/pubmed/23721732

403. Damschen EI, Harrison S, Ackerly DD, Fernández-Going BM, Anacker BL. 2012. Endemic plant communities on special soils: early victims or hardy survivors of climate change? Journal of Ecology 100:1122-1130.

Type: Journal

Geographic Area: Global

Keywords: assisted migration, azonal vegetation, community, conservation, edaphic, functional diversity, managed relocation, plant-climate interactions, risk, serpentine, species diversity

Abstract: Predicting and mitigating climate change effects on ecological communities is a tremendous challenge. Little

attention has been given to how endemic-rich communities on isolated patches of low-nutrient soil (e.g. serpentine) will respond to climate change. To address spatial factors (the isolated nature of outcrops), we incorporate habitat patchiness into species distribution models under climate change. The degree of overlap between current and future suitable habitat does not change when patchy habitats are incorporated, probably because serpentine occurs in mountainous regions where climatically and edaphically suitable regions geographically coincide. The dispersal distances required to move to newly suitable habitat are large, however, making successful migration unlikely. To address how non-spatial factors affect the climate change responses of serpentine plant communities (e.g. the impacts of nutrient limitation and stress-tolerant functional traits), we conduct a literature review. Some studies suggest that serpentine communities may be at less risk than 'normal' soil communities due to their stress-tolerant functional traits, but there is also evidence to the contrary. Assessing climate change risk for the world's diverse edaphic floras requires determining impacts on both special and 'normal' soil communities. Studies are needed that use functional traits, evaluate the role of evolutionary and ecological plasticity, examine responses across spatial and temporal scales and assess the efficacy of managed relocation efforts.

404. Davies AL. 2011. Long-term approaches to native woodland restoration: palaeoecological and stakeholder perspectives on Atlantic forests of northern Europe. Forest Ecology and Management 261:751-763.

Type: Journal

Geographic Area: Northern Europe

Keywords: long-term ecology, western oakwood, stakeholder perspectives, palaeoecology, adaptive management

Abstract: The long timeframes involved in woodland regeneration and adaptation introduce considerable uncertainty into management and conservation planning as most ecological datasets span only a small part of ecosystem dynamics. This is a particular concern in vulnerable habitats, such as Atlantic birch-oak woods in north-western Britain, where range edge populations are at risk from herbivory and climate change. This study combines historical palaeoecology and stakeholder observations to assess how multiple perspectives can inform existing models, expectations and goals for Atlantic woodland management. Long-term evidence for changing woodland composition addresses stakeholder uncertainties over the currently restricted distribution of oak, alder and hazel. Oak has remained a secondary component of birch-dominated woods and habitat definitions based on oak are too narrow to ensure sustainability. Birch has survived numerous periods of climatic and biotic adversity and shows the strongest positive response to historic reductions in grazing pressure. This has led to a pulse of regeneration since c. AD 1900, so current restoration efforts are taking place within the strongest period of woodland expansion in the last c. 500 years. Positive and negative cultural legacies are evident and intervention is considered a necessary restoration tool. Managed grazing at key stages of habitat development can support continued recruitment and regeneration. A more flexible and integrated management approach is recommended. Long-term ecology can provide direction and address uncertainties, while ecological and stakeholder evidence provide the detail necessary to develop effective management that incorporates ecosystem perspectives. This can help shape management strategies that balance possible conflicts over perceived short-term 'damage' to secure longer term processes. Learning based on multiple temporal perspectives has the potential to contribute to conservation and restoration planning and practice. These principles are more widely applicable in adaptive management.

405. Diaz S, Cabido M. 1997. Plant functional types and ecosystem function in relation to global change. Journal of Vegetation Science 8:463-474.

Type: Journal

Geographic Area: Global

Keywords: Argentina, climate change, plant functional trait, regional gradient

Abstract: Plant functional types (PFTs) bridge the gap between plant physiology and community and ecosystem processes, thus providing a powerful tool in climate change research. We aimed at identifying PFTs within the flora of central-western Argentina, and to explore their possible consequences for ecosystem function. We analyzed 24 vegetative and regenerative traits of the 100 most abundant species along a steep climatic gradient. Based on plant traits and standard multivariate techniques, we identified eight PFTs. Our results confirmed, over a wide range of climatic conditions, the occurrence of broad recurrent patterns of association among plant traits reported for other floras; namely trade-offs between high investment in photosynthesis and growth on the one hand, and preferential allocation to storage and defense on the other. Regenerative traits were only partially coupled with vegetative traits. Using easily-measured plant traits and individual species cover in 63 sites, we predicted main community ecosystem processes along the regional gradient. We hypothesized likely impacts of global climatic change on PFTs and ecosystems *in situ*, and analysed their probabilities of migrating in response to changing climatic conditions. Finally, we discuss the advantages and limitations of this kind of approach in predicting changes in plant distribution and in ecosystem processes over the next century.

Link: http://www.dpi.inpe.br/referata/arq/16_Andre/Diaz_e_Cabido_1997.pdf

406. Drayton B, Primack RB. 2012. Success rates for reintroductions of eight perennial plant species after 15 years. Restoration Ecology 20:299-303.

Type: Journal

Geographic Area: Eastern USA

Keywords: plant conservation, plant reintroduction, reintroduction methods

Abstract: The creation of new populations of rare and endangered plant species has become well-established as a standard technique in conservation and restoration ecology. However, much remains unknown about the actual rates of success or failure of such reintroductions. Recent research suggests that in part this reflects under-reporting of failures. In 2000, the authors published a paper reporting rates of success in reintroducing eight perennial plant species into two reserves near Boston, MA, in 1994-1995. In 2010, the authors conducted a census of the experimental sites 15 years after reintroduction; almost all the populations reported in 2000 had disappeared. The implications for reintroduction methodology, with respect to establishing and reporting both successful and unsuccessful experiments are discussed.

407. Duran KL, Lowrey TK, Parmenter RR, Lewis PO. 2005. **Genetic diversity in Chihuahuan Desert populations of creosotebush (Zygophyllaceae: *Larrea tridentata*).** American Journal of Botany 92:722-729.

Type: Journal

Geographic Area: Mexico, Southwestern USA

Keywords: biogeography, Chihuahuan Desert, creosotebush, genetic variation, isozymes, *Larrea tridentata*, population genetics, Zygophyllaceae

Abstract: We examined isozyme variation in the dominant Chihuahuan Desert shrub, *Larrea tridentata* (creosotebush), to determine the genetic variation within and among populations, the biogeographic relationships of populations, and the potential inbreeding in the species. We surveyed 17 populations consisting of 20 to 50 individuals per population along a 1600 km north–south transect across the Chihuahuan Desert. The southernmost population was near Villa Hidalgo, Mexico, and the northernmost near Isleta Pueblo, New Mexico. All 12 isozyme loci examined were polymorphic ($H_t = 0.416$), with up to nine alleles per locus. Despite high levels of variation, we detected moderate inbreeding in *L. tridentata* populations. Most variation was found within rather than among populations ($G_{ST} = 0.118$). Furthermore, recently established populations in the northern limits of the Chihuahuan Desert did not show decreased levels of genetic variation ($H_o = 0.336$). A significant correlation was found between pairwise genetic and geographic distances ($r = 0.305$). *Larrea tridentata* showed and continues to show a massive range expansion into the arid and semi-arid regions of the American Southwest, but as shown by the high genetic variation, this expansion took place as a wave, rather than a series of founder events.

Link: http://sev.lternet.edu/sites/default/files/sev306_duran_etal_ajb_2005.pdf

408. Elith J, Leathwick JR. 2009. **Species distribution models: ecological explanation and prediction across space and time.** Annual Review of Ecology, Evolution, and Systematics 40:677-697.

Type: Journal

Geographic Area: Global

Keywords: climate change, invasions, niche, predict, presence-only, spatial

Abstract: Species distribution models (SDMs) are numerical tools that combine observations of species occurrence or abundance with environmental estimates. They are used to gain ecological and evolutionary insights and to predict distributions across landscapes, sometimes requiring extrapolation in space and time. SDMs are now widely used across terrestrial, freshwater, and marine realms. Differences in methods between disciplines reflect both differences in species mobility and in “established use.” Model realism and robustness is influenced by selection of relevant predictors and modeling method, consideration of scale, how the interplay between environmental and geographic factors is handled, and the extent of extrapolation. Current linkages between SDM practice and ecological theory are often weak, hindering progress. Remaining challenges include: improvement of methods for modeling presence-only data and for model selection and evaluation; accounting for biotic interactions; and assessing model uncertainty.

Link: http://mgel.env.duke.edu/wp-content/workshop-dropbox/Elith_Leathwick_2009.pdf

409. Elith J, Phillips SJ, Hastie T, Dudík M, Chee YE, Yates CJ. 2011. **A statistical explanation of MaxEnt for ecologists.** Diversity and Distributions 17:43-57.

Type: Journal

Geographic Area: Global

Keywords: absence, ecological niche, entropy, machine learning, presence-only, species distribution model

Abstract: MaxEnt is a program for modelling species distributions from presence only species records. This paper is written for ecologists and describes the MaxEnt model from a statistical perspective, making explicit links between the structure of the model, decisions required in producing a modelled distribution, and knowledge about the species and the data that might affect those decisions. To begin we discuss the characteristics of presence-only data, highlighting implications for modelling distributions. We particularly focus on the problems of sample bias and lack of information on species prevalence. The keystone of the paper is a new statistical explanation of MaxEnt which shows that the model minimizes the relative entropy between two probability densities (one estimated from the presence data and one, from the landscape) defined in covariate space. For many users, this viewpoint is likely to be a more accessible way to understand the model

than previous ones that rely on machine learning concepts. We then step through a detailed explanation of MaxEnt describing key components (e.g. covariates and features, and definition of the landscape extent), the mechanics of model fitting (e.g. feature selection, constraints and regularization) and outputs. Using case studies for a Banksia species native to south-west Australia and a riverine fish, we fit models and interpret them, exploring why certain choices affect the result and what this means. The fish example illustrates use of the model with vector data for linear river segments rather than raster (gridded) data. Appropriate treatments for survey bias, unprojected data, locally restricted species, and predicting to environments outside the range of the training data are demonstrated, and new capabilities discussed. Online appendices include additional details of the model and the mathematical links between previous explanations and this one, example code and data, and further information on the case studies.

Link: http://nate2.myweb.uga.edu/FANR8400/Elith_etal_2010_maxent%20for%20ecologists.pdf

410. Fernández M, Hamilton H, Kueppers LM. 2013. Characterizing uncertainty in species distribution models derived from interpolated weather station data. Ecosphere 4:1-17.

Type: Journal

Geographic Area: North America

Keywords: climate-based niche models, gridded climate, uncertainty

Abstract: Species distribution models (SDMs) are used to generate hypotheses regarding the potential distributions of species under different environmental conditions, such as forecasts of species range shifts in response to climate change and predictions of invasive species range expansions. However, an accurate description of species' geographic ranges as a function of the environment requires that species observations and climatic variables are measured at the same spatial and temporal resolution, which is usually not the case. Weather station data are interpolated and these resulting continuous data layers are incorporated into SDMs, often without any uncertainty assessment. Here we quantify the effects of three unrelated but complementary aspects of uncertainty in weather station interpolations on SDM performance using MaxEnt. We examine the influence of topographic heterogeneity, interannual variability, and distance to station on the over- and under-prediction of modeled North American bird distributions. Our species observations are derived from presence-absence information for 20 bird species with well-known distributions. These three metrics of uncertainty in interpolated weather station data have varying contributions to over- and under prediction errors in SDMs. Topographic heterogeneity had the highest contribution to omission errors; the lowest contribution to commission errors was from Euclidean distance to station. The results confirm the importance of establishing an appropriate relational basis in time and space between species and climatic layers, providing key operational criteria for selection of species observations fed into SDMs. Our findings highlight the importance of identifying weather stations locations used in interpolated products, which will allow a characterization of some aspects of uncertainty and identification of regions where users need to be particularly careful when making a decision based on a SDM.

411. Fischer J, Lindenmayer DB. 2000. An assessment of the published results of animal relocations. Biological Conservation 96:1-11.

Type: Journal

Geographic Area: Global

Keywords: translocation, re-introduction, supplementation, relocation, re-introduction success

Abstract: We reviewed 180 case studies and a number of theoretical papers on animal relocations published in 12 major international scientific journals over the last 20 years. The study focused on re-introductions, supplementations and translocations. We did not assess introductions. Re-introductions were the most common type of relocation (116/180); three quarters of these were conducted for conservation purposes. Supplementations (48/180) and translocations (36/180) occurred less frequently, and both were commonly carried out for reasons other than conservation. Simple descriptive statistics were used to analyze factors influencing relocation success. Translocations that aimed to solve human animal conflicts generally failed. Re-introduction success was not found to have changed over the last two decades, but re-introductions appeared to be more successful when the source population was wild, a large number of animals was released (n >100), and the cause of original decline was removed. More complex trends were found for the effect of predation and the use of supportive measures such as provision of food or shelter, or predator control prior to release. The success of 47% of reintroductions was uncertain at the time case studies were published in journals. This was partly due to the lack of generally accepted and widely applied criteria to assess success. Very few case studies (3%) reported the cost of the relocation attempt. We conclude that there were three primary aims for animal relocations. These were to solve human-animal conflicts, to restock game populations, and conservation. Our extensive review of the present literature leads us to conclude that the value of animal relocations as a conservation tool could be enhanced through (1) more rigorous testing for the appropriateness of the approach in a given case, (2) the establishment of widely used and generally accepted criteria for judging the success or failure of relocations, (3) better monitoring after a relocation, (4) better financial accountability, and (5) greater effort to publish the results of relocations, even ones that are unsuccessful.

412. Freeman DC, Turner WA, McArthur ED, Graham JH. 1991. Characterization of a narrow hybrid zone between two subspecies of big sagebrush. American Journal of Botany 78:805-815.

Type: Journal

Geographic Area: Utah, USA

Compilers' Keywords: *Artemisia tridentata*, morphological variation

Abstract: Hybridization between *Artemisia tridentata* ssp. *tridentata* and *A. t.* ssp. *vaseyana* occurs in a narrow elevational zone along the west face and canyons of the Wasatch Mountains of Utah. Two sites in central Utah (Orem and Salt Creek) were examined. The parental taxa differ in anatomy, morphology, flavonoid and coumarin content, as well as various growth parameters. Hybrids are intermediate for the majority of traits examined, including flavonoid and coumarin composition. Multivariate statistics show that these taxa can be unambiguously identified using simple field measures of morphology. A hybrid index was constructed using principal component analyses on morphological variables.

Link: http://facultyweb.berry.edu/jgraham/Wang%20Narrow%204%20Rec.pdf

413. Godefroid S, Piazza C, Rossi G, Buord S, Stevens A, Aguraiuja R, Cowell C, Weekley CW, Vogg G, Iriondo JM, Johnson I, Dixon B, Gordon DR, Magnanon S, Valentin B, Bjureke K, Koopman R, Vicens M, Virevaire M, Vanderborght T. 2011. How successful are plant species reintroductions? Biological Conservation 144:672-682.

Type: Journal

Geographic Area: Global

Keywords: species translocation, population reinforcement, population supplementation, population augmentation, restored populations

Abstract: Reintroduction of native species has become increasingly important in conservation worldwide for recovery of rare species and restoration purposes. However, few studies have reported the outcome of reintroduction efforts in plant species. Using data from the literature combined with a questionnaire survey, this paper analyses 249 plant species reintroductions worldwide by assessing the methods used and the results obtained from these reintroduction experiments. The objectives were: (1) to examine how successful plant species reintroductions have been so far in establishing or significantly augmenting viable, self-sustaining populations in nature; (2) to determine the conditions under which we might expect plant species reintroductions to be most successful; (3) to make the results of this survey available for future plant reintroduction trials. Results indicate that survival, flowering and fruiting rates of reintroduced plants are generally quite low (on average 52%, 19% and 16%, respectively). Furthermore, our results show a success rate decline in individual experiments with time. Survival rates reported in the literature are also much higher (78% on average) than those mentioned by survey participants (33% on average). We identified various parameters that positively influence plant reintroduction outcomes, e.g., working in protected sites, using seedlings, increasing the number of reintroduced individuals, mixing material from diverse populations, using transplants from stable source populations, site preparation or management effort and knowledge of the genetic variation of the target species. This study also revealed shortcomings of common experimental designs that greatly limit the interpretation of plant reintroduction studies: (1) insufficient monitoring following reintroduction (usually ceasing after 4 years); (2) inadequate documentation, which is especially acute for reintroductions that are regarded as failures; (3) lack of understanding of the underlying reasons for decline in existing plant populations; (4) overly optimistic evaluation of success based on short-term results; and (5) poorly defined success criteria for reintroduction projects. We therefore conclude that the value of plant reintroductions as a conservation tool could be improved by: (1) an increased focus on species biology; (2) using a higher number of transplants (preferring seedlings rather than seeds); (3) taking better account of seed production and recruitment when assessing the success of reintroductions; (4) a consistent long-term monitoring after reintroduction.

Link: http://www.researchgate.net/publication/229104055_How_successful_are_plant_species_reintroductions/file/d912f513efbd06d991.pdf

414. Gray LK. 2011. Assisted migration to address climate change: recommendations for reforestation in western Canada [Dissertation]. Edmonton, Alberta, Canada: University of Alberta. 229 p.

Type: Dissertation

Geographic Area: Western Canada

Compilers' Keywords: tree populations, seed sources, forest management

Abstract: A changing climate is the largest threat to forest productivity in western Canada and to the ability of forested landscapes to provide ecological and economic services, both now and in the future. As climate changes, locally adapted tree populations become mismatched with local conditions, leading to mal-adaptation that may result in a reduction in forest health and productivity. This problem can be reduced with interventions that match reforestation stock to anticipated future environments. As such, there is a pressing need to inform such actions by carefully developing and contextualizing scientific information and by applying it to provincial reforestation policies. Assisted migration is a climate change adaptation strategy used in the forestry sector, where species and seed

sources are moved to new locations. The goal of this thesis is to develop a methodological framework to guide assisted migration efforts for forest trees in western Canada, under a comprehensive range of future climate projections. To assist with these management needs I create a new ecosystem-based climate envelope modeling approach for 16 commercially important tree species. Habitat projections show populations already geographically lag behind their optimal climate and the magnitude of this lag is projected to double for the 2020s. The most pronounced habitat shifts are projected to occur in the boreal forests and the Rocky Mountains, predominately affecting black spruce, tamarack, white spruce and aspen populations. In a case study for Alberta, I find that genotypes of species that are adapted to drier climatic conditions will be the preferred planting stock over much of the commercially managed boreal forest. Interestingly, no alternate non-native species to Alberta that were examined in this study can be recommended with any confidence as planting stock. Finally, I observe high uncertainty in projections of suitable habitat for most species making reforestation planning beyond the 2050s difficult. Using genetic and remote sensing data for aspen populations, I show that habitat projections from climate envelope models under observed climate change conform well to empirical data on loss of aspen productivity and genetic data on sub-optimal growth due to mal-adaptation.

415. Gray LK, Hamann A. 2013. Tracking suitable habitat for tree populations under climate change in western North America. Climatic Change 117:289-303.

Type: Journal

Geographic Area: Western North America

Compilers' Keywords: transfer guidelines, assisted migration, bioclimate envelope modeling, Random Forest, optimal climate

Abstract: An important criticism of bioclimate envelope models is that many wide-ranging species consist of locally adapted populations that may all lag behind their optimal climate habitat under climate change, and thus should be modeled separately. Here, we apply a bioclimate envelope model that tracks habitat of individual populations to estimate adaptation lags for 15 wide-ranging forest tree species in western North America. An ensemble classifier modeling approach (Random Forest) was used to spatially project the climate space of tree populations under observed climate trends (1970s to 2000s) and multi-model projections for the 2020s, 2050s, and 2080s. We find that, on average, populations already lag behind their optimal climate niche by approximately 130 km in latitude, or 60 m in elevation. For the 2020s we expect an average lag of approximately 310 km in latitude or 140 m in elevation, with the most pronounced geographic lags in the Rocky Mountains and the boreal forest. We show that our results could in principle be applied to guide assisted migration of planting stock in reforestation programs using a general formula where 100 km north shift is equivalent to approximately 44 m upward shift in elevation. However, additional non-climatic factors should be considered when matching reforestation stock to suitable planting environments.

Link: http://www.ualberta.ca/~ahamann/publications/pdfs/Gray_Hamann_2012.pdf

416. Gray LK, Gylander T, Mbogga MS, Chen P, Hamann A. 2011. Assisted migration to address climate change: recommendations for aspen reforestation in western Canada. Ecological Applications 21:1591-1603.

Type: Journal

Geographic Area: Western Canada

Keywords: bioclimate envelope modeling, climate change, ecological genetics, reforestation, remote sensing, seed transfer guidelines, seed zones

Abstract: Human-aided movement of species populations in large-scale reforestation programs could be a potent and cost-effective climate change adaptation strategy. Such large-scale management interventions, however, tend to entail the risks of unintended consequences, and we propose that three conditions should be met before implementing assisted migration in reforestation programs: (1) evidence of a climate related adaptation lag, (2) observed biological impacts, and (3) robust model projections to target assisted migration efforts. In a case study of aspen (*Populus tremuloides* Michaux.) we use reciprocal transplant experiments to study adaptation of tree populations to local environments. Second, we monitor natural aspen populations using the MODIS enhanced vegetation index as a proxy for forest health and productivity. Last, we report results from bioclimate envelope models that predict suitable habitat for locally adapted genotypes under observed and predicted climate change. The combined results support assisted migration prescriptions and indicate that the risk of inaction likely exceeds the risk associated with changing established management practices. However, uncertainty in model projections also implies that we are restricted to a relatively short 20-year planning horizon for prescribing seed movement in reforestation programs. We believe that this study exemplifies a safe and realistic climate change adaptation strategy based on multiple sources of information and some understanding of the uncertainty associated with recommendations for assisted migration. Ad hoc migration prescriptions without a similar level of supporting information should be avoided in reforestation programs.

Link: http://ualberta.ca/~ahamann/publications/pdfs/Gray_et_al_2011.pdf

417. Green BS, Gardner C, Linnane A, Hawthorne PJ. 2010. The good, the bad and the recovery in an assisted migration. PLoS ONE 5:e14160.

Type: Journal

Geographic Area: Australia

Compilers' Keywords: animal migration, biomass, conservation, ecosystem, fisheries, geography, Palinuridae, rock lobster, *Jasus edwardsii*, population dynamics, Tasmania

Abstract: Assisted migration or translocation of species to ameliorate effects of habitat loss or changing environment is currently under scrutiny as a conservation tool. A large scale experiment of assisted migration over hundreds of kilometres was tested on a morph from a commercial fishery of southern rock lobster *Jasus edwardsii*, to enhance depleted populations, improve the yield and sustainability of the fishery, and test resilience to a changing climate. Approximately 10,000 lower-valued, pale-coloured lobsters were moved from deep water to inshore sites (2 in Tasmania [TAS] and 2 in South Australia [SA]) where the high-value, red morph occurs. In TAS this was a northwards movement of 1 degree latitude. Growth was measured only in TAS lobsters, and reproductive status was recorded in lobsters from all locations. Pale females (TAS) grew 4 times faster than resident pale lobsters from the original site and twice as fast as red lobsters at their new location. Approximately 30% of translocated pale lobsters deferred reproduction for one year after release (SA and TAS), and grew around 1 mm yr^{-1} less compared to translocated pale lobsters that did not defer reproduction. In spite of this stress response to translocation, females that deferred reproduction still grew 2-6 mm yr^{-1} more than lobsters at the source site. Lobsters have isometric growth whereby volume increases as a cube of length. Consequently despite the one-year hiatus in reproduction, increased growth increases fecundity of translocated lobsters, as the increase in size provided a larger volume for producing and incubating eggs in future years. Assisted migration improved egg production and growth, despite a temporary stress response, and offers a tool to improve the production, sustainability and resilience of the fishery.

Link: http://www.ncbi.nlm.nih.gov/pubmed/21151965

418. Griffith B, Scott JM, Carpenter JW, Reed C. 1989. **Translocation as a species conservation tool: status and strategy.** Science 245:477-780.

Type: Journal

Geographic Area: Global

Compilers' Keywords: review, migration, wildlife, endangered species, surveys

Abstract: Surveys of recent (1973 to 1986) intentional releases of native birds and mammals to the wild in Australia, Canada, Hawaii, New Zealand, and the United States were conducted to document current activities, identify factors associated with success, and suggest guidelines for enhancing future work. Nearly 700 translocations were conducted each year. Native game species constituted 90 percent of translocations and were more successful (86 percent) than were translocations of threatened, endangered, or sensitive species (46 percent). Knowledge of habitat quality, location of release area within the species range, number of animals released, program length, and reproductive traits allowed correct classification of 81 percent of observed translocations as successful or not.

Link: http://lynx.uio.no/lynx/ibelynxco/04_library/4_3_publications/G/Griffith_et_al_1989_Translocation_as_a_species_conservation_tool.pdf

419. Guerrant EO Jr. 2012. **Characterizing two decades of rare plant reintroductions.** Chapter 2. In: Maschinski J, Haskins KE, editors. Plant Reintroduction in a Changing Climate: Promises and Perils. Washington (DC): Island Press. p 9-29.

Type: Book Section

Geographic Area: Global

Compilers' Keywords: migration, endangered species, rare plant conservation, review

Summary: This chapter presents an overview of reintroduction projects that were documented in the CPC International Reintroduction Registry. The goal of the registry and database is to assist the conservation community in its ongoing efforts to advance the science and improve the practice of conservation. The effort is ongoing, and readers are invited to provide information about additional projects by accessing the registry on the Center for Plant Conservation website. Any reported projects can provide additional insights to the practice of reintroduction, its successes and failures.

420. Guerrant EO Jr, Kaye TN. 2007. **Reintroduction of rare and endangered plants: common factors, questions and approaches.** Australian Journal of Botany 55:362-370.

Type: Journal

Geographic Area: Global

Compilers' Keywords: review, species extinction, conservation

Abstract: The science of reintroduction for conservation purposes is young, and there is still much to learn about the practice. As a means to achieving biological goals of successfully establishing new populations to enhance a species survival prospects, and project goals, such as learning how to go about establishing new populations, reintroduction projects are best done as well designed scientific experiments that test explicit hypotheses. Focusing on a range of factors common to any reintroduction, we review several empirical reintroduction projects with respect to hypotheses tested, experimental materials and methods employed, and evaluate their success in both biological and project terms.

Link: http://appliedeco.org/reports/Guerrant%20and%20Kaye%202007.pdf

421. Hamann A, Aitken SN. 2012. Conservation planning under climate change: accounting for adaptive potential and migration capacity in species distribution models. Diversity and Distributions 19:268-280.

Type: Journal

Geographic Area: Western Canada

Keywords: bioclimate envelope models, climate change, conservation, genetic adaptation, migration, niche models

Abstract: A number of assumptions underpinning the use of species distribution models to predict biological responses to climate change are violated for temperate and boreal tree species that are widespread, long-lived and genetically adapted to local climate conditions. To address this situation, we propose a methodology to account for the potential effects of genetic structure, adaptive potential and limited migration capacity. Similar to the widely used 'no migration' and 'unlimited migration' scenarios, we employ more refined biological response scenarios to evaluate the potential effects of genetic adaptation to local environments and the capacity of species to adapt and migrate. These scenarios are realized by two sets of geographic delineations that partition the species range into multiple populations and that subdivide the study area into smaller landscape units. In a case study for British Columbia, we demonstrate how the approach can be used to evaluate the adequacy of a reserve system of 90 protected areas to ensure long-term maintenance of forest genetic resources for 48 tree species. We find that between 35% and 85% of locally adapted populations in protected areas are maintained under a median climate change scenario until the end of the century. A sensitivity analysis shows that assumptions about migration and adaptation capacity of species have a major effect on the projected conservation status. We propose that the results of species distribution models have practical value for conservation planning if the focus on maintenance rather than loss of suitable habitat. Accounting for genetic structure, adaptive potential and migration capacity through best-case and worst-case scenarios provide important information to effectively allocate limited resources available for conservation action.

Link: http://www.ualberta.ca/~ahamann/publications/pdfs/Hamann_Aitken_2013.pdf

422. Hamann A, Roberts DR, Barber QE, Carroll C, Nielsen SE. 2014. Velocity of climate change algorithms for guiding conservation and management. Global Change Biology 21:997-1004.

Type: Journal

Geographic Area: North America

Keywords: assisted migration, climate change adaptation, climate change vulnerability, conservation, no-analogue climates

Abstract: The velocity of climate change is an elegant analytical concept that can be used to evaluate the exposure of organisms to climate change. In essence, one divides the rate of climate change by the rate of spatial climate variability to obtain a speed at which species must migrate over the surface of the earth to maintain constant climate conditions. However, to apply the algorithm for conservation and management purposes, additional information is needed to improve realism at local scales. For example, destination information is needed to ensure that vectors describing speed and direction of required migration do not point toward a climatic cul-de-sac by pointing beyond mountain tops. Here, we present an analytical approach that conforms to standard velocity algorithms if climate equivalents are nearby. Otherwise, the algorithm extends the search for climate refugia, which can be expanded to search for multivariate climate matches. With source and destination information available, forward and backward velocities can be calculated allowing useful inferences about conservation of species (present-to-future velocities) and management of species populations (future-to-present velocities).

Link: http://www.ncbi.nlm.nih.gov/pubmed/25310933

423. Hampe A. 2011. Plants on the move: the role of seed dispersal and initial population establishment for climate-driven range expansions. Acta Oecologica 37:666-673.

Type: Journal

Geographic Area: Global

Keywords: biotic interactions, dispersal pathways, leading edge, long-distance seed dispersal, range dynamics, tree recruitment

Abstract: Recent climate change will presumably allow many plant species to expand their geographical range up to several hundred kilometres towards the poles within a few decades. Much uncertainty exists however to which extent species will actually be able to keep pace with a rapidly changing climate. A suite of direct and indirect research approaches have explored the phenomenon of range expansions, and the existing evidence is scattered across the literature of diverse research subdisciplines. Here I attempt to synthesise the available information within a population ecological framework in order to evaluate implications of patterns of seed dispersal and initial population establishment for range expansions. After introducing different study approaches and their respective contributions, I review the empirical evidence for the role of long-distance seed dispersal in past and ongoing expansions. Then I examine how some major ecological determinants of seed dispersal and colonisation processes—population fecundity, dispersal pathways, arrival site conditions, and biotic interactions during recruitment—could be altered by a rapidly changing climate. While there is broad consensus that long-distance dispersal is likely to be critical for rapid range expansions, it remains challenging to relate dispersal processes and pathways with the establishment of pioneer populations ahead of the continuous species range. Further transdisciplinary efforts are clearly needed to address this link, key for understanding how plant populations 'move' across changing landscapes.

Link: http://www.sciencedirect.com/science/article/pii/S1146609X11000749

424. Hampe A, Petit RJ. 2005. Conserving biodiversity under climate change: the rear edge matters. Ecology Letters 8:461-467.

Type: Journal

Geographic Area: Global

Keywords: demography, diversification, extinction, genetic differentiation, glacial refugia, global change, leading edge, peripheral populations, Quaternary, trailing edge

Abstract: Modern climate change is producing poleward range shifts of numerous taxa, communities and ecosystems worldwide. The response of species to changing environments is likely to be determined largely by population responses at range margins. In contrast to the expanding edge, the low-latitude limit (rear edge) of species ranges remains understudied, and the critical importance of rear edge populations as long-term stores of species genetic diversity and foci of speciation has been little acknowledged. We review recent findings from the fossil record, phylogeography and ecology to illustrate that rear edge populations are often disproportionately important for the survival and evolution of biota. Their ecological features, dynamics and conservation requirements differ from those of populations in other parts of the range, and some commonly recommended conservation practices might therefore be of little use or even counterproductive for rear edge populations.

Link: http://eeslmu.de/eeswiki/images/RearEdgeEcolLetters05.pdf

425. Hardy OJ, Maggia L, Bandou E, Breyne P, Caron H, Chevallier MH, Doligez A, Dutech C, Kremer A, Latouche-Halle C, Troispoux V, Veron V, Degen B. 2006. Fine-scale genetic structure and gene dispersal inferences in 10 neotropical tree species. Molecular Ecology 15:559-571.

Type: Journal

Geographic Area: South America

Keywords: French Guiana, gene dispersal, seed dispersal, spatial genetic structure, tropical trees

Abstract: The extent of gene dispersal is a fundamental factor of the population and evolutionary dynamics of tropical tree species, but directly monitoring seed and pollen movement is a difficult task. However, indirect estimates of historical gene dispersal can be obtained from the fine-scale spatial genetic structure of populations at drift-dispersal equilibrium. Using an approach that is based on the slope of the regression of pairwise kinship coefficients on spatial distance and estimates of the effective population density, we compare indirect gene dispersal estimates of sympatric populations of 10 tropical tree species. We re-analysed 26 data sets consisting of mapped allozyme, SSR (simple sequence repeat), RAPD (random amplified polymorphic DNA) or AFLP (amplified fragment length polymorphism) genotypes from two rainforest sites in French Guiana. Gene dispersal estimates were obtained for at least one marker in each species, although the estimation procedure failed under insufficient marker polymorphism, limited sample size, or inappropriate sampling area. Estimates generally suffered low precision and were affected by assumptions regarding the effective population density. Averaging estimates over data sets, the extent of gene dispersal ranged from 150 m to 1200 m according to species. Smaller gene dispersal estimates were obtained in species with heavy diaspores, which are presumably not well dispersed, and in populations with high local adult density. We suggest that limited seed dispersal could indirectly limit effective pollen dispersal by creating higher local tree densities, thereby increasing the positive correlation between pollen and seed dispersal distances. We discuss the potential and limitations of our indirect estimation procedure and suggest guidelines for future studies.

Link: http://www.ncbi.nlm.nih.gov/pubmed/16448421

426. Hereford J. 2009. A quantitative survey of local adaptation and fitness trade-offs. American Naturalist 173:579-588.

Type: Journal

Geographic Area: Global

Keywords: genetic drift, genotype-by-environment interaction, local adaptation, natural selection, population divergence, reciprocal transplant

Abstract: The long history of reciprocal transplant studies testing the hypothesis of local adaptation has shown that populations are often adapted to their local environments. Yet many studies have not demonstrated local adaptation, suggesting that sometimes native populations are no better adapted than are genotypes from foreign environments. Local adaptation may also lead to trade-offs, in which adaptation to one environment comes at a cost of adaptation to another environment. I conducted a survey of published studies of local adaptation to quantify its frequency and magnitude and the costs associated with local adaptation. I also quantified the relationship between local adaptation and environmental differences and the relationship between local adaptation and phenotypic divergence. The overall frequency of local adaptation was 0.71, and the magnitude of the native population advantage in relative fitness was 45%. Divergence between home site environments was positively associated with the magnitude of local adaptation, but phenotypic divergence was not. I found a small negative correlation between a population's relative fitness in its native environment and its fitness in a foreign environment, indicating weak trade-offs associated with local adaptation. These results suggest that populations are often locally adapted

but stochastic processes such as genetic drift may limit the efficacy of divergent selection.

Link: http://www.webpages.uidaho.edu/~snuismer/Nuismer_Lab/548_readings_files/Hereford%202009.pdf

427. Hu FS, Hampe A, Petit RJ. 2009. Paleoecology meets genetics: deciphering past vegetational dynamics. Frontiers in Ecology and the Environment 7:371-379.

Type: Journal

Geographic Area: Global

Compilers' Keywords: paleoecology, migration, Quaternary, climate change, tree distribution, refugia, genetic conservation

Abstract: Genetic analysis adds a novel dimension to paleoecology that is becoming increasingly important for elucidating vegetational dynamics in relation to climate change. Because past vegetational changes have often left distinct genetic imprints on current plant populations, genetic analysis can add detail to fossil-based reconstructions. Recent surveys of DNA polymorphisms yield new insights into past vegetational changes and address long-standing paleoecological questions. These studies reveal that small tree populations survived in mid- to high-latitude refugia throughout the Quaternary glacial episodes. They further reveal migration pathways and demographic processes during postglacial range expansion. These results challenge previous notions regarding tree species responses to climate change and help to identify genetic conservation targets. Here, we review these recent advances and outline research prospects at the interface between paleoecology and genetics.

Link: http://www.esajournals.org/doi/abs/10.1890/070160

428. Huntley B. 1991. How plants respond to climate change: migration rates, individualism and the consequences for plant communities. Annals of Botany 67:15-22.

Type: Journal

Geographic Area: Global

Keywords: climate change, pollen analysis, Quaternary, migration, individualism, plant communities

Abstract: The magnitude of climate changes forecast for the next century is comparable to the magnitude of warming during the last deglaciation. No climate change of similar magnitude has occurred since that event. The palaeoecological evidence of the response, especially of plants, to past climate change indicates that evolutionary adaptation has played no more than a minor role and that migration is the usual response of organisms to climate change. The individualism of response has important implications with respect to changes in the nature of vegetation and ecosystems. The maximum realized rates of migratory response by trees, although perhaps matching the maximum potential rates, are close to the maximum that it is believed can be achieved by such long-lived sessile organisms. The rate of climate change forecast for the future is 10–100 times faster than the rate of deglacial warming. Unless steps are taken to facilitate the migratory response of organisms to the forecast changes, then widespread extinction is likely. Artificial dispersal of trees and other organisms of limited dispersal and/or migratory capacity, the general extension of the legal protection currently afforded to some threatened organisms only within designated reserves, and the integration of wildlife habitat requirements and of wildlife corridors into human landscape utilization are all likely to be necessary. Stringent measures to limit the extent of future climate change by limiting emissions of greenhouse gases will also be necessary if the possibility of widespread and even catastrophic extinction is to be avoided.

Link: http://download.bioon.com.cn/view/upload/month_1006/20100628_92d6aa5f6c76c0ba6913YYtpqqnBmHzn.attach.pdf

429. Huntley B. 1991. Historical lessons for the future. Chapter 19. In: Spellerberg IF, Goldsmith FB, Morris MK, editors. Scientific Management of Temperate Communities for Conservation. Blackwell, Oxford: British Ecological Society. p 473-503.

Type: Book Section

Geographic Area: Global

Compilers' Keywords: climate change, conservation, succession, pollen, vegetation, species distribution, migration, review

Introduction (end paragraph): Chapter presents examples illustrating the use of palynological data at various spatial scales, and with varying temporal resolution, to address conservation problems. They show evidence of changes in communities at various scales, of the degree of permanence of particular communities, of the former character of the vegetation in particular localities, of the transient nature of some past communities and of the mechanisms of response to broad-scale environmental changes. Because few examples of small-scale palynological studies that adress conservation problems have been published, and because many conservation efforts will continue to be directed towards individuals sites, account are given of several such studies. In contrast, many of the broad-scale results have already been published and so only the major conclusions are presented here. However, it is from these conclusions that the most important implications for conservation arise, calling into question current strategies that focus primarily upon the establishment of nature reserves at sites that are today occupied by particular organisms or communities. It is also at the broad scale that palynological data can contribute to current research related to global environmental change and to global conservation.

430. Ibanez I, Clark JS, Dietze MC. 2008. Evaluating the sources of potential migrant species: implications under climate change. Ecological Applications 18:1664-1678.

Type: Journal

Geographic Area: Southeastern USA

Keywords: climate change, climate envelope, migration, seedling recruitment, source of migrant species, survival, transplant experiment, tree species

Abstract: As changes in climate become more apparent, ecologists face the challenge of predicting species responses to the new conditions. Most forecasts are based on climate envelopes (CE), correlative approaches that project future distributions on the basis of the current climate often assuming some dispersal lag. One major caveat with this approach is that it ignores the complexity of factors other than climate that contribute to a species' distributional range. To overcome this limitation and to complement predictions based on CE modeling we carried out a transplant experiment of resident and potential-migrant species. Tree seedlings of 18 species were planted side by side from 2001 to 2004 at several locations in the southern Appalachians and in the North Carolina Piedmont (USA). Growing seedlings under a large array of environmental conditions, including those forecasted for the next decades, allowed us to model seedling survival as a function of variables characteristic of each site, and from here we were able to make predictions on future seedling recruitment. In general, almost all species showed decreased survival in plots and years with lower soil moisture, including both residents and potential migrants, and in both locations, the southern Appalachians and the Piedmont. The detrimental effects that anticipated arid conditions could have on seedling recruitment contradict some of the projections made by CE modeling, where many of the species tested are expected to increase in abundance or to expand their ranges. These results point out the importance of evaluating the potential sources of migrant species when modeling vegetation response to climate change, and considering that species adapted to the new climate and the local conditions may not be available in the surrounding regions.

Link: http://www.srs.fs.usda.gov/pubs/ja/2008/ja_2008_ibanez_001.pdf

431. Isaac-Renton MG, Roberts DR, Hamann A, Spiecker H. 2014. Douglas-fir plantations in Europe: a retrospective test of assisted migration to address climate change. Global Change Biology 20:2607-2617.

Type: Journal

Geographic Area: Europe

Keywords: bioclimatic envelope models, exotic species, model validation, no-analogue climates, provenance trials, *Pseudotsuga menziesii*, species distribution models

Abstract: We evaluate genetic test plantations of North American Douglas-fir provenances in Europe to quantify how tree populations respond when subjected to climate regime shifts, and we examined whether bioclimate envelope models developed for North America to guide assisted migration under climate change can retrospectively predict the success of these provenance transfers to Europe. The meta-analysis is based on long-term growth data of 2,800 provenances transferred to 120 European test sites. The model was generally well suited to predict the best performing provenances along north-south gradients in Western Europe, but failed to predict superior performance of coastal North American populations under continental climate conditions in Eastern Europe. However, model projections appear appropriate when considering additional information regarding adaptation of Douglas-fir provenances to withstand frost and drought, even though the model partially fails in a validation against growth traits alone. We conclude by applying the partially validated model to climate change scenarios for Europe, demonstrating that climate trends observed over the last three decades warrant changes to current use of Douglas-fir provenances in plantation forestry throughout Western and Central Europe.

Link: http://www.ncbi.nlm.nih.gov/pubmed/24737595

432. Iverson LR, Prasad AM. 1998. Predicting abundance of 80 tree species following climate change in the eastern United States. Ecological Monographs 68:465-485.

Type: Journal

Geographic Area: Eastern USA

Keywords: climate change, envelope analysis, forest inventory, geographic information systems (GIS), global change, landscape ecology, predictive vegetation mapping, regression tree analysis (RTA), species—environment relationships, tree species distribution, tree species migration, tree species ranges

Abstract: Projected climate warming will potentially have profound effects on the earth's biota, including a large redistribution of tree species. We developed models to evaluate potential shifts for 80 individual tree species in the eastern United States. First, environmental factors associated with current ranges of tree species were assessed using geographic information systems (GIS) in conjunction with regression tree analysis (RTA). The method was then extended to better understand the potential of species to survive and/or migrate under a changed climate. We collected, summarized, and analyzed data for climate, soils, and use, elevation, and species assemblages for > 2,100 counties east of the 100th meridian. Forest Inventory Analysis (FIA) data for > 100,000 forested plots in the East provided the tree species range and abundance information for the trees. RTA was used to devise prediction rules from current species–environment relationships, which were then used to replicate the current distribution as well as predict the future potential distributions under two scenarios

of climate change with twofold increases in the level of atmospheric CO_2. Validation measures prove the utility of the RTA modeling approach for mapping current tree importance values across large areas, leading to increased confidence in the predictions of potential future species distributions. With our analysis of potential effects, we show that roughly 30 species could expand their range and/or weighted importance at least 10%, while an additional 30 species could decrease by at least 10%, following equilibrium after a changed climate. Depending on the global change scenario used, 4–9 species would potentially move out of the United States to the north. Nearly half of the species assessed (36 out of 80) showed the potential for the ecological optima to shift at least 100 km to the north, including seven that could move > 250 km. Given these potential future distributions, actual species redistributions will be controlled by migration rates possible through fragmented landscapes.

Link: http://www.clas.ufl.edu/users/mbinford/GEOXXXX_Biogeography/LiteratureForLinks/iverson_and_prasad_1998_predicting_abundance_80_tree_species_climate_change_EUS_EcolMonogr.pdf

433. Iverson LR, Schwartz MW, Prasad AM. 2004.

How fast and far might tree species migrate in the eastern United States due to climate change? Global Ecology and Biogeography 13:209-219.

Type: Journal

Geographic Area: Eastern USA

Keywords: climate change, *Diospyros virginiana*, fragmented habitat, global warming, *Liquidambar styraciflua*, migration, *Oxydendrum arboretum*, *Pinus taeda*, *Quercus falcate*, United States

Abstract: We describe and use a model, SHIFT, to estimate potential migration due to climate change over the next 100 years in the eastern United States. Five species, currently confined to the eastern half of the United States and not extending into Canada, were used to assess migration potential: *Diospyros virginiana* (persimmon), *Liquidambar styraciflua* (sweetgum), *Oxydendrum arboreum* (sourwood), *Pinus taeda* (loblolly pine), and *Quercus falcata* var. *falcata* (southern red oak). SHIFT is a matrix simulation model using simple inverse power functions to provide a distance decay of seed dispersal and is driven primarily by the abundance of the species near the boundary, the forest density within and beyond the boundary, and the distance between cells. For each cell outside the current boundary, the model creates an estimate of the probability that each unoccupied cell will become colonized over a period of 100 years. SHIFT is a ‘fat-tailed’ migration model that allows rare very long distance dispersal events and colonization could occur up to 500 km beyond the current distribution boundary. Model outputs were analysed using transects through sections showing relatively low and high colonization probabilities as a result of low and high densities of target trees (high source strength) as well as high densities of forest (high sink strength). We also assess migration potential for species by concentric rings around the current boundary. Model outputs show the generally limited nature of migration for all five species over 100 years. There is a relatively high probability of colonization within a zone of 10–20 km (depending on habitat quality and species abundance) from the current boundary, but a small probability of colonization where the distance from the current boundary exceeds about 20 km. Whether biologically plausible or not, rare very long distance migration events are not sufficient to rescue migration. Species abundance (the source strength of migration) near the range boundary carried relatively more influence than percentage forest cover (sink strength) in determining migration rates. The transect evaluation revealed the importance of abundance of the species near the boundary, indicating that rare species may have much more difficulty in unassisted northward migration due to climate change. The concentric rings analysis of the model outputs showed that only the first 10–20 km of area would have a reasonably high probability of colonization. Rare, long-distance events permit colonization of remote outliers, but much more needs to be understood about the likelihood of these rare events to predict the frequency of outlier establishment.

Link: http://www.des.ucdavis.edu/faculty/mschwartz/Website%20publications/IversonGlobalEcol2004.pdf

434. Iverson LR, Prasad AM, Matthews SN, Peters MP. 2011.

Lessons learned while integrating habitat, dispersal, disturbance, and life-history traits into species habitat models under climate change. Ecosystems 14:1005-1020.

Type: Journal

Geographic Area: Eastern USA

Keywords: climate change, eastern United States, randomForest, statistical modeling, migration, trees, birds, DISTRIB, SHIFT, ModFacs

Abstract: We present an approach to modeling potential climate-driven changes in habitat for tree and bird species in the eastern United States. First, we took an empirical-statistical modeling approach, using RandomForest, with species abundance data from national inventories combined with soil, climate, and landscape variables, to build abundance-based habitat models for 134 tree and 147 bird species. We produced lists of species for which suitable habitat tends to increase, decrease, or stay the same for any region. Independent assessments of trends of large trees versus seedlings across the eastern U.S. show that 37 of 40 species in common under both studies are currently trending as modeled. We developed framework, ModFacs, in which we used the literature to assign default modification factor scores for species characteristics that cannot be readily assessed in such models, including 12 disturbance factors (for example, drought, fire, insect pests), nine biological factors (for example, dispersal, shade tolerance), and assessment scores of novel climates, long-distance extrapolations, and output variability by climate model and emission scenario. We also used a spatially explicit cellular model, SHIFT, to calculate colonization potentials for some species, based on their abundance, historic dispersal distances, and the fragmented nature of the landscape. By combining results from the three efforts, we can create projections of potential climate change impacts over the next 100 years or so. Here we emphasize some of the lessons we have learned over 16 years in hopes that they may help guide future experiments, modeling efforts, and management.

Link: http://www.researchgate.net/publication/225455924_Lessons_Learned_While_Integrating_Habitat_Dispersal_Disturbance_and_Life-History_Traits_into_Species_Habitat_Models_Under_Climate_Change/file/9fcfd501955d5a053e.pdf

435. Jump AS, Penuelas J. 2005. Running to stand still: adaptation and the response of plants to rapid climate change. Ecology Letters 8:1010-1020.

Type: Journal

Geographic Area: Global

Keywords: adaptation, climate change, conservation, decreased fitness, extinction risk, gene flow, genetic diversity, habitat fragmentation, migration, plant populations

Abstract: Climate is a potent selective force in natural populations, yet the importance of adaptation in the response of plant species to past climate change has been questioned. As many species are unlikely to migrate fast enough to track the rapidly changing climate of the future, adaptation must play an increasingly important role in their response. In this paper we review recent work that has documented climate-related genetic diversity within populations or on the microgeographical scale. We then describe studies that have looked at the potential evolutionary responses of plant populations to future climate change. We argue that in fragmented landscapes, rapid climate change has the potential to overwhelm the capacity for adaptation in many plant populations and dramatically alter their genetic composition. The consequences are likely to include unpredictable changes in the presence and abundance of species within communities and a reduction in their ability to resist and recover from further environmental perturbations, such as pest and disease outbreaks and extreme climatic events. Overall, a range-wide increase in extinction risk is likely to result. We call for further research into understanding the causes and consequences of the maintenance and loss of climate-related genetic diversity within populations.

Link: http://www3.botany.ubc.ca/riesebergla b/plantevol/Jump_and_Penuelas2005.pdf

436. Jump AS, Matyas C, Penuelas J. 2009. The altitude-for-latitude disparity in the range retractions of woody species. Trends in Ecology and Evolution 24:694-701.

Type: Journal

Geographic Area: Global

Compilers' Keywords: review, migration, climate change, species distribution, ecosystem services, dendroecology, genetic adaptation, provenance trial, phenology, rates, range shifts

Abstract: Increasing temperatures are driving rapid upward range shifts of species in mountains. An altitudinal range retreat of 10 m is predicted to translate into an approx. 10-km latitudinal retreat based on the rate at which temperatures decline with increasing altitude and latitude, yet reports of latitudinal range retractions are sparse. Here, we examine potential climatic, biological, anthropogenic and methodological explanations for this disparity. We argue that the lack of reported latitudinal range retractions stems more from a lack of research effort, compounded by methodological difficulties, rather than from their absence. Given the predicted negative impacts of increasing temperatures on wide areas of the latitudinal distributions of species, the investigation of range retractions should become a priority in biogeographical research.

437. Kaye TN. 2008. Vital steps toward success of endangered plant reintroductions. Native Plants Journal 9:313-322.

Type: Journal

Geographic Area: Global

Keywords: recovery, rare species, restoration, translocation, population, augmentation

Abstract: Reintroduction of endangered plants faces many challenges, but the survival of some species may depend on its success. What measures should practitioners take to ensure a successful project, and how should success be measured? Steps in the reintroduction process include planning and identification of objectives, finding source material, propagation, site selection, site preparation, outplanting, monitoring, evaluation and interpretation, feedback to improve protocols, communication with others, habitat maintenance, and repeated actions if necessary to meet objectives. Conducting reintroductions as designed experiments and applying the results through adaptive management will maximize the effectiveness of reintroductions.

Link: http://appliedeco.org/reports/Kaye%202008%20Reintroduction%20Native%20Plants%20Journal.pdf

438. Kelly AE, Goulden ML. 2008. Rapid shifts in distribution with recent climate change. Proceedings of the National Academy of Science USA 105:11823-11826.

Type: Journal

Geographic Area: California, USA

Keywords: plant migration, range shift

Abstract: A change in climate would be expected to shift plant distribution as species expand in newly favorable areas and decline in increasingly hostile locations. We compared surveys of plant cover that were made in 1977 and 2006–2007 along a 2,314-m elevation gradient in Southern California's Santa Rosa Mountains. Southern California's climate warmed at the surface, the precipitation variability increased, and the amount of snow decreased during the 30-year period preceding the second survey. We found that the average elevation of the dominant plant species rose by 65 m between the surveys. This shift cannot be attributed to changes in air pollution or fire frequency and appears to be a consequence of changes in regional climate.

Link: http://listmail.energy.ca.gov/sitingcases/genesis_solar/documents/others/testimony_centr_biological_diversity/exhibits/Exh.%20816.%20Kelly%20and%20Goulden%202008%20%20%20Rapid%20shifts%20in%20plant%20distribution%20with%20recent%20climate%20change.pdf

439. Khasa PD, Dancik BP. 1996. **Rapid identification of white-Engelmann spruce by RAPD markers.** Theoretical Applications of Genetics 92:46-52.

Type: Journal

Geographic Area: North America

Keywords: hybridization, PCR, *Picea*, RAPD fingerprints

Abstract: Fragments of random amplified polymorphic DNA (RAPDs) were used as markers to distinguish *Picea glauca* (Moench) Voss (white spruce) and *Picea engelmannii* Parry (Engelmann spruce). These species and their putative hybrids are difficult to differentiate morphologically and are collectively known as interior spruce. Four oligodeoxynucleotide decamer primers showed species specific amplification products between white spruce and Engelmann spruce. These fragments are highly conserved among seed lots and individual trees of each species from diverse geographic origins. The consistency and reproducibility of these species-specific amplification products were tested in more than two amplification reactions. Therefore, RAPD markers can provide genetic markers for easy and rapid identification of the specific genetic entry of these spruce species and their reported putative hybrids. According to the frequencies of the species-specific RAPD markers, it is possible to estimate the hybrid fraction, indicative of true introgression between the two species. These results are useful for quick identification of both species and their hybrid swarms at any stage in the sporophyte phase of the life cycle, for determining the occurrence and the magnitude of introgressive hybridization in an overlap zone between the two species, and for certification purposes in operational re-forestation and tree-improvement programs.

440. Kim M-S, Richardson BA, McDonald GI, Klopfenstein NB. 2011. **Genetic diversity and structure of western white pine (*Pinus monticola*) in North America: a baseline study for conservation, restoration, and addressing impacts of climate change.** Tree Genetics & Genomes 7:11-21.

Type: Journal

Geographic Area: Western USA

Keywords: genetic variation, tree population structure, *Pinus monticola*

Abstract: Western white pine (*Pinus monticola*) is an economically and ecologically important species in western North America that has declined in prominence over the past several decades, mainly due to the introduction of *Cronartium ribicola* (cause of white pine blister rust) and reduced opportunities for regeneration. Amplified fragment length polymorphism (AFLP) markers were used to assess the genetic diversity and structure among populations at 15 sites (e.g., provenances) across the native range of western white pine. The level of genetic diversity was different among 15 populations tested using 66 polymorphic AFLP loci. Nei's gene diversity (HE) at the population level ranged from 0.187 to 0.316. Genetic differentiation (GST) indicated that 20.1% of detected genetic variation was explained by differences among populations. In general, populations below 45° N latitude exhibited a higher level of genetic diversity than higher latitude populations. Genetic distance analysis revealed two major clades between northern and southern populations, but other well supported relationships are also apparent within each of the two clades. The complex relationships among populations are likely derived from multiple factors including migration, adaptation, and multiple glacial refugia, especially in higher latitudes. Genetic diversity and structure revealed by this study will aid recognition and selection of western white pine populations for species management and conservation programs, especially in consideration of current and future climate changes.

Link: http://www.rmrs.nau.edu/publications/kim_et_al_2010b/kim_et_al_2010b.pdf

441. King MG, Horning ME, Roalson EH. 2009. **Range persistence during the last glacial maximum: *Carex macrocephala* was not restricted to glacial refugia.** Molecular Ecology 18:4256-4269.

Type: Journal

Geographic Area: Northwestern North America

Keywords: coastal refuge, Cyperaceae, Pleistocene glaciation, population genetics

Abstract: The distribution of many species inhabiting northwestern North America has been heavily influenced by the climatic changes during the late Pleistocene. Several studies have suggested that species were restricted to glacial refugia north and/or south of the continental ice sheet front. It is also

hypothesized that the coast of northwestern North America could have been a prime location for glacial refugia because of the lowering of the eustatic sea level and the concomitant rise of the continental shelf because of tectonic rebound. Alternatively, some coastal species distributions and demographics may have been unaffected in the long-term by the last glacial maximum (LGM). We tested the glacial refugium hypothesis on an obligate coastal plant species, *Carex macrocephala* by sampling 600 individuals from 41 populations with 11 nuclear microsatellite loci and the *rpL16* plastid intragenic spacer region. The microsatellite data sets suggest a low level of population differentiation with a standardized $G'_{ST} = 0.032$ and inbreeding was high with an $F = 0.969$. The homogenization of the populations along the coast was supported by a principal coordinate analysis, AMOVAS and SAMOVA analyses. Analyses using the *rpL16* data set support the results of the microsatellite analyses, with a low F_{ST} of 0.042. Coalescent and mismatch analyses using *rpL16* suggest that C. macrocephala has not gone through a significant bottleneck within the past 100, 000 years, although a much earlier population expansion was indicated by the mismatch analysis. *Carex macrocephala* exhibits the characteristics of metapopulation dynamics and on the basis of these results, we concluded that it was not restricted to glacial refugia during the LGM, but that it existed as a large metapopulation.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19754517

442. Kranabetter JM, Stoehr MU, O'Neill GA. 2012. **Divergence in ectomycorrhizal communities with foreign Douglas-fir populations and implications for assisted migration.** Ecological Applications 22:550-560.

Type: Journal

Geographic Area: Western Canada

Keywords: climate change mitigation, coevolution, community genetics, foundation species, maladaptation, Southwestern British Columbia, Canada

Abstract: Assisted migration of forest trees has been widely proposed as a climate change adaptation strategy, but moving tree populations to match anticipated future climates may disrupt the geographically based, coevolved association suggested to exist between host trees and ectomycorrhizal fungal (EMF) communities. We explored this issue by examining the consistency of EMF communities among populations of 40 year-old Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) trees in common-garden field trial using four provenances from contrasting coastal climates in southwestern British Columbia. Considerable variation in EMF community composition within test sites was found, ranging from 0.38 to 0.65 in the mean similarity index, and the divergence in EMF communities from local populations increased with site productivity. Clinal patterns in colonization success were detected for generalist and specialist EMF species on only the two productive test sites. Host population effects were limited to EMF species abundance rather than species loss, as richness per site averaged 15.0 among provenances and did not differ by transfer extent (up to 450 km), while Shannon's diversity index declined slightly. Large differences in colonization rates of specialist fungi, such as *Tomentella stuposa* and *Clavulina cristata*, raise the possibility that EMF communities maladapted to soil conditions contributed to the inferior growth of some host populations on productive sites. The results of the study suggest locally based specificity in host-fungal communities is likely a contributing factor in the outcome of provenance trials, and should be a consideration in analyzing seed-transfer effects and developing strategies for assisted migration.

443. Kremer A, Ronce O, Robledo-Arnuncio JJ, Guillaume F, Bohrer G, Nathan R, Bridle JR, Gomulkiewicz R, Klein EK, Ritland K, Kuparinen A, Gerber S, Schueler S. 2012. **Long-distance gene flow and adaptation of forest trees to rapid climate change.** Ecology Letters 15:378-392.

Type: Journal

Geographic Area: Global

Keywords: adaptation, climate change, forest trees, gene flow, selection

Abstract: Forest trees are the dominant species in many parts of the world and predicting how they might respond to climate change is a vital global concern. Trees are capable of long-distance gene flow, which can promote adaptive evolution in novel environments by increasing genetic variation for fitness. It is unclear, however, if this can compensate for maladaptive effects of gene flow and for the long-generation times of trees. We critically review data on the extent of long-distance gene flow and summarize theory that allows us to predict evolutionary responses of trees to climate change. Estimates of long-distance gene flow based both on direct observations and on genetic methods provide evidence that genes can move over spatial scales larger than habitat shifts predicted under climate change within one generation. Both theoretical and empirical data suggest that the positive effects of gene flow on adaptation may dominate in many instances. The balance of positive to negative consequences of gene flow may, however, differ for leading edge, core and rear sections of forest distributions. We propose future experimental and theoretical research that would better integrate dispersal biology with evolutionary quantitative genetics and improve predictions of tree responses to climate change.

Link: http://www.ncbi.nlm.nih.gov/pubmed/22372546

444. Kreyling J, Wiesenberg GLB, Thiel D, Wohlfart C, Huber G, Walter J, Jentsch A, Konnert M, Beierkuhnlein C. 2012. **Cold hardiness of *Pinus nigra* Arnold as influenced by geographic origin, warming, and**

extreme summer drought. Environmental and Experimental Botany 78:99-108.

Type: Journal

Geographic Area: Europe

Keywords: frost hardiness, black pine, ecotype, cold tolerance, global warming, winter ecology

Abstract: Adaptation to the adverse effects of climate change is being investigated more and more through the introduction of species from warmer and drier climates, such as the (sub-) Mediterranean *Pinus nigra* to dry sites in temperate Central Europe. Winter survival, however, may pose a serious threat to this strategy as cold extremes, which naturally determine the poleward range limits of forest trees, are not expected to follow the general warming trend in the near future. Here, juveniles of *P. nigra* from eight provenances throughout Europe were exposed to different climate change scenarios (factorial combinations of 42 days of drought and warming by 1.6 °C) in a common garden experiment in Bayreuth, Germany. Cold hardiness (LT50) was determined by the Relative Electrolyte Leakage method (REL) in two consecutive winters. Cold hardiness of foliage differed by 10 °C between the provenances studied and a local adaptation to minimum temperature was found. Cold hardiness was further affected by extreme summer drought, increasing cold hardiness by 3.9 °C on average in the subsequent winter, and by summer warming, increasing cold hardiness by 3.4 °C. Year-round warming had no significant effect on cold hardiness. Cold hardiness was related to the content of soluble carbohydrates and to the composition of fatty acids and alkanes in the needles. Juveniles of *P. nigra* exhibited a comparable cold hardiness as juveniles of species native to Central Europe (*P. sylvestris*, *Picea abies*, *Fagus sylvatica* and *Quercus petraea*) under the same climatic conditions. Cold hardiness of the fine roots of *P. nigra* averaged -16.5 °C compared to -23.8 °C on average for needles. Our results imply that the cold hardiness of the foliage is adaptive to both long-term growing conditions at the seed origin (genetic heritage) and short-term alterations of these conditions (individual plasticity), while first hints suggest that cold hardiness of the roots is high and might not be adaptive. For *P. nigra*, below- and above-ground cold hardiness of selected provenances in mid-winter appears suitable for cultivation in temperate regions.

Link: http://www.sciencedirect.com/science/article/pii/S0098847211003339

445. Krutovsky KV. 2012. Forest genomics for mitigating climate change and breeding resilient trees. In: International Plant and Animal Genome Conference. San Diego (CA): Plant and Animal Genome. p 1.

Type: Conference Paper

Geographic Area: Southeastern USA

Compilers' Keywords: migration, forest management, assisted migration, Douglas-fir, *Pseudotsuga menziesii* var. *menziesii*, loblolly pine, *Pinus taeda*, conference paper

Abstract: Global climate change and the demand for an alternative, renewable and ecologically friendly source of energy significantly increases the role of pine forests in the southeastern United States and population and ecological genomic studies of their adaptive, ecological and economic potential. The accelerating global climate change can exceed the adaptive potential of pine forests and lead to their contraction on large areas. However, some forest tree populations growing now in the regions that have ecological conditions similar to the future changes are likely to possess an adaptive potential necessary for spreading adaptation into other regions with similar ecological conditions expected in the future. Unfortunately, phenotypic plasticity and historically established gene flow between remote populations can be insufficient for fast natural propagation of genetic adaptations. In this connection the role of conservation management and especially that of assisted migration (also called assisted colonization, managed relocation or translocation done by physically moving the plant material (pollen, seeds and seedlings) to other regions where this material is better adapted to the future environments) increases. Modern methods and tools of population, landscape and ecological genomics allow to study the genetic basis of adaptation in forest tree species and also detect the main genes responsible for important adaptive and economic traits that can be used in assisted gene migration and tree breeding for biomass growth, water use efficiency, cellulose content and other traits important for adaptation and for bioenergy and biofuel production. The recent data on Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) and loblolly pine (*Pinus taeda* L.) populations studied for thousands different genes are presented to illustrate population and ecological genomic studies in conifers.

Link: https://pag.confex.com/pag/xx/webprogram/Paper1651.html

446. Krutovsky KV, Burczyk J, Chybicki I, Finkeldey R, Pyhäjärvi T, Robledo-Arnuncio JJ. 2012. Gene flow, spatial structure, local adaptation, and assisted migration in trees. Chapter 4. In: Schnell RJ, Priyadarshan PM, editors. Genomics of Tree Crops. New York (NY): Springer New York. p 71-116.

Type: Book Section

Geographic Area: Global

Keywords: assisted migration, gene flow, dispersal, introgression, local adaptation, molecular genetic markers, spatial structure

Abstract: Gene flow is a process of transferring and exchanging genetic material among groups of organisms and is an important evolutionary factor that greatly affects genetic variation and differentiation in trees. Gene flow within and among

populations of forest trees plays an important role in forest tree improvement, conservation genetics, and containment of genetically modified trees (GM trees). Although trees are a very diverse group of woody plants, they share many common life traits that affect gene flow, which we discuss in this review. Some unfavorable processes in current forest tree ecosystems, such as habitat loss and fragmentation, increased environmental stress due to global climate change, introgression from domesticated trees into their wild relatives, introduction of maladapted germplasm during reforestation, etc., may badly affect naturally established balance between gene flow, isolation, and local adaptation. Therefore, estimation of gene flow becomes increasingly important for monitoring these processes and developing the best possible strategy to manage and protect forest ecosystems. Here, we review what has been done in this area recently and the methods and approaches currently used to measure gene flow in forest tree populations.

Link: http://dx.doi.org/10.1007/978-1-4614-0920-5_4

447. La Sorte FA, Jetz W. 2010. Avian distributions under climate change: towards improved projections. Journal of Experimental Biology 213:862-869.

Type: Journal

Geographic Area: Global

Keywords: birds, biophysical model, bioclimate envelopment model, climate change, community composition, geographic range shifts, global climate change, migration

Abstract: Birds are responding to recent climate change in a variety of ways including shifting their geographic ranges to cooler climates. There is evidence that northern-temperate birds have shifted their breeding and non-breeding ranges to higher latitudes, and tropical birds have shifted their breeding ranges to higher altitudes. There is further evidence these shifts have affected migration strategies and the composition and structure of communities. Projections based on correlative distributional models suggest many birds will experience substantial pressures under climate change, resulting in range contraction and shifts. Inherent limitations of correlative models, however, make it difficult to develop reliable projections and detailed inference. Incorporating a mechanistic perspective into species distribution models enriches the quality of model inferences but also severely narrows the taxonomic and geographic relevance. Mechanistic distributional models have seen increased applications, but so far primarily in ectotherms. We argue that further development of similar models in birds would complement existing empirical knowledge and theoretical projections. The considerable data already available on birds offer an exciting basis. In particular, information compiled on flight performance and thermal associations across life history stages could be linked to distributional limits and dispersal abilities, which could be used to develop more robust and detailed projections. Yet, only a broadening of taxonomic scale, specifically to appropriately represented tropical diversity, will allow for truly general inference and require the continued use of correlative approaches that may take on increasingly mechanistic components. The trade-off between detail and scale is likely to characterize the future of global change biodiversity research, and birds may be an excellent group to improve, integrate and geographically extend current approaches.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20190111

448. Ledig FT, Rehfeldt GE, Jaquish B. 2012. Projections of suitable habitat under climate change scenarios: implications for trans-boundary assisted colonization. American Journal of Botany 99:1217-1230.

Type: Journal

Geographic Area: Western USA

Keywords: assisted colonization, climatic models, conservation, *Picea breweriana*, Pinaceae, Random Forests

Abstract: Climate change may threaten endemic species with extinction, particularly relicts of the Arcto-Tertiary Forest, by elimination of their contemporary habitat. Projections of future habitat are necessary to plan for conservation of these species. We used spline climatic models and modified Random Forests statistical procedures to predict suitable habitats for Brewer spruce (*Picea breweriana*), which is endemic to the Klamath Region of California and Oregon. We used three general circulation models and two sets of carbon emission scenarios (optimistic and pessimistic) for future climates. Our procedures predicted present occurrence of Brewer spruce perfectly. For the decades 2030, 2060, and 2090, its projected range within the Klamath Region progressively declined, to the point of disappearance in the decade 2090. The climate niche was projected to move north to British Columbia, the Yukon Territory, and southeastern Alaska. The results emphasize the necessity of assisted colonization and trans-boundary movement to prevent extinction of Brewer spruce. The projections provide a framework for formulating conservation plans, but planners must also consider regulations regarding international plant transfers.

Link: http://www.ncbi.nlm.nih.gov/pubmed/22763352

449. Lenoir J, Gegout JC, Marquet PA, de Ruffray P, Brisse H. 2008. A significant upward shift in plant species optimum elevation during the 20th century. Science 320:1768-1771.

Type: Journal

Geographic Area: Western Europe

Compilers' Keywords: range shifts, forest plant species, climate change

Abstract: Spatial fingerprints of climate change on biotic communities are usually associated with changes in the distribution of species at their latitudinal or altitudinal extremes.

By comparing the altitudinal distribution of 171 forest plant species between 1905 and 1985 and 1986 and 2005 along the entire elevation range (0 to 2600 meters above sea level) in west Europe, we show that climate warming has resulted in a significant upward shift in species optimum elevation averaging 29 meters per decade. The shift is larger for species restricted to mountain habitats and for grassy species, which are characterized by faster population turnover. Our study shows that climate change affects the spatial core of the distributional range of plant species, in addition to their distributional margins, as previously reported.

Link: http://www.researchgate.net/publication/224903439_A_significant_upward_shift_in_plant_species_optimum_elevation_during_the_20th_century/file/9fcfd504cba44ab9ed.pdf

450. Linhart YB, Grant MC. 1996. Evolutionary significance of local genetic differentiation in plants. Annual Review of Ecology and Systematics 27:237-277.

Type: Journal

Geographic Area: Global

Compilers' Keywords: selection, genetic variation, microdifferentiation, evolutionary dynamics, natural selection

Abstract: The study of natural plant populations has provided some of the strongest and most convincing cases of the operation of natural selection currently known, partly because of amenability to reciprocal transplant experiments, common garden work, and long-term *in situ* manipulation. Genetic differentiation among plant populations over small scales (a few cm to a few hundred cm) has been documented and is reviewed here, in herbaceous annuals and perennials, woody perennials, aquatics, terrestrials, narrow endemics, and widely distributed species. Character differentiation has been documented for most important features of plant structure and function. Examples are known for seed characters, leaf traits, phenology, physiological and biochemical activities, heavy metal tolerance, herbicide resistance, parasite resistance, competitive ability, organellar characters, breeding systems, and life history. Among the forces that have shaped these patterns of differentiation are toxic soils, fertilizers, mowing and grazing, soil moisture, temperature, light intensity, pollinating vectors, parasitism, gene flow, and natural dynamics. The breadth and depth of the evidence reviewed here strongly support the idea that natural selection is the principal force shaping genetic architecture in natural plant populations; that view needs to be more widely appreciated than it is at present.

451. Liu H, Feng C-L, Chen B-S, Wang Z-S, Xie X-Q, Deng Z-H, Wei X-L, Liu S-Y, Zhang Z-B, Luo Y-B. 2012. Overcoming extreme weather challenges: successful but variable assisted colonization of wild orchids in southwestern China. Biological Conservation 150:68-75.

Type: Journal

Geographic Area: China

Keywords: extreme weather event, hydropower projects, managed relocation, out-of-range translocation, population dynamics, tropical forest

Abstract: Assisted colonization of endangered species to locations outside their native ranges in response to projected climate change has emerged as a potential, but highly controversial conservation tool. The debate has been largely philosophical and hypothetical as little biological data exist in the literature. In 2006, nearly 1,000 endangered wild orchid plants belonging to 29 species were translocated to higher elevations in subtropical southwestern China in response to inundation threats from a hydropower project. We took advantage of this upward translocation to address one of the main biological concerns associated with assisted colonization, i.e., whether the target endangered species can survive in the novel environment that is projected to be suitable for them, sometime in the near future. We assessed the impacts of two extreme weather events, translocation shock and herbivory, on survival of 20 of these species and 462 individuals that were translocated beyond their current range vs. within that range. A cold spell in 2008 on average caused 10% mortality, less than the mortality rate from herbivores. However, the cold spell was the only forces that extirpated an out-of-range population. No mortality resulted from a drought event in 2010. The 5-year survival percentages were not different between low and wide elevation species (69.3% mean ± 36.3% standard deviation vs. 67.3% ± 30.9%). Orchids represent 10% of flowering plant diversity and are among the most endangered group of organisms due to combination of their often specialized ecological requirements, habitat destruction, and overexploitation. The demonstrated ability to survive extreme environmental challenges indicates that assisted colonization may be a viable conservation tool for the many endangered orchids worldwide due to climate change and/or other reasons.

Link: http://english.xtbg.cas.cn/at/sr/201207/P020120716522880199452.pdf

452. Lo Y, Blanco JA, Kimmins JP, Seely B, Welham C. 2011. Linking climate change and forest ecophysiology to project future trends in tree growth: a review of forest models. Chapter 4. In: Blanco J, editor. Climate Change - Research and Technology for Adaptation and Mitigation. Rijeka, Croatia: InTech. p 63-87.

Type: Book Section

Geographic Area: Western Canada

Compilers' Keywords: species distribution, historical ecosystem, range shift

Introduction: Climate change is already altering tree species ranges, with tree lines shifting upwards and polewards around the world. A recent analysis of the potential effects of climate change on tree distribution in British Columbia suggested that important timber species including white spruce and lodgepole pine may lose suitable habitat and suffer adversely from a combination of warming trends and reduced growing season precipitation. In contrast, species such as Douglas fir and ponderosa pine may actually expand their range and potentially show improved growth rates in parts of their existing range. A recent study in the mountains of interior British Columbia showed how at high elevation, trees historically responded positively to increased temperatures, while at low elevations trees showed a negative response to growing season maximum temperature and a positive correlation with growing season precipitation. Given these species-specific responses it is not surprising that recent research has failed to identify direct links between warmer temperatures and observed changes in species ranges. The important ecological and socio-economic consequences of such changes have prompted multiple modelling efforts to predict the future location of habitat suitable for tree species and to assess the potential implications for tree growth of changes in climate. Defining such areas and estimating the losses or gains due to climate change in timber production have important consequences on forest management and conservation. The most popular approaches to project future areas of suitable habitat for commercial tree species have involved analysis of historical records of tree lines in boreal and alpine environments, using climate envelope models. Similarly, dendroclimatology (studying historical tree growth rates by analyzing tree ring width) has been used to link climate and tree growth rates. These approaches are based mostly on climatic information, although their combination with other information such as soil or topography has been used to produce maps of potential future habitat suitability. Such predictions are useful to understand the relationships between climate and tree distribution, abundance and growth, and could be a starting point for helping to plan forest management at broad scales under changing climate. However, such approach has several shortcomings, which have been discussed in the scientific literature before but it seems that this discussion has not been translated into the forest management community yet.

Link: http://www.researchgate.net/publication/221915588_Linking_Climate_Change_and_Forest_Ecophysiology_to_Project_Future_Trends_in_Tree_Growth_A_Review_of_Forest_Models/file/60b7d5141a7b103241.pdf

453. Loarie SR, Duffy PB, Hamilton H, Asner GP, Field CB, Ackerly DD. 2009. The velocity of climate change. Nature 462:1052-1055.

Type: Journal

Geographic Area: Global

Compilers' Keywords: animals, biodiversity, conservation, ecosystem, global warming, biological models, temporal factors, migration, species distribution

Abstract: The ranges of plants and animals are moving in response to recent changes in climate. As temperatures rise, ecosystems with 'nowhere to go', such as mountains, are considered to be more threatened. However, species survival may depend as much on keeping pace with moving climates as the climate's ultimate persistence. Here we present a new index of the velocity of temperature change (km yr^{-1}), derived from spatial gradients (°C km^{-1}) and multimodel ensemble forecasts of rates of temperature increase (°C yr^{-1}) in the twenty-first century. This index represents the instantaneous local velocity along Earth's surface needed to maintain constant temperatures, and has a global mean of 0.42 km yr^{-1} (A1B emission scenario). Owing to topographic effects, the velocity of temperature change is lowest in mountainous biomes such as tropical and subtropical coniferous forests (0.08 km yr^{-1}), temperate coniferous forest, and montane grasslands. Velocities are highest in flooded grasslands (1.26 km yr^{-1}), mangroves and deserts. High velocities suggest that the climates of only 8% of global protected areas have residence times exceeding 100 years. Small protected areas exacerbate the problem in Mediterranean-type and temperate coniferous forest biomes. Large protected areas may mitigate the problem in desert biomes. These results indicate management strategies for minimizing biodiversity loss from climate change. Montane landscapes may effectively shelter many species into the next century. Elsewhere, reduced emissions, a much expanded network of protected areas, or efforts to increase species movement may be necessary.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20033047

454. Lu P, Man R. 2011. Assessment of assisted migration effects on spring bud flush in white spruce (*Picea glauca*) seedlings. The Forestry Chronicle 87:391-397.

Type: Journal

Geographic Area: Ontario, Canada

Keywords: bud flush, provenance, frost damage

Abstract: In a changing climate, delaying the time of bud flush may be advantageous to boreal forest species to reduce the risk of spring frost damage. In this study, we examined the potential effect of assisted migration of tree seed on time to bud flush for white spruce. Flushing times of seedlings from 23 white spruce provenances from Ontario were observed under varying temperature conditions simulated in controlled environment chambers. Results indicated that time to bud flush varied considerably among provenances. Although higher temperatures significantly promoted bud flushing for all provenances, provenance-by-temperature interactions were negligible, indicating stable performance of white spruce provenances for this adaptive trait. Spatial patterns of variation among provenances in bud flushing were not consistent with patterns found in range-wide provenance tests. Assisted migration of tree seed across relatively short distances is unlikely to delay bud flushing time in white spruce. Some southern populations may flush

earlier at more northerly sites, which would exacerbate spring frost risk. Tree improvement may be an effective approach to utilize among- and within provenance variation to enhance this fitness trait for better climatic adaptation.

455. Malcolm JR, Markham A, Neilson RP, Garaci M. 2002. Estimated migration rates under scenarios of global climate change. Journal of Biogeography 29:835-849.

Type: Journal

Geographic Area: North America

Keywords: global warming, plant migration, biomes, greenhouse effect, biodiversity

Abstract: Greenhouse-induced warming and resulting shifts in climatic zones may exceed the migration capabilities of some species. We used fourteen combinations of General Circulation Models (GCMs) and Global Vegetation Models (GVMs) to investigate possible migration rates required under CO_2-doubled climatic forcing. Migration distances were calculated between grid cells of future biome type x and nearest same-biome-type cells in the current climate. In 'base-case' calculations, we assumed that $2 \cdot CO_2$ climate forcing would occur in 100 years, we used ten biome types and we measured migration distances as straight-line distances ignoring water barriers and human development. In sensitivity analyses, we investigated different time periods of $2 \cdot CO_2$ climate forcing, more narrowly defined biomes and barriers because of water bodies and human development. In the base-case calculations, average migration rates varied significantly according to the GVM used (BIOME3 vs. MAPSS), the age of the GCM (older- vs. newer-generation GCMs), and whether or not GCMs included sulfate cooling or CO_2 fertilization effects. However, high migration rates ($\geq$ 1000 m year^{-1}) were relatively common in all models, consisting on average of 17% grid cells for BIOME3 and 21% for MAPSS. Migration rates were much higher in boreal and temperate biomes than in tropical biomes. Doubling of the time period of $2 \cdot CO_2$ forcing reduced these areas of high migration rates to c. 12% of grid cells for both BIOME3 and MAPSS. However, to obtain migration rates in the Boreal biome that were similar in magnitude to those observed for spruce when it followed the retreating North American Glacier, a radical increase in the period of warming was required, from 100 to > 1,000 years. A reduction in biome area by an order of magnitude increased migration rates by one to three orders of magnitude, depending on the GVM. Large water bodies and human development had regionally important effects in increasing migration rates. In conclusion, evidence from coupled GCMs and GVMs suggests that global warming may require migration rates much faster than those observed during postglacial times and hence has the potential to reduce biodiversity by selecting for highly mobile and opportunistic species. Several poorly understood factors that are expected to influence the magnitude of any such reduction are discussed, including intrinsic migration capabilities, barriers to migration, the role of outlier populations in increasing migration rates, the role of climate in setting range limits and variation in species range sizes.

Link: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.215.1388&rep=rep1&type=pdf

456. Malcolm JR, Liu C, Neilson RP, Hansen L, Hannah L. 2006. Global warming and extinctions of endemic species from biodiversity hotspots. Conservation Biology 20:538-548.

Type: Journal

Geographic Area: Global

Keywords: biomes, climate change, general circulation models, global vegetation models, migration, species extinctions

Abstract: Global warming is a key threat to biodiversity, but few researchers have assessed the magnitude of this threat at the global scale. We used major vegetation types (biomes) as proxies for natural habitats and, based on projected future biome distributions under doubled-CO_2 climates, calculated changes in habitat areas and associated extinctions of endemic plant and vertebrate species in biodiversity hotspots. Because of numerous uncertainties in this approach, we undertook a sensitivity analysis of multiple factors that included (1) two global vegetation models, (2) different numbers of biome classes in our biome classification schemes, (3) different assumptions about whether species distributions were biome specific or not, and (4) different migration capabilities. Extinctions were calculated using both species-area and endemic-area relationships. In addition, average required migration rates were calculated for each hotspot assuming a doubled-CO_2 climate in 100 years. Projected percent extinctions ranged from < 1 to 43% of the endemic biota (average 11.6%), with biome specificity having the greatest influence on the estimates, followed by the global vegetation model and then by migration and biome classification assumptions. Bootstrap comparisons indicated that effects on hotpots as a group were not significantly different from effects on random same biome collections of grid cells with respect to biome change or migration rates; in some scenarios, however, hotspots exhibited relatively high biome change and low migration rates. Especially vulnerable hotspots were the Cape Floristic Region, Caribbean, Indo-Burma, Mediterranean Basin, Southwest Australia, and Tropical Andes, where plant extinctions per hotspot sometimes exceeded 2,000 species. Under the assumption that projected habitat changes were attained in 100 years, estimated global-warming-induced rates of species extinctions in tropical hotspots in some cases exceeded those due to deforestation, supporting suggestions that global warming is one of the most serious threats to the planet's biodiversity.

Link: http://www.atlanticcoastconservancy.org/Global%20Warming%20Articles/Malcolm%20et%20al.%202005.pdf

457. Mandák B, Placková I. 2009. How does population genetic diversity change over time? An experimental seed bank study of *Atriplex tatarica* (Chenopodiaceae). Flora - Morphology, Distribution, Functional Ecology of Plants 204:423-433.

Type: Journal

Geographic Area: Czech Republic, Europe

Keywords: allozyme, competition, heterozygosity, seed bank, succession, Wright's F statistics

Abstract: *Atriplex tatarica* is an annual, early successional, facultative halophilic species of frequently disturbed human-made habitats in Central and Eastern Europe. We investigated to what extent the plants grown from seeds extracted from soil seedbank differed genetically to mature aboveground plants in experimental populations of *A. tatarica* over two successive years. At each of five plots 50 aboveground plants and 50 plants extracted from seeds stored in soil were assayed for allozyme analysis in 2003 and 2004. At the start of experiment, we introduced 1,000 seeds of the study species into each of five experimental plots. While the species dominated in all of the experimental plots in the first year, the second year *A. tatarica* cover age decreased dramatically. Over all allele frequencies of soil seeds and mature plants showed significant differences between life history stages in both years, but not within years in soil seeds as well as mature plants stages. While mature plants showed a significantly greater amount of single and multilocus heterozygosity in both consecutive years, comparison between years did not yield any significant differences. In the same way, despite a relatively large seedbank the species population genetic parameters, i.e., allelic richness (A), observed heterozygosity (H_o), gene diversity (H_s), inbreeding coefficient (F_{IS}) and fixation index (F_{ST}), did not change over the years between as well as within life history stages. The soil seeds and mature plants significantly differed in H_o, H_s and F_{IS}, while the A and F_{ST} were not significantly different between life history stages.

458. Marris E. 2009. Planting the forest for the future. Nature 459:906-908.

Type: Journal

Geographic Area: North America

Compilers' Keywords: assisted migration, forest plant species, conservation, climate change, common garden, plant migration, Assisted Migration Adaptation Trial

Introduction: A valley in British Columbia, a few kilometres outside the town of Vernon, orderly rows of trees run alongside the road. Many of the conifers stand tall and full, producing seeds destined for plantations around the province. But one dusty brown field is filled with lines of seedlings just ankle high. Greg O'Neill, 45, who planted the trees in April, walks among them with a slightly paternal air. They are part of a very slow experiment that will yield the first results that are useful to policymakers just about in time for him to retire. In a world in which many scientists fret about the toll that global warming is exacting on nature, O'Neill is actually doing something about it. A research scientist for the British Columbia Ministry of Forests, he is moving seedlings to areas that are outside their current comfort zone to test how they might handle the warmer conditions of the future. And he is behind a government push to move tree populations into new areas to prepare them for the warming climate.

459. Maschinski J, Haskins KE. 2012. Plant reintroduction in a changing climate: promises and perils. Washington (DC): Island Press. 402 p.

Type: Book

Geographic Area: North America

Compilers' Keywords: migration, relocation, review, guidelines, plants, conservation, species extinction

Introduction: In the face of mounting numbers of plant species at risk of extinction, increasing rates of habitat destruction, spreading invasive species, and effects of climate change, there is a great need for urgent action to preserve species before they are extirpated. This book tells a story of the good fight to save and restore some of the rarest plant species in the world. A review of plant reintroductions is paramount because plant management techniques are fundamentally different from those used for animals. Herein we take stock of our progress with reintroduction in an effort to facilitate the wise decisions needed to preserve future biodiversity. This book is intended to be a resource for students, practitioners, and conservation scientists.

Link: http://islandpress.org/ip/books/book/islandpress/P/bo8073733.html

460. Maschinski J, Baggs JE, Quintana-Ascencio PF, Menges ES. 2006. Using population viability analysis to predict the effects of climate change on the extinction risk of an endangered limestone endemic shrub, Arizona cliffrose. Conservation Biology 20:218-228.

Type: Journal

Geographic Area: Arizona, USA

Keywords: drought, endangered species, global warming, population viability analysis, *Purshia subintegra*

Abstract: The threat of global warming to rare species is a growing concern, yet few studies have predicted its effects on rare populations. Using demographic data gathered in both drought and nondrought years between 1996–2003 in central Arizona upper Sonoran Desert, we modeled population viability for the federally endangered *Purshia subintegra* (Kearney) Henrickson (Arizona cliffrose). We used deterministic matrix projection models and stochastic models simulating weather conditions during our study, given historical weather variation

and under scenarios of increased aridity. Our models suggest that the *P. subintegra* population in Verde Valley is slowly declining and will be at greater risk of extinction with increased aridity. Across patches at a fine spatial scale, demographic performance was associated with environmental factors. Moist sites (patches with the highest soil moisture, lowest sand content, and most northern aspects) had the highest densities, highest seedling recruitment, and highest risk of extinction over the shortest time span. Extinction risk in moist sites was exacerbated by higher variance in recruitment and mortality. Dry sites had higher cumulative adult survival and lower extinction risk but negative growth rates. Steps necessary for the conservation of the species include introductions at more northern latitudes and *in situ* manipulations to enhance seedling recruitment and plant survival. We demonstrate that fine spatial-scale modeling is necessary to predict where patches with highest extinction risk or potential refugia for rare species may occur. Because current climate projections for the 21st century imply range shifts at rates of 300 to 500 km/century, which are beyond even exceptional examples of shifts in the fossil record of 100–150 km, it is likely that preservation of many rare species will require human intervention and a long-term commitment. Global warming conditions are likely to reduce the carrying capacity of many rare species' habitats.

Link: http://pascencio.cos.ucf.edu/classes/Research%20publications/PDFManuscripts/Maschinski%20et%20al%202006.pdf

461. Massa AN, Larson SR. 2005. **Phylogeography of North American mountain bromes.** Native Plants Journal 6:29-35.

Type: Journal

Geographic Area: North America

Keywords: AFLP, genetic diversity, *Bromus carinatus*

Abstract: Although native grasses are often desired and used for revegetation of disturbed areas, genetic differences may exist within and among natural and cultivated germplasm sources. This phylogeographic study compares geographic origin and genealogical linkages of 25 natural and cultivated germplasm sources of mountain brome (*Bromus carinatus* Hook. & Arn. [Poaceae]) from western North America. Significant variation among accessions (F_{ST} = 0.70) was detected by analysis of molecular variance (AMOVA), based on the number of amplified fragment length polymorphisms (AFLPs) between individual plants. Likewise, significant differences among 4 hierarchical genotypic groups, encompassing all but 5 unique accessions, were also detected (F_{CT} = 0.47).This study identified at least one well-defined genealogical lineage, comprising 8 accessions, distributed over a broad geographic region and different ecosystems of western North America. Two other hierarchical groups, comprising 6 accessions and 3 accessions, were located within or near specific ecoregions. Results of this study indicate that natural genealogical lineages of cultivars, such as Garnet mountain brome, have dispersed and succeeded over broad geographical regions. However, more research and plant material work are needed before specific recommendations can be made over the entire species distribution.

Link: http://nativeplantnetwork.org/Content/Articles/6-1NPJ29-35.pdf

462. Matthews SN, Iverson LR, Prasad AM, Peters MP, Rodewald PG. 2011. **Modifying climate change habitat models using tree species-specific assessments of model uncertainty and life history-factors.** Forest Ecology and Management 262:1460-1472.

Type: Journal

Geographic Area: Eastern USA

Keywords: climate change adaptation, Eastern United States, trees, species distribution models, disturbance, model uncertainty

Abstract: Species distribution models (SDMs) to evaluate trees' potential responses to climate change are essential for developing appropriate forest management strategies. However, there is a great need to better understand these models' limitations and evaluate their uncertainties. We have previously developed statistical models of suitable habitat, based on both species' range and abundance, to better understand potential changes of 134 tree species habitats in the eastern United States (http://www.nrs.fs.fed.us/atlas). Our focus here is to build on these results via a more robust assessment framework called modification factors (ModFacs) that is made up of five components. ModFac 1 addresses nine biological characteristics (e.g., shade tolerance and seedling establishment) that quantify the influence of species life-history traits. ModFac 2 considers 12 disturbance characteristics (e.g., insect pests, drought, and fire topkill) which address the capacity of a species to tolerate and respond to climate-induced changes in habitat. ModFac 3–5 distill the tree SDM results and facilitate communication of model uncertainty; we quantified the variability in projected change for General Circulation Models (GCM) and emissions scenarios (ModFac 3), the extent to which each species' habitat intersects novel climate conditions (Mod-Fac4), and accounted for long-distance extrapolations beyond a species' current range (ModFac5). The life-history components of ModFacs 1 and 2 demonstrate the marked variability among species in terms of biological and disturbance characteristics, suggesting diverse abilities to adapt to climate change. ModFacs 3–5 show that the information from the SDMs can be enhanced by quantifying the variability associated with specific GCM/emission scenarios, the emergence of novel climates for particular tree species, and the distances of species habitat shifts with climate change. The ModFacs framework has high interpretive value when considered in conjunction with the outputs of species habitat models for this century. Importantly, the intention

of this assessment was not to create a static scoring system, but to broadly assess species characteristics that likely will play an important role in adaptation to climate change. We believe these scores based on biological, disturbance, and model synthesis factors provide an important expansion of interpretive and practical value to habitat model projections.

Link: http://obcp.osu.edu/files/Rodewald%201.pdf

463. McCarragher SR, Goldblum D, Rigg LS. 2011.

Geographic variation of germination, growth, and mortality in sugar maple (*Acer saccharum*): common garden and reciprocal dispersal experiments. Physical Geography 32:1-21.

Type: Journal

Geographic Area: Northeastern USA

Compilers' Keywords: biogeography, GCM, migration, conservation

Abstract: If current temperature trends continue and increase as predicted by general circulation models, the persistence and migration of sugar maple (*Acer saccharum*) at its northern limit will become crucial to its continued existence in North America. Specifically, anthropogenic warming may affect germination success and growth of sugar maple. To evaluate this potential limitation, our study addresses two questions. The first involves a growth chamber: Do temperatures at and above (1, 7, and 14 °C) sugar maple's optimal germination temperature affect its germination? The second involves a common garden: Do sugar maple germination and subsequent growth and mortality rates show evidence of geographic variation under current climatic conditions? While sugar maple germinated successfully at 7 °C in the lab, field results suggest that other environmental variables may limit its future establishment as climate changes. Germination of seeds from sugar maple's northern range limit was significantly reduced under warmer conditions, and subsequent seedling mortality rates were significantly increased when grown at a more southerly latitude. Local adaptation was evident with respect to germination, survival, and growth in the field. Ultimately, results from this study further the understanding of how predicted anthropogenic climate change may affect the regeneration of sugar maple in the future.

464. McConkey KR, Prasad S, Corlett RT, Campos-Arceiz A, Brodie JF, Rogers H, Santamaria L. 2012.

Seed dispersal in changing landscapes. Biological Conservation 146:1-13.

Type: Journal

Geographic Area: Global

Keywords: biological invasions, climate change, fragmentation, hunting, overharvesting, seed dispersal

Abstract: A growing understanding of the ecology of seed dispersal has so far had little influence on conservation practice, while the needs of conservation practice have had little influence on seed dispersal research. Yet seed dispersal interacts decisively with the major drivers of biodiversity change in the 21st century: habitat fragmentation, overharvesting, biological invasions, and climate change. We synthesize current knowledge of the effects these drivers have on seed dispersal to identify research gaps and to show how this information can be used to improve conservation management. The drivers, either individually, or in combination, have changed the quantity, species composition, and spatial pattern of dispersed seeds in the majority of ecosystems worldwide, with inevitable consequences for species survival in a rapidly changing world. The natural history of seed dispersal is now well understood in a range of landscapes worldwide. Only a few generalizations that have emerged are directly applicable to conservation management, however, because they are frequently confounded by site-specific and species-specific variation. Potentially synergistic interactions between disturbances are likely to exacerbate the negative impacts, but these are rarely investigated. We recommend that the conservation status of functionally unique dispersers be revised and that the conservation target for key seed dispersers should be a population size that maintains their ecological function, rather than merely the minimum viable population. Based on our analysis of conservation needs, seed dispersal research should be carried out at larger spatial scales in heterogeneous landscapes, examining the simultaneous impacts of multiple drivers on community-wide seed dispersal networks.

Link: http://www.researchgate.net/publication/235331752_Seed_dispersal_in_changing_landscapes/file/9fcfd510e8cfabead7.pdf

465. McDonald-Madden E, Runge MC, Possingham HP, Martin TG. 2011.

Optimal timing for managed relocation of species faced with climate change. Nature Climate Change 1:261-265.

Type: Journal

Geographic Area: Global

Compilers' Keywords: assisted migration, decision framework, management, model

Abstract: Managed relocation is a controversial climate-adaptation strategy to combat negative climate change impacts on biodiversity. While the scientific community debates the merits of managed relocation, species are already being moved to new areas predicted to be more suitable under climate change. To inform these moves, we construct a quantitative decision framework to evaluate the timing of relocation in the face of climate change. We find that the optimal timing depends on many factors, including the size of the population, the demographic costs of translocation and the expected carrying capacities over time in the source and destination habitats. In some settings, such as when a small population would benefit from time to grow

before risking translocation losses, haste is ill advised. We also find that active adaptive management is valuable when the effect of climate change on source habitat is uncertain, and leads to delayed movement.

Link: http://www.seaturtle.org/PDF/McDonald-MaddenE_2011_NatureClimChange.pdf

466. McKenney DW, Pedlar J, O'Neill GA. 2009.

Climate change and forest seed zones: past trends, future prospects and challenges to ponder. The Forestry Chronicle 85:258-265.

Type: Journal

Geographic Area: Canada

Keywords: climate change, seed sources, British Columbia, Ontario, Douglas-fir, seed transfer, assisted migration

Abstract: Canada regenerates more than 400,000 ha of forest land annually through planting and seeding operations. Much of the stock for this effort is selected to be climatically suited to the planting site—a match that is often facilitated through the development of seed zones. However, if climate change proceeds as predicted, stock that is well matched under current climate will be growing in sub-optimal conditions within the next 20 to 50 years—in some parts of the country, trees may already be growing outside their optimal climates. To provide a sense of the magnitude of these changes, we present past and predicted future climate trends for Ontario and British Columbia seed zones. For Ontario, over the period 1950 to 2005, minimum temperature of the coldest month has already increased by up to 4.3 °C, growing season has lengthened by up to 6 days, and precipitation during the growing season has increased by up to 26%. Changes were more pronounced across British Columbia's Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seed zones, with minimum temperature increasing by up to 8 °C, a growing season extension of up to 30 days, and growing season precipitation increases of up to 40%. Projections for the end of the current century include: minimum temperature increase of 5 °C to 10 °C, growing season extension of 31 to 60 days, and growing season precipitation increases of 3% to 42% across the seed zones in both provinces. These changes are certain to have extensive impacts on forest ecosystems. We briefly discuss 3 forest management adaptation strategies intended to mitigate the negative impacts of climate change in Canada.

467. McLachlan JS, Clark JS, Manos PS. 2005.

Molecular indicators of tree migration capacity under rapid climate change. Ecology 86:2088-2098.

Type: Journal

Geographic Area: North America, Europe

Keywords: climate change, molecular markers, paleoecology, range expansion

Abstract: Recent models and analyses of paleoecological records suggest that tree populations are capable of rapid migration when climate warms. Fossil pollen is commonly interpreted as suggesting that the range of many temperate tree species expanded at rates of 100–1,000 m/yr during the early Holocene. We used chloroplast DNA surveys to show that the geography of postglacial range expansion in two eastern North American tree species differs from that expected from pollen-based reconstructions and from patterns emerging from European molecular studies. Molecular evidence suggests that American beech (*Fagus grandifolia*) and red maple (*Acer rubrum*) persisted during the late glaciation as low-density populations, perhaps within 500 km of the Laurentide Ice Sheet. Because populations were closer to modern range limits than previously thought, postglacial migration rates may have been slower than those inferred from fossil pollen. Our estimated rates of < 100 m/yr are consistent with model predictions based on life history and dispersal data, and suggest that past migration rates were substantially slower than the rates that will be needed to track 21st-century warming.

Link: http://forestbiology.ucdavis.edu/docs/MolecularIndicators_treeMigration.pdf

468. McLane SC. 2011.

Establishment and growth responses of whitebark and lodgepole pine populations in a changing climate [Dissertation]. Vancouver, British Columbia, Canada: The University of British Columbia. 125 p.

Type: Dissertation

Geographic Area: North America

Compilers' Keywords: *Pinus contorta* ssp. *latifolia*, *Pinus albicaulis*, climate change, common garden, migration

Abstract: Climate change will affect the regeneration, growth, survival and distribution of trees. Here, I use common gardens to empirically test establishment, growth and the potential for persistence, adaptation and migration for two iconic North American trees, whitebark pine (*Pinus albicaulis*) and lodgepole pine (*Pinus contorta* ssp. *latifolia*). Whitebark pine is of conservation concern due to range-wide diebacks, while lodgepole pine is critical to forest productivity and carbon sequestration. Whitebark seeds were planted north of the current range in areas predicted to be climatically suitable through the 2050s; these germinated and survived in varying proportions at all locations. Establishment and growth were positively affected by moderate snow-cover durations, heavier seed weights, and warmer provenance temperatures. Whitebark pine seedlings grown from seeds sown in growth chambers spanning current and predicted-future temperatures demonstrated positive responses to warmer growing seasons. Lodgepole pine seedlings in the same chambers outgrew the whitebark pine seedlings at all but the coldest temperatures. Together, these results suggest that whitebark pine may lose its competitive advantage to other species within its narrow alpine-treeline niche as the climate warms, but that it is capable of establishing in climatically-suitable areas north of

its current range. Using tree-ring data from long-term lodgepole pine common garden trials, I built universal growth-trend response functions to forecast future growth trends relative to genetics, climate and tree age. The models predict growth reductions for all populations by the end of the 21st century based on middle-of-the-road climate models, except in far northern areas near and within Yukon, Canada. Analogous models built using summer and winter climate indices indicate that the growth declines are primarily caused by warmer summers, and may be offset by growth increases resulting from warmer winters. I found that populations are most sensitive to annual temperatures and summer aridity, but that sensitivity to climate varies due to local adaptation. Overall, my research will help forest professionals and conservationists forecast changes in forest productivity and species growth and survival under warming temperatures.

Link: https://circle.ubc.ca/bitstream/handle/2429/34087/ubc_2011_spring_mclane_sierra.pdf

469. McLane SC, Aitken SN. 2012. Whitebark pine (*Pinus albicaulis*) assisted migration potential: testing establishment north of the species range. Ecological Applications 22:142-153.

Type: Journal

Geographic Area: Western Canada

Keywords: climate change, common garden, managed relocation, quantitative genetics, species distribution model, species range limits

Abstract: The translocation of species into habitable locations outside of their current ranges, termed assisted migration, has been proposed as a means of saving vulnerable species from extinction as a result of climate change. We explore the use of this controversial technique using a threatened keystone species in western North America, whitebark pine (*Pinus albicaulis*), as a case study. Species distribution models predict that whitebark pine will be extirpated from most of its current range as temperatures rise over the next 70 years. However, the same models indicate that a large area within northwestern British Columbia, Canada, is climatically suitable for the species under current conditions and will remain so throughout the 21st century. To test the capacity of whitebark pine to establish relative to climatic and habitat features within its predicted climatic range, we planted seeds from seven populations in eight locations spanning from 600 km southeast to 800 km northwest of the northern boundary of the current species range. During the first three growing seasons, germination occurred in all locations. Nearly three times as many treated (induced maturation and broken dormancy) than untreated seeds germinated, and most treated seeds germinated a year earlier than the untreated seeds. Germination, survival, and growth were primarily influenced by seed mass, site climate conditions related to the duration of snow cover, and provenance temperature. Our experiment provides a preliminary test of models predicting the existence of climatically suitable whitebark pine habitat north of the current species ranges. More broadly, our techniques and results inform the development of scientific guidelines for assisting the migration of other species that are highly threatened by climate change. Applied case studies of this kind are critical for assessing the utility of species distribution models as conservation planning tools.

470. Menges ES. 2008. Restoration demography and genetics of plants: when is a translocation successful? Australian Journal of Botany 56:187-196.

Type: Journal

Geographic Area: Global

Compilers' Keywords: assisted migration, key species, review

Abstract: Restorations are complex, often involving restoring ecological processes, vegetation structure, and species' populations. One component of restorations is translocation of key species. Translocations (introductions, reintroductions, augmentations) are often necessary to recover species diversity and install key species. In this review, I consider the ways translocations have been evaluated at various stages during the process of restoration. Vital rates (survival, growth, fecundity) of propagules (seeds, transplants) are commonly used to evaluate initial success. Transplants usually provide greater initial success than do sown seeds. Beyond initial rates, completion of the life cycle through flowering, fruiting, dispersal and subsequent seedling recruitment is a key benchmark. Modelling population viability of translocated populations is a logical next step and can bring in many powerful inferential tools. Of factors affecting the success of translocations, genetic issues are paramount, as restorationists need to consider inbreeding depression, reproductive viability, local adaptation, and evolutionary potential of translocated populations. The success of translocations is also clearly context-dependent, with herbivory, disturbance, competition and other ecological factors important. Future translocations need to make better use of comparisons with reference populations, a long-term perspective on success and an experimental framework that can provide both practical and basic knowledge. Demographic data collection and analysis in restorations has great potential to elucidate causes of translocation failure and improve the prognosis of future restorations.

Link: http://pascencio.cos.ucf.edu/classes/Restoration%20Ecology/Menges%202008%20restoration%20demography.pdf

471. Millar MA, Byrne M, Nuberg IK, Sedgley M. 2012. High levels of genetic contamination in remnant populations of *Acacia saligna* from a genetically divergent planted stand. Restoration Ecology 20:260-267.

Type: Journal

Geographic Area: Australia

Keywords: fragmented vegetation, gene flow, genetic contamination, paternity analysis, pollen dispersal, risk assessment

Abstract: It is essential to understand the patterns of pollen dispersal in remnant vegetation occupying highly disturbed landscapes in order to provide sustainable management options and to inform restoration programs. Direct and indirect methods of paternity analysis were used to detect genetic contamination via inter-subspecific pollen dispersal from a planted stand of nonlocal *Acacia saligna* ssp. *saligna* (ms) into remnant roadside patches of local *A. saligna* ssp. *lindleyi* (ms). Genetic contamination was detected in 25.5% (indirect paternity assignment) to 32% (direct paternity assignment) of ssp. *lindleyi* progeny and occurred over a distance of 1.6 km. The results support studies that suggest genetic continuity is maintained by high levels of pollen dispersal in temperate entomophilous species. The results also indicate that patchily distributed remnant populations may be exposed to substantial amounts of genetic contamination from large scale restoration with native taxa in the highly fragmented agricultural landscape of southern Western Australia. Management practices to reduce the risk of genetic contamination are considered.

472. Moir ML, Vesk PA, Brennan KE, Poulin R, Hughes L, Keith DA, McCarthy MA, Coates DJ. 2012. Considering extinction of dependent species during translocation, *ex situ* conservation, and assisted migration of threatened hosts. Conservation Biology 26:199-207.

Type: Journal

Geographic Area: Australia

Keywords: assisted colonization, coextinction conservation planning, extinction risk, introductions, managed relocation, parasites, plant-insect interactions, translocation

Abstract: Translocation, introduction, reintroduction, and assisted migrations are species conservation strategies that are attracting increasing attention, especially in the face of climate change. However, preventing the extinction of the suite of dependent species whose host species are threatened is seldom considered, and the effects on dependent species of moving threatened hosts are unclear. There is no published guidance on how to decide whether to move species, given this uncertainty. We examined the dependent-host system of 4 disparate taxonomic groups: insects on the feather-leaf banksia (*Banksia brownii*), montane banksia (*B. montana*), and Stirling Range beard heath (*Leucopogon gnaphalioides*); parasites of wild cats; mites and ticks on Duvaucel's gecko (*Hoplodactylus duvaucelii*) and tuatara (*Sphenodon punctatus*); and internal coccidian parasites of Cirl Bunting (*Emberiza cirlus*) and Hihi (*Notiomystis cincta*). We used these case studies to demonstrate a simple process for use in species- and community-level assessments of efforts to conserve dependents with their hosts. The insects dependent on Stirling Range beard heath and parasites on tigers (*Panthera tigris*) appeared to represent assemblages that would not be conserved by *ex situ* host conservation. In contrast, for the cases of dependent species we examined involving a single dependent species (internal parasites of birds and the mite *Geckobia naultina* on Duvaucel's gecko), *ex situ* conservation of the host species would also conserve the dependent species. However, moving dependent species with their hosts may be insufficient to maintain viable populations of the dependent species, and additional conservation strategies such as supplementing populations may be needed.

Link: http://www.ncbi.nlm.nih.gov/pubmed/22443127

473. Mooring JS. 2008. An *Eriophyllum lanatum* (Asteraceae) hybrid zone in Oregon. Madroño 55:269-279.

Type: Journal

Geographic Area: Oregon, USA

Keywords: artificial hybridizations, Asteraceae, barriers to interbreeding, *Eriophyllum*, hybrid zone, pollen fertility, species complex, supernumerary chromosomes

Abstract: *Eriophyllum lanatum* vars. *achilleoides* and *leucophyllum* intergrade in southwestern Oregon. Some populations cannot be unequivocally assigned to either variety. Chromosome counts showed polyploid populations predominating where the varieties meet in southwestern Oregon. Pollen fertility, estimated by cotton blue-lactophenol staining, was the main criterion used to assess barriers to interbreeding. Artificial hybridizations between diploids revealed barriers to interbreeding between vars. *achilleoides* and *leucophyllum*, and between each of them and a morphologically intermediate population. The barriers to interbreeding are substantially less developed than those present between most of the other eight varieties of the *E. lanatum* complex. Supernumerary chromosomes are postulated to be adaptive in *Eriophyllum* hybrid zones.

474. Moritz C, Patton JL, Conroy CJ, Parra JL, White GC, Beissinger SR. 2008. Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science 322:261-264.

Type: Journal

Geographic Area: California, USA

Compilers' Keywords: land-use change, modelling, migration, threatened species, high elevation

Abstract: We provide a century-scale view of small-mammal responses to global warming, without confounding effects of land-use change, by repeating Grinnell's early–20th century survey across a 3,000-meter-elevation gradient that spans Yosemite National Park, California, USA. Using occupancy modeling to control for variation in detectability, we show substantial (~500 meters on average) upward changes in elevational limits for half of 28 species monitored, consistent with the

observed ~3 °C increase in minimum temperatures. Formerly low-elevation species expanded their ranges and high-elevation species contracted theirs, leading to changed community composition at mid- and high elevations. Elevational replacement among congeners changed because species' responses were idiosyncratic. Though some high elevation species are threatened, protection of elevation gradients allows other species to respond via migration.

Link: http://www.nwf-wcr.org/PDFs-ClimateChangeFWP/NRNRC-GW-FWP-Moritz-Paper.pdf

475. Mueller JM, Hellmann JJ. 2008. An assessment of invasion risk from assisted migration. Conservation Biology 22:562-567.

Type: Journal

Geographic Area: USA

Keywords: assisted migration, climate change, extinction risk, geographic distribution, invasive species, translocation

Abstract: To reduce the risk of extinction due to climate change, some ecologists have suggested human-aided translocation of species, or assisted migration (AM), to areas where climate is projected to become suitable. Such intentional movement, however, may create new invasive species if successful introductions grow out of control and cause ecologic or economic damage. We assessed this risk by surveying invasive species in the United States and categorizing invaders based on origin. Because AM will involve moving species on a regional scale within continents (i.e., range shifts), we used invasive species with an intracontinental origin as a proxy for species that would be moved through AM. We then determined whether intracontinental invasions were more prevalent or harmful than intercontinental invasions. Intracontinental invasions occurred far less frequently than invasions from other continents, but they were just as likely to have had severe effects. Fish and crustaceans pose a particularly high threat of intracontinental invasion. We conclude that the risk of AM to create novel invasive species is small, but assisted species that do become invasive could have large effects. Past experience with species reintroductions may help inform policy regarding AM.

Link: http://www.ncbi.nlm.nih.gov/pubmed/18577085

476. Neilson RP, Pitelka LF, Solomon AM, Nathan R, Midgley GF, Fragoso JMV, Lischke H, Thompson K. 2005. Forecasting regional to global plant migration in response to climate change. BioScience 55:749-759.

Type: Journal

Geographic Area: Global

Keywords: climate change, dispersal, migration, long-distance dispersal, dynamic global vegetation models

Abstract: The rate of future climate change is likely to exceed the migration rates of most plant species. The replacement of dominant species by locally rare species may require decades, and extinctions may occur when plant species cannot migrate fast enough to escape the consequences of climate change. Such lags may impair ecosystem services, such as carbon sequestration and clean water production. Thus, to assess global change, simulation of plant migration and local vegetation change by dynamic global vegetation models (DGVMs) is critical, yet fraught with challenges. Global vegetation models cannot simulate all species, necessitating their aggregation into plant functional types (PFTs). Yet most PFTs encompass the full spectrum of migration rates. Migration processes span scales of time and space far beyond what can be confidently simulated in DGVMs. Theories about climate change and migration are limited by inadequate data for key processes at short and long time scales and at small and large spatial scales. These theories must be enhanced to incorporate species-level migration and succession processes into a more comprehensive definition of PFTs.

Link: http://bio.huji.ac.il/ese/PDFs/Neilson_etalBioScience2005.pdf

477. Notaro M, Mauss A, Williams JW. 2012. Projected vegetation changes for the American Southwest: combined dynamic modeling and bioclimatic-envelope approach. Ecological Applications 22:1365-1388.

Type: Journal

Geographic Area: Southwestern USA

Keywords: bioclimatic envelope model, biodiversity, climate change, dynamic global vegetation model, Southwest United States

Abstract: This study focuses on potential impacts of 21st century climate change on vegetation in the Southwest United States, based on debiased and interpolated climate projections from 17 global climate models used in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Among these models a warming trend is universal, but projected changes in precipitation vary in sign and magnitude. Two independent methods are applied: a dynamic global vegetation model to assess changes in plant functional types and bioclimatic envelope modeling to assess changes in individual tree and shrub species and biodiversity. The former approach investigates broad responses of plant functional types to climate change, while considering competition, disturbances, and carbon fertilization, while the latter approach focuses on the response of individual plant species, and net biodiversity, to climate change. The dynamic model simulates a region-wide reduction in vegetation cover during the 21st century, with a partial replacement of evergreen trees with grasses in the mountains of Colorado and Utah, except at the highest elevations, where tree cover increases. Across southern Arizona, central New Mexico, and eastern Colorado, grass cover declines, in some cases abruptly. Due to the prevalent warming

trend among all 17 climate models, vegetation cover declines in the 21st century, with the greatest vegetation losses associated with models that project a drying trend. The inclusion of the carbon fertilization effect largely ameliorates the projected vegetation loss. Based on bioclimatic envelope modeling for the 21st century, the number of tree and shrub species that are expected to experience robust declines in range likely outweighs the number of species that are expected to expand in range. Dramatic shifts in plant species richness are projected, with declines in the high-elevation evergreen forests, increases in the eastern New Mexico prairies, and a northward shift of the Sonoran Desert biodiversity maximum.

478. O'Neill GA, Hamann A, Wang T. 2008. Accounting for population variation improves estimates of the impact of climate change on species' growth and distribution. Journal of Applied Ecology 45:1040-1049.

Type: Journal

Geographic Area: Western Canada

Keywords: adaptation, assisted migration, ecological modelling, forest productivity, growth response function, *Pinus contorta*, population differentiation, seed transfer, transfer function

Abstract: Large differences exist in the predictions of plant responses to climate change among models that consider population variation and those that do not. Models that treat species as homogeneous entities typically predict net positive impacts of climate change on temperate forest productivity, while most studies that consider adaptive genetic variation within species conclude that the impacts of climate change on forest productivity will be negative. We present a modelling approach that predicts plant responses to climate change using both ecological and genetic variables. The model uses growth data from multi-site provenance trials together with climate data for provenance source locations and test sites to predict distribution and productivity of tree populations under climate change. We used an extensive lodgepole pine *Pinus contorta* provenance data set to illustrate the model. Spatially explicit predictions of the impacts of climate change on production were developed and suggested that different populations of lodgepole pine will respond very differently to climate change. Large production losses will be seen in many areas, although modest production increases may occur in some areas by 2085. The model further projects a significant redistribution of the species' potential habitat northwards and upwards in altitude over the next several decades. This study points to the need to consider population differences when modelling biotic responses to climate change, and suggests that climate change will render populations maladapted in many areas. The model also provides a key tool potentially to mitigate climate change impacts by identifying populations expected to be best adapted throughout the next generation of forests. Finally, the study highlights the value of wide-ranging long-term provenance tests in addressing key issues in ecology and climate change.

Link: http://www.ualberta.ca/~ahamann/publications/pdfs/ONeill_et_al_2008.pdf

479. O'Neill GA, Berger V, Carlson M, Ukrainetz NK. 2013. Assisted migration adaptation trial. British Columbia, Canada: BC Ministry of Forests, Lands and Natural Resource Operations. 2 p

Type: Government Document

Geographic Area: Western North America

Keywords: assisted migration, AMAT, Canada, tree management, forestry

Background: Seedlings are planted in the western USA, British Columbia (BC) and Yukon each year. Many climatologists predict that the climate could be 3–4 °C warmer when those trees are harvested 60-80 years after planting. These changes to climate will expose trees to increased stress and health risks, compromising the many goods and services we receive from our forests. Consequently, BC Forest Service researchers, with the assistance of the USDA Forest Service and industry, have initiated a large, long-term climate change research study—the Assisted Migration Adaptation Trial (AMAT)—to better understand tree species climate tolerances.

Link: https://www.for.gov.bc.ca/HRE/forgen/interior/AMAT.htm

480. Parker KA, Seabrook-Davison M, Ewen JG. 2008. Opportunities for nonnative ecological replacements in ecosystem restoration. Restoration Ecology 18:269-273.

Type: Journal

Geographic Area: Australia

Keyword: *Coturnix novaezelandiae*, *Coturnix ypsilophora*, ecological analog, ecological restoration, translocation

Abstract: Translocations can take a variety of forms, and there is considerable debate as to what defines an acceptable translocation. This is particularly so if a proposal suggests moving a species beyond its natural range, which might be necessary for conservation purposes if habitat within the natural range is extensively modified. An extension of this approach is to use closely related ecological analogs to replace extinct species. This approach is controversial, and opportunities to do so will be rare, particularly for vertebrate species, but the use of ecological analogs is not without precedent, and ultimately will provide for more complete ecological restoration. We discuss the current use of ecological analogs to replace extinct species and conclude with a rare opportunity to replace the extinct New Zealand quail *Coturnix novaezelandiae* with the extant Australian brown quail *Conturnix ypsilophora*.

481. Parmesan C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics 37:637-669.

Type: Journal

Geographic Area: Global

Keywords: aquatic, global warming, phenology, range shift, terrestrial, trophic asynchrony

Abstract: Ecological changes in the phenology and distribution of plants and animals are occurring in all well-studied marine, freshwater, and terrestrial groups. These observed changes are heavily biased in the directions predicted from global warming and have been linked to local or regional climate change through correlations between climate and biological variation, field and laboratory experiments, and physiological research. Range-restricted species, particularly polar and mountaintop species, show severe range contractions and have been the first groups in which entire species have gone extinct due to recent climate change. Tropical coral reefs and amphibians have been most negatively affected. Predator-prey and plant-insect interactions have been disrupted when interacting species have responded differently to warming. Evolutionary adaptations to warmer conditions have occurred in the interiors of species' ranges, and resource use and dispersal have evolved rapidly at expanding range margins. Observed genetic shifts modulate local effects of climate change, but there is little evidence that they will mitigate negative effects at the species level.

Link: http://www.law.arizona.edu/depts/ele/AdaptationConference/PDFs/ParmesanAREES_Impacts2006.pdf

482. Parmesan C, Yohe G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37-42.

Type: Journal

Geographic Area: Global

Compilers' Keywords: migration, biological trends, IPCC, range shifts, meta-analysis, plants, animals, phenology, modelling

Abstract: Casual attribution of recent biological trends to climate change is complicated because non-climatic influences dominate local, short-term biological changes. Any underlying signal from climate change is likely to be revealed by analyses that seek systematic trends across diverse species and geographic regions; however, debates within the Intergovernmental Panel on Climate Change (IPCC) reveal several definitions of a 'systematic trend'. Here, we explore these differences, apply diverse analyses to more than 1,700 species, and show that recent biological trends match climate changes predictions. Global meta-analyses documented significant range shifts averaging 6.1 km per decade towards the poles (or metres per decade upward), and significant mean advancement of spring events by 2.3 days per decade. We define a diagnostics fingerprint of temporal and spatial 'sign-switching' responses uniquely predicted by twentieth century climate trends. Among appropriate long-term/large-scale/multi-species data sets, this diagnostic fingerprint was found for 279 species. This suite of analyses generates 'very high confidence' (as laid down by the IPCC) that climate change is already affecting living systems.

Link: http://www.geo.utexas.edu/courses/387H/Lectures/parmesan.pdf

483. Parmesan C, Ryrholm N, Stefanescu C, Hill JK, Thomas CD, Descimon H, Huntley B, Kaila L, Kullberg J, Tammaru T, Tennent WJ, Thomas JA, Warren M. 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature 399:579-583.

Type: Journal

Geographic Area: Europe

Compilers' Keywords: climate change, range shifts, global temperature, migration

Abstract: Mean global temperatures have risen this century, and further warming is predicted to continue for the next 50–100 years. Some migratory species can respond rapidly to yearly climate variation by altering the timing or destination of migration, but most wildlife is sedentary and so is incapable of such a rapid response. For these species, responses to the warming trend should be slower, reflected in poleward shifts of the range. Such changes in distribution would occur at the level of the population, stemming not from changes in the pattern of individuals' movements, but from changes in the ratios of extinctions to colonizations at the northern and southern boundaries of the range. A northward range shift therefore occurs when there is net extinction at the southern boundary or net colonization at the northern boundary. However, previous evidence has been limited to a single species or to only a portion of the species' range. Here we provide the first large-scale evidence of poleward shifts in entire species' ranges. In a sample of 35 non-migratory European butterflies, 63% have ranges that have shifted to the north by 35–240 km during this century, and only 3% have shifted to the south.

484. Parolo G, Rossi G. 2008. Upward migration of vascular plants following a climate warming trend in the Alps. Basic and Applied Ecology 9:100-107.

Type: Journal

Geographic Area: Italy, Europe

Compilers' Keywords: alpine-nival ecosystems, climate change, diaspora, historical records, long-term observation, monitoring, species richness, wind-dispersion, alpine plants

Summary: The aim of this study was to understand (1) whether warmer climatic conditions affected the vascular plant species composition, (2) the magnitude and rate of altitudinal changes in species distributions, and (3) whether an upward migration of alpine plants is connected to wind dispersal of diaspores. We compared historical records (1954–1958) with results from

recent plant surveys (2003–2005) from alpine to nival ecosystems in the Rhaetian Alps, N-Italy. The presence of all vascular plant species and their maximum altitude were recorded along a continuous altitudinal transect of 730 m. An increase in species richness from 153 to 166 species was observed. Moreover, 52 species were recorded from altitudes 30–430 m higher than their 1950s limits, which corresponds to a median migration rate of 23.9 m/decade. In order to explain the observed migrations, the species wind-dispersal ability (diaspore weight and morphology) and the air temperature variation from 1926 to 2003 were considered. Species with more pronounced altitudinal shifts possess lighter diaspores. The highest increase in species richness was found between 2,800 and 3,100 m a.s.l.; this appears to be related to an estimated shift of the permafrost limit by +240 m during the last 50 years. The mean air temperature in the region rose by +1.6 °C in summer and by +1.1 °C in winter within this period. Climate warming is therefore considered as a primary cause of the observed upward migration of high mountain plants. Calculated altitudinal migration rates, however, varied remarkably among species. This would imply differential abilities of species to persist in an increasingly warmer climate. Species-specific conservation measures, including *ex situ* conservation, may therefore be required.

485. Pearson RG. 2006. Climate change and the migration capacity of species. Trends in Ecology and Evolution 21:111-113.

Type: Journal

Geographic Area: Global

Compilers' Keywords: pollen, species and specificity, review, trees, migration rates

Abstract: In a recent paper, McLachlan et al. presented evidence that migration rates of two tree species at the end of the last glacial (c. 10-20 thousand years ago) were much slower than was previously thought. These results provide an important insight for climate-change impacts studies and suggest that the ability of species to track future climate change is limited. However, the detection of late-glacial refugia close to modern range limits also implies that some of our most catastrophic projections might be overstated.

Link: http://www.ncbi.nlm.nih.gov/pubmed/16701483

486. Pearson RG, Dawson TP. 2005. Long-distance plant dispersal and habitat fragmentation: identifying conservation targets for spatial landscape planning under climate change. Biological Conservation 123:389-401.

Type: Journal

Geographic Area: Global

Keywords: long-distance dispersal, climate change, habitat fragmentation, spatially explicit model, systematic conservation planning

Abstract: Climate change presents a potentially severe threat to biodiversity. Species will be required to disperse rapidly through fragmented landscapes in order to keep pace with the changing climate. An important challenge for conservation is therefore to manage landscapes so as to assist species in tracking the environmental conditions to which they are adapted. Here we develop a stochastic spatially explicit model to simulate plant dispersal across artificial fragmented landscapes. Based on certain assumptions as to the dispersal mechanism, we assess the impact that varying potential for rare long-distance dispersal (LDD) has on the ability to move over landscapes with differing spatial arrangements of suitable habitat clumped versus fragmented). Simulations demonstrate how the relative importance of landscape structure in determining migration ability may decrease as the potential for LDD increases. Thus, if LDD is the principal mechanism by which rapid large-scale migrations are achieved, strategically planned networks of protected habitat may have a limited impact on rates of large-scale plant migrations. We relate our results to conventional principles for conservation planning and the geometric design of reserves, and demonstrate how reversal of these principles may maximise the potential for conservation under future climates. In particular, we caution against the justification of large-scale corridors on grounds of climate change since migration along corridors by standard dispersal mechanisms is unlikely to keep pace with projected change for many species. An improved understanding of the dispersal mechanisms by which species achieve rapid migrations, and the way that these processes are affected by patterns of landscape fragmentation, will be important to inform future conservation strategies.

Link: http://www.agci.org/dB/PDFs/05S3_RPearson_TDawson_conservation%20targets_0722.pdf

487. Phillips SJ, Anderson RP, Schapire RE. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190:231-259.

Type: Journal

Geographic Area: Global

Keywords: maximum entropy, distribution, modeling, niche, range

Abstract: The availability of detailed environmental data, together with inexpensive and powerful computers, has fueled a rapid increase in predictive modeling of species environmental requirements and geographic distributions. For some species, detailed presence/absence occurrence data are available, allowing the use of a variety of standard statistical techniques. However, absence data are not available for most species. In this paper, we introduce the use of the maximum entropy method (Maxent) for modeling species geographic distributions with presence-only data. Maxent is a general-purpose machine learning method with a simple and precise mathematical formulation, and it has a number of aspects that make it well-suited for species distribution modeling. In order to investigate the efficacy of the method, here we perform a continental-scale case study using two Neotropical mammals: a lowland species of sloth, *Bradypus variegatus*, and a small montane murid rodent, *Microryzomys minutus*. We compared Maxent predictions with those of a commonly used presence-only modeling method, the Genetic Algorithm for Rule-Set Prediction (GARP). We made predictions on 10 random subsets of the occurrence records for both species, and then used the remaining localities for testing. Both algorithms provided reasonable estimates of the species' range, far superior to the shaded outline maps available in field guides. All models were significantly better than random in both binomial tests of omission and receiver operating characteristic (ROC) analyses. The area under the ROC curve (AUC) was almost always higher for Maxent, indicating better discrimination of suitable versus unsuitable areas for the species. The Maxent modeling approach can be used in its present form for many applications with presence-only datasets, and merits further research and development.

Link: http://perceval.bio.nau.edu/downloads/grail/climate_seminar/section2/Phillips_Anderson_and_Schapire06.pdf

488. Pluess AR. 2011. **Pursuing glacier retreat: genetic structure of a rapidly expanding *Larix decidua* population.** Molecular Ecology 20:473-485.

Type: Journal

Geographic Area: Swiss Alps, Europe

Keywords: climate change, founder effects, glacier foreland, range expansion, spatial genetic structure, succession

Abstract: One of the greatest threats to the long-term viability of migrating plant species is the loss of genetic diversity due to founder effects. Populations can expand as a response to climate change, but it is uncertain if long lived plant species can maintain sufficient genetic diversity at the leading edge of migrating populations. This study uses an expanding *Larix decidua* population investigated along a chronosequence at landscape (350 ha) and local (0.8 ha) scales to test whether accelerated migration as a result of climate warming has the potential to intensify genetic erosion. Nine SSR markers revealed similar genetic diversity among eight sub-populations along the chronosequence (overall $He = 0.73$; SE = 0.04). Sub-populations were not genetically differentiated and all sampled individuals ($N = 730$) formed one major genetic cluster indicating homogenizing gene flow despite spatial genetic structure (SGS) up to 80 m. At the local scale, individuals at the leading edge [early successional sub-population (ESSP), $N = 140$] and a sub-population at equilibrium [late successional sub-population (LSSP), $N = 290$] revealed high genetic diversity in largest-sized cohorts. SGS among juveniles occurred up to 30 m in LSSP but there was no structure in ESSP. Accordingly, a maximum likelihood paternity assignment revealed local gene dispersal in LSSP (2-48 m) and intermediate-to-long distance dispersal into ESSP (115-3132 m). The findings indicate intensive mixing of the genes in this expanding population instead of founder effects and support the view that genetic diversity can be maintained in a long-lived species during rapid population expansion driven by climate warming.

Link: http://www.ncbi.nlm.nih.gov/pubmed/21199030

489. Potter KM, Hargrove WW. 2012. **Determining suitable locations for seed transfer under climate change: a global quantitative method.** New Forests 43:581-599.

Type: Journal

Geographic Area: Southeastern USA

Keywords: restoration, conservation genetics, quantitative ecoregions, multivariate clustering, seed sources, human-assisted migration

Abstract: Changing climate conditions will complicate efforts to match seed sources with the environments to which they are best adapted. Tree species distributions may have to shift to match new environmental conditions, potentially requiring the establishment of some species entirely outside of their current distributions to thrive. Even within the portions of tree species ranges that remain generally suitable for the species, local populations may not be well-adapted to altered local conditions. To assist efforts to restore forests and to maximize forest productivity in the face of climate change, we developed a set of 30,000 quantitatively defined seed transfer "ecoregions" across the globe. Reflecting current and future conditions, these were created by combining global maps of potentially important environmental characteristics using a large-scale statistical clustering technique. This approach assigns every 4 km^2 terrestrial raster cell into an ecoregion using nonhierarchical clustering of the cells in multivariate space based on 16 environmental variables. Two cells anywhere on the map with similar combinations of environmental characteristics are located near each other in this data space; cells are then classified into relatively homogeneous ecoregion clusters. Using two global circulation models and two emissions scenarios, we next mapped the predicted environmentally equivalent future locations of each ecoregion in 2050 and 2100. We further depicted areas of decreasing environmental similarity to given ecoregions, both in current time and under climate change. This approach could help minimize the risk that trees used for production, restoration, reforestation, and afforestation are maladapted to their planting site.

Link: http://www.forestthreats.org/products/publications/Determining_suitable_locations_for_seed_transfer.pdf

490. Prunier J, Gerardi S, Laroche J, Beaulieu J, Bousquet J. 2012. **Parallel and lineage-specific molecular adaptation to climate in boreal black spruce.** Molecular Ecology 21:4270-4286.

Type: Journal

Geographic Area: North America

Keywords: adaptation, gene SNP, genetic lineages, natural selection, phylogeography, *Picea mariana*

Abstract: In response to selective pressure, adaptation may follow different genetic pathways throughout the natural range of a species due to historical differentiation in standing genetic variation. Using 41 populations of black spruce (*Picea mariana*), the objectives of this study were to identify adaptive genetic polymorphisms related to temperature and precipitation variation across the transcontinental range of the species, and to evaluate the potential influence of historical events on their geographic distribution. Population structure was first inferred using 50 control nuclear markers. Then, 47 candidate gene SNPs identified in previous genome scans were tested for relationship with climatic factors using an FST-based outlier method and regressions between allele frequencies and climatic variations. Two main intraspecific lineages related to glacial variance were detected at the transcontinental scale. Within-lineage analyses of allele frequencies allowed the identification of 23 candidate SNPs significantly related to precipitation and/or temperature variation, among which seven were common to both lineages, eight were specific to the eastern lineage and eight were specific to the western lineage. The implication of these candidate SNPs in adaptive processes was further supported by gene functional annotations. Multiple evidences indicated that the occurrence of lineage-specific adaptive SNPs was better explained by selection acting on historically differentiated gene pools rather than differential selection due to heterogeneity of interacting environmental factors and pleiotropic effects. Taken together, these findings suggest that standing genetic variation of potentially adaptive nature has been modified by historical events, hence affecting the outcome of recent selection and leading to different adaptive routes between intraspecific lineages.

Link: http://www.ncbi.nlm.nih.gov/pubmed/22805595

491. Ravenscroft C, Scheller RM, Mladenoff DJ, White MA. 2010. **Forest restoration in a mixed-ownership landscape under climate change.** Ecological Applications 20:327-346.

Type: Journal

Geographic Area: Minnesota, USA

Keywords: climate change, desired conditions, forest ecosystem model, LANDIS-II, forest management, historical variability, Minnesota, (USA), range of natural variability (RNV), restoration, species migration

Abstract: The extent to which current landscapes deviate from the historical range of natural variability (RNV) is a common means of defining and ranking regional conservation targets. However, climate induced shifts in forest composition may render obsolete restoration strategies and conservation targets based on historic climate conditions and disturbance regimes. We used a spatially explicit forest ecosystem model, LANDIS-II, to simulate the interaction of climate change and forest management in northeastern Minnesota, USA. We assessed the relevance of restoration strategies and conservation targets based on the RNV in the context of future climate change. Three climate scenarios (no climate change, low emissions, and high emissions) were simulated with three forest management scenarios: no harvest, current management, and a restoration-based approach where harvest activity mimicked the frequency, severity, and size distribution of historic natural disturbance regimes. Under climate change there was a trend toward homogenization of forest conditions due to the widespread expansion of systems dominated by maple (*Acer* spp.). White spruce (*Picea glauca*), balsam fir (*Abies balsamea*), and paper birch (*Betula papyrifera*) were extirpated from the landscape irrespective of management activity; additional losses of black spruce (*P. mariana*), red pine (*Pinus resinosa*), and jack pine (*P. banksiana*) were projected in the high emissions scenario. In the restoration management scenario, retention and conversion to white pine (*P. strobus*) restricted maple expansion. But, widespread forest loss in the restoration scenario under high-emissions projections illustrates the potential pitfalls of implementing an RNV management approach in a system that is not compositionally similar to the historic reference condition. Given the uncertainty associated with climate change, ensuring a diversity of species and conditions within forested landscapes may be the most effective means of ensuring the future resistance of ecosystems to climate-induced declines in productivity.

Link: http://flux.aos.wisc.edu/~adesai/documents/macrosys_papers-ankur/management/Ravenscroft_EcoApps_2010.pdf

492. Regan HM, Syphard AD, Franklin J, Swab RM, Markovchick L, Flint AL, Flint LE, Zedler PH. 2012. **Evaluation of assisted colonization strategies under global change for a rare, fire-dependent plant.** Global Change Biology 18:936-947.

Type: Journal

Geographic Area: California, USA

Keywords: assisted colonization, bioclimatic envelope, climate change, fire, population model

Abstract: As a clear consensus is emerging that habitat for many species will dramatically reduce or shift with climate change attention is turning to adaptation strategies to address these impacts. Assisted colonization is one such strategy that has been predominantly discussed in terms of the costs of introducing potential competitors into new communities and the benefits of reducing extinction risk. However, the success or failure of assisted colonization will depend on a range of population-level factors that have not yet been quantitatively evaluated—the quality of the recipient habitat, the number and life stages of translocated individuals, the establishment of translocated individuals in their new habitat and whether

the recipient habitat is subject to ongoing threats all will play an important role in population persistence. In this article, we do not take one side or the other in the debate over whether assisted colonization is worthwhile. Rather, we focus on the likelihood that assisted colonization will promote population persistence in the face of climate-induced distribution changes and altered fire regimes for a rare endemic species. We link a population model with species distribution models to investigate expected changes in populations with climate change, the impact of altered fire regimes on population persistence and how much assisted colonization is necessary to minimize risk of decline in populations of Tecate cypress, a rare endemic tree in the California Floristic Province, a biodiversity hotspot. We show that assisted colonization may be a risk-minimizing adaptation strategy when there are large source populations that are declining dramatically due to habitat contractions, multiple nearby sites predicted to contain suitable habitat, minimal natural dispersal, high rates of establishment of translocated populations and the absence of nonclimatic threats such as altered disturbance regimes. However, when serious ongoing threats exist, assisted colonization is ineffective.

493. Rehfeldt GE. 2004. Interspecific and intraspecific variation in *Picea engelmannii* and its congeneric cohorts: biosystematics, genecology, and climate change. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-134. 22 p.

Type: Government Document

Geographic Area: Western North America

Keywords: common garden studies, quantitative traits, climatic clines, response to climate

Abstract: A series of common garden studies of 336 populations representing *Picea engelmannii*, *P. pungens*, *P. glauca*, *P. mexicana*, and *P. chihuahuana* provided as many as 13 growth and morphologic characters pertinent to biosystematics and genecology. Canonical discriminant analyses discretely segregated populations of *P. pungens* and *P. chihuahuana* while positioning *P. engelmannii* populations along a continuum anchored by Southwestern United States populations at one extreme and those classified as hybrids of *P. engelmannii* with *P. glauca* on the other. A population of *P. mexicana* was closely aligned with Southwest populations of *P. engelmannii*, while populations of *P. glauca* were intermixed with and peripheral to those identified as hybrid. While consistent with most taxonomic treatments of these taxa, the analyses nonetheless suggested that Southwestern United States populations should be considered as a variety of *P. engelmannii* that most likely should include *P. mexicana*. Genecological analyses detected ample genetic variation among the 295 populations in the *P. engelmannii* complex. The analyses demonstrated that populations were distributed along clines driven primarily by the winter temperature regime of the provenance. For northern populations, summer temperatures also became a key factor in accounting for genetic differences among populations. Analyses also detected clines for the 19 *P. pungens* and 23 *P. glauca* populations. An assessment of the effects of global warming according to the IS92a scenario of two general circulation models demonstrated for the current century: (1) an increasingly favorable climate for *P. pungens* as its distribution moves upward in elevation throughout much of the Great Basin, Colorado Rockies, and mountain islands of the Southwest; (2) a widespread reduction in the areal extent of *P. engelmannii* in the inland Northwestern United States to the extent that *Picea* may become rare in the local flora; (3) extirpation of *P. glauca* from the Black Hills and Cypress Hills; and (4) a widespread redistribution of genotypes across the landscape as contemporary populations adjust genetically to change.

Link: http://www.treesearch.fs.fed.us/pubs/6952

494. Rehfeldt GE, Jaquish BC. 2010. Ecological impacts and management strategies for western larch in the face of climate-change. Mitigation and Adaptation Strategies for Global Change 15:283-306.

Type: Journal

Geographic Area: Northwestern North America

Keywords: bioclimate models, mapped genetic variation, seed zones, seed transfer guidelines, climate responses, climatic niche

Abstract: Approximately 185,000 forest inventory and ecological plots from both USA and Canada were used to predict the contemporary distribution of western larch (*Larix occidentalis* Nutt.) from climate variables. The random forests algorithm, using an 8 variable model, produced an overall error rate of about 2.9%, nearly all of which consisted of predicting presence at locations where the species was absent. Genetic variation among 143 populations within western larch's natural distribution was predicted from multiple regression models using variables describing the climate of the seed source as predictors and response data from two separate genetic tests: 1) 15-year height at a field site in British Columbia, Canada, and, 2) two principal components of 8 variables describing growth, disease tolerance, and phenology of 6-year-old trees in a test in Idaho, USA. Presence and absence of the species and genetic variation within the species were projected into future climates provided by three General Circulation Models and two scenarios. Although the projections described pronounced impacts on the species and its populations, concurrence among the six projections pinpointed areas where the probability would be high that the future climate would be suitable for western larch. Concurrence among projections also was used to locate those sources of seed that should be best attuned genetically to future climates. The procedures outline a logical approach for developing management strategies for accommodating climate-change while taking into account the variability imposed by the differences among climatic estimates.

Link: http://www.treesearch.fs.fed.us/pubs/35211

495. Rehfeldt GE, Wykoff WR, Ying CC. 2001. Physiologic plasticity, evolution, and impacts of a changing climate on *Pinus contorta*. Climatic Change 50:355-376.

Type: Journal

Geographic Area: Western North America

Compilers' Keywords: *Pinus contorta*, lodgepole pine, forest productivity, adaptation

Abstract: Climate response functions for 125 *Pinus contorta* populations were updated to assess the impact of 16 climate change scenarios on forest productivity. Productivity was defined as the volume of wood expected per hectare at age 20 and was calculated as the product of predicted individual tree volumes, an initial stocking (1600 trees ha^{-1}), and predicted survival. Impact was considered according to the transient effects of a changing climate governed by (1) physiological plasticity in the contemporary generation and (2) long-term evolutionary adjustments that provide adaptedness and optimize productivity in future generations. Direct short-term plastic responses were geographically complex and had repercussions throughout the species' distribution even when temperature fluctuations were small (±1 °C) and changes in distribution were inconsequential. Evolutionary adjustments ameliorated negative short term impacts while enhancing the positive. Scenarios that encompassed predictions for global warming produced short-term impacts that were negative in the south and positive in the north, but subsequent evolutionary adjustments projected substantial increases in productivity. The long-term adjustments may require only 1 to 3 generations in the north but 6 to 12 generations in the south, thereby taking between 200 and 1,200 years.

496. Rehfeldt GE, Ying CC, Spittlehouse DL, Hamilton DAJ. 1999. Genetic responses to climate in *Pinus contorta*: niche breadth, climate change, and reforestation. Ecological Monographs 69:375-407.

Type: Journal

Geographic Area: Western Canada

Keywords: climatic gradients, climate models, climate response functions of populations, fundamental niche vs. realized niche, genetic variation, global climate change, microevolution, niche breadth, *Pinus contorta*, population differentiation, reforestation in a changing environment, responses to a changing environment

Abstract: Fundamental plant–environment relationships were revealed by analyses of 20-yr height and survival of 118 populations representing two subspecies of *Pinus contorta* growing in common gardens at 60 environmentally disparate test sites in British Columbia. The approach involved (1) preparing models that described the general climate of British Columbia, (2) developing population-specific response functions driven by predicted climate variables, (3) developing general transfer functions that predict performance from the climatic distances over which populations were transferred, and (4) interpreting the results in terms of niche breadth, effects of climate change on adaptedness of populations, and reforestation in a changing environment. Polynomial regression models used physiographic descriptors to predict seven climate variables from normalized records of 513 weather stations. Values of R^2 ranged over 0.80–0.97 for thermal variables and 0.54–0.61 for precipitation variables. Validations with independent data from 45 stations were strong and suggested that the models were generally free of bias within the limits of the original data. Response functions describing the height or survival of each population were developed from quadratic regressions using predicted climate variables for each test site. Mean annual temperature and mean temperature in the coldest month were the most effective variables for predicting population height, while the ratio of summer temperature to summer moisture was the best predictor of survival. Validation of the response functions with independent data from two additional test sites produced values of R^2 between actual and predicted values that were as high as 0.93 for height and 0.73 for survival. The results demonstrated that natural populations have different climatic optima but tend to occupy suboptimal environments. Nevertheless, the general transfer functions showed that optimal growth and survival of the species as a whole is associated with the null transfer distance. These seemingly anomalous results suggest that the same processes thought to determine the distribution of species control the distribution of genotypes within species: (1) environmental selection to produce a broad fundamental niche, and (2) density-dependent selection to produce a relatively narrow realized niche within which most populations are relegate to suboptimal environments. Consequently, the steep geographic clines typical of *P. contorta* seem to be driven more by density-dependent selection than by environmental selection. Asymmetric gene flow from the center of distribution toward the periphery is viewed as a primary regulator that provides the fuel for both environmental and density dependent selection and thereby indirectly perpetuates suboptimality. The response functions predict that small changes in climate will greatly affect growth and survival of forest tree populations and, therefore, that maintaining contemporary forest productivities during global warming will require a wholesale redistribution of genotypes across the landscape. The response functions also provide the climatic bases to current reforestation guidelines and quantify the adjustments necessary for maintaining adaptedness in planted trees during periods of small (~1˚C) temporal temperature shifts.

497. Rehfeldt GE, Crookston NL, Warwell MV, Evans JS. 2006. Empirical analysis of plant-climate relationships for the western United States. International Journal of Plant Science 167:1123-1150.

Type: Journal

Geographic Area: Western USA

Keywords: bioclimatic models, Random Forests multiple-regression tree, climatic distributions, climatic niche, response to climate change, global warming

Abstract: The Random Forests multiple-regression tree was used to model climate profiles of 25 biotic communities of the western United States and nine of their constituent species. Analyses of the communities were based on a gridded sample of ca. 140,000 points, while those for the species used presence-absence data from ca. 120,000 locations. Independent variables included 35 simple expressions of temperature and precipitation and their interactions. Classification errors for community models averaged 19%, but the errors were reduced by half when adjusted for misalignment between geographic data sets. Errors of omission for species specific models approached 0, while errors of commission were less than 9%. Mapped climate profiles of the species were in solid agreement with range maps. Climate variables of most importance for segregating the communities were those that generally differentiate maritime, continental, and monsoonal climates, while those of importance for predicting the occurrence of species varied among species but consistently implicated the periodicity of precipitation and temperature-precipitation interactions. Projections showed that unmitigated global warming should increase the abundance primarily of the montane forest and grassland community profiles at the expense largely of those of the subalpine, alpine, and tundra communities but also that of the arid woodlands. However, the climate of 47% of the future landscape may be extramural to contemporary community profiles. Effects projected on the spatial distribution of species-specific profiles were varied, but shifts in space and altitude would be extensive. Species-specific projections were not necessarily consistent with those of their communities.

Link: http://www.treesearch.fs.fed.us/pubs/25706

498. Rehfeldt GE, Crookston NL, Saenz-Romero C, Campbell EM. 2012. **North American vegetation model for land-use planning in a changing climate: a solution to large classification problems.** Ecological Applications 22:119-141.

Type: Journal

Geographic Area: North America

Keywords: climate change impacts, climate niche modeling, land management alternatives, Random Forests classification tree, vegetation models

Abstract: Data points intensively sampling 46 North American biomes were used to predict the geographic distribution of biomes from climate variables using the Random Forests classification tree. Techniques were incorporated to accommodate a large number of classes and to predict the future occurrence of climates beyond the contemporary climatic range of the biomes. Errors of prediction from the statistical model averaged 3.7%, but for individual biomes, ranged from 0% to 21.5%. In validating the ability of the model to identify climates without analogs, 78% of 1, 528 locations outside North America and 81% of land area of the Caribbean Islands were predicted to have no analogs among the 46 biomes. Biome climates were projected into the future according to low and high greenhouse gas emission scenarios of three General Circulation Models for three periods, the decades surrounding 2030, 2060, and 2090. Prominent in the projections were (1) expansion of climates suitable for the tropical dry deciduous forests of Mexico, (2) expansion of climates typifying desert scrub biomes of western USA and northern Mexico, (3) stability of climates typifying the evergreen–deciduous forests of eastern USA, and (4) northward expansion of climates suited to temperate forests, Great Plains grasslands, and montane forests to the detriment of taiga and tundra climates. Maps indicating either poor agreement among projections or climates without contemporary analogs identify geographic areas where land management programs would be most equivocal. Concentrating efforts and resources where projections are more certain can assure land managers a greater likelihood of success.

Link: http://www.treesearch.fs.fed.us/pubs/40382

499. Rehfeldt GE, Tchebakova NM, Parfenova EI, Wykoff WR, Kuzmina NA, Milyutin LI. 2002. **Intraspecific responses to climate in *Pinus sylvestris*.** Global Change Biology 8:912-929.

Type: Journal

Geographic Area: North America, Europe, Asia

Keywords: climate-change impacts, climate response functions, microevolution, population adaptation, genetic responses to climate, predicting responses to change

Abstract: Five population-specific response functions were developed from quadratic models for 110 populations of *Pinus sylvestris* growing at 47 planting sites in Eurasia and North America. The functions predict 13 year height from climate: degree-days > 5 °C; mean annual temperature; degree-days < 0 °C; summer-winter temperature differential; and a moisture index, the ratio of degree-days > 5 °C to mean annual precipitation. Validation of the response functions with two sets of independent data produced for all functions statistically significant simple correlations with coefficients as high as 0.81 between actual and predicted heights. The response functions described the widely different growth potentials typical of natural populations and demonstrated that these growth potentials have different climatic optima. Populations nonetheless tend to inhabit climates colder than their optima, with the disparity between the optimal and inhabited climates becoming greater as the climate becomes more severe. When driven by a global warming scenario of the Hadley Center, the functions described short-term physiologic and long-term evolutionary

effects that were geographically complex. The short-term impacts, enhance the positive, and in time, substantially increase productivity throughout most of the contemporary pine forests of Eurasia. Realizing the long-term gains will require redistribution of genotypes across the landscape, a process that should take up to 13 generations and therefore many years.

Link: http://forest.akadem.ru/PDF/060322/tchebakova_9.pdf

500. Renton M, Shackelford N, Standish RJ. 2012. **Habitat restoration will help some functional plant types persist under climate change in fragmented landscapes.** Global Change Biology 18:2057-2070.

Type: Journal

Geographic Area: Australia

Keywords: assisted migration, corridors, dynamic model, functional traits, individual-based, intervention ecology, spatially-explicit, species distribution

Abstract: In the next century, global climate change is predicted to have large influences on species' distributions. Much of the research in this area has focused on predicting the areas where conditions will be suitable for the species in future and thus the potential distribution of the species. However, it is equally important to predict the relative abilities of species to migrate into new suitable areas as conditions shift, while accounting for dynamic processes, such as dispersal, maturation, mortality, and reproduction, as well as landscape characteristics, such as level of habitat fragmentation and connectivity. In this study, we developed a spatially explicit individual-based model that addresses these factors. As a motivating case study, we based aspects of the model on southwest Australia, a global biodiversity hotspot, but stress that the results obtained are generalizable beyond this region. Using the model, we enhanced current understanding of climate change impacts by investigating how and to what extent the functional traits of plant species affect their ability to move with climate change across landscapes with various levels of fragmentation. We also tested the efficacy of strategic restoration, such as planting corridors to increase connectivity among fragments. We found that even if the landscape is fully intact, only an average of 34.2% of all simulated functional groups had a good change of successfully tracking climate change. However, our study highlights the power of strategic restoration as a tool for increasing species persistence. Corridors linking fragments increase species persistence rates by up to 24%. The lowest persistence rates were found for trees, a functional group with high dispersal but also long generation times. Our results indicate that for trees intervention techniques, such as assisted migration might be required to prevent species losses.

501. Renton M, Childs S, Standish RJ, Shackelford N. 2013. **Plant migration and persistence under climate change in fragmented landscapes: does it depend on the key point of vulnerability within the lifecycle?** Ecological Modelling 249:50-58.

Type: Journal

Geographic Area: Global

Keywords: spatially explicit, individual-based, dynamic model, dispersal, lifecycle, species distribution, functional traits, PPunCC

Abstract: Many organisms are threatened by global climate change, but as sessile organisms, plants are particularly vulnerable. Unable to individually move to areas with more suitable conditions as the climate changes, plants must instead rely on their seeds dispersing far and often in order to migrate fast enough to keep pace with the changing climate. The fragmentation of natural landscape by clearing for agricultural or urban development, or a species' requirement for particular soil types or topography, makes this migration even more problematic. The likelihood of a plant species persisting will thus depend on factors such as the rate of climate change, the degree of landscape fragmentation, and also the plant species' lifecycle, seed production, dispersal, and establishment. This paper presents a dynamic model, called PPunCC (Plant Persistence under Climate Change), that represents the important factors and processes likely to affect a plant species' capacity to migrate across a landscape fast enough to avoid extinction. We use the model to show that creating large-scale corridors that increase the connectivity of fragmented landscapes through targeted restoration could help species migrate naturally and find suitable environments in new climates. We also examine the effect of varying the key point of vulnerability within its life cycle between juvenile establishment, adult mortality or seed production and conclude that this has a relatively minor effect on the prognosis for the plant and does not affect the predicted benefits of restoration.

502. Rice KJ, Emery NC. 2003. **Managing microevolution: restoration in the face of global change.** Frontiers in Ecology and the Environment 1:469-478.

Type: Journal

Geographic Area: California, USA

Compilers' Keywords: local adaptation, climate change, plant conservation genetics, review, vernal pools, blue oak woodlands

Abstract: Evidence is mounting that evolutionary change can occur rapidly and may be an important means by which species escape extinction in the face of global change. Consequently, biologists need to incorporate evolutionary thinking into management decisions in conservation and restoration ecology. Here, we review the genetic and demographic properties that influence the ability of populations to adapt to rapidly changing selective pressures. To illustrate how evolutionary thinking can influence conservation and restoration strategies, we compare the potential of two California plant communities (vernal pools and blue oak woodlands) to evolve in response to global change. We then suggest ways in which restoration biologists can manipulate the genetic architecture of target populations to increase their ability to adapt to changing conditions. While there may not be any universal rules regarding the adaptive potential of species, an understanding of the various processes involved in microevolution will increase the short- and long-term success of conservation and restoration efforts.

Link: https://www.bio.purdue.edu/people/faculty/faculty_files/publications/36121_1838168986.PDF

503. Richardson BA, Meyer SE. 2012. Paleoclimate effects and geographic barriers shape regional population genetic structure of blackbrush (*Coleogyne ramosissima*: Rosaceae). Botany 90:293-299.

Type: Journal

Geographic Area: Southwestern USA

Keywords: amplified fragment length polymorphisms, biogeography, Colorado Plateau, Mojave, postglacial colonization

Abstract: *Coleogyne ramosissima* Torr. (blackbrush) is a dominant xerophytic shrub species in the ecotone between the warm and cold deserts of interior western North America. Amplified fragment length polymorphisms (AFLPs) were used to survey genetic diversity and population genetic structure at 14 collection sites across the species range. Analysis revealed significant population differentiation (F_{ST} = 0.103, $p < 0.0001$) and reasonably high levels of genetic diversity (expected heterozygosity; H_E = 0.26), a surprising result for a putative paleoendemic species. Model-based Bayesian clustering, principal coordinates analysis, and neighbor-joining analysis all produced support for the existence of two metapopulations, the first centered on the Mojave Desert and the second on the Colorado Plateau. These genetic data, coupled with information from Late Pleistocene and Holocene packrat (genus *Neotoma* Say and Ord, 1825) middens, illustrate a demographic history in which eastern and western distributions were disjunct during the Last Glacial Maximum and remained so through the Holocene, forming the present-day metapopulations in the Mojave Desert and Colorado Plateau. This strong regional genetic differentiation has implications for population persistence and migration in response to future climate change, as well as for shrubland restoration following anthropogenic disturbances such as annual grass invasion and wildfire.

Link: http://www.treesearch.fs.fed.us/pubs/40435

504. Rogers DL, Millar CI, Westfall RD. 1996. Genetic diversity within species. Chapter 28. In: Erman DC, editor. Sierra Nevada Ecosystem Project: Final Report to Congress. Davis (CA): University of California, Davis. p 759-838.

Type: Book Section

Geographic Area: California, USA

Compilers' Keywords: review, plant taxa

Abstract: Based on our review of literature and survey of geneticists working on California taxa, we find genetic information lacking for most species in the Sierra Nevada. This situation is likely to remain in the future, with specific groups of taxa or occasional rare or high-interest species receiving specific study. Where we do have empirical information, we find few generalities emerging, except occasionally within closely related or ecologically similar taxa. Despite these difficulties in assessing genetic diversity, we direct attention to situations estimated to be most deserving of attention from a genetic standpoint.

Link: http://www.treesearch.fs.fed.us/pubs/6671

505. Saenz-Romero C, Rehfeldt GE, Crookston NL, Duval P, Beaulieu J. 2012. Spline models of contemporary, 2030, 2060 and 2090 climates for Michoacán state, Mexico. Impacts on the vegetation. Revista Fitotecnica Mexicana 35:333-345.

Type: Journal

Geographic Area: Michoacán, Mexico

Index words: *Pinus hartwegii*, *Pinus pseudostrobus*, assisted migration, climate change, emission scenarios, Michoacán, thin plate smoothing splines

Summary: Climate data from 149 weather stations of Michoacán State, at Western México, were extracted from a spline climate model developed for México's contemporary climate (1961–1990), and for climate projected for the decades centered in years 2030, 2060 and 2090. The model was constructed using outputs from three general circulation models (GCMs: Canadian, Hadley and Geophysical Fluid Dynamics) from two emission scenarios (A "pessimistic" and B "optimistic"). Mean annual temperature (MAT), mean annual precipitation (MAP), annual degree days > 5 °C (DD5), and annual aridity index ($DD^{50.5}$/MAP) were mapped for Michoacán at an 1 km^2 scale, and means were estimated averaging all weather stations. The state average in GCMs and emission scenarios point out that mean annual temperature would increase 1.4 °C by year 2030, 2.2 °C by year 2060 and 3.6 °C by year 2090; whereas annual precipitation would decrease 5.6 % by year 2030, 5.9 % by year 2060 and 7.8 % by year 2090. Climate models can be used for inferring plant-climate relationships and for developing programs to counteract global warming effects. Climate variables were estimated also at *Pinus hartwegii* and *Pinus pseudostrobus* growth locations, at Pico de Tancítaro in Central Western Michoacán and Nuevo San Juan Parangaricutiro (near Tancítaro), respectively. According to the annual aridity index values estimated for such locations, it is necessary to conduct assisted migration to match current genotypes to projected climates. This translates into an altitudinal shift of 400 to 450 m higher to match 2030 climates

predicted by Canadian Model scenario A2, and 600 to 800 m to match 2060 climates.

Link: http://scielo.unam.mx/pdf/rfm/v35n4/v35n4a10.pdf

506. Sáenz-Romero C, Rehfeldt GE, Duval P, Lindig-Cisneros RA. 2012. ***Abies religiosa*** **habitat prediction in climatic change scenarios and implications for monarch butterfly conservation in Mexico.** Forest Ecology and Management 275:98-106.

Type: Journal

Geographic Area: Michoacán, Mexico

Keywords: *Danaus plexippus*, suitable climatic habitat, Random Forests classification tree, assisted migration, climate change impacts, responses to climate

Abstract: *Abies religiosa* (HBK) Schl. & Cham. (oyamel fir) is distributed in conifer-dominated mountain forests at high altitudes along the Trans-Mexican Volcanic Belt. This fir is the preferred host for overwintering monarch butterfly (*Danaus plexippus*) migratory populations which habitually congregate within a few stands now located inside a Monarch Butterfly Biosphere Reserve. Our objectives were to predict and map the climatic niche for *A. religiosa* for contemporary and future (2030, 2060 and 2090) climates, suggest management strategies to accommodate climate changes, and discuss implications for conservation of monarch butterfly overwintering sites in Mexico. A bioclimate model predicting the presence or absence of *A. religiosa* was developed by using the Random Forests classification tree on forest inventory data. The model used six predictor variables and was driven primarily by the mean temperature of the warmest month, an interaction between summer precipitation to and winter temperatures, and the ratio of summer to annual precipitation. Projecting the contemporary climate niche into future climates provided by three General Circulation Models and two scenarios suggested that the area occupied by the niche should diminish rapidly over the course of the century: a decrease of 69.2% by the decade surrounding 2030, 87.6% for that surrounding 2060, and 96.5% for 2090. We discuss assisted migration of *A. religiosa* upwards in altitude by 275 m so that populations of 2030 would occupy the same climates as today. The projections also show that by the end of the century, suitable habitat for the monarch butterfly may no longer occur inside the Biosphere Reserve. We therefore discuss management options and associated research programs necessary for assuring perpetuation of future butterfly habitat.

Link: http://www.treesearch.fs.fed.us/pubs/41323

507. Sáenz-Romero C, Rehfeldt GE, Crookston NL, Duval P, St-Amant R, Beaulieu J, Richardson BA. 2009. **Spline models of contemporary, 2030, 2060 and 2090 climates for Mexico and their use in understanding climate-change impacts on the vegetation.** Climatic Change 102:595-623.

Type: Journal

Geographic Area: USA, Mexico

Compilers' Keywords: climate change, GCM, *Pinus chiapensis*

Abstract: Spatial climate models were developed for México and its periphery (southern USA, Cuba, Belize and Guatemala) for monthly normals (1961–1990) of average, maximum and minimum temperature and precipitation using thin plate smoothing splines of ANUSPLIN software on ca. 3,800 observations. The fit of the model was generally good: the signal was considerably less than one-half of the number of observations, and reasonable standard errors for the surfaces would be less than 1 °C for temperature and 10–15% for precipitation. Monthly normals were updated for three time periods according to three General Circulation Models and three emission scenarios. On average, mean annual temperature would increase 1.5 °C by year 2030, 2.3 °C by year 2060 and 3.7 °C by year 2090; annual precipitation would decrease −6.7% by year 2030, −9.0% by year 2060 and −18.2% by year 2090. By converting monthly means into a series of variables relevant to biology (e.g., degree-days > 5 °C, aridity index), the models are directly suited for inferring plant–climate relationships and, therefore, in assessing impact of and developing programs for accommodating global warming. Programs are outlined for (a) assisting migration of four commercially important species of pine distributed in altitudinal sequence in Michoacán State (b) developing conservation programs in the floristically diverse Tehuacán Valley, and (c) perpetuating *Pinus chiapensis*, a threatened endemic. Climate surfaces, point or gridded climatic estimates and maps are available at http://forest.moscowfsl.wsu.edu/climate/.

Link: http://www.treesearch.fs.fed.us/pubs/36311

508. Schwartz MW. 1992. **Modelling effects of habitat fragmentation on the ability of trees to respond to climatic warming.** Biodiversity and Conservation 2:51-61.

Type: Journal

Geographic Area: Eastern North America

Keywords: tree migration, deforestation, Holocene, simulation model, global warming

Abstract: The ability of trees to migrate in response to climatic warming was simulated under various conditions of habitat availability. The model uses Holocene tree migration rates to approximate maximum migration rates in a forested landscape. Habitat availability and local population size was varied systematically under two dispersal and colonization models. These dispersal models varied in the likelihood of long-distance dispersal events. The first model used a negative exponential function that severely limited the probability of long-distance dispersal. The results of this model indicate that migration rate could decline an order of magnitude where the habitat availability is reduced from 80 to 20% of the matrix. The second model, using an inverse power function, carried a higher probability of long-distance dispersal events. The results from this model predict relatively small declines in migration rates when habitat availability is reduced to 50% of the simulation matrix. Below 50% habitat availability, mean migration rate was similar to the negative exponential model. These results predict a failure of many trees to respond to future climatic change through range expansion.

509. Schwartz MW. 1992. Potential effects of global climate change on the biodiversity of plants. The Forestry Chronicle 68:462-471.

Type: Journal

Geographic Area: Global

Compilers' Keywords: migration, trees, emissions, carbon dioxide

Abstract: Climatologists have observed a consistent increase in atmospheric CO_2 over the past 30 years. It is predicted that CO_2 levels could double the pre-industrial level of 280 ppm by the year 2100, perhaps much earlier. Climate models of doubled atmospheric CO_2 predict that mean temperatures will increase between 1.5 and 4.5 °C globally; these temperature changes will be greater at high latitudes. Mid-continental regions will experience lower rainfall. Predictions of species northward range shifts in response to climate change vary from 100 km to over 500 km. Historical evidence of species range movements following the Pleistocene indicate that tree species typically migrated at rates of 10 km to 40 km per century. A simulation model that predicts the migration response of trees through modern fragmented landscapes predicts migration rates much lower than Pleistocene observations. Thus migration response is likely to lag far behind rates of climate change, potentially threatening narrowly distributed species whose predicted future ranges do not overlap with their current range. Insect pests and microbial pathogens should respond to climatic warming faster than long-lived trees. Predicted increased drought frequency may increase plant stress and thereby increase the frequency of insect outbreaks and disease. Predictions of species responses are complicated by direct effects of increased CO_2 such as increased water-use efficiency. However, response to elevated CO_2 varies among species. Thus, shifts in composition within plant communities are also likely, but are, as yet, unpredictable.

510. Shaw RG, Etterson JR. 2012. Rapid climate change and the rate of adaptation: insight from experimental quantitative genetics. New Phytologist 195:752-765.

Type: Journal

Geographic Area: Global

Keywords: adaptive evolution, additive genetic variation in fitness, geographic range, phenotypic plasticity, resurrection biology

Summary: Evolution proceeds unceasingly in all biological populations. It is clear that climate-driven evolution has molded plants in deep time and within extant populations. However, it is less certain whether adaptive evolution can proceed sufficiently rapidly to maintain the fitness and demographic stability of populations subjected to exceptionally rapid contemporary climate change. Here, we consider this question, drawing on current evidence on the rate of plant range shifts and the potential for an adaptive evolutionary response. We emphasize advances in understanding based on theoretical studies that model interacting evolutionary processes, and we provide an overview of quantitative genetic approaches that can parameterize these models to provide more meaningful predictions of the dynamic interplay between genetics, demography and evolution. We outline further research that can clarify both the adaptive potential of plant populations as climate continues to change and the role played by ongoing adaptation in their persistence.

Link: http://www.ncbi.nlm.nih.gov/pubmed/22816320

511. Smith SA, Beaulieu JM. 2009. Life history |influences rates of climatic niche evolution in flowering plants. Proceedings of the Royal Society Biological Sciences 276:4345-4352.

Type: Journal

Geographic Area: Global

Keywords: life history, rates of evolution, phylogenetics, climatic niche

Abstract: Across angiosperms, variable rates of molecular substitution are linked with life-history attributes associated with woody and herbaceous growth forms. As the number of generations per unit time is correlated with molecular substitution rates, it is expected that rates of phenotypic evolution would also be influenced by differences in generation times. Here, we make the first broad-scale comparison of growth-form-dependent rates of niche evolution. We examined the climatic niches of species on large time-calibrated phylogenies of five angiosperm clades and found that woody lineages have accumulated fewer changes per million years in climatic niche space than related herbaceous lineages. Also, climate space explored by woody lineages is consistently smaller than sister lineages composed mainly of herbaceous taxa. This pattern is probably linked to differences in the rate of climatic niche evolution. These results have implications for niche conservatism; in particular, the role of niche conservatism in the distribution of plant biodiversity. The consistent differences in the rate of climatic niche evolution also emphasize the need to incorporate models of phenotypic evolution that allow for rate heterogeneity when examining large datasets.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19776076

512. Smith JA, Trulock A. 2010. The decline of Florida torreya: an endemic conifer on the edge of extinction. Gainesville (FL): University of Florida. FOR276. 5 p.

Type: Report

Geographic Area: Southeastern USA

Compilers' Keywords: species extinctions, endemic species

Overview: The Florida torreya (*Torreya taxifolia*) is a critically endangered conifer endemic to the Apalachicola River drainage of the Florida panhandle and adjacent southern Georgia. Florida torreya has experienced a significant die-off and subsequent decline during the past century. Although the decline has been attributed to numerous abiotic and biotic causes, however, our findings are that the most likely reason for the decline is fungal disease. This fungal disease is likely caused by a *Fusarium* species and our suggestions for a new understanding of the actual cause of the decline are addressed in this fact sheet. Current efforts to assess the population and develop a recovery plan are discussed.

Link: http://edis.ifas.ufl.edu/pdffiles/FR/FR33800.pdf

513. Souto CP, Heinemann K, Kitzberger T, Newton AC, Premoli AC. 2011. Genetic diversity and structure in *Austrocedrus chilensis* populations: implications for dryland forest restoration. Restoration Ecology 20:568-575.

Type: Journal

Geographic Area: Argentina, South America

Keywords: beyond-range restoration, fire, glaciations, passive restoration, Patagonia

Abstract: In South America, 94% of dry-temperate lands present some degree of environmental degradation, highlighting the need for ecological restoration. We analyzed geographic patterns of genetic variation in *Austrocedrus chilensis*, a dominant conifer of the steppe-forest ecotone in the eastern Andes, to examine its potential for restoration. We sampled 67 locations in Argentina and estimated genetic parameters to determine the effects of historical factors affecting diversity, together with inbreeding and gene flow, using 12 allozyme loci. Genetic diversity decreased southwards in eastern populations, which are marginal for the range of the species and patchily distributed, while high genetic admixture was detected in continuous western populations, possibly reflecting postglacial migrations from northern and eastern sources. Higher inbreeding ($F_{IS} > 0.14$) was recorded in northern compared with southern populations, attributed to the impact of recent bottlenecks resulting from anthropogenic fires. Gene flow was found to be moderate overall ($F_{ST} = 0.12$). The implications of these results for restoration on actions focusing on *Austrocedrus* were explored. Relatively small, inbred yet genetically diverse northern populations should be the subject of passive restoration efforts, while experimental common gardens should be established toward the south, to support active restoration approaches. This illustrates how ahead of time information on patterns of genetic variation can support restoration efforts for dryland tree species.

Link: http://www.researchgate.net/publication/233926307_Genetic_Diversity_and_Structure_in_Austrocedrus_chilensis_Populations_Implications_for_Dryland_Forest_Restoration/file/79e4150d0aab77ac20.pdf

514. Spores S. 2009. Alaska yellow-cedar moves north. Juneau, AK: USDA Forest Service, Alaska Region. 3 p.

Type: Government Document

Geographic Area: Alaska

Compilers' Keywords: facilitated migration, Tongass National Forest, yellow-cedar, assisted migration, forest management

Introduction: Climate change has become an increasingly prevalent topic in the news and in how the Forest Service will manage national forest lands for long term diversity and sustainability. The Forest Service has developed a strategic framework to guide management actions that address the challenges of climate change. One of the goals of this framework is "adaptation." This means enhancing the capacity of forests to adapt to climate change in order to maintain ecosystem services. One of the methods that has been increasingly discussed is the idea of "facilitated migration," or the moving of a species into an area where it doesn't currently grow, but is anticipated to expand its range to that area in a warming climate. This kind of planting may be necessary because trees cannot migrate quickly enough keep up with the pace of anticipated climate change.

Link: http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5251356.pdf

515. St. Clair JB. 2013. Landscape variation in adaptation and implications for managing the future climates. In: Assisted Migration: A Primer for Reforestation and Restoration Decision Makers; Portland, OR. 136 p.

Type: Presentation

Geographic Area: Pacific Northwest USA

Compilers' Keywords: assisted migration, forest management, Douglas-fir, genomics, provenance tests, bud burst

Abstract: Plant populations have evolved through natural selection to be genetically adapted to their local climates. Consequently, when climates change populations may become maladapted to the climate at their native location unless they can evolve through natural selection or migration at a pace that is fast enough to keep up with the change. Given the slow generation turnover of forest trees, along with other considerations, this seems unlikely. Assisted migration is an important management option for maintaining adaptation, productivity and sustainability of forest ecosystems. Knowledge of landscape variation in adaption and adaptive traits is important for guiding decisions of population movement for purposes of assisted migration. Scientists study adaptation through genecology studies which consider correlations between population variation in traits and the environments of source locations where they evolved, or through reciprocal transplant studies which compare responses of different populations from a range of source environments grown in the same or similar range of environments. Results from genecology and reciprocal transplant studies of Douglas-fir are presented. Management options for responding to climate change are considered. One option is to do nothing, and it is important to consider the consequences of continuing to use current see zones and population movement guidelines. Silvicultural measures such as density management and fuels treatment may be an important option for maintaining resiliency and resisting change, but may just delay the inevitable as aging stands become increasingly maladapted. Managers may increase the likelihood of gene flow and migration by avoiding fragmentation and maintaining corridors for gene flow. But that may not be sufficient to keep pace with climate change. Assisted migration may be one of our most powerful tools for responding to climate change. Movement need not be geographically large at this point. The most critical phase of stand development is most likely to be the seedling and sampling stage; thus, movements should focus on the amount of climate change in the next couple of decades, generally, less than 2 °C. Movements of this magnitude are within current practices of transfers within current seed zones. Thus, risk is likely to be small, and managers should pay attention that movements are in the direction of warmer sources to cooler planting sites, and not both directions as is current practice. To facilitate assisted migration, seed zones and seed movement guidelines should be based on climate rather than geography, and seed collections should be bulked over a narrower climatic range than bulking using current seed zones.

Link: http://www.rngr.net/resources/assisted-migration

516. Tarazi R, Mantovani A, dos Reis MS. 2009.

Fine-scale spatial genetic structure and allozymic diversity in natural populations of *Ocotea catharinensis* Mez. (Lauraceae). Conservation Genetics 11:965-976.

Type: Journal

Geographic Area: Brazil, South America

Keywords: Atlantic rain forest, Lauraceae, endangered species, genetic diversity, spatial autocorrelation

Abstract: In order to establish a strategy for conservation, the distribution of genetic diversity in four natural populations of *Ocotea catharinensis* in the Brazilian Atlantic rain forest was investigated using 18 allozyme loci. Estimates of the average number of alleles per loci (2.2), percentage of polymorphic loci (83.3%) and expected genetic diversity (0.427) in adult individuals were high; suggesting that all populations have genetic potential for conservation. The inbreeding within populations ($\hat{F}$ = -0.011) and the total inbreeding ($\hat{f}$ = 0.133) suggest population structure, since a high level of divergence among populations (θ_p = 0.143) was also detected. Significant values of spatial genetic structure were found inside the four populations. This study demonstrates that the realized gene flow among the remaining populations of *O. catharinensis* is not sufficient to stop population divergence due to genetic drift and local selection, which threatens the future viability of this species.

517. Tchebakova NM, Rehfeldt GE, Parfenova EI. 2010.

From vegetation zones to climatypes: effects of climate warming on Siberian ecosystems. In: Osawa A, Zyryanova OA, Matsuura Y, Kajimoto T, Wein RW, editors. Permafrost Ecosystems: Siberian Larch Forests. 209. Netherlands: Springer. p 427-446.

Type: Book Section

Geographic Area: Siberia, Asia

Compilers' Keywords: climate change, range shifts, boreal forest, *Pinus sylvestris, Larix sibirica*

Introduction: Evidence for global warming over the past 200 years is overwhelming, based on both direct weather observation and indirect physical and biological indicators such as retreating glaciers and snow/ice cover, increasing sea level, and longer growing seasons. Recent GCM projections of the Hadley Centre for Siberia show an increase in temperature of 4 °C to 6 °C and an increase in precipitation of as much as 25% by 2100. These changes, moreover, could occur at a rate of 0.1 °C to 0.4 °C per decade. The rapid rate of change coupled with the large absolute amount of change is expected to have profound effects on plants of the boreal forests at all hierarchical levels: from forest zones, to ecosystems, to species, to populations within species. Our goals are to estimate effects of a warming climate on Siberian vegetation, first, at the highest level of organization, and, second, the lowest. The first considers the effects of global warming as zonal vegetation shifts across the plains and plateaus of central Siberia, and the second considers intraspecific effects within the mountains of southern Siberia. For the second objective, we invoke Turesson's concept of climatypes, the climatic ecotypes that comprise species, and illustrate intraspecific effects for *Pinus sylvestris* and *Larix sibirica*.

Link: http://www.treesearch.fs.fed.us/pubs/36298

518. Tchebakova NM, Parfenova EI, Soja AJ. 2011.

Climate change and climate-induced hot spots in forest shifts in central Siberia from observed data. Regional Environmental Change 11:817-827.

Type: Journal

Geographic Area: Siberia, Asia

Keywords: instrumental climate record, IPCC climate change projections, forest shift, Siberia

Abstract: Regional Siberian studies have already registered climate warming over the last several decades. We evaluated ongoing climate change in central Siberia between 1991 and 2010 and a baseline period, 1961–1990, and between 1991 and 2010 and Hadley 2020 climate change projections, represented by the moderate B1 and severe A2 scenarios. Our analysis showed that winters are already 2–3 °C warmer in the north and 1–2 °C warmer in the south by 2010. Summer temperatures increased by 1 °C in the north and by 1–2 °C in the south. Change in precipitation is more complicated, increasing on average 10% in middle latitudes and decreasing 10–20% in the south, promoting local drying in already dry landscapes. Hot spots of possible forest shifts are modeled using our Siberian bioclimatic vegetation model and mountain vegetation model with respect to climate anomalies observed pre-2010 and predicted 2020 Hadley scenarios. Forests are predicted to shift northwards along the central Siberian Plateau and upslope in both the northern and southern mountains. South of the central Siberian Plateau, steppe advancement is predicted that was previously non-existent north of 56° N latitude. South of 56° N, steppe expansion is predicted in the dry environments of Khakasiya and Tyva. In the southern mountains, it is predicted that the lower tree line will migrate upslope due to increased dryness in the intermontane Tyvan basins. The hot spots of vegetation change that are predicted by our models are confirmed by regional literature data.

519. Thiel D, Nagy L, Beierkuhnlein C, Huber G, Jentsch A, Konnert M, Kreyling J. 2012. **Uniform drought and warming responses in *Pinus nigra* provenances despite specific overall performances.** Forest Ecology and Management 270:200-208.

Type: Journal

Geographic Area: Germany, Europe

Keywords: European black pine, local adaptation, within-species diversity, provenance trial, plant-climate interactions, lag effect

Abstract: Climate extremes are expected to increase in frequency and magnitude as a consequence of global warming, threating the functioning, services and goods of forest ecosystems. The introduction of species from drier and warmer climates is one option that is discussed to adapt forest ecosystems to these adverse effects of climate change. The (sub)-Mediterranean *Pinus nigra* is a potential candidate for such assisted migration, especially for dry sites in Central Europe. The high genetic diversity within this species and thus the potential differences in adaptive capacity, however, makes it necessary to assess the response of *P. nigra* provenances to climatic extremes and identify suitable populations or ecotypes which are better adapted to projected future climates than indigenous species. Here, we tested juvenile plants of 6 provenances of *P. nigra* for their response to different climate change scenarios (42-days drought and warming by 1.6K) in a full-factorial common-garden experiment in Bayreuth, Germany. In the second year only the warming treatment was imposed. Height, shoot mortality and needle phenology were determined for the two consecutive years. Provenances differed in absolute growth (from 6.0 to 7.4 in 2009 and from 4.4 to 5.9 cm in 2010) and survival rates (from 78.6% to 97.6%), but not in terms of shoot quantity and, surprisingly, sensitivity to drought and warming. The drought treatment showed a delayed impact on height growth, as a significant growth reduction was detected for the second year (-2.6 cm), but not for the first year, when the actual treatment took places. Drought decreases survival rates by 20.6%. The drought treatment had no effect on needle phenology. Warming did not impact growth performance (height, shoot quantity). However, warming in combination with the drought treatment decreased the survival rate (-13%). Plants exposed to the warming treatment showed an earlier onset of needle development (-10.6 days). Our results imply that no significant local adaptation of growth and survival to drought and warming occurs in *P. nigra*. Performance and growth response in face of warming and drought cannot be predicted by the climate at the places of origin. We therefore recommend that an introduction of *P. nigra* to regions outside its natural distribution range should not aim at introducing a single best-adapted provenance but at establishing populations with a high genetic diversity, e.g. by promoting natural regeneration in native stands or by intermixing with different genotypes in order to maintain a high adaptive capacity to climate change.

Link: http://www.researchgate.net/profile/Carl_Beierkuhnlein/publication/224758416_Uniform_drought_and_warming_responses_in_Pinus_nigra_provenances_despite_specific_overall_performances/links/0046351a5b0e193e7d000000.pdf

520. Thorpe AS, Kaye TN. 2011. **Conservation and reintroduction of the endangered Willamette daisy.** Native Plants Journal 12:289-300.

Type: Journal

Geographic Area: Oregon, USA

Keywords: reintroduction, Willamette Valley, prairie, endangered species, allee effect, *Erigeron decumbens*, Asteraceae

Abstract: Our research suggests that habitat fragmentation and reduced population size in Willamette daisy has led to loss of fitness in some populations and to population differentiation. In outcrossing species, habitat fragmentation and reduced population size can lead to increased genetic drift, local adaptation, and (or) inbreeding. We explored some of these issues for the endangered forb Willamette daisy (*Erigeron decumbens* Nutt. [Asteraceae]). This species is currently restricted

to approximately 40 sites in the Willamette Valley, Oregon; more than half of the known populations have fewer than 100 individuals. We found a positive relationship between seed viability (as measured by the percentage of filled seeds) and population size. In populations with 20 or fewer individuals, seed viability dropped to less than 2.5%. In modified reciprocal transplant and common-garden experiments, we found that although there were some differences in survival, growth, and reproduction in transplants from 2 source populations, the effect of source varied depending on response variable, year of planting, year of monitoring, and habitat. Conservation of Willamette daisy will benefit from increasing the size and genetic diversity of existing populations and from reintroducing genetically diverse populations within the historic range of the species. Knowledge of genetic diversity of populations can be critical for making appropriate management decisions for rare species, including determining if population augmentation is necessary and, if so, from which source populations.

Link: http://appliedeco.org/reports/Kaye%202008%20Reintroduction%20Native%20Plants%20Journal.pdf

521. Thuiller W, Lavorel S, Araujo MB. 2005. Niche properties and geographical extent as predictors of species sensitivity to climate change. Global Ecology and Biogeography 14:347-357.

Type: Journal

Geographic Area: Europe, Global

Keywords: bioclimatic 'envelope' modelling, climate change, future potential habitats, niche breadth, niche position, range size

Abstract: Bioclimatic envelope models are often used to make projections of species' potential responses to climate change. It can be hypothesized that species with different kinds of distributions in environmental niche and geographical space may respond differently to changes in climate. Here, we compare projections of shifts in species ranges with simple descriptors of species niche (position and breadth) and geographical (range size) distributions. The future distribution for 1,200 European plant species were predicted by niche-based models using seven climate variables known to have an important role in limiting plant species distributions. Ecological niche properties were estimated using a multivariate analysis. Species range changes were then related to species niche properties using generalized linear models. Generally, percentage of remaining suitable habitat in the future increased linearly with niche position and breadth. Increases in potential suitable habitat were associated with greater range size, and had a hump-shaped relationship with niche position on temperature gradient. By relating species chorotypes to percentage of remaining or gained habitat, we highlighted biogeographical patterns of species sensitivity to climate change. These were clearly related to the degree of exposure according to regional patterns of projected climate change. This study highlights general patterns about the relationships between sensitivity of species to climate change and their ecological properties. There is a strong convergence between simple inferences based on ecological characteristics of species and projections by bioclimatic 'envelope' models, confirming macroecological assumptions about species sensitivity based on niche properties. These patterns appear to be most strongly driven by the exposure of species to climate change, with additional effects of species niche characteristics. We conclude that simple species niche properties are powerful indicators of species' sensitivity to climate change.

Link: http://www.researchgate.net/publication/228851892_Niche_properties_and_geographical_extent_as_predictors_of_species_sensitivity_to_climate_change/file/79e4150c60275ab41b.pdf

522. Thuiller W, Albert C, Araújo MB, Berry PM, Cabeza M, Guisan A, Hickler T, Midgley GF, Paterson J, Schurr FM, Sykes MT, Zimmermann NE. 2008. Predicting global change impacts on plant species' distributions: future challenges. Perspectives in Plant Ecology, Evolution and Systematics 9:137-152.

Type: Journal

Geographic Area: Global

Keywords: species distribution modeling, habitat models, process-based models, global change, conservation planning

Abstract: Given the rate of projected environmental change for the 21st century, urgent adaptation and mitigation measures are required to slow down the on-going erosion of biodiversity. Even though increasing evidence shows that recent human-induced environmental changes have already triggered species' range shifts, changes in phenology and species' extinctions, accurate projections of species' responses to future environmental changes are more difficult to ascertain. This is problematic, since there is a growing awareness of the need to adopt proactive conservation planning measures using forecasts of species' responses to future environmental changes. There is a substantial body of literature describing and assessing the impacts of various scenarios of climate and land-use change on species' distributions. Model predictions include a wide range of assumptions and limitations that are widely acknowledged but compromise their use for developing reliable adaptation and mitigation strategies for biodiversity. Indeed, amongst the most used models, few, if any, explicitly deal with migration processes, the dynamics of population at the "trailing edge" of shifting populations, species' interactions and the interaction between the effects of climate and land-use. In this review, we propose two main avenues to progress the understanding and prediction of the different processes occurring on the leading and trailing edge of the species' distribution in response

to any global change phenomena. Deliberately focusing on plant species, we first explore the different ways to incorporate species' migration in the existing modelling approaches, given data and knowledge limitations and the dual effects of climate and land-use factors. Secondly, we explore the mechanisms and processes happening at the trailing edge of a shifting species' distribution and how to implement them into a modelling approach. We finally conclude this review with clear guidelines on how such modelling improvements will benefit conservation strategies in a changing world.

Link: http://biology.mcgill.ca/grad/cecile/PDFs/3_Thuiller2008.pdf

523. Tingley MW, Monahan WB, Beissinger SR, Moritz C. 2009. Birds track their Grinnellian niche through a century of climate change. Proceedings of the National Academy of Sciences USA 106 Supplement 2:19637-19643.

Type: Journal

Geographic Area: California, USA

Keywords: climatic niche, geographic range, elevational gradient, occupancy dynamics

Abstract: In the face of environmental change, species can evolve new physiological tolerances to cope with altered climatic conditions or move spatially to maintain existing physiological associations with particular climates that define each species' climatic niche. When environmental change occurs over short temporal and large spatial scales, agile species are expected to move geographically by tracking their climatic niches through time. Here, we test for evidence of niche tracking in bird species of the Sierra Nevada Mountains of California, focusing on 53 species resurveyed nearly a century apart at 82 sites on four elevational transects. Changes in climate and bird distributions resulted in focal species shifting their average climatological range over time. By comparing the directions of these shifts relative to the centroids of species' range-wide climatic niches, we found that 48 species (90.6%) tracked their climatic niche. Analysis of niche sensitivity on an independent set of occurrence data significantly predicted the temperature and precipitation gradients tracked by species. Furthermore, in 50 species (94.3%), site-specific occupancy models showed that the position of each site relative to the climatic niche centroid explained colonization and extinction probabilities better than a null model with constant probabilities. Combined, our results indicate that the factors limiting a bird species' range in the Sierra Nevada in the early 20th century also tended to drive changes in distribution over time, suggesting that climatic models derived from niche theory might be used successfully to forecast where and how to conserve species in the face of climate change.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19805037

524. Trivedi MR, Morecroft MD, Berry PM, Dawson TP. 2008. Potential effects of climate change on plant communities in three montane nature reserves in Scotland, UK. Biological Conservation 141:1665-1675.

Type: Journal

Geographic Area: Scotland, United Kingdom

Keywords: Arctic-alpine plants, classification tree, Grampian highlands, mountains, Natura 2000, special area of conservation, species distribution models, topography

Abstract: Mountain ecosystems are often identified as being particularly sensitive to climate change, however this has rarely been investigated at the scale of individual mountain ranges using local relationships between plants and climate. This study uses fine resolution data to assess the potential changes to internationally important Arctic-alpine plant communities in three national nature reserves in the Scottish Highlands, United Kingdom. Distribution models were created for 31 species, representing a range of community types. A relationship between distribution and temperature was found for all species. These models were aggregated to explore potential future changes to each community under two Intergovernmental Panel on Climate Change warming scenarios for the 2080s. The results indicate that Arctic-alpine communities in these reserves could undergo substantial species turnover, even under the lower climate change scenario. For example, *Racomitrium-Carex* mossheath, a distinctive community type of the British uplands, could lose suitable climate space as other communities spread uphill. These findings highlight the need to maintain these communities in an optimal condition in which they can be most resilient to such change, to monitor them for signals of change and to develop more flexible conservation policies which account for future changes in mountain protected areas.

Link: https://edit.ethz.ch/ecology/education/BE_documents/Trivedi_et_Al_2008_plant_community_shift_climate_change.pdf

525. Ukrainetz NK, O'Neill GA, Jaquish B. 2011. Comparison of fixed and focal point seed transfer systems for reforestation and assisted migration: a case study for interior spruce in British Columbia. Canadian Journal of Forest Research 41:1452-1464.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: assisted colonization, assisted migration, maladaptation, *Picea engelmannii*, *Picea glauca*

Abstract: In forestry, science-based seed transfer systems, the foundation of effective reforestation programs, will likely be used in some form to mitigate the negative effects of climate change. In this study, we developed fixed and focal point seed transfer systems for interior spruce (*Picea glauca*

(Moench) Voss, *Picea engelmannii* Parry ex Engelm., and their hybrids) in British Columbia, Canada, and compared the effectiveness of both systems. Growth, phenology, and physiology traits were measured for 112 populations, and population means were transformed to principal components that were modeled using climate variables and multiple regression analysis. Compared with the fixed seed zone system, the focal point system had a greater area of seed use for a given risk of maladaptation. The relationship between growth and adaptive distance (i.e., adaptive similarity between test populations and populations local to test sites) was used to calculate critical seed transfer distances for focal point seed zones, which were defined according to expected forfeiture of growth. Changes in climate observed over the past 100 years and predicted in the next one third of a rotation were used to calculate appropriate assisted migration distances and develop methods for incorporating assisted migration into a focal point seed transfer system.

526. Van der Veken S, Hermy M, Vellend M, Knapen A, Verheyen K. 2008. Garden plants get a head start on climate change. Frontiers in Ecology and the Environment 6:212-216.

Type: Journal

Geographic Area: Europe

Compilers' Keywords: assisted migration, horticulture, commercial nurseries

Abstract: Conservation biologists are concerned that climate change will cause widespread extinctions because limited capacity for migration could compromise species' ability to adjust to geographic shifts in habitat condition. However, commercial plant nurseries may provide a head start for northward range shifts among some plant species. To investigate this possibility, we compared the natural ranges of 357 native European plant species with their commercial ranges, based on 246 plant nurseries throughout Europe. In 73% of native species, commercial northern range limits exceeded natural northern range limits, with a mean difference of ~ 1000 km. With migration rates of ~ 0.1–5 km per year required for geographic ranges to track climate change over the next century, we expect nurseries and gardens to provide a substantial head start on such migration for many native plants. While conservation biologists actively debate whether we should intentionally provide "assisted migration," it is clear that we have already done so for a large number of species.

Link: http://www3.botany.ubc.ca/vellend/Van_der_Veken_Frontiers2008.pdf

527. Vegas-Vilarrúbia T, Nogué S, Rull V. 2012. Global warming, habitat shifts and potential refugia for biodiversity conservation in the neotropical Guayana Highlands. Biological Conservation 152:159-168.

Type: Journal

Geographic Area: Venezuelan Guayana, South America

Keywords: habitat loss, fragmentation, extinction, refugia, microrefugia, conservation, Venezuelan Guayana, neotropics

Abstract: Current global average temperatures are 2 °C cooler than during the last interglacial period. The expected increase in temperature during the 21st century will be most stressful for cold-adapted and stenothermic mountain species, forcing them to migrate upwards, and eventually to concentrate into either large areas with favourable climates (refugia) or small stands under locally favourable microclimates (microrefugia). We investigate potential refugia in the neotropical Guayana Highlands mountain biome (Pantepui), consisting of ~50 isolated table mountains (tepuis), to develop strategies for conserving biodiversity during future global warming. We predict the amount of loss of altitudinal habitats of endemic vascular flora of 26 tepuis and evaluate potential threats to these taxa with respect to species extinction, habitat loss, habitat connectivity and the degree of isolation. We compare past, present, and future Pantepui landscape configurations through fragmentation analysis and identify potential *in situ* refugia. Spatial analysis forecasts more species isolation and declining biodiversity at the end of this century relative to current and past levels. Habitats are predicted to experience > 80% loss, with the disappearance of 38 habitat patches. One large patch (Chimanta massif) accounts for 46% of the predicted remaining habitat. This patch can be considered a potential refugium for future vascular flora, as it is predicted to contain some present-day resistant species from lower altitudinal levels and other species eventually persisting in microrefugia. The easternmost Pantepui district, containing the Chimanta massif and other tepuis, seems to be the most suitable for the application of *in situ* conservation strategies.

528. Wagner M, Heinrich W, Jetschke G. 2006. Seed bank assembly in an unmanaged ruderal grassland recovering from long-term exposure to industrial emissions. Acta Oecologica 30:342-352.

Type: Journal

Geographic Area: Germany, Europe

Keywords: derelict industrial ecosystem, grassland, *Puccinellia distans*, regeneration, secondary succession, seed bank composition, similarity patterns

Abstract: The main aim of this 3-year study was to relate the temporal patterns in seed bank composition of a ruderal grassland previously subjected to industrial pollution with the successional patterns in the above ground vegetation. In particular, we tested whether the observed changes conformed to a paradigm of declining seed numbers and diversity and decreasing similarity between seed bank and vegetation, as previously formulated for secondary successions. We found that seed numbers and the number of species per soil sample increased during the 3 years of the study. The compositional similarity between seed bank and vegetation did increase for the 0–2 cm surface layer, and remained roughly constant for deeper soil layers. Thus, the patterns found differed from those of other secondary successional communities and do not support the tested paradigm. Rather, our findings resemble those from a number of primary successional ecosystems. We suggest that temporal patterns of similarity between seed bank and vegetation should be interpreted in terms of the factors that determine the relative rates of compositional change in vegetation and seed bank at different stages of succession. Our study also provides information about the seed bank persistence of 22 species, including several species for which such knowledge previously was scarce. In particular, this study indicates the extreme longevity of the seeds of the halophytic grass Puccinellia distans. Several years after its rapid decline in the vegetation, this species dominated the seed bank, and no measurable decline in seed density was detected during this study.

529. Wallis CM, Huber DP, Lewis KJ. 2011. Ecosystem, location, and climate effects on foliar secondary metabolites of lodgepole pine populations from central British Columbia. Journal of Chemical Ecology 37:607-621.

Type: Journal

Geographic Area: Western Canada

Keywords: climate change, gas chromatography-mass spectrometry (GC-MS), lignin, lodgepole pine, monoterpenoid, phenolics, *Pinus contorta* latifolia, sesquiterpenoid, diterpenoid

Abstract: Lodgepole pines, *Pinus contorta* Douglas ex Louden var. *latifolia* Engelm. ex S. Watson, are encountering increased abiotic stress and pest activity due to recent increases in temperature and changes in precipitation throughout their range. This tree species counters these threats by producing secondary metabolites, including phenolics and terpenoids. We examined foliar levels of lignin, soluble phenolics, monoterpenoids, sesquiterpenoids, and diterpenoids in 12 stands in British Columbia, Canada. We used these data to assess associations among foliar secondary metabolite levels and ecosystem, geographic, and climatic variables. Regressions were also performed to observe which combinations of variables best explained secondary metabolite variance. Stands of *P. c. latifolia* in the Coastal Western Hemlock and Interior Cedar/Hemlock biogeoclimatic zones had consistently greater foliar levels of almost all measured secondary metabolites than did other stands. Lignin was present in greater amounts in Boreal White/Black Spruce ecosystem (i.e., northern) stands than in southern stands, suggesting a role for this metabolite in pine survival in the boreal forest. Attempts to develop regression models with geographic and climatic variables to explain foliar secondary metabolite levels resulted in multiple models with similar predictive capability. Since foliar secondary metabolite levels appeared to vary most between stand ecosystem types and not as much due to geographic and climatic variables, metabolic profiles appeared best matched to the stress levels within local environments. It is unknown if differences in secondary metabolite levels are the result of genetic adaptation or phenotypic plasticity, but results from this and other studies suggest that both are important. These results are interpreted in light of ongoing efforts to assist in the migration of certain populations of *P. c. latifolia* northward in an effort to counter predicted effects of climate change.

Link: http://www.ncbi.nlm.nih.gov/pubmed/21537900

530. Wang T. 2012. Projecting future distributions of ecosystem climate niches in British Columbia. Journal of Ecosystems and Management 13:1-3.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: climate change, random forest, bioclimate envelope modeling, IPCC, model projections, tree distribution, range shift, migration

Introduction: With accumulating evidence showing the ecological impacts of global climate change, scientists, land managers, and policymakers in British Columbia have become increasingly concerned about its impact on local ecosystems. One of the major concerns is the mismatch between the climate that an ecosystem is adapted to and the climate that the ecosystem will experience in the future. If such a mismatch occurs, the health and productivity of the ecosystem are likely to be compromised. Niche-based bioclimate envelope models have been widely used to project future geographic distributions of ecosystem climate niches. However, challenges arising from model accuracy as well as the uncertainties of future climates make it difficult to apply the model projections with confidence in developing adaptive strategies in natural resource management. The bioclimate envelope models are built based on the relationships between the observed presence of an ecosystem type and the climatic conditions of a given ecosystem. However, such relationships are complicated and difficult to model. For the future climates, there are over 140 climate change scenarios from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, and they vary substantially in magnitude as well as in spatial and temporal patterns. Using different climate change scenarios may lead to totally different adaptation strategies. Several individual scenarios can be averaged to create an "ensemble scenario," but specific details are lost in this process. The Centre for Forest Conservation Genetics, Department of Forest Sciences, University of British Columbia (Tongli Wang and Sally Aitken), in collaboration with the Ministry of Forests, Lands, and Natural Resources Operations (Elizabeth Campbell and Greg O'Neill), have accurately modelled the Biogeoclimatic (BGC) ecosystem zones with climate variables. The model was built using Random Forest (a machine-learning classifier) with high-resolution climate variables generated by ClimateWNA (http://www.genetics.forestry.ubc.ca/cfcg/climate-models.html) and validated with an independent dataset. Consensus projections based on multiple climate change scenarios were used to cope with the uncertainty in future climate. The major results of this study are summarized below.

Link: http://www.jem.forrex.org/index.php/jem/article/viewFile/551/476

531. Wang T, O'Neill GA, Aitken SN. 2010. **Integrating environmental and genetic effects to predict responses to tree populations to climate.** Ecological Applications 20:153-163.

Type: Journal

Geographic Area: Western Canada

Keywords: adaptation, assisted migration, British Columbia, Canada, ClimateBC, climate change, provenance test, response function, sample size, species range, transfer function

Abstract: Climate is a major environmental factor affecting the phenotype of trees and is also a critical agent of natural selection that has molded among-population genetic variation. Population response functions describe the environmental effect of planting site climates on the performance of a single population, whereas transfer functions describe among-population genetic variation molded by natural selection for climate. Although these approaches are widely used to predict the responses of trees to climate change, both have limitations. We present a novel approach that integrates both genetic and environmental effects into a single "universal response function" (URF) to better predict the influence of climate on phenotypes. Using a large lodgepole pine (*Pinus contorta* Dougl. ex Loud.) field transplant experiment composed of 140 populations planted on 62 sites to demonstrate the methodology, we show that the URF makes full use of data from provenance trials to: (1) improve predictions of climate change impacts on phenotypes; (2) reduce the size and cost of future provenance trials without compromising predictive power; (3) more fully exploit existing, less comprehensive provenance tests; (4) quantify and compare environmental and genetic effects of climate on population performance; and (5) predict the performance of any population growing in any climate. Finally, we discuss how the last attribute allows the URF to be used as a mechanistic model to predict population and species ranges for the future and to guide assisted migration of seed for reforestation, restoration, or afforestation and genetic conservation in a changing climate.

Link: http://izt.ciens.ucv.ve/ecologia/Archivos/ECO_POB%202010/ECOPO2_2010/Wang%20et%20al%202010.pdf

532. Wang J, Li D, Ren H, Yang L. 2010. **Seed supply and the regeneration potential for plantations and shrubland in southern China.** Forest Ecology and Management 259:2390-2398.

Type: Journal

Geographic Area: Heshan City, Guangdong, Southern China

Keywords: indigenous species, plant recruitment, seed bank, seed dispersal, seed limitation, succession

Abstract: Assessing the characteristics of seed supply will be vital to better understand the dynamics of forest regeneration. In this study, we surveyed the aboveground vegetation, the seed rain, the seed bank, and natural seedling emergence in four typical 24-year-old plantations (eucalyptus, mixed-native, mixed legume, and mixed-conifer) and a naturally successional shrubland in southern China. The dominant species in the understory were similar among the five plant communities. The seed rain and the seed bank were dominated by shrubs and herbs but indigenous tree species were rare. Species that were common to all five-plant communities represented a great proportion of the seeds in the seed rain and seed bank. The seed rain consisted mostly of seeds derived from the local plant community. Seed abundance was greater in the seed bank than in the seed rain, and species richness was greater in the seed bank and in the corresponding plant community than in the seed rain. Species composition similarity between the seed rain, the seed bank, and the aboveground vegetation was low, because the seed rain contained much fewer species, and the seed bank and aboveground vegetation contained many different species, respectively. These findings indicate that both the seed rain and the seed bank play important roles in providing seeds for plant recruitment in the understory, but the seed bank contributes more than the current seed rain to the diversity of recruited plants. The current plant community has little impact on the qualitative composition of the seed rain and seed bank. Based on these data, it appears that succession to the desired zonal, mature forest community is unlikely to result from seeds in the seed rain or seed bank. Lack of seed availability of desired zonal mature forest species is the main bottleneck currently limiting succession in the plantations. Reintroduction of late-successional species could facilitate the desired succession.

533. Wang T, Campbell EM, O'Neill GA, Aitken SN. 2012. **Projecting future distributions of ecosystem climate niches: uncertainties and management applications.** Forest Ecology and Management 279:128-140.

Type: Journal

Geographic Area: Western Canada

Keywords: climate change, forest management, ecosystem, climate envelope, Random Forest, consensus map

Abstract: Projecting future distributions of ecosystems or species climate niches has widely been used to assess the potential impacts of climate change. However, variability in such projections for the future periods, particularly the variability arising from uncertain future climates, remains a critical challenge for incorporating these projections into climate change adaptation strategies. We combined the use of a robust statistical modeling technique with a simple consensus approach consolidating projected outcomes for multiple climate change scenarios, and exemplify how the results could guide reforestation planning. Random Forest (RF) was used to model relationships between climate (1961–1990), described by 44 variables, and the geographic distribution of 16 major ecosystem types in British Columbia (BC), Canada. The model predicted current ecosystem distributions with high accuracy (mismatch rate = 4–16% for most ecosystem classes). It was then used to predict the distribution of ecosystem climate niches for the last decade (2001–2009) and project future distributions for 20 climate change scenarios. We found that geographic distributions of the suitable climate habitats for BC ecosystems have already shifted in 23% of BC since the 1970s. Consensus projections for future periods (2020s, 2050s, 2080s) indicated climates suitable for grasslands, dry forests, and moist continental cedar–hemlock forests would substantially expand; climate habitat for coastal rainforests would remain relatively stable; and habitat for boreal, subalpine and alpine ecosystems would decrease substantially. Using these consensus projections and data on the occurrence of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in BC ecosystems, we estimated a twofold increase in seedling demand for this frost-sensitive, commercially important timber species, suggesting managers could begin planning to expand seed inventories and seed orchard capacity to more widely plant this species on logged sites. The results of this work demonstrate the power of RF for building climate envelope models and illustrate the utility of consensus projections for incorporating uncertainty about future climate into management planning. It also emphasizes the immediate need for adapting natural resource management to a changing climate.

Link: http://bcwildfire.ca/ftp/HET/external/!publish/Web/climate/Projecting-future-distributions-of-ecosystem-climate-niches.pdf

534. Wang T, Hamann A, Yanchuk A, O'Neill GA, Aitken SN. 2006. **Use of response functions in selecting lodgepole pine populations for future climates.** Global Change Biology 12:2404-2416.

Type: Journal

Geographic Area: Western Canada

Keywords: climate change impacts, facilitated migration, forest productivity, growth response function, local adaptation, *Pinus contorta*, seed deployment

Abstract: Although growth response functions have previously been developed for lodgepole pine (*Pinus contorta* Dougl. ex Loud.) populations in British Columbia, new analyses were conducted: (1) to demonstrate the merit of a new local climate model in genecological analysis; (2) to highlight new methods for deriving response functions; and (3) to evaluate the impacts of management options for existing geographically defined seed planning units (SPUs) for reforestation. Results of this study suggest that new methods for anchoring population response functions, and a multivariate approach for incorporating climate variables into a single model, considerably improve the reliability of these functions. These functions identified a small number of populations in central areas of the species distribution with greater growth potential over a wide range of mean annual temperature (MAT). Average productivity of lodgepole pine is predicted to increase (up to 7%) if moderate warming (~2 °C MAT) occurs in the next few decades as predicted, although productivity would substantially decline in some SPUs in southern BC. Severe global warming (> 3 °C MAT) would result in either a drastic decline in productivity or local populations being extirpated in southern SPUs. New deployment strategies using the best seed sources for future reforestation may not only be able to mitigate the negative impact of global warming, but may even be able to increase productivity in some areas.

535. Webber BL, Scott JK. 2012. **Rapid global change: implications for defining natives and aliens.** Global Ecology and Biogeography 21:305-311.

Type: Journal

Geographic Area: Global

Keywords: anthropogenic disturbance, assisted migration, climate change, dispersal, exotic, introduced, invasion, landscape modification, movement ecology

Abstract: The ability to ascribe native or alien status to species in a rapidly changing world underpins diverse research fields that overlap with global change and biological invasions via biodiversity. Current definitions generally link alien status to anthropogenic dispersal events, but this can create conflicts for active management and global change adaptation strategies, such as managed relocation and restoration ecology. Here we propose a unifying approach that allows for the incorporation of rapid global change into biological invasion terminology. We introduce the concept of a projected dispersal envelope (PDE) to define the region where a species is or could be native, irrespective of human involvement. The PDE integrates biogeography and niche theory with existing invasion terminology to place a spatial and temporal context on species movements. We draw on diverse suite of topical organism movements to illustrate these concepts. Our restructured definitions allow for native species to move into or with rapidly shifting climatic regions, as well as identifying the inappropriate introduction of alien species to new areas. Moreover,

our definitions framework forms a timely and essential component of adaptation policies and responses for invasive species management and the enhancement of biodiversity in a rapidly changing world.

536. Wendelberger KS, Maschinski J. 2009. Linking geographical information systems and observational and experimental studies to determine optimal seedling microsites of an endangered plant in a subtropical urban fire-adapted ecosystem. Restoration Ecology 17:845-853.

Type: Journal

Geographic Area: Florida, USA

Keywords: *Amorpha herbacea* var. *crenulata*, fire ecology, litter depth, management, rare plant conservation, restoration

Abstract: Understanding microsite requirements is critical for restoring sustainable rare plant populations and creating meaningful management plans that will enhance native species' population viability. Natural areas bordered by urban communities have restricted size and constrained management options that confound goals of preserving biodiversity. Using geographical information systems and observational and experimental studies, we determined that current microsites required for seedling establishment within existing habitat of the federally endangered Crenulate leadplant are few and spatially restricted, resulting in little wild seedling recruitment. Experimental and wild seedlings had highest germination rates in litter layers 1–2 cm in depth and survived the longest in litter 0.5–2 cm deep. Fire suppression and aggressive native and exotic plants have accumulated litter up to 33 cm near some of the wild adult Crenulate leadplant. Only 9% of habitat occupied by this taxon at its largest population is conducive to seedling establishment. Similarly, 30% is conducive to seedling establishment in the second largest population. Fire plays a critical role in south Florida ecosystem dynamics and the restoration and preservation of its landscape and biodiversity. When fire is not possible, other management is needed. Manual litter and downed debris removal are recommended at both population sites to improve the probability of Crenulate leadplant seedling establishment and population persistence.

537. Wendelberger KS, Fellows MQN, Maschinski J. 2008. Rescue and restoration: experimental translocation of *Amorpha herbacea* Walter var. *crenulata* (Rybd.) Isley into a novel urban habitat. Restoration Ecology 16:542-552.

Type: Journal

Geographic Area: Florida, USA

Keywords: *Amorpha herbacea* var. *crenulata*, propagule type, rare plant conservation, restoration, translocation

Abstract: Though translocations of rare populations should be considered only as the last resort for species' conservation, when habitat destruction is imminent, it may be the only means to preserve a species. With over half the known, wild federally endangered Crenulate leadplant (*Amorpha herbacea* var. *crenulata*), Fabaceae, growing on unprotected land slated for development, preserving this unprotected population was critical. We rescued whole plants, cuttings, and seeds for an experimental translocation. Into a restored pine rockland, once dominated by the invasive exotic tree Brazilian pepper (*Schinus terebinthifolius*), we transplanted plants from different sources and of different sizes. Plants used were rescued from an unprotected site, seedlings, and 1-, 2-, and 7-year-old plants from Fairchild Tropical Botanic Garden's *ex situ* collection, creating a novel population in a new habitat. We also evaluated which propagule type and source had the best survival, growth, and reproduction. After 40 months, overall transplant survival was 71%. Large whole plants, rescued and nursery grown, had the best survival rates (86 and 78%), whereas cuttings had 67% survival and seedlings had only 26% survival. The restored site, once nearly a monoculture of *S. terebinthifolius*, is now dominated by 104 native plant species, including 17 naturally recruited state listed, plus the one translocated federally endangered plant species. In addition, one federally threatened snake species was observed on the site. These studies demonstrate that botanic garden collections not only play a vital role in the conservation of species' genetic diversity but also can be used as source material for habitat restoration.

538. Williams JW, Shuman BN, Webb TI, Bartlein PJ, Leduc PL. 2004. Late-quaternary vegetation dynamics in North America: scaling from taxa to biomes. Ecological Monographs 74:309-334.

Type: Journal

Geographic Area: North America

Keywords: biome maps, biome reconstruction, pollen-based, fossil pollen data, North America, vegetation history, paleoecology, plant functional types, Quaternary, vegetation dynamics

Abstract: This paper integrates recent efforts to map the distribution of biomes for the late Quaternary with the detailed evidence that plant species have responded individualistically to climate change at millennial timescales. Using a fossil-pollen data set of over 700 sites, we review late-Quaternary vegetation history in northern and eastern North America across levels of ecological organization from individual taxa to biomes, and apply the insights gained from this review to critically examine the biome maps generated from the pollen data. Higher-order features of the vegetation (e.g., plant associations, physiognomy) emerge from individualistic responses of plant taxa to climate change, and different representations of vegetation history reveal different aspects of vegetation dynamics. Vegetation distribution and composition were relatively stable during full-glacial times (21,000–17,000 yr BP) [calendar years] and during the mid- to late Holocene (7,000 – 500 yr BP), but changed rapidly during the late-glacial period and early Holocene (16,000 – 8,000 yr BP) and after 500 yr BP. Shifts in plant taxon distributions were characterized by individualistic changes in population abundances and ranges and included large east–west shifts in distribution in addition to the northward redistribution of most taxa. Modern associations such as *Fagus–Tsuga* and *Picea–Alnus–Betula* date to the early Holocene, whereas other associations common to the late-glacial period (e.g., *Picea–Cyperaceae–Fraxinus–Ostrya/Carpinus*) no longer exist. Biomes are dynamic entities that have changed in distribution, composition, and structure over time. The late-Pleistocene suite of biomes is distinct from those that grew during the Holocene. The pollen-based biome reconstructions are able to capture the major features of late-Quaternary vegetation but downplay the magnitude and variety of vegetational responses to climate change by (1) limiting apparent landcover change to ecotones, (2) masking internal variations in biome composition, and (3) obscuring the range shifts and changes in abundance among individual taxa. The compositional and structural differences between full-glacial and recent biomes of the same type are similar to or greater than the spatial heterogeneity in the composition and structure of present-day biomes. This spatial and temporal heterogeneity allows biome maps to accommodate individualistic behavior among species but masks climatically important variations in taxonomic composition as well as structural differences between modern biomes and their ancient counterparts.

Link: http://www.clas.ufl.edu/users/mbinford/GEOXXXX_Biogeography/LiteratureForLinks/Williams_et_al_2004_Late_Quaternary_veg_dynamics-scaling_taxa_to_biomes_EcolMonogr.pdf

539. Woodall CW, Nowak DJ, Liknes GC, Westfall JA. 2010. Assessing the potential for urban trees to facilitate forest tree migration in the eastern United States. Forest Ecology and Management 259:1447-1454.

Type: Journal

Geographic Area: Eastern USA

Keywords: climate change, urban, facilitated migration, assisted migration, eastern United States, forest ecosystems

Abstract: Latitudinal shifts in tree species distributions are a potential impact of climate change on forest ecosystems. It has been hypothesized that some tree species may become extirpated as climate change effects may exceed their migration ability. The goal of this study was to compare tree species compositions in northern urban areas to tree compositions in forestland areas in the eastern U.S. as an indicator of the potential for urban trees to facilitate future forest tree species migration. Results indicated that a number of tree species native to eastern U.S. forests of southern latitudes are currently present in northern urban forests. The biomass density (Mg/ha) of urban tree species is typically less than half of forestland densities with the majority of urban tree species found in nearby (< 100 km) forestland. Urban tree propagation is often facilitated by humans, whereas the necessary pollinators and agents of tree seed dispersal in forestlands may be lacking regardless of climate change. It is suggested that urban areas may serve divergent, dual roles as both a native tree seed source and refuge for a limited number of forestland tree species, but also a facilitator of non-native tree invasion.

Link: http://www.treesearch.fs.fed.us/pubs/34734

540. Zhu K, Woodall CW, Clark JS. 2012. Failure to migrate: lack of tree range expansion in response to climate change. Global Change Biology 18:1042-1052.

Type: Journal

Geographic Area: Eastern USA

Keywords: biogeography, climate change, Forest Inventory and Analysis, latitude, presence/absence, range shift, seedling, tree migration

Abstract: Tree species are expected to track warming climate by shifting their ranges to higher latitudes or elevations, but current evidence of latitudinal ranges shifts for suites of species is largely indirect. In response to global warming, off-spring of trees are predicted to have ranges extend beyond adults at leading edges and the opposite relationship at trailing edges. Large-scale forest inventory data provide an opportunity to compare present latitudes of seedlings and adult trees at their range limits. Using the USDA Forest Service's Forest Inventory and Analysis data, we directly compared seedling and tree 5th and 95th percentile latitudes for 92 species in 30 longitudinal bands for 43,334 plots across the eastern United States. We further compared these latitudes with 20th century temperature and precipitation change and functional traits, including seed size and seed spread rate. Results suggest that 58.7% of the trees species examined show the pattern expected for a population undergoing range contraction, rather than expansion, at both northern and southern boundaries. Fewer species show a pattern consistent with a northward shift (20.7%) and fewer still with a southward shift (16.3%). Only 4.3% are consistent with expansion at both range limits. When compared with the 20th century climate changes that have occurred at the range boundaries themselves, there is no consistent evidence that population spread is greatest in areas where climate has changed most; nor are patterns related to seed size or dispersal characteristics. The fact that the majority of seedling extreme latitudes are less than those for adult trees may emphasize the lack of evidence for climate-mediated migration, and should increase concerns for the risks posed by climate change.

Link: http://www.nicholas.duke.edu/people/faculty/clark/pages/publications/gcbZhu2011.pdf

Migration

General (339–380)—debates, reviews, trends, surveys, summaries

Research (381–540)—migration studies, range shifts, reintroductions

Strategies (541–580)—adaptation options, frameworks, decision support

Resources (581–582)—tools, websites, software

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

541. Bergelson J, Roux F. 2010. Towards identifying genes underlying ecologically relevant traits in *Arabidopsis thaliana.* Nature Reviews Genetics 11:867-879.

Type: Journal

Geographic Area: France, Europe

Compilers' Keywords: biological adaptation, *Arabidopsis thaliana*, ecosystem, environment, plant genes, genetic variation, genome-wide association study, review

Abstract: A major challenge in evolutionary biology and plant breeding is to identify the genetic basis of complex quantitative traits, including those that contribute to adaptive variation. Here we review the development of new methods and resources to fine-map intraspecific genetic variation that underlies natural phenotypic variation in plants. In particular, the analysis of 107 quantitative traits reported in the first genome-wide association mapping study in *Arabidopsis thaliana* sets the stage for an exciting time in our understanding of plant adaptation. We also argue for the need to place phenotype-genotype association studies in an ecological context if one is to predict the evolutionary trajectories of plant species.

Link: http://www.ncbi.nlm.nih.gov/pubmed/21085205

542. Booth TH, Williams KJ, Belbin L. 2012. Developing biodiverse plantings suitable for changing climatic conditions 2: using the Atlas of Living Australia. Ecological Management & Restoration 13:274-281.

Type: Journal

Geographic Area: Australia

Keywords: Atlas of Living Australia, biodiversity, climate change, revegetation, maxent models, species distribution models

Abstract: There has been an increasing investment of taxpayer dollars in revegetation in Australia over the past 20 years, at both federal and state levels. The largest of these, the Australian Government's Biodiversity Fund, will invest A$946 million to revegetate, rehabilitate and restore landscapes to store carbon, enhance biodiversity and build environmental resilience under climate change. The universal challenge for restoration practitioners working within these programmes is species selection for both current and future environmental conditions at a given site. For policy makers, the challenge is to provide guidelines and tools for this process. The first paper in this series of two papers looked at scientific methods that could provide underpinning knowledge to improve the assessment of species vulnerability to climatic and atmospheric change. In this paper, the publically accessible Atlas of Living Australia is used to demonstrate how revegetation project leaders can assess whether the species and provenances used in their revegetation projects are likely to be suitable for changing environmental conditions. While using the Atlas can assist current selections, ways in which more reliable selections for changing climatic conditions could be made are also outlined.

543. Chauvenet ALM, Ewen JG, Armstrong DP, Blackburn TM, Pettorelli N, Gompper M. 2012. Maximizing the success of assisted colonizations. Animal Conservation 16:161-169.

Type: Journal

Geographic Area: Global

Keywords: translocation, climate-change adaptation, population dynamics, species distribution modelling, assisted migration, managed relocation

Abstract: Climate change is causing spatio-temporal shifts in environmental conditions, and species that are not able to track suitable environments may face increased risks of extinction. Assisted colonization, a form of translocation, has been proposed as a tool to help species survive the impacts of climate change. Unfortunately, translocations generally have a low success rate, a well-documented fact that is not considered in most of the recent literature on assisted colonization. One of the main impediments of translocation success is inadequate planning. In this review, we argue that by using well-known analytical tools such as species distribution models and population dynamics modelling we can maximize the success of assisted colonization. In particular, we present guidelines as to which questions should be investigated when planning assisted colonization and suggest methods for answering them. Finally, we also highlight further implementation and research issues that remain to be solved for assisted colonizations to be efficient climate change adaptation tools.

Link: http://www.researchgate.net/publication/233895747_Maximizing_the_success_of_assisted_colonizations/file/79e4150d036521d74c.pdf

544. Frascaria-Lacoste N, Fernández-Manjarrés J. 2012. Assisted colonization of foundation species: lack of consideration of the extended phenotype concept-response to Kreyling et al. (2011). Restoration Ecology 20:296-298.

Type: Journal

Geographic Area: Global

Keywords: assisted migration, ecosystem engineers, forest tree, genetic diversity, managed translocation, restoration actions

Abstract: Assisted colonization (AC), or the intentional translocation of populations to compensate for risks related to climate change, is receiving increasing attention. It has been recently suggested by Kreyling et al. (2011) that rather than relocating endangered species, a focus should be placed on local adaptations of foundation or keystone species, and that these local ecotypes should be moved within their own range. Hence, this type of relocation could be applied with minimal risk in many restoration efforts. We think that caution is needed when considering the translocation of these foundation species, even within their range. Many recent studies have shown that foundation species can influence community structure and ecosystem processes through heritable traits, which suggests a genetic basis for ecosystem services. Thus, the translocation of different genotypes of foundation species might lead to unexpected results of colonization and might not be as "predictable" as Kreyling et al. have argued. Here, in our response, we stress how AC of foundation species can have important evolutionary consequences that might be impossible to reverse. We propose, whenever possible, 1) to favor population mixes of the foundation species to minimize the potential negative effects of specific genotypes; and 2) to collect from adjacent populations along ecological clines of the foundation species to mimic natural processes of migration under climate change.

Link: http://www.researchgate.net/publication/233207938_Assisted_Colonization_of_Foundation_Species_Lack_of_Consideration_of_the_Extended_Phenotype_ConceptResponse_to_Kreyling_et_al._(2011)/file/9fcfd509c2919ebb6f.pdf

545. Garcia D, Zamora R, Amico GC. 2010. Birds as suppliers of seed dispersal in temperate ecosystems: conservation guidelines from real-world landscapes. Conservation Biology 24:1070-1079.

Type: Journal

Geographic Area: Global

Keywords: anthropogenic landscapes, Cantabrian forest, ecosystem services, fleshy-fruited plants, frugivorous birds, Mediterranean shrubland, mobile links, Patagonian forest, seed dispersal

Abstract: Seed dispersal by animals is considered a pivotal ecosystem function that drives plant-community dynamics in natural habitats and vegetation recovery in human-altered landscapes. Nevertheless, there is a lack of suitable ecological knowledge to develop basic conservation and management guidelines for this ecosystem service. Essential questions, such as how well the abundance of frugivorous animals predicts seeding function in different ecosystems and how anthropogenic landscape heterogeneity conditions the role of dispersers, remain poorly answered. In three temperate ecosystems, we studied seed dispersal by frugivorous birds in landscape mosaics shaped by human disturbance. By applying a standardized design across systems, we related the frequency of occurrence of bird-dispersed seeds throughout the landscape to the abundance of birds, the habitat features, and the abundance of fleshy fruits. Abundance of frugivorous birds in itself predicted the occurrence of dispersed seeds throughout the landscape in all ecosystems studied. Even those landscape patches impoverished due to anthropogenic disturbance received some dispersed seeds when visited intensively by birds. Nonetheless, human-caused landscape degradation largely affected seed-deposition patterns by decreasing cover of woody vegetation or availability of fruit resources that attracted birds and promoted seed dispersal. The relative role of woody cover and fruit availability in seed dispersal by birds differed among ecosystems. Our results suggest that to manage seed dispersal for temperate ecosystem preservation or restoration one should consider abundance of frugivorous birds as a surrogate of landscape-scale seed dispersal and an indicator of patch quality for the dispersal function; woody cover and fruit resource availability as key landscape features that drive seedfall patterns; and birds as mobile links that connect landscape patches of different degrees of degradation and habitat quality via seed deposition.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20136873

546. Gray LK, Hamann A. 2011. **Strategies for reforestation under uncertain future climates: guidelines for Alberta, Canada.** PLoS ONE 6:1-9.

Type: Journal

Geographic Area: Alberta, Canada

Compilers' Keywords: climate change, commercial forestry, assisted migration, projections, distribution

Abstract: Commercial forestry programs normally use locally collected seed for reforestation under the assumption that tree populations are optimally adapted to local environments. However, in western Canada this assumption is no longer valid because of climate trends that have occurred over the last several decades. The objective of this study is to show how we can arrive at reforestation recommendations with alternative species and genotypes that are viable under a majority of climate change scenarios. In a case study for commercially important tree species of Alberta, we use an ecosystem based bioclimate envelope modeling approach for western North America to project habitat for locally adapted populations of tree species using multi-model climate projections for the 2020s, 2050s and 2080s. We find that genotypes of species that are adapted to drier climatic conditions will be the preferred planting stock over much of the boreal forest that is commercially managed. Interestingly, no alternative species that are currently not present in Alberta can be recommended with any confidence. Finally, we observe large uncertainties in projections of suitable habitat that make reforestation planning beyond the 2050s difficult for most species. More than 50,000 hectares of forests are commercially planted every year in Alberta. Choosing alternative planting stock, suitable for expected future climates, could therefore offer an effective climate change adaptation strategy at little additional cost. Habitat projections for locally adapted tree populations under observed climate change conform well to projections for the 2020s, which suggests that it is a safe strategy to change current reforestation practices and adapt to new climatic realities through assisted migration prescriptions.

Link: http://ualberta.ca/~ahamann/publications/pdfs/Gray_Hamann_2011.pdf

547. Hannah L, Midgley GF, Andelman S, Araujo M, Hughes G, Martinez-Meyer E, Pearson R, Williams P. 2007. **Protected area needs in a changing climate.** Frontiers in Ecology and the Environment 5:131-138.

Type: Journal

Geographic Area: Global

Compilers' Keywords: range shifts, conservation, species distribution modeling, biodiversity

Abstract: Range shifts due to climate change may cause species to move out of protected areas. Climate change could therefore result in species range dynamics that reduce the relevance of current fixed protected areas in future conservation strategies. Here, we apply species distribution modeling and conservation planning tools in three regions (Mexico, the Cape Floristic Region of South Africa, and Western Europe) to examine the need for additional protected areas in light of anticipated species range shifts caused by climate change. We set species representation targets and assessed the area required to meet those targets in the present and in the future, under a moderate climate change scenario. Our findings indicate that protected areas can be an important conservation strategy in such a scenario, and that early action may be both more effective and less costly than inaction or delayed action. According to our projections, costs may vary among regions and none of the three areas studied will fully meet all conservation targets, even under a moderate climate change scenario. This suggests that limiting climate change is an essential complement to adding protected areas for conservation of biodiversity.

Link: http://courses.washington.edu/cfr550/pdfs/Hannah%20et%20al%202007.pdf

548. Havens K, Vitt P, Still S, Kramer AT, Fant JB, Schatz K. 2015. **Seed sourcing for restoration in an era of climate change.** Natural Areas Journal 35:122-133.

Type: Journal

Geographic Area: USA

Keywords: assisted migration, climate change, provenance, restoration, seed sourcing

Abstract: Proper sourcing of seed for ecological restoration has never been straightforward, and it is becoming even more challenging and complex as the climate changes. For decades, restoration practitioners have subscribed to the "local is best" tenet, even if the definition of "local" was often widely divergent between projects. However, given our increasing ability to characterize habitats, and rapid climate change, we can no longer assume that locally sourced seeds are always the best or even an appropriate option. We discuss how plants are responding to changing climates through plasticity, adaptation, and migration, and how this may influence seed sourcing decisions. We recommend focusing on developing adequate supplies of "workhorse" species, undertaking more focused collections in both "bad" years and "bad" sites to maximize the potential to be able to adapt to extreme conditions as well as overall genetic diversity, and increasing seed storage capacity to ensure we have seed available as we continue to conduct research to determine how best to deploy it in a changing climate.

Link: http://www.bioone.org/doi/abs/10.3375/043.035.0116

549. Hoegh-Guldberg O, Hughes L, McIntyre S, Lindenmayer DB, Parmesan C, Possingham HP, Thomas CD. 2008. Assisted colonization and rapid climate change. Science 321:345-346.

Type: Journal

Geographic Area: Global

Compilers' Keywords: conservation, extinction risk, decision framework, translocation, assisted migration, policy forum, review, tool

Synopsis (4th paragraph): We developed a decision framework that can be used to outline potential actions under a suite of possible future climate scenarios. Determining whether a species faces significant risk of decline or extinction under climate change requires an in-depth knowledge of the underlying species' biology as well as the biological, physical, and chemical changes occurring within its environment. The risk of extinction for many widespread, generalist species found across a range of habitats may be low. In this case, the option of moving such species outside their present ranges would be dismissed. Some species will also disperse sufficiently to maintain large populations and range sizes (for example, highly dispersive insects or birds with generalist life histories) and others may adapt *in situ*. Where species are perceived as being at moderate risk from climate change, improvements in connectivity to actual or potential habitat at higher latitudes and altitudes may be sufficient.

Link: http://www.law.arizona.edu/depts/ele/AdaptationConference/PDFs/ParmesanAssistedColonization.pdf

550. Johnson R, Boyce S, Brandt L, Erickson VJ, Iverson LR, Kujawa G, Stritch L, Tkacz B. 2013. Policy and strategy considerations for assisted migration on USDA Forest Service Lands. In: Browing J, Palacios P, editors. Proceedings of the 60th Annual Western International Forest Disease Work Conference. Tahoe City (CA): USDA Forest Service. p 35-41.

Type: Conference Paper

Geographic Area: USA

Compilers' Keywords: policy, forest management, species rescue, ecosystem

Introduction (5th paragraph): Actions associated with assisted migration cover a wide variety of movements for a number of different purposes, ranging from moving a seed source to another location within the species range in order to maintain ecosystem productivity, to moving a suite of species, or a community, outside of its historical range to prevent extinction. This paper examines two major categories of assisted migration that primarily impact management decisions on National Forest System (NFS) lands, assisted migration to maintain ecosystem services (Ecosystem AM) and species rescue assisted migration (Species Rescue AM); these definitions closely follow what is presented by Pedlar et al. (2012) for forest trees. These two categories differ in the types of species managed, management objectives, relative feasibility, and associated risks. Most discussions in the literature focus on species rescue and little on Ecosystem AM.

Link: http://www.treesearch.fs.fed.us/pubs/45424

551. Jones TA, Monaco TA. 2009. A role for assisted evolution in designing native plant materials for domesticated landscapes. Frontiers in Ecology and the Environment 7:541-547.

Type: Journal

Geographic Area: Western USA

Compilers' Keywords: restoration, assisted migration, genetic patterns, function, concepts, native plant material development

Abstract: Developers of native plant propagation materials for wildland restoration may emphasize naturally occurring genetic patterns or, in contrast, the material's empirical performance in comparative field trials. We contend that both approaches have value and need not be mutually exclusive. Anthropogenic influences have pushed many ecosystems across ecological thresholds, to less desirable states, so that actively managing for "domesticated nature"—nature as modified, either intentionally or inadvertently, by humans—is more realistic and more likely to succeed than recreating the original ecosystem. Furthermore, when domesticated nature is the most reasonable objective, empirical performance, together with geographical origin, are plausible criteria for choosing restoration plant material. For altered ecosystems, we suggest that evolution should be assisted by the inclusion of plants that (1) reflect general historical evolutionary patterns, (2) are particularly suited to the modified environment, (3) are able to adapt to contemporary selection pressures, and (4) contribute to the restoration of ecosystem structure and function.

Link: http://sfc.smallfarmcentral.com/dynamic_content/uploadfiles/152/jones-a%20role%20for%20assisted%20evolution.pdf

552. Klenk NL. 2015. The development of assisted migration policy in Canada: an analysis of the politics of composing future forests. Land Use Policy 44:101-109.

Type: Journal

Geographic Area: Canada

Keywords: discursive institutionalism, forestry, climate change, policy development, actor-network theory, agonistic pluralism

Abstract: One could argue that the development of western larch assisted migration (AM) policy in British Columbia was the result of a "policy window" largely caused by factors external to the actions of policy actors: western larch plantations in northern BC indicate that the species thrives even if planted far beyond its current range, thus representing an economic motive for AM; climate change projections and the mountain pine beetle epidemic represented a crisis situation that facilitated the deployment of a new and controversial policy option, the assisted migration of western larch, in forest policy in British Columbia. However, this "policy window" explanation disregard the relationship between the performative meaning of AM in its social and ecological context, and masks the actual politics of the discursive practices enlisting particular actor-networks in the western larch AM policy process. My analysis suggests that the western larch AM policy emerged from the relationship of specific policy actors with specific non-humans actors—including exotic and invasive species. Yet, aware of potential political risks of deploying this controversial practice, policy actors in British Columbia carefully circumscribed the purpose of western larch AM, distancing the western larch AM policy from exotic and invasive species. Additionally, western larch AM was framed as a natural extension of current tree regeneration standards and best practices in BC—thus seemingly representing "business as usual", rather than a major reassemblage of the actor-networks structuring forest policy in BC. Comparing western larch policy discourses to policy discourses on AM in other provinces suggest that the differences in what actor networks are enlisted largely explains why no other province in Canada has yet to develop an assisted migration policy. The policy implications of this study are that in the composition of Canada's future forests we should keep exotic and invasive species present in view.

Link: http://www.sciencedirect.com/science/article/pii/S0264837714002749

553. Klenk NL, Larson BMH. 2015. The assisted migration of western larch in British Columbia: a signal of institutional change in forestry in Canada? Global Environmental Change 31:20-27.

Type: Journal

Geographic Area: Western Canada, British Columbia

Keywords: forestry, climate change, policy development, discourse analysis, new institutionalism, forest genetics conservation

Abstract: The idea of moving species beyond their historic range, known as assisted migration, challenges some of the conservation ideas and norms guiding sustainable forest management in North America: relying on historical benchmarks, mimicking natural disturbances, and reproducing current ecological species assemblages. In this context, our paper focuses on how an assisted migration policy for western larch has been developed in British Columbia, Canada, specifically examining institutional change at three different levels of policy ideas and in discourses oriented internally or externally in the policy process. Based on 46 interviews with policy actors across Canada, our results suggest that the deployment of the first assisted migration policy in Canada successfully avoided the controversy surrounding the idea in the scientific community by changing the scientific discourse associated with best forest management practices. The shift from an ecological discourse to a genetics discourse over forest policy in British Columbia signals what we might expect in future forest adaptation policy development in Canada.

Link: http://www.sciencedirect.com/science/article/pii/S0959378014002003

554. Koralewski TE, Wang H-H, Grant WE, Byram TD. 2015. Plants on the move: assisted migration of forest trees in the face of climate change. Forest Ecology and Management 344:30-37.

Type: Journal

Geographic Area: Southeastern USA

Keywords: assisted migration, Categorical Universal Response Function, climate change, *Pinus taeda*, seed deployment, Universal Response Function

Abstract: Climate change is impacting distributions of both fauna and flora, including many crops. In order to ensure the health and vigor of the species we depend upon for food and fiber, assisted migration strategies may need to be implemented. This is especially true for long-lived forest trees. Multinomial logit regression was used to develop a Categorical Universal Response Function (CURF) to delineate deployment zones for loblolly pine (*Pinus taeda* L.) using 15-year measurements from the Western Gulf Forest Tree Improvement Program (WGFTIP) Geographic Seed Source Study (GSSS). The CURF uses performance categories for the response variable, and the model assigns the probabilities with which the performance for a given seed source will fall into these various categories. First and second powers of minimum temperature of the coldest month, summer precipitation, and variation measures of these two metrics at both the seed source site of origin and the test location were used as independent variables. Planted tree volume, accounting for both survival and growth,

was used as the response variable. Model performance was good, with the AUC score ranging from 0.785 to 0.808, depending on (1) whether or not the variable interactions were included and (2) the variable selection criterion used (AIC or BIC). Resulting models were then applied to historic weather patterns to illustrate inferred deployment zones for three seed sources. The projected performance generally agreed with the current consensus on loblolly pine seed movement guidelines. The models developed here can be readily implemented in a Decision Support System as they (1) suggest sets of adapted loblolly pine families from which foresters can choose based on local knowledge, (2) can be easily expanded to include other variables, and (3) can be applied to outputs from projected climate scenarios to extrapolate into the future.

Link: http://www.sciencedirect.com/science/article/pii/S0378112715000729

555. Kostyack J, Lawler JJ, Goble DD, Olden JD, Scott JM. 2011. **Beyond reserves and corridors: policy solutions to facilitate the movement of plants and animals in a changing climate.** BioScience 61:713-719.

Type: Journal

Geographic Area: USA

Keywords: climate change, adaptation, species movement, policy

Abstract: As the Earth's climate changes, many species will have to move across human-dominated landscapes to track suitable climates and changing ecosystems. Given the magnitude of projected future climate change, expanding and connecting reserve networks—two of the most commonly recommended adaptation strategies for protecting biodiversity in a changing climate—will be necessary but insufficient for preventing climate-induced extinctions. In the present , we explore additional policy options that could be implemented to facilitate species movements in a changing climate. We discuss both existing and new policies that have the potential to increase landscape permeability, protect species on the move, and physically move species to address climate change.

556. Kreyling J, Bittner T, Jaeschke A, Jentsch A, Jonas Steinbauer M, Thiel D, Beierkuhnlein C. 2011. **Assisted colonization: a question of focal units and recipient localities.** Restoration Ecology 19:433-440.

Type: Journal

Geographic Area: Global

Keywords: adaptation strategy, assisted migration, core species, ecosystem engineers, managed relocation, managed translocation, species conservation

Abstract: Assisted colonization as an adaptation strategy to conserve or restore biodiversity in the face of climate change deservedly evokes controversy. Assisted colonization is perceived by some as a last option for conserving endangered species and by others as a risky and unwise management effort due to current gaps of knowledge. Based on the pros and cons of the recent debate, we show that the current discussion mainly focuses on the assisted colonization of rare and endangered species beyond their natural range of distribution. We suggest that a more useful approach for the conservation of endangered species could occur by focusing on the relevant foundation or keystone species, which ensure ecosystem integrity for a multitude of dependent species by governing the habitat structure and microclimate of the site. Examples of foundation species include dominant tree species in forests or dominant corals in coral reefs. For a given conservation or restoration need (e.g. conservation of rare species), we recommend the assisted colonization of pre-adapted ecotypes of the relevant foundation species from climates similar to future expectations for the target site. This approach could lead to climate safe habitats for endangered species with minimal adverse effects on recipient ecosystems.

Link: http://www.researchgate.net/publication/229953735_Assisted_Colonization_A_Question_of_Focal_Units_and_Recipient_Localities/file/e0b4951a5c24071def.pdf

557. Krosby M, Tewksbury J, Haddad NM, Hoekstra J. 2010. **Ecological connectivity for a changing climate.** Conservation Biology 24:1686-1689.

Type: Journal

Geographic Area: Global

Compilers' Keywords: biodiversity, climate change, conservation, ecosystem, migration,

Introduction (1st paragraph): A frequently proposed strategy to reduce the negative effects of climate change on biological diversity is to increase ecological connectivity the flow of organisms and ecological processes across landscapes. Traditionally, conservation professionals have sought to maintain or restore connectivity to ensure gene flow among isolated populations and promote recolonization of vacant patches. Given the rapid emergence of connectivity enhancement as a climate-change adaptation strategy, we considered whether connectivity should be emphasized in conservation strategies as global or regional temperatures increase and what principles for connectivity enhancement could be applied to maximize the usefulness of the strategy.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20961330

558. Leites LP, Rehfeldt GE, Robinson AP, Crookston NL, Jaquish B. 2012. **Possibilities and limitations of using historic provenance tests to infer forest species growth responses to climate change.** Natural Resource Modeling 25:409-433.

Type: Journal

Geographic Area: North America

Keywords: climate-change response functions, provenance tests, genotype by environment interaction, provenance transfer functions, *Larix occidentalis* Nutt, linear mixed-effects models

Abstract: Under projected changes in global climate, the growth and survival of existing forests will depend on their ability to adjust physiologically in response to environmental change. Quantifying their capacity to adjust and whether the response is species- or population-specific is important to guide forest management strategies. New analyses of historic provenance tests data are yielding relevant insights about these responses. Yet, differences between the objectives used to design the experiments and current objectives impose limitations to what can be learned from them. Our objectives are (i) to discuss the possibilities and limitations of using such data to quantify growth responses to changes in climate and (ii) to present a modeling approach that creates a species- and population-specific model. We illustrate the modeling approach for *Larix occidentalis* Nutt. We conclude that the reanalysis of historic provenance tests data can lead to the identification of species that have population-specific growth responses to changes in climate, provide estimates of optimum transfer distance for populations and species, and provide estimates of growth changes under different climate change scenarios. Using mixed-effects modeling techniques is a sound statistical approach to overcome some of the limitations of the data.

Link: http://www.treesearch.fs.fed.us/pubs/41324

559. Loss SR, Terwilliger LA, Peterson AC. 2011.

Assisted colonization: integrating conservation strategies in the face of climate change. Biological Conservation 144:92-100.

Type: Journal

Geographic Area: Global

Keywords: assisted colonization, assisted migration, managed relocation, climate change, landscape connectivity, conservation genetics

Abstract: Global climate change poses an immense challenge for conservation biologists seeking to mitigate impacts to species and ecosystems. Species persistence will depend on geographic range shifts or adaptation in response to warming patterns as novel climates and community assemblages arise. Assisted colonization has been proposed as a method for addressing these challenges. This technique, which consists of transporting species to a new range that is predicted to be favorable for persistence under future climate scenarios, has become the subject of controversy and discussion in the conservation community due to its highly manipulative nature, questions about widespread feasibility, and uncertainty associated with the likelihood of translocated species becoming invasive. We reviewed the discussion and criticism associated with assisted colonization and sought to identify other conservation techniques that also display potential to promote the colonization and adaptation of species in response to climate change. We propose an integrated conservation strategy that includes management for habitat connectivity, conservation genetics, and when necessary, assisted colonization of species that are still unable to shift their ranges even given implementation of the above standard conservation approaches. We argue that this integrated approach will facilitate persistence for a larger proportion of species than is possible by solely using assisted colonization. Furthermore, a multi-faceted approach will likely reduce the uncertainty of conservation outcomes and will become increasingly necessary for conservation of biodiversity in a changing climate.

560. Lunt ID, Byrne M, Hellmann JJ, Mitchell NJ, Garnett ST, Hayward MW, Martin TG, McDonald-Maddden E, Williams SE, Zander KK. 2013.

Using assisted colonization to conserve biodiversity and restore ecosystem function under climate change. Biological Conservation 157:172-177.

Type: Journal

Geographic Area: Global

Keywords: ecological replacement, managed relocation, climate change adaptation, ecosystem management, restoration, translocation

Abstract: Assisted colonization has received considerable attention recently, and the risks and benefits of introducing taxa to sites beyond their historical range have been vigorously debated. The debate has primarily focused on using assisted colonization to enhance the persistence of taxa that would otherwise be stranded in unsuitable habitat as a consequence of anthropogenic climate change and habitat fragmentation. However, a complementary motivation for assisted colonization could be to relocate taxa to restore declining ecosystem processes that support biodiversity in recipient sites. We compare the benefits and risks of species introductions motivated by either goal, which we respectively term ‘push’ versus ‘pull’ strategies for introductions to preserve single species or for restoration of ecological processes. We highlight that, by focusing on push and neglecting pull options, ecologists have greatly under estimated potential benefits and risks that may result from assisted colonization. Assisted colonization may receive higher priority in climate change adaptation strategies if relocated taxa perform valuable ecological functions (pull) rather than have little collateral benefit (push). Potential roles include enhancing resistance to invasion by undesired species, supporting co-dependent species, performing keystone functions, providing temporally critical resources, replacing taxa of low ecological redundancy, and avoiding time lags in the provisioning of desired functions.

561. Maschinski J, Ross MS, Liu H, O'Brien J, Wettberg EJ, Haskins KE. 2011. Sinking ships: conservation options for endemic taxa threatened by sea level rise. Climatic Change 107:147-167.

Type: Journal

Geographic Area: Florida Keys, USA

Compilers' Keywords: climate change, endangered species, extinction

Abstract: Low-elevation islands face threats from sea level rise (SLR) and increased storm intensity. Evidence of endangered species' population declines and shifts in vegetation communities are already underway in the Florida Keys. SLR predictions indicate large areas of these habitats may be eliminated in the next century. Using the Florida Keys as a model system, we present a process for evaluating conservation options for rare and endemic taxa. Considering species characteristics and habitat, we assess central issues that influence conservation options. We contrast traditional and controversial options for two animal and two plant species giving special emphasis to perceptions of ecological risk and safety from SLR and suggest courses of action. Multiple strategies will be required to spread extinction risk and will be effective for different time periods. Global climate change presents an uncertain, perhaps no-analog future that will challenge land managers and practitioners to re-evaluate equilibrium-state-conceived laws and policies not only for these taxa, but for many facing similar threats. To embrace conservation in a changing world will require a new dialogue that includes controversial ideas, a review of existing laws and policies, and preparation for the oncoming change.

Link: http://softel.fiu.edu/projects/Peer%20Reviewed%20Journal%20Articles/1307-Maschinski.pdf

562. Matyas C. 1994. Modeling climate change effects with provenance test data. Tree Physiology 17:797-804.

Type: Journal

Geographic Area: North America

Keywords: adaptation, distribution, ecological distance, growth, species survival, successional change

Summary: Provenance tests of forest trees, which were originally intended to identify suitable seed sources for planting at different locations, provide valuable data for assessing the response of populations to environmental change. Environmental differences between the location of origin and the planting (test) site have been calculated by principal component analysis and termed ecological distance. Based on ecological distance values, the growth response of tree populations can be modeled as a function of the test site macroclimate. These models can then be used to predict the effects of climatic change on growth and survival. The growth response model predicts that increasing annual mean temperatures will result in accelerated growth if precipitation is sufficient, but only within the limits characteristic of the species. At the southern limits of distribution, growth and competitive ability of the species will decline, leading to successional changes.

Link: http://treephys.oxfordjournals.org/content/14/7-8-9/797.full.pdf

563. Matyas C. 1996. Climatic adaptation of trees: rediscovering provenance tests. Euphytica 92:45-54.

Type: Journal

Geographic Area: Global

Keywords: adaptation, climate change, provenance research, phenotypic stability, natural selection, genetic diversity

Summary: Common garden testing of populations of different origin started with forest trees more than two hundred years ago. Since then, so-called provenance tests have been established with most commercially important species. Beyond the strictly silvicultural goals, the tests offer excellent opportunities to study intraspecific genetic variation patterns and represent probably the most powerful available tool for testing hypotheses of climatic adaptation in trees. Analysis of adaptive traits (mostly juvenile height growth) in provenance experiments indicate the existence of very effective constraints on adaptedness. The performance of populations plotted against an ecological-climatic factor exhibits a characteristic pattern and can be described by response functions. The population average of a fitness related trait for a locally adapted population is often significantly lower than that of populations from other environments; usually the ones from milder climate perform better. The phenomenon is interpreted as adaptation lag. Suboptimal adaptation is compensated by a high level of genetic diversity. Molecular genetic studies confirm the high level of allelic and individual genetic diversity in forest trees. A consequence of individual homeostasis, phenotypic stability of populations is usually also high; the sensitivity to environmental changes is generally moderate. Phenotypically stable populations are valuable not only because of a wider range of potential cultivation but specifically because of a greater ability to adjust to unexpected changes. This trait should receive more attention in the future for obvious reasons. The maintenance of a high within-population genetic variance is favored by the genetic system of the investigated species (effective gene flow, outbreeding, high genetic load, etc.). Random events and long-lasting biotic interactions are further effects impairing the efficiency of natural selection. In view of expected climate instability, genetic adaptability of forest trees causes serious concern due to their long lifespan compared to the rapidity of expected changes in environmental conditions. The potential of provenance tests to interpret long-term adaptation processes should be utilized to analyze, model and predict response of trees to climate change. Although seldom appreciated, provenance research might be among the most important contributions of forestry to biological sciences.

564. McIntyre S. 2011. Ecological and anthropomorphic factors permitting low-risk assisted colonization in temperate grassy woodlands. Biological Conservation 144:1781-1789.

Type: Journal

Geographic Area: Australia

Keywords: grasslands, eucalypt woodlands, plant conservation, translocation, managed relocation

Abstract: There is a risk that the potential of assisted colonization to contribute to biodiversity conservation will be lost in the storm of controversy that currently surrounds it. This paper describes a low-risk scenario for assisted colonization using plants. Using an analysis of temperature grassy woodlands from Australia, relevant ecosystem attributes are identified which make assisted colonization a sensible strategy, and that may characterize other favorable situations globally. The contributing elements include: a biota adapted to resource to resource conservationism, a naturally connected landscape with component species having wide distributions over a large climatic gradient, current land use unrelated to endogenous disturbance regimes resulting in extensive replacement and modification of the ecosystem overs its entire range. Intensive agriculture can create a highly-disturbed and nutrient-enriched landscape matrix, which effectively fragments the species assemblage. Relocation of plant species within and close to their range is not going to create an invasive situation in these landscapes. Candidates for assisted colonization are forbs and interstitial grasses that have persisted over much of their range, but which have declined within that range due to land use impacts. The suggested priority receiving sites would be those with a moderate level of past modifications, now being managed for conservation and with low nutrient status. The proposed use of assisted colonization is a conservative strategy that will build on current conservation practice and greatly improve the prospects for native plants where climate change is superimposed on a fragmented plant community.

565. Moat J, Smith PP. 2003. Applications of geographical information systems in seed conservation. Chapter 4. In: Smith RD, Dickie JB, Linington SL, Pritchard HW, Probert RJ, editors. Seed Conservation: Turning Science into Practice. London, United Kingdom: Royal Botanic Gardens. p 79-88.

Type: Book Section

Geographic Area: Global

Compilers' Keywords: GIS, remote sensing, seed collection, reintroduction

Summary: The use of Geographic Information Systems (GIS) in seed conservation has enormous potential. This paper examines the use of spatial technology (both GIS and remote sensing) in the context of seed conservation planning. It explores three major areas to which GIS technology can be applied, with practical and visual examples. These three applications are: targeting species and habitats for seed collecting, facilitation of collecting and of reintroduction of species. The current limitations to the accessibility of this technology for seed conservation are discussed.

Link: http://www.kew.org/ucm/groups/public/documents/document/ppcont_013766.pdf

566. O'Neill GA. 2013. Seed transfer 2.0: assisting assisted migration. In: Assisted Migration: A Primer for Reforestation and Restoration Decision Makers; Portland, OR. 51 p.

Type: Presentation

Geographic Area: North America

Compilers' Keywords: Assisted Migration Adaptation Trial, climate change, forest management, seed transfer guidelines, seed transfer zones, genecology, provenance tests, seed transfer distance

Abstract: A growing body of provenance test data highlights the importance of seed source selection in reforestation and also suggests that climate change will render many tree populations substantially maladapted in the near future. Maladaptation may result in significant changes in health, productivity and distributions of foundation tree species, with attendant impacts on ecosystem function, carbon sequestration and the forest industry. Assisting the natural migration of seed sources to ensure forests are adapted to future climates is emerging as a key strategy to mitigate anticipated maladaptation in forest trees. These observations have placed new demands on seed source selection systems in forestry, while the availability of geographic information systems, fine scale climate models, a new era of provenance tests, and new analytical techniques have revolutionized opportunities for the development of new seed transfer systems. This presentation examines opportunities for creating new seed transfer systems and for implementing assisted migration, and discusses the design of seed transfer systems from the perspective of their structure, critical seed transfer distance calculation, and zone delineation methods, and ability to accommodate assisted migration. A hybrid fixed/focal point seed transfer system and methods to integrate assisted migration into existing fixed and focal point seed transfer systems will be proposed.

Link: http://www.rngr.net/resources/assisted-migration

567. O'Neill GA, Ukrainetz NK, Carlson M, Cartwright C, Jaquish B, King J, Krakowski J, Russell JH, Stoehr MU, Xie CY, Yanchuk A. 2008. Assisted migration to address climate change in British Columbia: recommendations for interim seed transfer standards. Victoria, British Columbia, Canada: B.C. Ministry of Forest and Range, Research Branch. 048. 38 p.

Type: Government Document

Geographic Area: Western Canada

Compilers' Keywords: seed transfer guideline, forest management, policies

Summary: Climate change is expected to result in trees in most regions of British Columbia becoming increasingly maladapted to the climates in which they are planted. Consequently, planting seedlings adapted to future climates (assisted migration) is recognized as a key strategy to address climate change, as it will help maintain healthy, productive forests, and ensure capture of gains obtained from decades of selective breeding. To examine opportunities to incorporate assisted migration into British Columbia's seed transfer system, the feasibility of increasing the upper elevational transfer limit of British Columbia's Class A and Class B seed was assessed by calculating the climatic transfer distance associated with elevational transfers. A rationale was developed for quantifying an appropriate climatic distance and range to migrate seed, and was used to evaluate elevational transfer increases of 100 and 200 m. Results indicate that of the 30 Class A Seed Planning Units (SPUs) examined, eight should retain their current upper elevation limits, one should have their upper elevation limit increased by 100 m, and the remainder should have their upper elevation limits increased by 200 m for eight species, by 100 m for two species, and should remain unchanged for three species. Specific recommendations are provided in Tables 2 and 3. Deployment of orchard seed in the lowest 200 m of the western white pine—Maritime and interior spruce—East Kootenay SPUs is discouraged, as is transfer of Class B seed of amabilis fir and western hemlock more than 200 m downward and western redcedar more than 300 m downward.

Link: http://www.for.gov.bc.ca/hfd/pubs/Docs/Tr/Tr048.pdf

568. Pedlar J, McKenney DW, Beaulieu J, Colombo S, McLachlan JS, O'Neill GA. 2011. The implementation of assisted migration in Canadian forests. The Forestry Chronicle 87:766-777.

Type: Journal

Geographic Area: Canada

Keywords: assisted migration, implementation, provenance data, seed procurement, Canada, forest, seed transfer, climate change

Abstract: We outline the major steps involved in implementing assisted migration (AM) and assess, in a general way, the capacity to carry out each step in Canadian forests. Our findings highlight the fact that capacity to implement AM differs between forest species; in particular, the existence of established provenance trials, seed transfer guidelines, seed procurement systems, and plantation establishment protocols makes AM considerably more feasible for most commercial tree species than for most species of conservation concern. We report on several AM efforts involving commercial tree species that are already underway in Canada and identify a number of initiatives that could be undertaken to help build AM capacity. This paper is not intended as an endorsement of the AM approach; however, we feel there is considerable value in discussing implementation issues at this point in the AM debate.

569. Richardson DM, Hellmann JJ, McLachlan JS, Sax DF, Schwartz MW, Gonzalez P, Brennan EJ, Camacho A, Root TL, Sala OE, Schneider SH, Ashe DM, Clark JR, Early R, Etterson JR, Fielder ED, Gill JL, Minteer BA, Polasky S, Safford HD, Thompson AR, Vellend M. 2009. Multidimensional evaluation of managed relocation. Proceedings of the National Academy of Sciences USA 106:9721-9724.

Type: Journal

Geographic Area: Global

Keywords: assisted migration, climate change, conservation biology, conservation strategy, sustainability science

Abstract: Managed relocation (MR) has rapidly emerged as a potential intervention strategy in the toolbox of biodiversity management under climate change. Previous authors have suggested that MR (also referred to as assisted colonization, assisted migration, or assisted translocation) could be a last-alternative option after interrogating a linear decision tree. We argue that numerous interacting and value-laden considerations demand a more inclusive strategy for evaluating MR. The pace of modern climate change demands decision making with imperfect information, and tools that elucidate this uncertainty and integrate scientific information and social values are urgently needed. We present a heuristic tool that incorporates both ecological and social criteria in a multidimensional decision-making framework. For visualization purposes, we collapse these criteria into 4 classes that can be depicted in graphical 2-D space. This framework offers a pragmatic approach for summarizing key dimensions of MR: capturing uncertainty in the evaluation criteria, creating transparency in the evaluation process, and recognizing the inherent tradeoffs that different stakeholders bring to evaluation of MR and its alternatives.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19509337

570. Stapley J, Reger J, Feulner PG, Smadja C, Galindo J, Ekblom R, Bennison C, Ball AD, Beckerman AP, Slate J. 2010. Adaptation genomics: the next generation. Trends in Ecology and Evolution 25:705-712.

Type: Journal

Geographic Area: Global

Compilers' Keywords: animals, biological evolution, genomics, plants

Abstract: Understanding the genetics of how organisms adapt to changing environments is a fundamental topic in modern evolutionary ecology. The field is currently progressing rapidly because of advances in genomics technologies, especially DNA sequencing. The aim of this review is to first briefly summarize

how next generation sequencing (NGS) has transformed our ability to identify the genes underpinning adaptation. We then demonstrate how the application of these genomic tools to ecological model species means that we can start addressing some of the questions that have puzzled ecological geneticists for decades such as: How many genes are involved in adaptation? What types of genetic variation are responsible for adaptation? Does adaptation utilize pre-existing genetic variation or does it require new mutations to arise following an environmental change?

Link: http://www.ncbi.nlm.nih.gov/pubmed/20952088

571. Ungerer MC, Johnson LC, Herman MA. 2008. **Ecological genomics: understanding gene and genome function in the natural environment.** Heredity 100:178-183.

Type: Journal

Geographic Area: Global

Keywords: ecological genomics, ecology, genomics, functional genomics, interdisciplinary, multidisciplinary

Abstract: The field of ecological genomics seeks to understand the genetic mechanisms underlying responses of organisms to their natural environments. This is being achieved through the application of functional genomic approaches to identify and characterize genes with ecological and evolutionary relevance. By its very nature, ecological genomics is an interdisciplinary field. In this review, we consider the significance of this new area of study from both an ecological and genomic perspective using examples from the recent literature. We submit that by considering more fully an ecological context, researchers may gain additional insights into the underlying genetic basis of ecologically relevant phenotypic variation. Likewise, genomic approaches are beginning to offer new insights into higher-level biological phenomena that previously occupied the realm of ecological investigation only. We discuss various approaches that are likely to be useful in ecological genomic studies and offer thoughts on where this field is headed in the future.

Link: http://www.ncbi.nlm.nih.gov/pubmed/17519970

572. Vitt P. 2013. **Using multiple lines of evidence to prioritize assisted migration of both rare and common species.** In: Assisted Migration: A Primer for Reforestation and Restoration Decision Makers; Portland, OR. 47 p.

Type: Presentation

Geographic Area: USA

Compilers' Keywords: MaxEnt, species vulnerability, climate change, species mapping, management

Abstract: The weather just keeps getting more and more strange, record heat in 2012, coupled with storms and fires causing billions of dollars in damage. And 2013 began with freak tornados caused by unseasonably warm temperatures in the northern U.S. colliding with the more typical colder weather moving down out of Canada. Seeing the evidence of climate change prompts many conservation and restoration professionals to ask: what can we do to help our natural systems adapt to these rapid catastrophic changes? One common answer is assisted migration of taxa unable to move or adapt rapidly enough. But, how do we identify which taxa? Or where to move them? To undertake a successful assisted migration program requires the synthesis of multiple lines of evidence that cut across disciplines. We will present the most common tools that are currently being employed to understand the potential impacts of climate change on select taxa of plants, and provide the background necessary to evaluate their effectiveness.

Link: http://www.rngr.net/resources/assisted-migration

573. Vitt P, Havens K, Hoegh-Guldberg O. 2009. **Assisted migration: part of an integrated conservation strategy.** Trends in Ecology and Evolution 24:473-474.

Type: Journal

Geographic Area: Global

Compilers' Keywords: response letter, biological invasions, assisted colonization

Compilers' Summary: A response letter to an article written by Ricciardi and Simberloff (2009). "Although we agree with several of their points, we believe that assisted migration could become an important part of integrated conservation strategies. Ricciardi and Simberloff focus on extreme examples of species translocations, including the 're-wilding' of North America with African mammals and other examples of intercontinental and long distance transport of species. We do not condone these practices as legitimate conservation strategies because we also recognize the risk of biological invasions."

Link: http://noss.cos.ucf.edu/papers/Vitt%20et%20al%20 2009%20and%20Schwartz%20et%20al%202009.pdf

574. Vitt P, Havens K, Kramer AT, Sollenberger D, Yates E. 2010. **Assisted migration of plants: changes in latitudes, changes in attitudes.** Biological Conservation 143:18-27.

Type: Journal

Geographic Area: Great Lakes, USA, Global

Keywords: assisted migration, assisted colonization, managed relocation, climate change, range shifts, seed banking, biodiversity conservation

Abstract: Rapid climate change has the potential to alter the location of bioclimatic envelopes for a significant portion of the world's flora. Plant species will respond variously via phenotypic plasticity, evolutionary adaptation, migration, or extinction. When fragmentation limits migration potential of many species or when natural migration rates are outstripped by the pace of climate change, some propose purposeful, human mediated migration (assisted migration) as a solution. Here, we join the debate on assisted migration, and while recognizing

the potential negative impacts, present a strategy to collect and bank seeds of plant species at risk of extinction in the face of rapid climate change to ensure that emerging habitats are as species-diverse as possible. We outline the framework currently being used by the Dixon National Tallgrass Prairie Seed Bank to prioritize species for seed banking, both for restoration purposes and for potential assisted migration in the future. We propose a strategy for collecting across the entirety of a species range, while targeting populations likely to go extinct under climate change, determined by application of species distribution models. Finally, we discuss current international efforts to collect and bank the global flora, as well as the research needs necessary to fully undertake the strategy presented.

Link: http://www.researchgate.net/publication/222155402_Assisted_migration_of_plants_Changes_in_latitudes_changes_in_attitudes/file/9c96051a4fcaab7382.pdf

575. Wheeler NC, Neale DB. 2013. **Landscape genomics: genetic tools to inform seed source decisions for assisted migration.** In: Assisted Migration: A Primer for Reforestation and Restoration Decision Makers; Portland, OR. 22 p.

Type: Presentation

Geographic Area: Global

Compilers' Keywords: landscape management, genetic adaptation, climate change, tool

Abstract: Climate change in North America, characterized by warming trends and some shifts in precipitation patterns, is now a generally accepted reality. Evidence of shifting natural ranges, both expansion and contraction, can already be seen in forest trees. Assisted migration offers a means to maintain forest productivity and ecological function by expediting species movements. Identifying which seed sources to move to optimize goals will not be trivial task. Those managing plantation forests deal with few species and typically have extensive knowledge of their planting stock. Intensive tree improvement programs, based on extensive genetic evaluation trials over the landscape provide excellent guides to which seed sources may be moved, and how far, to optimize program goals. In recent years, traditional tree improvement approaches have been supplemented with tools that use a rapidly expanding genomic resource and database. Public land managers are typically not so fortunate in the genetic resources available to guide them in issues concerning reforestation following disturbance, habitat restoration, conservation or assisted migration. With respect to reforestation, decisions regarding seed source have typically relied on natural seeding in, seed zone collections, or in special cases, information gleamed from common garden or provenance trials. Neither of the first two methods is guaranteed to produce a standing crop adapted to the future environment. Good provenance trials can significantly improve those chances, but offer a number of fiscal and logistical hurdles. Genomic studies, conducted at the landscape level, may potentially offer a suite of complementary, precision tools for guiding seed source selection assisted migration or other reforestation needs. This talk outlines the scientific basis of landscape genomics, reviews results of early studies in the field and discusses potential applications.

Link: http://www.rngr.net/resources/assisted-migration

576. Williams MI. 2013. **Charting assisted migration as a climate change adaptation strategy.** In: Assisted Migration: A Primer for Reforestation and Restoration Decision Makers; Portland, OR. 40 p.

Type: Presentation

Geographic Area: USA

Compilers' Keywords: review, native plants, native plant transfer guidelines, seed transfer zones

Abstract: Assisted migration, defined as the movement of native plants to facilitate natural range expansion in direct management response to climate change, has gained attention as an adaptation strategy since 2007. It can occur as the movement of 1) seed sources and populations within their current range (assisted population migration), 2) seed sources and populations from their current range to suitable areas immediately adjacent (assisted range expansion), and 3) species to locations far outside their current range to curtail extinction (assisted species migration). Across federal, state, and private groups in the U.S., very few adaptation and mitigation plans have been implemented or evaluated despite the increase in the amount of management planning during the past 30 years. Uncertainties about future climate conditions, risks with moving species and populations outside their current ranges, and existing policies have hampered formal actions. Drawing from conventional reforestation practices and proposed adaptation strategies, we chart the implementation of assisted migration and provide resources for researchers, landowners, and nurseries to facilitate collaboration and development of reforestation and restoration plans.

Link: http://www.rngr.net/resources/assisted-migration

577. Williams MI, Dumroese RK. 2013. **Preparing for climate change: forestry and assisted migration.** Journal of Forestry 111:287-297.

Type: Journal

Geographic Area: North America

Keywords: assisted migration, climate change, forest management, seed transfer, seed zones

Abstract: Although plants have moved across the landscape in response to changing climate for millennia, projections of contemporary climate change suggest that forest tree species and populations will need to migrate faster than their natural ability. Therefore, climate change adaptation strategies, such as assisted migration, have gained attention since 2007.

Effective implementation of assisted migration can only occur if target transfer guidelines are developed because our current seed transfer guidelines, established to guide the movement of plant materials, lack inherent spatial and temporal dynamics associated with climate change. This limitation restrains reforestation practitioners from making decisions about assisted migration. Lack of operating procedures, uncertainties about future climate conditions, risks associated with moving plants outside their current ranges, and existing policies have hampered formal actions in forest management and conservation. We review the current thinking on assisted migration of forest tree species and provide information that could facilitate implementation.

Link: http://www.treesearch.fs.fed.us/pubs/44260

578. Williams MI, Dumroese RK. 2013. Climate change and assisted migration: strategic options for forest and conservation nurseries. Forest Nursery Notes 33:33-35.

Type: Newsletter

Geographic Area: North America

Compilers' Keywords: forest nurseries, management

Introduction: In light of current studies that show climate will change faster than plants can adapt or migrate naturally, it begs the question, "What does this mean for forestry, specifically forest and conservation nurseries?" In this article, we discuss options for forest nurseries, such as assisted migration.

Link: http://www.treesearch.fs.fed.us/pubs/43883

579. Williams MI, Dumroese RK. 2014. Role of climate change in reforestation and nursery practices. Western Forester 59:11-13.

Type: Newsletter

Geographic Area: North America

Compilers' Keywords: forest management, nursery practices, assisted migration, seed transfer, Society of American Foresters

Introduction (2nd paragraph): The divergence in rates between climate change and tree adaptation will have important consequences for reforestation and nursery practices. Plant materials outplanted today must be able to meet and face the climatic challenges during this century. Unfortunately, most state and commercial nurseries in the U.S. have not yet explored how changes in climate will impact their operations. This article highlights some adaptation strategies to help reforestation and nursery practices, such as moving populations to new locations, modifying seed transfer guidelines, and targeting diversity in plant materials.

Link: http://www.forestry.org/northwest/westernforester/2014/

580. Winder R, Nelson EA, Beardmore T. 2011. Ecological implications for assisted migration in Canadian forests. The Forestry Chronicle 87:731-744.

Type: Journal

Geographic Area: Canada

Keywords: adaptation, assisted migration, climate change, colonization, constraints, ecology, establishment, mitigation, translocation, trees

Abstract: Forest ecosystems are already being impacted by climate change as natural migration rates are outpaced by rapidly changing climate conditions. Human assisted migration has been proposed as a potential management option to maintain optimal health and productivity of Canada's forests; however, a better understanding of the ecological implications is needed to inform decision-making on assisted migration (AM). This paper examines the ecological constraints and consequences of AM, and discusses options for their mitigation at three scales: translocation over long distances (assisted long-distance migration), translocation just beyond the range limit (assisted range expansion), and translocation of genotypes within the existing range (assisted population migration). From an ecological perspective, we find that AM is a feasible management option for tree species and that constraints and consequences can be minimized through careful application of available knowledge and tools.

Migration

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

581. Center for Plant Conservation. Reintroduction registry. (URL accessed 29 November 2015)

Type: Web Page

Geographic Area: USA

Compilers' Keywords: conservation, extinction, plant species, online database, repository, restoration, Endangered Species Act

About: The Center for Plant Conservation (CPC) is dedicated solely to preventing the extinction of U.S. native plants. The Center was one of the first organizations created to meet this need. The Center is a network of 39 leading botanic institutions. Founded in 1984, the Center operates the only coordinated national program of off-site (*ex situ*) conservation of rare plant material. This conservation collection ensures that material is available for restoration and recovery efforts for these species. CPC also works in research, restoration, technical assistance, education and advocacy through the efforts of the network and the national office. The cooperative CPC network maintains the National Collection of Endangered Plants. Believed to be the largest living collection of rare plants in the world, the collection contains more than 750 of America's most imperiled native plants. Live plant material is collected from nature under controlled conditions and then carefully maintained as seed, rooted cuttings or mature plants. Network institutions conduct horticultural research and carefully monitor these materials so that imperiled plants can be grown and returned to natural habitats. Several CPC institutions are also involved in restoration projects in the field (*in situ*). Scientists are stabilizing current populations of imperiled plants and reintroducing new populations in appropriate habitats. These conservation efforts are undertaken to complement other preservation activities for our nation's flora, such as habitat protection and management. Off-site storage and cultivation of genetically appropriate plant material is a critical step in supporting restoration in the wild. The Center's goal is to protect the most imperiled U.S. plants from extinction and restore them to secure habitats in cooperation with multiple conservation agencies and organizations. Almost 1,000 U.S. plant species are already listed under the federal Endangered Species Act or qualify for listing. Without human intervention, many of these species may be gone within our lifetime. Research by CPC has shown that 80 percent of the at-risk plants of the United States are closely related to plants with economic value somewhere in the world, and more than 50 percent are related to crop species.

Link: http://www.centerforplantconservation.org/welcome.asp

582. Maschinski J, Albrecht MA, Monks L, Haskins KE. 2012. Center for plant conservation best reintroduction practice guidelines. Appendix 1. In: Maschinski J, Haskins KE, editors. Plant Reintroductions in a Changing Climate: Promises and Perils. Washington (DC): Island Press. p 30.

Type: Book Section

Geographic Area: Global

Compilers' Keywords: climate change, plant restoration, translocation

Introduction (2nd paragraph): This is a quick reference for practitioners to use when planning and executing rare plant reintroductions. The term reintroduction in this appendix implies any attempt to introduce propagules to an unoccupied patch, including augmentations, introductions, and translocations. Managed relocations would require following these same guidelines in addition to the points presented by Haskins and Keel (this volume) and the modeling, interdisciplinary, multiagency, and potentially international collaborations cautioned by Kennedy and colleagues (this volume). The sections are intended to help practitioners do the following: justify the decision to conduct a reintroduction, prepare the reintroduction design with legal, funding, species biology, horticulture, and recipient site considerations in mind, implement the reintroduction, conduct project aftercare, and design monitoring to document long-term establishment of the rare population. All phases of the reintroduction process should include opportunities for public involvement. In addition, we suggest a template to use for documenting all aspects of the reintroduction that can be found on the North Carolina Botanical Garden website.

Transfer Guidelines and Zones

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

583. Auld GS, Stead JW, Aitken SN, Bull GQ. 2002. Forest genetics and certification: global and local issues facing tree breeders, policy-makers, and forest managers in British Columbia. Vancouver, British Columbia, Canada: Centre for Forest Gene Conservation, University of British Columbia. 200 p.

Type: Report

Geographic Area: Western Canada

Compilers' Keywords: forest management, seed transfer

Executive Summary: Since the early 1990s, forest certification has become an internationally recognized mechanism for assessing and encouraging the practice of responsible forest management. Markets are increasingly demanding independent assurances that forest products come from sustainable sources. British Columbia (BC) forest managers, the provincial government and other stakeholders are keenly aware of these pressures; creating significant interest in assessing how BC's present forest management regulations, standards, requirements and practices compare to the requirements set by the various certification initiatives. In this report, we examine one such issue. Our attention focuses on the way four different forest certification initiatives address the conservation and management of forest genetic resources. The intention being two-fold: 1) Describe how certification has developed internationally to deal with forest genetics issues and; 2) Relate these findings to the BC situation to uncover the current and potential future issues that face BC tree breeders, silviculturalists, forest companies, forest managers, and policy makers as they attempt to evaluate the application of certification to how BC's forests are managed.

584. Curtis RO, DeBell DS, Miller RE, Newton M, St. Clair JB, Stein WI. 2007. Silvicultural research and the evolution of forest practices in the Douglas-fir region. Portland (OR): USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-696. 172 p.

Type: Government Document

Geographic Area: Pacific Northwest USA

Keywords: forest history, silviculture, Douglas-fir, forest research, *Pseudotsuga menziesii*

Abstract: Silvicultural practices in the Douglas-fir region evolved through a combination of formal research, observation, and practical experience of forest managers and silviculturists, and changing economic and social factors. This process began more than a century ago and still continues. It has had a great influence on the economic well-being of the region and on the present characteristics of the region's forests. This long history is unknown to most of the public, and much of it is unfamiliar to many natural resource specialists outside (and even within) the field of silviculture. We trace the history of how we got where we are today and the contribution of silvicultural research to the evolution of forest practices. We give special attention to the large body of information developed in the first half of the past century that is becoming increasingly unfamiliar to both operational foresters and—perhaps more importantly—to those engaged in forestry research. We also discuss some current trends in silviculture and silviculture-related research.

Link: http://www.treesearch.fs.fed.us/pubs/27615

585. Everett RL. 1994. Restoration of stressed sites, and processes. Portland (OR): USDA Forest Service, Pacific Northwest Region. General Technical Report PNW-GTR-330. Volume IV. 123 p.

Type: Government Document

Geographic Area: Pacific Northwest USA

Keywords: restoration, forest health, ecosystem processes, disturbance effects, ecosystem management, insects, disease, and fire hazard

Abstract: Portions of forest ecosystems in eastern Oregon and Washington are in poor health, are not meeting societies' expectations, and have elevated hazard for fire, insects, and disease. Diversity in stream habitats and associated fisheries has declined over the last several decades in several drainage basins, requiring conservation and restoration efforts in key watersheds. Required first steps in restoring forest and aquatic ecosystems are the immediate reduction in hazard for catastrophic loss of biodiversity, site quality, resource commodities, and improved conditions for public health. To prevent loss of future options we need to simultaneously reestablish ecosystem processes and disturbance effects that create and maintain desired sustainable ecosystems, while conserving genetic, species, community, and landscape diversity and long-term site productivity. Restoration of stressed sites is site specific, but the context for the action should be defined by the desired condition(s) of the next higher landscape scale and achieve desired positive cumulative effects over time. Restoration actions should be consistent with the desired level of disturbance effects required to maintain sustainable ecosystems, and standards and guides should reflect the inherent variability associated with dynamic systems. Costs associated with restoration activities should be weighed against the foregone benefits if no action is taken. The restoration of the biological components of ecosystems should provide increased opportunities for the restoration of human cultural, social, and economic ecosystem components and increase options for resource-dependent communities.

Link: http://www.treesearch.fs.fed.us/pubs/6939

586. Friedman ST, Foster GS. 1997. Forest genetics on federal lands in the United States: public concerns and policy responses. Canadian Journal of Forest Research 27:401-408.

Type: Journal

Geographic Area: USA

Compilers' Keywords: tree improvement, public land, public concern

Abstract: The challenge of managing public lands is to balance the current and future needs of people and the long-term health of ecosystems. In addition, public land management requires being responsive to the public and their elected representatives, and ensuring that public agencies are efficient, effective, and representative of the diversity of the American public. In this paper, the results of an informal survey of key stakeholders, and U.S. Forest Service employees with direct public contact are summarized. There are a host of public concerns about genetic diversity and tree improvement on public land. At the broadest level, species choice and the decision to artificially or naturally regenerate are issues in their own right, and yet are often linked to genetic concerns. If artificial regeneration is an option, there is the general concern about the impacts of changes in the genetics of future trees on components of the ecosystem. These concerns lie in three main areas: (1) reduction of genetic diversity, (2) loss of adaptation, and (3) changes in other ecosystem components from the directed selection of trees. At the current time, citizens range widely in their knowledge and concern about these issues. Developing policy to address public concerns can be approached through a variety of perspectives. Silvicultural techniques, including genetic resource management, are tools toward broader policy objectives for public land management. These objectives are currently the subject of much debate and controversy. Given that the broader policy context is dynamic, some policy options for genetics in public land management include (1) gene conservation only, (2) no frills, (3) appropriate technology with public support, and (4) application of economic criteria. Also discussed is the need for a framework to coordinate local and national policies regarding gene resource management.

587. Isaac LA. 1952. Advantages of selecting tree seeds with care. Tree Planters' Notes 11:1-8.

Type: Government Document

Geographic Area: USA, Canada, Europe

Compilers' Keywords: seed selection, forest management, reforestation, forest genetics, nursery stock

Introduction: The vast virgin forests of North America are gradually being cut away and converted into managed stands. The movement is well under way in the United States and advancing in the same direction in Canada. For the most part, foresters and timberland owners have been content to accept such regeneration as came in naturally regardless of parentage or even of species. For early artificial reforestation, any seed source was acceptable. But the rising costs of timber growing and increasing competition for land use have forced owners to recognize that it is necessary and profitable to secure the best seed for a given site. We discuss the strains of forest trees, climatic limitation of forest trees, climatic guides for seed selection, selection of stands and nursery stock, and finally provide steps for better seed.

Link: http://www.rngr.net/publications/tpn/3-2/PDF.2004-10-08.3621

588. Johnson R. 2000. **Tree improvement in the Pacific Northwest.** In: Rose R, Hasse DL. Proceedings: Advances and Challenges in Forest Regeneration. Corvallis (OR): Oregon State University. p 29-34.

Type: Book Section

Geographic Area: Pacific Northwest USA

Keywords: tree breeding, genetic gain, genetic diversity, disease resistance

Abstract: Advanced-generation tree breeding programs are underway for Douglas-fir and coastal western hemlock. These programs will continue to improve rates and other traits. Regardless of whether seed is from a seed orchard or natural collection, it must be used in its appropriate breeding zone or seed zone. These zones vary by species. Breeding programs are underway for other species as well, with many of these programs emphasizing disease and insect resistance. Absolute gains at rotation are still unknown, but absolute (not percentage) gains observed early in the rotation should increase to some degree with time.

Link: http://www.treesearch.fs.fed.us/pubs/4921

589. Johnson GR, Sorensen FC, St. Clair JB, Cronn RC. 2004. **Pacific northwest forest tree seed zones: a template for native plants?** Native Plants Journal 5:131-140.

Type: Journal

Geographic Area: Pacific Northwest USA

Keywords: seed movement, genetic variation, adaptation

Abstract: Seed movement guidelines for restoration activities are lacking for most native grasses, forbs, and shrubs. The forestry community has decades of experience in establishing seed zones and seed movement guidelines that may be of value to restoration managers. We review the history of seed zone development in forest trees, with emphasis on the Pacific Northwest, and make some suggestions concerning seed transfer guidelines for other native plants.

Link: http://www.treesearch.fs.fed.us/pubs/25517

590. Johnson R, Stritch L, Olwell P, Lambert S, Horning ME, Cronn RC. 2010. **What are the best seed sources for ecosystem restoration on BLM and USFS lands?** Native Plants Journal 11:117-131.

Type: Journal

Geographic Area: USA

Keywords: seed zones, ecotypes

Abstract: Native plant restoration policy calls for use of "genetically appropriate" native plant material on USDI Bureau of Land Management (BLM) and USDA Forest Service (USFS) lands. In this article, we summarize experimental evidence showing that local adaptation is widespread in all kingdoms of life, and how this "home-field advantage" has been exploited in forest restoration activities to develop and promote regionally adapted, genetically diverse restoration materials. The importance of such materials is highlighted in the context of changing environmental conditions, such as those predicted in future climate change scenarios. Although the adaptive properties of most restoration species remains unexamined, numerous tools exist for identifying similar environments and ecosystems, and these can be used to develop first-generation seed zones. Finally, general recommendations for establishing foundation populations are outlined so that pre-adapted populations retain sufficient genetic diversity to acclimate to new evolutionary challenges, while minimizing the likelihood of deleterious genetic outcomes (for example, inadvertent selection of undesirable traits; inbreeding depression).

Link: http://www.treesearch.fs.fed.us/pubs/37836

591. Jones TA. 2005. **Genetic principles and the use of native seeds—just the FAQs, please, just the FAQs.** Native Plants Journal 6:14-24.

Type: Journal

Geographic Area: Global

Keywords: genetics, adaptation, polyploidy, inbreeding depression, outbreeding depression, cross-pollination, self-pollination, apomixis, ecoregion, ecotype, seed transfer zones, cultivar, hybridization, selection

Abstract: To make intelligent choices in the marketplace, native seed customers should have a working understanding of genetic principles and terminology as they apply to self-pollinated, cross-pollinated, and apomictic plant materials. Customers should understand the genetic implications of a species' breeding system, the various approaches used to decide what should be planted where, the risk of inbreeding or outbreeding depression, the meaning of commonly misunderstood terms such as "ecotype" and "cultivar," and the role of hybridization and artificial selection in plant materials development. Plant material selection involves consideration of geographic (such as ecoregion, precipitation, winter hardiness, soil type), genetic (molecular markers), and adaptation (field testing) data.

592. Kaye TN. 2001. Common ground and controversy in native plant restoration: the SOMS debate, source distance, plant selections, and a restoration-oriented definition of native. In: Haase DL, Rose R, editors. Native Plant Propagation and Restoration Strategies. Portland (OR): Nursery Technology Cooperative and Western Forestry and Conservation Association. p 5-12.

Type: Conference Paper

Geographic Area: Global

Compilers' Keywords: transfer

Abstract: Propagation and planting of native plants for habitat restoration is a multi-faceted process. There are many issues over which there is general agreement among restorationists, but there are a number of subjects that cause disagreement. For example, restorationists often agree that native plants should be emphasized, but disagree over where seeds or transplants should come from. In this paper, I examine four areas of controversy: the use single or multiple sources of a species at a given restoration site (the SOMS debate), source distance of plant materials, the use of native plant selections, and the importance of one's definition of "native plant." I conclude that some of these issues may be resolved through careful research, while others will remain a matter of personal opinion, and can only be resolved through a clear statement and scope of objectives of each restoration project.

Link: http://appliedeco.org/reports/restoration-source-genetics.pdf

593. Knapp EE, Rice KJ. 1994. Starting from seed: genetic issues in using native grasses for restoration. Restoration and Management Notes 12:40-45.

Type: Journal

Geographic Area: USA

Compilers' Keywords: genetic resources, seed collection, seed storage

Introduction: Historical records of the botanical composition of grasslands in their pristine state are often incomplete or lacking, yet it is evident that many native species were at one time much more widespread than they are today. Changing land use, including agricultural conversion, urbanization, overgrazing, fire suppression, and introduction of non-native weedy annuals, have all dramatically altered the landscape and the flora. In recent years, the public has become better informed about the decline of our natural heritage due to human influence, and the importance of biodiversity is not widely understood. Together with and perhaps in part due to this increasing public awareness has been a mounting interest in restoration using native species, including grasses. This paper will discuss, in a broader sense, some genetic issues that may be useful to consider when collecting and utilizing native grasses for restoration.

Link: http://www.fs.fed.us/psw/publications/knapp/psw_1994_knapp001.pdf

594. Knight TM, Havens K, Vitt P. 2011. Will the use of less fecund cultivars reduce the invasiveness of perennial plants? BioScience 61:816-822.

Type: Journal

Geographic Area: Global

Keywords: invasive plant, ornamental plant, cultivar, demography

Abstract: Many invasive species were originally introduced for horticultural purposes, and several continue to be profitable for the green (nursery, horticulture, and landscape) industry. Recently, some plant suppliers have marketed less fecund cultivars of several invasive species, including glossy buckthorn (*Frangula alnus*), burning bush (*Euonymus alatus*), and Japanese barberry (*Berberis thunbergii*), as "safe" alternatives to invasive relatives. We use published matrix population models to simulate the effect of reducing fecundity on the population growth rates of invasive species. We show that large changes in fecundity result in relatively small changes to the population growth rates of long-lived species, which suggests that less fecund cultivars may still provide an invasive threat. Furthermore, many cultivars are clonal selections, and if crossed with other cultivars or selfed, they produce offspring with traits and fecundities that do not resemble the parent plant. On the basis of these two lines of evidence, we suggest that only female sterile cultivars that cannot reproduce asexually should be considered "safe" and noninvasive. Marketing less fecund cultivars as "safe" is premature at this time, and further research is necessary to determine the potential invasiveness of different cultivars.

Link: http://wubio.wustl.edu/files/biology/imce/knight_et_al_2011_bioscience.pdf

595. Kramer AT, Havens K. 2009. Plant conservation genetics in a changing world. Trends in Plant Science 14:599-607.

Type: Journal

Geographic Area: USA

Compilers' Keywords: adaptation, biodiversity, endangered species, molecular evolution, genetic variation, population genetics, population dynamics, gene flow, seed transfer zones, species specificity, restoration, review, climate change

Abstract: Plant conservation genetics provides tools to guide conservation and restoration efforts, measure and monitor success, and ultimately minimize extinction risk by conserving species as dynamic entities capable of evolving in the face of changing conditions. We consider the application of these tools to rare and common species alike, as ongoing threats that increasingly limit their resilience, evolutionary potential and survival. Whereas neutral marker studies have contributed much to conservation genetics, we argue for a renewed focus on quantitative genetic studies to determine how, or if, species will adapt to changing conditions. Because restoration plays an increasingly vital role in conservation, we discuss additional genetic considerations and research questions that must be actively studied now to effectively inform future actions.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19748300

596. Langlet O. 1971. Two hundred years genecology. Taxon 20:653-721.

Type: Journal

Geographic Area: Global

Compilers' Keywords: genetic research, review, provenance trial, forest management, genotype, environmental interactions, climate change, local adaptation

Epilogue: This essay is a review of the research and literature concerning intraspecific diversity in ecologically significant features. In this category may be most of the relative importance and possibly also the course of influence of antecedent work. In a way it is tempting simply to summarize the result with the verse in the Ecclesiastes (I: 8): "... and there is nothing new under the sun." But, indeed, there is. Roughly, there may be discerned three main stages of genecological work. First, the observation and statement of the mere existence of an intraspecific diversity in ecologically significant features. In this category may be most of the provenance work in respect to forest trees, agricultural and horticultural plants, as well as much of the investigations on herbaceous ecotypes, as Turrill (1940) put it: "The deservedly well-known experimental researches of Turesson must, for the most part as at present published, be considered under the heading of simple cultivation." Second, the correlation of the diversity in ecologically significant features to the external environmental factors allows a preliminary estimation of the ecological importance of the extrinsic influences. Also, the patterns of intra-specific diversity are related to the patterns of environmental factors. The local interbreeding community or deme is found to be the basic genecological concept. Third, the intricate mechanisms of adaptations and the development of adaptations need to be experimentally investigated. Phytotrone or temperature-controlled growth-chamber experiments may be the next method to investigate the reactions of variously adapted populations to different external factors. Such work was first begun in the 1950's (cf. Hiesey 1953; Mooney & Billings 1961) and there is still much to be done and much to be gained in this field. Even if it may be of importance to delimit the ranges of different branches of biology from one another, as stressed above, it is equally important not to isolate these branches from teamwork. The great and real progress may be expected from the joint efforts of various specialists, not least from the cooperation of statisticians and computer specialists. I have learned one really important lesson in preparing this essay, viz., to avoid second-hand quotation as far as possible and, what is still more important, not to accept other peoples' labelling, criticism—or laudation—of antecedent as well as contemporary authors uncritically. All of them have generally published much more material worthy of consideration than that which is usually attached to their names. The field is wide enough for bestowing on classical and other early authors the reference they by their works and writings are rightfully entitled to, as well as quoting contemporaries as they merit consideration. The old authors did not have the plenty of facts and experimental evidence as we have, and, above all, they were not strained by a publication explosion such as we now experience. They had, and took, more time to reflect and speculate upon the subjects within range of their knowledge. And one thing is evident: they were not a bit less intelligent that the authors of today. Darwin is an amazingly modern author, and he is in no way unique in this respect. Ecological experimental work is often laborious and frequently it does not elucidate the problems as perfectly as we hoped for. There is then nothing else to do than to proceed with new experiments and to follow the wisdom by the classical author, the famous Lamarck (in his Philosophie zoologique II, p. 174, 1809), here in the good translation by Greene (1959, p. 158): "Let us collect with care the facts we can observe, let us consult experience wherever we can, and when this experience is inaccessible to us, let us assemble all the inductions which observation of facts analogous to those which escape us can furnisbh and let us assert nothing categorically; in this way, we shall be able little by little to discover the causes of a multitude of natural phenomena, and, perhaps, even of phenomena which seem the most incomprehensible..."

597. Mahalovich MF. 1997. Communicating the role of genetics in management. In: Communicating the Role of Silviculture in Managing the National Forests: Proceedings of the National Silviculture Workshop. Radnor (PA): USDA Forest Service, Northeastern Forest Experiment Station. General Technical Report NE-238. p 58-64.

Type: Government Document

Geographic Area: Global

Compilers' Keywords: forest management, tree improvement, silviculture

Abstract: Three current issues serve as examples to convey the role of genetics in management. (1) Consequences of (qualitative) data. Results of simulated data for diameter (quantitative data) over several generations, illustrate the pitfalls of working towards balanced uneven-aged silvicultural systems in northern red oak, under natural regeneration constraints and existing management direction. (2) Comparisons of section boundaries within an ecological classification system and climatic zones (homoclines) as surrogates for managing genetic resources are of limited utility in describing patterns of genetic variation for adaptive, growth, and disease resistance traits. (3) Reporting gains and seed yields from tree improvement programs in

Forest Service decision documents is recommended as means of showing consequences of 'action vs. no action' for genetic resources, thereby placing genetics in a more active role in the Agency's next round of forest planning.

Link: http://www.treesearch.fs.fed.us/pubs/14994

598. McKay JK, Christian CE, Harrison S, Rice KJ. 2005. **"How Local Is Local?" A review of practical and conceptual issues in genetics of restoration.** Restoration Ecology 13:432-440.

Type: Journal

Geographic Area: Global

Keywords: ecotype, local adaptation, outbreeding depression, restoration, seed zones

Abstract: In plant conservation, restoration (the augmentation or reestablishment of an extinct population or community) is a valuable tool to mitigate the loss of habitat. However, restoration efforts can result in the introduction of novel genes and genotypes into populations when plant materials used are not of local origin. This movement is potentially important because many plant species are subdivided into populations that are adapted to local environmental conditions. Here we focus on genetic concerns arising from ongoing restoration efforts, where often little is known about "How local is local?" (i.e., the geographic or environmental scale over which plant species are adapted). We review the major issues regarding gene flow and local adaptation in the restoration of natural plant populations. Finally, we offer some practical, common-sense guidelines for the consideration of genetic structure when restoring natural plant populations.

Link: http://www.des.ucdavis.edu/faculty/Harrison/people/sue/papers/mckay_etal2005_RE.pdf

599. Millar CI, Libby WJ. 1989. **Disneyland or native ecosystem: genetics and the restorationist.** Restoration and Management Notes 7:18-24.

Type: Journal

Geographic Area: USA

Compilers' Keywords: seed transfer guidelines, forestry, genetic variation, cline, climate, seed zone, review, reforestation

Compilers' Summary: Drawing from literature and their professional experience, the authors discuss the impacts of introduced genetic material in restoration plantings and propose general guidelines to avoid short and long term failures. Since the observation was made that seeds of different geographic origins produce trees with different survival and growth characteristics within the same plantation (HL Duhamel de Monceau of France in early 1700s), research forestry has supported two points: 1) species are genetically structured in a hierarchical fashion, and 2) variation can reflect adaptations to environmental conditions in which the ancestral populations evolved. The consequences of introducing stock without consideration of genetic variability are 1) the stock may die after planting because they lack adaptive characteristics, 2) delayed death; plants that evolved within the system already have the toolbox of adaptive genes, 3) poor growth, 4) inbreeding depression, and 5) genetic contamination. To curb these consequences, they recommend the following guidelines: 1) don't buy planting stock unless there is no other option; instead collect it on or near the plant site but consider site conditions (elevation, slope, aspect, soil, drainages, frost dates, etc.), 2) collect from adjacent lands of similar topography and vegetation and be aware of changes in conditions that would favor genetic differences, 3) gather all information about the species' genetic variation; when lacking match the collection sites with restoration sites by picking sites similar in elevation, soils, vegetation, and ecology, 4) collect from many parents at least 100 m apart to avoid inbreeding depression, 5) find a nursery that maintains records of stock origin, number of parent plants; if stock and origin unknown keep the numbers high and buy from several different nurseries, 6) give nature a chance first; sometimes it's best not to intervene, and 7) if no material is available, build a new landrace. In any restoration effort, it is important to record location of planting site, origin, age and date of planting, survival and performance over time, and ecological behavior of stock.

Link: http://er.uwpress.org/content/7/1/18.full.pdf

600. Pike C. 2008. **What is local? An introduction to genetics and plant selection in the urban context.** Urban Habitats 5:3-6.

Type: Journal

Geographic Area: Global

Compilers' Keywords: urban landscapes, inbreeding depression, assisted migration, local adaptation

Introduction: The urban landscape comprises myriad isolated green spaces inhabited by an assortment of vegetation types. To many city dwellers, these green spaces interrupt the monotony of concrete and steel and foster deep social attachment between city dwellers and nature. To a conservationist, these vegetation islands provide unique opportunities to restore ecological function to degraded areas by revegetating them with native plants. However, the restoration ecologist faces many challenges unique to the urban landscape. A significant investment in site preparation may be needed to offset the impacts of abiotic factors including compacted soil, drought, and air pollution. Seedlings that survive to maturity are not guaranteed immunity from these abiotic stresses, as is evident in the tree dieback and declines that plague many city landscapes. Abiotic factors are rarely the sole causal agent of urban tree declines since the presence of a multitude of other factors, such as insects and disease, are associated with symptoms of this decline. For example, drought in combination with insect defoliation predisposed black oak (*Quercus velutina*) to decline, while defoliation and several pathogens were causal agents in the decline of English oak (*Quercus robur*). The impacts of biotic factors on plant health may be heightened or lessened in urban areas depending on the ecology of the insect or disease. In these examples, black oaks in urban areas were more susceptible to damage from gall wasps than trees surrounded by contiguous forest. In contrast, the pathogens inciting decline in *Quercus robur* are less problematic in urban settings where soil disturbance prevent Armillaria fungus from spreading great distances.

Link: http://www.urbanhabitats.org/v05n01/local_pdf.pdf

601. Powers RF. 1999. On the sustainable productivity of planted forests. New Forests 17:263-306.

Type: Journal

Geographic Area: Global

Keywords: history of plantations, site potential, nutrition, soil properties, plantation yield

Abstract: Planted forests have more than a millennium of history and represent the world's best hope for meeting global wood requirements in the twenty-first century. Advances in genetic improvement, nursery practices, stand establishment, and tending, harvesting, and manufacturing have boosted plantation yields to a higher level than at any point in history. Despite this, forest managers face a mounting challenge to demonstrate that plantation productivity is sustainable. Tackling this challenge requires a sound understanding of the principles of forest productivity, how they apply to a developing plantation, and how they are influenced by management. In this paper criticisms of plantation forestry are discussed from the basis of world experience, and examples of productivity decline are described. Obvious declines are rare, and can be attributed to poor soil management. However, ambiguities exist and controversy will continue until sustainable productivity can be demonstrated conclusively. Proposed programs aim to provide the technical base needed for sound soil management and sustainable plantation productivity.

Link: http://rothforestry.com/Resources/Powers1999.pdf

602. Rinehart S, Mahalovich MF. 2008. Development of seed transfer zones through common garden studies in Region One. Missoula (MT): USDA Forest Service, Northern Region. 1 p.

Type: Government Document

Geographic Area: Northwestern USA

Compilers' Keywords: native grass, Idaho fescue, bluebunch wheatgrass

Introduction: In 2008 Region One initiated a multi-year project to develop seed transfer zones for core native revegetation species. The R1 Common Garden Study will contribute to our understanding of genetic variation in selected revegetation species within their range in Region One. The results of the study will be used to develop seed transfer guidelines for Forest Service System lands in Region One as well as adjacent areas. Results will also be used to compare native genotypes to "restoration cultivars."

Link: http://www.fs.fed.us/wildflowers/nativeplantmaterials/documents/npmreports/fy2008/R1/Seed_Transfer_Zone_Common_Garden_Study.pdf

603. Rinehart S, Mahalovich MF. 2009. Development of seed transfer zones for Idaho fescue and bluebunch wheatgrass through common garden studies in region one. Missoula (MT): USDA Forest Service, Northern Region. 1 p.

Type: Government Document

Geographic Area: Northwestern USA

Compilers' Keywords: native grass

Introduction: In 2008 Region One initiated a multi-year project to develop seed transfer zones for core native revegetation species. The project utilizes common garden study methodology and will contribute to our understanding of genetic variation in selected revegetation species within their range in Region One. The results of the study will be used to develop seed transfer guidelines for Forest Service System lands in Region One as well as adjacent areas. Results will also be used to compare native genotypes to "restoration cultivars." During the 2008 field season, R1 forests and grasslands conducted wildland seed collection for two revegetation species, Idaho fescue (*Festuca idahoensis*) and bluebunch wheatgrass (*Pseudoroegneria spicata*).

Link: http://www.fs.fed.us/wildflowers/nativeplantmaterials/documents/npmreports/fy2009/R1/Seed_Transfer_Zone_Study_FEID_PSSP6.pdf

604. Rinehart S, Mahalovich MF. 2009. Development of seed transfer zones for two native shrubs through common garden studies in Region One. Missoula (MT): USDA Forest Service, Northern Region. 1 p.

Type: Government Document

Geographic Area: Northwestern USA

Compilers' Keywords: Red osier dogwood, Shinyleaf spirea

Introduction: The Five-Year Action Plan for the R1 Native Plant Program identified the need to develop seed transfer zones for core native revegetation species. In 2008 a multi-year project was initiated to utilize common garden study methodology in collecting data on select native plant species commonly used for revegetation. This project will contribute to our understanding of genetic variation in native species within their range in the northern Rocky Mountain Ecosystem and northern Great Plains. The results of the study will be used to develop seed transfer guidelines for Forest Service System lands in Region One as well as adjacent areas. Results will also be used to compare native genotypes to "restoration cultivars." During the 2009 field season, Region One forests and grasslands conducted wildland seed collection for two shrub species: red osier dogwood (*Cornus sericea* ssp. *sericea*) and shinyleaf spirea (*Spiraea betulifolia* var. *lucida*). Common garden studies for these two species will be conducted by the Coeur d'Alene Nursery from 2010 through 2012. Seedlings will be grown out in the greenhouse in early spring, 2010, before being transferred to common garden study field plots. Data collection will involve plant morphology and phenology assessments at various plant growth stages.

Link: http://www.fs.fed.us/wildflowers/nativeplantmaterials/documents/npmreports/fy2009/R1/Shrub_Seed_Transfer_Zone_Study.pdf

605. Rogers DL. 2004. Genetic erosion: no longer just an agricultural issue. Native Plants Journal 5:113-122.

Type: Journal

Geographic Area: Global

Keywords: genetic diversity, reforestation, restoration, revegetation, source materials, natural areas, conservation

Abstract: Genetic considerations pertaining to planting projects usually emphasize locally adapted source material. However, the amount of genetic diversity in the plant materials is important as well. Genetic erosion is the loss of genetic diversity—often magnified or accelerated by human activities. In native plant populations, genetic erosion results from habitat loss and fragmentation, but it also can result from a narrow genetic base in the original collections or by practices that reduce genetic diversity. Although species specific guidelines are not available, managers can minimize the risk of genetic erosion by being familiar with the biology of the affected species (including breeding system, mode of reproduction, and pattern of genetic diversity). Narrowly based genetic collections should be avoided, providers of plant materials for revegetation projects should offer information on their collection methods, and nursery managers should endeavor to minimize diversity losses at all stages of nursery culture.

Link: http://npj.uwpress.org/content/5/2/112.full.pdf+html

606. Rogers DL, Montalvo AM. 2004. Genetically appropriate choices for plant materials to maintain biological diversity. Davis (CA): University of California. 343 p.

Type: Report

Geographic Area: Northwestern USA

Compilers' Keywords: genetic material, native plant material development, guidelines, seed zones, seed transfer guidelines

Forward: Native plant material use in revegetation or restoration efforts has increased nationally over the past couple of decades, replacing to some extent our past reliance on European grasses. This shift to natives has raised questions about the selection of appropriate genetic stocks, similar to the issues involved in using native trees for reforestation. There is a need and an opportunity for dialog between land managers choosing native plant materials for wildland use, and geneticists who can provide counsel on relevant (but often complicated) details. This guide is intended to foster such a dialog. It synthesizes important genetic principles and provides many examples to better inform land managers, and help them understand the context for advice from geneticists. It focuses on details relevant to the USDA Forest Service's Rocky Mountain Region, but contains a wealth of information that is relevant elsewhere, as well. Revegetation, restoration, or emergency rehabilitation efforts are conducted at the local level, but assistance can be provided from regional or national levels. Tools are needed to help local land managers make informed decisions when native materials suitable for the site are not commercially available (or feasible), and when seed transfer guidelines or seed zones have not been developed for the particular plant species of interest. Regional strategies can help provide guidance, and lead to economies of scale. Development of this Guide was the top priority in a strategic effort in the Rocky Mountain Region in 2002, to assist our National Forests and Grasslands in addressing their needs for native plant materials. The other products (for example, prioritized lists of species, seed procurement plans, native seed collections from the Forests and Grasslands, common garden studies) remain unfunded at this time. A tremendous amount of scientific study, policy, and infrastructure support the use of merchantable native tree species for reforestation following timber harvest, fire, disease or insect epidemics, and other disturbances. But we are in the early stages of developing and incorporating genetic information into our selection of other native plant materials in public land management. There is also a significant need to understand the interplay between our choices of germplasm and its ecological interaction in the landscape (for example, competitive interactions, pollination ecology, herbivory, etc.). It is hoped that this Guide will be further developed over time or lead to the production of other documents, workshops, policies or procedures, and serve as a catalyst to elevate the need (increase the awareness) for native seed collections and common garden studies.

Link: http://www.fs.fed.us/r2/publications/botany/plantgenetics.pdf

607. Saenz-Romero C, Snively AE, Lindig-Cisneros R. 2003. Conservation and restoration of pine forest genetic resources in Mexico. Silvae Genetica 52:233-237.

Type: Journal

Geographic Area: Michoacán, Mexico

Keywords: *Pinus*, genetic resources, adaptive genetic variation, conservation, biodiversity, reforestation, ecological restoration, seed zones, Mexico

Abstract: Deforestation rates in México are about 670,000 ha/year. This threatens the richness of forest genetic resources in México, causing the disappearance of locally adapted populations and rare and endangered pine species. México is one of the six megadiverse countries in the world, with half of the world's *Pinus* species. *Pinus* is one of the most economically and ecologically important forest genera in México. We suggest that delineation of seed zones and the establishment of a network of Forest Genetic Resource Conservation Units (FGRCUs), linked with forest management and ecological restoration programs will protect this valuable resource. We estimate that FGRCUs should include 25 to 50 ha each, with at least one FGRCU for each priority species in each seed zone. We highlight the need for studies of adaptive genetic variation among pine populations and for new methodologies and techniques to suit ecological restoration under Mexican forest conditions. We briefly describe ongoing research on these topics on forests owned by a well-organized indigenous community in Nuevo San Juan Parangaricutiro, Michoacán, western México.

608. Smith SE, Halbrook K. 2004. A plant genetics primer: basic terminology. Native Plants Journal 5:105-111.

Type: Journal

Geographic Area: Global

Keywords: terminology, concepts, glossary

Abstract: We present a basic introduction to genetic terminology that has implications for growers and users of native plants. An understanding of underlying genetic concepts is essential for ensuring that plant material of an appropriate source is planted on restoration sites.

Link: http://npj.uwpress.org/content/5/2/105.full.pdf+html

609. Smith SL, Sher AA, Grant TAI. 2007. Genetic diversity in restoration materials and the impacts of seed collection in Colorado's restoration plant production industry. Restoration Ecology 15:369-374.

Type: Journal

Geographic Area: Colorado, USA

Keywords: ecotype, genetic diversity, native plant production, seed collection

Abstract: The ever increasing demand for native plants and seed for use in restoration and revegetation has created a sizable industry. The large scale production and planting of native plants have given rise to a suite of ecological concerns including collection impacts, genetic diversity, and provenance. This study examines the practices and beliefs of 12 restoration plant production companies in Colorado with regard to arising ecological issues and identifies where further research is needed. We found that native seed collection in Colorado was largely unregulated and unmonitored and impacts were unknown. Maintaining genetic diversity in restoration materials is costly and does not have universal support. The use of provenance material (or local ecotypes) was hotly contested with strong and sound arguments on both sides of the issue. Procurement of pure ecotypes was difficult because of the variety of institutions involved in production and complications such as artificial selection and cross-pollination.

610. St. Clair JB, Johnson R. 2004. Structure of genetic variation and implications for the management of seed and planting stock. In: Riley LE, Dumroese RK, Landis TD, editors. Forest and Conservation Nursery Associations—2003. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-33. p 64-71.

Type: Government Document

Geographic Area: Western USA

Keywords: genetic structure, seed zones, breeding zones, seed transfer guidelines, genecology

Abstract: This paper reviews what is known about genetic structure of forest trees, and how that knowledge is used to determine safe limits to the movement of plant material. Geographic genetic variation in adaptive traits is of greatest importance to concerns of seed movement. Genetic structure in adaptive traits may be ascertained through long-term provenance and progeny tests, or short-term common garden studies in a nursery or nursery-like environment. These studies have shown that variation patterns are not consistent among species, among regions within a species, or among traits. The first seed zones were developed based on differences in climate and vegetation, and did not account for differences among species. Seed zones were recently revised in Oregon and Washington to reflect current knowledge of geographic genetic variation for individual species. Seed zones are an administrative convenience that directs managers how to bulk seeds from different stands. The use of seed transfer guidelines, on the other hand, allows greater flexibility and better knowledge of the risks of seed movement. Transfer guidelines, however, require keeping track of many small seed lots, which involves more time and expense.

Link: http://www.fs.fed.us/rm/pubs/rmrs_p033/rmrs_p033_064_071.pdf

611. Turesson G. 1922. The species and the variety as ecological units. Hereditas 111:100-113.

Type: Journal

Geographic Area: Global

Compilers' Keywords: genomics, plant adaptation, biogeography

Introduction (4th paragraph): In the efforts made by the writer to arrive at an understanding of the Linnean species from an ecological point of view—of the ecospecies, as I prefer to say in the following—studies have been made of a number of plant species. Usually species with extensive distribution, each occurring in as many different localities as possible, have been selected. The conditions in the natural habitats have been noted as far as possible, and seeds and pieces of turf have been collected and brought home from various habitats in order that the types might be followed in permanent cultures laid out in the experimental fields. A review at this stage of some of the results of these studies is intended to show the necessity and importance of a comparative study of organisms in their natural habitats and in the experimental field when the question of the differentiation of species and varieties is to be discussed.

612. Vander Mijnsbrugge K, Bischoff A, Smith B. 2010. **A question of origin: where and how to collect seed for ecological restoration.** Basic and Applied Ecology 11:300-311.

Type: Journal

Geographic Area: Global

Keywords: seed provenance, commercial seed collection, home-site advantage, local adaptation, habitat differentiation, seed collection zones, inbreeding and outbreeding depression, seed transfer, seed orchard

Abstract: Native plant species are routinely planted or sown in ecological restoration projects, but successful establishment and survival depend on where and how seeds are collected. Research suggests that it is important to use locally adapted seeds. Local populations often show a home-site advantage and non-local genotypes may be maladapted to local environmental conditions. Furthermore, intraspecific hybridisation of local and non-local genotypes may have a negative impact on the genetic structure of local populations via mechanisms such as outbreeding depression. Many species show a strong small-scale genetic differentiation between different habitats so that matching habitats of the restoration and donor site can be more important than minimizing geographical separation. It is a challenge to identify appropriate seed sources because strong small-scale population differentiation makes it difficult to delineate geographically defined seed zones to which seed exchange should be limited. Moreover, it is important to consider the genetic diversity of introduced material because it may be crucial to avoid genetic bottlenecks, inbreeding depression and poor establishment of plant populations. Repeated propagation in stock, which is often required to obtain a sufficient amount of seeds, can further reduce genetic diversity and may select for particular genotypes. Negative impacts of improper seed choice for nursery planting stock may become detectable only after many years, especially in long-lived and slow growing plants. Although scientific information on many species remains limited, the increasing demand for translocation of seed means that mandatory regulations are necessary. Guidelines should prescribe a specification of seed provenance, a record of genetic diversity of wild collections and rules for subsequent processing such as direct transfer and propagation of stock or seed orchards. We use a literature review to evaluate current legislation and to develop recommendations for herbaceous and woody species.

613. Willan RL, Barner H. 1993. **Matching seed source to planting site.** Humlebaek, Denmark: Danida Forest Seed Centre. Lecture Note B3. 25 p.

Type: Government Document

Geographic Area: Denmark, Europe

Compilers' Keywords: restoration, seed transfer, local adaptation, seed provenance

Compilers' Summary: This is a lecture on matching seed source to planting site from the Danida Forest Seed Centre in Denmark. It defines and discusses planting sites and seed sources in reference to considerations in reforestation efforts. Organized into six sections, it covers needs and methods for describing seed sources and planting sites, categories of sites and seed sources, problems in seed transfer of local and non-local sources, survey requirements, and use of improved seed sources (phenotypically or genetically) to new planting sites.

Link: http://curis.ku.dk/ws/files/20656861/b3_002.pdf

614. Williams G. 2007. **Local provenance plant seed and restoration: scientific imperative or romantic diversion?** New South Wales, Australia. 20 p.

Type: Report

Geographic Area: Australia

Compilers' Keywords: seed source, restoration

Introduction: It is a widely held assumption that plants used in revegetation projects should be derived from "local provenance" seed. Throughout the last twenty years or so this notion has been a central tenet of the extension literature in government funded natural resource management programs such as Landcare. On the whole I believe this assumption is based on unjustified and tenuous interpretations on the related scientific literature. Indeed in the last five years or so some individuals and organizations have begun to acknowledge that poor or even over-excited interpretation of provenance research has stymied good operational practice for ecological restoration. It is hoped that we are now seeing the beginning of the end of a simplistic application of the phenomenon of provenance to the practice of restoration. Nonetheless an insistence on using "local" seed retains a dominant place in the thinking of many practitioners within the natural resource management sector, contributing, in my view, to wasted resources and poor conservation outcomes. In this paper I argue that attempts at defining provenance in terms of fixed geography are unnecessary, technically unfeasible, and ultimately non-scientific, and that habitat matching is a better approach to identifying suitable sources of seed. I also attempt to use the discourse surrounding the promotion of provenance and local seed to address the broader idea of the relationship between culture, ecological knowledge and landscape-scale conservation "design." The practice of ecological restoration represents a cultural aspiration that inevitably results in the creation of new kinds of ecosystems no matter how ecologically stringent or scientifically objective our criteria and strategies appear to be. The provenance issue sheds light on the negative impact that poorly thought out ideas and approaches in applied ecology have to progress in achieving restoration goals. This is particularly the case where there is a failure to candidly acknowledge our role as active landscape designers and managers, and agents of landscape change.

Link: http://www.florabank.org.au/files/documents/provenance/Local_Provenance_Seed_Design_Romance_Science.pdf

615. Withrow-Robinson B, Johnson R. 2006. Selecting native plant material for restoration projects: ensuring local adaptation and maintaining genetic diversity. Corvallis (OR): Oregon State University Extension Service. EM 8885-E. 10 p.

Type: Report

Geographic Area: Pacific Northwest USA

Compilers' Keywords: common garden, ecoregion, seed zones, transfer guidelines

Introduction: Selecting appropriate plant materials for restoration projects contributes to the success of the project by ensuring better adaptation and survival of the plants. "Appropriate" means choosing species that are suitable for the site, are grown from locally adapted sources, and have a solid genetic base. This publication is for people involved in the important task of rehabilitating and restoring Oregon's threatened or degraded habitats. Growing numbers of private landowners, local organizations, and government entities are embarking on projects to restore the health or function of their riparian areas, wetlands, prairies, savannas, and other habitats. Choosing the right plants is critical to the long-term success of these projects, but it is not always as straightforward as it seems. Managers often lack a strong background in genetics and may be confused by competing (and sometimes conflicting) claims when collecting or buying seeds, seedlings, or other plant materials. The purpose of this publication is to help restoration managers ask and respond to two important questions: 1. Where should our plants come from; or, more specifically, what are the appropriate sources of origin for the plants to be used in our project? 2. Are we maintaining adequate genetic diversity in the plant materials we introduce? In this publication, we describe important concepts, such as source of origin, and management mechanisms, such as transfer guidelines. (Terms in bold are in the glossary, page 9.) Other commonly used terms such as "native" and "local" have vague or imprecise meanings and are discussed in the context of plant selection.

Link: http://extension.oregonstate.edu/catalog/pdf/em/em8885-e.pdf

616. Ying CC, Yanchuk AD. 2006. The development of British Columbia's tree seed transfer guidelines: purpose, concept, methodology, and implementation. Forest Ecology and Management 227:1-13.

Type: Journal

Geographic Area: Western Canada

Keywords: seed transfer, genecology, seed zones, climate change

Abstract: The development of forest tree seed transfer research, guidelines, regulations and policy has a long history in Canada, as well as in many other parts of the world. While the implicit assumptions of what is involved in developing seed transfer limits, guidelines and policy are generally accepted, the scientific and biological processes that underpin their validity are not readily available to most foresters. We provide an overview of the historical and current technical approaches to the development of seed transfer in British Columbia, and the overall framework which incorporates key biological, statistical and administrative issues in regulating the movement of forest tree seed. An example of how seed transfer information is developed from field experiments to guidelines or limits is provided from the lodgepole pine provenance tests in BC. Seed transfer research as it relates to the movement of wild or seed orchard seed will need to factor in the complications being predicted with climate change. As such, seed transfer research will continue to evolve as field experiments mature, new tests are established, statistical approaches and geographic information systems improve, and climate prediction tools attain greater resolution.

Link: http://www.abtreegene.com/toolkit/pdf/Adapt_Ying.pdf

Transfer Guidelines and Zones

General (583–616)—reviews, history, summaries, justification

Research (617–802)—genetic studies, tree improvement, climate change

Strategies (803–827)—framework, delineation, modelling

Resources (828–877)—guidelines, zones, maps, tools, software

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

617. Adams WT, Zuo J, Shimizu JY, Tappeiner JC. 1998. Impact of alternative regeneration methods on genetic diversity in coastal Douglas-fir. Forest Science 44:390-396.

Type: Journal

Geographic Area: Oregon, USA

Keywords: *Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco, allozymes, artificial reforestation, natural regeneration, gene conservation

Abstract: Genetic implications of natural and artificial regeneration following three regeneration methods (group selection, shelterwood, and clearcut) were investigated in coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* [Mirb.] Franco) using genetic markers (17 allozyme loci). In general, harvesting followed by either natural or artificial regeneration resulted in offspring populations little altered from those in the previous generation. Cutting the smallest trees to form shelterwoods, however, resulted in the removal of rare, presumably deleterious, alleles, such that slightly fewer alleles per locus were observed among residual trees (2.76) and natural regeneration (2.75) than found in uncut (control) stands (2.86). Thus, although the shelterwood regime appears quite compatible with gene conservation, it would be best to leave parent trees of a range of sizes in shelterwoods designated as gene conservation reserves, in order to maximize the number of alleles (regardless of current adaptive value) in naturally regenerated offspring. Seedling stocks used for artificial regeneration in clearcut, shelterwood, and group selection stands (7 total) had significantly greater levels of genetic diversity, on average, than found in natural regeneration. This is probably because the seeds used in artificial seedling stocks came from many wild stands and thus, sampled more diversity than found in single populations.

Link: http://www.fsl.orst.edu/pnwtirc/Electronic%20version%20of%20some%20pubs/Adams,%20Zuo,%20Shimizu,%20et%20al%20(1998).pdf

618. Andrew RL, Wallis IR, Harwood CE, Foley WJ. 2010. Genetic and environmental contributions to variation and population divergence in a broad-spectrum foliar defense of *Eucalyptus tricarpa*. Annals of Botany 105:707-717.

Type: Journal

Geographic Area: Australia

Keywords: additive genetic variance, open-pollinated common-garden experiment, genotype × environment interaction, plasticity, *Eucalyptus tricarpa*, sideroxylonal, formylated phloroglucinol compounds (FPCs), chemical defence

Abstract: Both environmental and genetic effects contribute to phenotypic variation within and among populations. Genetic differentiation of quantitative traits among populations has been shown in many species, yet it can also be accompanied by other genetic changes, such as divergence in phenotypic plasticity and in genetic variance. Sideroxylonal (a formylated phloroglucinol compound or FPC) is an important chemical defense in eucalypts. The effect of environmental variation on its production is a critical gap in our understanding of its genetics and evolution. The stability of genetic variation in sideroxylonal was assessed within and among populations of *Eucalyptus tricarpa* in three replicated provenance/progeny trials. The covariance structure of the data was also modelled to test whether genetic variances were consistent among populations and Fain's test was applied for major gene effects. A significant genotype x environment interaction occurred at the level of population, and was related to temperature range and seasonality in source populations. Within-population genetic variation was not affected by genotype × environment effects or different sampling years. However, within-population genetic variance for sideroxylonal concentration differed significantly among source populations. Regression of family variance on family mean suggested that this trait is subject to major gene effects, which could explain the observed differences in genetic variances among populations. These results highlight the importance of replicated common-garden experiments for understanding the genetic basis of population differences. Genotype × environment interactions are unlikely to impede evolution or responses to artificial selection on sideroxylonal, but the lack of genetic variation in some populations may be a constraint. The results are broadly consistent with localized selection on foliar defence and illustrate that differentiation in population means, whether due to selection or to drift, can be accompanied by changes in other characteristics, such as plasticity and genetic variance.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20228089

619. Barnes MG. 2009. The effect of plant source location on restoration success: a reciprocal transplant experiment with winterfat (*Krasheninnikovia lanata*) [Dissertation]. Albuquerque (NM): University of New Mexico. 156 p.

Type: Dissertation

Geographic Area: New Mexico, USA

Compilers' Keywords: common garden, genetic differentiation, *In situ*, morphological variation

Abstract: Ecological restoration is becoming more frequent due to the increased pace of land disturbance, more comprehensive government regulations, and the recognition of the valuable ecosystem services that natural areas provide. One part of restoration is revegetation, or the introduction of off-site plant materials to the restoration site. As the applications of revegetation have become more diverse, so too have the objectives of these projects. More specifically, it is increasingly important that plant propagules used in revegetation projects are from a location that is geographically or ecologically similar to the planting site. Local adaptation and population genetic differentiation studies have provided evidence supporting the use of local plant materials for revegetation with several native plant species, primarily grasses. However, along with grass species, shrub species are also frequently used in revegetation seed mixes. To better understand the consequences of using non-local plant materials, I chose to study the population biology of the widespread shrub winterfat (*Krascheninnikovia lanata*, Chenopodiaceae) among five populations in New Mexico, USA. The investigation of winterfat population biology included a comparison of winterfat plant morphology *In situ*, quantification of the ecological distance between the five sites, and measurement of the rate of emergence and floral onset in a greenhouse common garden. I also carried out a reciprocal transplant experiment in which individuals from different locations were planted in replicate common gardens. Transplant survival, size, and reproduction were quantified for two years. To complement the morphological studies, the genetic structure of winterfat was quantified using nine isozyme loci. Genetic variation, population differentiation, and correlations among genetic, geographic, and ecological distance were assessed. The following questions were addressed: (1) Do winterfat populations differ in the vegetative or inflorescence size of individuals in the field? (2) Do winterfat populations differ in emergence phenology in the greenhouse? (3) Do winterfat populations differ in floral phenology in the greenhouse? (4) How do study sites differ in soil characteristics, climate, and plant community composition? (5) Do winterfat plants perform better than plants from other locations at their site of origin? (6) Was the weather at the planting locations during the experiment different from the historical climate at those locations? (7) How much neutral genetic variation do these populations of winterfat possess? (8) How is this neutral genetic variation partitioned among populations? (9) Is genetic distance correlated with geographic or ecological distance? The data from these experiments will assist restoration practitioners in determining appropriate plant material sources for revegetation project.

620. Barnett JP, Brissette JC. 2007. Regenerating shortleaf pine: results of a 5-year cooperative research initiative. In: Kabrick JM, Dey DC, Gwaze D, editors. Shortleaf Pine Restoration and Ecology in the Ozarks. Newtown Square (PA): USDA Forest Service, Northern Research Station. General Technical Report NRS-P-15. p 105-111.

Type: Government Document

Geographic Area: Southern USA

Compilers' Keywords: shortleaf pine, *Pinus echinata*, reforestation, transfer guidelines

Abstract: Shortleaf pine (*Pinus echinata* Mill.) is unique among the southern pines. It has the widest natural range and thrives on shallow rocky soils of the Interior Highlands, where most other pine species perform poorly.

Although wood quality is excellent, it has been one of the most neglected species from both research and operational standpoints. It has a history of poor performance following outplanting with survival of less than 50%. The technology to change this situation was developed after formation of the Shortleaf Pine Artificial Regeneration Taskforce in 1984. Over a 6-year period, 15 studies were installed in Arkansas and Oklahoma to address seedling production and establishment. Information resulting from these studies resulted in increased seedling survival in both the Ozark and Ouachita National Forests. This paper summarizes research from these and other studies that led to the improved success in reforestation of the species.

Link: http://www.treesearch.fs.fed.us/pubs/12840

621. Bates CG. 1930. The frost hardiness of geographic strains of Norway pine. Journal of Forestry 28:327-333.

Type: Journal

Geographic Area: Central USA

Compilers' Keywords: geographic strains

Introduction: Norway pine (*Pinus resinosa*) is a species which covers a comparatively narrow latitudinal range, although in its range from the northeastern coast to the Lake States and southern Canada it encounters summer temperature differences of about 10 °F and considerably greater differences in mid-winter temperatures (-35 and -40 °F in the northwestern part of the range to not much below zero in the Alleghenies, these being mean annual minima). Nearly as great differences are found in winter if mean January temperatures be considered, of from 0 to 30 °F. Because of its great commercial value and its extensive use on reforestation projects, Norway pine has been chosen by the Lake States Forest Experiment Station as the first species to be subjected to a scrutinizing study of geographical, varietal, and individual differences, or in other words to a "breeding" study whose primary purpose is to determine what "seed zones" should be recognized in order to avert failures in planting due to lack of local adaptation. But because of the great uniformity of appearance and development of the species, as well as the considerations mentioned in the first paragraph above, the writer has felt some doubts as to whether outstanding differences would be likely to be developed by such a study. Therefore, to "anticipate" to some extent the results of field comparisons which were started at the same time through nursery sowings of 41 different collections of Norway pine seed, an indoor experiment was begun which it was hoped would bring out the existence of physiological differences affecting hardiness. Without going into the question of what comprises hardiness to freezing temperatures, it may be stated as more or less obvious that differences within a species should develop according as its local forms have become adapted to long or short growing seasons, and to moderately or extremely low winter temperatures.

622. Benowicz A, Hirondelle SL, El-Kassaby YA. 2001. Patterns of genetic variation in mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) with respect to height growth and frost hardiness. Forest Ecology and Management 154:23-33.

Type: Journal

Geographic Area: Western Canada

Keywords: *Tsuga mertensiana*, intra-specific variation, frost hardiness, growth rate, seed transfer

Abstract: Genetic structure (variance among and within populations) and geographic pattern of variations in growth and frost hardiness of mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) populations from coastal British Columbia (BC) were examined. Populations fell into two main groups—south coast (16 sources) and north coast (two sources). Height growth of greenhouse grown seedlings was measured during the first growing season on a weekly basis whereas frost hardiness and branch water content were evaluated during the fall at monthly intervals. Significant differences among the populations were found in maximum instantaneous growth rate, height at the end of the growing season and in October and November front hardiness. There were no differences in date of maximum growth rate, branch water content and September frost hardiness. Most of the genetic variance was found within populations: 77% for height, maximum growth rate and November frost hardiness and 87% for October frost hardiness. Geographic trends were identified using multiple linear regression and canonical correlation analyses based on population means and latitude, longitude and elevation of the population origin. The uneven distribution of sources limited the extrapolation, but some general trends appeared. Maximum instantaneous growth rates increased with latitude, elevation and decreased longitude ($R^2 = 0.64$) and consequently were negatively correlated with the length of the growing season in the seed collection sites. Both populations from the north coast developed frost hardiness earlier than any population from the south coast. The relationship between climate coldness and growth rates has potential implications for seed transfer guidelines. Due to their higher growth rates, plants from higher altitudes may accomplish the same amount of growth within a shorter period compared to plants from lower altitudes when both are transferred north. Results of the frost hardiness tests indicate that seed transfer along the British Columbia coast of more than 3 degrees northward will considerably increase chances of frost damage in plantations.

Link: http://www.researchgate.net/publication/222958778_Patterns_of_genetic_variation_in_mountain_hemlock_(Tsuga_mertensiana_(Bong.)_Carr.)_with_respect_to_height_growth_and_frost_hardiness/file/79e41513134e126d13.pdf

623. Bhattarai K, Bushman BS, Johnson DA, Carman JG. 2010. Phenotypic and genetic characterization of western prairie clover collections from the western United States. Rangeland Ecology & Management 63:696-706.

Type: Journal

Geographic Area: Western USA

Keywords: amplified fragment length polymorphism (AFLP), conservation, *Dalea*, Great Basin, legume, population structure, revegetation

Abstract: Few North American legumes are available for rangeland revegetation in the semiarid western United States. Western prairie clover (*Dalea ornata* [Douglas ex Hook.] Eaton & J. Wright) is a perennial legume with desirable forage characteristics and is distributed in the northern Great Basin, Snake River Basin, and southern Columbia Plateau. Understanding the genetic and ecotypic variability of this species is a prerequisite for developing populations suitable for revegetation purposes. To address this need, we established two common-garden plots of western prairie clover from 22 sites in Idaho, Oregon, and Washington. Significant variation was detected among the collections for all traits measured. Among the measured traits, flowering date was correlated with collection-site temperature and elevation. Population structure estimates from 474 amplified fragment length polymorphism markers resulted in two distinct, genetically differentiated groups and a third admixed group, and flowering date played a significant role in discriminating those genetic-based groupings of collections. Positive correlations were observed between phenotypic and genetic distance matrices ($r = 0.33$, $P = 0.005$), phenotypic and geographic distance matrices ($r = 0.35$, $P = 0.002$), and genetic and geographic distance matrices ($r = 0.31$, $P = 0.009$). Based on these results, we recommend that two germplasm sources of western prairie clover be developed for use across the collection area, one from the Deschutes River region and the other encompassing Idaho, Washington, and eastern Oregon collection sites.

624. Bouvet JM, Vigneron P. 1996. Variance structure in Eucalyptus hybrid populations. Silvae Genetica 45:2-3.

Type: Journal

Geographic Area: Congo, Africa

Compilers' Keywords: reciprocal recurrent selection, factorial mating design, variance components, *Eucalyptus urophylla*, *Eucalyptus pellita*, *Eucalyptus grandis*

Summary: This article presents the analyses of the first mating designs established in the reciprocal recurrent selection scheme of *Eucalyptus* in Congo. Two selection schemes were involved, the first one concerning *E. urophylla* • *grandis*, the second one concerning *E. urophylla* • *pellita*. For each of the hybrid species, height, circumference and volume were measured until 3 of 4 years (half of the rotation age). Male additive variance was lower than female additive variance (30% of the additive variance) for the 2 hybrids. It was demonstrated by studying correlation between parent phenotype and parent crossbreeding value in *E. urophylla* that the higher additive variance for females was probably due to selection of males for their phenotypic value. This result implies a weaker selection intensity for the males in order not to heavily reduce the variability. Variance structure was different according to considered hybrids. For circumference, additive variance accounted for 80% of total genetic variance in *E. urophylla* • *grandis* and only 40% in *E. urophylla* • *pellita*. Sampling of parents and/or genetic distance between species could be an explanatory factor of this difference.

Link: http://www.silvaegenetica.com/fileadmin/content/dokument/archiv/silvaegenetica/45_1996/45-2-3-171.pdf

625. Bower AD, Aitken SN. 2006. Geographic and seasonal variation in cold hardiness of whitebark pine. Canadian Journal of Forest Research 36:1842-1850.

Type: Journal

Geographic Area: California, USA

Compilers' Keywords: *Pinus albicaulis*, common garden, adaptation

Abstract: Artificial freeze-testing utilizing the electrolyte-leakage method was used to test the cold hardiness of 2-year-old whitebark pine (*Pinus albicaulis* Engelm.) seedlings growing in a common garden. Testing across all seasons was used to determine the annual pattern of cold hardiness, and more intensive sampling in the fall and spring was used to assess genetic variation in cold injury among geographic regions spanning the range of the species. Mean hardiness varied widely from −9 °C in early summer to below −70 °C in the winter. Trees from interior and northern regions were the hardiest in the fall, while trees from California were the least hardy. Geographic patterns of hardiness in the spring were reversed. Significant differences in cold injury among regions were detected on all dates except during the winter. Heritability was low to moderate for both the spring ($h^2 = 0.18$) and the fall ($h^2 = 0.28$), and genetic correlation was weak ($r_A = 0.18$). Only spring cold injury was genetically correlated with date of needle flush ($r_A = 0.34$). Mean cold injury in the fall was most closely correlated with mean temperature of the coldest month in the parental environment ($r = 0.81$). Whitebark pine is well adapted to the low temperatures of the harsh environments where it is found; however, regional variation indicates that moving seed for restoration purposes from areas with higher winter temperatures to colder environments may increase the chance of fall cold injury.

626. Bower AD, Aitken SN. 2007. Genetic diversity and geographic differentiation in quantitative traits and seed transfer guidelines for whitebark pine. In: Goheen EM, Sniezko R, editors. Whitebark Pine: A Pacific Coast Perspective. Portland (OR): USDA Forest Service, Pacific Northwest Region. R6-NR-FHP-2007-01. p 98-101.

Type: Government Document

Geographic Area: Western Canada

Compilers' Keywords: *Pinus albicaulis*, restoration, common garden, white pine blister rust, mountain pine beetle, *Dedroctonus ponderosae*

Introduction: Whitebark pine (*Pinus albicaulis* Englem.) has declined dramatically throughout its range due to white pine blister rust (caused by the fungus *Cronartium ribicola* J.C. Fisch.), successional replacement resulting from fire suppression, and attack by mountain pine beetle (*Dendroctonus ponderosae* Hopkins). Restoration is needed to halt or reverse this decline; however, no information regarding genetic diversity and local adaptation of quantitative traits is available to guide these efforts. A seedling common garden experiment was employed to assess genetic diversity and geographic differentiation of quantitative traits (Q_{ST}) of whitebark pine and to determine the climatic variables driving local adaptation. Seedlings from 48 provenances from a near range-wide seed collection were grown in raised beds in Vancouver, B.C. for two years in two soil temperature treatments (ambient and cold). Seedlings were measured for second year height increment, total biomass, root : shoot ratio, date of needle flush, fall and spring cold injury, and survival. Significant differences were found between soil temperature treatments for height growth and survival, with seedlings in the cold treatment performing better. The environment where the test was grown (Vancouver, B.C.) is considerably warmer than the natural habitat of whitebark pine. While most temperate forest trees would likely benefit from the warmer soil temperatures, it appears that this is a stressor for a species adapted to cold, harsh environments.

Link: http://www.fs.fed.us/outernet/r6/nr/fid/wbpine/papers/2007-wbp-wpbr-resist-bower.pdf

627. Bower AD, Aitken SN. 2008. Ecological genetics and seed transfer guidelines for *Pinus albicaulis* (Pinaceae). American Journal of Botany 95:66-76.

Type: Journal

Geographic Area: Western North America

Keywords: genetic variation, geographic differentiation, local adaptation, *Pinus albicaulis*, quantitative traits, seed transfer, whitebark pine, white pine blister rust

Abstract: Whitebark pine (*Pinus albicaulis* Engelm.) has greatly declined throughout its range as a result of introduced disease, fire suppression, and other factors, and climate change is predicted to accelerate this decline. Restoration is needed; however, no information regarding the degree of local adaptation is available to guide these efforts. A seedling common-garden experiment was employed to assess genetic diversity and geographic differentiation (Q_{ST}) of whitebark pine for traits involved in growth and adaptation to cold and to determine climatic variables revealing local adaptation. Seedlings from 48 populations were grown for two years and measured for height increment, biomass, root to shoot ratio, date of needle flush, fall and spring cold injury, and survival. Significant variation was observed among populations for most traits. The Q_{ST} was low (0.07–0.14) for growth traits and moderate (0.36–0.47) for cold adaptation related traits, but varied by region. Cold adaptation traits were strongly correlated with mean temperature of the coldest month of population origins, while growth traits were generally correlated with growing season length. We recommend that seed transfer for restoration favor seed movement from milder to colder climates to a maximum of 1.9 °C in mean annual temperature in the northern portion of the species range, and 1.0 °C in the U.S. Rocky Mountains to avoid maladaptation to current conditions yet facilitate adaptation to future climates.

628. Broadhurst LM, North T, Young AG. 2006. Should we be more critical of remnant seed sources being used for revegetation? Ecological Management and Restoration 7:211-217.

Type: Journal

Geographic Area: Australia

Keywords: *Acacia*, fitness, fragmentation, genetics, restoration, revegetation, seed quality, self-incompatibility

Abstract: A challenge for land managers restoring degraded agricultural landscapes across southern Australia will be to ensure the viability of remnant vegetation while simultaneously supplying the quantities of appropriate seed required for revegetation. To ensure such revegetation programs have the best chance of success, seed that is both genetically diverse and locally adapted will be required. Identifying suitable seed sources can be particularly difficult in regions where local seed sources are restricted to small and isolated remnants. Gold-dust Wattle (*Acacia acinacea* Lindl.) is a key revegetation species in the Deniliquin region of New South Wales; however, broadscale land clearing in the area has limited local seed sources to a few remnant stands. Field-based experience suggests that revegetation success may depend upon the source of seed used, raising the question of whether differences in the germination and survival of seed reflect functional problems within these source populations. To test this possibility, seed was collected from 15 mothers in each of three seed sources regularly used for local restoration programs. Seed quality for each mother was assessed in terms of seed production and seedling fitness. In addition, genetic diversity and mating system parameters were determined to assess whether these explained the seed quality responses observed. Differences among the seed sources with respect to seed quality were generally congruent with field-based predictions. High levels of correlated paternity in the two poorly performing seed sources probably reflect limited mating availability due to smaller population sizes and genetic incompatibility being mediated by a self-incompatible reproductive strategy. Further research

is now required to determine whether observed variability in the quality of seed from remnant vegetation in degraded landscapes is compromising revegetation efforts, and to help practitioners develop strategies to critically evaluate their seed sources.

629. Broadhurst LM, Young AG, Thrall PH, Murray BG. 2006. **Sourcing seed for *Acacia acinacea*, a key revegetation species in South Eastern Australia.** Conservation Genetics 7:49-63.

Type: Journal

Geographic Area: Australia

Keywords: AFLP, morphology, ploidy, revegetation, seed sourcing

Abstract: Intensive large-scale revegetation programs are a major activity in degraded landscapes. The collection and deployment of seed for revegetation is primarily based on local seed sources to preclude concerns associated with local adaptation as well as outbreeding depression in small remnant populations. For most species however, little is known about the levels of genetic diversity being sourced and deployed, or even of the levels of adaptively significant variation present across the species range. *Acacia acinacea* (Gold Dust wattle) is a key revegetation species widely distributed across south eastern Australia. Levels of variation in terms of morphology, fitness, ploidy level and AFLPs were assessed using seed lots from 35 populations across the Murray Darling Basin in south eastern Australia. Multivariate analysis indicated that three of the populations were misidentified while the remaining populations were differentiated into three groups. One of these groups (Bendigo) was highly geographically localized and tetraploid while the other two (Group 1 and Group 2) were both diploid with overlapping distributions. Fitness differences were also evident among these three groups while AFLPs indicated that they were genetically differentiated and that lower levels of diversity were captured from some populations. A major finding of this study was that no one technique was able to fully describe the variation present in *A. acinacea* and seed sourcing guidelines based on any single approach could have resulted in erroneous decisions being made. Information generated from this study has been used to refine seed sourcing guidelines.

630. Campbell RK. 1974. **Use of phenology for examining provenance transfers in reforestation of Douglas-fir.** Journal of Applied Ecology 11:1069-1080.

Type: Journal

Geographic Area: Pacific Northwest USA

Compilers' Keywords: *Pseudotsuga menziesii*, seed transfer guideline, genetic differentiation, adaptive phenotype

Introduction: 'Seed transfer' in reforestation is the process of moving seed, or seedlings, from place of origin to alternative planting sites. Strong support for the theory of optimality of local populations has been presented by Langlet (1936) and Clausen, Keck & Hiesey (1948). Consequently, use of non-local seed is avoided if possible to minimize losses of vigor or fitness; but in cases where local seed is not available, transfer guides are necessary. For Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in western Washington and Oregon, present guides are rules of thumb taken from Swedish models. Therefore, a method for early examination of effects of moving seed would be helpful. This report presents a simple predictive model which uses timing of vegetative bud burst for examining responses of seedlings to transfer. The main assumptions included in the model were: (1) genetic differentiation in timing of bud burst is in response to adaptive selection; (2) the timing of bud burst in an adapted phenotype is a function of the physiological response of that provenance to temperature; (3) chilling requirements of all provenances will be satisfied by normal winter temperatures, regardless of the part of the region to which they are moved. Only the first assumption is examined in this report, by the method of provenance- habitat correlations. The other two assumptions are supported in the literature; for example, timing of bud burst appears to be almost exclusively temperature mediated if chilling requirements are met (Wommack 1964; Lavender & Hermann 1970). Also the chilling requirement of Douglas-fir is less than 80 days of temperatures lower than 10 °C (Wommack 1964), whilst in any winter most of the region under consideration will have more than 100 days in which maximum temperatures will not rise above 120 °C (Wakefield 1969). The exceptions are in south-coastal Oregon and California, a negligible part of the Douglas-fir region. The model required two sets of equations. The first, based on an experiment using forty-four provenances, describes timing of bud burst as a function of average daily temperature. The second describes pattern of average daily temperature at stations where provenances were collected. Together, the equations provided functions for predicting bud-burst dates. Predicted dates were then used to examine hypothetical effects of transferring seed along elevational and latitudinal gradients.

631. Campbell RK. 1979. **Genecology of Douglas-fir in a watershed in the Oregon Cascades.** Ecology 60:1036-1050.

Type: Journal

Geographic Area: Oregon, USA

Keywords: adaptation, Douglas-fir, genetic differentiation, genetic variance, natural selection, provenance, seed source, seed transfer, topocline

Abstract: To gain insight into genetic microstructure of subregional populations of coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*), genetic variability in a population found on a 6,100-ha, central Oregon watershed is described.

Genotypic values of 193 parent trees located throughout the watershed were estimated from progeny grown in a common garden. Then, genetic variation was partitioned into components attributable to parent-tree location and to differences among trees within locations. Within-location variation appeared to be homogeneous in the watershed; between-location variation was related to topography, but the patterns of trait variation differed depending on the trait measured. Growth traits exhibited strong gradients with elevation, but the relationship varied depending on position within the watershed. Based on estimates of proportions of nonadapted seedlings in hypothetical transfers of seed from one part of the watershed to another, genetic differentiation within the watershed was surprisingly large. In one transfer of 3.5 km between north- and south-facing slopes at the same elevation: 80% of seedlings were estimated to be poorly adapted. Although other possibilities exist, the topoclinal variation in traits probably results from selection as does the large within-location variation. Both kinds of variation are due to high selection intensities in the seedling stage, the former to selection by average environmental differences along gradients, the latter to microenvironmental heterogeneity. The combination of high within- and between-habitat variation is suited to a species which episodically colonizes an environment that is extremely heterogeneous in time and space.

Link: http://andrewsforest.oregonstate.edu/pubs/pdf/pub1701.pdf

632. Campbell RK. 1986. Mapped genetic variation of Douglas-fir to guide seed transfer in southwest Oregon. Silvae Genetica 35:2-3.

Type: Journal

Geographic Area: Oregon, USA

Compilers' Keywords: seed source, seed transfer zones, provenance, *Pseudotsuga menziesii*

Summary: A procedure is illustrated for using mapped genetic variation in indigenous species to develop provisional seed transfer rules and seed zones. Genotypic values for 13 traits of 135 parent trees from 80 locations furnished data for Douglas-fir in a region in southwest Oregon. Values were estimated from open-pollinated progeny grown in two nursery beds. Two principal components accounted for about 96% of the total family and seed-source variation in all traits. There were strong gradients with location variables: elevation, latitude, distance from the ocean, slope, and sun exposure as affected by shade of adjacent mountains. Seed transfer rules and a procedure for calculating relative risk indicated that risks were large when seed was transferred either east-west along the southern boundary or north-south along the western boundary of the region. These gradients in risk coincide with the steepest precipitation and temperature gradients in the region. Advantages, disadvantages, and potential sources of error in the procedure are discussed. In spite of the limitations of genetic mapping, the conclusion is that for genetically heterogeneous species in mountainous regions, genetic mapping is a prerequisite to directly estimating transfer effects by long-term tests.

Link: http://www.silvaegenetica.com/fileadmin/content/dokument/archiv/silvaegenetica/35_1986/35-2-3-85.pdf

633. Campbell RK. 1991. Soils, seed-zone maps, and physiography: guidelines for seed transfer of Douglas-fir in southwestern Oregon. Forest Science 37:973-986.

Type: Journal

Geographic Area: Oregon, USA

Keywords: *Pseudotsuga menziesii*, adaptation, ecogeographic center-genetic variation, genecology

Abstract: One procedure for guiding seed transfer is to partition the species habitat into zones within which there is little genetic variation from location to location. This report compares soil types and the existing regional seed zones as bases for classifying geographic genetic variation into zones. The data used were genotypic values of 135 Douglas-fir (*Pseudotsuga menziesii*) trees from 80 locations in southwestern Oregon. Genotypic values were estimated by measuring traits expressing phenology and growth potential of 2-yr seedlings in a common-garden experiment. Neither the soils model nor the seed-zones model satisfactorily classified geographic genetic variation (significant lack of fit). When physiographic variables (latitude, longitude, elevation, etc.) were added to the models, the added variables accounted for 16% to 23% of the total variation among locations. Gradients of genetic variation therefore exist within soil types and present seed zones. These gradients reflect the overall gradients of geographic variation with latitude, longitude, and elevation that occur in the region. The results suggest that zones constructed from physiographic model may explain more of the genetic variation in southwestern Oregon than do either soils or seed-zones models.

634. Campbell RK, Sorensen FC. 1978. Effect of test environment on expression of clines and on delimitation of seed zones in Douglas-fir. Theoretical Applications of Genetics 51:233-246.

Type: Journal

Geographic Area: Pacific Northwest USA

Keywords: *Pseudotsuga menziesii*, genecology, provenance, genotype-temperature interactions, fertilizer interactions

Abstract: Clinal models of population structure in an indigenous tree species can be used to delineate seed collection zones and breeding zones, and to devise transfer rules. Models may be developed by growing populations in test environments; however, a clinal description may be a function of test environments as well as of population genotypes. This possibility was studied by growing seedlings from 40 populations of northwestern U.S. Douglas-fir (*Pseudotsuga* *menziesii* var. '*menziesii*' [Mirb.] Franco) in eight nursery-bed treatments which contrasted air and soil temperatures and nutrition. Growth traits measured were stem diameter, top height, and dry weight; phenological traits were bud-burst and bud-set dates, extension period, and extension period midpoint. Population samples interacted significantly with soil temperature for growth traits, and with soil and air temperatures combined for phenological traits. Interactions were at least partly explained by complex clinal associations of seedling performance with elevation, with latitude, and with distance from the ocean of the populations sampled. Both the complexity and the gradient of the clinal pattern depended on the trait and on the specific test environment. The clinal patterns of greatest complexity were expressed in warm air and soil treatments. Dry top-weights of population samples were associated with latitudes for samples grown in warm soils, but this relationship was not apparent in cool soils. A discrepancy in bud-burst dates between extreme coastal and more inland populations was greatest in warm soil-warm air treatments and was negligible in cool soil-cool air treatments. Populations x temperature interactions were attributed to the differential response of population samples to spring temperature and photoperiod. It is proposed that first attempts at devising a model can be based on nursery or growth chamber tests, and that test environments should stress contrasting photo- and temperature-regimes. The estimate of clinal structure in Douglas-fir suggests that there is more risk within northwestern U.S. in moving provenances east-west than north-south, that this risk increases with elevation of provenances, and that north-south transfers are more critical near the coast than inland.

635. Campbell KA, Hawkins CDB. 2004. Effect of seed source and nursery culture on paper birch (*Betula papyrifera*) uprooting resistance and field performance. Forest Ecology and Management 196:425-433.

Type: Journal

Geographic Area: Western Canada

Keywords: root strength, paper birch, nursery practices, stocktype, seed source, ground line diameter

Abstract: Little is known about the effect of seed source and nursery culture on the growth and performance of artificially regenerated paper birch planted in the field. In the summer of 2000, trees were vertically uprooted in Prince George, BC using a tripod and winch device to determine if seed source and nursery culture significantly affected the root strength of 5-year-old paper birch. Trees from a seed source in the Skeena region had the greatest uprooting resistance, and the most root biomass, but the least root strength compared to the other three seed sources tested. The Skeena trees may be exhibiting an adaptive strategy which provides maximum root reinforcement across a wide range of environments. Uprooting resistance was similar for the 415D stocktypes grown at Red Rock and Kalamalka nurseries. However, trees grown in 515A styroblock at Kalamalka had the least uprooting resistance and root biomass of all treatments. In addition, the relationship between uprooting resistance and ground line diameter was different between nurseries. The results of this study suggest that regardless of height and diameter leaving the nursery, seed source root resistance and growth continued to be impacted by nursery culture 5 years after planting.

636. Campbell KA, Pawuk WA, Harris AS. 1989. Microgeographic genetic variation of Sitka spruce in southeastern Alaska. Canadian Journal of Forest Research 19:1004-1013.

Type: Journal

Geographic Area: Alaska, USA

Compilers' Keywords: Sitka spruce, *Picea sitchensis*, common garden, principal component analysis, seed transfer, microgeographic

Abstract: Microgeographic genetic variation among populations of Sitka spruce on Mitkof Island in southeastern Alaska is described. In two common-garden environments, we evaluated genotypes of 208 parent trees from 114 locations in a 17,000-ha area. Two principal components accounted for most of the variation among locations in 11 traits measured to evaluate growth vigor and rhythm of 2-yr old seedlings. Regression analyses of factor scores derived from principal components revealed genetic gradients associated with elevation, slope, aspect, and west-east and north-south directions. Large amounts of additive genetic variation in factor scores occurred among trees within locations. When this variation within locations was used as a scale, variation among locations was also large. In an extreme case, locations differed in factor scores of the first principal component by about 3.0 units of the standard deviation of additive genetic variation in factor scores. Of the total differentiation in this case, elevational range (600 m) contributed 0.7 units of standard deviation, aspect contributed 0.9 units, and distance (16 km) from north central to southeastern parts of the island contributed 1.4 units.

637. Carles S, Lamhamedi MS, Beaulieu J, Stowe DC, Margolis HA. 2011. Differences in growth and mineral nutrition of seedlings produced from ten white spruce seed orchards. New Forests 42:195-214.

Type: Journal

Geographic Area: Eastern Canada

Keywords: *Picea glauca*, seed orchard, seedlings, logistic function, mineral nutrition, seed zones

Abstract: To meet the needs for improved spruce seeds in the province of Quebec, Canada, 17 first-generation white spruce seed orchards (SO) were established. These SOs are located in different bioclimatic domains and contain seed trees originating from geographically and genetically distinct sources. To evaluate the influence of SO on seedling growth and morphology, seedlings produced with seeds originating from the ten most commonly used first-generation white spruce SO in Quebec were raised under similar nursery conditions. Tissue nutrient concentrations of seedlings evolved similarly among seed orchards during the second growing season. At the end of the growing season, only shoot phosphorus concentrations were significantly different. When modeled with a logistic function, there was a significant difference between height and diameter growth curve parameters of seedlings from distinct SO during the second growing season. These differences led to significant differences in the height and shoot dry mass of the seedlings at the end of their second growing season, but not in their diameter or root dry mass. The ten SOs were clustered in two groups according to the above-ground characteristics of their progeny. This limited amount of morphological diversity suggests that expanding the size of the present seed zones may be an appropriate course of action for white spruce seed production in Quebec.

638. Casler MD, Stendal CA, Kapich L, Vogel KP. 2007. **Genetic diversity, plant adaptation regions, and gene pools for switchgrass.** Crop Science 47:2261-2273.

Type: Journal

Geographic Area: Central and Eastern USA

Compilers' Keywords: *Panicum virgatum*, transfer guidelines, seed transfer zone, ecoregion

Abstract: Switchgrass (*Panicum virgatum* L.) is a perennial grass native to the North American tallgrass prairie and broadly adapted to the central and eastern USA. Transfer of germplasm throughout this region creates the potential of contaminating local gene pools with genes that are not native to a locale. The objective of this study was to identify structural patterns and spatial variation for molecular markers of switchgrass populations from the northern and central USA. Forty six prairie-remnant populations and 11 cultivars were analyzed for random amplified polymorphic DNA (RAPD) markers. Although there was significant population differentiation, little of this variation was associated with geographic regions. A small amount of population differentiation was associated with hardiness zones and ecoregions, suggesting that a recent proposal to use these two criteria for defining plant adaptation regions has merit for defining gene pools and seed-transfer zones of switchgrass. Cultivars of switchgrass cannot be differentiated from prairie-remnant populations in the northern and central USA on the basis of RAPD markers, indicating that they are still highly representative of natural germplasm. Seed sources of switchgrass can be moved considerable distance within hardiness zones and ecoregions without causing significant contamination, pollution, swamping, or erosion of local gene pools.

Link: http://afrsweb.usda.gov/SP2UserFiles/Place/36200000/Casl-S2.pdf

639. Chen THH, Howe GT, Bradshaw HDJ. 2002. **Molecular genetic analysis of dormancy-related traits in poplars.** Weed Science 50:232-240.

Type: Journal

Geographic Area: USA

Keywords: black cottonwood, *Populus trichocarpa* Torr. & Gray, eastern cottonwood, *Populus deltoids* Bartr. Ex Marsh.

Abstract: We studied the molecular genetics of dormancy-related traits in an F_2 family of poplar (*Populus*) hybrids derived from a cross between a northern genotype of black cottonwood and a southern genotype of eastern cottonwood by mapping quantitative trait loci (QTLs) and candidate genes. Dormancy-related traits included timing of vegetative bud set, fall frost damage, chilling response, timing of vegetative bud flush, and winter survival under field conditions, as well as photoperiodic responses (timing of bud set and number of new leaves) in a warm greenhouse under either a uniform 8-h photoperiod or a naturally shortening photoperiod in the fall. QTL analyses were conducted using a linkage map consisting of AFLP, microsatellite, and candidate gene markers. The candidate genes were chosen because of their potential roles in either photoperiodic perception (*PHYB1, PHYB2*) or abscisic acid signal transduction (*ABI1B, ABI1D, ABI3*). Significant QTLs were detected for all dormancy-related traits, except for winter survival, which had a relatively low heritability compared with the other traits. Interestingly, half of the field bud set QTLs did not map near photoperiodic QTLs. This is consistent with the moderate genetic correlation between these traits (0.53 to 0.60) and suggests that genetic differences in photoperiodic responses play only a modest role in explaining genetic differences in the timing of bud set under field conditions. Except for *ABI1D*, each of the candidate genes tested mapped near one or more of the dormancy-related QTLs. We conclude that molecular markers and QTL analyses can be used to study the genetics of dormancy-related traits, to design more effective breeding programs, and to provide new insights into tree physiology.

640. Conkle MT. 1973. **Growth data for 29 years from the California elevational transect study of ponderosa pine.** Forest Science 19:31-39.

Type: Journal

Geographic Area: California, USA

Keywords: *Pinus ponderosa* Laws., elevational transect, genetic adaptation, genotype and environmental interaction

Abstract: Ponderosa pine progenies from parents restricted in latitude but spanning 7,000 feet of elevation show significant growth differences in plantations at low-, mid-, and high-elevation test sites. At low- and mid-elevation sites tree heights and diameters of progenies from high-elevation parents were the smallest; those from the low-elevation parents, intermediate; and those from mid-elevation seed parents,

largest. At the high elevation site, trees from mid- and high-elevation sources grew equally well, whereas trees from low-elevation parents showed poorest growth. The variation associated with elevation zone of parent trees accounted for 8 percent of the total experimental variation. About 9 percent of the total was attributed to the interaction between parent tree elevational zones and plantations. Height rankings of progenies for different ages showed little change over the 29-year growth period of the study in low- and mid-elevation test sites. But at the high-elevation test site, height means for zone groups shifted with age as the relative heights of the higher elevation progenies increased.

Link: http://www.treesearch.fs.fed.us/pubs/32836

641. Czarnecki DM, Norcini JG, Zhanao D. 2007. **Phenotypic diversity of *Coreopsis leavenworthii* TORR. & GRAY (Asteraceae).** Native Plants Journal 8:45-57.

Type: Journal

Geographic Area: Florida, USA

Keywords: common-garden study, phenotypic variation, genetic diversity, population differentiation, wildflower

Abstract: *Coreopsis leavenworthii* Torr. & Gray (Asteraceae), one of the Florida state wildflowers, is nearly endemic to and very ubiquitous in Florida. Interest in commercial seed or plant production of this species as well as use for highway beautification, native plant community restoration, and mine reclamation has been increasing in recent years. This study aimed to understand the level and geographic distribution of phenotypic diversity of this species, a critical step before engaging in large-scale commercial production of native plants. Plants derived from natural and commercial seed production populations exhibited a substantial amount of phenotypic diversity when grown in a common garden study. North Florida natural populations typically had bipinnately compound leaves with dark-yellow ray flowers, while natural populations originating in central or south Florida had simpler, needle-like leaves, and light-yellow and dark-yellow ray flowers. Populations were grouped into 3 clusters in principal component analysis. Two natural populations from central Florida were dissimilar and grouped into separate clusters, indicating possible existence of genetic isolation in the species' distribution. Three production populations originating from the same native population in central Florida were phenotypically similar even though they had been grown under different climatic zones in Florida and represented different generations (G1, G2, or G4). This suggests that the genetic identity of the seed-source origin may be maintained under production practices even when plants are grown in locations distant from the seeds' origin. Despite the clustering of these populations, there seems to be no evidence that precludes the statewide use of most populations in this study.

642. Darris DC, Wilson BL, Fiegener R, Johnson R, Horning ME. 2008. **Polycross populations of the native grass *Festuca roemeri* as pre-varietal germplasm: their derivation, release, increase, and use.** Native Plants Journal 9:305-312.

Type: Journal

Geographic Area: Northwestern USA

Keywords: common-garden study, seed transfer zones, habitat restoration, erosion control, selected class release

Abstract: Results of a recent common-garden study provide evidence needed to delineate appropriate seed transfer zones for the native grass *Festuca roemeri* (Pavlick) E. B. Alexeev (Poaceae). That information has been used to develop pre-variety germplasm releases to provide ecologically and genetically appropriate seeds for habitat restoration, erosion control, and other revegetation projects in 5 regions of the Pacific Northwest, U.S. Seed sources for these composite populations were chosen to represent a broad base of genetic diversity found within each region, while using plants that overlap in flowering time, have average to high seed yield, and originate at similar elevations. The process of selecting appropriate seed sources and developing the germplasm releases is described here. Ongoing and future investigations are likely to include seed production technology, establishment methods, stand management, and adaptation to diverse sites and specific uses.

Link: http://www.treesearch.fs.fed.us/pubs/34859

643. Davidson RH, Edwards DGW, Sziklai O, El-Kassaby YA. 1997. **Genetic variation in germination parameters among populations of Pacific silver fir.** Silvae Genetica 45:2-3.

Type: Journal

Geographic Area: Western Canada

Keywords: *Abies amabilis*, germination, stratification, intra-class correlation

Abstract: Strong genetic control was detected for germination capacity and germination speed in 6 populations of Pacific silver fir (*Abies amabilis* [DOUGL.] FORBES) from northern, central and southern Vancouver Island, British Columbia. Intra-class correlation estimates were high and varied between 0.6 and 0.7 and 0.7 and 0.8 for stratified and unstratified seeds, respectively. Stratified seeds showed marked differences in germination capacity and speed among populations when compared to unstratified seeds. Family differences in germination determined by intra class correlation, irrespective of seed pretreatment, were the most pronounced factor when compared to regions and/or populations within regions. The implications of these differences to nursery seedling production was discussed. The inadvertent selection for more-rapidly germinating families in bulked seedlots may represent the most important factor affecting the genetic diversity of seedling crops.

Link: http://www.silvaegenetica.de/fileadmin/content/dokument/archiv/silvaegenetica/45_1996/45-2-3-165.pdf

644. DeWald LE, Mahalovich MF. 2008. Historical and contemporary lessons from ponderosa pine genetic studies at the Fort Valley Experimental Forest, Arizona. In: Olberding SD, Moore MM, editors. Fort Valley—A Century of Research 1908–2008. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-55. p 150-155.

Type: Government Document

Geographic Area: Western USA

Compilers' Keywords: genetic integrity, *Pinus ponderosa*, forest management, provenance, adaptation, seed transfer, review

Abstract: Forest management will protect genetic integrity of tree species only if their genetic diversity is understood and considered in decision-making. Genetic knowledge is particularly important for species such as ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) that are distributed across wide geographic distances and types of climates. A ponderosa pine study initiated in 1910 at the Fort Valley Experimental Forest is among the earliest ponderosa pine genetic research efforts in the United States. This study contributed to the description of ponderosa pine's varietal differences, genetic diversity and adaptation patterns, and helped confirm the importance of using local seed sources. The role this and other pioneer studies had in improving forest management of ponderosa pine was, and still is critical. These early studies have long-term value because they improve our knowledge of responses to climate change and our understanding of genetic variability in physiology and pest resistance in older trees. More recently, studies of natural ponderosa pine stands at Fort Valley using molecular markers have shown the importance of stand structure and disturbance regimes to genetic composition and structural patterns. This knowledge is important to ensure ecological restoration efforts in ponderosa pine forests will also restore and protect genetic integrity into the future. Highlights of these historical and contemporary studies at Fort Valley are summarized and their applications to management of ponderosa pine forests are described.

Link: http://www.treesearch.fs.fed.us/pubs/32505

645. Doede DL. 2005. Genetic variation in broadleaf lupine (*Lupinus latifolius*) on the Mt Hood National Forest and implications for seed collection and deployment. Native Plants Journal 6:36-48.

Type: Journal

Geographic Area: Oregon, USA

Keywords: adaptation, seed transfer risk, seed transfer zones, common-garden

Abstract: Analysis of a common-garden study of broadleaf lupine (*Lupinus latifolius* Lindl. ex J.G.Agardh ssp. *latifolius* [Fabaceae]) indicates that use of watershed delineations is better than use of plant association series for determining seed zones on the Mt Hood National Forest. Risk analysis further confirmed that only 4 seed zones are required, providing a reasonable compromise between managing costs and maintaining local adaptation. Overall, moderate amounts of genetic variation were found in 84 seed sources. Two principal components (PCs) summarized 58% of the variation in 24 measured traits, and variation in PC scores was significantly correlated with topographic, geographic, and climatic variables. Regression analyses showed that these variables accounted for 47% of the variation in the first PC and 34% of the variation in the second PC.

Link: http://www.nativeplantnetwork.org/Content/Articles/6-1NPJ36-48.pdf

646. Eckert AJ, Bower AD, Gonzalez-Martinez SC, Wegrzyn JL, Coop G, Neale DB. 2010. Back to nature: ecological genomics of loblolly pine (*Pinus taeda*, Pinaceae). Molecular Ecology 19:3789-3805.

Type: Journal

Geographic Area: Southeastern USA

Keywords: adaptation, ecological genomics, environmental gradients, *Pinus taeda*, population structure, single nucleotide polymorphisms

Abstract: Genetic variation is often arrayed in latitudinal or altitudinal clines, reflecting either adaptation along environmental gradients, migratory routes, or both. For forest trees, climate is one of the most important drivers of adaptive phenotypic traits. Correlations of single and multilocus genotypes with environmental gradients have been identified for a variety of forest trees. These correlations are interpreted normally as evidence of natural selection. Here, we use a genome-wide dataset of single nucleotide polymorphisms (SNPs) typed from 1730 loci in 682 loblolly pine (*Pinus taeda* L.) trees sampled from 54 local populations covering the full-range of the species to examine allelic correlations to five multivariate measures of climate. Applications of a Bayesian generalized linear mixed model, where the climate variable was a fixed effect and an estimated variance-covariance matrix controlled random effects due to shared population history, identified several well-supported SNPs associating to principal components corresponding to geography, temperature, growing degree-days, precipitation and aridity. Functional annotation of those genes with putative orthologs in Arabidopsis revealed a diverse set of abiotic stress response genes ranging from transmembrane proteins to proteins involved in sugar metabolism. Many of these SNPs also had large allele frequency differences among populations (F_{ST} = 0.10-0.35). These results illustrate a first step towards an ecosystem perspective of population genomics for non-model organisms, but also highlight the need for further integration of the methodologies employed in spatial statistics, population genetics and climate modeling during scans for signatures of natural selection from genomic data.

Link: http://www.ncbi.nlm.nih.gov/pubmed/20723060

647. Erickson VJ, Mandel NL, Sorensen FC. 2004. Landscape patterns of phenotypic variation and population structuring in a selfing grass, *Elymus glaucus* (blue wildrye). Canadian Journal of Botany 82:1776-1789.

Type: Journal

Geographic Area: Oregon, USA

Keywords: *Elymus glaucus*, morphological variation, local adaptation, seed transfer, seed zones, polyploidy

Abstract: Source-related phenotypic variance was investigated in a common garden study of populations of *Elymus glaucus* Buckley (blue wildrye) from the Blue Mountain Ecological Province of northeastern Oregon and adjoining Washington. The primary objective of this study was to assess geographic patterns of potentially adaptive differentiation in this self-fertile allotetraploid grass, and use this information to develop a framework for guiding seed movement and preserving adaptive patterns of genetic variation in ongoing restoration work. Progeny of 188 families were grown for 3 years under two moisture treatments and measured for a wide range of traits involving growth, morphology, fecundity, and phenology. Variation among seed sources was analyzed in relation to physiographic and climatic trends, and to various spatial stratifications such as ecoregions, watersheds, edaphic classifications, etc. Principal component (PC) analysis extracted four primary PCs that together accounted for 67% of the variance in measured traits. Regression and cluster analyses revealed predominantly ecotypic or stepped-clinal distribution of genetic variation. Three distinct geographic groups of locations accounted for over 84% of the variation in PC-1 and PC-2 scores; group differences were best described by longitude and ecoregion. Clinal variation in PC-3 and PC-4 scores was present in the largest geographic group. Four geographic subdivisions were proposed for delimiting *E. glaucus* seed transfer in the Blue Mountains.

Link: http://www.fs.fed.us/pnw/pubs/journals/pnw_2004_erickson001.pdf

648. Fan S, Grossnickle SC, Russell JH. 2008. Morphological and physiological variation in western redcedar (*Thuja plicata*) populations under contrasting soil water conditions. Trees 22:671-683.

Type: Journal

Geographic Area: Western North America

Keywords: carbon isotope discrimination, gas exchange, precipitation, adaptation, water use efficiency

Abstract: Adaptation to precipitation conditions may induce genetic diversity that changes morphological and physiological traits. This hypothesis was investigated in the seedlings of seven western redcedar (*Thuja plicata* Donn ex D. Don) populations, which were collected along a precipitation transect from the Pacific coast to the southern interior of British Columbia, Canada. The experimental seedlings were either well-watered or soil-droughted and measured for growth, gas exchange rates, transpiration efficiency, and carbon isotope discrimination during or at the end of the third growing season. Significant variation was found in most of these morphological and physiological traits among the populations. Much of this variation occurred under well watered, but not so much under droughted conditions. Mean height increments and transpiration efficiency showed a significant linear relationship, but biomass increments exhibited a quadratic relationship with precipitation on the origin site of these populations. Measurements of water use efficiency obtained from instantaneous gas exchange measurements, carbon isotope discrimination, and transpiration efficiency were intercorrelated in the seedlings. However, neither did any of these measurements consistently rank the populations, nor were they indicative of adaptation to climatic precipitation conditions in these western redcedar populations.

Link: http://www.researchgate.net/publication/216860712_Morphological_and_physiological_variation_in_western_redcedar_(Thuja_plicata_Donn._Ex_D._Don)_populations_under_contrasting_soil_water_conditions/file/79e4150f5b1e8c69c6.pdf

649. Fant JB, Holmstrom RM, Sirkin E, Etterson JR, Masi S. 2008. Genetic structure of threatened native populations and propagules used for restoration in a clonal species, American beachgrass (*Ammophila breviligulata* Fern.). Restoration Ecology 16:594-603.

Type: Journal

Geographic Area: Central USA

Keywords: American beachgrass (*Ammophila breviligulata* Fern.), clonal plants, ISSR, molecular diversity, population genetic structure, restoration genetics

Abstract: An important goal of native plant restorations was to reconstitute populations that are genetically similar to native ones, thereby increasing the probably of successful establishment and persistence. We examined the extent to which this goal has been accomplished in Great Lakes restorations of *Ammophila breviligulata* Fern., a beachgrass species that is widely used for habitat restoration and is considered threatened in the study areas. In parallel studies on Lake Michigan and Lake Superior, we used polymorphic Intersimple Sequence Repeat markers to assess genetic similarity between well-established and new native populations, restored populations, and restoration

propagules obtained from two commercial suppliers. Native populations were generally more diverse than expected for a clonal species, whereas the commercially cultivated releases were monotypic. One of the commercial releases used in Minnesota was exclusively found in restored populations and did not occur in any other native population at this site. The propagules used in the newly planted restoration in Illinois were derived from a release that commercial suppliers maintain was derived from a native Michigan population, as opposed to a selected release. Diversity in this restoration was equivalent to that native Illinois' populations; however, many of the genotypes were not of local origin. Overall, study underscores the importance of obtaining baseline genetic surveys of remnant native populations and restoration propagules before restoration efforts are initiated, especially when the populations are threatened or endangered.

650. Ferrell WK, Woodward ES. 1966. Effects of seed origin on drought resistance of Douglas-fir (*Pseudotsuga menziesii*) (Mirb.) Franco. Ecology 47:499-503.

Type: Journal

Geographic Area: Pacific Northwest, USA, Canada

Compilers' Keywords: drought hardiness, population variation

Abstract: Douglas-fir seedlings from a number of seed origins were subjected to drought conditions in the greenhouse and laboratory. Interior mountain seedlings showed significantly greater drought resistance than seedlings from origins west of the Cascade Mountains. Differences were also found within each of these groupings. In the Corvallis, Oregon, area seedlings produced from seed on a south slope had more drought resistance than those from a short distance away on a north slope. Differences in drought resistance may involve either drought hardiness or drought avoidance, or both.

651. Gerson EA, Kelsey RG, St. Clair JB. 2009. Genetic variation of piperidine alkaloids in *Pinus ponderosa*: a common garden study. Annals of Botany 103:447-457.

Type: Journal

Geographic Area: Western USA

Keywords: *Pinus ponderosa* var. *ponderosa*, Pinacea, 2,6-disubstituted piperidine alkaloids, secondary products, geographic variation, progeny study, plant defense, Growth-Differentiation Balance Hypothesis, PRISM

Abstract: Previous measurements of conifer alkaloids have revealed significant variation attributable to many sources, environmental and genetic. The present study takes a complementary and intensive, common garden approach to examine genetic variation in *Pinus ponderosa* var. *ponderosa* alkaloid production. Additionally, this study investigates the potential trade-off between seedling growth and alkaloid production, and associations between topographic/climatic variables and alkaloid production. Piperidine alkaloids were quantified in foliage of 501 nursery seedlings grown from seed sources in west-central Washington, Oregon and California, roughly covering the western half of the native range of ponderosa pine. A nested mixed model was used to test differences among broad-scale regions and among families within regions. Alkaloid concentrations were regressed on seedling growth measurements to test metabolite allocation theory. Likewise, climate characteristics at the seed sources were also considered as explanatory variables. Quantitative variation from seedling to seedling was high, and regional variation exceeded variation among families. Regions along the western margin of the species range exhibited the highest alkaloid concentrations, while those further east had relatively low alkaloid levels. Qualitative variation in alkaloid profiles was low. All measures of seedling growth related negatively to alkaloid concentrations on a natural log scale; however, coefficients of determination were low. At best, annual height increment explained 19.4% of the variation in ln (total alkaloids). Among the climate variables, temperature range showed a negative, linear association that explained 41.8% of the variation. Given the wide geographic scope of the seed sources and the uniformity of resources in the seedlings' environment, observed differences in alkaloid concentrations are evidence for genetic regulation of alkaloid secondary metabolism in ponderosa pine. The theoretical trade-off with seedling growth appeared to be real, however slight. The climate variables provided little evidence for adaptive alkaloid variation, especially within regions.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19010800

652. Gibbs JP, Smart LB, Newhouse AE, Leopold DJ. 2012. A molecular and fitness evaluation of commercially available versus locally collected blue lupine *Lupinus perennis* L. seeds for use in ecosystem restoration efforts. Restoration Ecology 20:456-461.

Type: Journal

Geographic Area: New York, USA

Keywords: blue lupine, genetics, habitat restoration, Karner blue butterfly, *Lupinus perennis*, *Lycaeides melissa samuelis*, microsatellite, seed source

Abstract: Dependence on wild seed sources is often impractical for large-scale habitat restoration programs. Reliance on commercial seed supplies of unknown provenance and fitness is thereby warranted. Little consideration has been given, however, to how the large volumes of seed required should be sourced. We evaluated commercial and locally collected seed sources for potential use in a New York State-based, landscape-scale program for restoring blue lupine *Lupinus perennis*. Through analysis of microsatellite markers we determined that “native” lupine designations by some commercial suppliers were in fact interspecific hybrids and therefore unreliable; at least two commercial sources, however, were genetically as close to native New York populations as native New York populations were to one other. Common garden experiments revealed that seed source influenced first-year overwintering survival and subsequent height growth of surviving plants; seed sources more closely related genetically to native New York populations survived better and produced more stems per individual in the field in the area targeted for restoration. We conclude that (1) commercial suppliers often but not always offer reliably characterized seed sources of sufficient genetic similarity to native populations to warrant their use in restoration projects and (2) genetic affinity of potential seed stock to native populations is positively related to its fitness in the environment targeted for restoration.

653. Gooding GD. 1998. Genetic variation and mating system of ponderosa pine in the Willamette Valley of Oregon [Thesis]. Corvallis (OR): Oregon State University. 104 p.

Type: Thesis

Geographic Area: Pacific Northwest USA

Compilers' Keywords: genetic structure, genetic diversity, *Pinus ponderosa*, outcrossing, inbreeding and outbreeding depression, fragmentation, pollen management

Abstract: The population genetic structure of ponderosa pine (*Pinus ponderosa* Dougl.) in the Willamette Valley of Oregon was investigated. Cones were collected from native stands of ponderosa pine from the Willamette Valley, eastern Oregon, southwest Oregon and the Puget Sound Basin of Washington. Seeds were subjected to isozyme analysis of 12 enzyme systems controlled by 20 different loci. Population genetic parameters for progeny, parent trees and pollen were estimated from isozyme data using BIOSYS-2, a population genetic statistical software package. For progeny data, total gene diversity (H_T) was 0.249; average genic diversity within stands (H_s) was 0.231; average genic diversity among stands (D_{ST}) was 0.017; the proportion of total genic diversity due to differences among stands (G_{ST}) was 0.067. Based on gene diversity statistics and genetic distances, stands of Willamette Valley ponderosa pine do not differ substantially from one another or from other populations of ponderosa pine in Washington and Oregon. These results suggest that protection of the Willamette Valley population can be accomplished by conserving a large number of individuals in a few large stands or many small stands. Multilocus and single-locus estimates of outcrossing rate were determined for six stands within the Willamette Valley. Outcrossing rates were estimated for seven polymorphic loci using MLTR, a mating system analysis software package. Estimates of multilocus outcrossing for these stands (mean 0.642; range 0.365 to 0.879) were substantially lower than estimates previously reported for other populations of ponderosa pine, other pine species, and other species in the family Pinaceae. No significant difference was detected among stands in outcrossing rate. The high level of inbreeding observed in this population could be attributable to population fragmentation due to human activities, or to reduced levels of pollen production in this population compared to other populations of ponderosa pine. Genetic conservation strategies for this population should include the protection of the large native stands that remain and the use of local, adapted sources for afforestation. Management of pollen in a seed orchard should improve the genetic quality of seed over wild stand seed by reducing inbreeding levels.

Link: http://scholarsarchive.library.oregonstate.edu/xmlui/handle/1957/10704

654. Gordon DR, Rice KJ. 1998. Patterns of differentiation in wiregrass (*Aristida beyrichiana*): implications for restoration efforts. Restoration Ecology 6:166-174.

Type: Journal

Geographic Area: Florida, USA

Compilers' Keywords: local adaptation, genetic diversity, longleaf pine, common garden, reciprocal transplant

Abstract: *Aristida beyrichiana* (wiregrass) is increasingly being planted in restoration projects across the southeastern coastal plain, with little focus on genetic differences among populations across the region. Local and regional population differentiation for establishment and growth traits were examined in common garden and reciprocal transplant experiments. Seeds from up to 20 plants from each of seven populations were collected in northern and central Florida sites that encompassed gradients of soils, hydrology, and temperature. Reciprocal seed transplants using three of the common garden populations were conducted in two consecutive years. In the common garden, significant population differences were seen in seed weight, seedling emergence and survival, tiller height, number of tillers, the relationship between tiller number and tiller height, and flowering. Variation among maternal families was seen in tiller number and in the relationship between tiller number and tiller height. The reciprocal transplant study did not detect either local adaptation to sites of origin or consistent superiority of one source population or planting site in seedling establishment. These results suggest that the probability of seedling establishment is primarily dependent on environmental conditions rather than genetic differences. Genetic variation for traits related to fitness (e.g., tiller number) may be retained within populations because phenotypically plastic growth responses of seedlings to environmental variation buffer genetic variation against the action of selection. But despite the lack of evidence for genetic influences on initial establishment in wiregrass, our common garden study suggests genetic differences among populations. This result, when combined with previous results indicating local adaptation in later life stages of wiregrass, suggests that restoration efforts involving this

species should use local seed sources from sites with similar soil and hydrological conditions.

655. Goto S, Iijima H, Ogawa H, Ohya K. 2011. Outbreeding depression caused by intraspecific hybridization between local and nonlocal genotypes in *Abies sachalinensis*. Restoration Ecology 19:243-250.

Type: Journal

Geographic Area: Japan

Keywords: *Abies sachalinensis*, ecological restoration, elevation, intraspecific hybridization, local adaptation, outbreeding depression

Abstract: To evaluate the effects of intraspecific hybridization of local and nonlocal genotypes on growth traits of progeny in *Abies sachalinensis*, we performed reciprocal crossing between nonlocal trees in a high-elevation zone (1,100–1,200 m asl) and local trees in a low-elevation zone (530 m asl) in Hokkaido, northern Japan, in 1979 and established a common garden experiment using local × local (female × male), local × nonlocal, nonlocal × local, and nonlocal × nonlocal progeny in the low-elevation zone in 1986. Survival, height, diameter at breast height (dbh), needle nitrogen content, specific leaf area (SLA), and needle area per shoot diameter (NA) of 25-year-old progeny were measured in 2005. The survival rate was consistently high (> 85% on average). Reductions in height and dbh were apparent in F1 hybrids compared with local × local progeny. Furthermore, outbreeding depression was significant in height growth of nonlocal × local F1 hybrids and in dbh of both F1 hybrids. Reductions in growth traits may be related to morphological needle traits, such as the low values of SLA and NA. Elevation guidelines for *A. sachalinensis* seed zones are discussed to ensure the long-term viability of both restored and native populations.

656. Griess VC, Acevedo R, Härtl F, Staupendahl K, Knoke T. 2012. Does mixing tree species enhance stand resistance against natural hazards? A case study for spruce. Forest Ecology and Management 267:284-296.

Type: Journal

Geographic Area: Germany, Europe

Keywords: mixed species stand, survival analysis, risk, forest management, forest damage survey, Weibull

Abstract: In this study, survival of spruce (*Picea abies* [L.] Karst.) trees in mixed- and mono-species stands was analyzed using the database of Rhineland Palatinate's forest damage survey (FDS). The influence of species mixture on tree survival probability was analyzed using data from 9,864 trees, of which 2,866 spruce trees have been analysed in detail. Data was collected on 495 research plots in a series of continuous measurements taken since 1984. For estimating survival probability, the Kaplan–Meier method was applied to achieve a first overview about possible effects. The analysis was then extended using Accelerated Failure Time (AFT) models to estimate the parameters of a Weibull function, used to describe survival times. The resulting models were used to simultaneously analyze the effects of intensity of mixture (represented by Shannon–Weaver-Index and, alternatively, by species proportion), time since harvest and site characteristics. Results obtained indicate positive effects of species mixture on resistance of spruce trees: survival probabilities increase with increasing intensity of mixture, regardless whether mixture is characterized by Shannon–Weaver-Index or species proportion. Spruce trees in monocultures on average site conditions will reach age 100 with a probability of 80%. Spruce trees growing in a moderately mixed stand(average Shannon–Weaver-Index 0.4) show a slight increase in survival probability to a 83% probability of reaching age 100 whilst spruce trees in a more diverse stand (average Shannon–Weaver-Index 1.2) have a 97% probability of reaching age 100. An admixture of 50% thus leads to an increase in survival probability of 17 percentage points. Site variables even show a stronger impact on survival than tree species mixture. From these variables wet soils had the strongest negative influence on spruce survival, while orographic conditions of saddles, anticlines, valleys, trenches or dells showed the strongest positive influence on survival. However, the strongest influence on spruce survival was recent harvest activity. The more time had passed since the harvest operation, the less likely residual trees were to succumb to stresses.

[Note: **Griess VC, Acevedo R, Härtl F, Staupendahl K, Knoke T. 2012.** Erratum to **"Does mixing tree species enhance stand resistance against natural hazards? A case study for spruce"** [Forest Ecol. Manage. 267 (2012) 284–296]. Forest Ecology and Management 276:259.]

657. Griffin AR, Ching KK. 1977. Geographic variation in Douglas-fir from the coastal ranges of California. Silvae Genetica 26:149-157.

Type: Journal

Geographic Area: California, USA

Compilers' Keywords: *Pseudotsuga menziesii*, common garden, bud set, cold hardiness

Summary: 181 wind-pollinated families of Douglas-fir from through-out the coastal ranges of northern California were raised in a nursery at Corvallis, Oregon and assessed for growth, phenology, cold hardiness, and response to moisture stress. Variation patterns for seed weight, germination rate and cotyledon number were also determined. All characters varied genetically, and with the exception of date of bud burst the most significant contrast was between samples from the coastal fog-belt and those from the interior ranges. Coastal seed was relatively small and germinated more slowly, and seedlings had fewer cotyledons, less hypocotyl,

but greater epicotyl growth; grew for a longer period before setting buds; showed less capacity to set buds in response to moisture stress; and were less cold hardy. Lesser variation patterns were associated with elevation and latitude. In spite of broad similarities in variation patterns, the distribution of variation among sampling levels was not the same for all characters. For example, time of bud set and epicotyl growth were closely associated with the regional difference in climate, the ratio of geographic : within stand variation being > 10, compared with values < 1 for seed-related characters. Cold hardiness variation was also predominantly regional. Such differences indicate a variable complex of selection pressure gradients, and militate against any systematic distinction of the coastal and interior range populations.

Link: http://silvaegenetica.com/fileadmin/content/dokument/archiv/silvaegenetica/26_1977/26-5-6-149.pdf

658. Grossnickle SC, Sutton BCS. 1999. Applications of biotechnology for forest regeneration. New Forests 17:213-226.

Type: Journal

Geographic Area: Canada

Keywords: tissue culture, molecular genetics, microbial inoculations, ecophysiology, *Picea*, somatic embryo

Abstract: The Forest Biotechnology Centre is an interdisciplinary research group dedicated to the development and application of advanced technology for the enhancement of forest regeneration. The Centre carries out contracts on behalf of clients in forest-related industries and government agencies. In addition, there are a number of long-term, in-house projects aimed at the development of proprietary technologies in genetics and propagation, and seedling production and establishment. Technical capabilities include: tissue culture, molecular genetics, pathology and microbial inoculants, and ecophysiology. These techniques are also being used to improve nursery culture regimes, disease assessment, planting regimes, and new product development for a variety of conifer species. Additional programs relate population genetics to adaptive traits, and develop clonal testing within elite families from tree-breeding programs.

Link: http://www.cbd.int/doc/articles/2008/A-00665.pdf

659. Grossnickle SC, Russell JH. 2010. Physiological variation among western redcedar (*Thuja plicata* Donn ex D. Don) populations in response to short-term drought. Annals of Forest Science 67:506-506.

Type: Journal

Geographic Area: Western Canada

Keywords: western redcedar population, performance, gas exchange, water relations, drought response

Abstract: Variation in the ability of western redcedar (*Thuja plicata* Donn ex D. Don) populations to withstand water stress may exist because this species is found in coastal and interior biogeoclimatic subzones representing the full range of precipitation regimes in British Columbia, Canada. Seven western redcedar populations from locations in British Columbia, representing a wide range of habitat types, were assessed for their gas exchange and water relations response to controlled drought. Before drought, population variation occurred in stomatal conductance, net CO_2 assimilation rate and intrinsic water use efficiency and the relative water content at turgor loss point. During drought, populations had different responses of net CO_2 assimilation to decreasing predawn shoot water potential. After drought, populations differed in stomatal conductance and intrinsic water use efficiency, plus osmotic potential at turgor loss point, osmotic potential at saturation and apparent cuticular transpiration. Western redcedar populations from drier-inland habitats had a lower osmotic potential at turgor loss point, lower relative water content at turgor loss point and lower apparent cuticular transpiration in response to drought than populations from coastal origin with temperate maritime habitat. Reduction of cuticular water loss and adjustments of cellular water relations in response to drought was found to occur among seven western redcedar populations originating along a precipitation gradient while; there were minimal population differences in the gas exchange response to drought.

Link: http://www.researchgate.net/publication/216860649_Physiological_variation_among_western_redcedar_(Thuja_plicata_Donn._Ex_D._Don)_populations_in_response_to_short-term_drought/file/9fcfd50f5b1b7e68c0.pdf

660. Grossnickle SC, Sutton BCS, Folk RS, Gawley RJ. 1996. Relationship between nuclear DNA markers and physiological parameters in Sitka x interior spruce populations. Tree Physiology 16:547-555.

Type: Journal

Geographic Area: Western Canada

Keywords: freezing tolerance, nuclear DNA markers, *Picea engelmannii*, *Picea glauca*, *Picea sitchensis*, water relations parameters

Summary: Eight populations of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and interior spruce (*Picea glauca* (Moench) Voss × *Picea engelmannii* Parry ex. Engelm.) seedlings were sampled from a zone of Sitka-interior spruce introgression in British Columbia, Canada. Restriction fragment length polymorphisms of the nuclear ribosomal RNA genes (rDNA) were used to define species-specific hybridization patterns for the Sitka spruce and interior spruce populations. Hybridization was estimated from an index based on the relative abundance of polymorphic rDNA combining bands for each population. Sitka × interior hybrid seedlings had an index value for the relative abundance of interior spruce rDNA (Si-rDNA) ranging from 0.07 (Lower Nass; the most westerly collected source) to 0.95 (Bulkley Valley low-elevation seed orchard). During shoot elongation, osmotic potential at saturation (Ψ_{sat}) and turgor loss point (Ψ_{tlp}) increased, whereas total turgor (Ψ_{PTotal}) decreased. After bud set in the summer and throughout the fall, Ψ_{sat} and Ψ_{tlp} decreased, whereas Ψ_{PTotal} increased. At all times of year, populations with a higher Si-rDNA index had lower Ψ_{tlp} and Ψ_{sat} and higher Ψ_{PTotal} than populations with a lower Si-rDNA index. During the fall, Sitka × interior hybrid seedlings exhibited a seasonal decline in the temperature causing 50% needle electrolyte leakage (LT_{50}) and in the critical temperature indicating the initial point of freezing injury. Seedlings with a higher Si-rDNA index had lower LT_{50} and critical temperature values indicating greater freezing tolerance in the fall. Throughout most of the year, seedling population Si rDNA index was related to the degree of drought and freezing tolerance.

661. Gylander T. 2011. **The potential of aspen clones and hybrids for enhanced forest management in Alberta [Thesis].** Edmonton, Alberta, Cananda: University of Alberta. 112 p.

Type: Thesis

Geographic Area: Western Canada

Compilers' Keywords: aspen management, *Populus tremuloides,* genetic variation, assisted migration, provenance, forest productivity

Abstract: This thesis presents results from an industrial aspen tree improvement program for Alberta, evaluating a series of provenance, clonal and hybrid field trials. The goals were to (1) investigate geographic patterns of genetic variation in order to delineate breeding regions, (2) to assess the potential of clonal forestry systems to enhance forest productivity, and (3) to evaluate the potential of hybridization to enhance growth through hybrid vigor. Partitioning of genetic variance with geographic predictor variables suggests two breeding regions for Alberta should be appropriate: a Sub-Boreal Rocky Mountain Foothill region between 52°30' N and 56° N latitude, and a Boreal Mixedwood region between 56° N and 59° N latitude. Broad-sense heritabilities for height and diameter ranged from 0.36 to 0.64 on selected sites, allowing 5–15% genetic gains in height and 9–34% in diameter based on selections from current trials. The best genotypes within hybrid families could have some additional potential in improving yields.

Link: http://www.ualberta.ca/~ahamann/people/pdfs/Gylander_2011_MSc.pdf

662. Hamann A. 1999. **Utilization and management of red alder genetic resources in British Columbia [Dissertation].** Vancouver, British Columbia, Canada: The University of British Columbia. 13 p.

Type: Dissertation

Geographic Area: Western Canada

Compilers' Keywords: genetic variation, genecology, climate change, seed transfer guidelines, tree improvement

Abstract: In this thesis genecology, phylogeography, and quantitative genetics of red alder were investigated. Further, literature with respect to red alder product values, market demand, forest resources, and red alder biology were reviewed. Implications of these aspects for genetic resources management were evaluated and a breeding strategy for red alder in British Columbia was developed. Genetic differentiation among provenances in British Columbia was investigated based on six polymorphic allozyme loci and measurements of six quantitative traits. Multivariate analysis revealed complex associations of quantitative traits with the latitude, distance to the coast, and elevation of the seed source. Nei's genetic distance revealed a strong differentiation among island and mainland provenances at one allozyme locus. This differentiation can be interpreted as a result of migration from two different refugia since the last glaciation. Adaptation of red alder provenances was investigated based on trials in multiple planting environments. Significant genotype × environment interactions were found at the population and family level. Provenances close to each planting site showed superior performance in growth and survival, suggesting adaptation of red alder to local environments. Seed transfer guidelines and seed procurement zones were developed under the assumption of local optimality using improved methodology based on risk associated with seed transfer. In order to assess the potential benefits from selection and evaluate different options for tree improvement, genetic parameters for growth and adaptive traits were estimated from progeny tests. Estimated heritabilities for growth and adaptive traits were moderate with values between 0.30 and 0.50. Genetic gain in growth traits from individual selection would range from 25 to 35%. Small improvements (approximately 5%) would indirectly be achieved in the form score due to positive genetic correlations. Removal of spatially autocorrelated error variation in field experiments increased heritabilities and gains from selection. A multiple population breeding strategy for uncertain climatic conditions in British Columbia was derived as a synthesis, using information on genecology, risk associated with seed transfer, and genetic parameters. Six breeding populations of red alder, some with novel trait combinations, were found to be necessary to cope with possible effects of climatic warming in British Columbia.

Link: http://www.ualberta.ca/~ahamann/publications/pdfs/Hamann_1999_Abstract.pdf

663. Hamann A, Koshy MP, Namkoong G, Ying CC. 2000. **Genotype x environment interactions in *Alnus rubra*: developing seed zones and seed-transfer guidelines with spatial statistics and GIS.** Forest Ecology and Management 136:107-119.

Type: Journal

Geographic Area: Western Canada

Keywords: red alder, genecology, seed zones, seed transfer guidelines, Kriging, British Columbia

Abstract: Multiple provenance trials of red alder (*Alnus rubra* Bong.) were used to demonstrate how geostatistical methods can be applied to develop better seed-transfer guidelines and seed-procurement zones for forestry. Height and survival of 65 provenances from British Columbia were measured at four test sites. Significant genotype-environment interactions were found at the population and family level. Provenances close to each planting site showed superior performance in growth and survival, suggesting adaptation of red alder to local environments. The environmental basis of local adaptations was evaluated using redundancy analysis. Geographic and climatic variates accounted for approximately equal amounts of the variation in height growth (21 and 23%, respectively), while geographic variates accounted for 60% of the variation in climatic variables. Loadings of the redundancy variates suggested that both, gene flow and selection by environmental factors shaped geographic patterns of genetic differentiation in red alder. Performance of seed sources at unknown locations was predicted with ordinary kriging throughout the natural range of red alder in British Columbia. General seed-transfer guidelines were then generated with principal component analysis of predicted reaction norms. We found clinal differentiation of reaction norms along the coast from northwest to southeast. Further, the Georgia depression was identified as an area of genetic differentiation. Based on predicted height and survival at two trials that most realistically represented operational planting sites, we derived simple rules for seed transfer. A transfer of 100 km in either direction along the coast was associated with a decline of 2.5% in survival, and 5 cm in 2-year height. Finally, we showed how maps of predicted performance and associated variance surfaces can be used to develop seed zones for specific objectives, where seed zones are given as maps of probabilities of a seed source performing above or below a given threshold for any combination of traits.

Link: http://www.ualberta.ca/~ahamann/publications/pdfs/Hamann_et_al_2000.pdf

664. Hamlin J, Kegley A, Sniezko R. 2011. Genetic variation of whitebark pine (*Pinus albicaulis*) provenances and families from Oregon and Washington in juvenile height growth and needle color. In: Keane RE, Tomback DF, Murray MP, Smith CM, editors. High Five Symposium. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-63. p 133-139.

Type: Government Document

Geographic Area: Pacific Northwest USA

Compilers' Keywords: common garden, seed zones, gene conservation, seed collection

Abstract: A three year common garden study was conducted on whitebark pine (*Pinus albicaulis*) which included 215 families from the eight provenances or seed zones in Oregon and Washington. Total height and needle color were assessed. Height differed significantly among provenances and families, and was primarily associated with source elevation, longitude, and precipitation. A moderate to high heritability was estimated for total height. Seedling needle color differed among provenances and was associated with temperature : moisture indexes and source elevation. Height growth along the Cascade mountain range (USA), representing four adjoining provenances or seed zones, appeared to be similar and clinal in nature. The four remaining provenances, representing seed zones from a more moderate or extreme environmental settings, differed significantly from the Cascade provenances for one or more traits that were examined. It would seem prudent to restrict seed transfers to within each of these four seed zones respectively. This study also supports the need to plan gene conservation collections within each seed zone for whitebark pine in the Pacific Northwest region.

Link: http://www.treesearch.fs.fed.us/pubs/38209

665. Hancock N, Leishman MR, Hughes L. 2012. Testing the "Local Provenance" paradigm: a common garden experiment in Cumberland Plain Woodland, Sydney, Australia. Restoration Ecology 21:569-577.

Type: Journal

Geographic Area: Australia

Keywords: adaptive potential, home-site advantage, local adaptation, local superiority, restoration, seed source

Abstract: Seed for restoration projects has traditionally been sourced locally to "preserve" the genetic integrity of the replanted site. Plants grown from locally sourced seeds are perceived to have the advantage of being adapted to local conditions, and the use of local provenance is a requirement of many restoration projects. However, the processes of climate change and habitat fragmentation, with the subsequent development of novel environments, are forcing us to reconsider this basic tenet of restoration ecology. We tested the "local provenance is best" paradigm, by comparing the performance of plants grown from local with non-local seed sources within a common garden experiment. We selected six species representing a range of growth forms (*Acacia falcata*, *Bursaria spinosa* ssp. *spinosa*, *Eucalyptus crebra*, *E. tereticornis*, *Hardenbergia violacea* and *Themeda australis*) from an assemblage known as the Cumberland Plain Woodland, a threatened community in western Sydney. Multiple provenances were collected from within the range of each species and grown at two field sites on the Cumberland Plain. Growing time varied between species and ranged from 7 months to 2 years. With the exception of *B. spinosa*, and to a lesser extent *T. australis*, we found little evidence that local

provenance plants were superior to distant provenances in terms of survival and establishment.

666. Horning ME, McGovern TR, Darris DC, Mandel NL, Johnson RC. 2010. **Genecology of *Holodiscus discolor* (Rosaceae) in the Pacific Northwest, U.S.A.** Restoration Ecology 18:235-243.

Type: Journal

Geographic Area: Western USA

Keywords: common garden, genecology, germplasm, Holodiscus discolor, oceanspray

Abstract: An important goal for land managers is the incorporation of appropriate (e.g., locally adapted and genetically diverse) plant materials in restoration and revegetation activities. To identify these materials, researchers need to characterize the variability in essential traits in natural populations and determine how they are related to environmental conditions. This common garden study was implemented to characterize the variability in growth and phenological traits relative to climatic and geographic variables of 39 *Holodiscus discolor* (Pursh) Maxim. accessions from locations throughout the Pacific Northwest, U.S.A. Principal component analysis of 12 growth and phenological traits explained 48.2% of the observed variability in the first principal component (PC-1). With multiple regressions, PC-1 was compared to environmental values at each source location. Regression analysis identified a four-variable model containing elevation, minimum January temperature, maximum October temperature, and February precipitation that explained 86% of the variability in PC-1 ($r^2 = 0.86$, $p < 0.0001$). Spatial analysis using this regression model identified patterns of genetic diversity within the Pacific Northwest that can help guide germplasm selection (i.e., seed collections) for restoration and revegetation activities.

Link: http://www.fs.fed.us/wwetac/threat_map/seed_zones/Horning%20holodiscus%20genecology.pdf

667. Howe GT, Aitken SN, Neale DB, Jermstad KD, Wheeler NC, Chen THH. 2003. **From genotype to phenotype: unraveling the complexities of cold adaptation in forest trees.** Canadian Journal of Botany 81:1247-1266.

Type: Journal

Geographic Area: North America

Keywords: association genetics, cold hardiness, dormancy, genecology, bud phenology, quantitative trait loci

Abstract: Adaptation to winter cold in temperate and boreal trees involves complex genetic, physiological, and developmental processes. Genecological studies demonstrate the existence of steep genetic clines for cold adaptation traits in relation to environmental (mostly temperature related) gradients. Population differentiation is generally stronger for cold adaptation traits than for other quantitative traits and allozymes. Therefore, these traits appear to be under strong natural selection. Nonetheless, high levels of genetic variation persist within populations. The genetic control of cold adaptation traits ranges from weak to strong, with phenological traits having the highest heritabilities. Within-population genetic correlations among traits range from negligible to moderate. Generally, bud phenology and cold hardiness in the fall are genetically uncorrelated with bud phenology and cold hardiness in the spring. Analyses of quantitative trait loci indicate that cold adaptation traits are mostly controlled by multiple genes with small effects and that quantitative trait loci × environment interactions are common. Given this inherent complexity, we suggest that future research should focus on identifying and developing markers for cold adaptation candidate genes, then using multilocus, multiallelic analytical techniques to uncover the relationships between genotype and phenotype at both the individual and population levels. Ultimately, these methods may be useful for predicting the performance of genotypes in breeding programs and for better understanding the evolutionary ecology of forest trees.

Link: http://www.treesearch.fs.fed.us/pubs/42203

668. Hufford KM, Mazer SJ. 2003. **Plant ecotypes: genetic differentiation in the age of ecological restoration.** Trends in Ecology and Evolution 18:147-155.

Type: Journal

Geographic Area: Global

Compilers' Keywords: local adaptation, seed transfer, translocation, introduced, genetic dilution, restoration genetics, review, seed zones, common garden

Abstract: Recent studies illustrate the emerging field of restoration genetics, which is a synthesis of restoration ecology and population genetics. The translocation of organisms during the restoration of native ecosystems has provoked new questions concerning the consequences of sampling protocols and of intraspecific hybridization between locally adapted and transplanted genotypes. Studies are now underway to determine both the extent of local adaptation among focal populations and the potential risks of introducing foreign genotypes, including founder effects, genetic swamping and outbreeding depression. Data are needed to delineate 'seed transfer zones', or regions within which plants can be moved with little or no consequences for population fitness. Here, we address the revival of transplant and common garden studies, the use of novel molecular markers to predict population genetic consequences of translocation, and their combined power for determining appropriate seed transfer zones in restoration planning for native plant populations.

Link: http://www.researchgate.net/publication/222650495_Plant_ecotypes_genetic_differentiation_in_the_age_of_ecological_restoration/file/60b7d517ead892c10a.pdf

669. Hufford KM, Mazer SJ. 2011. Local adaptation and the effects of grazing on the performance of *Nassella pulchra*: implications for seed sourcing in restoration. Restoration Ecology 20:688-695.

Type: Journal

Geographic Area: California, USA

Keywords: California grassland, home-site advantage, reciprocal transplant

Abstract: The use of local seed sources for revegetation is accepted practice to reduce the potential that propagules will be poorly adapted to site conditions. However, data are often lacking to determine the distance within which seed sources represent local genotypes. Short-term reciprocal transplant studies represent a class of tools to detect local adaptation of target species. We conducted a reciprocal transplant of *Nassella pulchra* between two central California locations to test for adaptation to local environmental conditions over a 3-year period. Experimental plots at one location were split between grazed and ungrazed sites to evaluate the potential influence of livestock grazing on the detection or magnitude of local adaptation. During each year of the study, evidence of a home site advantage depended on the location, traits studied, and population. At the end of the 3-year study period, however, we detected consistent evidence of a home-site advantage for seedling biomass among grazed sites at one location and ungrazed plots at the other location. In effect, local adaptation was only apparent in the final year of the study. Short-term reciprocal transplant studies are an effective tool to guide the selection of seed sources most likely to germinate and to become established at a restoration site, but such studies cannot rule out local adaptation, which may not be immediately detectable.

670. Hufford KM, Mazer SJ, Camara MD. 2008. Local adaptation and effects of grazing among seedlings of two native California bunchgrass species: implications for restoration. Restoration Ecology 16:59-69.

Type: Journal

Geographic Area: California, USA

Keywords: *Bromus carinatus*, California grassland, *Elymus glaucus*, grazing, local adaptation, reciprocal transplant

Abstract: Adaptation to environmental factors may influence the germination and establishment of focal species in ecological restoration. Reciprocal transplants remain one of the best methods to detect local adaptation, but long-term studies are often not feasible. We conducted reciprocal transplants of the native California bunchgrasses *Elymus glaucus* and *Bromus carinatus* between two central California locations to seek evidence of adaptation to local environmental conditions in a single growing season. Experimental plots at one location included grazed and ungrazed sites. The combination of locations and grazing treatments allowed us to determine whether the ability to detect evidence for adaptation depended on grazing regime. In addition, we measured the direct effects of grazing on seedling growth and survival concurrent with our investigation of local adaptation. We detected a home-site advantage for seedling growth or survival in both species, but the factors contributing to adaptive differentiation were species specific. Evidence of local adaptation was detected for seedling biomass in *Bromus* and for survivorship in *Elymus*. The home-site advantage observed in both species was greatly reduced under grazed conditions and in *Elymus* was significant only in the ungrazed plots. Climate and soil analyses detected significant differences between locations in five soil attributes and two climate variables. In particular, differences in exchangeable magnesium indicated that one of the two transplant locations consisted of serpentine soil, which is widely known to drive adaptation in plant populations. Together, these results suggest that it is possible to investigate the scale and factors involved in local adaptation with short-term transplant studies.

671. Hultine KR, Marshall JD. 2000. Altitude trends in conifer leaf morphology and stable carbon isotope composition. Oecologia 123:32-40.

Type: Journal

Geographic Area: Idaho, Montana, USA

Keywords: carbon isotope ration, stomatal density, leaf nitrogen content, leaf mass per area, evergreen conifers

Abstract: The natural ratio of stable carbon isotopes ($\delta^{13}C$) was compared to leaf structural and chemical characteristics in evergreen conifers in the north-central Rockies, United States. We sought a general model that would explain variation in $\delta^{13}C$ across altitudinal gradients. Because variation in $\delta^{13}C$ is attributed to the shifts between supply and demand for carbon dioxide within the leaf, we measured structural and chemical variables related to supply and demand. We measured stomatal density, which is related to CO_2 supply to the chloroplasts, and leaf nitrogen content, which is related to CO_2 demand. Leaf mass per area was measured as an intermediate between supply and demand. Models were tested on four evergreen conifers: *Pseudotsuga menziesii*, *Abies lasiocarpa*, *Picea engelmannii*, and *Pinus contorta*, which were sampled across 1,800 m of altitude. We found significant variation among species in the rate of $\delta^{13}C$ increase with altitude, ranging from 0.91‰ km^{-1} for *A. lasiocarpa* to 2.68‰ km^{-1} for *Pinus contorta*. Leaf structure and chemistry also varied with altitude: stomatal density decreased, leaf mass per area increased, but leaf nitrogen content (per unit area) was constant. The regressions on altitude were particularly robust in *Pinus contorta*. Variables were derived to describe the balance between supply and demand; these variables were stomata per gram of nitrogen and stomata per gram of leaf mass. Both derived variables should be

positively related to internal CO_2 supply and thus negatively related to $\delta^{13}C$. As expected, both derived variables were negatively correlated with $\delta^{13}C$. In fact, the regression on stomatal density per gram was the best fit in the study ($r^2 = 0.72$, $P < 0.0001$); however, the relationships were species specific. The only general relationship observed was between $\delta^{13}C$ and LMA: $\delta^{13}C$ (‰) = –32.972 + 0.0173×LMA ($r^2 = 0.45$, $P < 0.0001$). We conclude that species specificity of the isotopic shift indicates that evergreen conifers demonstrate varying degrees of functional plasticity across environmental gradients, while the observed convergence of $\delta^{13}C$ with LMA suggests that internal resistance may be the key to understanding interspecific isotopic variation across altitude.

672. Isik F, Keskin S, McKeand SE. 2000. Provenance variation and provenance-site interaction in *Pinus brutia* Ten.: consequences of defining breeding zones. Silvae Genetica 49:213-223.

Type: Journal

Geographic Area: Turkey, Mediterranean

Keywords: *Pinus brutia*, provenance variation, genotype-environment interaction, seed transfer zones, stability parameters

Abstract: Forty-nine provenances of *Pinus brutia* were tested on 13 sites in Turkey, and 10-year results were evaluated. Provenances did not differ for survival except at two sites. There were highly significant differences among the provenances in height and diameter in all test sites located in the Mediterranean, Marmara and in the southeastern regions of Turkey. However, provenances did not differ in Aegean region sites except for diameter at one site. The fastest growing provenances had up to 55% greater height and 50% greater diameter than the site means, implying considerable gain can be realized if the best provenances were selected for plantations. Provenances from the middle elevation zone (400 m to 900 m) of the Mediterranean region had greater growth than the provenances from peripheral distribution of the species at most sites. In general, the results did not support seed transfer zoning which was based on geographic and climatic data. Sub zoning of the Aegean region was not justified, as type B provenance correlations were high, well over the threshold value ($r_B = 0.8$). For northern Marmara (Kesan site) and southeast Anatolia regions, a land race should be developed. Provenances were significantly different for stability variances, indicating the potential to select for stable genotypes across sites or for genotypes that are the most productive at specific sites.

Link: http://www.silvaegenetica.de/fileadmin/content/dokument/archiv/silvaegenetica/49_2000/49-4-5-213.pdf

673. Iwata H, Kamijo T, Tsumura Y. 2004. Genetic structure of *Miscanthus sinensis* ssp. *condensatus* (Poaceae) on Miyake Island: implications for revegetation of volcanically devastated sites. Ecological Research 20:233-238.

Type: Journal

Geographic Area: Japan

Keywords: revegetation, genetic differentiation, chloroplast DNA (cpDNA), amplified fragment length polymorphisms (AFLPs), PCR-RFLP

Abstract: We investigated the genetic structure of *Miscanthus sinensis* ssp. *condensatus* on Miyake Island, which was devastated by a volcanic eruption in 2000, by amplified fragment length polymorphisms (AFLPs) and polymerase chain reaction restriction fragment length polymorphism (PCR-RFLP) for chloroplast DNA (cpDNA) variation, to develop recommendations for the revegetation of devastated sites. Genetic differentiation among populations was significant, and five populations were classified into three regional groups. The aspect ratios of leaf-blades varied significantly among populations, but both geographical proximity and morphological similarities did not precisely reflect genetic similarities. In the airport population, we found a rare haplotype that may have been transmitted from outside the island. These findings will assist the revegetation of the island.

674. Iwata H, Kamijo T, Tsumura Y. 2006. Assessment of genetic diversity of native species in Izu Islands for a discriminate choice of source populations: implications for revegetation of volcanically devastated sites. Conservation Genetics 7:399-413.

Type: Journal

Geographic Area: Japan

Keywords: AFLPs, *Alnus sieboldiana*, cpDNA, *Miscanthus sinensis* ssp. *condensatus*, *Polygonum cuspidatum* var. *terminalis*

Abstract: In using native species for revegetation, it is necessary choose source populations carefully to reduce the risk of planting suboptimal germplasm. To make preliminary recommendations for native species to use in the revegetation of a volcanically devastated area on Miyake Is., Japan, we investigated the genetic variation of *Alnus sieboldiana*, *Miscanthus sinensis* ssp. *condensatus*, and *Polygonum cuspidatum* var. *terminalis* in the Izu Islands and on the Izu Peninsula based on chloroplast DNA (cpDNA) sequence variations and amplified fragment length polymorphisms (AFLPs). The amount and pattern of differentiation differ between organelle and nuclear markers, suggesting the necessity of evaluation based on both types of markers. Within-population diversity did not vary among populations, suggesting that it does not need to be considered in the choice of a source population. The pattern and degree of differentiation varied among species, and geographical proximity did not necessarily accord with genetic similarity, suggesting that the site of an appropriate source population varies among species and should be determined empirically rather than by assuming that close proximity predicts genetic similarity. The Izu Peninsula populations deviated from the island populations in all species. Comparison of cpDNA sequences with those of related species indicates the possibility of hybridization with related species on the Izu Peninsula, suggesting that seeds collected from populations where related species live sympatrically should not be used for revegetation. These findings indicate the need to assess the genetic diversity empirically by using organelle and nuclear markers to avoid unintended consequences of genetic mixing associated with revegetation.

675. Jacobs DF, Davis AS. 2005. Genetic considerations in the operational production of hardwood nursery stock in the eastern United States. Native Plants Journal 6:4-13.

Type: Journal

Geographic Area: Eastern USA

Keywords: tree improvement, seed zones, seed orchards, forestry, timber production, restoration

Abstract: A recent survey of forest tree nurseries in the eastern U.S. indicated that hardwood tree improvement is not extensively practiced at an operational level, with only 6.8% of hardwood seedlings produced from improved materials (compared to 36% for conifer seedlings at those nurseries that produce both). Fine hardwoods represent less than 20% of improved hardwood seedling production. Most respondents indicated that the use of genetically improved materials would benefit forestry in their region; however, less than 40% have germplasm of hardwood species in improvement programs. Because most respondents stated their intention to use more genetically improved hardwood material in seedling production over the next 10 y, availability of improved materials will likely limit future use. More integration of research involving genetic improvement into operational nursery production will help sustain the future value and supply of our hardwood forest resource.

676. Jaquish B. 2010. Review of British Columbia's contemporary and projected western larch seed planning zones in light of climate change. Vernon, British Columbia, Canada: BC Ministry of Forests and Range. 1-18 p.

Type: Government Document

Geographic Area: Western Canada

Compilers' Keywords: *Larix occidentalis*, bioclimatic model, GCM, seed zones, seed transfer, management

Background: The objectives of this range-wide project were to: (1) define the climate profile with a bioclimatic model that predicts the presence or absence of western larch from climate variables; (2) develop models of genetic variation that predict genetic differences among populations from inhabited climate; (3) develop and map seed zones within predicted distributions for present and future climates; (4) identify populations that are likely to become threatened and identify appropriate conservation strategies; and, (5) develop management strategies for the transfer of the seed sources to future location of their optimal climate, taking into consideration future distributions, adaptation of populations, and variability among General Circulation Models (GCM).

Link: http://bcwildfire.ca/ftp/HTI/external/!publish/Interim_Measures/Lw_Review_March_19_2010/INTERIM_Lw_Report_(Jaquish)_FINAL.pdf

677. Jenkinson JL. 1975. Increasing planting stock size by family selection in California ponderosa pine. Berkeley (CA): USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. Research Paper PSW-108. 14 p.

Type: Government Document

Geographic Area: California, USA

Compilers' Keywords: *Pinus ponderosa*, transfer guidelines, forest management, tree improvement, genetic adaptation

Summary: This paper describes family differences in 1- and 2-year nursery growth of ponderosa pine from natural stands in the northern Sierra Nevada. Wind-pollinated seed was obtained from 48 parent trees selected in eight stands. The stands sampled four geographic areas-three west and one east of the Sierra crest-to represent climates typical for ponderosa pine. In each area, one stand was selected on a fertile soil and the other on infertile ultramafic soil.

Link: http://www.fs.fed.us/psw/publications/documents/psw_rp108/psw_rp108.pdf

678. Jenkinson JL, Nelson JA, Huddleston ME. 1993. Improving planting stock quality—the Humboldt experience. Albany (CA): USDA Forest Service, Pacific Southwest Research Station. PSW-GTR-143. 238 p.

Type: Government Document

Geographic Area: Western USA

Keywords: artificial regeneration, nursery management, plantation establishment, reforestation, seedling culture, seedling root growth capacity, seedling survival, *Abies concolor, A. grandis, A. magnifica* var. *shastensis, A. procera, Libocedrus decurrens, Picea stichensis, Pseudotsuga menziesii* var. *menziesii, Thuja plicata, Tsuga heterophylla*

Abstract: A seedling testing program was developed to improve the survival and growth potential of planting stock produced in the USDA Forest Service Humboldt Nursery, situated on the Pacific Coast in northern California. Coastal and inland seed sources of Douglas-fir and eight other conifers in the Pacific Slope forests of western Oregon and northern California were assessed in both nursery and field studies. Seedling top and root growth capacities were evaluated just after lifting and after cold storage, and stored seedlings were tested for survival and growth on cleared planting sites in the seed zones of origin. Safe lifting and cold storage schedules were defined, and seedling cultural regimes were formulated to produce successful 1-0, 1-1, and 2-0 stock types. Testing demonstrated the

critical elements of reforestation and proved that rapid establishment is attainable on diverse sites. Accomplishments of the Humboldt program recommend similar programs for other forest nurseries and their service regions.

Link: http://www.treesearch.fs.fed.us/pubs/24160

679. Jensen KB, Mott IW, Robins JG, Waldron BL, Nelson M. 2012. Genetic improvement and diversity in Snake River wheatgrass (*Elymus wawawaiensis*) (Poaceae: *Triticeae*). Rangeland Ecology & Management 65:76-84.

Type: Journal

Geographic Area: Western USA

Keywords: forage quality, genetic diversity, germplasm improvement, seedling establishment

Abstract: With the increased emphasis on using native plant materials in range revegetation programs in the western United States it is critical to identify genetically similar groups and develop native grasses that are competitive with invasive weeds, easy to establish, and persistent, and that produce high seed yield. A grass that shows appreciable drought tolerance on arid rangelands is Snake River wheatgrass (*Elymus wawawaiensis* J. Carlson & Barkworth). This study was designed to estimate genetic relationships and underlying genetic components for seed and forage trait improvement between plant introductions (PIs) of Snake River wheatgrass, 28 half-sib Snake River wheatgrass families (HSFs), and cultivars Secar and Discovery at Nephi, Utah, between 2005 and 2006. Based on molecular genetic diversity data in Snake River wheatgrass, with the exception of the PIs originating from Enterprise, Oregon, all other collections and cultivars are not genetically different and represent a common gene pool from which to develop improved Snake River wheatgrass germplasm. Selection in Snake River wheatgrass for total seed yield (g/plot), 100 seed weight (g), and seedling emergence from a deep planting depth had a positive effect. Further increases through selection and genetic introgression from hybridization with PIs will likely increase seed yield and 100-seed weight, but will not increase seedling emergence. Increases in dry matter yield (DMY) were observed after two cycles of selection in the HSFs compared to the PIs. There remains considerable genetic and phenotypic variation to further increase DMY in Snake River wheatgrass through selection and hybridization. Trends in forage nutritional quality were not observed after two cycles of selection in the HSFs or the PIs and will not likely result in improvement. Through recurrent selection, populations of Snake River wheatgrass have been and can be developed to more effectively establish and compete on annual weed–infested rangelands.

680. Johnson O, Skroppa T. 2000. Provenances and families show different patterns of relationship between bud set and frost hardiness in *Picea abies*. Canadian Journal of Botany 30:1858-1866.

Type: Journal

Geographic Area: Norway, Europe

Compilers' Keywords: Norway spruce, frost hardiness

Abstract: We have compared bud set and frost hardiness among Norway spruce (*Piceas abies* (L.) Karst.) provenances and families in two cold-acclimation regimes in a phytotron; low light intensity and high night temperatures (LL–HNT), and high light intensity and low night temperatures (HL–NT) under shortening day lengths. Nine provenances from 59–66° N and altitude 100–700 m within Norway, and nine open-pollinated families from a single stand (61° N, 270 m elevation) were used. Both provenances and families started bud set and frost hardening earlier in LL–HNT than in HL–LNT. Correlations between the same trait expressed in two regimes were high for both bud set and hardiness at the provenance level and slightly lower at the family level. The variation among family means in bud set and hardiness was large. The differences found between the family extremes were up to 75% of those found between provenance extremes. The relationship between bud set and frost hardiness was strong among the provenance means within both environments ($r = 0.92$) but weak for the families ($r = 0.22–0.44$). Causal factors influencing phenotypic variation within traits and covariation among traits may differ for provenances and families within stands. The strong relationships among traits that are found at the provenance level cannot be generalized to the levels of families or clones.

681. Johnson RC, Cashman MJ, Vance-Borland K. 2012. Genecology and seed zones for Indian ricegrass collected in the southwestern United States. Rangeland Ecology & Management 65:523-532.

Type: Journal

Geographic Area: Southwestern USA

Keywords: *Achnatherum hymenoides*, common garden, genetic resources, germplasm, restoration, revegetation

Abstract: Indian ricegrass (*Achnatherum hymenoides* [Roemer & J.A. Schultes] Barkworth) is a widely distributed, highly desirable native species in desert ecosystems in the western United States. Yet there are no studies linking genetic variation in Indian ricegrass with climate across major areas of its natural distribution. In this study, seeds from 106 collection locations from the southwestern United States were established in common gardens and four phenological traits (Phen; such as blooming date), six production traits (Pro; such as dry weight), and eight morphology traits (Morph; such as leaf dimensions) were measured in 2007 and 2008. Analyses of variance revealed that all basic garden traits differed among source locations ($P < 0.01$), indicating widespread genetic variation. Within Phen, Pro, and Morph categories, canonical correlation was completed between basic garden traits and source location temperature and precipitation. This resulted in six significant ($P < 0.01$)

canonical variates (Phen 1, Pro 1 and 2, and Morph 1, 2, and 3) representing each category of traits. Linear correlations ($r > \pm 25$, $P < 0.01$) consistently linked monthly temperature at collection locations with Phen 1, Pro 1, and Morph 1. For precipitation, however, correlations were more dependent on month, with the strongest correlations during the spring developmental period. Using regression models between traits and climate, a map with 12 seed zones was developed representing much of the southwestern United States. This generally distinguished genetic variation between cooler and warmer regions, usually separating more northern, higher elevation areas from more southern, lower elevation areas. The correspondence between climate and genetic variation suggested climate-driven differences in natural selection, likely leading to adaptation. The seed zone map is recommended to guide and broaden germplasm collection and utilization for Indian ricegrass restoration.

Link: http://www.treesearch.fs.fed.us/pubs/42159

682. Johnson RC, Erickson VJ, Mandel NL, St. Clair JB, Vance-Borland KW. 2010. Mapping genetic variation and seed zones for *Bromus carinatus* in the Blue Mountains of eastern Oregon, USA. Botany 88:725-736.

Type: Journal

Geographic Area: Oregon, USA

Keywords: genecology, *Bromus carinatus*, seed zones, plant adaptation

Abstract: Seed transfer zones ensure that germplasm selected for restoration is suitable and sustainable in diverse environments. In this study, seed zones were developed for mountain brome (*Bromus carinatus* Hook. & Arn.) in the Blue Mountains of northeastern Oregon and adjoining Washington. Plants from 148 Blue Mountain seed source locations were evaluated in common-garden studies at two contrasting test sites. Data on phenology, morphology, and production were collected over two growing seasons. Plant traits varied significantly and were frequently correlated with annual precipitation and annual maximum temperature at seed source locations ($P < 0.05$). Plants from warmer locations generally had higher dry matter production, longer leaves, wider crowns, denser foliage, and greater plant height than those from cooler locations. Regression models of environmental variables with the first two principal components (PC 1 and PC 2) explained 46% and 40% of the total variation, respectively. Maps of PC 1 and PC 2 generally corresponded to elevation, temperature, and precipitation gradients. The regression models developed from PC 1 and PC 2 and environmental variables were used to map seed transfer zones. These maps will be useful in selecting mountain brome seed sources for habitat restoration in the Blue Mountains.

Link: http://www.treesearch.fs.fed.us/pubs/40063

683. Johnson RC, Hellier B, Cashman M, Shaw NL, Erickson VJ, St. Clair JB, Vance-Borland KW. 2010. Genecology and seed zones for native grasses and forbs. In: National Native Seed Conference: Native Plant Materials for Development, Production, and Use in Habitat Restoration. Corvallis (OR): Institute for Applied Ecology. 31 p.

Type: Presentation

Geographic Area: USA

Compilers' Keywords: policy, germplasm

Abstract: Western landscapes are managed to a large extent for wildlife habitat, recreation, and grazing resources. However, urbanization, frequent fires and increasing pressure from invasive weeds are interacting to cause an unsustainable cycle of environmental degradation to plant communities and ecosystems. Restoration efforts that emphasize native germplasm adapted to "local" environments may be the best approach to ensure long-term sustainable management. Developing seed zones is a way to ensure that plant materials used for revegetation match the local environment, and are neither too broad nor unnecessarily local. Ongoing work with native grasses and forbs for conservation and seeds zone development has shown 1) extensive genetic variation across the landscape for plant traits associated with growth and development, 2) growth and development traits are linked to climate variables at seed source locations, suggesting adaptive variation, 3) genetic variation in plant traits can be used with climate data to develop manageable seed zones to guide restoration.

Link: http://nativeseed.info/2010/presentations/Johnson-RC.pdf

684. Joly RJ, Adams WT, Stafford SG. 1989. Phenological and morphological responses of mesic and dry site sources of coastal Douglas-fir to water deficit. Forest Science 35:987-1005.

Type: Journal

Geographic Area: Oregon, USA

Keywords: *Pseudotsuga menziesii*, adaptation, genetic variation, growth, water stress

Abstract: Patterns of genetic variation in morphological and phenological responses to water deficit are described in seedling progeny of four populations of coastal Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*), sampled from coastal and inland sites in Oregon. Progeny of coastal and inland populations differed for all traits measured, and differences appear to reflect adaptation to the source environment. Inland populations were characterized by early budset, slower rates of shoot extension, and higher root-shoot ratios. A significant fraction of total variability was attributable to differences among families within populations. Little evidence for irrigation x population interaction was found when seedling traits were examined singly. Of 16 traits analyzed, only average daily rate of growth and seedling height had significant interaction terms. Interactions between irrigation and families-within-population were more prevalent. A canonical discriminant analysis was used to identify a subset of variables that best reveals differences among progeny of coastal and inland populations. Implications for seed transfer and for selection and breeding of genotypes suitable for xeric environments are discussed.

685. Jonsson A, Eriksson G, Franzen A. 1986. Within-population variation in frost damage in *Pinus contorta* Dougl. seedlings after simulated autumn or late-winter conditions. Silvae Genetica 35:96-102.

Type: Journal

Geographic Area: Canada, Sweden

Keywords: *Pinus contorta*, climate chamber, frost damange, within-population variation

Summary: Single-tree progenies from a few populations of *Pinus contorta* were cultivated in a climate chamber and tested with respect to frost tolerance. The plants were exposed to -10 °C for three hours during the hardening period, simulating autumn conditions. Single-tree progenies and population samples were exposed to two, six, or twelve large diurnal temperature fluctuations, -10 to +20 °C, simulating conditions inducing dehardening during late winter. Significant differences in frost damage were found between populations as well as between single-tree progenies from one of the populations after freezing during autumn conditions. The family repeat abilities for frost damage exceeded 0.50 in two of the three populations studied. Damage to plants increased with increasing number of simulated late-winter temperature fluctuations. This was the case both for the roots and the upper parts of the plants. No significant within-population variation in frost damage following exposure to simulated late-winter conditions as obtained. The simulating technique used is laborious and will not be further developed. There was a non-significant, positive relationship between frost damage induced in single-tree progenies by simulated autumn and late-winter conditions.

Link: http://www.silvaegenetica.com/fileadmin/content/dokument/archiv/silvaegenetica/35_1986/35-2-3-96.pdf

686. Joyce DG. 1988. Adaptive variation in cold hardiness of eastern larch, *Larix laricina*, in northern Ontario. Canadian Journal of Botany 18:85-89.

Type: Journal

Geographic Area: Ontario, Canada

Compilers' Keywords: local adaptation, cold hardiness, transfer guidelines

Abstract: Adaptive differentiation in cold hardiness of *Larix laricina* (DuRoi) K. Koch from 66 populations, primarily from northern Ontario, was studied using laboratory freezing tests. Population differentiation was greatest before the first frost however, relative hardiness of populations before and after the first frost were strongly correlated. Hardiness was related to latitude, longitude, and elevation of population origins. Multiple regression analyses accounted for 74% of the variance among population means. Population differentiation was detected across relatively small geographic and elevational intervals. Consequently, in order to limit maladaptation, transfer of plant material in artificial reforestation should be carefully controlled.

687. Joyce D, Rehfeldt GE. 2013. Climatic niche, ecological genetics, and impact of climate change on eastern white pine (*Pinus strobus* L.): guidelines for land managers. Forest Ecology and Management 295:173-192.

Type: Journal

Geographic Area: Ontario, Canada

Keywords: bioclimate models, ecological genetics, climate niche, climate response models, seed transfer guidelines, seed zones

Abstract: Approximately, 123,500 forest inventory and ecological ground plots representing eastern North America were used to predict the contemporary distribution of eastern white pine (*Pinus strobus* L.) from climate. The random forests classification tree procedures produced an 8-variable algorithm that had an 8% overall error rate. Erroneous predictions of presence, or errors of commission, were 13%, while falsely predicting absence, or errors of omission were 1%. Climate-based multiple regression models were developed to describe patterns of genetic variation among 112 populations representing the range of *P. strobus* in Ontario, Canada east of Lake Superior. Degree days > 5 °C was the best predictor of variation in phenology and growth potential, with 5-year height providing the greatest resolution of inter-population variation (R^2 = 0.68). Cold hardiness in the fall was most closely associated with mean minimum temperature (R^2 = 0.26). Height growth data from four disparate provenance test series that together included a total of 354 provenances corroborated the range-wide applicability of the regional genetic models. Although variation in growth potential in the central Appalachian Mountains was most closely associated with mean minimum temperature, degree days > 5 °C remained the best predictor of range-wide variation in growth potential (R^2 = 0.41). The contemporary distribution and inter-population genetic variation were projected into future climates predicted by three General Circulation Models, two scenarios, and three time steps. All projections indicate early and sustained deterioration in the contemporary habitat. Concurrence among projections regarding the redistribution of suitable habitat to the north of the contemporary distribution identifies geographic locations with the highest probability of supporting vigorous stands of *P. strobus*. Concurrences among genetic projections clarify the intraspecific redistribution required to conserve adaptive variation. The

projections have direct relevance in developing management strategies for accommodating the changing climate.

Link: http://forest.moscowfsl.wsu.edu/climate/JoyceRehfeldt2013.pdf

688. Kabrick JM, Dey DC, Gwaze D. 2007. Shortleaf pine restoration and ecology in the Ozarks: proceedings of a symposium. Delaware (OH): USDA Forest Service, Northern Research Station. General Technical Report NRS-P-15. 224 p.

Type: Government Document

Geographic Area: Southeastern USA

Compilers' Keywords: *Pinus echinata*, transfer zones, seed zones

Foreward: The Shortleaf Pine Restoration and Ecology in the Ozarks Symposium was held at the University Plaza Hotel and Convention Center in Springfield, Missouri, on November 7-9, 2006. The purpose of the symposium was to communicate experiences, research, successes, challenges, and inspire inquiries into the ecology, management, and restoration of shortleaf pine communities and ecosystems in which shortleaf pine is prominent. The symposium brought together more than 200 registrants including private landowners, state and federal resource managers, consultants, members of conservation groups, and scientists from public and private institutions to exchange ideas and share knowledge about ecosystems containing shortleaf pine. Altogether, the symposium featured eight plenary presentations, 36 oral presentations, and nine poster presentations.

Link: http://www.treesearch.fs.fed.us/pubs/12785

689. Kapeller S, Lexer MJ, Geburek T, Hiebl J, Schueler S. 2012. Intraspecific variation in climate response of Norway spruce in the eastern alpine range: selecting appropriate provenances for future climate. Forest Ecology and Management 271:46-57.

Type: Journal

Geographic Area: Austria, Europe

Keywords: climate change impacts, Gaussian response model, quantitative genetic variation, provenance test, *Picea abies*

Abstract: Enhancing adaptation of forest ecosystems to prospective climate change is a major challenge in current forest management. Beyond potential negative effects of climate change such as decreasing productivity due to an increasing number of drought periods and damages from intensified disturbance regimes, there is also a potential for increasing productivity due to prolonged vegetation periods and higher photosynthetic rates. Quantitative genetic variation is crucial for adaptability of species towards environmental changes. The use of suitable reproductive material for forest regeneration will be a key factor essential for both, mitigating negative effects and making the most of potential positive effects. Therefore, insights into intraspecific variation within and among tree populations in climate response are of paramount importance. In our study we investigated intraspecific variation in climate response among Norway spruce (*Picea abies*) populations in the eastern Alpine range. Results from a comprehensive Austrian provenance test, comprising tree heights at age 15 from 379 populations planted at 29 test sites across Austria, were used to calibrate climate response functions for groups of Norway spruce populations. Potential future changes in productivity for climate change conditions as represented by a regionalized A1B scenario were estimated using height at age 15 as a productivity proxy. Climate response functions were calculated for single populations and aggregated clusters of populations from climatically similar origins. Our results hardly revealed any declines in employed proxies for productivity of Norway spruce throughout its current distribution range in Austria. For most parts of Austria an increase of tree heights up to 45 percent can be expected until 2080. However, the impact of a warming climate is different for individual population groups. Generally, variation in climate response increases with higher temperatures and less precipitation. Thus, an optimized choice of seed material according to prospective future climate conditions has the potential for an additional increase of productivity up to 11 percent. In general, populations from currently warm and drought prone areas seem to be well adapted to respective climate conditions and may be appropriate candidates for extended utilization in future. Furthermore, populations showing the best productivity indices originate from regions, which are phylogenetically distinct from the core distribution area of Norway spruce, suggesting that population history might explain part of the variation in climate response among populations.

Link: http://www.researchgate.net/publication/220039116_Intraspecific_variation_in_climate_response_of_Norway_spruce_in_the_eastern_Alpine_range_Selecting_appropriate_provenances_for_future_climate/file/d912f4fdeea8cb6ea9.pdf

690. Keir KR, Bemmels JB, Aitken SN. 2011. Low genetic diversity, moderate local adaptation, and phylogeographic insights in *Cornus nuttallii* (Cornaceae). American Journal of Botany 98:1327-1336.

Type: Journal

Geographic Area: USA

Keywords: adaptive cline, chloroplast diversity, Cornaceae, *Cornus nuttallii*, microsatellite markers, Pacific dogwood, phenotypic variation, population structure, postglacial recolonization

Abstract: Genetic knowledge is completely lacking for Pacific dogwood (*Cornus nuttallii*), a western North American temperate tree that is pollinated and dispersed by biological vectors. We investigated how history, geography, and climate have affected population genetic structure, local adaptation,

and the phylogeography of this species. We examined patterns and levels of diversity in nuclear microsatellites (SSRs) and cpDNA haplotypes in populations from across the species range. We compared these results to population differentiation and genetic clines in phenotypic traits in a common garden. Genetic diversity was low for both nuclear SSRs and cpDNA. There was a lack of population structure (F_{ST} = 0.090) in the coastal portion of the species range, with estimates of population genetic diversity in microsatellite markers decreasing with latitude from California to British Columbia. A disjunct interior population in Idaho 450 km from the coastal range had the lowest diversity but the highest divergence of all populations studied. Only a single nucleotide polymorphism was discovered after sequencing 5547 base pairs in seven noncoding regions of cpDNA. Both cpDNA haplotypes were widely distributed throughout the species range. Quantitative variation among populations was moderate ($0.11 \leq Q_{ST} \leq 0.63$), and weak but significant adaptive clines were found between quantitative traits and population climatic variables ($0.09 \leq R^2 \leq 0.34$). *Cornus nuttallii* likely faced a population bottleneck in a single southern refugium during the Last Glacial Maximum. Despite low genetic diversity, it is weakly to moderately locally adapted.

Link: http://www.ncbi.nlm.nih.gov/pubmed/21821593

691. Kitzmiller JH. 2005. Provenance trials of ponderosa pine in northern California. Forest Science 51:595-607.

Type: Journal

Geographic Area: California, USA

Keywords: tree improvement, genetics, seed zones, seed transfer

Abstract: Growth of 17 ponderosa pine populations transferred within the southern Cascades–Sierra Nevada ranges were tested for 19 years on two contrasting sites, Cherry Hill (CH) and Peanut Springs (PS). Seven additional southern Sierra populations were tested at PS. Results provide guidance to forest managers seeking to reforest ponderosa pine after large wildfires or to improve productivity of plantations. PS represented warm, moist, lower mixed-conifer sites in the central Sierra. CH represented colder, drier climates at the southern limit of the Cascades in upper elevation mixed conifer. High inherent site productivity at PS was reduced by topsoil displacement and brush competition for moisture and/or nutrients. Contrasting magnitudes and patterns of growth among provenances were expressed between sites. The local provenance at PS outgrew more distant sources by 12 to 74%. However, high elevation, nonlocal Sierra sources grew best at CH, where volume decreased with source latitude and increased with source elevation. All sources had stockier form at CH. In both tests, Sierra sources outgrew and were stockier than Cascade sources; stockiness increased with source elevation. Current results at CH support matching provenance elevation with site, using southern sources. Results at PS strongly support the use of local seed, with allowance for transferring seed to adjacent zones.

692. Kitzmiller JH. 2009. Regional genetic variation in three native grasses in northern California. Native Plants Journal 10:263-280.

Type: Journal

Geographic Area: California, USA

Keywords: geographic variation, seed transfer zones, adaptive traits, *Elymus glaucus*, *Bromus carinatus*, *Bromus orcuttianus*

Abstract: Germination, growth, and flowering traits varied widely in a common-garden nursery environment and expressed coarse-textured geographic patterns among Plumas National Forest seed sources of 3 native grasses (Poaceae): blue wildrye (*Elymus glaucus* Buckley ssp. *glaucus*, California brome (*Bromus carinatus* Hook. & Arn. var. *carinatus*), and Orcutt's brome (*B. orcuttianus* Vasey). Seed zones are justified to partition the geographic variation in grasses on the Plumas National Forest because: 1) adaptive traits varied significantly with geographic surrogates for climate and photoperiod; 2) a coarse-textured geographic and topographic pattern overshadowed microsite variation; and 3) paired (proximal) sources were more similar to one another than more distal sources, all of which indicated selection may have contributed to population differentiation. Each species displayed a different geographic pattern, but *Bromus* species were most similar. Low-elevation southwestern sources of *B. carinatus* had earlier and higher germination and slightly higher shoot dry weight, while high-elevation northern lots had later and lower germination and dry weight. Southern sources of *B. orcuttianus* produced more flowers and germinated earlier than northern sources. *Elymus glaucus* from lower-elevation and more eastern sources, where summer drought is most pronounced, had higher dry weight and flowers.

693. Kitzmiller JH, Hanson L. 2011. Patterns of adaptation in three native grasses in northern California. Native Plants Journal 12:45-61.

Type: Journal

Geographic Area: California, USA

Keywords: seed transfer zones, local adaptation, *Elymus glaucus, Bromus carinatus, Bromus orcuttianus,* Sierra Nevada, Poaceae

Abstract: Provisional seed transfer zones were developed for 3 Poaceae grasses, *Elymus glaucus* Buckley ssp. *glaucus*, *Bromus carinatus* Hook. & Arn., and *Bromus orcuttianus* Vasey, from a 4-y study with 11 reciprocal-transplant gardens across the Plumas National Forest. To conserve existing adaptive patterns, 4 seed zones were proposed for *B. carinatus* and *B. orcuttianus,* and six for *E. glaucus*. Adaptive traits of source

populations were correlated with their geographic, climatic, and ecologic origins. Findings based on seed source x environment interactions and the geographic-climatic patterns for local, distant, and proximal paired populations suggest that natural selective pressures have produced weak to moderate broad-scale local adaptation. Three consistent "coarse-textured" adaptive patterns emerged: 1) sources from mesic west-side and east-side ecological zones formed two well-differentiated groups; 2) sources from the broad intermediate area (west side central and transition) were less differentiated and often intergraded with the mesic west-side (southwestern) and east-side (northeastern) groups; and 3) mesic west-side was divided into 2 elevation bands. Local adaptation was found less often on a finely tuned local scale.

694. Knapp EE, Rice KJ. 1996. Genetic structure and gene flow in *Elymus glaucus* (blue wildrye): implications for native grassland restoration. Restoration Ecology 4:1-10.

Type: Journal

Geographic Area: Western USA

Compilers' Keywords: seed zones, genetic variation, allozyme variation, electrophoresis, revegetation, native grass, population genetic structure, seed collection, self-pollination

Abstract: Interest in using native grass species for restoration is increasing, yet little is known about the ecology and genetics of native grass populations or the spatial scales over which seed can be transferred and successfully grown. The purpose of this study was to investigate the genetic structure within and among populations of *Elymus glaucus* in order to make some preliminary recommendations for the transfer and use of this species in revegetation and restoration projects. Twenty populations from California, Oregon, and Washington were analyzed for allozyme genotype at 20 loci, and patterns of variation within and among populations were determined. Allozyme variation at the species level was high, with 80% of the loci polymorphic and an average expected heterozygosity (an index of genetic diversity) of 0.194. All but two of the populations showed some level of polymorphism. A high degree of population differentiation was found, with 54.9% of the variation at allozyme loci partitioned among populations (F_{st} = 0.549). A lesser degree of genetic differentiation among closely spaced subpopulations within one of the populations was also demonstrated (F_{st} = 0.124). Self-pollination and the patchy natural distribution of the species both likely contribute to the low level of gene flow (Nm = 0.205) that was estimated. Zones developed for the transfer of seed of commercial conifer species may be inappropriate for transfer of *E. glaucus* germplasm because conifer species are characterized by high levels of gene flow. Limited gene flow in *E. glaucus* can facilitate the divergence of populations over relatively small spatial scales. This genetic differentiation can be due to random genetic drift, localized selective pressures, or both. In order to minimize the chances of planting poorly adapted germplasm, seed of *E. glaucus* may need to be collected in close proximity to the proposed restoration site.

695. Knapp EE, Rice KJ. 1997. Ecotypes of native species: how local is local in restoration plantings? In: Kelly M, Wagner E, Warner P, editors. California Exotic Pest Plant Council 1997 Symposium Proceedings Volume 3. Trabuco Canyon (CA): California Exotic Pest Plant Council. p 1-5.

Type: Conference Paper

Geographic Area: California, USA

Compilers' Keywords: local adaptation, native grasses, genetic diversity, *Elymus glaucus*, *Nassella pulchra*, reciprocal transplant

Conclusion: Populations of native species growing in different environments and separate regions are often genetically distinct. These genetic differences should be considered when source material of native species is obtained for restoration and revegetation. We investigated patterns of genetic variation for different types of traits among populations of a popularly planted native grass (*Nassella pulchra*), and determined the extent to which local populations of *Elymus glaucus*, and *N. pulchra* are better adapted than non-local populations. We found strong genetic differences among populations of *N. pulchra* for both isozyme markers and quantitative traits, but the patterns of genetic differentiation visualized by the two methods were not similar. Thus, management recommendations and seed transfer guidelines should not be based on data for only one type of trait. In addition, patterns of quantitative trait variation in *N. pulchra* were strongly correlated with climatic variation among sites, suggesting that it may be possible to obtain a rough match between seed sources and planting sites by using readily available climate zone data.

Link: http://www.cal-ipc.org/symposia/archive/pdf/1997_symposium_proceedings1941.pdf

696. Knapp EE, Rice KJ. 2011. Effects of competition and temporal variation on the evolutionary potential of two native bunchgrass species. Restoration Ecology 19:407-417.

Type: Journal

Geographic Area: California, USA

Keywords: *Elymus glaucus*, genetic variation, *Nassella pulchra*, phenotypic plasticity, selection response

Abstract: The capacity of restored plant populations to adapt to new environmental challenges depends on within population genetic variation. We examined how much genetic and environmentally based variation for fitness associated traits exists within populations of two native grasses commonly used for restoration in California. We were also interested in understanding how phenotypic expression of genetic variation for these traits varies with growth environment. Thirty maternal families of *Elymus glaucus* (Blue wild rye) and *Nassella* *pulchra* (Purple needlegrass) were sampled from both coastal and interior populations and reciprocally transplanted into three replicated common gardens with and without interspecific competition at each site. Reproductive output of families differed both among years and with competition treatments. Phenotypic expression of genetic variation in culm production differed among populations and was very low when families were grown with interspecific competition. Without interspecific competition, the degree of genetic determination peaked in year two in both species (8.4 and 15.1% in *E. glaucus* and *N. pulchra*, respectively). Significant genetic differences in reproduction and phenotypic plasticity were found among *N. pulchra* subpopulations sampled less than 3 km apart, further highlighting the importance of thoroughly sampling available genetic variation in populations used for restoration. The variable and generally low expression of genetic variation indicates that rates of adaptation in restored populations of these native grasses may vary temporally and may be especially slow within competitive environments.

Link: http://www.fs.fed.us/psw/publications/knapp/psw_2009_knapp005.pdf

697. Kochanek J, Steadman KJ, Probert RJ, Adkins SW. 2011. **Parental effects modulate seed longevity: exploring parental and offspring phenotypes to elucidate pre-zygotic environmental influences.** New Phytologist 191:223-233.

Type: Journal

Geographic Area: Australia

Keywords: maternal, paternal environment, paternal, *Plantago cunninghamii*, pre-zygotic, seed ageing, seed longevity, transgenerational

Abstract: Seed longevity, which is essential for germplasm conservation and survival of many land plant species, can vary considerably within species and cultivars. Here, we explore the relationship between parental and offspring phenotypes to elucidate how pre-zygotic environment affects seed longevity. Plants of the wild species *Plantago cunninghamii* were exposed to wet or dry soil within a warm or cool glasshouse until flowering and then moved to a common environment. Seeds subsequently produced were collected at maturity, and longevity was assessed by controlled ageing at 45 °C, 60% relative humidity. Multivariate analysis was used to examine relationships between the parental and offspring phenotypes. The pre-zygotic environment resulted in a highly plastic parental response which was passed on to offspring seeds and changed their longevity (p_{50}) by more than a factor of 2. Seed longevity is a function of the seed population's distribution of deaths in time (σ) and quality (K_i); σ was associated with plant size, and Ki with reproductive plant traits. The pre-zygotic growth environment modulated seed longevity via a parental effect. Reproductive performance and seed quality (K_i) were highly correlated with each other and unrelated to the maternal plant phenotype. Hence seed quality may be associated with the paternal plant response to the environment.

Link: http://www.ncbi.nlm.nih.gov/pubmed/21434931

698. Krakowski J, Stoehr MU. 2009. **Coastal Douglas-fir provenance variation: patterns and predictions for British Columbia seed transfer.** Annals of Forest Science 66:811-821.

Type: Journal

Geographic Area: Western Canada

Keywords: adaptation, genecology, provenance, *Pseudotsuga menziesii*, seed transfer

Abstract: We evaluated performance variability in two series of provenance trials of *Pseudotsuga menziesii* var. *menziesii*. EP 480 included 16 reciprocal provenances planted from British Columbia to Oregon, measured up to age 45. EP 599.03 featured five common provenances, plus the local source, planted at 23 British Columbia sites, measured up to age 33. Although residual variance was high, site accounted for 31 to 60% of the volume variance, while provenance accounted for 1–6%. Interactions were also significant across ages and trials. Genotype environment interaction was evident in EP 599.03, but not EP 480, which may reflect differences in experimental design. The worst provenances always ranked low across sites and over time. No geographic or climatic (annual, seasonal, monthly) variables consistently explained patterns of volume across sites or ages, singly or in combination for either trial, similar to findings from other studies of coastal Douglas-fir. Provenances from Washington to central Oregon often performed as well as the local provenance or better at British Columbia trial sites. Populations from higher elevations, poor sites and submaritime provenances were less vigorous. Results support maintaining elevational and ecotypic transfer limits, emphasizing site-specific decision making, and permitting wider latitudinal transfer on similar quality sites.

699. Krauss SL, He TH. 2006. **Rapid genetic identification of local provenance seed collection zones for ecological restoration and biodiversity conservation.** Journal for Nature Conservation 14:190-199.

Type: Journal

Geographic Area: Australia

Keywords: *Acacia*, AFLP, genetic diversity, habitat restoration, home-site advantage, provenance

Abstract: The ecological restoration of native plant communities requires the collection of large amounts of seed. Use of non-local provenance seed can have detrimental consequences for the success of restoration if there is a home-site advantage, and for nature conservation through the erosion of natural patterns of population genetic structuring and/or genetic swamping (and extirpation) of locally significant

genotypes. As part of an ongoing project to genetically delineate local provenance seed collection zones for species within a large urban bushland remnant of high conservation value, we assessed population genetic differentiation in two widespread coastal leguminous species, *Acacia rostellifera* and *A. cochlearis* (Fabaceae), commonly used in restoration programmes in SW Australia. Using amplified fragment length polymorphism (AFLP), we found very high levels of genetic differentiation among populations, with an analysis of molecular variance (AMOVA) showing more than 50% of the total genetic variance to be partitioned among populations (φ_{st} = 0.58 and 0.51 for *A. rostellifera* and *A. cochlearis*, respectively), and marked non-overlap of almost all potential seed source populations from the local population in ordinations. Our results suggest extremely restricted natural dispersal among populations, possibly due to a combination of low seed set, seed dispersal by ants, clonality, a linear distribution of naturally fragmented populations and possibly low outcrossing rates. We suggest a narrow seed collection zone should be applied to these species for the conservation of genetic diversity and natural patterns of population genetic structure, and we highlight the value and importance of provenance evaluation to ecological restoration.

Link: http://peeg-curtin.com/wp-content/uploads/2013/05/26.pdf

700. Kuser JE, Ching KK. 1980. Provenance variation in phenology and cold hardiness of western hemlock seedlings. Forest Science 26:463-470.

Type: Journal

Geographic Area: Western North America

Keywords: *Tsuga heterophylla*, bud burst, bud set

Abstract: Seedlings from a range-wide sample of 20 western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] provenances showed much variation in phenology and cold hardiness at Corvallis, Oregon. Seedlings of northern, high-elevation, or Rocky Mountain provenances set and burst bud earlier and survived early frost and winter cold better than seedlings of southern, low elevation, or coastal provenances. A strong north-south cline was found in the variation among coastal provenances. A sample of three families per provenance revealed four cases of marked intraprovenance variation, two in bud-set date and two in cold survival.

701. Leites LP, Robinson AP, Rehfeldt GE, Marshall JD, Crookston NL. 2012. Height-growth response to climate changes differs among populations of Douglas-fir: a novel analysis of historic data. Ecological Applications 22:154-165.

Type: Journal

Geographic Area: Northwestern USA

Keywords: climate change response functions, genotype by environment interaction, provenance tests, provenance transfer functions, *Pseudotsuga menziesii* var. *glauca*

Abstract: Projected climate change will affect existing forests, as substantial changes are predicted to occur during their life spans. Species that have ample intraspecific genetic differentiation, such as Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), are expected to display population-specific growth responses to climate change. Using a mixed-effects modeling approach, we describe three-year height (HT) growth response to changes in climate of interior Douglas-fir populations. We incorporate climate information at the population level, yielding a model that is specific to both species and population. We use data from provenance tests from previous studies that comprised 236 populations from Idaho, Montana, and eastern Washington, USA. The most sensitive indicator of climate was the mean temperature of the coldest month. Population maximum HT and HT growth response to changes in climate were dependent on seed source climate. All populations had optimum HT growth when transferred to climates with warmer winters; those originating in sites with the warmest winters were taller across sites and had highest HT growth at transfer distances closest to zero; those from colder climates were shortest and had optimum HT growth when transferred the farthest. Although this differential response damped the height growth differences among populations, cold-climate populations still achieved their maximum growth at lower temperatures than warm climate populations. The results highlight the relevance of understanding climate change impacts at the population level, particularly in a species with ample genetic variation among populations.

Link: http://www.treesearch.fs.fed.us/pubs/40383

702. Lesica P, Allendorf FW. 2002. Ecological genetics and the restoration of plant communities: mix or match? Restoration Ecology 7:42-50.

Type: Journal

Geographic Area: Global

Compilers' Keywords: conceptual framework, native plant materials, hybrids, mixed species, local adaptation, cultivar

Abstract: We present a conceptual framework for choosing native plant material to be used in restoration projects on the basis of ecological genetics. We evaluate both the likelihood of rapid establishment of plants and the probability of long-term persistence of restored or later successional communities. In addition, we consider the possible harmful effects of restoration projects on nearby ecosystems and their native resident populations. Two attributes of the site to be restored play an important role in determining which genetic source will be most appropriate: 1) degree of disturbance and 2) size of the disturbance. Local plants or plants from environments that "match" the habitat to be restored are best suited to restore

sites where degree of disturbance has been low. Hybrids or "mixtures" of genotypes from different sources may provide the best strategy for restoring highly disturbed site to which local plants are not adapted. Cultivars that have been modified by intentional or inadvertent selection have serious drawbacks. Nevertheless, cultivars may be appropriate when the goal is rapid recovery of small sites that are highly disturbed.

Link: http://www.esalq.usp.br/lcb/lerf/divulgacao/recomendados/artigos/lesica1999.pdf

703. Lesser MR, Parker WH. 2006. Comparison of canonical correlation and regression based focal point seed zones of white spruce. Canadian Journal of Forest Research 36:1572-1586.

Type: Journal

Geographic Area: Canada

Compilers' Keywords: *Picea glauca*, CANCOR, seed transfer, methods

Abstract: The focal point seed zone methodology determines spatially explicit areas of adaptive similarity for any selected geographic point and is used to match seed sources and planting sites. A total of 127 seed sources (provenances) of white spruce (*Picea glauca* (Moench) Voss) from Ontario and western Quebec were established at a greenhouse and in six field trials throughout Ontario. Growth and phenological variables were measured over three growing seasons. Two focal point seed zone methodologies were employed: (i) using models derived from principal components analysis (PCA) of biological response variables followed by multiple linear regression against climate variables and (ii) using models derived from canonical correlation analysis (CANCOR). While both approaches use climate data to model adaptive variation, CANCOR reduces the number of steps in the analysis by simultaneously finding the relationships of biological and climatic variables that maximize the covariance between two data sets. Although more of the variation in adaptive biological traits was actually described by climate variables using the PCA-regression approach, this method produced intuitively less realistic patterns. Both methods showed similar overall geographic trends, but the CANCOR method had a finer resolution, especially in southern Ontario, presumably due to statistical efficiency; growth was modeled by all climate variables.

Link: http://flash.lakeheadu.ca/~whparker/CJFR2006.pdf

704. Li P, Beaulieu J, Bousquet J. 1997. Genetic structure and patterns of genetic variation among populations in eastern white spruce (*Picea glauca*). Canadian Journal of Botany 27:189-198.

Type: Journal

Geographic Area: Canada

Compilers' Keywords: seed transfer guidelines, provenance, breeding zones

Abstract: Known patterns of genetic variation among provenances are useful in gene resource management such as guiding seed transfer and delineating breeding zones. The objectives of this study were (1) to determine the genetic structure of white spruce (*Picea glauca* (Moench) Voss) from Quebec and southeastern Ontario, (2) to develop models describing patterns of genetic variation among provenances and their relationships with environmental variation, (3) to test the validity of the models by using independent data sets, and (4) to guide seed transfer and to delineate provisional breeding zones for white spruce in Quebec. A sample of 63 provenances was used in this study, with each provenance composed of one to five separate families (a total of 263 families). Data were collected on seedling heights at various ages, 1-year branch number, and 3-year bud burst and bud set. Significant differences were found for each trait among provenances and among families within provenances. Provenances and families within provenances accounted for similar amounts of the genetic variability. All traits were moderately to strongly intercorrelated at the provenance level. Two principal components composed 87% of the total variation for all traits. Regression models explained between 19% and 65% (an average of 47%) of provenance variation and showed that patterns of provenance variation followed mainly a south-north cline and to a lesser extent a west-east cline. The regression models were tested using data from seven field tests, which showed that the models performed fairly well in predicting relative risk of seed transfer. White spruce provenances could be transferred long distances with small relative risk. We delineated two provisional breeding zones for white spruce in Quebec from the models describing patterns of genetic variation among provenances.

705. Li H, Wang X, Hamann A. 2010. Genetic adaptation of aspen (*Populus tremuloides*) populations to spring risk environments: a novel remote sensing approach. Canadian Journal of Botany 40:2082-2090.

Type: Journal

Geographic Area: North America

Compilers' Keywords: genetic variation, climate change, seed transfer, spring drought

Abstract: This study investigates geographic patterns of genetic variation in aspen (*Populus tremuloides*) spring phenology with the aim of understanding adaptation of populations to climatic risk environments and the practical application of guiding seed transfer. We use a classical common garden experiment to reveal genetic differences among populations from western Canada and Minnesota, and we present a novel method to seamlessly map heat-sum requirements in northern and high-elevation aspen populations from the central boreal plains of Saskatchewan and Alberta, and populations from

Minnesota exhibit moderately low heat-sum requirements for budbreak. Analysis of corresponding climate normal data shows that late budbreak due to both frost and drought risks in early spring. We therefore caution against distance seed transfer of Minnesota provenances to the boreal plains of Alberta and Saskatchewan. Although such transfers have been shown to increase tree growth in short-term field tests, this planting material may be susceptible to exceptional spring droughts.

Link: http://www.ualberta.ca/~xianli/pdfs/Li%20et%20al%202010%20-%20CJFR.pdf

706. Li P, Beaulieu J, Daoust G, Plourde A. 1997. Patterns of adaptive genetic variation in eastern white pine (*Pinus strobus*) from Quebec. Canadian Journal of Botany 27:199-206.

Type: Journal

Geographic Area: Canada

Compilers' Keywords: provenance, progeny test, genetic variation, genetic structure

Abstract: Genetic structure and patterns of genetic variation among provenances for eastern white pine (*Pinus strobus* L.) in Quebec were examined by a provenance-progeny test. A sample of 66 provenances of eastern white pine from Quebec and adjacent Ontario was tested, with each provenance composed of one to eight separate families (a total of 159 families). Data were collected on total seedling heights at different ages up to 4 years, 4-year branch number, and 3 year bud burst and bud set. Analysis of variance showed significant differences in each trait among provenances and among families within provenances, with one exception. Variance due to provenances was on average twice that due to families within provenances. All traits were intercorrelated at the provenance level. Two principal components summarized 77% of the total variation for all traits. Regressions of different traits on geographical variables accounted for 16% to 62% of provenance variation and disclosed complex patterns of genetic variation among provenances. Provenances from the southeastern part of the sampling area were taller and burst and set terminal buds later than the northwestern ones. The regression models were tested using 10-year height and survival from three field tests, which gave mixed results. We used the models describing patterns of provenance variation to guide seed transfer and delineated two provisional breeding zones for eastern white pine in Quebec.

707. Lipow SR, Vance-Borland K, St. Clair JB, Henderson JA, McCain C. 2007. In situ gene conservation of six conifers in Western Washington and Oregon. Western Journal of Applied Forestry 22:176-187.

Type: Journal

Geographic Area: Pacific Northwest USA

Keywords: gap analysis, biodiversity, genetic resources, conservation planning, GIS

Abstract: A gap analysis was conducted to evaluate the extent to which genetic resources are conserved *in situ* in protected areas for six conifer species in the Pacific Northwest (Sitka spruce, sugar pine, western white pine, ponderosa pine, western redcedar, and western hemlock). The gap analysis involved producing a GIS database detailing the location of protected areas and the distribution and abundance of tree species as inferred from data on potential plant association groups, actual plant associations, and actual land cover type. We used two schemes for stratifying the distribution of each species into genetic populations for gap analysis: seed zones and ecoregions. The results show that most seed zones and ecoregions contain at least 5,000 mature individuals in protected areas, indicating strong *in situ* gene conservation. Protection is less complete, however, for western white pine in the Puget lowlands, where urbanization on disease have reduced populations below safe levels. These populations represent the highest priority for additional gene conservation. Other species and areas warranting further evaluation include Sitka spruce in some parts of the Puget lowlands, remnant western white pine stands in the Oregon Coast Range, and sugar pine within the white pine blister rust zone.

Link: http://www.treesearch.fs.fed.us/pubs/29710

708. Lu P, Joyce DG, Sinclair RW. 2003. Geographic variation in cold hardiness among eastern white pine (*Pinus strobus* L.) provenances in Ontario. Forest Ecology and Management 178:329-340.

Type: Journal

Geographic Area: Ontario, Canada

Keywords: *Pinus strobus*, cold hardiness, geographic variation, seed transfer

Abstract: Needle and shoot samples of eastern white pine provenances in Ontario were subjected to a series of artificial freezing tests to determine provenance differentiation in fall and winter cold hardiness. Results indicated that under the natural processes of cold acclimation in the fall, above ground tissues of eastern white pine could withstand low freezing temperatures in September–October that exceeded the local long-term minimum climate extremes of the same periods. The severity of cold damage increased at a faster rate in September than in October and November when temperature was further decreased below the thresholds that started to cause cold damage. Under the selected freezing temperatures that inflicted between 15 and 85% average needle or/and cambium damage, consistent results were observed among freezing tests that were conducted using samples of different ages and cold acclimation stages. A clinal pattern of geographic variation in the severity of cold damage was detected with a trend parallel to that of growth potential. As thermal conditions improve from the north to south in Ontario, the growth potential of a provenance increases but the degree of cold hardiness decreases. Based on risk assessments using a spatial regression approach, it was, however, believed that northward seed transfer within a distance of 2–2.5° in latitude could be acceptable to promote stand growth while incurring no statistically significant increase in cold damage.

709. Lynch M, Walsh B. 1998. Genetics and analysis of quantitative traits. Sunderland (MA): Sinauer Associates, Inc. 980 p.

Type: Book

Geographic Area: Global

Compilers' Keywords: genotype-environment interaction

Abstract: Genetics and Analysis of Quantitative Traits brings together the diverse array of theoretical and empirical applications of quantitative genetics under one cover, in a way that is both comprehensive and accessible to anyone with a rudimentary understanding of statistics and genetics. What was originally envisioned as a single text has now become two, with the focus of this first book being on the basic biology and methods of analysis of quantitative characters. (The second book, Evolution and Selection of Quantitative Traits, will address the basic principles that govern the evolutionary dynamics of quantitative characters under the forces of mutation, random genetic drift, and natural and/or artificial selection, integrating the theory of evolution of such characters with existing empirical data from natural and domesticated plant and animal populations.) Written as a general text in quantitative genetics, the book will also be useful as a basic reference for the seasoned professional. Throughout, central theoretical concepts are developed from first principles. To aid the less statistically sophisticated reader, several chapters and appendices focus on the basic statistical tools needed to digest the book. Wherever possible, theoretical and analytical concepts are illustrated with empirical examples from diverse settings. Three major features of Genetics and Analysis of Quantitative Traits distinguish it from earlier work. First, it reflects the explosive influx over the past few years of quantitative-genetic thinking into evolutionary biology. Second, in animal breeding, enormous strides have been made in the development of new techniques for estimating breeding values (for the purposes of identifying elite individuals in selection programs) and for estimating variance components from samples of complex pedigrees. In this text's last two chapters, the authors outline the basic principles of complex pedigree analysis, without getting bogged down in technical details. Third, Genetics and Analysis of Quantitative Traits provides a broad overview of the newly emerging array of techniques for quantitative-trait loci (QTL) analysis, currently one of the most active fields of quantitative-genetic research. Genetics and Analysis of Quantitative Traits contains numerous fully-worked examples and illustrations of theoretical concepts, as well as over 2,000 references with indices by subject, author, and organism. In addition, the authors maintain a World Wide Web site featuring up-to-date lists of computer programs and on-line resources, and added information on various topics presented in the text.

Link: http://www.invemar.org.co/redcostera1/invemar/docs/RinconLiterario/2011/febrero/AG_8.pdf

710. Mahalovich MF, Dickerson GA. 2004. Whitebark pine genetic restoration program for the Intermountain West (United States). In: Sniezko R, Samman S, Schlarbaum SE, Kriebel HB, editors. IUFRO Working Party 2.02.15. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. RMRS-P-32. p 181-187.

Type: Government Document

Geographic Area: Western USA

Keywords: white pine blister rust resistance, fire restoration, genetic conservation, seed transfer guidelines

Abstract: A strategy to restore whitebark pine communities is presented that emphasizes genetic resistance to white pine blister rust (*Cronartium ribicola* Fisch.) and mountain pine beetle (*Dendroctonus ponderosae* Hopkins), in combination with an active tree planting program. Early and active intervention may prevent listing of whitebark pine under the Endangered Species Act and further aid in the successful recovery of the grizzly bear (*Ursus arctos horribilis*). The restoration program initiated in 2001 includes a multi-State effort (Idaho, Montana, Oregon, Nevada, Wyoming, and Washington) designating permanent leave trees, emphasizing clean trees in high blister rust areas or areas with a high incidence of mountain pine beetle, or areas where both conditions are present. Cone collections from these trees will provide an immediate seed source for fire restoration, reforestation, *ex situ* genetic conservation, and seedlings to be screened for blister rust resistance. Pollen will be collected for genetic conservation and to advance blister rust resistance in seed and breeding orchards. Data generated from the rust screenings will identify whitebark pine seed sources that provide high levels of blister rust resistance and provide information needed to refine seed transfer guidelines. Leave trees elevated to elite-tree status, as identified by their rust resistant progeny in the rust screenings, will serve as a seed source for operational collections and seed trees for natural regeneration. Survivors from the blister rust screening will be planted in clone banks for genetic conservation purposes, to serve as donors for future seed orchard establishment, and to facilitate selective breeding for blister rust resistance.

Link: http://prdp2fs.ess.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5341433.pdf

711. Mahalovich MF, Burr KE, Foushee DL. 2006. Whitebark pine germination, rust resistance, and cold hardiness among seed sources in the Inland Northwest: planting strategies for restoration. In: Riley LE, Dumroese RK, Landis TD, editors. Forest and Conservation Nursery Associations—2005. Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-43. p 91-101.

Type: Government Document

Geographic Area: Northwestern USA

Keywords: *Pinus albicaulis*, progeny test, genecology, heritability, electrolyte leakage test, index of injury

Abstract: A synthesis of several studies highlights above-average performing seed sources ($n = 108$) of whitebark pine (*Pinus albicaulis*), which practitioners can utilize for restoration, wildlife habitat improvement, and operational planting programs. It is the first report of this magnitude of blister rust resistance for this species. Whitebark pine does have genetic variation and demonstrated resistance to white pine blister rust, increasing from the southeast to the northwest in the Inland Northwest. Early outplanting reports have shown that some seedlings have frost damage or exhibit increased mortality in cold pockets or swales. Cold hardiness, measured in late winter on a smaller sample of sources ($n = 55$), also showed genetic variability increasing from the northwest to the southeast. Seed zones were delineated by Mahalovich and Hoff (2000) based on information on relative rust hazard and demarcation of mountain ranges. These geographic seed zones support conservative seed transfer with a special emphasis on blister rust infection levels. Sufficient variability exists to maintain these seed zone boundaries, because whitebark pine exhibits more of an intermediate adaptive strategy as compared to the generalist adaptive strategy of western white pine (*P. monticola*). Based on this composite information, it is feasible to outplant whitebark pine without the additional delay of waiting until blister rust resistant seedlings are developed from a breeding program. There are sources within each seed zone that have both rust resistance and greater cold hardiness, so those factors should not limit tree planting for restoration or critical wildlife habitat improvement objectives. Typical stock orders involve container-grown seedlings. A comparison between Economy and copper-lined Ray Leach Super Cell Cone containers™ (10 in^3 [164 cm^3]) shows no advantage to using copper lining.

Link: http://www.treesearch.fs.fed.us/pubs/26662

712. Malaval S, Lauga B, Regnault-Roger C, Largier G. 2010. Combined definition of seed transfer guidelines for ecological restoration in the French Pyrenees. Applied Vegetation Science 13:113-124.

Type: Journal

Geographic Area: France, Europe

Keywords: genetic distance, genetic variation, local provenance, mantel correlograms, native plant, phytogeographic boundaries, RAPD markers, seed collection strategy

Abstract: Can genetic tools combined with phytogeography help to define local plants and how geographically close the source population should be to the restoration site? The main phytogeographic boundaries in the French Pyrenees described by different authors were studied and this geographic pattern was compared with the results of genetic analysis for the four Pyrenean plants studied (*Trifolium alpinum, Festuca eskia, Festuca gautieri* and *Rumex scutatus*), based on random amplified polymorphic DNA (RAPD) marker analysis, unweighted pair-group method with arithmetic averages (UPGMA) analysis and Mantel correlograms comparing geographic and genetic distances. Results: The genetic analysis allowed definition of two main evolutionarily significant units (ESUs) for the plants under study. Although the limit between the two zones was slightly variable according to the species considered, an eastern and a western ESU was consistently observed. This delineation was concordant with the main phytogeographic boundaries of the French Pyrenees. RAPD markers and associated Mantel correlograms can be useful to draw ESUs for individual species when the sampling intensity is relatively dense, and similarities were revealed between species sharing the same distribution range. This delineation allowed integration of intraspecific plant variation in the management of natural resources for revegetation in the Pyrenees. Nevertheless, caution is needed for the establishment of seed pools in order to maximize genetic diversity in each of the pools during collection and production.

713. Merkle SA, Adams WT. 1987. Patterns of allozyme variation within and among Douglas-fir breeding zones in southwest Oregon. Canadian Journal of Forest Research 17:402-407.

Type: Journal

Geographic Area: Oregon, USA

Compilers' Keywords: breeding zone, seed transfer, *Pseudotsuga menziesii*, adaptive variation

Abstract: Gametophytes from wind-pollinated seeds of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) parent trees (mean 56) in each of 22 breeding zones in southwest Oregon were analyzed electrophoretically for gene frequency patterns at 27 loci. Allozyme variability levels were high, as shown by breeding-zone averages for the percentage of polymorphic loci (71.7%, 0.99 criterion), mean number of alleles per locus (2.46), and expected heterozygosity (0.178). Differences among zones in allele frequency were significant ($p < 0.05$) for only 2 of the 27 loci surveyed, and analysis of hierarchical population structure showed that less than 1% of genetic diversity was attributable to differences among breeding zones. Genetic distance between zones was small ($D = 0.0013$) and, in general, bore no relation to geographical or environmental distance. The limited allozyme differentiation among zones contrasts strikingly with the environment-related variation in seedling quantitative traits previously reported for southwest Oregon Douglas-fir. Allozymes do not appear to be useful for mapping patterns of adaptive variation or for certifying Douglas-fir seed in this region.

714. Michalski SG, Durka W. 2012. Assessment of provenance delineation by genetic differentiation patterns and estimates of gene flow in the common grassland plant *Geranium pratense*. Conservation Genetics 13:581-592.

Type: Journal

Geographic Area: Germany, Europe

Keywords: *Geranium pratense*, population structure, local provenance, AFLP, outcrossing rate, genome scan

Abstract: The use of local provenances in restoration, agriculture and forestry has been identified and widely implemented as a measure for species and community conservation. In practice, provenances are often delineated based on climate, geomorphology and correlated spatial descriptors following the boundaries of larger natural regions. They are thought to comprise genetically homogenous plant material. Here we investigate genetic variation at AFLP loci in 26 natural populations of the regionally common grassland species *Geranium pratense*, which is often used in seed mixtures. Most studied populations are located in one previously delineated provenance in Germany. We assess within- and among provenance differentiation patterns and aspects of gene flow by investigating the mating system, the genetic structure at regional and local scale, gene dispersal and potential selective mechanisms that may have contributed to differentiation patterns found. Compared to other herbaceous, insect-pollinated grassland species and despite being outcrossed (mean $t_m = 0.88$), *G. pratense* showed low genetic diversity (mean $H_E = 0.15$), considerable genetic differentiation among populations within provenances (mean pairwise $F_{ST} = 0.20$) and a pronounced within-population spatial genetic structure (mean $Sp = 0.064$). A genome scan approach identified three potentially adaptive loci. However, their allelic frequencies were only weakly related to climatic parameters thus providing little evidence for adaptive divergence. Nevertheless, the distribution of genetic diversity and derived gene dispersal estimates indicate limited dispersal ability, suggesting that gene flow at distances larger than 10 km is negligible. Our findings may question the approach of delineating provenances by general criteria, and highlight the importance of species specific studies on differentiation and adaptation patterns.

Link: http://www.ufz.de/export/data/global/33126_Michalski_Durka_2012.pdf

715. Miller SA, Bartow A, Gisler M, Ward K, Young AS, Kaye TN. 2011. Can an ecoregion serve as a seed transfer zone? Evidence from a common garden study with five native species. Restoration Ecology 19:268-276.

Type: Journal

Geographic Area: Pacific Northwest USA

Keywords: common garden, ecoregion, restoration, seed transfer zone

Abstract: Prairie restoration is often limited by the availability of appropriate local plant materials. Use of locally adapted seed is a goal in restoration, yet little information to inform seed transfer guidelines is available for native plant species. We established common gardens of five plants (*Eriophyllum lanatum* var. *leucophyllum*, *Epilobium densiflorum*, *Potentilla gracilis* var. *gracilis*, *Lupinus polyphyllus* var. *polyphyllus*, and *Saxifraga oregana*) frequently used in prairie restoration in the Pacific Northwest of North America to determine if populations differed in morphological and phenological traits and whether this variability was structured by geography, climate, or habitat. Ordination techniques were used to summarize the observed variability of multiple traits for each species. Ordination distance was significantly correlated with geographic distance in *L. polyphyllus* var. *polyphyllus*, and populations of this species differed significantly among geographic groups within an ecoregion. Little or no spatial structure was detected in the remaining species, despite correlations between ordination scores and monthly temperatures. We suggest that a single seed zone in the Willamette Valley ecoregion may be appropriate for all species examined except *L. polyphyllus* var. *polyphyllus*. Ecoregions in general may be useful boundaries for seed transfer zones, especially in regions with relatively little topographical or climatic variation.

Link: http://www.snprsip.com/resources/publications/seed-plant-development/Miller_2011.pdf

716. Montalvo AM, Ellstrand NC. 2001. Nonlocal transplantation and outbreeding depression in the subshrub *Lotus scoparius* (Fabaceae). American Journal of Botany 88:258-269.

Type: Journal

Geographic Area: California, USA

Keywords: coastal sage scrub, common garden, cumulative fitness, ecological genetics, environmental distance, geographic distance, genetic distance, local adaptation, restoration, seed source

Abstract: The genetic background of transplants used to create or augment wild populations may affect the long-term success of restored populations. If seed sources are from differently adapted populations, then the relative performance of progeny from crosses among populations may decrease with an increase in genetic differences of parents and in the differences of parental environments to the transplant location. We evaluated the potential for such outbreeding depression by hybridizing individuals from six different populations of *Lotus scoparius* var. *scoparius* and *L. s.* var. *brevialatus*. We used allozyme data to calculate genetic distances between source populations, and compiled climatic data and measured soil traits to estimate environmental distances between source populations. We found significant outbreeding depression following controlled crosses. In the greenhouse, the success of crosses (seeds/flower × seedlings/seed) decreased with increasing

genetic distance between populations revealing genetically based outbreeding depression unrelated to local adaptation. After outplanting to one native site (*in situ* common garden), field cumulative fitness of progeny (survival × fruit production) decreased significantly with mean environmental distance of the parental populations to the transplant site, but not with genetic distance between the crossed populations. This result is consistent with a disruption of local adaptation. At the second, ecologically contrasting common garden, where low survival reduced statistical power, field cumulative fitness (survival × progeny height) did not decrease significantly with either environmental distance or genetic distance. Overall, intervariety crosses were 40 and 50% as fit (seeds/flower × seedlings/seed × survival × fruits at the first garden or × height at the second) as intravariety crosses. These results suggest that the cumulative outbreeding depression was caused by a combination of genetically based ecological differences among populations and other genomic coadaptation. We conclude that mixing genetically differentiated seed sources of *Lotus scoparius* may significantly lower the fitness of augmented or restored populations. Genetic and environmental similarities of source populations relative to the transplant site should be considered when choosing source materials, a practice recommended by recent seed transfer policies. Geographic separation was not a good surrogate for either of these measures.

717. Mylecraine KA, Kuser JE, Zimmermann GL, Smouse PE. 2005. Rangewide provenance variation in Atlantic white-cedar (*Chamaecyparis thyoides*): early survival and growth in New Jersey and North Carolina plantations. Forest Ecology and Management 216:91-104.

Type: Journal

Geographic Area: USA

Keywords: Cupressaceae, local adaptation, phenotypic variation, *Chamaecyparis thyoides*, growth phenology, geographic variation

Abstract: Atlantic white-cedar, *Chamaecyparis thyoides* (L.) B.S.P., is an important wetland tree species occurring along the Atlantic coast of the United States, from Maine to Florida, and westward along the Gulf of Mexico coast to Mississippi. Within this range, its distribution is patchy and disjunct, due to the scattered occurrence of suitable wetland habitat, natural range disjunctions and historic declines. Much recent interest has focused on the species, its management and its restoration, but very little is known about its geographic pattern of phenotypic variation. This study presents second year results from the first rangewide white-cedar provenance test. Rooted cuttings were propagated from 34 source populations, encompassing the entire latitudinal range (29°12'–44°20' N) of the species, and planted in three common garden plantations, two in New Jersey and one in North Carolina. Survival was generally high for Atlantic coastal populations at all three planting locations, ranging from 72% to 100% for individual provenances, but many Florida and Gulf coast populations exhibited reduced survival and winter hardiness in New Jersey, with 44–94% survival and 11–67% of surviving trees experiencing winter dieback. Height growth varied significantly between planting sites and provenances, and a significant site by provenance interaction suggested that relative performance of provenances varied across sites. All populations grew significantly more at Hofmann Forest, North Carolina than at the two New Jersey plantations, with mean 2-year height growth ranging from 54 to 96 cm for individual provenances at this site. By comparison, mean height growth ranged from 23 to 63 cm at Richard Stockton College, and from 12 to 32 cm at Brendan T. Byrne State Forest, New Jersey. Within individual sites, we identified polynomial relationships between height growth and latitude of origin, with southern Atlantic coastal populations among the best performers at all sites. Patterns of growth phenology were significantly correlated with latitude of origin. Spring growth rate and the percent of total growth occurring during spring were positively correlated with latitude, while fall growth rate and the percent of growth occurring during fall were negatively correlated with latitude. These early results suggest that significant provenance variation exists among white-cedar populations, and that local sources should be preferred for regeneration and restoration purposes.

718. Namkoong G, Conkle MT. 1976. Time trends in genetic control of height growth in ponderosa pine. Forest Science 22:2-12.

Type: Journal

Geographic Area: California, USA

Keywords: *Pinus ponderosa*, geographic variation, elevation effects, tree growth, genetic variation

Abstract: Height growth in ponderosa pine plantation with 71 families in 7 elevational zone sources was analyzed at ages 3, 5, 7, 8, 12, 20, 25, and 29. Height growth varied by seed source zone and by family within zone. Zonal variances were well established at an early age, and the differences were maintained with minor variations through the study period. Family variances were smaller than zonal and environmental variances, the differences were not well correlated between the earlier and later phases, and the correlations were sometimes negative. Three observed growth phases, related to ecological dominance and competition, affected the levels of variance attributable to genetics and environment.

719. Nanos N, González-Martínez SC, Bravo F. 2004. Studying within-stand structure and dynamics with geostatistical and molecular marker tools. Forest Ecology and Management 189:223-240.

Type: Journal

Geographic Area: Spain, Europe

Keywords: geostatistics, spatial structure, stand dynamics, competition, molecular markers

Abstract: We established a circular experimental plot (radius = 100 m) that consists of 380 trees of maritime pine (*Pinus pinaster* Ait.). The plot is located in central Spain (Segovia province) and within a pure, even aged and naturally regenerated stand of the species. Every tree was initially mapped using polar coordinates. The objective of the study was to explore the spatial arrangement of some stand attributes such as age of trees, diameter at breast height (DBH), total height, diameter increment and number of female strobili and cones. Genetic data (three highly polymorphic nuclear microsatellites) were used to investigate extend of relatedness within the stand and differentiate between genetic and environmental causes of spatial aggregation. We employed, in the analysis of tree attributes, only geostatistical tools (direct and cross variograms as well as their indicator counterparts). The results revealed that all the studied attributes are spatially correlated and some of them cross-correlated. Competition and height were found to be key-variables in stand dynamics, which influence the rest of the attributes. Fine-scale genetic structure exists within the stand (0–30 m range). Relatedness between neighboring trees can partially explain the spatial aggregation of individual tree attributes. Geostatistical tools are recommended for this type of spatial analysis of forest stands. Their use can provide useful insights into the nature of stand organization and can guide future silvicultural treatment toward higher stand productivity or better and faster regeneration.

720. Navarro C, Boshier D, Cavers S, Lowe A. 2010.

Genetic resources and conservation of mahogany in Mesoamerica. Forests and Society 20:369-383.

Type: Journal

Geographic Area: Mexico

Keywords: mahogany, *Swietenia*, conservation, management, policies, genetic diversity, genetic resource, agroforestry

Abstract: We review here the scale of neutral and adaptive genetic variation of mahogany (*Swietenia* spp.), one of the most valuable tree species in the world, and relate this information directly to provenance performance, and seed transfer and sourcing recommendations. Further, we explore a series of scientific issues directly related to critical day-to-day management of mahogany, giving guidelines to maximise genetic diversity outcomes in natural, remnant, sustainably harvested, and/or restored forest landscapes. The study concludes that conservation and sustainable management of mahogany genetic resources cannot be simply defined in terms of one-size-fits-all solutions, and requires local community involvement to prevent illegal logging and ensure mutual benefit. Landscape level strategies for the effective management of mahogany trees outside of forests urgently need to be developed, together with strategies to promote the benefits of different agroforestry practices. There is also a requirement for conservation planners to consider that trees found outside protected areas have a role in the conservation. In wide-ranging species, promoting international collaboration for collecting, characterizing, and conserving genetic resources is vital as international consensus is needed to streamline phytosanitary procedures, to facilitate the exchange of forest reproductive material, and assist genetic resource conservation efforts.

Link: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCoQFjAA&url=http%3A%2F%2Fwww.iufro.org%2Fdownload%2Ffile%2F5907%2F4668%2F369-384_pdf%2F&ei=PwZ4Uv2gMaewjAKN34DACg&usg=AFQjCNFzp_g0nqmcx_F2XFqLA7zTAJYlSA&sig2=DEsdQQrwOnk-w_-fELAbNQ&bvm=bv.55980276,d.cGE

721. O'Brien EK, Mazanec RA, Krauss SL. 2007.

Provenance variation of ecologically important traits of forest trees: implications for restoration. Journal of Applied Ecology 44:583-593.

Type: Journal

Geographic Area: Australia

Keywords: ecological restoration, forest trees, genetic variation, jarrah, provenance trial, quantitative traits, seed collection zones

Abstract: The source of seed or plant material can have profound implications for the success of restoration efforts because most species exhibit adaptive genetic variation within their range. Understanding the geographical distribution of ecologically relevant genetic variation and the environmental factors driving adaptive divergence within species will help to ensure appropriate sourcing of material for ecological restoration. We present a study of geographical variation of ecologically important traits of the forest tree jarrah *Eucalyptus marginata* from a 15-year-old provenance trial in southwestern Australia. We assessed trait variation in association with rainfall, latitude and slope position at the site of origin. Survival and stem diameter varied at the largest scale, between northern and southern jarrah forest provenances. Stem diameter also varied among rainfall zones, while latitude was a more important determinant of variation of reproductive traits (flowers and buds). None of the environmental variables accounted for significant variation of height, growth form or the presence of capsules. Slope position at the site of origin did not account for significant variation of any trait. Trees from low rainfall sites had smaller stem diameters, possibly reflecting selection for slower growth. Such a strategy could prevent drought stress and may explain why trees from the high rainfall southern jarrah forest, which showed the fastest growth, had the poorest survival at the drier northern trial site. Variation in the presence of buds and flowers among latitudinal divisions may be because of variation in flowering time, which has been observed

previously among *E. marginata* populations. However, variation among replicate blocks within the trial suggests that the environment also strongly influences expression of these traits. We have demonstrated divergence of several ecologically important traits in association with different types of environmental variation. Our findings support an argument for 'habitat matching' when sourcing material for restoration; however, differences among trait types in the distribution of variation highlight the need to consider environmental variation at a range of geographical scales. Consideration of ecologically important genetic variation within species is important and this information should be integrated into seed collection strategies for ecological restoration.

722. O'Neill GA, Nigh G, Wang T, Ott PK. 2007. Growth response functions improved by accounting for nonclimatic site effects. Canadian Journal of Forest Research 37:2724-2730.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: lodgepole pine, *Pinus contorta*, provenance study

Abstract: Growth response functions (GRFs) that relate the growth of a population to the climate of the sites in which it is tested are gaining attention for their ability to predict impacts of climate change on tree growth. However, nonclimatic site to site variation introduces error into GRFs. Using data from a large lodgepole pine (*Pinus contorta* Dougl. ex Loud.) provenance test in British Columbia and the Yukon, Canada, a technique is presented that accounts for the effect of non-climatic variation in GRFs. The mean height of the "local" provenances at each test site was used to predict "site height" from site climate variables in multiple regression. Residuals from the site height equation provided an index of the nonclimatic effect for each site and were included as a covariate in quadratic GRFs that related provenance height at each test site to mean annual temperature at each test site. Inclusion of the nonclimatic index in the model resulted in a moderate or large displacement of GRFs for 25% of the provenances, while increasing mean R^2 values for 138 of 140 provenances and decreasing the root mean squared error for 113 of 140 provenances. These results suggest that inclusion of the nonclimatic index in GRF models could substantially affect height predictions for some provenances and reduce prediction error for most provenances.

723. O'Reilly C, Owens JN. 1987. Long-shoot bud development, shoot growth, and foliage production in provenances of lodgepole pine. Canadian Journal of Forest Research 17:1421-1433.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: *Pinus contorta*, long-shoot bud development, axillary bud, terminal apical

Abstract: Long-shoot bud development, shoot growth, and foliage production were studied in seven provenances of *Pinus contorta* Dougl. ssp. *latifolia* Engelm. from the major sites in British Columbia and one Yukon source growing in a provenance trial at Prince George, B.C. Branch terminal apical mitotic activity began in early March and continued until late September. Initiation of axillary buds began in May, about 2 weeks after the initiation of the subtending cataphyll. Differentiation of dwarf shoots began in early July to mid-August and continued until late October in some sources. Distal axillary buds had not always differentiated by late October in the southern sources. The duration of the period of apical growth and apical size during activity were related to final cataphyll numbers. Provenances with the widest, flattest, dormant apices produced the most cataphylls. The two northern provenances had more terminal sterile cataphylls but fewer sterile cataphylls lower in the long-shoot bud and shorter mean stem unit lengths than the others. Differences among provenances in shoot length were due mostly to variation in stem unit numbers. The large proportion of polycyclic long shoots in some provenances contributed to variation in dwarf shoot numbers.

724. O'Reilly C, Owens JN. 1989. Polycyclic growth and branching in the upper crown in provenances of lodgepole pine. Canadian Journal of Forest Research 19:79-87.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: provenance study, branch numbers, *Pinus contorta*, seed source

Abstract: The percentage of shoots that originated from polycyclic growth in first-order branches and branch numbers in upper annual segments of leader growth were determined from trees of seven provenances of *Pinus contorta* Dougl. ssp. *latifolia* Engelm. from British Columbia and the Yukon, growing in a provenance trial at Prince George, B.C. The number of first-order branches varied among provenances and year of growth and was related to the frequency of extra cycles. The percentage of polycyclic shoots was greatest in the 2nd and 4th years of branch growth, although this varied with year and provenance. Total branch numbers were influenced mostly by variation in first- and second-order branch numbers. Second-order branch numbers were greatest in the second and third segments of leader growth (from the top down), but this was influenced by year of growth and provenance. The high levels of second-order branching corresponded to the greater frequency of polycyclic branches in these positions. The fast-growing southern provenance had the most branches, while the slow-growing Yukon source had the least. The slower-growing provenances had the most first-order branches per unit height.

725. Oswald BP, Neuenschwander LF. 1995. Mortality of western larch seedlings in relation to seedbed characteristics at the dry end of its ecological range. Bulletin of the Torrey Botanical Club 122:101-108.

Type: Journal

Geographic Area: Idaho, USA

Keywords: safe sites, western larch, seedbed, seedling mortality, *Larix*

Abstract: The effects of different seedbeds on western larch (*Larix occidentalis* Nutt.) germination and seedling mortality were assessed in a grand fir/ninebark (*Abies grandis* ((Dougl. ex. D. Don) Lindl.))/ (*Physocarpus malvaceus* ((Greene) Kuntze)) habitat type in northern Idaho, U.S.A. Two plots were established on each of four sites, and 150 western larch seeds (66% viable) were distributed on each of 16 randomly applied seedbed modification combinations (burned or mechanical scarified, mineral soil or duff, shaded or non-shaded, caged or non-caged for protection from predation). Germination percentages and seedling development were significantly greater (4–10 times) on caged units than on uncaged units by mid-July. Shading did not significantly affect germination percentage or initial seedling establishment. No significant differences occurred in germination or initial seedling establishment between burned and unburned treatments. Mortality of seedlings, most likely caused by a month-long dry period with high temperatures, resulted in no significant differences in seedling numbers among treatments by mid-August the first year after seed dispersal. On the dry end of this species' range, there does not appear to be any difference in seedling survival from seedbed modification.

726. Parker WH. 1992. Focal point seed zones: site-specific seed zone delineation using geographic information systems. Canadian Journal of Forest Research 22:267-271.

Type: Journal

Geographic Area: Ontario, Canada

Compilers' Keywords: Jack pine, *Pinus banksiana*, GIS, provisional zones, seed transfer zone, common garden

Abstract: A new site-specific approach to defining seed zones in North American conifers is described. Using focal point seed zones, an individual site to be reforested becomes the focal point, and a unique seed zone is established for that site as needed. This approach depends upon (i) obtaining good comparative data in adaptive characteristics from throughout the range to be regenerated based upon a series of short-term growth tests in a common garden and (or) greenhouse and (ii) graphic analysis of multivariate summary scores by geographic information systems software to delimit boundaries of unique seed zones for any location to be reforested. A sample focal point seed zone is delineated for jack pine (*Pinus banksiana* Lamb.) reforestation of a site in northern Ontario. This approach has considerable potential to help prevent decreased growth and yield due to the planting of maladapted seed.

727. Parker WH, van Niejenhuis A. 1996. Regression-based focal point seed zones for *Picea mariana* from northwestern Ontario. Canadian Journal of Botany 74:1227-1235.

Type: Journal

Geographic Area: Ontario, Canada

Keywords: black spruce, *Picea mariana*, adaptive variation, focal point seed zones

Abstract: The results of a recent study of adaptive variation of black spruce in northwestern Ontario, together with additional freezing damage data, were used to produce regression-based focal point seed zones for this species. The procedure required two data bases as follows: (i) the biological data derived from two common garden growth trials, one greenhouse trial, and freezing trials of 75 black spruce seed sources and (ii) climatic data for the period 1951-1980. Principal components analysis (PCA) was used to summarize the main components of growth and freezing variation, and the PCA axis scores for the seed sources were regressed against climatic variables. The regression equations were used to model the patterns of adaptive variation, and these patterns were graphically reproduced as contour maps by a geographic information system (GIS). A series of focal point seed zone maps for black spruce was produced by GIS intersection of the regression-based contour maps. Focal point seed zones were more restricted in the south near Lake Superior, reflecting the more rapidly changing climate in this part of the study area. Since black spruce is closely adapted to local climate, these results will be useful to formulate successful seed transfers in this area. There are additional potential applications for matching seed sources to changing climates and for the identification of genetically unique populations.

Link: http://flash.lakeheadu.ca/~whparker/FPSZ1996reprint.pdf

728. Parsons MC, Jones TA, Larson SR, Mott IW, Monaco TA. 2011. Ecotypic variation in *Elymus elymoides* subsp. *brevifolius* in the northern Intermountain West. Rangeland Ecology & Management 64:649-658.

Type: Journal

Geographic Area: Western USA

Keywords: AFLP, common garden, Great Basin, ecotype, squirreltail

Abstract: Bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey) is an important native bunchgrass for rangeland restoration in western North America. This species is taxonomically complex and has diverged into as many as four subspecies, including subsp. *brevifolius*, for which four geographically

distinct races have been described (A, B, C, and D). Of these four races, only C occurs in the northern Intermountain West. Our objectives were to describe phenotypic and genetic variation within C and to ascertain its taxonomic status. We evaluated 32 populations of C collected across the northern Intermountain West for a battery of biomass, phenological, and functional traits in common-garden settings in the field and greenhouse. Genetic variation was assessed with the use of amplified fragment length polymorphism (AFLP) markers, and correlations were calculated among phenotypic, genetic, environmental, and geographic distance matrices with the use of Mantel tests. Values for these four distance measures were positively correlated, suggesting that environmental heterogeneity and isolation by distance are shaping ecotypic divergence driven by natural selection. We describe three phenotypic zones for C that correspond to previously established ecoregion boundaries. Because genetic data group C apart from subsp. *brevifolius* races A, B, and D, which originate in the Rocky Mountains and western Great Plains, the so called race C merits description as a new subspecies apart from subsp. *brevifolius*.

729. Pastorino MJ, Ghirardi S, Grosfeld J, Gallo LA, Puntieri JG. 2010. Genetic variation in architectural seedling traits of Patagonian cypress natural populations from the extremes of a precipitation range. Annals of Forest Science 67:508-508.

Type: Journal

Geographic Area: Argentina, South America

Keywords: differentiation, phenotypic plasticity, heritability, *Austrocedrus*

Abstract: Species distributed along wide environmental ranges are expected to be either plastic or adapted to local optima. The elucidation of which of these alternatives prevails, is crucial in planning breeding and conservation strategies for not yet domesticated species. *Austrocedrus chilensis* (Cupressaceae) is the most commercially important conifer of the temperate forests of Argentina and the target of a domestication program. A steep precipitation gradient characterizes its Argentinean range. Variation within and differentiation among four natural populations of this Patagonian cypress representative of two contrasting precipitation regimes (> 1,300 and 330 mm per y) were assessed by analyzing several morpho/architectural traits in one-year-old seedlings grown in a greenhouse. Progenies from one of the two xeric populations did not differ from those corresponding to both humid-site populations. The two most variable populations in terms of additive genetic variance belonged to contrasting precipitation regimes. Differentiation among populations was low as measured by each and every variable (average Q_{st} = 0.088). Morphological traits related to the main axis size would have a dubious adaptive meaning. The results suggest that the Patagonian cypress would have not evolved genetic pools adapted to local optima, and thus it appears to be a phenotypically plastic species, at least regarding growth at juvenile age.

730. Pedersen AP, Hansen JK, Mtika JM, Msangi TH. 2007. Growth, stem quality and age-age correlations in a teak provenance trial in Tanzania. Silvae Genetica 56:142-148.

Type: Journal

Geographic Area: Tanzania, Africa

Keywords: *Tectona grandis*, land races, provenance variation

Abstract: This study examines the growth and stem straightness variation between teak (*Tectona grandis* L. f.) provenances in a 30-year-old field trial in the coastal lowland of Tanzania. The results are compared with earlier results. The findings demonstrate that it is possible to find large height and yield differences between teak provenances. The best performing provenance grows some 10% (height) to 40% (volume) better than the average. The provenance Topslip, India, consistently proved to be outstanding in terms of growth and stem quality confirming earlier evaluations at age 5 and 17 years. Tanzanian land races also proved to be superior, especially as regards stem straightness.

Link: http://www.silvaegenetica.com/fileadmin/content/dokument/archiv/silvaegenetica/56_2007/56-3-4-142.pdf

731. Perks MP, McKay HM. 1997. Morphological and physiological differences in Scots pine seedlings of six seed origins. Forestry 70:223-232.

Type: Journal

Geographic Area: Scotland, United Kingdom

Compilers' Keywords: *Pinus sylvestris*, provenance study

Summary: One-year-old seedlings of Scots pine (*Pinus sylvestris* L.) of four native seed origins (Loch Maree Islands, Glengarry/Glen Morriston, Glen Affric and Abernethy), a commercial British seedlot, and a seedlot from Hedesunda, in middle Sweden, were compared at monthly intervals from October 1993 to April 1994. Seedling morphology, root condition, root frost hardiness and bud dry matter were determined at each date. There were clear morphological differences among seed origins. Seedlings raised from the commercial seedlot (A70) were larger but had a poorer root : shoot ratio than the other seed origins. Of the native pines tested, the Loch Maree Islands origin allocated a larger proportion of its photosynthate to fine roots and needles and smaller proportion to woody structures. Seedlings raised from the commercial British seedlot tended to have poorer bud lignification than the other origins and also, in autumn, higher electrolyte leakage rates from its fine roots. During winter, the Swedish origin had the lowest fine root electrolyte leakage. Seedlings of all origins showed a progressive increase in fine root hardiness towards mid-winter with maximum hardiness (–7 °C) in January. Dehardening occurred over subsequent months reaching –3 °C in April. Differences among origins were evident. The Swedish seedlot developed greater frost resistance than the other origins, hardening began earlier in autumn and dehardening began later in spring. The commercial seedlot hardened later than the other origins but reached a similar level of frost hardiness by January. Of the native pines, seedlings of the Loch Maree Islands origin were slowest to develop root hardiness.

Link: http://forestry.oxfordjournals.org/content/70/3/223.full.pdf

732. Pharis RP, Ferrell WK. 1966. Differences in drought resistance between coastal and inland sources of Douglas fir. Canadian Journal of Botany 44:1651-1659.

Type: Journal

Geographic Area: Western North America

Compilers' Keywords: *Pseudotsuga menziesii*, provenance study

Abstract: By two drought-hardiness tests, "time to death" and "soil-moisture content at the death point," Douglas-fir seedlings from three coastal sources were shown to be less drought resistant than those from five inland sources. Lethal needle-moisture values, useful as an index of whole plant viability, were established for the various sources. Two of the coastal sources differed from five inland sources in the level of these values, but the lethal points for two other sources from the Oregon Cascade Range were similar to the five inland sources. Needle moisture appears to be a workable index for determining the whole plant viability except when the plant is very close to its time of death. Plants could also be classified into coastal and inland groups on the basis of their needle moisture under well-watered conditions, with the exception of seedlings from the Arizona source which are like the coastal group.

733. Phillips NC, Larson SR, Drost DT. 2008. Detection of genetic variation in wild populations of three *Allium* species using amplified fragment length polymorphisms. HortScience 43:637-643.

Type: Journal

Geographic Area: Utah, USA

Compilers' Keywords: genetic diversity, germplasm, divergence, AFLP, geographic variation, genetic isolation, native onion

Abstract: Three wild onion species native to the intermountain west in the United States—*Allium acuminatum*, *A. brandegei*, and *A. passeyi*—show horticultural potential, but little is known about patterns of genetic diversity among localized populations and geographical regions. We examined amplified fragment length polymorphisms (AFLP) within and among five *Allium acuminatum*, four *A. brandegei* and three *A. passeyi* collection sites in Utah. These three congeners with contrasting abundance and distribution patterns provide an opportunity to investigate the role of geographic distance, altitude, and rarity in patterns of genetic divergence. The collection sites were selected along an altitudinal gradient to reflect ecogeographic variation. Individual plants from each of the 12 sites were genotyped using six AFLP primer combinations detecting DNA variation within and among all three species. Genetic differences between species were high enough to render comparisons among species impractical, so each species was analyzed separately for differences between populations and variability within populations. Similarity coefficients were significantly greater within collection sites versus among collection sites indicating divergence between populations. Within-population genetic diversity was not correlated with elevation for any of the three species. Analysis of molecular variance revealed that 66% (*A. acuminatum*), 83% (*A. passeyi*), and 64% (*A. brandegei*) of observed variation is found within populations. Genetic divergence among populations (φ_{ST}) was higher in the widely distributed species, suggesting that interpopulation gene flow may be negatively correlated with range size. *Allium acuminatum* and *A. brandegei* individuals cluster into groups corresponding strictly to collection sites based on neighbor-joining analysis of the total number of DNA polymorphisms between individual plants. *Allium passeyi* populations, however, had less overall genetic variation between populations. Genetic isolation by distance appeared responsible for much of the variability among populations, although there was one notable exception showing significant differences between two geographically close populations in *A. acuminatum*.

734. Raddad EAY. 2007. Ecophysiological and genetic variation in seedling traits and in first-year field performance of eight *Acacia senegal* provenances in the Blue Nile, Sudan. New Forests 34:207-222.

Type: Journal

Geographic Area: Sudan, North Africa

Keywords: agroforestry, adaptation, clay plain, gum belt, reforestation, relative growth rate

Abstract: The genetic variation in seed weight, seed number per kg and seedling traits was compared among eight *Acacia senegal* provenances originating from the clay plain (east) and sand plains (west) of the gum belt in Sudan. The main objective of this study was to identify germplasm sources of *A. senegal* that have a good seed germination capacity and seedling traits suitable for reforestation in the clay-soil part of the dryland gum belt in the Blue Nile region in Sudan. A specific objective was to tentatively explore the adaptive strategy of *A. senegal* populations. Seventeen-week old seedlings were planted in the field at spacing of 3 m · 3 m, giving 100 trees per plot and replication; within a randomized complete block design with four replications. The experimental site was in the clay plain region. Seed variables showed significant differences. Clay plain provenances showed considerable variation in seed weight and seed number. They had the smallest seed weight but the highest seed number, while the sand (western) provenances had the largest seed weight but lowest seed number. Seedling branch number, root length, root to shoot ratio and shoot dry weight differed significantly among the provenances 12 weeks after germination. Clay provenances had the highest branch number and shoot dry weight but the shortest roots and lowest root to shoot ratio. This was interpreted as showing better adaptation to the site in these local provenances in comparison to those originating from the western sandy soil regions. High positive correlations were observed between seedling variables, such as root nodule and branch numbers; this could be used for early selection. The variation was greater between provenance groups than within them, suggesting that especially selection among groups would yield genetic gain.

735. Ramirez-Valiente JA, Lorenzo Z, Soto A, Valladares F, Gil L, Aranda I. 2009. Elucidating the role of genetic drift and natural selection in cork oak differentiation regarding drought tolerance. Molecular Ecology 18:3803-3815.

Type: Journal

Geographic Area: Spain, Europe

Keywords: adaptation, carbon isotope discrimination, drift, F_{ST}, leaf size, Q_{ST}, *Quercus suber*, selection

Abstract: Drought is the main selection agent in Mediterranean ecosystems and it has been suggested as an important evolutionary force responsible for population diversification in these types of environments. However, population divergence in quantitative traits can be driven by either natural selection, genetic drift or both. To investigate the roles of these forces on among-population divergence in ecophysiological traits related to drought tolerance (carbon isotope discrimination, specific leaf area, leaf size and leaf nitrogen content), we compared molecular and quantitative genetic differentiation in a common garden experiment including thirteen cork oak (*Quercus suber* L.) populations across a gradient of rainfall and temperature. Population differentiation for height, specific leaf area, leaf size and nitrogen leaf content measured during a dry year far exceeded the molecular differentiation measured by six nuclear microsatellites. Populations from dry-cool sites showed the lowest nitrogen leaf content and the smallest and thickest leaves contrasting with those from humid-warm sites. These results suggest (i) these traits are subjected to divergence selection and (ii) the genetic differences among populations are partly due to climate adaptation. By contrast, the low among-population divergence found in basal diameter, annual growth and carbon isotopic discrimination (a surrogate for water use efficiency) suggests low or no divergence selection for these traits. Among-population differentiation for neutral markers was not a good predictor for differentiation regarding the quantitative traits studied here, except for leaf size. The correlation observed between the genetic differentiation for leaf size and that for molecular markers was exclusively due to the association between leaf size and the microsatellite QpZAG46, which suggests a possible linkage between QpZAG46 and genes encoding for leaf size.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19732337

736. Rehfeldt GE. 1979. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) populations I. North Idaho and north-east Washington. Heredity 43:383-397.

Type: Journal

Geographic Area: Pacific Northwest USA

Compilers' Keywords: provenance, genetic × environment interaction, seed transfer guidelines, tree growth, elevation

Summary: Growth, phenology and frost tolerance of seedlings from 50 populations of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) were compared in 12 environments. Statistical analyses of six variables (bud burst, bud set, 3-year height, spring and fall frost injuries, and deviation from regression of 3-year height on 2-year height) showed that populations not only differed in mean performance, but also reacted differently to the environmental gradient. Most of the population environment interaction was attributable to heterogeneous regressions of population means on environmental means. For all variables except growth rate, the variance of heterogeneous regression coefficients was explained by convergence of regression lines to a common point on the environmental gradient. Consequently, mean values for populations were significantly correlated with regression coefficients. Thus, main effects of populations in those single environments that induced the greatest mean differences reflected the interaction. Multiple regression analyses associated adaptive differentiation of populations with geographic and ecologic characteristics of the seed source. Differentiation was controlled primarily by elevation and secondarily by latitude. Whereas longitude was a minor factor, habitat types accounted for no differentiation beyond that associated with elevation, a factor closely correlated with habitat types. From these results it is recommended that seed for reforestation should not be moved more than 140 m elevation, l6° latitude, or 27° longitude in northern Idaho and eastern Washington.

Link: http://www.treesearch.fs.fed.us/pubs/38633

737. Rehfeldt GE. 1982. Ecological adaptations in Douglas-fir populations. II. Western Montana. Ogden (UT): USDA Forest Service, Intermountain Forest and Range Experiment Station. RP-INT-295. 12 p.

Type: Government Document

Geographic Area: Montana, USA

Compilers' Keywords: *Pseudotsuga menziesii* var. *glauca*, common garden, provenance study, tree populations, seed transfer guidelines

Research Summary: Seedlings from 50 populations of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) from Montana west of the Continental Divide were compared in nursery, laboratory, and shadehouse studies. Analyses of variance indicated significant differences among populations in six traits: bud burst, bud set, 3-year height, growth rate, cold injury, and flushing periods during the first or third growing season. Most traits were highly intercorrelated; thus, populations that expressed a high growth potential also set buds late, flushed twice, grew at a rapid rate, but were most severely injured by freezing. Consequently, adaptation of populations for numerous traits is viewed as a balance between selection of high growth potential in relatively mild environments and selection for cold hardiness in severe environments. Multiple regression analyses related genetic differentiation of populations to geographic and ecologic conditions of the seed source. The regression model that best fit the data described adaptive variation according to two physiographic zones, elevation within each zone, and latitude within zones. Patterns of adaptive differentiation were used to develop seed transfer guidelines for reforestation and tree improvement.

Link: http://www.treesearch.fs.fed.us/pubs/37659

738. Rehfeldt GE. 1983. Genetic variability within Douglas-fir populations: implications for tree improvement. Silvae Genetica 32:9-14.

Type: Journal

Geographic Area: Idaho, Montana, USA

Keywords: *Pseudotsuga menziesii*, adaptive strategy, adaptation

Abstract: Genetic variances and covariances for growth potential, phenology and patterns of first year elongation were calculated from 30 half-sib families from each of three contrasting populations. Analyses of 4-year old trees growing in a single environment revealed high levels of additive genetic variance within populations. As a consequence, rather high estimates of genetic gains in growth potential were associated with weak selection intensities. However, genetic correlations were strong. Gains in growth potential were associated with delayed bud set and increased susceptibility to early fall frosts. For tree improvement to increase the growth potential of Douglas-fir without inadvertent degeneration of adaptation, selections must be based on several traits.

Link: http://sauerlaender-verlag.com/fileadmin/content/dokument/archiv/silvaegenetica/32_1983/32-1-2-9.pdf

739. Rehfeldt GE. 1983. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) populations. III. Central Idaho. Canadian Journal of Forest Research 13:626-632.

Type: Journal

Geographic Area: Idaho, USA

Compilers' Keywords: common garden, genetic variability, seed source, genetic × environment interaction, phenology

Abstract: Growth, phenology, and cold hardiness of seedlings from 74 populations of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) from central Idaho were compared in four contrasting environments. Analyses of 3-year-old seedlings revealed population differentiation for eight variables: bud burst, bud set, multiple flushing, height, deviation from regression of 3-year height on 2-year height, spring frost damage, fall frost damage, and winter injury. These analyses, as well as high intercorrelations among population means, suggested that adaptations result from a balance between selection for a high growth potential in mild environments and selection for cold hardiness in severe environments. Consequently, genetic variation among populations was closely related to the elevation, geography, and climate of the seed source.

Link: http://www.treesearch.fs.fed.us/pubs/38632

740. Rehfeldt GE. 1985. Ecological genetics of *Pinus contorta* in the Wasatch and Uinta Mountains of Utah. Canadian Journal of Forest Research 15:524-530.

Type: Journal

Geographic Area: Utah, USA

Compilers' Keywords: lodgepole pine, genetic differentiation, shoot elongation, genetic x environment interaction, seed transfer

Abstract: Genetic differentiation of 45 populations of *Pinus contorta* primarily from the Wasatch and Uinta Mountains was studied in field, greenhouse, and laboratory tests. Analyses of variables reflecting growth potential, morphology, cold hardiness, and periodicity of shoot elongation revealed population differentiation for a variety of traits. Regression models related as much as 77% of the variance among population means to the elevation and geographic location of the seed source. For genetic variation to be arranged along relatively steep environmental clines implies pronounced adaptive differentiation. As a result, seed transfer in reforestation should be restricted severely if maladaptation is to be controlled.

741. Rehfeldt GE. 1985. Genetic variances and covariances in *Pinus contorta*: estimates of genetic gains from index selection. Silvae Genetica 34:26-33.

Type: Journal

Geographic Area: Pacific Northwest USA

Keywords: *Pinus contorta*, additive genetic variances, genetic correlations, genetic gains, restricted selection indices

Summary: Genetic variances and covariances were estimated for 6-year-old trees from 10 families within eight populations of *Pinus contorta* from the northern Rocky Mountains (USA). Analyses of 10 traits reflecting growth, quality, and adaptedness revealed substantial genetic variances for nearly all traits. As a consequence, univariate selection for height should provide genetic gains of about 5% per unit selection intensity. However, strong genetic correlations linked height with branch length (0.75), crown width (0.75), and the amount of shoot elongation that continues into mid-summer (0.70). Height was

also related to the number of whorls on the current shoot and, consequently, to the number of branches. Thus, multi-trait selections are necessary to prevent genetic gains in productivity from being accompanied by inadvertent degeneration of traits related to adaptation and quality. Multi-trait selections, however, reduce anticipated genetic gains in productivity. Restricted selection indices are developed to exemplify procedures for holding constant the correlated responses while maximizing gains in height.

Link: http://silvaegenetica.com/fileadmin/content/dokument/archiv/silvaegenetica/34_1985/34-1-26.pdf

742. Rehfeldt GE. 1986. Adaptive variation in *Pinus ponderosa* from Intermountain regions. I. Snake and Salmon River Basins. Forest Science 32:79-92.

Type: Journal

Geographic Area: Idaho, USA

Keywords: genetic variation, population differentiation, ecological genetics, genecology

Abstract: Genetic differentiation of 64 populations from central Idaho was studied in field, greenhouse and laboratory tests. Analyses of variables reflecting growth potential, phenology, morphology, cold hardiness and periodicity of shoot elongation revealed population differentiation for a variety of traits. Regression models related as much as 61 percent of the variance among populations to the elevation and geographic location of the seed source. Clinal patterns of adaptive variation provide the basis for developing seed transfer guidelines that will control maladaptation in reforestation. In central Idaho, for example, seed transfer should be limited to within 180 m of the seed source.

Link: http://www.treesearch.fs.fed.us/pubs/38631

743. Rehfeldt GE. 1986. Adaptive variation in *Pinus ponderosa* from intermountain regions. II. Middle Columbia River System. Ogden (UT): USDA Forest Service, Intermountain Research Station. RP-INT-373. 12 p.

Type: Government Document

Geographic Area: Northwestern USA

Compilers' Keywords: ponderosa pine, adaptive variation, drought tolerance, common garden, seed transfer guidelines, growing season length

Research Summary: Seedlings representing 138 populations of ponderosa pine from drainages of the middle Columbia River system were grown and compared in common environments. Field studies of 3-year-old trees on mesic and xeric test sites detected population differentiation for traits reflecting growth and development. Populations that expressed the greatest growth potential under mesic culture suffered the greatest reduction in height under xeric culture. Consequently, a different set of populations was performing the best on the two sites when 3-year height was expressed as the growth from a common height at age 2. Greenhouse studies of the periodicity of shoot elongation revealed that populations of high growth potential achieved a large stature by means of a long duration, late cessation, rapid rate, and large amount of elongation. Multiple regression models accounted for as much as 60 percent of the variance between populations and described adaptive landscapes in which populations from low elevation have a high growth potential while those from high elevations have a low growth potential. Geographic variation at a common elevation indicated that populations of high growth potential come from areas where the frostfree period is long and precipitation is relatively high. Thus, growth potential is directly related to the length of the growing season, which can be truncated by either frost or moisture stress. Adaptive landscapes are used to construct guidelines for limiting seed transfer in artificial reforestation. In general, seed from a single source should not be transferred more than ±200 m in elevation.

Link: http://www.treesearch.fs.fed.us/pubs/38597

744. Rehfeldt GE. 1988. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). IV. Montana and Idaho near the Continental Divide. Western Journal of Applied Forestry 3:101-105.

Type: Journal

Geographic Area: Idaho, Montana, USA

Compilers' Keywords: genetic differentiation, growing season length, genetic x environment interaction, cline, seed transfer guidelines

Abstract: Seventy-seven seedlings populations of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) sampled from near the Continental Divide in Idaho and Montana exhibited pronounced genetic differences when compared in three common environments. Differentiation involved several traits several traits that are components of an annual developmental cycle that must be completed within a growing season of finite length. Consequently, elevational and geographic clines of genetic variation tend to parallel variation in the length of the growing season at the seed source. Such clines suggest that maladaptation in artificial reforestation can be controlled by limiting the transfer of seeds. While geographic transfers can be relatively liberal, elevational transfers should be limited to ±90 m (300 ft) from the seed source at elevations below 1,400 m (4,600 ft), to ±125 m (410 ft) for elevations between 1,400 and 2,000 m (4,600 and 6,550 ft), and ±200 m (560 ft) for elevations above 2,000 m (6,550 ft).

Link: http://www.treesearch.fs.fed.us/pubs/38630

745. Rehfeldt GE. 1988. Ecological genetics of *Pinus contorta* from the Rocky Mountains (USA): a synthesis. Silvae Genetica 37:131-135.

Type: Journal

Geographic Area: Rocky Mountains USA

Keywords: population differentiation, genecology, adaptive variation

Abstract: Studies of population differentiation in *Pinus contorta*, which were conducted in common gardens, are summarized according to the growth, freezing tolerance, and the periodicity of shoot elongation of seedlings from 173 Rocky Mountain (USA) populations. Regression models accounted for 45 to 77% of the variance among populations, coordinated the results of previous studies and described clinal patterns of variation that generally reflect elevational and geographic gradients in the frost-free period.

Link: http://germanjournalofforestresearch.com/fileadmin/content/dokument/archiv/silvaegenetica/37_1988/37-3-4-131.pdf

746. Rehfeldt GE. 1989. Ecological adaptations in Douglas-fir (*Pseudotsuga menziesii* var. *glauca*): a synthesis. Forest Ecology and Management 28:203-215.

Type: Journal

Geographic Area: Pacific Northwest USA

Compilers' Keywords: common garden, genetic variation, seed transfer

Abstract: Measurements of 3rd-year height of 228 seedling populations, grown in four separate studies in two of the same common gardens, were used to summarize patterns of genetic variation for Douglas-fir across 250,000 km^2 of forested lands in Idaho and Montana, U.S.A. Because each study was conducted in different years with a different set of populations, measurements were transformed to standard deviates and then were scaled according to the performance of populations common between studies. Genetic variation in 3rd-year height was related to the elevation and geographic location of the seed source by a regression model that accounted for 87% of the variance among populations. In addition, 3rd-year height of 169 of the populations was strongly correlated (r = 0.80) to freezing injury observed in previous studies. Both variables showed that populations from elevational or geographically mild sites were tall but had low freezing tolerance. Populations from harsh sites were short and cold hardy. In Douglas-fir, adaptation to heterogeneous environments can be viewed as physiological specialization for a relatively small portion of the environmental gradient; populations separated by a relatively short distance along the environmental gradient (e.g., 20 frost-free days) tend to be different genetically.

Link: http://www.treesearch.fs.fed.us/pubs/38629

747. Rehfeldt GE. 1990. Genetic differentiation among populations of *Pinus ponderosa* from the Upper Colorado River Basin. Botanical Gazette 151:125-137.

Type: Journal

Geographic Area: Southwestern USA

Compilers' Keywords: ponderosa pine, common garden, genetic variability, genetic × environment interaction, clinal variation

Abstract: Genetic variation among 62 populations of ponderosa pine was studied by comparing seedlings from all populations according to (1) growth and development of 4-yr-old seedlings in three disparate common gardens and (2) patterns of shoot elongation of 2-yr-old seedlings in a greenhouse. Genetic variation was detected among populations for 19 of the variables, most of which were intercorrelated. Two principal components accounted for 60% of the total interpopulation variance. Multiple regression analyses were used to relate genetic variation in 19 variables and two principal components to the elevation and geographic origin of the seed. The regression models produced values of R^2 as large as 0.78 and accounted for more than 40% of the variance among populations for 14 of the variables, including both the first and second principal components. These models described genetic variation as occurring along a relatively steep elevational cline and along both primary and secondary geographic clines of relatively gentle slope. All clines paralleled patterns of environmental variation, particularly the length of the frost-free season and patterns of precipitation. Because genetic variation occurs along three clines simultaneously, genetic differentiation can be described as rampant. Nevertheless, similar genotypes tend to recur in similar environments.

Link: http://www.treesearch.fs.fed.us/pubs/38628

748. Rehfeldt GE. 1991. A model of genetic variation for *Pinus ponderosa* in the Inland Northwest (USA): applications in gene resource management. Canadian Journal of Forest Research 21:1491-1500.

Type: Journal

Geographic Area: Northwestern USA

Compilers' Keywords: ponderosa pine, common garden, genetic x environment interaction, gene conservation, seed zones, seed transfer, phenotypic variation, breeding zones

Abstract: Models were developed to describe the genetic variation among 201 seedling populations of *Pinus ponderosa* var. *ponderosa* in the Inland Northwest of the United States. Common-garden studies provided three variables that reflected growth and development in the field environments and three principal components of six variables that reflected patterns of shoot elongation. Regression models were developed for describing genetic variation across the landscape. Using functions of latitude, longitude, and elevation as descriptors, these models produced values of R^2 that were as large as 0.66, while averaging 0.39. The models described genetic variation as occurring along relatively steep elevational clines and gentle geographic (i.e., latitudinal and longitudinal) clines. An exercise at validating the models with independent data supported their veracity. Predictions made by the models are applied to limiting seed transfer, designing breeding zones, planning gene conservation programs, interpreting phenotypic variation, and predicting the effects of environmental change on the adaptedness of populations.

Link: http://www.treesearch.fs.fed.us/pubs/38627

749. Rehfeldt GE. 1993. Genetic variation in the Ponderosae of the Southwest. American Journal of Botany 80:330-343.

Type: Journal

Geographic Area: Southwestern USA

Compilers' Keywords: *Pinus ponderosa*, common garden, genetic × environment interaction, population differentiation, model application, seed transfer guidelines, seed zones

Abstract: Ninety-five seedling populations of southwestern ponderosa pine (*Pinus ponderosa* var. *scopulorum*) along with single populations of *Pinus engelmannii* and *Pinus arizonica* were compared in four environmentally disparate common gardens. Differentiation among ponderosa pine populations was detected for a diverse assortment of variables that included patterns of shoot elongation, measure of growth potential, winter and spring freezing damage, and leaf characteristics. Multiple regression models accounted for as much as 85% of the variance among populations and described complex clines that were dominated by elevational and latitudinal effects. Although *P. ponderosa*, *P. arizonica*, and *P. engelmannii* were readily differentiated, the performance of progenies from one population suggested introgression primarily involving *P. ponderosa* and *P. arizonica* but also implicating *P. engelmannii*.

Link: http://www.treesearch.fs.fed.us/pubs/38626

750. Rehfeldt GE. 1995. Genetic variation, climate models and the ecological genetics of *Larix occidentalis*. Forest Ecology and Management 78:21-37.

Type: Journal

Geographic Area: Northwestern North America

Keywords: population differentiation, climate patterns, genecology

Abstract: Provenance tests of 143 populations of *Larix occidentalis* revealed genetic differentiation for eight variables describing growth, phenology, tolerance to spring frosts, effects of Meria laricis needle cast, and survival. Geographic variables accounted for as much as 34% of the variance among Rocky Mountain populations. Patterns of genetic variation were dominated by the effects of latitude and elevation, with populations from the north and from high elevations having the lowest growth potential, the least tolerance to the needle cast, and the lowest survival. However, the slope of the geographic clines was relatively flat. Populations in the same geographic area, for instance, need to be separated by about 500 m in elevation before genetic differentiation can be expected. Regression models using geographic predictors were developed to describe variation in ten climatic variables from 192 weather stations that best represented the Rocky Mountain distribution of *L. occidentalis*. Values of R^2 ranged from 0.43 to 0.92 and were higher for temperature than for precipitation variables. Using climatic effects predicted for each provenance to describe genetic variation produced values of R^2 between 0.15 and 0.27 which accounted for nearly as much (68-100%) of the genetic variance as had geographic variables. The analyses suggested that genetic differentiation was controlled primarily by the relative mildness of the climate. Secondary effects of precipitation were implicated for variables measuring the impact of Meria needle cast and survival.

751. Rehfeldt GE. 1999. Systematics and genetic structure of Washoe pine: applications in conservation genetics. Silvae Genetica 48:167-173.

Type: Journal

Geographic Area: Western North America

Keywords: *Pinus washoensis*, quantitative traits, genetic structure, systematics, conservation biology

Abstract: Independent studies of seedling populations of Washoe (*Pinus washoensis*) and ponderosa (*P. ponderosa*) pines grown in common gardens demonstrated that: (1) the systematic relationship between Washoe pine and the North Plateau race of ponderosa pine is close and (2) the allocation of genetic variability among and within populations of the narrow endemic, Washoe pine, is similar to that of the broadly dispersed ponderosa pine. The results from this quantitative analysis of adaptive traits thus support previous works involving morphology, terpene chemistry, allozyme variation, mating systems, DNA biochemistry, and classical taxonomy that lead to a conclusion of synonymity for Washoe pine and ponderosa pine. The results also provide no genetic evidence that small population sizes and isolated distributions have had deleterious genetic consequences. Populations of Washoe pine nevertheless have unique characteristics that may be worthy of conservation. Programs should concentrate on habitat preservation and range expansion.

Link: http://silvaegenetica.com/fileadmin/content/dokument/archiv/silvaegenetica/48_1999/48-3-4-167.pdf

752. Rehfeldt GE. 2001. Introduction of ponderosa pine and Douglas-fir to Argentina. New Forests 21:35-44.

Type: Journal

Geographic Area: USA, Argentina

Keywords: afforestation, land races, provenance selection, reforestation, shoot elongation, tree introduction

Abstract: Patterns of shoot elongation of 2-yr seedlings from native North American populations of ponderosa pine and

Douglas-fir were compared to those of Argentine land races originating from unknown provenances. The comparisons were conducted in Moscow, Idaho (USA), and suggested that the ponderosa pine land race was descended from a California provenance at low or middle elevations but that the growth potential of the land race was only mediocre in comparison to eight native populations. The Douglas-fir land race exhibited a relatively high growth potential in comparison to 19 native provenances and undoubtedly originated from a mild coastal environment. The results provide concrete recommendations for upgrading the growth potential of the Argentine land races by importing germplasm of specific provenances.

Link: http://www.treesearch.fs.fed.us/pubs/38625

753. Rehfeldt GE. 2005. Geographic clines in genetic variation. In: Mardsen M, Downing M, Riffe M, editors. Workshop Proceedings: Quantitative Techniques for Deriving National Scale Data. Fort Collins (CO): USDA Forest Service, Forest Health Technology Enterprise Team. FHTET-2005-12. p 223-261.

Type: Government Document

Geographic Area: Western North America

Compilers' Keywords: *Pseudotsuga menziesii*, genetic variation, geographic clines, risk mapping, climate modeling, seed zone delineation, seed transfer guidelines, climate change

Abstract: In risk mapping, the primary considerations are the presence of the host tree species, some measure of its density, and the distribution of the pest agent. High-density or overstocked stands are often considered to be of higher risk then stands with lower stocking levels; also important is the climatic stress on the population. This presentation shows how the predictions from a climate model can be converted to variables that may indicate the status of the stress of conifer species and their populations in the western USA and southwestern Canada. Forty-eight monthlies were derived from the basic temperature and precipitation data and fit to geographic surfaces with thin plate splines. These monthlies were then used to describe the clines of genetic variation that exist within species for growth characteristics. The mapping of clinal variation is useful in delineating seed zones and deriving seed transfer guidelines. The reverse image of such maps should indicate where the species would be under stress due to climatic conditions. For this reason, it is recommended that the monthlies and the climatic limits could be useful in risk mapping.

Link: http://www.fs.fed.us/foresthealth/technology/pdfs/QuantitativeTechniques.pdf

754. Rehfeldt GE, Hoff RJ, Steinhoff RJ. 1984. Geographic patterns of genetic variation in *Pinus monticola*. Botanical Gazette 145:229-239.

Type: Journal

Geographic Area: Western USA

Compilers' Keywords: western white pine, geographic pattern, genetic variability, common garden, genetic × environment interaction

Abstract: Genetic differentiation of 59 populations, representing the geographic distribution of *Pinus monticola*, was studied in field, greenhouse, and laboratory tests. Geographic variation was described by regression models, which accounted for as much as 85% of the variance among populations. Populations from the north (Rocky Mountains, northern Cascades, and northern coastal areas) are generally of high growth potential and low cold hardiness. Southern populations (Sierra Nevada) exhibit low growth potential and high hardiness. Populations from the central and southern Cascades are arranged along relatively steep latitudinal lines that connect northern and southern groups. Although differentiation within the transitional region was readily detected, patterns of variation within northern and southern regions were either weak or nonexistent. Nowhere was genetic variation related to the elevation of the seed source.

755. Rehfeldt GE, Tchebakova NM, Milyutin LI, Parfenova EI, Wykoff WR, Kouzmina NA. 2003. Assessing populations responses to climate in *Pinus sylvestris* and *Larix* spp. of Eurasia with climate-transfer models. Eurasian Journal of Forest Research 6:83-98.

Type: Journal

Geographic Area: USA, Canada, Russia

Keywords: climate change responses, climatypes, genetic variation, reforestation, seed transfer guidelines

Abstract: Weibull regression models were used to relate height and survival of Eurasian populations of Scots pine (*Pinus sylvestris* L.) at age 13 and three species of larch (*L. sukaczewii* Dylis, *L. sibirica* Ledeb., and *L. gmelinii* (Rupr.) Rupr.) at age 12 to the difference in climate between their provenance and a planting site. Univariate models using five climate variables as predictors all were statistically significant ($p < 0.01$), and all but the pine survival functions received strong verification with independent data. The models showed that the growth and survival of most populations of the pine and each species of larch are enhanced when populations are transferred from their provenance to warmer climates. The results are consistent with the view that most populations occur in climates that are suboptimal, the degree of which is directly related to the severity of the climate. Because of this, projected responses to a climate-change scenario of the Hadley Centre were highly variable geographically. Short-term plastic responses tended to be strongly negative for the least severe climates and strongly positive for the most severe. Long-term evolutionary responses primarily reflected extirpation and immigration for the species of larch but showed additionally for the pine that

the accommodation of global warming will require a redistribution of genotypes throughout the species' range.

Link: http://133.87.26.249/dspace/bitstream/2115/22164/1/6(2)_P83-98.pdf

756. Rehfeldt GE, Jaquish BC, López-Upton J, Sáenz-Romero C, St. Clair JB, Leites LP, Joyce DG. 2014. Comparative genetic responses to climate for the varieties of *Pinus ponderosa* and *Pseudotsuga menziesii*: realized climate niches. Forest Ecology and Management 324:126-137.

Type: Journal

Geographic Area: Western North America

Keywords: niche modeling, climate change impacts, Douglas-fir, ponderosa pine, biogeography, genecology

Abstract: The Random Forests classification algorithm was used to predict the occurrence of the realized climate niche for two sub specific varieties of *Pinus ponderosa* and three varieties of *Pseudotsuga menziesii* from presence-absence data in forest inventory ground plots. Analyses were based on ca. 271,000 observations for *P. ponderosa* and ca. 426,000 observations for *P. menziesii*, with ca. 6% of the observations in each dataset recording the presence of one of the varieties. Classification errors to the respective databases attributable to fitting the models were ca. 5%, most of which were from falsely predicting varietal occurrence. Confusion in classifying varieties was nil. The primary drivers of the niche model were summer precipitation, winter precipitation and summer degree-days >5 ˚C for the varieties of *P. ponderosa* and the summer-winter temperature differential, summer maximum temperatures and summer precipitation for the varieties of *P. menziesii*. Projected impacts of global warming using output from an ensemble of 17 general circulation models were greater for *P. ponderosa* than for *P. menziesii* and for varieties of both species from inland climates than from coastal. Projected impacts imply dire consequences for the varieties of *P. menziesii* occurring in Mexico.

Link: http://www.treesearch.fs.fed.us/pubs/46900

757. Rehfeldt GE, Leites LP, Bradley St. Clair J, Jaquish BC, Sáenz-Romero C, López-Upton J, Joyce DG. 2014. Comparative genetic responses to climate in the varieties of *Pinus ponderosa* and *Pseudotsuga menziesii*: clines in growth potential. Forest Ecology and Management 324:138-146.

Type: Journal

Geographic Area: Western North America

Keywords: genetic variation, climate-change impacts, genecology, mixed effects models, provenance tests

Abstract: Height growth data were assembled from 10 *Pinus ponderosa* and 17 *Pseudotsuga menziesii* provenance tests. Data from the disparate studies were scaled according to climate similarities of the provenances to provide single datasets for 781 *P. ponderosa* and 1193 *P. menziesii* populations. Mixed effects models were used for two sub-specific varieties of each species to describe clines in growth potential associated with provenance climate while accounting for study effects not eliminated by scaling. Variables related to winter temperatures controlled genetic variation within the varieties of both species. Clines were converted to climatypes by classifying genetic variation, using variation within provenances in relation to the slope of the cline to determine climatype breadth. Climatypes were broader in varieties of *P. ponderosa* than in *P. menziesii* and were broader for varieties inhabiting coastal regions of both species than for varieties from interior regions. Projected impacts of climate change on adaptedness used output from an ensemble of 17 general circulation models. Impacts were dependent on cline steepness and climatype breadth but implied that maintaining adaptedness of populations to future climates will require a redistribution of genotypes across forested landscapes.

Link: http://www.treesearch.fs.fed.us/pubs/46901

758. Rehfeldt GE, Jaquish BC, Sáenz-Romero C, Joyce DG, Leites LP, Bradley St. Clair J, López-Upton J. 2014. Comparative genetic responses to climate in the varieties of *Pinus ponderosa* and *Pseudotsuga menziesii*: reforestation. Forest Ecology and Management 324:147-157.

Type: Journal

Geographic Area: Western North America

Keywords: management strategies, climate-change impacts, Douglas-fir, ponderosa pine, seed transfer guidelines

Abstract: Impacts of climate change on the climatic niche of the sub-specific varieties of *Pinus ponderosa* and *Pseudotsuga menziesii* and on the adaptedness of their populations are considered from the viewpoint of reforestation. In using climate projections from an ensemble of 17 general circulation models targeting the decade surrounding 2060, our analyses suggest that a portion of the lands occupied today primarily by coastal varieties of each species contain genotypes that should remain suitable for the future climate. A much larger portion, particularly for varieties occupying inland sites, should require either introduction of better suited species or conversion to better adapted genotypes. Regeneration strategies are considered with the goal of matching growth potential of contemporary populations to the future climate where that potential can be realized. For some lands, natural reproduction should be suitable, but most lands will require forest renewal to maintain forest health, growth, and productivity. Projected impacts also illustrate the urgent need for conservation programs for *P. menziesii* in Mexico.

Link: http://www.treesearch.fs.fed.us/pubs/46902

759. Richardson BA, Kitchen SG, Pendleton RL, Pendleton BK, Germino MJ, Rehfeldt GE, Meyer SE. 2014. Adaptive responses reveal contemporary and future ecotypes in a desert shrub. Ecological Applications 24:413-427.

Type: Journal

Geographic Area: Southwestern USA

Keywords: assisted migration, blackbrush, climate change, *Coleogyne ramosissima*, ecological restoration, seed transfer zones

Abstract: Interacting threats to ecosystem function, including climate change, wildfire, and invasive species necessitate native plant restoration in desert ecosystems. However, native plant restoration efforts often remain unguided by ecological genetic information. Given that many ecosystems are in flux from climate change, restoration plans need to account for both contemporary and future climates when choosing seed sources. In this study we analyze vegetative responses, including mortality, growth, and carbon isotope ratios in two blackbrush (*Coleogyne ramosissima*) common gardens that included 26 populations from a range-wide collection. This shrub occupies ecotones between the warm and cold deserts of Mojave and Colorado Plateau ecoregions in western North America. The variation observed in the vegetative responses of blackbrush populations was principally explained by grouping populations by ecoregions and by regression with site-specific climate variables. Aridity weighted by winter minimum temperatures best explained vegetative responses; Colorado Plateau sites were usually colder and drier than Mojave sites. The relationship between climate and vegetative response was mapped within the boundaries of the species-climate space projected for the contemporary climate and for the decade surrounding 2060. The mapped ecological genetic pattern showed that genetic variation could be classified into cool-adapted and warm-adapted ecotypes, with populations often separated by steep clines. These transitions are predicted to occur in both the Mojave Desert and Colorado Plateau ecoregions. While under contemporary conditions the warm-adapted ecotype occupies the majority of climate space, climate projections predict that the cool-adapted ecotype could prevail as the dominant ecotype as the climate space of blackbrush expands into higher elevations and latitudes. This study provides the framework for delineating climate change-responsive seed transfer guidelines, which are needed to inform restoration and management planning. We propose four transfer zones in blackbrush that correspond to areas currently dominated by cool-adapted and warm-adapted ecotypes in each of the two ecoregions.

Link: http://www.treesearch.fs.fed.us/pubs/45555

760. Ritland C, Pape T, Ritland K. 2001. Genetic structure of yellow cedar (*Chamaecyparis nootkatensis*). Canadian Journal of Botany 79:822-828.

Type: Journal

Geographic Area: Western North America

Keywords: *Chamaecyparis nootkatensis*, yellow cedar, genetic structure, inbreeding, phylogeography, isozymes

Abstract: A range-wide survey of isozyme variation in yellow cedar (*Chamaecyparis nootkatensis* (D. Don) Spach; or Alaska cedar) found significant inbreeding and a striking geographical structure. The proportion of diversity among populations (G_{ST}) was 0.139, and three major geographical groups were evident: (1) Vancouver Island – mid-north coast British Columbia (B.C.); (2) south coast B.C. – Washington state; (3) southeast Alaska. This may indicate the presence of multiple refugia during ice-age range contractions. Geographically disjunct populations in Oregon and southeastern B.C. were also genetically distinct. Adult inbreeding coefficients (F) were usually positive but varied widely among populations, as did gene diversity. The overall average of $F = 0.18$ suggests that considerable selfing (ca. 30%) occurs in this species. Other statistics were more typical for a conifer: within population heterozygosity (H_S) averaged 0.148, total gene diversity (H_T) was 0.171, and the number of alleles per locus and percentage polymorphic loci averaged 1.68 and 50, respectively. This geographic structure has implications for species conservation and for breeding programs. Also, previous studies of other Cupressoideae (Rich. ex Sweet) species indicate that these levels of inbreeding and population structure are not uncommon, and may influence evolutionary divergence in the Cupressoideae.

Link: http://www.genetics.forestry.ubc.ca/ritland/reprints/2001_CJB_YellowCedarIsozymes.pdf

761. Roberds JH, Conkle MT. 1984. Genetic structure in loblolly pine stands: allozyme variation in parents and progeny. Forest Science 30:319-329.

Type: Journal

Geographic Area: Southeastern USA

Keywords: population subdivision, allele frequencies, F statistics, isozymes, *Pinus taeda*

Abstract: Genetic population structure in two adjacent old-field stands of loblolly pine was studied by analyzing allele frequencies for eight polymorphic isozyme loci. The stands represented different generations with trees in the older stand being parents of trees in the younger one. The parental stand consisted of three fairly distinct age classes which differed significantly in allele frequencies for four of the allozyme loci, yet no differences were found among the spatial divisions studied. Within the progeny stand, no genetic differentiation was detected with respect to either age class or spatial grouping. Although allele frequencies did not differ between the two stands, genetic population structure was not the same, demonstrating that local genetic structure can differ between successive generations and that varying

structures can exist in localized regions. Evidence suggesting a low level of inbreeding was found in both stands.

762. Rogers DL, Harry DE, Libby WJ. 1994. Genetic variation in incense-cedar (*Calocedrus decurrens*): I. provenance differences in a twelve-year-old common-garden study. Western Journal of Applied Forestry 9:113-117.

Type: Journal

Geographic Area: Oregon, California, USA

Compilers' Keywords: tree improvement, provenance test

Abstract: Results are reported from a provenance study of incense-cedar (*Calocedrus decurrens*), a tree species native to forested regions of Oregon, California, and Baja California. Seedlings from six geographically distinct regions were measured over a 12 yr period in a common-garden study located near the center of the species' native range. In general, among-region genetic variation was small. However, differences in height, stem volume, and crown form between trees from the southernmost region sampled and trees from the other five study regions were large and significant. Further studies of within-population genetic variation are recommended prior to initiating any tree improvement activities.

763. Romani M, Pecetti L, Tosca A, Della Marianna G, Gusmeroli F, Paoletti R, Piano E. 2009. Evaluation of morphology and seed production of alpine cat's tail [*Phleum rhaeticum* (Humph.) Rauschert] germplasm in view of its use for ecological restoration at high altitude. Restoration Ecology 17:386-392.

Type: Journal

Geographic Area: Italy, Europe

Keywords: genetic resources, high-altitude restoration, *Phleum rhaeticum*, seed production, selection, "site-specific" vegetation

Abstract: "Site-specific" vegetation, that is germplasm ecologically adapted to the prevailing pedoclimatic conditions and native to the target region, is increasingly required in the revegetation of disturbed areas at high altitude. Some key site-specific species have been reported for the Alpine region. Better knowledge is needed on the existing variability of these species, while high seed yield is required to ensure the availability of commercially adequate seed supply. Natural populations of Alpine cat's tail from the Rhaetian Alps were evaluated for morphology and seed production at a mountain and at a lowland site of northern Italy aiming at (1) identifying possible superior populations for the selection of adapted high yielding cultivars and (2) verifying whether the seed multiplication of site-specific species could also be undertaken in areas different from those of origin. The germplasm from one valley featured an interesting architecture of traits, representing a possible ideotype for seed production purposes. Individual populations across different valleys also proved to be a valuable source of variation for economically useful traits. A discussion on possible implications of use of nonlocal germplasm sources for restoration purposes is provided. The lowland site gave much lower seed production than the mountain location and experienced outstanding plant mortality after the first summer. The specific site conditions, namely the occurrence of an appreciable level of heat and drought stress in summer and a severe rust infection rather than the altitude per se, limited the suitability of this site for seed production of the alpine germplasm.

764. Roy BA, Mulder CPH. 2014. Pathogens, herbivores, and phenotypic plasticity of boreal *Vaccinium vitis-idaea* experiencing climate change. Ecosphere 5:1-19.

Type: Journal

Geographic Area: Alaska, USA

Keywords: Alaska, climate change, *Exobasidium vaccinia*, global warming, herbivory, local adaptation, lingonberry, Phenolic, *Phomopsis columnaris*, plasticity, reciprocal transplant, *Vaccinium vitis-idaea*

Abstract: Climate warming is occurring at a rapid rate in the boreal forest; mean winter temperature has increased about 4 °C in Alaska over the last 40 years and about the same increase is predicted over the next 40 years. Warming temperatures tend to increase the number and kinds of herbivores and pathogens. How will boreal plants to respond to these abiotic and biotic changes? To address these questions we used common gardens and reciprocal transplants of *Vaccinium vitis-idaea* at sites with contrasting abiotic conditions near Fairbanks, Alaska. Plant morphology, chemistry, resistance to pathogens and herbivores, and survival were all strongly influenced by the destination environment (planting site and block within site), and less by the site of origin for the seed. Overall, seedlings survived significantly better at the summer cold site, which was buffered from drought as a result of its northern aspect, presence of sphagnum moss and permafrost (86.4% survival versus 48.5%). However, this cool damp site had more stem-killing consumers, the pathogens *Phomopsis columnaris* and *Exobasidium vaccinii* and mammalian browse, all of which became more common over the three years of the study as the plants became larger. Taken together, these results suggest that the seedling stage is likely to be vulnerable to droughts, except at sites with thick moss cover, which results in greater duration of summer moisture. Thus, as the climate warms, seedling growth will be restricted to those sites where the adult stages will later suffer from more stem-killing pathogen attack and mammalian browse.

Link: http://www.esajournals.org/doi/abs/10.1890/ES13-00271.1

765. Rukavina H, Hughes H, Johnson R. 2008. Variation in saltgrass growth and time of fall dormancy related to geographical and climatic factors. Journal of the American Society for Horticultural Science 133:127-132.

Type: Journal

Geographic Area: Western USA

Keywords: turfgrass breeding, phenotypic variability, cold hardiness, warm-season turfgrass

Abstract: Development of a new turfgrass cultivar requires an evaluation of numerous traits as well as an understanding of environmental factors influencing those traits. Growth or ability to fill in gaps and time of fall dormancy (fall color retention) that indicates cold hardiness are important traits for turfgrasses. This study was initiated to characterize variation in saltgrass [*Distichlis spicata* L. (Greene)] growth and time of fall dormancy related to climatic and geographical factors at the source location (geographical location of clone origin). Growth traits and time of fall dormancy were measured on 52 saltgrass clones collected from 41 locations and established at one location (common garden) in Fort Collins, CO. Principal component analysis on the morphological traits extracted the first principal component that explained 78% of the variability. The first principal component and time of fall dormancy were related to climatic and geographical factors at the source locations. Variation in growth traits was related to seasonal climatic variables of summer drying and fall cooling that explained 50% of variability in morphological traits. Variation in time of fall dormancy was related to longitude of clone origin and minimum winter temperature. These two variables explained 60% of the total variability in time of fall dormancy. Information obtained in this study may help breeders identify the best environments for specific traits and suggests that cold tolerance could be a problem for some clones from western sources if established too far east.

Link: http://www.treesearch.fs.fed.us/pubs/29634

766. Rweyongeza DM. 2011. Pattern of genotype–environment interaction in *Picea glauca* (Moench) Voss in Alberta, Canada. Annals of Forest Science 68:245-253.

Type: Journal

Geographic Area: Western Canada

Keywords: AMMI, climate, provenance trial, type B correlation, white spruce

Abstract: Genotype-environment interaction (GEI) among 19 white spruce provenances planted on eight sites in Alberta, Canada, was analyzed using type B correlations (r_p) and the additive main effects and multiplicative interaction (AMMI) model. The objectives were to quantify the extent of crossover interaction for height and diameter; evaluate the age trends in GEI for height and diameter; and examine the role of provenance and test site climate in causing GEI. A high latitude (~59° N) site was poorly correlated (r_p = –0.31 to 0.56) with sites located south of latitude 56° N; a high-elevation (1,220 m) site was poorly correlated ($r_p \leq 0.40$) with most of the sites located at medium and low elevations (≤ 800 m); additive main effects and multiplicative interaction analysis revealed a strong association between provenances and sites with similar climate; high-latitude provenances and sites with cool winters and dry summers, and high elevation provenances and sites with high precipitation and short growing seasons contributed the greatest to GEI. Because the relationship between GEI and climate corresponds well with latitudes and topography, seed transfer in Alberta can be effectively regulated by setting latitude and elevation transfer limits that are periodically adjusted to reflect the changing conditions caused by climate change.

767. Rweyongeza DM, Barnhardt LK, Hansen CR. 2011. Patterns of optimal growth for white spruce provenances in Alberta. Smoky Lake, Alberta, Canada: Government of Alberta, Sustainable Resource Development, Alberta Tree Improvement and Seed Centre. Ref. T/255. 37 p.

Type: Government Document

Geographic Area: Western Canada

Compilers' Keywords: genetic variation, climatic variability, seed source, seed transfer guidelines

Summary: This paper describes the pattern of genetic variation for growth potential among white spruce provenances in Alberta, Canada. It uses total height (H27) and diameter at breast height (D27) at 27-yrs from seed to identify provenance differences in relation to latitude and elevation of seed origin. Latitude and elevation are the main variables that adequately describe climatic variability in Alberta. Indirectly, latitude also describes regional variation in day length. Climate and day length are the main natural selection pressures governing genetic differentiation among forest tree populations. The regressions of height and diameter on latitude and elevation of seed origin are used to predict the location from which provenances of the highest growth potential on a specified site or environment are expected to originate. This location is referred to as an optimum seed source. By examining the pattern of provenance variation on similar sites and the correlation of provenance ranks among sites (genotype by environment interaction), it is possible to establish seed transfer guidelines that will enhance efficient use of seed while maintaining provenance climatic adaptation.

Link: http://srd.alberta.ca/MapsPhotosPublications/Publications/documents/PatternsOfOptimalGrowthFor-WhiteSpruce-Nov2011.pdf

768. Sáenz-Romero C, Guzmán-Reyna RR, Rehfeldt GE. 2006. Altitudinal genetic variation among *Pinus oocarpa* populations in Michoacán, Mexico: implications for seed zoning, conservation, tree breeding and global warming. Forest Ecology and Management 229:340-350.

Type: Journal

Geographic Area: Michoacán, Mexico

Keywords: *Pinus oocarpa*, provenances, altitudinal genetic variation, seed zoing, tree breeding, conservation, global warming, Mexico

Abstract: *Pinus oocarpa* has a large natural distribution in the sub-tropical forests of Mexico. Populations, however, are rapidly disappearing particularly in the Michoacán State as native forests are converted to avocado (*Persea* sp.) orchards. We investigated the patterning of genetic variation among *P. oocarpa* populations for quantitative traits along an altitudinal gradient by establishing a provenance/progeny test from wind-pollinated seeds collected along an altitudinal transect (1100–1500 m) near Uruapan, Michoacán, Mexico. Genetic variation was analyzed in relation to normalized climate records (temperature, precipitation, degree days > 58 °C and annual moisture index) for the provenances and the test site for the contemporary climate and for climates projected for the decades beginning in 2030, 2060, and 2090. Estimates of future climates used output from the Canadian and Hadley General Circulation Models. Results of a field test suggested an altitudinal pattern of genetic differentiation in juvenile height among *P. oocarpa* populations. Seedlings from populations originating from lower altitudes tended to grow more than seedlings originating from populations at the higher altitudes. However, this trend abates at the lowest altitudinal limit of the species distribution, a probable conservative growth strategy for avoiding drought stress. Thus, the cline appeared to arise from selection along a climatic gradient reflecting in a moisture index (ratio of degree days to precipitation) and is dependent, therefore, on a balance between temperature and moisture. For guiding seed and seedling transfer in ecological restoration, conservation of genetic resources, tree breeding and mitigating the effects of global warming, we suggest guidelines based on delimitation of three altitudinal seed zones of about 200 m in breadth. Alternatively, one can limit transfer to three climatic zones of about 0.75 units of annual moisture index. Predictions of future climates indicate an average annual temperature increase of 3.8 °C by year 2090, and, judging from an increase of an annual moisture index of 26%, an increase in aridity by the end of the century. However, the more difficult period for adaptation of *P. oocarpa* populations to the new climate should be between 2030 and 2060, when the increase in aridity is expected to be most pronounced. Changes of this magnitude should alter the natural distribution of the species and would create an adaptation lag, as the adaptedness of extant populations deteriorates. Mitigating these effects will require seeds to be transferred upwards in altitude, perhaps as much as 150 m initially.

Link: http://www.treesearch.fs.fed.us/pubs/27838

769. Salmela MJ. 2011. Adaptive genetic variation in Scots pine (*Pinus sylvestris* L.) in Scotland [Dissertation]. Edinburgh, Scotland, United Kingdom: The University of Edinburgh. 170 p.

Type: Dissertation

Geographic Area: Scotland, United Kingdom

Compilers' Keywords: phenotypic traits, common garden, genetic × environment interaction, seed transfer guidelines

Abstract: Genetic differentiation in phenotypic traits among populations from heterogeneous environments is often observed in common-garden studies on forest trees, but data on adaptive variation in Scots pine (*Pinus sylvestris* L.) in Scotland are limited. As a result, current seed transfer guidelines are based on earlier molecular marker studies and do not take into account environmental or adaptive genetic variation. An analysis of spatial variation in climate showed substantial differences in temperature and precipitation among the native Scots pine sites in Scotland. To investigate whether differentiation in response to environmental variation has occurred in Scotland, a glasshouse-based common-garden trial of ~3,360 seedlings from 21 populations and 84 open-pollinated families was established in 2007. At the beginning of the 2nd growing season, timing of bud flush showed evidence of genetic differentiation among populations, with those from cooler origins generally flushing earlier. Variation was also found among families within populations, suggesting that the trait is genetically controlled. Populations and families showed different levels of variability in this trait which could be partly due to variable levels of temporal climate fluctuation in different parts of Scotland. Chlorophyll fluorescence was used to examine drought response in three-year old seedlings from five populations on sites that experience contrasting levels of annual rainfall. It was found that the response was not related to rainfall, but possibly to more complex moisture variables that also take into account additional factors such as evaporation. Also, photosynthetic capacity in response to cold winter temperatures varied significantly among eight populations that were kept outdoors, and the largest reduction was seen in seedlings from the mildest, most maritime coastal site. The following spring, height growth and needle flush started earlier in seedlings from cooler locations. Earlier studies on genetic diversity of native pinewoods have shown high levels of selectively neutral variation in this predominantly outcrossing conifer, and a mating system analysis with a limited number of microsatellite markers supported this pattern. Together, these data suggest that despite significant historic population size decrease, environmental gradients have resulted in genetic differentiation among native pinewoods. In order to minimise the risk of planting poorly-adapted stock and to maximise the success of replanting programmes, it is important that the origins of planting stock are carefully considered in management guidelines for the species.

Link: https://www.era.lib.ed.ac.uk/bitstream/1842/5662/2/Salmela2011.pdf

770. Salmela MJ, Cavers S, Cottrell JE, Iason GR, Ennos RA. 2011. **Seasonal patterns of photochemical capacity and spring phenology reveal genetic differentiation among native Scots pine (*Pinus sylvestris* L.) populations in Scotland.** Forest Ecology and Management 262:1020-1029.

Type: Journal

Geographic Area: Scotland, United Kingdom

Keywords: adaptation, chlorophyll fluorescence, genetic differentiation, Scots pine, seasonal variation, spatial heterogeneity

Abstract: Environment-driven genetic differentiation among populations is a common feature among forest trees, and an understanding of how populations have adapted to their home site conditions is essential for management and conservation practices. In Scotland, 84 native Scots pine (*Pinus sylvestris* L.) woodlands are recognised by the Forestry Commission and they occupy highly diverse environments from the maritime west coast to continental sites in eastern Scotland. However, it is not known whether adaptations to local environments along sharp temperature and rainfall gradients have occurred in different populations and as a result, the seed transfer guidelines of the species are based only on data from isozymes and monoterpenes. In this study of an outdoor common garden trial, we used chlorophyll fluorescence to examine whether seedlings from 32 open-pollinated families and eight populations from sites experiencing contrasting annual temperature regimes differed in their response to variation in natural outdoor temperatures between September 2009 and May 2010. In addition, growth initiation in spring was recorded. Photochemical capacity at photosystem II Fv/Fm showed a distinct seasonal trend and remained at relatively high levels (~ 0.7) until November. Following a period of over 2 weeks with temperatures below or close to 0 °C, Fv/Fm started decreasing towards its minimum values recorded in early March when population means varied between 0.35 and 0.45. By early May and along with rising temperatures, photochemical capacity had recovered to the same level as observed in early November. Populations were found to respond differently to the cold period starting in December. The largest drop in photochemical capacity was observed in seedlings from a low-altitude population located in the maritime western Scotland, while in seedlings from higher altitude locations in the cooler eastern Scotland, the response was smaller. In March, the recovery of photochemical capacity was slowest in seedlings from the mildest and coolest sites. Evidence of adaptive genetic differentiation was also found in spring phenology. Initiation of shoot elongation and needle flush were earlier in families from higher altitudes (cooler areas), but population differences were not significant at the $\alpha = 0.05$ level. These results suggest that adaptation to the spatially heterogeneous environment in Scotland has taken place in Scots pine and that in order to minimise the risk of planting maladapted seed stock, the patterns of environmental and adaptive genetic variation should be taken into account in the management of genetic resources in this species.

771. Salmela MJ, Cavers S, Wachowiak W, Cottrell JE, Iason GR, Ennos RA. 2010. **Understanding the evolution of native pinewoods in Scotland will benefit their future management and conservation.** Forestry 83:535-545.

Type: Journal

Geographic Area: Scotland, United Kingdom

Compilers' Keywords: Scots pine, *Pinus sylvestris*, evolutionary adaptation, seed zones, heavy exportation, timber production, phenotypic variability, common garden

Summary: Scots pine (*Pinus sylvestris* L.) is a foundation species in Scottish highland forests and a national icon. Due to heavy exploitation, the current native pinewood coverage represents a small fraction of the postglacial maximum. To reverse this decline, various schemes have been initiated to promote planting of new and expansion of old pinewoods. This includes the designation of seed zones for control of the remaining genetic resources. The zoning was based mainly on biochemical similarity among pinewoods but, by definition, neutral molecular markers do not reflect local phenotypic adaptation. Environmental variation within Scotland is substantial and it is not yet clear to what extent this has shaped patterns of adaptive differentiation among Scottish populations. Systematic, range-wide common environment trials can provide insights into the evolution of the native pinewoods, indicating how environment has influenced phenotypic variation and how variation is maintained. Careful design of such experiments can also provide data on the history and connectivity among populations, by molecular marker analysis. Together, phenotypic and molecular datasets from such trials can provide a robust basis for refining seed transfer guidelines for Scots pine in Scotland and should form the scientific basis for conservation action on this nationally important habitat.

772. Schmidtling RC, Myszewski JH, McDaniel CE. 2005. **Geographic variation in shortleaf pine (*Pinus echinata* Mill.)—cortical monoterpenes.** In: McKeand SE, Li B, editors. Proceedings of the 28th Southern Forest Tree Improvement Conference. Springfield (VA): The National Technical Information Service. p 15.

Type: Conference Paper

Geographic Area: Eastern USA

Keywords: shortleaf pine, *Pinus echinata* Mill., loblolly pine, *Pinus taeda* L., pond pine, *Pinus serotina* Michx., spruce pine, *Pinus glabra* Walt., terpenes, geographic variation, hybridization

Abstract: Cortical monoterpenes were assayed in bud tissue from 16 Southwide Southern Pine Seed Source Study (SSPSS) sources and from 6 seed orchard sources from across

the natural range of the species, to examine geographic variation in shortleaf pine. Spruce pine and pond pine were also sampled. The results show geographic differences in all of the major terpenes. There was no north-south trend in any of the terpenes, but there was clinal variation in alpha pinene from west to east. One source, from New Jersey (SSPSSS) had very low alpha pinene and did not fit the trend, possibly because of hybridization with pitch pine. Some of the western sources had high limonene content, probably as a result of hybridization with loblolly pine, which has high limonene in western populations. Spruce pine had terpene levels similar to shortleaf pine, while pond pine had low alpha pinene and much higher limonene compared to shortleaf pine.

Link: http://www.treesearch.fs.fed.us/pubs/25247

773. Schuster WSF, Sandquist DR, Phillips SL, Ehleringer JR. 1994. High levels of genetic variation in populations of four dominant aridland plant species in Arizona. Journal of Arid Environments 27:159-167.

Type: Journal

Geographic Area: Arizona, USA

Keywords: evolution, genetic diversity, genetic variation, isozymes, life expectancy, plant ecology, population genetics

Abstract: Intrapopulation genetic variation in four dominant, perennial plant species from the deserts of south-western North America was assessed and compared using isozyme techniques. In each of two localities, a warm desert and a cold desert environment, one population of the most common long-lived perennial was compared with a nearby population of a dominant, comparatively short-lived perennial. The warm desert species were *Encelia farinosa* and *Larrea tridentata* while *Gutierrezia microcephala* and *Coleogyne ramosissima* were examined at the cold desert site. All samples were electrophoresed and stained for 18 enzyme systems. Mean values for these four species were 0.173 for gene diversity, 99.6% for polymorphism, and 2.02 for number of alleles per locus. These values are significantly greater than published means from recent survey of the plant isozyme literature, and are comparable to or higher than levels of genetic variation in other widespread plant species. Differences in level of variation among the species were not significant, thus failing to indicate any relationship between life expectancy and genetic variation. These results demonstrate that aridland plant populations can harbor high levels of genetic variation, and suggest that environmental heterogeneity may be important in the development and maintenance of this diversity.

Link: http://www.ehleringer.net/Jim/Publications/182.pdf

774. Seidel KW. 1986. Tolerance of seedlings of ponderosa pine, Douglas-fir, grand fir, and Engelmann spruce for high temperatures. Northwest Science 60:1-7.

Type: Journal

Geographic Area: Pacific Northwest USA

Compilers' Keywords: *Pinus ponderosa*, *Pseudotsuga menziesii*, *Abies grandis*, *Picea engelmannii*, heat tolerance, survival analysis, forest management

Abstract: The heat tolerance of 2- to 4-week old seedlings of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) was determined and compared by exposing them to various time-temperature combinations in a "dry water bath" apparatus. Isosurvival curves indicating the time-temperature combinations that resulted in approximately equal survival were constructed for each species. Small (2 to 4 °C) but significant differences in height tolerance were found among species with ponderosa pine having the greatest tolerance and Engelmann spruce the least. Douglas-fir and grand fir were generally intermediate in heat tolerance.

775. Shaw NL. 2008. Native forbs and restoration technology. Native Plants Conference; Park City, UT. 74 p.

Type: Presentation

Geographic Area: Great Basin USA

Compilers' Keywords: Great Basin Restoration Initiative, native plants, management, wildfire, plant materials, sagebrush

Compilers' Summary: This is a presentation about the Great Basin Restoration Initiative. It is a collaborative program to promote the health and sustainability of the Great Basin for the public to use and enjoy. Components of the strategy include planning, inventory/assessment, implementation, monitoring/evaluation, and science. The presentation focuses on one part of the initiative - the Great Basin Native Plant Selection and Increase Project, which provides tools and support to native seed growers in meeting native seed demands. Research on native grass and forb species are highlighted, including cultural methods to establish them on sites.

776. Shaw NL, Monsen SB. 1995. 'Lassen' antelope bitterbrush. In: Roundy BA, McArthur ED, Haley JS, Mann DK, compilers. Proceedings: Wildland Shrub and Arid Land Restoration Symposium. Ogden (UT): USDA Forest Service, Intermountain Research Station. General Technical Report INT-GTR-315. p 364-371.

Type: Government Document

Geographic Area: North America

Compilers' Keywords: antelope bitterbrush, *Purshia tridentata*, seed transfer guidelines

Abstract: 'Lassen' antelope bitterbrush is recommended for restoring depleted rangelands, burned areas, mined lands, and other disturbed sites in the Intermountain West.

Lassen was selected for its seedling vigor, upright growth habit, seed production, productivity, and retention of overwintering leaves. Selection trials indicate Lassen is adapted to antelope bitterbrush sites receiving 300 to 600 mm of precipitation at elevations ranging from 900 to 1,800 m. Best growth occurs on deep, coarse, well-drained, and neutral to slightly acidic soils. Productive Lassen plantings have been established on such sites in northeastern California, eastern Oregon, and central and southern Idaho.

Link: http://www.treesearch.fs.fed.us/pubs/34717

777. Simpson DG, Binder WD, L'Hirondelle S. 1999. **Paper birch genecology and physiology.** Journal of Sustainable Forestry 10:191-198.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: *Betula papyrifera*, common garden, seed transfer guidelines, seed origin

Introduction: Forest managers in British Columbia increasingly manage some forests as mixed species stands that include paper birch (*Betula papyrifera* Marsh.), which regenerates naturally or can be planted. This genecology study, in association with ongoing tree improvement field studies, is aimed at developing seed transfer guidelines and identifying faster growing sources of paper birch for use in BC forests. Two of the objectives discussed here are to examine the effects of seed origin on (1) dormancy release (bud flushing), and (2) growth cessation and cold acclimation.

778. Smith BM, Diaz A, Daniels R, Winder L, Holland JM. 2009. Regional and ecotype traits in *Lotus corniculatus* L., with reference to restoration ecology. Restoration Ecology 17:12-23.

Type: Journal

Geographic Area: United Kingdom

Keywords: ecological distance, geographical distance, local adaptation, seed origin

Abstract: To assess the relative importance of distance (geographical or ecological) as a consideration when collecting seeds for restoration projects, there is a need for more research on regional and ecotypic variation in a range of species. We used *Lotus corniculatus* L., a legume frequently included in grassland seed mixes, to investigate phenotypic variation between British accessions in a common garden experiment. The aim of this study was to investigate the effect of seed origin on plant phenotype and fecundity and to determine whether there was any evidence of correlation with distance (geographical or ecological) in populations grown from seed collected from different locations. Regional differences were detected in plant size, growth habit, pubescence, leaf shape, and fecundity. Geographical distance between sites was shown to be positively correlated with an increased difference in seed yield. Differences in size, growth habit, and leaf shape between paired habitats of origin within region and also between "ecotypes" were evident. However, there was no correlation between ecological distance and any of the measured traits. These findings suggest that: (1) Differences in phenotype and fecundity between geographically separated populations of *L. corniculatus* may be sufficient to lead to differences in survival and fitness when seeds are sown in a restoration environment. (2) Although it is important to consider geographical location, the choice of habitat within region is also important because phenotypic variation between ecotypes may have long-term consequences for plant persistence.

779. Sorensen FC, Mandel NL, Aagaard JE. 2001. Role of selection versus historical isolation in racial differentiation of ponderosa pine in southern Oregon: an investigation of alternative hypotheses. Canadian Journal of Forest Research 31:1127-1139.

Type: Journal

Geographic Area: Oregon, USA

Compilers' Keywords: *Pinus ponderosa*, cold hardiness, molecular marker, principal component analysis, climatic adaptation, physiography, common garden

Abstract: Continuous populations identified as Pacific and North Plateau races of ponderosa pine (*Pinus ponderosa* P. Laws. ex C. Laws.) are parapatric along the crest of the Cascade Range in southern Oregon. A 3-year common-garden study of bud phenology and seedling vigor was performed to estimate the nature and magnitude of differentiation between races, to characterize the transition zone between them, and to relate responses between and within races to topography and climate. Principal component (PC) analyses identified two significant character complexes, PC-1 (phenological traits) and PC-2 (size traits), that explained 73% of the geographic race-related variation. The races were differentiated in two regards. First, PC-1 scores, which were highly correlated with frost-free season and summer–winter temperature differential, displayed a sharp discontinuity in the transition zone. Second, PC-2 scores were significantly correlated with physiographic and climatic variables in the North Plateau but not in the Pacific race, even though these variables had greater ranges in the latter. The data supported a narrow, adaptive transition between races for a complex of traits probably related to cold hardiness, and provided evidence that plant vigor traits were more closely adapted to environments in the North Plateau than in the Pacific region, possibly as a consequence of past climatic-stress selection in the former and competitive-stress selection in the latter.

Link: http://www.treesearch.fs.fed.us/pubs/4984

780. St. Clair JB. 2006. Genetic variation in fall cold hardiness in coastal Douglas-fir in western Oregon and Washington. Canadian Journal of Botany 84:1110-1121.

Type: Journal

Geographic Area: Pacific Northwest USA

Keywords: cold hardiness, genetic variation, adaptation, *Pseudotsuga menziesii*

Abstract: Genetic variation in fall cold damage in coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) was measured by exposing excised branches of seedlings from 666 source locations grown in a common garden to freezing temperatures in a programmable freezer. Considerable variation was found among populations in fall cold hardiness of stems, needles, and buds compared with bud burst, bud set, and biomass growth after 2 years. Variation in fall cold hardiness was strongly correlated (r = 0.67) with cold-season temperatures of the source environment. Large population differences corresponding with environmental gradients are evidence that natural selection has been important in determining genetic variation in fall cold hardiness, much more so than in traits of bud burst (a surrogate for spring cold hardiness), bud set, and growth. Seed movement guidelines and breeding zones may be more restrictive when considering genetic variation in fall cold hardiness compared with growth, phenology, or spring cold hardiness. A regional stratification system based on ecoregions with latitudinal and elevational divisions, and roughly corresponding with breeding zones used in Oregon and Washington, appeared to be adequate for minimizing population differences within regions for growth and phenology, but perhaps not fall cold hardiness. Although cold hardiness varied among populations, within-population and within-region variation is sufficiently large that responses to natural or artificial selection may be readily achieved.

Link: http://tafcc.forestry.oregonstate.edu/pdf/St-Clair_2006.pdf

781. Stingemore JA, Krauss SL. 2012. Genetic delineation of local provenance in *Persoonia longifolia*: implications for seed sourcing for ecological restoration. Restoration Ecology 21:49-57.

Type: Journal

Geographic Area: Australia

Keywords: AFLP, ANOSIM, landscape genomics, seed collection zone, spatial analysis method

Abstract: Restoration of diverse native plant communities typically requires the collection of large amounts of seed. Thus, practitioners often struggle to find adequate supplies near project sites and need to know from how far they can collect without compromising restoration success—how far does local provenance extend? We addressed this issue by assessing genetic variation within, and differentiation among, 12 potential seed source populations of *Persoonia longifolia*, a key component of the jarrah forest of Western Australia. An analysis of molecular variance of 66 polymorphic amplified fragment length polymorphism markers partitioned 92% of the total genetic variation within populations and 8% among populations, indicating relatively weak but statistically significant population genetic differentiation. Ordination of these genetic data showed marked west/east and north/south gradients. Pairwise population genetic dissimilarity was correlated with both geographic distance and environmental distance derived from five climate variables. However, partial Mantel test showed that the relationship between genetic and geographic distance was not independent of environmental distance, suggesting a non-neutral signature in these markers. Bayesian outlier analysis identified two markers, and spatial analysis methods tests identified highly significant associations between these two markers and three environmental variables. Frequency differences at these markers across populations suggested the possibility of climatically adapted provenances. The global significance value from analyses of similarities for these two markers correlated to a general provenance distance of 47 km, in contrast to a threshold of 60 km for the complete dataset. Guidelines for seed sourcing that consider these population genetic data should lead to more effective ecological restoration with this species.

782. Stonecypher RW, Piesch RF, Helland GG, Chapman JG, Reno HJ. 1996. Results from genetic tests of selected parents of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in an applied tree improvement program. Forest Science 42:1-37.

Type: Journal

Geographic Area: Pacific Northwest USA

Keywords: genotype by environment interaction, genetic variation, stability, heritability, phenotypic selection

Abstract: Results from genetic tests, and genotype by environment interaction studies in six low elevation breeding zones of Weyerhaeuser Company's Western Washington and Oregon Douglas-fir tree improvement program are summarized. Phenotypic selection in natural stands resulted in a 5% improvement in juvenile height over nonselect seed lots. Comparisons with nonselect sources, of offspring from parents in the top 50% performers in tests, indicated a 10% increase for the same trait. Seed produced in a 50% rogued seed orchard is thus expected to provide improved planting stock with a gain of 10% in juvenile height growth. Several select parents are producing offspring that are consistently performing in excess of 10% over nonselects. Estimates of breeding zone, breeding zone by location, and family by location interaction effects are small relative to family and planting location effects. Tests of families established on environmentally diverse sites indicate a striking lack of large family by planting location interaction. In tests showing statistically significant interactions, such interactions are caused by a relatively small number of families. We did

observe earlier budbreak and a higher spring frost susceptibility of Oregon sources established on Washington sites. We conclude that allocation and utilization of select families within Weyerhaeuser's Oregon and Washington ownership should not be constrained by the currently defined breeding zone boundaries, but based on parental performance and stability for growth and adaptive traits in general. We further suggest that the necessity for maintaining separate breeding zones, within Washington and Oregon, in subsequent cycles of recurrent selection is questionable. Average individual tree heritability, from 65 6-parent disconnected diallels, is 0.13 for age 6 and age 8 height. Dominance genetic variance is estimated to be one-half that of additive genetic variance for the same traits. The environmental designs and test establishment methods used resulted in acceptable levels of statistical precision for juvenile growth traits. Individual test least significant range values (LSR) resulted in significant family mean percent height differences of 8 to 26, and averaged 13% for diallels, and full-sib and half-sib tests.

783. Thomson AM, Crowe KA, Parker WH. 2010. Optimal white spruce breeding zones for Ontario under current and future climates. Canadian Journal of Forest Research 40:1576-1587.

Type: Journal

Geographic Area: Ontario, Canada

Compilers' Keywords: climate change, *Picea glauca*, range shifts, seed transfer guidelines

Abstract: Optimal breeding zones were developed for white spruce (*Picea glauca* (Moench) Voss) in Ontario under present and future climate conditions to examine potential shifts due to climate change. These zones were developed by (i) determining a set of candidate breeding zones based on the relationship between measured performance variables and climate and (ii) employing a decision support model to select subsets of breeding zones that maximize geographic coverage subject to a constraint on the maximum number of zones. Current optimal breeding zones were based on 1961–1990 climate normals, and future breeding zones were based on three general circulation model (CGCM2, HADCM3, and CSIRO) predictions of 2041–2070 climate. Based on a maximum adaptive distance of 2.0 least significant difference values between sites within zones, 14 zones were required to cover the Ontario range of white spruce for the 1961–1990 data. Compared with breeding zones of other boreal-conifers, current optimal breeding zones for white spruce were quite large, spanning up to 38 latitude and 108–128 longitude and indicating large distances of effective seed transfer. Of the three general circulation models used to simulate future climate, HADCM3 B2 and CGCM2 B2 predicted 2041–2070 breeding zones that largely coincide with 1961–1990 zones. In contrast, CSIRO B2 indicated much narrower 2041–2070 breeding zones.

784. Turesson G. 1922. The genotypical response of the plant species to the habitat. Hereditas 3:211-350.

Type: Journal

Geographic Area: Global

Compilers' Keywords: genomics, plant adaptation, genotype, phenotype, transplant experiments

Introduction: The study of the variability of the plant species in relation to its environment, or its habitat, might be pursued along two lines of research, viz. the study of the effect of various environmental factors upon the individual plant, and the study of the effect of these environmental factors upon the genotypical composition of a species-population in a certain habitat. The one line of research is primarily a study of the modifications of the plant, the other is manifestly a study of the hereditary variations. The two groups of variation have long ago been dealt with from the point of view of the environment, but while the experimental study of the former problem has received much attention the latter problem, the hereditary variation of wild plants in relation to habitat, has remained experimentally almost unattacked. In the absence of critical acquaintance with the different forms of a plant species met with in nature, much speculation is to the origin of adaptive structures is to be found in writings on ecology. The following discussion includes a number of notorious adaptive forms, and an attempt is made to ascertain whether the existence in nature of such forms is the result of an advantageous response on the part of the individual, or whether these forms are brought into existence through a genotypical response of the species-population to definite habitat conditions.

785. Vihera-Aarnio A. 2009. Effects of seed origin latitude on the timing of height growth cessation and field performance of silver birch [Dissertation]. Vantaa, Finland: University of Helsinki. 47 p.

Type: Dissertation

Geographic Area: Finland, Europe

Keywords: climatic adaptation, critical night length, moose browsing, provenance, seed transfer, stem quality, yield

Abstract: The aim of this thesis was to increase our knowledge about the effects of seed origin on the timing of height growth cessation and field performance of silver birch (*Betula pendula* Roth) from different latitudes, with special attention paid to the browsing damage by moose in young birch plantations. The effect of seed origin latitude and sowing time on timing of height growth cessation of first-year seedlings was studied in a greenhouse experiment with seven seed origins (lat. 58º - 67º N). Variation in critical night length (CNL) for 50% bud set within two latitudinally distant stands (60º and 67º N) was studied in three phytotron experiments. Browsing by moose on 5-11 year-old silver birch saplings from latitudinally different seed origins (53º - 67º N) was studied in a field experiment in southern Finland. Yield and stem quality of 22-year-old silver birch trees of Baltic, Finnish and Russian origin (54º - 63º N) and the effect of latitudinal seed transfers were studied in two provenance trials at Tuusula, southern and Viitasaari, central Finland. The timing of height growth cessation depended systematically on latitude of seed origin and sowing date. The more northern the seed origin, the earlier the growth cessation and the shorter the growth period. Later sowing dates delayed growth cessation but also shortened the growth period. The mean CNL of the southern ecotype was longer, 6.3 ± 0.2 h (95 % confidence interval), than that of the northern ecotype, 3.1 ± 0.3 h. Within-ecotype variance of the CNL was higher in the northern ecotype (0.484 h^2) than in the southern ecotype (0.150 h^2). Browsing by moose decreased with increasing latitude of seed origin and sapling height. Origins transferred from more southern latitudes were more heavily browsed than the more northern native ones. Southern Finnish seed origins produced the highest volume per unit area in central Finland (lat. 63º11' N). Estonian and north Latvian stand seed origins, and the southern Finnish plus tree origins, were the most productive ones in southern Finland (lat. 60º21' N). The relationship of both survival and stem volume/ha to the latitudinal seed transfer distance was curvilinear. Volume was increased by transferring seed from ca. 2 degrees of latitude from the south. A longer transfer from the south, and transfer from the north, decreased the yield. The proportion of trees with a stem defect increased linearly in relation to the latitudinal seed transfer distance from the south.

Link: http://www.metla.eu/dissertationes/df87.pdf

786. Vila M, Carrillo-Gavilan A, Vayreda J, Bugmann H, Fridman J, Grodzki W, Haase J, Kunstler G, Schelhaas M, Trasobares A. 2013. Disentangling biodiversity and climatic determinants of wood production. PLoS ONE 8:e53530.

Type: Journal

Geographic Area: Europe

Compilers' Keywords: biodiversity, climate change, wood production, tree growth, carbon sequestration, species richness

Abstract: Despite empirical support for an increase in ecosystem productivity with species diversity in synthetic systems, there is ample evidence that this relationship is dependent on environmental characteristics, especially in structurally more complex natural systems. Empirical support for this relationship in forests is urgently needed, as these ecosystems play an important role in carbon sequestration. We tested whether tree wood production is positively related to tree species richness while controlling for climatic factors, by analyzing 55265 forest inventory plots in 11 forest types across five European countries. On average, wood production was 24% higher in mixed than in monospecific forests. Taken alone, wood production was enhanced with increasing tree species richness in almost all forest types. In some forests, wood production was also greater with increasing numbers of tree types. Structural Equation Modeling indicated that the increase in wood production with tree species richness was largely mediated by a positive association between stand basal area and tree species richness. Mean annual temperature and mean annual precipitation affected wood production and species richness directly. However, the direction and magnitude of the influence of climatic variables on wood production and species richness was not consistent, and vary dependent on forest type. Our analysis is the first to find a local scale positive relationship between tree species richness and tree wood production occurring across a continent. Our results strongly support incorporating the role of biodiversity in management and policy plans for forest carbon sequestration.

Link: http://www.ncbi.nlm.nih.gov/pubmed/23437038

787. Vitasse Y, Delzon S, Bresson CC, Michalet R, Kremer A. 2009. Altitudinal differentiation in growth and phenology among populations of temperate-zone tree species growing in a common garden. Canadian Journal of Forest Research 39:1259-1269.

Type: Journal

Geographic Area: Southwestern France

Compilers' Keywords: genetic variation, tree species, phenology, common garden, climate change, forest management planning

Abstract: The aim of the study was to determine whether there are genetic variations in growth and leaf phenology (flushing and senescence) among populations of six woody species (*Abies alba* Mill., *Acer pseudoplatanus* L., *Fagus sylvatica* L., *Fraxinus excelsior* L., *Ilex aquifolium* L., and *Quercus petraea* (Matt.) Liebl.) along altitudinal gradients, using a common-garden experiment. We found (i) significant differences in phenology and growth among provenances for most species and (ii) evidence that these among-population differences in phenology were related to the annual temperature at the provenance sites for ash, beech, and oak. It is noteworthy that along the same climatic gradient, species can exhibit opposing genetic clines: beech populations from high elevations flushed earlier than those from low elevations, whereas we observed the opposite trend for ash and oak. For most species, significant altitudinal clines for growth were also revealed. Finally, we highlighted the fact that both phenology timing and growth rate were highly consistent from year to year. The results demonstrated that despite the proximity of the populations in their natural area, differences in altitude led to genetic differentiation in their phenology and growth. These adaptive capacities acting along a natural climatic gradient could allow populations to cope with current climate change.

Link: http://www.nrcresearchpress.com/doi/abs/10.1139/X09-054#.VTndbpgcRLM

788. Viveros-Viveros H, Sáenz-Romero C, Vargas-Hernández JJ, López-Upton J, Ramírez-Valverde G, Santacruz-Varela A. 2009. Altitudinal genetic variation in *Pinus hartwegii* Lindl. I: Height growth, shoot

phenology, and frost damage in seedlings. Forest Ecology and Management 257:836-842.

Type: Journal

Geographic Area: Michoacán, Mexico

Keywords: altitudinal variation, genetic variation, population differentiation, frost damage, grass-stage, assisted migration, global warming, seed zones, *Pinus hartwegii*, Michoacán

Abstract: The altitudinal pattern of genetic variation in *Pinus hartwegii* Lindl. populations was explored for seedling height growth, frost damage, grass-stage, and phenological stage of the terminal shoot. A provenance test was conducted with open-pollinated seed from 13 populations collected along an altitudinal transect (3000–3600 m) at the National Park Pico de Tancítaro, Michoacán, center-west Mexico. Height growth of seedlings in a nursery was assessed at seven and 18 months of age. Frost damage at -15 °C was evaluated in laboratory at 18 months of age; proportion of plants that had left grass-stage and stage of shoot development was assessed at the age of 22 months. Significant differences among provenances ($P < 0.0001$) were detected for all of the evaluated characters. The variation among populations was structured as a moderate altitudinal cline, with populations from lower altitudes showing larger height growth in seedlings, larger proportion of frost damages, fewer seedlings in grass-stage and more seedlings with developed shoot, whereas in populations from higher altitudes, seedlings exhibiting shorter plant height, lower percentages of frost damage, more seedlings with unbroken grass-stage, and fewer seedlings with advanced shoot development were displayed. Options for seed and seedling movement along the altitudinal gradient are discussed under the scope of reforestation, aiming at ecological restoration, conservation of forest genetic resources, and assisted migration considering global warming. We suggest delineation of two latitudinal seed zones (Zone I: 3000–3350 m; Zone II: 3350–3700 m).

789. Wallis CM, Reich RW, Lewis KJ, Huber DPW. 2010. **Lodgepole pine provenances differ in chemical defense capacities against foliage and stem diseases.** Canadian Journal of Forest Research 40:2333-2344.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: *Pinus contorta*, provenance test

Abstract: Maximization of lodgepole pine (*Pinus contorta* Douglas ex Louden var. *latifolia* Engelm. ex S. Watson) growth in a future climate with increased pest activity requires an understanding of the natural variability of quantitative resistance to disease. Foliar and bark secondary metabolites from different lodgepole pine provenances (populations) were quantified and correlated with severity of foliar diseases caused by *Lophodermella* spp. (*Lophodermella concolor* (Dearn.) Darker or *Lophodermella montivaga* Petre.) or *Elytroderma deformans* (Wier) Darker and bark diseases caused by *Elytroderma* or *Endocronartium harknessii* (J.P. Moore) Y. Hiratsuka. Greater foliar concentrations of lignin, tannins, and some phenolics were associated with increased resistance to single or multiple foliar pathogens. Bark secondary metabolites levels were generally unassociated with resistance to bark diseases. Provenances appearing to originate in ecosystems where lodgepole pine are not the dominant species generally were more susceptible to foliar diseases and had less foliar defense associated compounds than trees from areas where pines were the dominant species, yet clear trends proved to be elusive. Regardless, pine provenances with greater foliar levels of identified defense-associated compounds should be preferred seed sources for replanting forests in areas in which foliar disease is expected to be increasingly prevalent.

790. Wang JR, Hawkins CDB, Letchford T. 1998. **Photosynthesis, water and nitrogen use efficiencies of four paper birch (*Betula papyrifera*) populations grown under different soil moisture and nutrient regimes.** Forest Ecology and Management 112:233-244.

Type: Journal

Geographic Area: Western Canada

Keywords: *Betula papyrifera*, paper birch, nitrogen use efficiency, photosynthesis, population, water use efficiency, silviculture

Abstract: A greenhouse experiment was conducted to determine how four populations of paper birch (*Betula papyrifera* Marsh.), adapted to particular temperature, water and photoperiod regimes responded physiologically to different soil water and nutrient regimes. Seedlings of each of the four populations (Eaglet, LeeCreek, Porcupine and Skeena) from British Columbia were planted in pots and subjected to high and low water and nitrogen regimes for 4 months. Net photosynthesis (*A*), stomatal conductance (*gs*), water use efficiency (WUE) and nitrogen use efficiency (NUE) were measured and compared among treatments. Trade-offs between WUE and NUE were examined. Soil moisture was the major factor affecting A for all the populations. All populations showed relatively high A in the high water and high-nitrogen (HWHN) treatment, ranging from 8.5 to 9.9 mmol CO_2 m^{-2} s^{-1}. Photosynthesis of trees in the low-water and high-nitrogen (LWHN) treatment was about 45% of that in the HWHN treatment. There was a linear increase in A as gs increased in all populations. A decreased with increasing vapor pressure deficit (VPD). The populations demonstrated significantly different relationships between *A* and *gs*, and VPD, with the LeeCreek population being the most conservative. This may provide a physiological basis for provenance selection and seed transfer. Eaglet and LeeCreek populations had lower WUE at the same level of NUE compared with Porcupine and Skeena populations. Porcupine and Skeena populations may be more suitable for moist sites due to their greater capacity to sequester water quickly, while the LeeCreek and

Eaglet populations may be more suitable for drier interior sites where long drought periods can occur.

791. Ward K, Gisler M, Fiegener R, Young A. 2008. **The Willamette Valley Seed Increase Program: developing genetically diverse germplasm using an ecoregion approach.** Native Plants Journal 9:334-350.

Type: Journal

Geographic Area: Oregon, USA

Keywords: native plant material development, prairies, restoration genetics, seed transfer zones, domestication selection, Diversity Enhancement Block design

Abstract: The goal of the Institute for Applied Ecology's Willamette Valley Seed Increase Program is to develop a supply of ecologically appropriate, genetically diverse native plant material for restoration of prairie ecosystems in the Willamette Valley. In creating restoration germplasm we seek to maximize genetic diversity while simultaneously protecting genetic integrity of extant native populations. In the absence of genetic data to guide appropriate movement of native seeds, we are testing the use of an ecoregion approach using a variety of research techniques. We collected seeds, defined preliminary seed transfer zones, and planted seed increase fields for each of 21 historically widespread, common species. We captured spatial and temporal genetic diversity by sampling from many populations per species over a 3-y period. Seed zone boundaries for each species were drawn at the scale of the ecoregion or smaller, depending on life history characteristics and potential for adverse genetic effects of translocation. To minimize loss of diversity through domestication selection, we planted increase fields using a novel design, the Diversity Enhancement Block. Seedlots from populations with different phenology or from different areas within the ecoregion were planted in separate adjacent blocks. This design allows harvest of each block separately as seeds mature, while still permitting plants from different regions of the valley to cross pollinate and to produce crop seeds with maximum genetic diversity. All of our production fields have been entered into the Oregon Seed Certification Service Pre-Variety Germplasm program. We are looking for partners to participate in a buyer's cooperative.

792. Waters CM. 2001. **Guiding the delimitation of local provenance for Australian native grasses.** In: Second National Conference of the Native Grasses Association. New South Wales, Australia: Stipa Native Grasses Association, Inc. 1 p

Type: Conference Paper

Geographic Area: Australia

Keywords: seed source, transfer guidelines, restoration, local adaptation

Abstract: The provenance of a seed source not only describes its point of collection but can also reflect its evolutionary development. Here, local provenance material may be the best site-adapted material and the use of non-local material, or less `fit' ecotypes may result in establishment failure, long-term mortality or disruption to the surrounding ecosystem. No guidelines for the definition of a provenance currently exist for any Australian native grass, providing a major obstacle for the broad-scale use of Australian native grasses. Understanding the evolutionary forces such as natural selection, gene flow and genetic drift as well as the factors that operate to drive these forces, can provide clues to the definition of a provenance boundary. If native grasses are to retain their adaptive and low input advantages over the use of exotic species then understanding the issues of provenance provides the key to their successful and widespread use.

Link: http://www.regional.org.au/au/stipa/papers/stipa2001-09.htm

793. Weißhuhn K, Auge H, Prati D. 2011. **Geographic variation in the response to drought in nine grassland species.** Basic and Applied Ecology 12:21-28.

Type: Journal

Geographic Area: Europe

Keywords: intraspecific variability, climate change, root allocation, reproductive allocation, specific leaf area

Abstract: Summer precipitation is expected to decrease in Europe due to climate change, which in turn will increase the risk for plants to suffer from drought. To maintain ecosystem functions in grasslands under the conditions of climate change, drought adapted varieties of plant species may be needed. With our experiment, we bridge the gap between single species experiments and field experiments with whole plant communities under proposed scenarios of climate change. In a greenhouse experiment, we investigated the drought response of nine common grassland species which are normally utilized for restoration of mesic grasslands. We chose five European provenances of each species to test for a consistent, provenance specific drought response. Plants of all nine species were negatively affected by drought with respect to their biomass production, and consistently allocated less resources to roots than control plants. On the other hand, reproductive allocation increased under drought conditions in some species whereas no response to drought could be detected in specific leaf area. In contrast to our expectation, we found little evidence for intraspecific variation in response to simulated drought. However, we found a clear correlation between responsiveness in root allocation, and climatic conditions at the provenance's origin. This pattern became evident only when all species were analysed together, highlighting the advantage of multi species experiments.

Link: http://www.botany.unibe.ch/planteco/abstr_repr/BAAE_12_21.pdf

794. Weng YH, Parker WH. 2008. Adaptive variation in fall cold hardiness of aspen from northwestern Ontario. Tree Physiology 28:143-150.

Type: Journal

Geographic Area: Ontario, Canada

Keywords: chlorophyll fluorescence, electrical conductivity, *Populus tremuloides*, principal component analysis, provenance trial, visual scoring

Abstract: We investigated adaptive variation in fall cold hardiness development based on the electrical conductivity of tissue diffusates (EC) among 20 aspen provenances from northwestern Ontario. Provenance accounted for over 40% of the total variation in cold injury for seven dates from September through November in three provenance trials. Principal component analysis was performed to summarize the combinations of results for all sampling sites, dates and temperatures (traits). Principal component (PC)-1 represented fully developed cold hardiness differences among provenances; PC-2 represented differences in the timing of the onset of cold hardiness development; and PC-3 represented a site-related difference in cold hardiness development. Heat sum in early summer and late summer precipitation together were the best predictors of absolute degree of cold hardiness (PC-1), whereas temperatures for mid- to late summer were best for predicting onset of cold hardiness development (PC-2). In a second study, we assessed the efficacy of chlorophyll fluorescence (CF) as a simpler technique for determining the cold hardiness of aspen stem samples. Fall cold hardiness of stem samples of 12 of the original 20 provenances was estimated by CF, and the results were evaluated by a visual scoring (VS) method. Correlations between EC and CF measurements from the two studies were moderately strong based on the extent of cold hardiness in October of each year, but were negative for September dates because of a later onset of cold hardiness in the EC study year. Although the EC and CF methods gave similar cold hardiness values for stem samples from 12 provenances, the CF method may be preferred to the EC or VS method for species with chlorophyllous stems because of its greater ease of use.

Link: http://treephys.oxfordjournals.org/content/28/1/143.full.pdf

795. Westfall RD, Conkle MT. 1992. Allozyme markers in breeding zone designation. New Forests 6:279-309.

Type: Journal

Geographic Area: Western USA

Keywords: geographic variation, multivariate analysis, trend-surface analysis, transfer risk

Abstract: Early studies of allozyme variation in plant populations suggested that allelic frequencies in some loci vary by geography. Since then, the expectation that allozymes might be useful in describing geographic patterns has generally not been borne out by single locus analyses, except on the broadest scale. Multi-locus analyses reveal the converse: canonical correlation analysis of individual, uniformly-spaced genotypes describe statistically-significant, complex patterns with geography. Multi-locus scores in four major species. *Abies concolor, Pinus lambertiana, P. ponderosa,* and *Pseudotsuga menziesii*, of the mixed conifer forest in the Sierra Nevada correlate 0.40 or greater with the first canonical vector of a geographical trend surface equation. The different species follow similar patterns by latitude and elevation. In contrast with patterns in the Sierra Nevada, large-scale differentiation is weak ($R^2 < 0.20$) among populations of *Pseudotsuga menziesii* in the Coast Ranges and Siskiyou Mountains of northern California and southern Oregon, where differentiation may be local. For the purpose of forming zones, we subdivided scores of the first two to four canonical vectors into groups and plotted them as multidimensional contour intervals. Reclassification by discriminant analysis serves as an approximate guide to transfer risks within and among these groups.

Link: http://www.treesearch.fs.fed.us/pubs/32853

796. Wilson BL, Darris DC, Fiegener R, Johnson R, Horning ME, Kuykendall K. 2008. Seed transfer zones for a native grass *Festuca roemeri*: genecological evidence. Native Plants Journal 9:287-303.

Type: Journal

Geographic Area: Western USA

Keywords: common-garden study, habitat restoration, inbreeding depression, conservation genetics

Abstract: A common-garden study of *Festuca roemeri* (Pavlick) E. B. Alexeev (Poaceae) revealed substantial genetic variation within and among 47 populations from throughout its range in the Pacific Northwest, U.S., for growth, fitness, phenological, and morphological traits. Using climatic and physiographic variables, genetic patterns over the landscape were examined through principal component and regression analysis. Elevation and latitude of the seed source, and to a lesser extent temperature and precipitation, explained a significant proportion of the genetic variation, suggesting that observed variation was associated with adaptation to local environments. Most plants from the Willamette Valley exhibited poor growth and survival, perhaps due to inbreeding. Festuca roemeri variation clustered into seed transfer zones corresponding to Level III ecoregions, and one zone was further subdivided. High-elevation populations separated from lower-elevation populations but did not cluster into a single seed zone. Seed transfer zones reported here provide a guide for plant community restoration efforts using this species.

Link: http://www.treesearch.fs.fed.us/pubs/35452

797. Wu HX, Ying CC, Ju H-B. 2005. Predicting site productivity and pest hazard in lodgepole pine using biogeoclimatic system and geographic variables in British Columbia. Annals of Forest Science 62:31-42.

Type: Journal

Geographic Area: Western Canada

Keywords: site productivity, pest hazard, western gall rust, needle cast, terminal weevil, ecological system

Abstract: A series of 60 lodgepole pine provenance tests was planted throughout the interior of British Columbia in 1974 to predict productivity and pest hazard based on ecological classification and geographical variables. These 60 tests cover eight biogeoclimatic zones and 25 subzones within the biogeoclimatic ecosystem classification (BEC) in British Columbia. Ten provenances are common among 60 provenances tested at each site. Mean height (20-year) was measured at 57 of the 60 sites, incidence of western gall rust assessed at 56 sites, terminal weevil at 49 sites, and needle cast at 50 sites. There is large site-to-site variation in all traits. Geographic models using latitude, longitude and elevation of test site location as predictors explained 47%, 35%, 33%, 27% and 8% of site variation for height, survival, incidence of needle cast, terminal weevil and western gall rust, respectively. BEC zones accounted for about the same amount of the site variation as geographic models, suggesting both accounted for the effect of site environments relating mainly to temperature and precipitation. Within BEC zones, site variation in height seems to be related to subzones associated with moisture gradient, but not temperature. Sites in the moist, mild ICH subzone and the dry, cool MS subzone along the southern Rocky Mt. Trench represent the best forest land for intensive silviculture of lodgepole pine, being highly productive with low pest hazard except needle cast. These sites are followed in productivity by sites across the vast interior stretching from the Skeena/Bulkley river basin in the northwest (moist SBS subzone), to the interior wetbelt on Shuswap Quesnel Highland (moist, cool ICH subzone), and the Thompson Plateau in the southern interior, where lodgepole pine grew well with relatively low pest hazard at most sites.

798. Xie CY, Ying CC. 1993. Geographic variation of grand fir (*Abies grandis*) in the Pacific coast region: 10-year results from a provenance trial. Canadian Journal of Forest Research 23:1065-1072.

Type: Journal

Geographic Area: Western North America

Compilers' Keywords: reforestation, geographic differentiation, coastal forests, seed source

Abstract: The performance of 23 grand fir (*Abies grandis* (Dougl.) Lindl.) seed sources representing the coastal range of the species was examined with respect to height, mortality, frost damage, stem defects, needle disease susceptibility, and lammas growth at four sites in the Vancouver forest region of British Columbia. Variation in height was highly significant among provenances and showed discernible patterns at all ages surveyed (1, 3, 6, 7, 8, 9, and 10 years from outplanting). Provenances from northern, coastal, and low-elevation regions grew tallest. The remaining characters were only investigated 10 years after outplanting. Among-provenance variation in mortality, frost damage, and stem defects was nonsignificant when two provenances from the southern end of the natural range were removed from the analysis. Resistance to needle disease (*Uredinopsis longimucronata* Faull) was significantly different among provenances and decreased with elevation. Geographic variation in the proportion of trees with lammas growth was also significant but did not display any apparent pattern. Variation patterns were similar at the four testing sites but among-site differences in the average performance were highly significant for all the traits investigated. Eastern Vancouver Island, British Columbia, and northeastern Olympia Peninsula, Washington, are recommended as primary areas of seed source for reforestation in the Vancouver forest region.

799. Yang J, Pedlar JH, McKenney DW, Weersink A. 2015. The development of universal response functions to facilitate climate-smart regeneration of black spruce and white pine in Ontario, Canada. Forest Ecology and Management 339:34-43.

Type: Journal

Geographic Area: Ontario, Canada

Keywords: climate change, seed deployment, seed procurement, universal response function, black spruce, white pine blister rust

Abstract: Climate change is expected to impact forest growth and survival as tree populations experience climates to which they are not well adapted. However, forest regeneration efforts represent opportunities to introduce genetic material on the landscape that is well matched to future climates. We estimated universal response functions (URF) for two economically and ecologically important tree species in eastern Canada – black spruce (*Picea mariana*) and eastern white pine (*Pinus strobus*). The URF approach models tree growth as a function of both the planting site climate (i.e., environmental effects) and seed source climate (i.e., genetic effects), allowing the growth of any seed source to be estimated at any location. Both species exhibited a relatively weak genetic effect, suggesting modest potential for seed movements to mitigate climate change impacts. The optimal provenance for any given location was not local, but rather located in environments that were approximately 1.5 °C warmer than the planting site; this shift is consistent in both direction and magnitude with that expected due to climate warming since the start of the industrial revolution. Both species exhibited a strong environmental effect with clear evidence for a central climatic optimum. As a result, climate warming is expected to enhance black spruce growth at sites with mean annual temperature colder than approximately 4.5 °C and white pine growth at sites colder than 11 °C. Thus, Ontario white pine populations may benefit from the climate changes projected to occur in the province over the next 50–100 years. For black spruce, populations in southern

and central Ontario may experience suboptimal climate conditions over the mid-to-end of the current century. Despite the relatively weak genetic effect, climate-smart seed movements could play a role in maintaining the productivity and genetic diversity of black spruce in these areas. While the URF approach has limitations, this work demonstrates its potential for informing regeneration decisions under climate change.

Link: http://www.sciencedirect.com/science/article/pii/S0378112714007087

800. Ying CC. 1997. Effects of site, provenance, and provenance and site interaction in Sitka spruce in coastal British Columbia. Forest Genetics 4:99-112.

Type: Journal

Geographic Area: Pacific Northwest, USA, Canada

Keywords: *Picea sitchensis*, site environment, provenance, interaction, growth

Abstract: The IUFRO International Sitka spruce (*Picea sitchensis*) provenance experiments were planted at eight sites in Coastal British Columbia in 1975. The tests were planted in two series, with four sites in each series and 10 provenances at each test. A total of 14 provenances were tested with 6 provenances common to both series. Total height and survival were recorded at 3, 6, 10, 15 and 20 years after planting, and diameter at ages 10, 15 and 20 at most tests. Test sites accounted for about two-thirds of the total variation. Size of provenance variance components was different between the two site series. Interaction between provenance and site was high and statistically significant in both series. Site climate and attack by the white pine weevil (*Pissodes strobi*) were the major determinants of site productivity and also the main causes of the interactions. Latitudinal pattern in provenance variation was eminent at most sites at early ages and maintained throughout at sites with strong maritime climate and free of weevil attack; at harsh northern and inland sites, geographic pattern of provenance variation shifted toward longitudinal (coast - inland) at later ages, and the harsher the site environment the earlier the shift. Practical implication in terms of seed transfer of the fast growing southern coastal sources and weevil resistant provenances in reforestation in coastal British Columbia was discussed.

Link: http://www.tuzvo.sk/files/fg/volumes/1997/FG04-2_099-112.pdf

801. Ying CC, Thompson C, Herring L. 1989. Geographic variation, nursery effects, and early selection in lodgepole pine. Canadian Journal of Forest Research 19:832-841.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: genetic variation, provenance, common garden, *Pinus contorta*, seed transfer guidelines, maladaptation

Abstract: Thirty provenances of lodgepole pine (*Pinus contorta* Dougl.) test shock raised at two nurseries, Cowichan Lake (coastal British Columbia) and RE Rock (interior British Columbia), were assessed in two 15-year field trials. Analyses indicated three broad geographic regions of genetic differentiation in British Columbia: coast, coast–interior transition, and central and southern interior. Provenance elevation was found to have a strong influence on growth. The results suggest that the present seed transfer guidelines for lodgepole pine in the interior region of this province are conservative enough to prevent the use of maladapted seed sources. Nursery effect declined over a period of 15 years, while provenance differences increased with the age of the trials. Interactions between provenances and sites also increased after age 9. This suggests that the effect due to seedling culture and environment in the nursery is short-term relative to the influence of the genetic component. Nursery growth was generally not a good predictor of provenance field performance.

802. Zhang JW, Feng Z, Cregg BM, Schumann CM. 1997. Carbon isotopic composition, gas exchange, and growth of three populations of ponderosa pine differing in drought tolerance. Tree Physiology 17:461-466.

Type: Journal

Geographic Area: Montana, South Dakota, USA

Keywords: carbon isotope ratio, net photosynthesis, *Pinus ponderosa*, relative growth rate, stomatal conductance, water-use efficiency, xylem pressure potential

Abstract: Effects of water supply on gas exchange, carbon isotopic composition, and relative growth rate were compared among seedlings from three populations of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) grown in a controlled environment chamber. The three populations were chosen to represent high, moderate and low drought tolerance. There was no indication that drought tolerance was related to high water use efficiency. Populations differed ($P < 0.05$) in relative growth rate (RGR), but did not differ ($P > 0.10$) in gas exchange variables or carbon isotope ratio ($\delta^{13}C$). Well-watered seedlings had significantly higher RGR, xylem pressure potential (Y_{xpp}), net photosynthesis (A), stomatal conductance to water vapor (g), and lower $\delta^{13}C$ and instantaneous water-use efficiency than water-stressed seedlings. With decreasing Y_{xpp}, A decreased linearly, whereas g decreased exponentially. Seedlings of the highly drought-tolerant population were more sensitive to water availability than seedlings from the other populations; they used water quickly when water was available, but closed their stomata in response to water stress. We conclude that, in ponderosa pine, the drought avoidance mechanism is more important for survival and growth in arid and semiarid environments than the efficient use of water.

Link: http://www4.nau.edu/direnet/publications/publications_z/files/J_W_Zhang.pdf

Transfer Guidelines and Zones

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803. Adair R, Johnson RC, Hellier B, Kaiser WJ. 2006. Collecting tapertip onion (*Allium acuminatum* Hook.) in the Great Basin using traditional and GIS methods. Native Plants Journal 7:141-148.

Type: Journal

Geographic Area: Great Basin USA

Keywords: National Plant Germplasm System, georeferencing, field sampling, in situ conservation

Abstract: As part of a biodiversity assessment and germplasm conservation project, we collected 55 populations of tapertip onion (*Allium acuminatum* Hook. [Alliaceae]) throughout the Great Basin region of the U.S. (Idaho, Oregon, Nevada). Population data from field observations and herbarium specimens were entered into a geographic information system (GIS) to facilitate efficient sampling strategies and maximize the number and diversity of ecoregions represented. Although limited by the quality of source data, GIS-based population location information greatly aided in the organization and time management of the field collection. We collected, measured, and described bulbs. The bulbs will be used in common garden studies and genetic research to evaluate species diversity throughout the region, and develop *in situ* germplasm conservation sites for future native rangeland restoration efforts. *Ex situ* collections will also be entered into the National Plant Germplasm System and be available for research, ecological restoration efforts, and germplasm enhancement.

Link: http://www.nativeplantnetwork.org/Content/Articles/7-2NPJ141-148.pdf

804. Breed MF, Stead MG, Ottewell KM, Gardner MG, Lowe AJ. 2013. Which provenance and where? Seed sourcing strategies for revegetation in a changing environment. Conservation Genetics 14:1-10.

Type: Journal

Geographic Area: Global

Keywords: climate change, habitat fragmentation, inbreeding, local adaptation, outbreeding depression, plant genetic resources, revegetation

Abstract: Revegetation is one practical application of science that should ideally aim to combine ecology with evolution to maximise biodiversity and ecosystem outcomes. The strict use of locally sourced seed in revegetation programs is widespread and is based on the expectation that populations are locally adapted. This practice does not fully integrate two global drivers of ecosystem change and biodiversity loss: habitat fragmentation and climate change. Here, we suggest amendments to existing strategies combined with a review of alternative seed-sourcing strategies that propose to mitigate against these drivers. We present a provenancing selection guide based on confidence surrounding climate change distribution modelling and data on population genetic and/ or environmental differences between populations. Revegetation practices will benefit from greater integration of current scientific developments and establishment of more long-term experiments is key to improving the long-term success. The rapid growth in carbon and biodiversity markets creates a favourable economic climate to achieve these outcomes.

Link: http://s3.amazonaws.com/academia.edu.documents/30181053/Breed_et_al_provenance_2012.pdf?AWSAccessKeyId=AKIAIR6FSIMDFXPEERSA&Expires=1382558363&Signature=pGq3eRDG2LawgufWthZN6Z8H3Lw%3D&response-content-disposition=inline

805. Broadhurst LM, Lowe A, Coates DJ, Cunningham SA, McDonald M, Vesk PA, Yates C. 2008. Seed supply for broadscale restoration: maximizing evolutionary potential. Evolutionary Applications 1:587-597

Type: Journal

Geographic Area: Australia

Keywords: evolutionary potential, genetic diversity, germplasm, provenance, restoration, seed quality

Abstract: Restoring degraded land to combat environmental degradation requires the collection of vast quantities of germplasm (seed). Sourcing this material raises questions related to provenance selection, seed quality and harvest sustainability. Restoration guidelines strongly recommend using local sources to maximize local adaptation and prevent outbreeding depression, but in highly modified landscapes this restricts collection to small remnants where limited, poor quality seed is available, and where harvesting impacts may be high. We review three principles guiding the sourcing of restoration germplasm: (i) the appropriateness of using 'local' seed, (ii) sample sizes and population characteristics required to capture sufficient genetic diversity to establish self-sustaining populations and (iii) the impact of over harvesting source populations. We review these topics by examining current collection guidelines and the evidence supporting these, then we consider if the guidelines can be improved and the consequences of not doing so. We find that the emphasis on local seed sourcing will, in many cases, lead to poor restoration outcomes, particularly at broad geographic scales. We suggest that seed sourcing should concentrate less on local collection and more on capturing high quality and genetically diverse seed to maximize the adaptive potential of restoration efforts to current and future environmental change.

Link: http://pages.uoregon.edu/ecolrest/Spring%202011%20Restoration%20Readings/Summer%20Course%20Docs/BR_2008_restoration_seed_selection.pdf

806. Crowe KA, Parker WH. 2005. Provisional breeding zone determination modeled as a maximal covering location problem. Canadian Journal of Forest Research 35:1173-1182.

Type: Journal

Geographic Area: Central Canada

Compilers' Keywords: seed zone, jack pine, modeling, focal point seed zone, common garden, *Pinus banksiana*, delineate breeding zones

Abstract: This study was a first attempt to model the problem of delineating breeding zones as a maximal covering location problem. The method involves two steps. First, a comprehensive set of candidate breeding zones is generated for a region using the focal point seed zone method. This method allows for control over the adaptive difference of genetic material within each zone. A grid of points is used to create the set of candidate breeding zones: one zone per point. Next, candidate zones are entered into a maximal covering location model formulated to suit this problem. The objective of this model is to select a subset of candidate zones that maximally covers the area of the region, given a limit on the number of zones to be selected and on the adaptive dissimilarity allowed within zones. Through use of this method, decision-makers can gain insight into how many breeding zones are needed to cover the region. Using different inputs from the focal point seed zone method, it is also possible to explore the trade-offs between the quantity and the quality of breeding zones. The method was tested on data from a series of jack pine (*Pinus banksiana* Lamb.) common garden trials of 102 seed sources from northwestern Ontario.

807. Crowe KA, Parker WH. 2008. Using portfolio theory to guide reforestation and restoration under climate change scenarios. Climatic Change 89:355-370.

Type: Journal

Geographic Area: Central Canada

Compilers' Keywords: decision support system, adaptation, *Picea glauca*, uncertainty, focal point seed zone, genotype, natural migration, management planning, seed transfer guidelines

Abstract: The general problem addressed by this study is that of designing a decision support system for planned adaptation to climate change that uses the principles of modern portfolio theory to minimise risk and maximise return of adaptive actions in an environment of deep uncertainty over future climate scenarios. Here we show how modern portfolio theory can use the results of a climate change impact model to select an optimal set of seed sources to be used in regenerating forests of white spruce in an environment of multiple, equally plausible futures climates. This study shows that components of solutions are not selected to perform equally well across all plausible futures; but rather, that components are selected to specialize in particular climate scenarios. The innovations of this research rests in demonstrating that the powerful and widely used principles of quantifying and planning for risk and return in the uncertain environment of asset markets can be applied successfully to serve the objectives of planned adaptation to climate change.

Link: http://flash.lakeheadu.ca/~whparker/ClimaticChange2008reprint.pdf

808. Echt CS. 1997. Use of molecular genetic markers in forest management. In: Communicating the Role of Silviculture in Managing the National Forests: Proceedings of the National Silviculture Workshop. Randor (PA): USDA Forest Service, Northeastern Forest Experiment Station. General Techinical Report NE-238. p 134-139.

Type: Government Document

Geographic Area: North America

Compilers' Keywords: biodiversity, silviculture, sustainability, white pine, timber management

Abstract: When managing forests for biodiversity or sustainability, attention must be given to how silvicultural practices affect genetic diversity. A new generation of DNA based markers affords a greater detail of genetic analysis than previously possible. These new markers, SSRs or microsatellites, have been used to demonstrate genetic diversity and infer evolutionary history of red pine, something that has not been possible with other markers. SSR markers developed by the Forest Service Research Biotechnology Unit are also being used to monitor how methods of sustainable timber management affect genetic diversity and breeding patterns within white pine stands on the Menominee Indian reservation.

Link: http://www.treesearch.fs.fed.us/pubs/15168

809. El-Kassaby YA, Lstiburek M. 2009. Breeding without breeding. Genetics Research 91:111-120.

Type: Journal

Geographic Area: Global

Compilers' Keywords: algorithms, computer simulation, genotype, genetic models, phenotype, plant genetics, *Pseudotsuga menziesii*, genotype selection, framework

Summary: An innovative approach to tree breeding called 'breeding without breeding' (BWB) is presented. The method, as applied on the material in hand, allows the capture of 75-85% of the genetic response to selection attained through conventional programmes without the need to do any controlled pollination and simplified or possibly no experimental field testing: both considered to be the most resource-demanding activities in breeding programmes. BWB combines the use of genotypic or phenotypic pre-selection of superior individuals, informative DNA markers for fingerprinting and pedigree reconstruction of offspring to assemble naturally created full- and half-sib families resulting from mating among selected parents, and quantitative genetics analyses to identify elite genotypes for further genetic improvement or the establishment of production populations. BWB utility is demonstrated using a retrospective study of Douglas-fir (*Pseudotsuga menziesii*) progeny tests consisting of offspring produced from 150 controlled crosses among 60 parents and established over three sites. The empirical results are supported by theoretical expectations demonstrating anticipated minimum genetic response compared with conventional approaches. The method's simplicity offers an exceptional opportunity for the development of comparable breeding efforts in developing countries, advanced and new breeding programmes, and economically important and 'minor' species.

Link: http://www.ncbi.nlm.nih.gov/pubmed/19393127

810. Erickson VJ. 2008. Developing native plant germplasm for national forests and grasslands in the Pacific Northwest. Native Plants Journal 9:255-266.

Type: Journal

Geographic Area: Pacific Northwest USA

Keywords: grassland restoration, prairie, herbicide, restoration methods, seed addition, native diversity, invasive species

Abstract: Revegetation needs on national forests and grasslands in the Pacific Northwest are extensive and are expected to increase in the future as a result of growing challenges such as climate change, severe wildfires, invasive plants, and at-risk species. In response to these needs, Region 6 of the USDA Forest Service has implemented a new program to develop native plant materials for restoration activities that will be economical, effective, and consistent with Forest Service policy to protect biological diversity and plant genetic resources. The program has required strategic investments and commitments to research, infrastructure, equipment, and technology transfer. This article summarizes methods for species selection, plant material needs projections, propagule collection, nursery culture, and agricultural seed production. Although many challenges and constraints remain, considerable success has been achieved due to a dedicated workforce and the strong nursery system and agricultural infrastructure in the Pacific Northwest. Plant materials are becoming increasingly available and affordable as nurseries and seed producers gain experience and knowledge in their culture and management. In addition, this program is benefiting rural economies and contributing to the development of secondary, non-federal markets for native plant material services and products.

[Note: **Erickson VJ. 2009. Developing native plant germplasm for national forests and grasslands in the Pacific Northwest** - corrected table 1. Native Plants Journal 10:302.]

811. Fay MF. 2003. Using genetic data to help guide decisions about sampling. Chapter 5. In: Smith RD, Dickie JB, Linington SL, Pritchard HW, Probert RJ, editors. Seed Conservation: Turning Science into Practice. London, United Kingdom: Royal Botanical Gardens. p 89-96.

Type: Book Section

Geographic Area: Global

Compilers' Keywords: conservation, AFLP, genetic variation, seed bank, guidelines

Summary: Many new genetic fingerprinting techniques were developed in the 1990s, and some of these are now being increasingly used to study genetic variation in populations of wild plant species. Examples are presented of the use of AFLP (amplified fragment length polymorphism) and plastid microsatellites in the characterization of genetic variation in wild species. How this information can be used to inform sampling strategies for seed banking is discussed.

Link: http://www.kew.org/ucm/groups/public/documents/document/ppcont_013767.pdf

812. Grossnickle SC, Sutton BCS, Fan S, King J. 1997. Characterization of *Sitka* x *interior* spruce hybrids: a biotechnological approach to seedlot determination. The Forestry Chronicle 73:357-362.

Type: Journal

Geographic Area: Western Canada

Keywords: biotechnology, molecular genetics, ecophysiology, Sitka spruce, interior spruce, introgression zone, seedlot deployment

Abstract: The Nass Skeena Transition is an area located in British Columbia (BC), Canada, where a large introgression zone occurs between Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and interior spruce (white spruce, *Picea glauca* (Moench) Voss x Engelmann spruce, *Picea engelmannii* Parry ex. Engelm.). When these species hybridize in this transition area, forestry programs face special problems in identifying seedlots that have the desired genetic makeup of source material collected from traditional seed zones. This paper presents an overview of a program that combined the disciplines of molecular genetics and ecophysiology to assist in defining the genetic makeup of seedlots based on DNA analysis results. Research first identified chloroplast, mitochondrial and nuclear DNA probes that were used to estimate species components for Sitka x interior spruce hybrid seedlots. Seedlings produced from Sitka x interior spruce hybrid seedlots were then characterized for ecophysiological parameters of drought tolerance, freezing tolerance and gas exchange patterns. DNA analysis results were then compared to ecophysiological parameters and findings indicated that seed source DNA profiles were related to drought tolerance throughout the year, freezing tolerance during fall acclimation and gas exchange patterns during the summer season. Using standard seed zone deployment practices in conjunction with these scientific findings provided a more comprehensive approach for defining seed transfer guidelines of Sitka and interior spruce populations. This program provided an example of how the field of biotechnology was used to assist in defining a seed deployment strategy for a region where introgression is a common occurrence between Sitka and interior spruce populations.

813. Hamann A, Gylander T, Chen P. 2011. Developing seed zones and transfer guidelines with multivariate regression trees. Tree Genetics and Genomes 7:399-408.

Type: Journal

Geographic Area: North America

Keywords: genetic diversity, tree improvement, ecological genetics, genecology, aspen, red alder

Abstract: Managing seed movement is an important component of forest resource management to minimize maladaptation of planting stock in forest plantations. Here, we describe a new approach to analyze geographic patterns of adaptive and neutral genetic variation in forest trees and to link this genetic information to geographic variables for the delineation of seed zones and the development of seed transfer guidelines. We apply multivariate regression trees to partition genetic variation, using a set of environmental or geographic predictor variables as partitioning criteria in a series of dichotomous splits of the genetic dataset. The method can be applied to any type of genetic data (growth, adaptive, or marker traits) and can simultaneously evaluate multiple traits observed over several environments. The predictor variables can be categorical (e.g., ecosystem of seed source), continuous (e.g., geographic or climate variables), or a combination of both. Different sets of predictor variables can be used for different purposes: In two case studies for aspen and red alder, we show (1) how latitude, longitude, and elevation of seed sources in a provenance trial can be used to develop simple seed transfer guidelines; (2) how ecosystem classes and elevation as predictor variables can be used to delineate seed zones and breeding regions; and (3) how climate variables as predictors can reveal adaptation of genotypes to the environments in which they occur. Partitioning of genetic variation appears very robust regarding the choice of predictor variables, and we find that the method is a powerful aid for interpreting complex genetic datasets.

Link: http://www.ualberta.ca/~ahamann/publications/pdfs/Hamann_et_al_2011.pdf

814. Heinze B, Westcott R, Schmidt J, Glossl J. 1996. Application of random amplified polymorphic DNA (RAPD) to detect genetic variation in Norway spruce. New Forests 11:173-184.

Type: Journal

Geographic Area: Europe

Keywords: *Picea abies*, genetic markers, clone identification, tissue culture, segregation

Abstract: The RAPD assay is a screening method for genetic variation; in Norway spruce biology research, it may find many applications. We have investigated into its suitability for Norway spruce genetics by optimizing the protocol, testing for stability in clones, especially tissue culture clones, assessing the variation in a seed sample, and checking for correct Mendelian segregation in haploid megagametophytes. The RAPD assay produced numerous genetic markers quickly. The data obtained gave insight into the genetic make-up of clones and seed.

815. Kitzmiller JH. 1990. Managing genetic diversity in a tree improvement program. Forest Ecology and Management 35:131-149.

Type: Journal

Geographic Area: Southwestern USA

Compilers' Keywords: reforestation, seed collection, silviculture, seed production

Abstract: Maintenance of species and within-species diversity is a goal of the USDA Forest Service, Pacific Southwest Region, which is examining and monitoring the genetic effects of silvicultural activities using isozyme analysis in conjunction with traditional methods. An effective monitoring and evaluation program will help improve silvicultural practices. Regional policies on gene conservation focus mainly on artificial regeneration. Tree improvement, nursery, and reforestation activities in the PSW Region may significantly affect adaptability, genetic diversity, and economic timber traits. The Base-Level Tree Improvement Program (TIP) aims for: (1) high adaptability via use of native species and local wild seed; (2) high within-species genetic diversity via designs for sampling several local seed stands and via long term plans for improvement using simple recurrent selection and bulking among the seed-production-area plantations; and (3) moderate improvement in performance via mild selection for superior phenotypes. The ceiling on genetic diversity is established by the seed collected. Nursery and reforestation practices may result in some loss of original (seed collection) diversity. Nursery practices aim to maximize plantable seedlings per unit of seed and thereby preserve diversity through sound management. Reforestation practices aim to achieve high local diversity by mixing appropriate species at planting, allowing natural regeneration to established in plantations, encouraging high survival and using higher planting densities so that natural selection can operate effectively. The High-Level TIP involving selective breeding and orchards will supplant the wild collections for major species and productive sites. Orchard seed will have a base of 50-60 unrelated, interbreeding parents, each representing a separate stand. Cooperative programs will enhance the genetic base by providing a broad range of material for breeding. New genes may be infused into breeding populations from material selected in natural forest reserves to increase diversity. Production plantations will be genetically more diverse than naturally regenerated stands.

816. Kung FH, Rink G. 1993. A graphic technique for identifying superior seed sources for central hardwoods. In: Gillespie AR, Parker GR, Pope PE, Rink G, editors. Ninth Central Hardwood Forest Conference. St. Paul (MN): USDA Forest Service, North Central Forest Experiment Station. General Technical Report NC-161. p 101-106.

Type: Government Document

Geographic Area: Central USA

Compilers' Keywords: forest production, genotype selection, tool, plantation, seed zones

Introduction: To maximize forest production, foresters need to plant the best genotypes provided by forest geneticists. Where should the forest geneticist search for the best seed sources? How far can one go south, or north to find them? The answer may rely on the species and the location of the test plantation. For example, when black walnut trees were tested in Illinois, Indiana, Missouri, and southern Michigan, trees from southern seed sources grew faster than those of local and northern seed sources. However, in Iowa and Minnesota, trees from northern sources were generally larger than trees from southern sources, and in Kansas and Ohio, tree size was not associated with latitude of seed source (Bey 1973, 1979). As the number of plantation increases, we may find that the most southern plantation will have only northern seed sources and the most northern plantation will have only southern seed sources, we may not be able to make a simple statement as to the best seed zone for each plantation location. Since a picture is better than a thousand words, we suggest a simple graphic solution useful to answer these questions.

Link: http://www.treesearch.fs.fed.us/pubs/15308

817. Lindgren D, Ying CC. 2000. A model integrating seed source adaptation and seed use. New Forests 20:87-104.

Type: Journal

Geographic Area: Sweden, Europe

Keywords: adaptability, seed zone, provenance, seed orchard, Scots pine

Abstract: A conceptual model that considers the performance (adaptability) of a seed source (= an origin) and the location or range of its deployment is developed employing the Cauchy function. The model assumes that there exists an optimal site type for each provenance origin (genetic material), and that loss in performance is a function of the "distance" (a measure of increasing maladaptation) from the optimal site. The model requires the estimate of three parameters: a site requirement value that measures site type in one dimension; a measure of

optimal performance; and a flexibility measure of the width of seed source adaptability. The Cauchy function has a known integral, thus the average adaptability over a range (a possible seed use zone) can be mathematically evaluated. The model was also extended to seed orchard crops representing progeny of parents of variable origins. Scots pine information in Sweden was used to demonstrate possible applications of the model.

818. Mangold RD, Libby WJ. 1978. **A model for reforestation with optimal and suboptimal tree populations.** Silvae Genetica 27:66-68.

Type: Journal

Geographic Area: Global

Keywords: reforestation model, developmental growth strategy, optimal and suboptimal populations, nonlocal seed

Summary: A hypothetical reforestation model is presented which postulates growth rates by "optimal" and "suboptimal" tree populations. Populations of trees from the central zone of a species' ecological tolerance may possess inherently greater capacities for rapid growth due to a "non-conservative" developmental growth strategy. Such a strategy probably evolves where environmental conditions are rarely limiting for growth, but biotic (competitive) interactions between neighboring trees are intense. When these populations are planted in less favorable sites, they may outgrow native populations. A method for determining the extent of planting zones for such populations is also presented.

Link: http://www.silvaegenetica.de/fileadmin/content/dokument/archiv/silvaegenetica/27_1978/27-2-66.pdf

819. Monserud RA, Rehfeldt GE. 1990. **Genetic and environmental components of variation of site index in inland Douglas-fir.** Forest Science 36:1-9.

Type: Journal

Geographic Area: Northern USA

Keywords: path analysis, provenance

Abstract: Results from two disparate and independent studies of inland Douglas-fir (*Pseudotsuga menziesii* [Mirb] Franco var. *glauca*) were combined to answer the following questions: First, how much variation in site index is associated with genetic variation? Second, what is the relative importance of the genetic and environmental components of phenotypic variation in explaining differences in mean height among stands of mature trees? Third, what is the magnitude of the interaction? An index to genetic variation, based on 3-year seedling height in provenance tests, accounted for approximately 40% of the variation in both 50-year and 100 year dominant height (i.e., site index) among 135 natural stands in northern Idaho and western Montana. Combining the genetic index and simple environmental variables (elevation, habitat series, latitude, longitude) accounted for nearly half the variation in site index. Path analyses estimated a strong correlation (0.76) between genotype and environment, reflecting the steep adaptive clines that are well known for this species. The analysis also indicated that the genotype is about a third more important than the contemporary environment in determining phenotypic variation in dominant height of natural stands. The results suggest that a combined genetic/mensuration model has potential to improve both tree breeding efforts and stand management.

820. Neale DB, Wheeler NC. 2004. **Mapping of quantitative trait loci in loblolly pine and Douglas-fir: a summary.** Forest Genetics 11:173-178.

Type: Journal

Geographic Area: USA

Keywords: QTLs, genomics, quantitative traits

Abstract: Classical quantitative genetic approaches have yielded a depth of understanding of the heritability and partitioning of variance of important traits in forest trees. Such knowledge has been applied in the genetic improvement of many species. Genetic improvement based on phenotypic selection in forest trees is rather slow however due to the long generation time in trees and the time to phenotypic evaluation. Genetic marker based approaches to tree improvement would increase the speed and precision of breeding. For this goal to be realized, the genes controlling quantitative traits must be identified. We summarize our progress toward achieving this goal based on a series of quantitative trait locus mapping experiments in two important conifer species. The path toward discovery of economically important alleles is now clear.

Link: http://www.tuzvo.sk/files/fg/volumes/2004/FG11-34_173-178.pdf

821. O'Neill GA, Aitken SN. 2004. **Area-based breeding zones to minimize maladaptation.** Canadian Journal of Forest Research 34:695-704.

Type: Journal

Geographic Area: Western Canada

Compilers' Keywords: white spruce, Engelmann spruce, *Picea glauca*, *Picea engelmannii*, GIS, genetic adaptation, delineation method

Abstract: A new breeding zone delineation scheme identifies for a given number of zones the zone-boundary placement that minimizes regional maladaptation in breeding programs. First, an adaptive map is created by using conventional genetic test data. Then, the large array of predicted adaptive values is subjected to cluster analysis, which assigns each grid cell of the region to one of a predetermined number of clusters (breeding zones) such that the sum of the squared distances between each cell's adaptive value and its cluster mean is minimized. This approach minimizes the average adaptive distance between the origin of a breeding program's selected trees and planting locations throughout the region of focus. The procedure is illustrated by the use of adaptive values of 69 interior spruce (*Picea engelmannii* Parry ex Engelm. × *Picea glauca* (Moench) Voss) open-pollinated families (sources) from southeast British Columbia, Canada. Adaptive values of each 1.5 km × 1.5 km grid cell in the 80,000-km^2 region were predicted using a genecological model (R^2 = 0.64), and the values were subjected to cluster analysis to identify breeding zone boundaries that were then mapped using a geographic information system. Regardless of the number of zones created, a regional maladaptation index was consistently smaller when zones were devised with area based cluster (ABC) analysis than when zones were created by dividing the region into bands of equal elevational or adaptive-value widths. Application of the ABC procedure should assist in identifying the optimum breeding-zone alignment for a given number of zones.

822. O'Neill GA, Dawson I, Sotelo-Montes C, Guarino L, Guariguata M, Current D, Weber JC. 2001. Strategies for genetic conservation of trees in the Peruvian Amazon. Biodiversity and Conservation 10:837-850.

Type: Journal

Geographic Area: Peru, South America

Keywords: agroforestry, genetic conservation, genetic erosion, Peruvian Amazon, tree genetic resources

Abstract: Forestry practices and high rates of land clearance for agriculture are causing genetic erosion of valuable tree species in the Peruvian Amazon, thereby endangering the economic sustainability of rural communities and limiting Peru's opportunities for the development of new timber and non-timber forest products. The potential utility and limitations of six low-input interventions to help forestall further genetic erosion in the region are discussed, with a focus on local community involvement. Improved agroforestry systems may help reduce deforestation by increasing farm productivity, although methods to increase the currently low adoption rate of these technologies need to be developed. Use of strategic tree domestication techniques can also improve farm productivity and prevent inadvertent genetic drift and inbreeding associated with traditional domestication practices, although to have a major impact, current programs need to be extended across the region. Woodlot forestry could supplant selective extraction of timber and offers an attractive opportunity for poverty alleviation if appropriate credit and land tenure policies can be developed. However, it may also result in increased deforestation if activities on public land cannot be controlled. The implementation of improved seed collection systems and simple seed transfer guidelines would help to reduce the collection of seed of poor quality and low genetic diversity, and avoid maladapted plantings, although such programs are difficult to monitor and seed costs may increase. Strategic identification and design of in situ conservation areas would help to ensure the viability of conserved populations, but requires the forfeiture of significant revenue from timber concessions.

Link: http://www.researchgate.net/publication/226767388_Strategies_for_genetic_conservation_of_trees_in_the_Peruvian_Amazon/file/60b7d5147da1149c2e.pdf

823. Parker WH. 2000. Rates of change of adaptive variation in *Picea mariana* visualized by GIS using a differential systematic coefficient. New Forests 20:259-276.

Type: Journal

Geographic Area: Ontario, Canada

Keywords: black spruce, breeding zones, Differential Systematic Coefficient, genecology, provenance test, delineation method

Abstract: Data from a short-term provenance trial of black spruce (*Picea mariana* (Mill.) B.S.P.) were used to illustrate a methodology to help locate breeding zone boundaries using adaptive variation models. Four height growth and survival variables were summarized by principal components analysis (PCA), and the first three axis scores were regressed against climate data determined from a recently developed Ontario Climate Model. The regression equations were used to model the PCA axes, and these models were interpreted as the three main components of adaptive variation in the data. These models were converted to geographic grids using GIS software. In a manner similar to that proposed for differential systematics applications, the Differential Systematic Coefficient (DSC) was adapted to be an indicator of the weighted average rate of change of clinally expressed adaptive variation over distance. An output grid was determined based on the DSC values, such that grid cells with higher coefficient values were made to appear darker on the resultant map; thus, the shaded areas corresponded to steeper portions of the clines of adaptive variation and serve as desirable indicators of the best locations for breeding zone boundaries.

824. Raymond CA, Lindgren D. 1990. Genetic flexibility: a model for determining the range of suitable environments for a seed source. Silvae Genetica 39:112-120.

Type: Journal

Geographic Area: USA, Sweden

Keywords: breeding zones, *Pinus sylvestris*, genotype by environment interaction

Abstract: A mathematical model describing the relative performance of different seed sources over a range of environments has been developed and tested using data from Scots pine in Sweden and white ash in USA. The components of the model have a direct biological interpretation in terms of the fundamental nature of the problem: i.e., the maximal performance of a seed source, where this maximum will occur and the range of suitable sites for such a seed source. Comparisons

can thus be made between seed sources as to their site preferences and the relative flexibility of each seed source calculated. Decisions regarding the optimal deployment of seed may thus be simplified and such information used to refine the allocation of breeding zones. The model requires that a one-dimensional environmental gradient be defined. Such gradients may relate to a single overriding environmental factor (e.g. winter cold) which can be described by geographical information such as latitude, altitude and distance from the sea. Definition of this gradient is a necessary prerequisite to application of this model. Methods for establishing such gradients are discussed.

Link: http://www.silvaegenetica.com/fileadmin/content/dokument/archiv/silvaegenetica/39_1990/39-3-4-112.pdf

825. St. Clair JB, Johnson GR, Erickson VJ, Johnson RC, Shaw NL. 2007. **Seed zones for maintaining adapted plant populations.** In: Norcini JG, editor. Native Wildflower Seed Production Research Symposium. Quincy (FL): University of Florida, Institute of Food and Agriculture, North Florida Research & Education Center. p 1.

Type: Conference Paper

Geographic Area: Western North America

Compilers' Keywords: seed transfer guideline, native plants, genetics, common garden

Abstract: Seed zones delineate areas within which plant materials can be transferred with little risk that they will be poorly adapted to their new location. They ensure successful restoration and revegetation, and help maintain the integrity of natural genetic structure. The value of seed zones is recognized in numerous policy statements from federal and state agencies. Results from common garden studies indicate that local sources are often best adapted to local environments, although the degree of local adaptation differs between species and between traits within species. Seed zones have been used for over 60 years in forest trees, whereas seed zones for grasses, forbs and shrubs used in restoration are largely lacking. We discuss several studies that have been completed or initiated to study adaptive genetic variation and the development of seed zones in species widely used in restoration in the western United States.

Link: http://www.treesearch.fs.fed.us/pubs/33640

826. Vogel KP, Schmer MR, Mitchell RB. 2005. **Plant adaptation regions: ecological and climatic classification of plant materials.** Rangeland Ecology and Management 58:315-319.

Type: Journal

Geographic Area: USA

Keywords: ecoregion, plant hardiness zone, ecotypes, plant germplasm, cultivars, native plants

Abstract: The effective use of plant materials for an array of objectives including conservation, restoration, renovation, landscaping, and bioremediation requires knowledge of the adaptation of each species and, more specifically, knowledge of the adaptation of cultivars, strains, accessions, or ecotypes of a species to specific sites or regions. For agronomic and horticultural plants, specific adaptation information has been and continues to be developed by extensive testing. Rangeland, grassland, park, and restoration project managers often lack the resources to determine adaptation areas for plant materials because of the large number of species that are used and the extensive geographical areas that are serviced. Problems often arise in delineating adaptation areas for plant materials of both native and introduced species. Since ecoregion and plant hardiness zone classification systems integrate many climatic and geographic variables that determine plant adaptation, these 2 systems can be combined to develop Plant Adaptation Regions (PARs). A PAR map of the contiguous United States was developed by merging a widely used ecoregion map with the USDA Plant Hardiness Zone map, and is available in GIS format. Based on their geographic origins and/or test results, plant materials and their general areas of adaptation can be classified using PARs.

Link: http://www.researchgate.net/publication/43257641_Plant_Adaptation_Regions_Ecological_and_Climatic_Classification_of_Plant_Materials/file/79e41512b945adf415.pdf

827. Wright JW. 1978. **A simplified design for combined provenance and progeny testing.** Silvae Genetica 27:68-70.

Type: Journal

Geographic Area: Global

Keywords: provenance test, design

Summary: It is often desirable to combine the functions of provenance and progeny tests into one experiment testing the offspring of several different trees from each of many stands. A design is proposed whereby such an experiment may be simplified. The proposal is a variation of the compact-family design, with plots representing stands randomized within blocks, small sub-plots representing families within stands, and sub-plots systematically arranged within plots. The systematic arrangement is obtained by color coding when planting. That feature permits simplifications in the labeling, mapping and record keeping procedures without a sacrifice in quality of data. With the proposed design, a combined provenance-progeny test can be conducted almost as simply as an ordinary provenance test.

Transfer Guidelines and Zones

Each reference contains the following:

#. Author(s), Date. Title. Source.	ID number and information
Type:	book, book section, conference paper, dissertation, government document, journal article, newsletter, presentation, report, thesis or web page
Geographic Area:	location of study
Keywords:	keywords written by the author(s) or provided by the compilers
Description:	abstract, summary, or portions of the introduction or conclusion written by the author(s) or provided by the compilers
Link:	internet address of reference

828. Alden JN. 1991. Provisional tree seed zones and transfer guidelines for Alaska. Portland (OR): USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-270. 35 p.

Type: Government Document

Geographic Area: Alaska, USA

Keywords: Alaska, seed zone, seed transfer and labeling guidelines, tree distribution, tree limit, forest area, genetic diversity, climate, physiography

Abstract: Four hundred and eighty-six provisional tree seed zones were delineated within 24 physiographic and climatic regions of Alaska and western Yukon Territory. Estimated forest and potential forest land within altitudinal limits of tree species in Alaska was 51,853,000 hectares (128,130,000 acres). Seed transfer guidelines and standard labeling of seed collections are recommended to reduce losses from maladaptation and maintain the genetic identity and productivity of future forests in Alaska.

Link: http://www.treesearch.fs.fed.us/pubs/25389

829. Atlas of Living Australia. (URL accessed 07 November 2015)

Type: Web Page

Geographic Area: Australia

Compilers' Keywords: climate change, restoration, seed source, native plants, decision support system

Synopsis: The Atlas of Living Australia (Atlas) contains information on all the known species in Australia aggregated from a wide range of data providers: museums, herbaria, community groups, government departments, individuals and universities. This site can be used to access information pages for each species containing photos, descriptions, maps and observations; access scientific and common names; explore the flora and fauna reported around your neighbourhood; learn about Australia's biodiversity collections at museums, herbaria and other institutions; learn about citizen science projects, map, analyze and visualize biodiversity and environmental data and trends; access tools to help track changes in biodiversity and the environment; download and use open source tools; download biodiversity data; access images, literature and genetic information through Australian nodes of international data repositories; and volunteer for digitization projects. As well, you can get facts and figures about the information contained in the Atlas from the website dashboard.

Link: http://www.ala.org.au/

830. Beaulieu J. 2009. Optisource: a tool for optimizing seed transfer. Quebec, Canada: Natural Resources Canada, Canadian Forest Service 55. 2 p.

Type: Government Document

Geographic Area: Eastern Canada

Compilers' Keywords: seed production, tool

Introduction: The ministère des Ressources naturelles et de la Faune du Québec (MRNF) oversees the production of tree seed and seedlings to meet the reforestation needs of public and private forests. Nearly 600 million viable seeds are required for forest regeneration every year. Tree seeds are produced in a variety of locations in Quebec. Optisource, the decision support tool used by the MRNF, was designed by Canadian Forest Service researchers using a geographic information system. This software combines data concerning ecological districts with data obtained from seed source transfer models. When improved or local seed sources are not available to reforest a given site and a different source needs to be used, Optisource can be used to determine which seed sources are best suited to the planting site.

Link: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/31544.pdf

831. Bower AD, St. Clair JB, Erickson VJ. 2008. Delineation of provisional seed zones for native plants. Portland (OR): USDA Forest Service.

Type: Map/Government Document

Geographic Area: USA

Compilers' Keywords: provisional seed zones, native plants, restoration, seed transfer guideline

Introduction: Deploying vigorous, well adapted, and ecologically appropriate plant materials is a core component of a successful restoration project. The key to identifying appropriate plant materials (e.g., seeds) lies in understanding the genetics of adaptation through common garden studies. However, restoration practitioners often deploy plant species on the landscape for which no seed transfer guidelines have been established through genetic research. So what are practitioners to do when no seed transfer guidelines have been established for a species of interest?

Link: http://www.fs.fed.us/wildflowers/nativeplantmaterials/rightmaterials.shtml

832. Bower AD, St. Clair JB, Erickson VJ. 2008. Provisional seed zones for native plants. USDA Forest Service. 5 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: provisional seed zones, native plants, restoration, seed transfer guidelines

Background: Deploying vigorous, well adapted, and ecologically appropriate plant materials is a core component of a successful restoration project. The key to identifying appropriate plant materials (e.g., seeds) lies in understanding the genetics of adaptation through common garden studies or reciprocal transplant experiments. However, restoration practitioners are frequently required to make seed collection and deployment decisions for species and landscapes which lack seed zones and transfer guidelines established through genetic research. So what are practitioners to do when no seed transfer guidelines exist for a species of interest? One approach for choosing germplasm in the absence of genetic information is to try and match the seed source and planting site conditions as closely as possible. Our provisional seed zone model provides a powerful decision support tool for characterizing site conditions and choosing plant material sources that originate from similar environments. The model integrates climate factors that are known to affect plant survival and growth (temperature and precipitation) and ecological factors. It builds on earlier efforts such as USDA plant hardiness zones (Cathy 1990, www.arborday.org) and "Plant Adaptation Regions" (PARs, Vogel et al. 2005). The provisional zones can be utilized to guide movement of plant material until species specific information becomes available via genetic research studies on adaptive traits.

Link: http://www.fs.fed.us/wwetac/threat_map/SeedZones_Intro.html

833. Bower AD, St. Clair JB, Erickson VJ. 2010. Generalized provisional seed zones for native plants. In: National Native Seed Conference: Native Plant Materials Development, Production and Use in Habitat Restoration. Corvallis (OR): Institute for Applied Ecology. 28 p.

Type: Presentation

Geographic Area: USA

Compilers' Keywords: seed transfer zones, provisional zones, ecoregion, climate change, genetic information, seed transfer guideline, plant materials, adaptation

Abstract: Deploying vigorous, well adapted, and ecologically appropriate plant materials is a core component of a successful restoration project. The key to identifying appropriate plant materials lies in understanding the genetics of adaptation through common garden studies. However, restoration practitioners often deploy plant species on the landscape for which no seed transfer guidelines have been established through genetic research. What are practitioners to do when no seed transfer guidelines have been established for a species of interest? We have developed generalized provisional seed zones that can be applied to any plant to help guide seed movement. These seed zones area based on the intersection of high resolution (800 m x 800 m cell size) observed climatic data. The intersection of winter minimum temperature and annual precipitation delineates zones for trees, shrubs, and woody plants, while the intersection of average maximum termperature and precipitation is used for zones for grasses and herbaceous plants. The resulting seed zones represent areas of relative climatic similarity, and movement of seed within these zones should help to minimize maladaptation. Superimposing Omernik's level III ecoregions over these seed zones helps to distinguish areas that are similar climatically yet different ecologically. These provisional seed zones should be considered a starting point as guidelines for seed transfer, and should be utilized in conjunction with appropriate species-specific information as well as local knowledge of microsite differences.

Link: http://www.fs.fed.us/rm/boise/research/shrub/projects/PowerPoint_Presentations/2011/bower.pdf

834. Bower AD, St. Clair JB, Erickson VJ. 2014. **Generalized provisional seed zones for native plants.** Ecological Applications 24:913-919.

Type: Journal Article

Geographic Area: USA

Keywords: adaptive traits, aridity, ecoregion, genetic variation, local adaptation, native plants, precipitation, restoration, seed transfer guideline, seed zone, temperature

Abstract: Deploying well-adapted and ecologically appropriate plant materials is a core component of successful restoration projects. We have developed generalized provisional seed zones that can be applied to any plant species in the United States to help guide seed movement. These seed zones are based on the intersection of high-resolution climatic data for winter minimum temperature and aridity (as measured by annual heat : moisture index), each classified into discrete bands. This results in the delineation of 64 provisional seed zones for the continental United States. These zones represent areas of relative climatic similarity, and movement of seed within these zones should help to minimize maladaptation. Superimposing Omernik's level III ecoregions over these seed zones distinguishes areas that are similar climatically yet different ecologically. A quantitative comparison of provisional seed zones with level III ecoregions and provisional seed zones within ecoregions for three species showed that provisional seed zone within ecoregion often explained the greatest proportion of variation in a suite of traits potentially related to plant fitness. These provisional seed zones can be considered a starting point for guidelines for seed transfer, and should be utilized in conjunction with appropriate species-specific information as well as local knowledge of microsite differences.

Link: http://www.treesearch.fs.fed.us/pubs/47587

835. Buck JM, Adams RS, Cone J, Conkle MT, Libby WJ, Eden CJ, Knight MJ. 1970. **California tree seed zones.** San Francisco (CA): USDA Forest Service. 7 p.

Type: Government Document

Geographic Area: California, USA

Compilers' Keywords: seed transfer guidelines, forest management, seed collection

Introduction: California forest tree seed zones were established originally by Fowells (1946), with revisions by Roy (1963) and Schubert (1966). The Forest Tree Seed Committee of the Northern California Section, Society of American Foresters, has revised the original zones and updated the recording systems described in the earlier reports. The Forest Tree Seed Committee acknowledges the assistance of foresters and tree seed dealers in California and the Pacific Northwest who reviewed the revised zone map and reporting system. The California Tree Seed Zone map is an integral part of the se3ed collection reporting system. Zones are delineated on the basis of collection criteria adopted in the USDA forest seed policy of 1939. The policy specifies that seed should 1) be collected within 100 miles north or south of the planting site and 2) differ in elevation by less than 1000 feet. Also, 3) careful consideration should be given to areas having a unusual climatic, topographic, or soil conditions that might greatly affect tree growth. On the basis of these three criteria, the State was divided into six physiographic and climatic regions, 32 subregions within regions, and 85 seed collection zones. One region is divided into four physiographic and climatic areas having 18 of the 85 zones. Seed collection zones are limited to about 50 miles in latitude. Where possible, boundaries have been chosen to follow natural features, such as crests of mountain ranges, ridgetops, and rivers, or physical features such as highways, canals, and railroads. The seed collection zones and three-digit method of designating the various zones are coordinated with the map and coding system developed by the Western Forest Tree Seed Council in 1966 and now used in Oregon and Washington.

Link: http://www.treesearch.fs.fed.us/pubs/41438

836. Burns KS, Schoettle AW, Jacobi WR, Mahalovich MF. 2007. **White pine blister rust in the Rocky Mountain Region and options for management.** Golden (CO): USDA Forest Service, Rocky Mountain Research Station. Biological Evaluation R2-07-04. 38 p.

Type: Government Document

Geographic Area: Western USA

Compilers' Keywords: forest management, *Pinus*

Introduction: White pine blister rust (WPBR) is an exotic, invasive fungal disease of white, stone, and foxtail pines (also referred to as white pines or five-needle pines) in the genus *Pinus* and subgenus *Strobus* (Price et al. 1998). The disease, which is native to Asia, was accidentally introduced separately into eastern and western North America at the beginning of the 20th century. In the west, blister rust was introduced on infected eastern white pine (*Pinus strobus*) nursery stock shipped to Vancouver, B.C. from France in 1910. Since then, white pine blister rust has spread throughout the distributions of sugar pine (*P. lambertiana*), western white pine (*P.*

monitcola) and eastern white pine and all but the southern extents of whitebark pine (*P. albicaulis*) and limber pine (*P. flexilis*) and the western extent of southwestern white pine (*P. strobiformis*). WPBR has not been found in most of the Rocky Mountain bristlecone pine (*P. aristata*) range and is yet to be found on Great Basin bristlecone pine (*P. longaeva*). It was once thought that the remote dry habitats occupied by these species would not support rust establishment, however WPBR can now be found at many of these sites. Cronartium ribicola, the fungus that causes WPBR, requires an alternate host, currants and gooseberries in the genus *Ribes* and possibly species of *Pedicularis* and *Castilleja* (McDonald et al. 2006, Zambino et al. 2007) to complete its life cycle. WPBR infects *Ribes* seasonally causing minimal damage such as leaf spots and premature defoliation; the infections are shed each year with leaf abscission. The disease is perennial on infected pines causing cankers that usually lead to mortality. WPBR has caused widespread decline and mortality over millions of acres resulting in dramatic changes in successional pathways and ecosystem functions and the disease continues to spread and intensify wherever five-needle pines occur.

Link: http://www.treesearch.fs.fed.us/pubs/29450

837. Campbell RK, Sugano AI. 1987. Seed zones and breeding zones for sugar pine in southwestern Oregon. Portland (OR): USDA Forest Service, Pacific Northwest Region. Research Paper PNW-RP-383. 18 p.

Type: Government Document

Geographic Area: Oregon, USA

Keywords: seed zones, geographic variation, genetic variation, adaptation (plant), sugar pine, *Pinus lambertiana*

Abstract: Provisional seed zones and breeding zones were developed for sugar pine (*Pinus lambertiana* Dougl.) in southwestern Oregon. Zones are based on a map of genetic variation patterns obtained by evaluating genotypes of trees from 142 locations in the region. Genotypes controlling growth vigor and growth rhythm were assessed in a common garden. Within southwestern Oregon, two zones are recommended for low elevations (< 740 m), two zones for middle elevations (> 740 and < 1172 m), and four zones for high elevations (> 1172 m).

Link: http://www.treesearch.fs.fed.us/pubs/9219

838. Campbell RK, Sugano AI. 1989. Seed zones and breeding zones for white pine in the Cascade range of Washington and Oregon. Portland (OR): USDA Forest Service, Pacific Northwest Region. Research Paper PNW-RP-407. 26 p.

Type: Government Document

Geographic Area: Pacific Northwest USA

Keywords: genetic variation, geographic variation, adaptation (plant), seed-transfer, *Pinus monticola*

Abstract: Provisional seed zones and breeding zones were developed for white pine (*Pinus monticola* Dougl. ex D. Don) in the Cascade Range of western Washington and Oregon. Recommendations were based on genetic variation patterns obtained by evaluating genotypes of trees from 115 locations. Genotypes controlling growth vigor and growth rhythm were assessed in common gardens. Five zones, delimited mainly by latitude, were recommended: two in Washington, two in Oregon, and one in both States adjoining the Columbia River.

Link: http://www.treesearch.fs.fed.us/pubs/9240

839. Campbell RK, Sugano AI. 1993. Genetic variation and seed zones of Douglas-fir in the Siskiyou National Forest. Portland (OR): USDA Forest Service, Pacific Northwest Region. Research Paper PNW-RP-461. 29 p.

Type: Government Document

Geographic Area: Oregon, USA

Abstract: *Pseudotsuga menziesii*, geographic genetic variation, adaptation, ecological genetics, genecology

Abstract: Provisional seed zones and breeding zones were developed for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in the Siskiyou National Forest in southwestern Oregon. Zones were based on maps of genetic variation patterns obtained by evaluating genotypes of trees from 260 locations in the region. Genotypes controlling growth vigor and growth rhythm were assessed in a common garden. Within the Forest, three breeding blocks were recommended, with different numbers of elevational bands in each block: from 0 to 610 meters, from 611 to 838 meters, and then a series of bands 152 meters wide at higher elevations.

Link: http://www.treesearch.fs.fed.us/pubs/20575

840. Cathey HM. 2012. USDA plant hardiness zone map. Washington (DC): USDA National Arboretum, Agricultural Research Service.

Type: Map/Government Document

Geographic Area: USA

Compilers' Keywords: plant hardiness zone, map, transfer guidelines, temperature delineation

Summary: The 2012 USDA Plant Hardiness Zone Map is the standard by which gardeners and growers can determine which plants are most likely to thrive at a location. The map is based on the average annual minimum winter temperature, divided into 10 °F zones.

Link: http://planthardiness.ars.usda.gov/PHZMWeb/Downloads.aspx

841. Cunningham RA. 1975. Provisional tree and shrub seed zones for the Great Plains. Fort Collins (CO): USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Publication 71. 21 p.

Type: Government Document

Geographic Area: Central USA

Compilers' Keywords: seed transfer zones, tree and shrub zones, transfer guidelines, seed collection, seed source

Preface: Seed collection zones are subdivisions of land areas established to identify seed sources and to control the movement of seed and planting stock. Seed zones are needed for many species because of the genetic variation associated with their geographic distribution. Zone boundaries may be delineated from experimental data that identify genetic variation, or by analysis of the environmental factors that most likely acted as selective forces in creating such genotypic variation.

Link: http://www.treesearch.fs.fed.us/pubs/24593

842. Forest Seedling Network. 2012. (URL accessed 07 November 2015)

Type: Web Page

Geographic Area: USA

Compilers' Keywords: seed zones, seed selection, forest management, seed transfer guidelines

Compilers' Synopsis: Interactive website connecting forest landowners with seedling providers and forest management services and contractors. The site includes seed zone maps for Washington, Oregon, California, Montana, and Idaho.

Link: http://www.forestseedlingnetwork.com/

843. British Columbia Ministry of Forests. 1994. Seed and vegetative material guidebook. British Columbia (CA): British Columbia Ministry of Forests.

Type: Government Document

Geographic Area: Western Canada

Compilers' Keywords: seed transfer guideline, forest management, forest practices code, guidelines

Introduction: This guidebook has been prepared to help forestry practitioners meet the requirements of the Forest Practices Code with respect to planning, collecting, registering and using seed and vegetative material. The guide is relevant to all forestry operations that use planting or direct seeding as a method of reforestation. The procedures, processes and options described are arranged in the same order as the business of reforestation—from planning to planting.

Link: http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/veg/seedtoc.htm

844. Hamann A. 2001. Utilization and management of red alder genetic resources in British Columbia. The Forestry Chronicle 77:705-712.

Type: Journal

Geographic Area: Western Canada

Keywords: red alder, *Alnus rubra*, tree improvement, quantitative genetics, genecology, resource management

Abstract: During the last two decades, the value of red alder wood products has substantially increased and several initiatives have been launched in the United States to use red alder for reforestation. Nonetheless, red alder is a largely neglected resource in British Columbia. This review paper examines the reasons behind the under-utilization of red alder in British Columbia and investigates whether changes in red alder management practices could improve the value of the resource. Red alder's potential for plantation forestry and genetic tree improvement are discussed, and possible breeding objectives were evaluated with consideration for the species biology, growth, product value and market demand. Seed transfer rules and the possibility of gains from selection are summarized in the light of new research results in genecology and quantitative genetics for red alder populations in British Columbia.

Link: http://www.ualberta.ca/~ahamann/publications/pdfs/Hamann_2001.pdf

845. Howe GT, St. Clair JB, Beloin R. 2009. Seedlot selection tool. Corvallis (OR): Oregon State University and USDA Forest Service. (URL accessed 29 November 2015)

Type: Web Page

Geographic Area: North America

Compilers' Keywords: seed transfer zone, model, GIS, reforestation, climate change, tools, seed transfer guideline, delineation method

Introduction: The Seedlot Selection Tool is a joint effort of the Department of Forest Ecosystems and Society at the Oregon State University College of Forestry and the U.S. Forest Service Pacific Northwest Research Station. Funding comes from the U.S. Forest Service. The seedlot selection tool (SST) is a GIS mapping program designed to help forest managers match seedlots with planting sites based on climatic information for the Northwest, Midwest, Central, and East in North America. The tool can be used to map current climates, or future climates based on selected climate change scenarios. Although it is tailored for matching seedlots and planting sites, it can be used by anyone interested in mapping present or future climates defined by temperature and precipitation.

Link: http://sst.forestry.oregonstate.edu/index.html

846. Howe GT, Jayawickrama K, Cherry M, Johnson GR, Wheeler NC. 2006. Breeding Douglas-fir. Plant Breeding Reviews 27:245-353.

Type: Journal

Geographic Area: Western North America

Compilers' Keywords: plant breeding, forest management, silviculture, genetics, *Pseudotsuga menziesii*, economic value

Objective: In this paper, we describe the (1) key elements that distinguish tree breeding from other types of crop breeding, (2) differences between Douglas-fir breeding and other types of tree breeding, (3) environmental, biological, and sociological factors that make Douglas-fir breeding unique, (4) current state of Douglas-fir breeding, and (5) future of Douglas-fir breeding and research needs. Although Douglas-fir improvement is practiced throughout the world, we will focus on Douglas-fir breeding in western North America (i.e., California, Oregon, Washington, British Columbia, Idaho, and Montana), and the Pacific Northwest in particular - where most of the Douglas-fir breeding is occurring.

Link: http://www.fsl.orst.edu/pnwtirc/Electronic%20version%20of%20some%20pubs/(2006)%20Howe%20et%20al%20%20Breeding%20Douglas-fir.pdf

847. Institute for Applied Ecology. **Native seed network.** Corvallis (OR): Institute for Applied Ecology. (URL accessed 25 November 2015)

Type: Web Page

Geographic Area: USA

Compilers' Keywords: seed selection, ecoregions, plant selection, native plant materials, seed directory

Mission: The Native Seed Network promotes the use of native plants in ways that support the ecological integrity of both natural and manipulated ecosystems. The Native Seed Network advocates using native plant materials from appropriate genetic sources to conserve biological diversity, and to maintain the adaptive capability of ecosystems, communities and plant populations. The Native Seed Network works with public agencies, educators and private groups to increase the availability of affordable native plant materials. The website is an interactive database of native plant and seed information and guidelines for restoration, native plant propagation, and native seed procurement by ecoregion for the United States.

Link: http://www.nativeseednetwork.org/

848. Lilleso JPB, Dhakal LP, Shrestha TB, Nayaju RP, Shrestha R, Dahl Kjaer E. 2001. **Tree planting zones in Nepal—an ecological approach based on vegetation types.** Kathmandu, Nepal: Danida Forest Seed Centre, Tree Improvement and Silviculture Component. DFSC Case Study No. 1, TISC Tech Paper 103. 45 p.

Type: Government Document

Geographic Area: Nepal, Southern Asia

Compilers' Keywords: seed transfer, tree planting zones, silviculture, seed source, adaptation, guidelines

Summary: A substantial number of species (especially fodder trees) are planted by farmers and it is likely that the demand for many species will increase in the future. Given the extraordinarily large ecological variation in Nepal, special attention should be given to ecological considerations. Different species and seed sources will be best at different planting sites, and the challenge is therefore to match species and seed sources to planting site. Well-adapted seed sources may ensure a reliable yield for farmers, while maladapted seed sources may result in loss—or even total failure. In the present 'Tree Planting Zones' planting sites with similar environmental conditions are grouped together into zones for which specific seed sources can be developed and thereby increase farmers' planting success. The 'Tree Planting Zones' can be recognised in the field by farmers and will be utilized where there is the greatest potential for seed demand. The distribution of vegetation types is the best indicator of growing conditions for trees and bushes. 'Tree Planting Zones' have been developed in the warmer ecological zones where most planting by farmers take place and consequently where most seed transfers are required. In the colder ecological zones transfer of seeds for the relatively limited planting should be avoided and seed should be collected at the planting site.

Link: http://curis.ku.dk/ws/files/35157079/Case_Study_1_Nepal.pdf

849. Mahalovich MF, Hoff RJ. 2000. **Whitebark pine operational cone collection instructions and seed transfer guidelines.** Nutcraker Notes 11:10-13.

Type: Newsletter

Geographic Area: Western USA

Compilers' Keywords: *Pinus albicaulis*, restoration, silviculture, seed transfer zones

Preface: This issue of Nutcracker Notes contains articles on the importance of genetics in whitebark pine research and management. On pages 10 through 13, Mahalovich and Hoff outline seed transfer guidelines and seed collection instructions for whitebark pine that are blister-rust resistant. They include criteria for collecting cones such as tree condition, form, age, cone condition, and caches. Other information provided are how to distinguish whitebark from limber pine, how to protect cones from predation and specific instructions on what parent trees to collect from. From isozyme studies, this species has little genetic diversity, thus is considered a generalist species. Seeds can be transferred within mountain ranges listed, but not across ranges. The guidelines are provisional, because of zone boundaries, limited genetic information, and issues associated with seed viability in storage, the author suggests a wider transfer from seed source, with emphasis on using seed collected from blister rust resistant trees: 1° latitude ± 50 miles, 1° longitude ± 50 miles and no restriction on elevation.

Link: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCoQFjAA&url=http%3A%2F%2Ffedgycc.org%2FNutcrackerNotesNo.11.doc.doc&ei=0IdyUrv1EOuajAKJkoHAAw&usg=AFQjCNGL8qA5uWuNH8jROjwPqRpMd0xeUQ&sig2=Ju89mEFn-lKwni43NYYgzw&bvm=bv.55819444,d.cGE

850. Mahalovich MF, McArthur ED. 2004. Sagebrush (*Artemisia* spp.): seed and plant transfer guidelines. Native Plants Journal 5:141-148.

Type: Journal

Geographic Area: North America

Keywords: seed zones, adaptive traits, elevation gradients, ecotypes, ploidy, hybridization

Abstract: Seed and plant transfer guidelines are offered for 11 species of sagebrush (*Artemisia arbuscula, A. bigelovii, A. cana, A. rothrockii, A. longiloba, A. argillosa, A. rigida, A. nova, A. tripartita, A. pygmaea,* and *A. tridentata*). These species constitute the true sagebrushes of the subgenus Tridentatae of *Artemisia*. The geographic distribution of each species serves as the geographic boundary for the 11 seed zones, with the additional restriction that seeds should not be moved farther than 483 km (300 mi) to their target planting site, and if less than 483 km, not outside of their native distribution. For *A. tridentata*, seed transfer should ensure that subspecies are planted with respect to moisture and elevational gradients. For all other species, no additional transfer guidelines are proposed based on changes in elevation, but when local data suggest moisture gradients and ranges of elevation in excess of 458 m (1,500 ft), conservative guidelines could further restrict seed transfer up 153 m (500 ft) in elevation, or down 305 m (1,000 ft) in elevation, from the origin collection area. Correctly applied, seed and plant transfer guidelines minimize the risk of planting maladapted stock, increasing the survival and reproductive success to achieve restoration, rehabilitation, reclamation, and wildlife habitat improvement objectives.

Link: http://npj.uwpress.org/content/5/2/141.full.pdf+html

851. McCall MA, Silcox FA, Myer DS, Wallace HA. 1939. Forest policy of U.S. Department of Agriculture. Journal of Forestry 37:820-821.

Type: Journal

Geographic Area: USA

Compilers' Keywords: seed transfer guidelines, restoration, seed zones, local adaptation, local seed, forest management, federal policy

Compilers' Abstract: This is a research note written by the USDA Chairman of the Seed Policy Committee, Chief of the Forest Service, Acting Chief of the Soil Conservation Service, and Secretary. It reports USDA Forest Service policy guidelines on tree and shrub planting with respect to location and objective. The seven guidelines are 1) use seed and stock of known origin, 2) provide proof of seed and stock origin, 3) details of the seed and stock including lot number, year, species, origin, and proof of origin, 4) use local seed from natural areas unless another source is superior, 5) use seed from a similar climate if local is not available, 6) determine usefulness of indigenous and exotic species, and delimit climate zones for safe seed/stock transfer, and 7) urge that public and private sectors follow this policy in all forest, shelter-belt, and erosion-control projects. The policy defines local as seed/stock from an area with similar climate conditions, or as that collected within 100 miles and 1000 feet in elevation of the planting site.

852. McKenney DW. 2002. Seedwhere: a computer tool for tree planting and ecological restoration. Sault Ste. Marie, Ontario, Canada: Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre. Bulletin No. 21. 2 p.

Type: Government Document

Geographic Area: Canada

Compilers' Keywords: seed transfer guidelines, genetic adaptation, GIS, planting zones, forest management, nursery stock, forest regeneration, climate change, restoration, tool

Introduction: It is generally recognized that plants are genetically adapted to the prevailing climate. Planting stock is often moved across environmental gradients with little knowledge of the ecological risks. For long-lived species (e.g., forest trees) this introduces risks of increased mortality, lowered potential growth rates, and increased susceptibility to insects and diseases. Thus mistakes in seed transfer in forest regeneration programs can be costly. Seedwhere is a Geographic Information System (GIS) tool designed to assist in making nursery stock and seed transfer decisions for forest regeneration activities over environmental gradients. Given a suitable database, Seedwhere maps out the similarity of a chosen location to the rest of the region of interest. The location could be a potential seed collection or planting area.

Link: http://cfs.nrcan.gc.ca/pubwarehouse/pdfs/20952.pdf

853. McKenney DW, Mackey BG, Joyce D. 1999. Seedwhere: a computer tool to support seed transfer and ecological restoration decisions. Environmental Modelling 14:589-595.

Type: Journal

Geographic Area: Global

Keywords: climate grids, GIS, forest management, Arcview, Gower metric

Abstract: It is generally recognized that plants are genetically adapted to prevailing climate. However, there are very few genecological studies that quantify these relationships. Planting stock is often moved across environmental gradients with little knowledge of the ecological risks. For long-lived species (e.g., forest trees) this introduces risks of increased mortality, lowered potential growth rates, and increased susceptibility to insects and diseases. Seedwhere is a computer-based tool to support decisions on moving plant material across environmental gradients. The Gower similarity metric has been invoked as an Avenue extension in the ARCVIEW Geographic Information System. The program can be used to map the similarity of potential seed collection sites across large regions. Considerable effort has gone into developing the required GIS database for the Great Lakes region of North America. Such data are becoming increasingly available in many parts of the world. Some example applications of Seedwhere are provided for the Great Lakes region. While no panacea for this complex and large problem, the Seedwhere tool provides a quantitative approach to visualizing the issue that should help resource managers.

854. McKenney DW, Mackey BG, Joyce D. 2006. ClimWhere (formerly SeedWhere). (URL accessed 29 November 2015)

Type: Web Page

Geographic Area: North America

Compilers' Keywords: climate change, seed transfer, forest management, seedlot selection, decision support system

About: Seedwhere is intended as a tool to support decisions on moving plant material across environmental gradients. Seedwhere is a pun on the word Software with the idea of "Where can I move Seed"? The model maps climate similarity across large geographic regions using the Gower similarity metric. This web-based beta-version allows users to access several North American wide climate models and investigate the similarity of current climate to projected future climates. The climate models used here are 300 arc seconds or approximately 10 km in resolution. While no panacea, the Seedwhere tool provides an intuitive approach to visualizing how far forest managers might risk moving seed or other plant material away from its maternal climate in the absence of detailed population genetics work. The types of questions this might be relevant for include: how similar are the environmental conditions at a seed collection site to other areas; how similar are the environmental conditions at a regeneration area to potential seed collection sites; how similar are the environmental conditions at a regeneration area to seed already in storage; how similar are the environmental conditions at areas where seed lots have been collected; where are the environmental conditions similar to a particular seedlot source; how similar are the environmental conditions between two particular sites; and how similar are the environmental conditions between two particular seedlots that have already been collected? Output is a color or black and white map that shows the similarity of climate on a 0 to 1 scale. Seedwhere normalizes the values for each selected climate variable so that the 0 to 1 similarity metric can be calculated for the set of selected variables. When using the climate change models, the program compares the current climate at the selected location to the projected climate in the selected region or Area of Interest—OR THE RECIPORICAL. The output also includes a table that summarizes the range of values of the selected climate variables over the geographic area selected. The table also shows what each .05 change in the Gower metric value means in terms of each climate variable. This is intended to help interpret the significance of the map legend in terms of climate.

Link: http://gmaps.nrcan.gc.ca/climwhere/

855. Omernik JM. 1987. Ecoregions of the conterminous United States.

Type: Map/Government Document

Geographic Area: USA

Keywords: ecoregion, ecosystems, cartographic analysis, resource management, regional geography

Abstract: A map of ecoregions of the conterminous United States has been compiled to assist managers of aquatic and terrestrial resources in understanding the regional patterns of the realistically attainable quality of these resources. The ecoregions are based on perceived patterns of a combination of causal and integrative factors including land use, land surface form, potential natural vegetation, and soils. A synoptic approach similar to that used to define these ecoregions is also useful for applications of the map. Initial efforts to use the framework are at the state level of resource management; they center on aquatic ecosystems—mainly attainable ranges in chemical quality, biotic assemblages, and lake trophic state. Ecoregion maps (EPA Level III) are used by the Native Seed Network (NSN, http://www.nativeseednetwork.org/article_view?id=27) to guide transfers. They recommend that in the absence of genetic information, this level of mapping offer a practical guide for seed transfer zone boundaries.

Link: http://www.epa.gov/wed/pages/ecoregions.htm

856. Oregon Department of Forestry. 2011. Sources of native forest nursery seedlings. Portland (OR): Oregon Department of Forestry. 26 p.

Type: Government Document

Geographic Area: Oregon, USA

Compilers' Keywords: seed zone maps, guidelines, manual, seed sources, catalog, forest management, nurseries

Introduction: Sources of Native Forest Nursery Seedlings is a service provided by the Oregon Department of Forestry to help meet the changing needs of family and non-industrial private forestland (NIPF) owners actively engaged in: Afforestation, Reforestation, Forest Management, Tax Incentives, Timber Production, Riparian Management, Forest Pest Management, Watershed Enhancement, Fish and Wildlife Habitat Improvement, Marketing of Forestry Carbon, Offsets, etc. Published annually, the catalog helps landowners locate suitable tree stock to meet their unique and individual resource objectives. This is just one of several valuable services that ODF provides to family and private non-industrial forestland owners. Other services include providing information and advice, technical assistance, and financial incentive guidance on: Forest Health Issues, Silvicultural Practices, and Land

Stewardship Activities. Nurseries included in the catalog may have additional stock available. Please contact individual nurseries for stock information, current seedling inventories and ordering procedures.

Link: http://www.oregon.gov/odf/privateforests/docs/SeedlingCatalogWeb.pdf

857. Parker WH, Lesser MR. 2004. Development of focal point seed zones for white spruce in Northern Ontario. Thunder Bay, Ontario, Canada: Lakehead University. Final Report Part 2 - Living Legacy Trust Project 04-012. 91 p.

Type: Report

Geographic Area: Ontario, Canada

Keywords: white spruce, *Picea glauca*, focal point seed zone, provenance test, adaptive variation

Abstract: White spruce (*Picea glauca* [Moench] Voss.) is distributed widely throughout the boreal forest of Ontario and the rest of Canada. Ecologically based management of this species requires an understanding of its patterns of adaptive variation. The development of focal point seed zones will assist in properly matching seed sources and planting sites. To develop focal point seed zones of white spruce, one hundred and thirty two provenances from Ontario and western Quebec were established at a greenhouse and five field trials throughout Ontario. Growth and phenological variables were measured over two growing seasons and selected variables regressed individually against geographic and climate variables to assess whether they exhibited adaptive variation. Principal components (PC) analysis was used to summarize the main components of variation. The first PC mainly represented growth potential. PCs 2 and 3 mainly represented phenological traits. PC factor scores were regressed against climate variables and the resulting equations were used to model the PC axes. Models were converted to spatial data and reproduced as contoured grids using GIS. For any given point in Ontario PC axis grids can be standardized and intersected, creating zones of adaptive similarity to that point. Focal point seed zones created for 20 example points selected from across the province show strong latitudinal trends and more regional longitudinal trends. Seed transfer for white spruce across traditional site region boundaries may be possible in most of north-central and north-eastern portions of Ontario.

Link: http://flash.lakeheadu.ca/~fpszsw/LLT%20REPORT3.pdf

858. Post LS, Schlarbaum SE, van Manen F, Cecich RA, Saxton AM, Schneider JF. 2003. Development of hardwood seed zones for Tennessee using a geographic information system. Southern Journal of Applied Forestry 27:172-175.

Type: Journal

Geographic Area: Tennessee, USA

Keywords: hardwood, seed zone, adaptation, geographic information system, Tennessee

Abstract: For species that have no or limited information on genetic variation and adaptability to nonnative sites, there is a need for seed collection guidelines based on biological, climatological, and/or geographical criteria. Twenty-eight hardwood species are currently grown for reforestation purposes at the East Tennessee State Nursery. The majority of these species have had no genetic testing to define guidelines for seed collection location and can be distributed to sites that have a very different environment than that of seed origin(s). Poor survival and/or growth may result if seedlings are not adapted to environmental conditions at the planting location. To address this problem, 30 yr of Tennessee county precipitation and minimum temperature data were analyzed and grouped using a centroid hierarchical cluster analysis. The weather data and elevational data were entered into a Geographic Information System (GIS) and separately layered over Bailey's Ecoregions to develop a seed zone system for Tennessee. The seed zones can be used as a practical guideline for collecting seeds to ensure that the resulting seedlings will be adapted to planting environments.

859. Randall WK, Berrang PC. 2002. Washington tree seed transfer zones. Olympia (WA): Washington State Department of Natural Resources. 84 p.

Type: Government Document

Geographic Area: Washington, USA

Compilers' Keywords: reforestation, maladaptation, seed zone map, forest management, seed transfer guidelines

Introduction: Choosing the appropriate seed to reforest a particular site is important for many reasons: producing a long-lived, healthy stand; limiting damage from climate or pests; promoting rapid production of commodities; and maintaining locally adapted gene pools. This document will provide information to land managers responsible for selecting forest tree seed for reforestation. The risk of moving seed from a source environment to a planting environment will be kept within acceptable levels by establishing seed zones and elevation bands within which seed can be transferred. These recommendations will supersede those of the Tree Seed Zone Map that was published for the State of Washington in 1966 (see next page). They apply to seed collected from natural populations of native forest trees unless otherwise noted. New tree seed zones or seed transfer guidelines are needed because the ones in current use are out of date. The old Tree Seed Zone Map was based only on climatic, vegetative, and topographic information. Now genetics information, which has accumulated over the past 30 years, needs to be incorporated into the recommendations. For example, the old tree seed zones were the same for all species, but it is now known that species differ tremendously in how far they can be moved safely. This guide summarizes published seed zone literature, seed transfer rules, genetics, and geographic variation for tree species used in reforestation, wildlife, and riparian planting. Specific guidelines are given for each species. These guidelines are meant to improve silvicultural prescriptions, not to replace them. Not all sites within a seed zone will be appropriate for a particular tree species. You must rely on your knowledge of species characteristics to determine which species is most appropriate for the site you plan to reforest. To determine the best source of seed for the area you want to plant, locate the page reference for that species in the table of contents and read the specific recommendation. Then refer to the species map for seed zones and elevations bands. Elevation bands are not mapped, but are considered in the seed transfer guidelines. Also, seed zones are only delineated for areas where the species naturally occurs. Each of these guidelines is for a particular forest tree species and should not be used for other plants. However, the 1966 Tree Seed Zones encompass areas where environmental variation is fairly uniform and could serve as guidelines for other species where no seed zones have been established.

Link: http://www.dnr.wa.gov/ResearchScience/Topics/ForestResearch/Pages/lm_tree_seed_zones.aspx

860. Rehfeldt GE. 1980. Seed transfer guidelines for Douglas-fir in North Idaho. Ogden (UT): USDA Forest Service, Intermountain Forest and Range Experiment Station. RN-INT-300. 4 p.

Type: Government Document

Geographic Area: Idaho, USA

Compilers' Keywords: seed transfer guidelines, *Pseudotsuga menziesii*, maladaptation, genetic adaptation, reforestation, delineations

Compilers' Summary: Seed transfer guidelines for Douglas-fir reforestation in Northern Idaho. Includes delineations based on elevation and latitude using current research (1980). Author mentions that there will be some maladaptation in planting even when adhering to the guidelines, but as more information becomes available through research they can be fine-tuned. Because patterns of variation in Douglas-fir are so high, these guidelines should be followed in plantings.

Link: http://books.google.com/books?hl=en&lr=&id=7yis1cDGdbUC&oi=fnd&dq=Seed+transfer+guidelines+for+Douglas-fir+in+North+Idaho&ots=Hmq45XH7XG&sig=7PdSwGR8grJyKXMHgQy6pD67yFI

861. Rehfeldt GE. 1983. Seed transfer guidelines for Douglas-fir in Western Montana. Ogden (UT): USDA Forest Service, Intermountain Forest and Range Experiment Station. RN-INT-329. 5 p.

Type: Government Document

Geographic Area: Montana, USA

Keywords: seed zones, seed transfer, adaptive variation

Abstract: Summary of transfer guidelines for Douglas-fir in western Montana. Guidelines based on adaptive differentiation found in juvenile trees related to physiographic characteristics and elevation. The author details both discrete and floating transfer guidelines for western and eastern provinces because elevational clines are steeper in the west (400') than in the east (800'). Small geographic and narrow elevation limits to transfer may be inappropriate, however expanding limits of transfer increases risk of maladaptation (reduced growth rate and increased cold damage). Regression techniques accounted for 81% of the variance in 3-year height of 54 Douglas-fir populations from western Montana. Seed transfer guidelines are developed from patterns of adaptive variation.

Link: http://books.google.com/books?id=p3RAcad3EZMC&printsec=frontcover&dq=Seed+transfer+guidelines+for+Douglas-fir+in+Western+Montana&hl=en&sa=X&ei=iycmUpvhF-TbigKS1ICgCQ&ved=0CEgQ6AEwAA#v=onepage&q=Seed%20transfer%20guidelines%20for%20Douglas-fir%20in%20Western%20Montana&f=false

862. Rehfeldt GE. 1987. Adaptive variation and seed transfer for ponderosa pine in Central Idaho. Ogden (UT): USDA Forest Service, Intermountain Research Station. RN-INT-373. 9 p.

Type: Government Document

Geographic Area: Idaho, USA

Keywords: *Pinus ponderosa*, seed zones, reforestation, forest genetics, ecological adaptation

Abstract: When planted and compared in the same environments, populations from elevationally or geographically mild sites demonstrated the most growth, mainly because of the long duration and rapid rate of shoot elongation. Populations from relatively cold sites were comparatively shorter largely because growth ceased early. Populations from the South Fork of the Salmon River, however, combined a high rate of shoot elongation with a short duration of growth and thereby were capable of high productivity while maintaining adaptability for severe sites. In artificial reforestation, seed transfer from most populations should be limited to ± 650 feet of the elevation at the source. Test should be established to determine if South Fork populations can be moved beyond the recommended limits in an attempt to increase productivity on harsh, cold sites.

Link: http://books.google.com/books?id=lbhLB80od2cC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

863. Riley LE, Dumroese RK, Landis TD. 2002. National proceedings: forest and conservation nursery associations—2002. Ogden (UT): USDA Forest Service, Rocky Mountain Research Station. RMRS-P-28. 187 p.

Type: Government Document

Geographic Area: USA

Keywords: bareroot nursery, container nursery, nursery practices, fertilization, pesticides, seeds, reforestation, restoration, plant propagation, native plants, tree physiology

Abstract: This proceedings is a compilation of 33 papers that were presented at the regional meetings of the forest and conservation nursery associations in the United States in 2002. The joint meeting of the Southern Forest Nursery Association and the Northeastern Forest and Conservation Nursery Association was held at the DoubleTree Hotel and Conference Center in Gainesville, Florida on July 15 to 18. The meeting was hosted by the Florida Division of Forestry, Andrews Nursery. In addition to technical sessions, tours included Andrews Nursery and Stansel Farm & Nursery. The combined meeting of the Western Forest and Conservation Nursery Association and the Forest Nursery Association of British Columbia occurred August 5 to 8 at the WestCoast Hotel in Olympia, Washington. The meeting was hosted by the Washington Department of Natural Resources, Webster Forest Nursery. Morning technical sessions were followed by field trips to Webster Nursery and the Weyerhaeuser Bonsai Garden. Subject matter for both sessions included seed transfer, collection, and processing; pest problems and pesticide use; nursery culturing; transplanting; harvesting, storage, and outplanting.

Link: http://www.fs.fed.us/rm/pubs/rmrs_p028.pdf

864. Saari C, Glisson W, Borzym N, Sotern B. 2011. **Chicago region restoration seed source policies.** Chicago (IL): Northwestern University. 30: 3. 59 p.

Type: Report

Geographic Area: Illinois, USA

Compilers' Keywords: seed source selection, native plants, climate change, provenance, decision-making, restoration

Abstract: This report seeks to summarize seed source policies and practices as understood and implemented by the conservation agencies and organizations of the Chicago region. We also consider current scientific research on seed provenance and discuss some approaches that take into account both the ongoing research as well as considerations suggested by global climate change. Our goal is to provide information and analysis that may be helpful to decision-making for seed provenance in ecosystem restoration.

Link: http://www.habitatproject.org/webdocs/misc/ChicagoRegionSeedSourcePolicies.pdf

865. Sanderson SC, McArthur ED. 2004. **Fourwing saltbush (*Atriplex canescens*) seed transfer zones.** Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-125. 15 p.

Type: Government Document

Geographic Area: Western USA

Compilers' Keywords: restoration, genetic x environment interaction, seed transfer guidelines

Abstract: *Atriplex canescens* (Pursh.) Nutt. is the most widespread species of perennial *Atriplex* in North America. Throughout its distributional range, *A. canescens* shows considerable between-population variation. Some of this variation may be due to phenotypic plasticity but most of it appears to be genetic. Mutations, polyploidy, introgressive hybridization, and segregation from interspecific hybrids all appear to have contributed to its extensive heritable variation. Polyploidy is unusually common with numerous chromosome races (2x, 4x, 6x, 8x, 10x, 12x, 14x, 20x). Fourwing saltbush is widely used for reclamation plantings. Proper identification is important to the utilization of fourwing saltbush in such plantings. While many of the races have been formally named as varieties, others have not. Even though differentiated by ploidy, chemical constituents, geographic distribution, and statistical distribution of morphological characters, races may lack sufficient diagnostic characters to allow facile identification, at least in the herbarium. Rather than combining named races under those that do have a taxonomic name, it seems better at present not to use the formal intraspecific categories in treating the fourwing saltbushes, but to consider them all as races. Seed transfer should be within the geographical distribution limits of each race. The most common race, by far, is Occidentalis. We recommend four overlapping seed transfer zones for race Occidentalis in the United States: (1) Northern Intermountain, (2) Western Great Plains, (3) Colorado Plateau/ Great Basin/ Columbia Basin, and (4) Southwestern. Source seed populations from near the planting sites generally do well; and populations generally perform better when moved south and/ or to lower elevations than when moved north and/or up in elevation.

Link: http://www.treesearch.fs.fed.us/pubs/6273

866. Schmidtling RC. 2001. **Southern pine seed sources.** Asheville (NC): USDA Forest Service, Southern Research Station. General Technical Report GTR-SRS-44. 35 p.

Type: Government Document

Geographic Area: Southeastern USA

Keywords: fusiform rust, geographic variation, loblolly pine, longleaf pine, provenance tests, sand pine, seed movement, seed sources, shortleaf pine, slash pine, Virginia pine

Abstract: The selection of an appropriate seed source is critical for successful southern pine plantations. Guidelines for selection of seed sources are presented for loblolly (*Pinus taeda* L.), slash (*P. elliottii* Engelm.), longleaf (*P. palustris* Mill.), Virginia (*P. virginiana* Mill.), shortleaf (*P. echinata* Mill.), and sand [*P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg.] pines. Seed movement guidelines in this handbook are based on climatic similarities between the seed source origin and the planting site. Because yearly average minimum temperature is the

most important climatic variable related to growth and survival, it has been used to define the rules of seed movement. This variable, which defines plant hardiness zones, has been used for many years by horticulturists to guide the transfer of plant materials. East-west movement to areas of similar climate is permissible, with the exception of loblolly pine.

Link: http://www.treesearch.fs.fed.us/pubs/2797

867. Schubert GH, Pitcher JA. 1973. **A provisional tree seed-zone and cone-crop rating system for Arizona and New Mexico.** Fort Collins (CO): USDA Forest Service, Rocky Mountain Research Station. RM-105. 15 p.

Type: Government Document

Geographic Area: Southwestern USA

Keywords: cone collecting, forest seed collecting, forest seed production

Abstract: The forested areas of Arizona and New Mexico were divided into 10 physiographic-climatic regions. These regions were then subdivided into five to nine seed collection zones about 50 miles wide. Provenance tests will be conducted to determine variation and need for adjustments. Seed used for reforestation should be limited to that collected within the local zone. A 10-unit classification system for rating cone crops is included.

Link: http://search.library.wisc.edu/catalog/ocm05165931

868. Sorensen FC. 1992. **Genetic variation and seed transfer guidelines for lodgepole pine in central Oregon.** Corvallis (OR): USDA Forest Service, Pacific Northwest Research Station. PNW-RP-453. 36 p.

Type: Government Document

Geographic Area: Oregon, USA

Keywords: *Pinus contorta* var. *murrayana*, lodgepole pine, geographic variation, seed transfer, breeding zones

Abstract: Cones were collected from 272 trees at 189 locations uniformly distributed over the east slopes of the Oregon Cascade Range and Warner Mountains. Variation in seed and seedling traits was related to (1) seed source latitude, distance from the Cascade crest, elevation, slope, and aspect in multiple regression analyses; and (2) seed zone and elevation band in classification analyses. Provisional seed transfer guidelines are presented. These include a regression equation for guiding seed transfer and estimating transfer risk, and a new outline of fixed seed zones.

Link: http://www.treesearch.fs.fed.us/pubs/20568

869. Sorensen FC. 1994. **Genetic variation and seed transfer guidelines for ponderosa pine in Central Oregon.** Corvallis (OR): USDA Forest Service, Pacific Northwest Research Station. PNW-RP-472. 30 p.

Type: Government Document

Geographic Area: Oregon, USA

Keywords: *Pinus ponderosa*, seedlings, provenance, geographic genetic variation, ecological genetics, genecology, genetic diversity

Abstract: Adaptive genetic variation in seed and seedling traits for ponderosa pine from the east slopes of the Cascade Range in Oregon was analyzed by using 307 families from 227 locations. Factor scores from three principal components based on seed and seedling traits were related by multiple regression to latitude, distance from the Cascade crest, elevation, slope, and aspect of the seed source and by classification analysis to seed zone and 300-meter elevation band within zone. A provisional transfer risk equation and tentative new seed zones were delineated to guide seed transfer in artificial regeneration.

Link: http://www.treesearch.fs.fed.us/pubs/4989

870. Sorensen FC, Weber JC. 1994. **Genetic variation and seed transfer guidelines for ponderosa pine in the Ochoco and Malheur National Forests of Central Oregon.** Portland (OR): USDA Forest Service, Pacific Northwest Region. Research Paper PNW-RP-468. 36 p.

Type: Government Document

Geographic Area: Oregon, USA

Keywords: *Pinus ponderosa*, seedlings, breeding zones, provenance, genetic variation, adaptive variation, genetic diversity

Abstract: Adaptive genetic variation in seed and seedling traits was evaluated for 280 families from 220 locations. Factor scores from three principal components were related by multiple regression to latitude, longitude, elevation, slope, and aspect of the seed source, and by classification analysis to seed zone and elevation band in seed zone. Location variance was significant but not large. Multiple regression equations explained less than 50 percent of location variance. Slope aspect variables were important.

Link: http://www.treesearch.fs.fed.us/pubs/20581

871. St. Clair JB, Johnson RC, Shaw NL. 2011. **Genecology and seed transfer guidelines for bluebunch wheatgrass (*Pseudoroegneria spicata*).** In: 2011 Great Basin Native Plant Selection and Increase Project Annual Meeting. 27 p.

Type: Presentation

Geographic Area: Western USA

Compilers' Keywords: genetic variation, cultivar, native bunchgrass, provenance test

Compilers' Summary: Presentation from the 2011 Great Basin Native Plant Selection and Increase Project Annual Meeting on the genecology and seed transfer guidelines for bluebunch wheatgrass to identify adapted and diverse populations for restoration. Using collections from 127 populations growing in Washington, Oregon, California, Nevada, Utah, Idaho and Montana and common gardens established in 3 test sites, the authors found large differences among test sites and between years in size and phenology, high levels of population variation in many traits, population means strongly correlated among test sites and years, size traits intercorrelated, phenology traits intercorrelated, other traits not correlated with each other, and strong correlations with climate. There is strong evidence for adaptively significant genetic variation in bluebunch wheatgrass, which supports the need to delineate seed zones along temperature and moisture (aridity) gradients.

Link: http://www.fs.fed.us/rm/boise//research/shrub/projects/PowerPoint_Presentations/2011/stclair.pdf

872. St. Clair JB, Howe GT, Wright JW, Beloin R. 2011. **Center for forest provenance data.** Corvallis (OR): Oregon State University and USDA Forest Service. (URL accessed 29 November 2015)

Type: Web Page

Geographic Area: North America

Compilers' Keywords: provenance test, forest, genetic research, online database, climate change

About: The Center for Forest Provenance Data is a place for researchers to archive provenance data and genecology studies of forest trees and make available for collaboration with other researchers. Studies consider genetic variation among forest trees from different source locations by growing them in replicated tests in a common environment such that observed differences are primarily due to genotype and not the environment. Consistent differences among sources that are associated with environmental gradients are indicative of adaptively significant variation. These studies are important for understanding genetic variation across the landscape and for managing genetic resources for reforestation, restoration, gene conservation, and responding to climate change. The Center for Forest Provenance Data has sections for submitting and retrieving data from the database. There is also a search tool for determining studies that are currently in the database. Currently, the database includes provenance information for ponderosa pine, Douglas-fir, whitebark pine, sugar pine, and white fir.

Link: http://cenforgen.forestry.oregonstate.edu/index.php

873. University of British Columbia. 2000. **Centre for forest conservation genetics.** Vancouver, British Columbia, Canada: University of British Columbia, Department of Forest Sciences. (URL accessed 29 November 2015)

Type: Web Page

Geographic Area: Western Canada

Compilers' Keywords: adaptation, forest management, tree populations, diversity, environmental change

About: It's easy to support a motherhood statement like "genetic diversity should be conserved." After more than a decade of attention to this topic, most of us realize that genetic variation provides the raw material for future selection in tree improvement programs for new traits (e.g., resistance to new insects or diseases, or changes in fiber quality to meet new industrial demands). We also realize that natural populations require genetic diversity to adapt to new environmental conditions, to allow evolution to proceed. But how do we go about conserving genetic diversity, and how can we rigorously assess whether we are meeting this goal? In 2000, the Forest Genetics Council of British Columbia (FGC) realized that, while gene conservation continued to be a high priority, this objective was not being met in a strategic and rigorous manner. As a result, the Centre for Forest Conservation Genetics (CFCG) was established in the Department of Forest Sciences at the University of British Columbia (UBC). Funding is provided from the Forest Investment Account (FIA). The CFCG has a mandate from the Forest Genetics Council to (1) study population genetic structure of forest trees using existing or new data; (2) assess the current degree of gene conservation both in situ in existing reserves and ex situ collections, and the need for additional protection; and (3) evaluate the current degree of maintenance of genetic diversity in breeding and deployment populations of improved varieties to meet current and future environmental challenges. This website is a portal for forest genetics and climate change research conducted in British Columbia, Canada.

Link: http://www.genetics.forestry.ubc.ca/cfcg/

874. University of British Columbia. 2010. **AdapTree.** Vancouver, British Columbia, Canada: University of British Columbia, Department of Forest Sciences, Centre for Forest Conservation Genetics. (URL accessed 29 November 2015)

Type: Web Page

Geographic Area: Western Canada

Compilers' Keywords: climate change, seed transfer, forest management, genomics

About: The primary objective of this project is to improve provincial seed transfer policy and operational forest management response to climate change by: comparing the adaptive portfolio of operational seedlots from tree breeding programs and seed orchards to the climatic distribution and landscape genomics of natural populations; developing strategies for operational seed transfer that will reduce the risk of loss of forest productivity and health due to maladaptation in planted forests; evaluating ecological, economic, social, and legal implications of these results for forest-dependent communities and ecosystems.

Link: http://adaptree.sites.olt.ubc.ca/

875. USDA Forest Service. 2008. **FSM 2000—National Forest Resource Management - Vegetation Ecology.** Washington (DC): USDA Forest Service. FSM 2000 Chapter 2070. 12 p.

Type: Government Document

Geographic Area: USA

Compilers' Keywords: native plant materials, restoration, vegetation, ecology, diversity

Compilers' Synopsis: USFS manual for vegetation ecology and include authority and law pertaining to management and use of native and non-native plant materials on NFS lands and other lands under Forest Service administration.

Link: http://www.fs.fed.us/cgi-bin/Directives/get_dirs/fsm?2000!

876. Western Wildland Environmental Threat Assessment Center. 2012. **Seed zone mapper.** Prineville (OR): USDA Forest Service. (URL accessed 29 November 2015)

Type: Web Page

Geographic Area: North America

Compilers' Keywords: seed zone delineation, tool, GIS, climate change, restoration, native plant transfer

About: Seed zone mapper is a mapping and planning tool for plant material development, gene conservation, and native plant restoration. A seed zone is an area within which plant materials can be transferred with little risk of being poorly adapted to their new location. This site allows end-users to view and acquire data on seed zones for use in plant material development, gene conservation and native plant restoration activities. Users can also evaluate seed zones in relation to other map services and wildland threats published by WWETAC such as climate change projections or wildfire risk. Client applications range in functionality from a simple geobrowser (requires only a web browser) to ArcGIS ArcMap, a full-feature GIS software platform that allows the user to integrate their own data and create map layouts. These seed zone mapping applications are part of a family of Wildland Threat Mapping (WTM) applications developed by WWETAC to portray the spatial interactions of wildland threats and high value resources that occur in wildlands. Visit WWETAC's WTM page for a collection of these mapping applications.

Link: http://www.fs.fed.us/wwetac/threat_map/SeedZones_Intro.html

877. Wright JW. 1957. **A bibliography on forest genetics and forest tree improvement 1955.** Upper Darby (PA): USDA Forest Service, Northeastern Forest Experiment Station. Station Paper NE-90. 60 p.

Type: Government Document

Geographic Area: North America

Compilers' Keywords: genetics, tree improvement

Introduction: The present boom in forest genetics makes it difficult for even the specialist to keep abreast of all the latest developments in this field. Therefore, in the fall of 1954 the committee on Forest Tree Improvement, Society of American Foresters, asked the author to prepare a bibliography of publications issued in 1954. As far as possible, all references that have a bearing on the genetics of forest trees are included. Also, some borderline references (for example, those on vegetative propagation) are included because they are primarily of interest to tree breeders. This bibliography was prepared from standard forestry, botanical, and abstracting journals; experiment station publications; and correspondence with tree breeders in this country and abroad. The bibliography is arranged alphabetically by authors. A subject-matter index can be found at the end.

Link: http://www.treesearch.fs.fed.us/pubs/13626

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Forest Service

Rocky Mountain Research Station