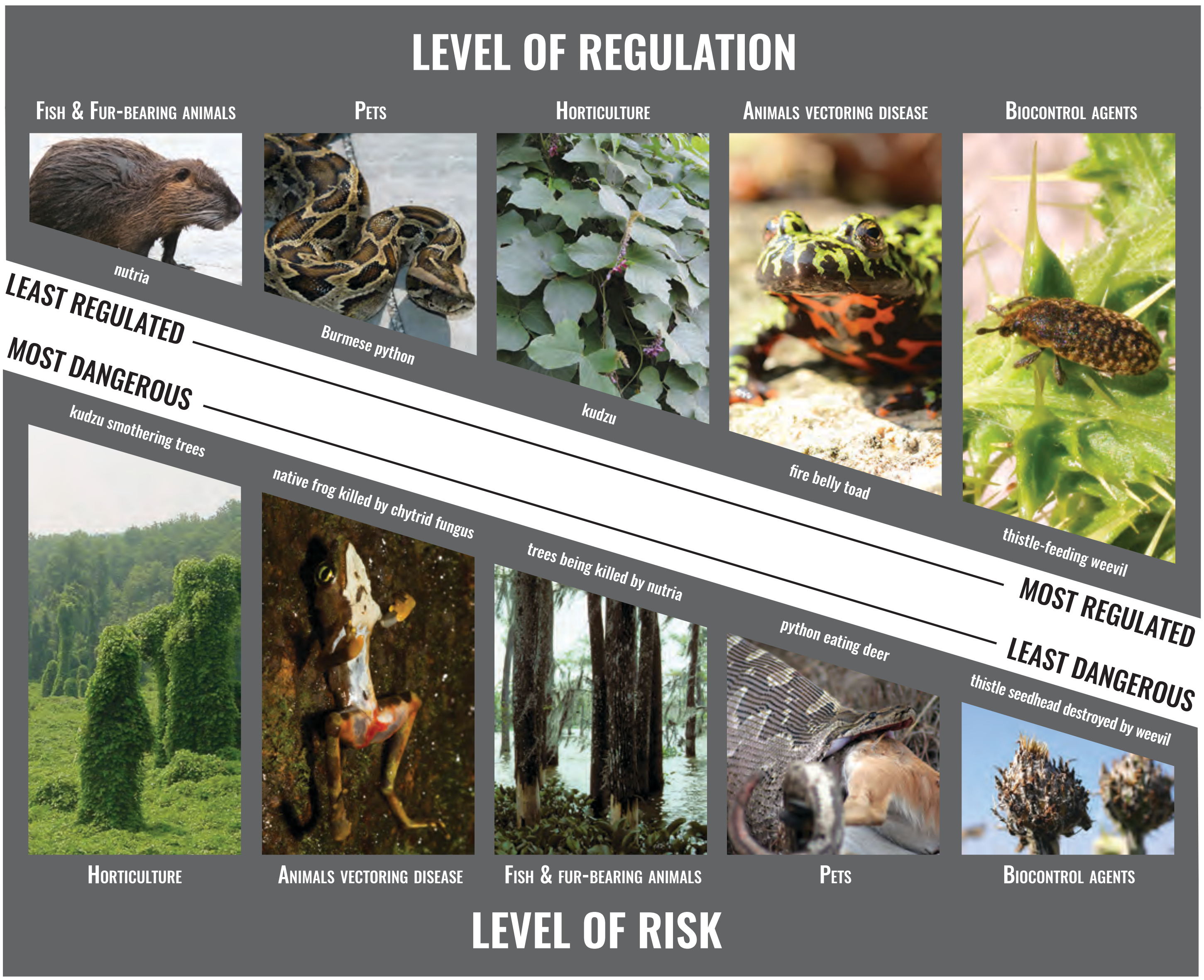
USDA
United States Department of Agriculture

A Misplaced Sense of Risk: Variation in U.S. Standards for Management of Risks Posed by New Species Introduced for Different Purposes

Roy G. Van Driesche, Robert M. Nowierski, and Richard C. Reardon



Forest Health Assessment and Applied Sciences Team

FHAAST-2019-02
July 2020

The Forest Health Technology Enterprise Team (FHTET) was created in 1995 by the Deputy Chief for State and Private Forestry, USDA, Forest Service, to develop and deliver technologies to protect and improve the health of American forests. FHTET became Forest Health Assessment and Applied Sciences Team (FHAAST) in 2016. This booklet was published by FHAAST as part of the technology transfer series.

https://www.fs.fed.us/foresthealth/applied-sciences/index.shtml

Cover Photos: (a) nutria (Philippe Amelant, Wikipedia.org); (b) Burmese python (Roy Wood, National Park Service, Bugwood.org); (c) kudzu (Marco Schmidt, iNaturalist.org); (d) fire belly toad (Kim, Hyun-tae, iNaturalist.org); (e) thistle-feeding weevil (Eric Coombs, Oregon Department of Agriculture, Bugwood.org); (f) kudzu blanketing trees (Kerry Britton, USDA Forest Service, Bugwood.org); (g) native frog killed by chytrid fungus (Brian Gratwicke, iNaturalist.org); (h) trees being killed by nutria (Gerald J. Lenhard, Louisiana State University, Bugwood.org); (i) python eating a deer (Alex Griffiths, Wikipedia.org); (j) thistle seedhead destroyed by weevil (Eric Coombs, Oregon Department of Agriculture, Bugwood.org)

Federal Recycling Program
Printed on Recycled Paper

A Misplaced Sense of Risk: Variation in U.S. Standards for Management of Risks Posed by New Species Introduced for Different Purposes

Roy G. Van Driesche
Department of Environmental Conservation, University of Massachusetts, Amherst, MA; vandries@umass.edu

Robert M. Nowierski
USDA /NIFA, Kansas City, MO; robert.nowierski@usda.gov

Richard C. Reardon
FHAAST (retired), USDA Forest Service, Morgantown, WV; richard.c.reardon@usda.gov

FHAAST-2019-02
July 2020

Acknowledgments

We thank Joseph Milan (BLM), Susan Jewell and Dolores Savignano (USFWS), Robert Pfannenstiel (USDA, APHIS), Dan Simberloff (University of Tennessee), Howard Frank (University of Florida), Norm Leppla (University of Florida), Mark Wright (University of Hawaii), and Lynn LeBeck (University of California) for their helpful reviews, which improved this publication. We extend our gratitude to all of the photographers who granted permission for the use of photos.

This publication was produced by Richard Reardon (FHAAST), and the layout was designed by Rachel Winston (MIA Consulting). During his career, Richard Reardon produced over 100 outreach publications in the FHTET/FHAAST Technical Series to improve communication and information transfer between scientists, land managers, and the public. The authors here join the biocontrol community in thanking Dr. Reardon for his long-term support. Roy Van Driesche thanks Rachel Winston for her editing diligence and detailed development and improvement of this publication.

For additional copies of this publication, contact:

Denise Binion FHAAST, USDA Forest Service, 180 Canfield Street, Morgantown, WV 26505; 304.285.1552; denise.binion@usda.gov

This publication is available online at:

https://www.fs.fed.us/foresthealth/technology/pdfs/FHAAST-2019-02_Misplaced_Sense_Risk.pdf

How to cite this publication:

Van Driesche, R.G., R.M. Nowierski, and R.C. Reardon. 2020. *A Misplaced Sense of Risk: Variation in U.S. Standards for Management of Risks Posed by New Species Introduced for Different Purposes.* FHAAST-2019-02. USDA Forest Service, Morgantown, West Virginia, USA. https://www.fs.fed.us/foresthealth/technology/pdfs/FHAAST-2019-02_Misplaced_Sense_Risk.pdf.

TABLE OF CONTENTS

INTRODUCTION

Biological control introductions, seen as a "green" technology that should be encouraged as a substitute for pesticides that were demonstrably polluting the environment when the authors were young graduate students (1970s), morphed in the public mind though the 1980s and 1990s into a potentially dangerous activity that should be more highly regulated than any other type of new species introductions. This change in public perception was facilitated by publications that overstated the risks and received disproportionate media attention. The purpose of this review is to consider that change in the public's view of our science. If biological control introductions are characterized as highly dangerous, the question that comes first to mind is "compared to what?" and the logical comparison would seem to be to introductions of new species made for other purposes. That is what we have attempted to discuss here—how the risks of biological control agent introductions compare to those of introductions made by other sectors, such as the horticultural trade, the pet industry, aquaculture, state fish and game department sport introductions, and others.

Over the previous 500+ years since European colonization of North America, new species of many sorts have arrived (Crosby, 2003). While some of the new species were accidental invasions, many others were deliberate introductions. Such intentional introductions were made for various reasons, but most were made because people were looking for economic advantage in some sector (agriculture, forestry, fisheries, etc.) or were motivated by nostalgia for familiar species left behind in the countries the colonists had come from. Views of the safety and benefits of such introductions were strongly influenced by people's assumptions rooted in the pleasure or value associated with the use of the species in question. So, beautiful plants and tasty fish, to name a few, were good things to have and thus were good to import if they were not already present. Early in the history of introductions, risks were either unrecognized or disregarded until resultant damage began to be recognized. Also determining the legal policies of countries in relation to the importation of new organisms was the presence of commercial groups with economic reasons to import species (such as the horticultural industry or the pet industry, both of which are heavily dependent on having new species to sell). Finally, another factor driving importations has been the activities of state agencies—departments of fish and game, agriculture, forestry, or those in charge of management of public grazing lands, etc.—either promoting or opposing species importations, according to the beliefs prevalent at the time.

In this review, we have organized the purposes behind intentional introductions into 17 groups: (#1) forestry, forage, and fodder plants, (#2) ornamental plants, (#3) crop plants, (#4) terrestrial mammals for ranching or viewing, (#5) fish used for aquaculture, (#6) commercially produced invertebrates, (#7) predatory mammals farmed for fur, (#8) herbivorous mammals farmed for fur, (#9) birds and mammals for hunting, (#10) non-native fish for sport or commercial fishing, (#11) animals sold as pets, (#12) animals introduced for medical uses, (#13) vertebrates for pest control, (#14) parasitoids for insect biocontrol, (#15) predatory insects and mites for insect biocontrol, (#16) insects or mites for weed biocontrol, and (#17) pathogens introduced for weed or insect biocontrol (Table 1). Note that these groups are defined with more attention as to why the species were introduced than to their taxonomy. Also, while most importations seem to fit into this scheme, very likely some examples exist that do not, and some species were introduced for multiple purposes.

Table 1. Types of potential risks posed by new species introductions and degree of regulation for species group x risk. For each group, each risk is classified as (1) regulated, (2) partly regulated, (3) not regulated, (4) degree of risk unknown, and (5) not applicable. Examples are worldwide for various time periods. Risk analysis is for the United States, at present.

Group/U.S. Example	Risk 1. Attack Non-Target Species	Risk 2. Vector Insects or Mites	Risk 3. Vector Pathogens	Risk 4. Damage Crops	Risk 5. Degrade Habitats	Risk 6. Change Food Webs
#1 FORESTRY, FORAGE, OR FODDER PLANTS Examples: forage grasses (buffel grass, *Cenchrus ciliaris* L.; Lehmann lovegrass, *Eragrostis lehmanniana* Nees) and kudzu, *Pueraria montana* var. *lobata* (Willd.) Maesen & S.M. Almeida ex Sanjappa & Predeep, introduced for forage and soil erosion control; *Melaleuca quinquenervia* (Cav.) S.T. Blake, introduced for timber and landscape potential, soil stabilization, and as a wind break	**NOT APPLICABLE** Most plants lack potential for direct trophic effects (other than parasitic species such as dodder and broomrape).	**REGULATED** Plant shipments inspected at port of entry.	**PARTIALLY REGULATED** Importation of plants that are known hosts of known pathogens are prohibited or screened before importation (NAPPRA, 2019a). Unrecognized pathogens capable of host range expansion to native plants are per force uncontrolled.	**PARTIALLY REGULATED** Introductions of a few known crop weeds are prohibited (NAPPRA, 2019b). Most plant species have not been evaluated for their weed potential.	**PARTIALLY REGULATED** A few plants known to be invasive in natural habitats are prohibited (NAPPRA-listed species). Most plant species have not been evaluated for invasiveness potential. In the U.S., grasses have more frequently become invasive than forestry trees.	**NOT REGULATED** Effects of invasive plants on food webs are known to be important, but this is not evaluated before introduction.
#2 ORNAMENTAL PLANTS Examples: waterhyacinth, *Pontederia* (formerly *Eichhornia*) *crassipes* (Mart.) Solms (Center et al., 2002); purple loosestrife, *Lythrum salicaria* L.	**NOT APPLICABLE** Most plants lack potential for direct trophic effects.	**REGULATED** Shipped plants must be found to be insect-free via partial inspection at port of entry (or be shipped as seed), and some plant x country importations that might vector pest insects are prohibited (NAPPRA, 2019A). However, multiple shipments periodically cause pest introductions, e.g., sweet potato whitefly, *Bemisia tabaci* (Gennadius), on poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) to Florida (Hamon and Salguero, 1987) or cycad scale, *Aulacaspis yasumatsui* Takagi, which destroyed native cycads on Guam (Marler and Lawrence, 2012).	**PARTIALLY REGULATED** Importation of plants that are hosts of known pathogens are prohibited or screened before importation (NAPPRA, 2019A). Unrecognized pathogens capable of host range expansion to native plants are uncontrolled (e.g., at the time of invasion, *Phytophthora ramorum* Werres et al., the causal agent of sudden oak death).	**PARTIALLY REGULATED** A few known crop weeds are prohibited (NAPPRA, 2019b). Most plant species have not been evaluated for weed potential.	**PARTIALLY REGULATED** A few plants known to be invasive in natural habitats are prohibited (NAPPRA, 2019b). Most plant species have not been evaluated for invasiveness potential. Many introduced ornamentals have become invasive and damaging to natural habitats. The USDA Noxious Weed List (USDA NRCS, 2020) is comprised of species already established in the U.S. and is useful only for slowing spread to new regions within the county.	**NOT REGULATED** Some introduced plants that become invasive may change food webs in ways that harm native species (e.g., Burghardt et al., 2010; Carvalheiro et al., 2010; Hladyz et al., 2011; Wang et al., 2013), but this risk is not regulated.

Table 1 (continued). Types of potential risks posed by new species introductions and degree of regulation for species group x risk. For each group, each risk is classified as (1) regulated, (2) partly regulated, (3) not regulated, (4) degree of risk unknown, and (5) not applicable. Examples are worldwide for various time periods. Risk analysis is for the United States, at present.

Group/U.S. Example	Risk 1. Attack Non-Target Species	Risk 2. Vector Insects or Mites	Risk 3. Vector Pathogens	Risk 4. Damage Crops	Risk 5. Degrade Habitats	Risk 6. Change Food Webs
#3 CROP PLANTS Example: water spinach, *Ipomoea aquatica* Forssk. (Austin, 2007)	**NOT APPLICABLE** Most plants lack potential for direct trophic effects.	**REGULATED** Shipped plants must be found to be insect-free via partial inspection at port of entry (or, as is common for many crops, be shipped as seed). Also, some plants that have potential to vector insects are listed under NAPPRA (2019a) and their importation is controlled as to the permitted plant parts and countries of origin so as to reduce risk of pest vectoring by crop introductions.	**PARTIALLY REGULATED** Importation of plants that are hosts of known pathogens are prohibited or screened before importation (NAPPRA, 2019a). Unrecognized pathogens capable of host range expansion to native plants are uncontrolled. Whether crop plants pose such risks needs consideration, especially as a wider range of crop plants is desired by new ethic communities.	**PARTIALLY REGULATED** Some herbs and minor crop plants have potential to become weeds themselves, e.g., water spinach. Some invasive grasses are prohibited from importation (NAPPRA, 2019b). Invasive plants already in the country are prohibited from interstate distribution if placed on the USDA Noxious Weed List (USDA NRCS, 2020).	**PARTIALLY REGULATED** Most crop plants probably lack the potential to damage natural habitats. However, water spinach can degrade aquatic habitats (Austin, 2007; USDA NRCS, 2015); the blackberry *Rubus niveus* Thunb. is an environmental pest in the Galapagos (Rentería et al., 2012); and strawberry guava (*Psidium cattleianum* Sabine) is a key environmental pest of forests in Hawaii (Patel, 2012). No crops not already present in the U.S. are prohibited from importation because of their potential to become environmental weeds.	**NOT REGULATED** Some introduced crop plants that become invasive may change food webs in ways that harm native species (e.g., Austin, 2007; Rentería et al., 2012; Patel, 2012; USDA NRCS, 2015).
#4 TERRESTRIAL MAMMALS FOR RANCHING OR VIEWING Example: goats in Hawaii	**NOT REGULATED** Escaped or released populations of farmed or otherwise imported mammals (e.g., deer, rabbits, goats, cattle, pigs, goats, foxes) have a high potential to destroy plant populations in natural areas (Fraser et al., 2003), or, for predatory species, to prey on native animals (e.g., for foxes: [Drummond and Leonard, 2010; Bytheway and Banks, 2019]), especially on islands.	**REGULATED** Introduction of exotic mammals (domesticated or wild species to be farmed) has the potential to spread ticks, e.g., Asian longhorned tick, *Haemaphysalis longicornis* Neumann, that can affect native mammals. This risk is controlled by animal inspection at the time of importation.	**REGULATED** Exotic mammals have significant potential to introduce microbial pathogens that can affect wildlife. Known risks are regulated via animal inspections at the time of importation.	**NOT REGULATED** Introduced herbivorous or omnivorous mammals have potential to become crops pests. For example, wild boar in the U.S. damage crops (USDA APHIS, 2019a). This risk is being mitigated by a special program, but the risk itself was not considered before introduction of wild boar.	**NOT REGULATED** Escaped or released populations of mammals (deer, rabbits, goats, cattle, pigs, goats) have extraordinarily high potential to destroy habitats, especially on islands.	**NOT REGULATED** Populations of domestic animals that destroy natural vegetation through grazing in natural habitats inevitably degrade and rearrange food webs.

Table 1 (continued). Types of potential risks posed by new species introductions and degree of regulation for species group x risk. For each group, each risk is classified as (1) regulated, (2) partly regulated, (3) not regulated, (4) degree of risk unknown, and (5) not applicable.

Group/U.S. example	Risk 1. Attack non-target species	Risk 2. Vector insects or mites	Risk 3. Vector pathogens	Risk 4. Damage crops	Risk 5. Degrade habitats	Risk 6. Change food webs
#5 FISH USED FOR AQUACULTURE Example: European common carp	**PARTIALLY REGULATED** Trophic effects of fish introduced for use in aquaculture are possible if fish escape from pens, are farmed in natural water bodies, or are transported from pens or farm ponds to wild areas. This risk overlaps with use of such fish for sport (i.e., unconfined fish populations in natural waters). In general, this risk is not assessed. However, a few species of fish on the list of "injurious wildlife" (USFWS, 2019a) are listed because they are harmful to fish or other aquatic wildlife (e.g., snakehead fish [Love and Newhard, 2012]).	**NOT APPLICABLE**	**REGULATED** The U.S. Fish and Wildlife Service can, under the Lacey Act, list species of fish as "injurious wildlife" whose introduction is prohibited or at least controlled. Of 408 species of fish listed in this way, 228 are species of Salmonidae that can vector pathogens to other fish. Fish pathogens can infect fish reared for aquaculture, and this process can accidentally move pathogens into wild populations if rearing water is connected to wild water or infected fish are released (e.g., whirling disease associated with trout in hatcheries reached wild trout in rivers in Colorado and Montana [Bartholomew and Reno, 2002]).	**NOT APPLICABLE**	**NOT REGULATED** Fish escaped from rearing ponds may establish in wild waters, and some species can affect habitat quality. For example, carp from Europe were introduced for pond aquaculture, but escaped and damaged habitats by increasing turbidity and algal levels (Tapia and Zambrano, 2003; Badiou and Goldsborough, 2015).	**NOT REGULATED** Fish introduced to rear as food in wild waters can affect food webs (e.g., Nile perch [*Lates niloticus* (L.)] in Lake Victoria [Goldschmidt, 1996; Welz, 2017]).
#6 COMMERCIALLY PRODUCED INVERTEBRATES Example: Introduction of new species of oysters	**NOT APPLICABLE** Direct trophic impacts of introduced mollusks or crustaceans seem unlikely unless escape leads to established populations.	**NOT APPLICABLE**	**PARTIALLY REGULATED** Historically, farmed oysters introduced at least two highly destructive pathogens into Chesapeake Bay, greatly damaging wild oysters. Also, abalone farming in California introduced a parasitic worm affecting mollusks into coastal water in California (Moore et al., 2007). For prevention of such introductions, pathogens associated with reared mollusks have been identified to reduce inadvertent spread due to aquaculture (Carnegie et al., 2016). While crayfish introductions to the U.S. have not yet brought in new pathogens, European introductions of U.S. crayfish did introduce new strains of the pathogen *Aphanomyces astaci*, which devastated local crayfish species (Jussila et al., 2016).	**PARTIALLY REGULATED** Land snails of the species consumed by people are generalist herbivores that eat many crop and horticultural plants. The brown garden snail, *Cornu aspersum* (Müller) (= *Helix aspersa*) has become established in the wild in California, where it is now a garden and horticulture pest (Stearns, 1900; UCANR, 2019).	**PARTIALLY REGULATED** Because oysters make their own habitat, the decline of oyster densities in Chesapeake Bay also degraded oyster reefs, a required structure for new oyster growth. Also, introduction of red swamp crawfish, *Procambarus clarkii* (Girard), in Spain contributed to the conversion of macrophyte-dominated water bodies to algal and plankton-dominated ones due to heavy grazing by exotic crawfish (Geiger et al., 2005).	**NOT REGULATED** Sharp drops (>90%) in oyster densities in Chesapeake Bay (at least substantially due to introduced pathogens spread by moving exotic oysters) led to dramatically lower levels of water filtration, leading to algal blooms and food web effects on other species.

Table 1 (continued). Types of potential risks posed by new species introductions and degree of regulation for species group x risk. For each group, each risk is classified as (1) regulated, (2) partly regulated, (3) not regulated, (4) degree of risk unknown, and (5) not applicable.

Group/U.S. Example	Risk 1. Attack non-target species	Risk 2. Vector insects or mites	Risk 3. Vector pathogens	Risk 4. Damage crops	Risk 5. Degrade habitats	Risk 6. Change food webs
#7 PREDATORY MAMMALS FARMED FOR FUR Example: American mink in Europe	**NOT REGULATED** Trophic impacts can be severe if exotic farmed animals escape (or are released) and establish, as occurred in the U.K. with American mink (Rushton et al., 2000; Macdonald and Harrington, 2003). Risk in the U.S. is unregulated because animals are assumed to remain in cages, and exotic species have not been used.	**REGULATED** Introduction of predatory mammals has the potential to spread ectoparasites that can affect native mammals. This risk is controlled by animal inspection at the time of importation.	**REGULATED** Most predators reared for fur in the U.S. are native. Exotic species, if used in this way in the future, would be screened by a veterinarian before introduction to exclude sick individuals.	**NOT APPLICABLE**	**NOT REGULATED** Potential exists for impacts on habitats if key herbivore species' densities were depressed by the predator. There are no known examples in the U.S.	**NOT REGULATED** In theory, this risk may occur, but there are no examples in the United States.
#8 HERBIVOROUS MAMMALS FARMED FOR FUR Example: Nutria, *Myocastor coypus* (Molina), in California, Maryland, and Louisiana	**NOT REGULATED** Herbivorous mammals farmed for fur are unlikely to be plant specialists, so the feeding impacts of populations of such animals would likely be born by many plant species. Rare plant species might be damaged incidentally, but the impacts of this group are treated as habitat destruction in cases such as nutria in the U.S. and brushtail possum, *Trichosurus vulpecula* (Kerr), in New Zealand.	**REGULATED** Introduction of exotic herbivorous mammals has the potential to spread ectoparasites that can affect native mammals. This risk is controlled by animal inspection at the time of importation.	**REGULATED** Exotic herbivores would be screened by a veterinarian before introduction to exclude sick individuals.	**NOT REGULATED** Nutria are indirect pests of agriculture due to their damage to irrigation and canal systems. Crop impact would depend on the specific biology of the imported species.	**NOT REGULATED** Marsh habitat destruction occurred in the U.S. from nutria (Taylor and Grace, 1995; CDFW, 2019), which is the precedent species for the U.S. In New Zealand, brushtail possum, imported to be reared for fur, is highly destructive to native forest habitats (Atkinson and Cameron, 1993); its importation to the U.S. is prohibited under the Lacey Act (USFWS, 2019a).	**NOT REGULATED** In theory, this risk may occur, but there are no examples in the United States.
#9 BIRDS AND MAMMALS FOR HUNTING Example: European boar	**NOT REGULATED** Trophic impacts of new sport animals are not calculated before their introduction.	**REGULATED** Introduction of exotic animals to be hunted have the potential to spread ectoparasites that can affect native mammals. This risk is controlled by animal inspection during the importation process.	**REGULATED** Animals would be screened by a veterinarian before introduction to exclude introduction of sick individuals.	**NOT REGULATED** Some introductions of birds and mammals for sport hunting have potential to become crop pests. Wild boar in the U.S. can damage crops (USDA APHIS, 2019a). This risk is being mitigated by a special program, but the risk itself was not considered before introduction of boar.	**NOT REGULATED** In Hawaii, wild hogs maintained as feral animals for hunting degrade native forests and ecosystem processes (Bruland et al., 2010; Wehr et al., 2018).	**NOT REGULATED** This risk is of considerable concern, but has not been studied in the United States.

Table 1 (continued). Types of potential risks posed by new species introductions and degree of regulation for species group x risk. For each group, each risk is classified as (1) regulated, (2) partly regulated, (3) not regulated, (4) degree of risk unknown, and (5) not applicable. Examples are worldwide for various time periods. Risk analysis is for the United States, at present.

Group/U.S. Example	RISK 1. ATTACK NON-TARGET SPECIES	RISK 2. VECTOR INSECTS OR MITES	RISK 3. VECTOR PATHOGENS	RISK 4. DAMAGE CROPS	RISK 5. DEGRADE HABITATS	RISK 6. CHANGE FOOD WEBS
#10 FISH FOR SPORT OR COMMERCIAL FISHING Example: releases of trout where they are not native have damaged populations of native fish (Dowling and Childs, 1992; Ward and Morton-Starner, 2015), insects (Englund and Polhemus, 2001), and amphibians (Nyström et al., 2001; Pilliod, and Peterson, 2001).	**PARTIALLY REGULATED** Trophic impacts on native fish, insects, and amphibians were not considered in the past before fish were introduced into new regions (Dowling and Childs, 1992; Englund and Polhemus, 2001; Nyström et al., 2001; Pilliod and Peterson, 2001; Ward and Morton-Starner, 2015). Few regulations currently control such fish introductions at the national level.	**NOT APPLICABLE** Introduced fish do not have the biological potential to vector insects or ticks.	**PARTIALLY REGULATED** Under the Lacey Act (18 U.S.C 42), the U.S. Fish and Wildlife Service can list species of fish as "injurious wildlife" whose introduction is prohibited with permit exceptions. Of 408 species of fish listed in this way, 228 are species of Salmonidae that can vector pathogens to other fish. Fish pathogens can infect fish reared for sport release, and this process can move pathogens into wild populations, e.g., *Myxobolus cerebralis* Hofer in Alaska (Arsan and Bartholomew, 2008).	**NOT APPLICABLE** Introduced fish do not have the biological potential to become crop pests.	**NOT REGULATED** Some fish, such as carp, can damage aquatic habitats, but the type of predatory fish introduced for sport or commercial fishing do not seem to pose such a risk.	**NOT REGULATED** Introduced fish causing harm that is indirectly mediated through food webs (rather than via direct predation) are not commonly documented, but Pope et al. (2008) show that trout introductions can facilitate snake predation on amphibians by acting as alternate prey ("apparent competition").
#11 ANIMALS SOLD AS PETS Examples: Burmese python, *Python bivittatus* (Kuhl), in Florida and red lionfish, *Pterois volitans* (L.), in Atlantic coastal waters of Florida.	**NOT REGULATED** Trophic impacts can be severe, as shown in both marine (red lion fish) (Albins and Hixon, 2008) and terrestrial (Burmese pythons) (Dorcas et al., 2012; Sovie et al., 2016) systems.	**REGULATED** Introduction of exotic pets have the potential to spread ectoparasites that can affect native animals. This risk is controlled by animal inspection during the importation process.	**PARTIALLY REGULATED** Risks of introducing lethal pathogens are demonstrated in Europe by the crayfish plague vectored by red swamp crayfish, *Procambarus clarkii* (Cammà et al., 2010; Aquiloni et al., 2011) and by the chytrid amphibian pathogen *Batrachochytrium dendrobatidis* Longcore, Pessier & D.K. Nichols, vectored by sale of live Asian toads (O'Hanlon et al., 2018). This risk has been partly regulated under the Lacey Act (USFWS, 2019a) by listing risky groups as "injurious wildlife"—in particular, the salamander genera whose species act as vectors of a related pathogen (Martel et al., 2014).	**PARTIALLY REGULATED** The risk of crop damage is generally less applicable to species introduced as pets, but it would depend on the species being sold. For example, some aquatic snails sold in the aquarium trade have the potential to become pests of rice or other paddy crops, such as *Pomacea canaliculata* (Lamarck) on taro, *Colocasia esculenta* (L.) Schott, plantations in Hawaii (Tamaru et al., 2006).	**PARTIALLY REGULATED** A few species have been listed as "injurious wildlife" because they pose risk to native habitats, but this risk is not consistently evaluated before new species are introduced in the United States.	**NOT REGULATED** The potential for invasive species brought in by the pet trade to damage native species' food webs is real, as illustrated by the effects of red lion fish on reef communities (Bumbeer et al., 2018; Sancho et al., 2018). This risk is not assessed before introduction.

Table 1 (continued). Types of potential risks posed by new species introductions and degree of regulation for species group x risk. For each group, each risk is classified as (1) regulated, (2) partly regulated, (3) not regulated, (4) degree of risk unknown, and (5) not applicable. Examples are worldwide for various time periods. Risk analysis is for the United States, at present.

Group/U.S. Example	Risk 1. Attack Non-Target Species	Risk 2. Vector Insects or Mites	Risk 3. Vector Pathogens	Risk 4. Damage Crops	Risk 5. Degrade Habitats	Risk 6. Change Food Webs
#12 ANIMALS INTRODUCED FOR MEDICAL USES Example: African clawed frog, *Xenopus laevis* Daudin, in California (Somma, 2019).	**NOT REGULATED** The African clawed frog, *Xenopus laevis* Daudin, has had direct impacts on non-target species in California (Somma, 2019).	**NOT APPLICABLE**	**REGULATED** Introduction of medical animals have the potential to spread ectoparasites that can affect native animals. This risk is controlled by animal inspection during the importation process.	**NOT APPLICABLE**	**NOT REGULATED** In theory, this risk may occur, but there are no examples in the United States.	**NOT REGULATED** In theory, this risk may occur, but there are no examples in the United States.
#13 VERTEBRATES USED FOR PEST CONTROL Example: mongoose in Hawaii; grass carp for aquatic weed suppression.	**REGULATED** Risks of direct predation on non-target wildlife due to historical introductions of terrestrial predatory mammals for biocontrol are well documented, but such species have not been introduced into the United States in more than 100 years (Pimentel, 1955; Seaman and Randall, 1962). Use of fish for pest control has continued, with further use of three previously-introduced species for mosquito or aquatic weed control.	**REGULATED** No examples are known of vertebrates introduced for biocontrol vectoring ticks or insects. Theoretically, such a risk could exist, but modern introductions would be screened for such parasites, as are other vertebrate introductions, effectively controlling the risk.	**REGULATED** No examples are known of vertebrates introduced for biocontrol vectoring pathogens. Theoretically, such a risk could exist, but modern introductions would be screened for pathogens, as are other vertebrate introductions, effectively controlling the risk.	**NOT APPLICABLE** Herbivorous fish used for weed biocontrol might pose risks to some aquatic crop species. However, since no new fish are being introduced for this purpose, the risk is moot.	**REGULATED** Carp used for weed biocontrol pose risks to aquatic habitats. However, these risks are regulated and would be considered prior to any introduction.	**REGULATED** The potential for introduced vertebrates to affect food webs certainly exists, e.g., the cane toad in Australia (Jolly et al., 2015). But, these risks are regulated, and no new vertebrate species are being introduced for biocontrol.
#14 PARASITOIDS FOR INSECT BIOLOGICAL CONTROL Example: *Compsilura concinnata* (Meigen) for gypsy moth, *Lymantria dispar* (L.) (Boettner et al., 2000).	**REGULATED** Since the 1990s, the standard applied has been that newly introduced parasitoids must not harm populations of non-target native insects (Plant Protection Act, 2000). Laboratory host range testing is required before introduction to minimize this risk.	**REGULATED** Since before 1900, introduced parasitoids have been screened to prevent the introduction of hyperparasitoids, the only undesirable insects conceivably associated with parasitoids.	**REGULATED** Parasitoids may sometimes vector insect pathogens, but typically if insect pathogens exist in shipments of parasitoids, and if they do not affect the health of the parasitoid, they are pathogens of the target pest (e.g., the NPV virus of spruce sawfly, *Gilpinia hercyniae* (Hartig) [Balch, 1943]). Pathogens that do affect the health of the parasitoids, such as microsporidia, would be observed (as sick parasitoids) during quarantine and destroyed.	**NOT APPLICABLE** Parasitoids have no biological potential to become plant pests.	**REGULATED** This risk is regulated, but difficult to foresee. Parasitoids may indirectly improve or harm habitats. If they control pests of native plants (e.g., scales in Queensland rain forest [Waterhouse and Sands, 2001; Van Driesche et al., 2010]), it is positive, but if they control pests of invasive plants, it would be negative (e.g., exotic scales attacking ice plants in California dunes [Tassan et al., 1982; Magnoli et al., 2013]).	**REGULATED** This risk is regulated, but interactions in food webs may be difficult to predict. Some cases, both positive and negative have been recognized (negative: Benson et al., 2003; positive: Herlihy et al., 2014).

Table 1 (continued). Types of potential risks posed by new species introductions and degree of regulation for species group x risk. For each group, each risk is classified as (1) regulated, (2) partly regulated, (3) not regulated, (4) degree of risk unknown, and (5) not applicable. Examples are worldwide for various time periods. Risk analysis is for the United States, at present.

Group/U.S. Example	Risk 1. Attack Non-Target Species	Risk 2. Vector Insects or Mites	Risk 3. Vector Pathogens	Risk 4. Damage Crops	Risk 5. Degrade Habitats	Risk 6. Change Food Webs
#15 PREDATORY INSECTS AND MITES FOR BIOLOGICAL CONTROL Example: *Harmonia axyridis* (Pallas), *Coccinella septempunctata* L. (Harmon et al., 2007; Losey et al., 2007)	**REGULATED** Since the 1990s, the standard applied has been that newly introduced predatory insects must not harm populations of non-target native insects (Plant Protection Act, 2000). Laboratory prey range testing is required before introduction to minimize this risk.	**REGULATED** Since before 1900, introduced predators have been screened to prevent the introduction of their own parasitoids, the only undesirable insects conceivably associated with predatory insects.	**REGULATED** Populations for introductions are screened for fungal or microsporidian pathogens, and laboratory colonies are cleared of pathogens before introduction.	**REGULATED** Introduced predatory insects must not damage crops or cause economic losses. Plant-feeding predaceous mirid bugs feed on crops as well as greenhouse pests (Moerkens et al., 2016), and decisions as to whether or not to introduce such zoophytophagous predators may differ between countries. *Harmonia axyridis* can cause irregular flavors in wine if adults contaminate the grapes (Pickering et al., 2004).	**REGULATED** This risk is now regulated. In some cases, predatory insects improve habitats if they control invasive pests that damage the habitat (e.g., cycad forests on Guam [Van Driesche and Reardon, 2017]).	**REGULATED** This risk is now regulated in principle, but it is difficult to predict. Impacts by two introduced coccinellids, *H. axyridis* and *C. septempunctata*, illustrate food web impacts and can be used as a model to avoid future similar events.
#16 INSECTS AND MITES FOR WEED BIOLOGICAL CONTROL Example: *Rhinocyllus conicus* (Frölich) (Louda, 1998; Louda et al., 2005) and *Cactoblastis cactorum* Berg (Stiling et al., 2004; Pemberton and Liu, 2007)	**REGULATED** Weed biocontrol agents undergo preintroduction host range evaluation (Wapshere, 1974), and they must not have the potential to significantly damage non-target plants or reduce their populations.	**REGULATED** Parasitic insects or nematodes attacking candidate weed biocontrol agents internally, if present, are eliminated during quarantine.	**REGULATED** Insects and mites in systems with such concerns can be screened for pathogen DNA, and groups of agents rejected if pathogen DNA is detected. For an example of such pathogen DNA-screening (for a parasitoid), see Hoy et al., 2001.	**REGULATED** Crop species that are potentially suitable for agent feeding are included in tests for evaluation of host range, and agents are rejected if they have the potential to feed on crops (e.g., Cristofaro et al., 2013).	**REGULATED** Habitats produced by native plants are not affected because feeding on native plants by biocontrol agents is nil to incidental. However, habitats created by invasive plants may be affected if the target invasive weed is successfully suppressed. Benefits from such weeds would have to be determined and weighed against the weed's ecological damage before initiating a project.	**REGULATED** No real examples are known of harm to native food webs from successful weed biocontrol. However, if the potential for impacts is suspected, they could be evaluated in the review of particular agents. In the case of melaleuca (*Melaleuca quinquenervia*) in Florida, the melaleuca sawfly, *Lophyrotoma zonalis* (Rohwer), produces toxins potentially poisonous to song birds eating the sawfly's larvae. To protect against this risk, this sawfly was not pursued for release as a biocontrol agent (Purcell and Goolsby, 2005).

Table 1 (continued). Types of potential risks posed by new species introductions and degree of regulation for species group x risk. For each group, each risk is classified as (1) regulated, (2) partly regulated, (3) not regulated, (4) degree of risk unknown, and (5) not applicable. Examples are worldwide for various time periods. Risk analysis is for the United States, at present.

Group/U.S. Example	**Risk 1.** Attack non-target species	**Risk 2.** Vector insects or mites	**Risk 3.** Vector pathogens	**Risk 4.** Damage crops	**Risk 5.** Degrade habitats	**Risk 6.** Change food webs
#17 Pathogens for weed or insect biological control Examples: **a) weed pathogens** The rust *Maravalia cryptostegiae* (Cummins) Y. Ono, a pathogen of rubber vine, *Cryptostegia grandiflora* (Roxb.) R.Br., in Australia (Vogler and Lindsay, 2002) **b) insect pathogens** *Entomophaga maimaiga* Humber, Shimazu, & R.S. Soper, a pathogen of gypsy moth in North America (Hajek et al., 2007)	**REGULATED** **a) weed pathogens** Plant pathogens used for weed biocontrol must not significantly affect non-target plants or reduce their populations. **b) insect pathogens** Risks to non-target insects would have to be evaluated at the time of introduction.	**NOT APPLICABLE** Both weed and insect pathogens lack potential to vector pest insects.	**NOT APPLICABLE** Both weed and insect pathogens lack potential to vector other pathogens.	**REGULATED** **a) weed pathogens** Pathogens used as weed biocontrol agents must not infect crops, including horticultural plants. For this reason, the pathogen causing rose rosette disease cannot be used for control of multiflora rose, *Rosa multiflora* Thunb. (Al-Rwahnih et al., 2019) **b) insect pathogens** Insect pathogens lack the potential to harm crops.	**REGULATED** **a) weed pathogens** Native plant populations must not be harmed by pathogens used for weed biocontrol. Therefore, native habitats will not be harmed. However, habitats created by invasive plants may be affected if the target invasive weed is successfully suppressed. Benefits from such weeds would have to be determined and weighed against the weed's ecological damage before initiating a project. **b) insect pathogens** If a pest insect damages native habitats (e.g., gypsy moth) then pathogen introduction, if successful, would benefit native habitats.	**REGULATED** **a) weed pathogens** No examples are known of harm to native food webs from successful weed biocontrol by a pathogen. However, if the potential for impacts is suspected, this risk could be evaluated in the review of particular agents. **b) Insect pathogens** No examples are known of harm to native food webs from successful insect biocontrol by a pathogen. However, if the potential for impacts is suspected, this risk could be evaluated in the review of particular agents.

Risks associated with deliberate introductions, unlike those from accidental invasions, were not immediately recognized by most people or government agencies. Rather, attention was focused on the expected benefits from the introductions. Because many benefits were associated with new kinds of plants (used as crops, timber, forage, or ornamentals), one of the earliest forms of risk recognized in the United States was that such plant introductions might not attain their full social benefits (or might harm other plants) if importations were not restricted to clean stock, free of damaging insects and plant pathogens. Consequently, plant quarantine acts were enacted early on to reduce such risks (Plant Quarantine Act, 1912). Importantly, however, the new plant species themselves were not considered to pose any risks that needed to be evaluated. The goal was merely to ensure the plants were vigorous, healthy, and free of pests. In contrast to our views of plants, deliberate introductions of mammals and birds (non-caged) were recognized very early as potentially damaging and were prohibited from 1900 to 1948, at which time the law was changed and this blanket prohibition was replaced with a black list of injurious wildlife.

As with plant importations, it has long been recognized that movement of livestock or other mammals had the potential to move pathogens or parasites to new areas. This again led quite early to regulatory efforts to ensure that livestock and live poultry entering the United States were free of pathogens and parasites. The U.S. Animal Industry Act of 1884 created the Bureau of Animal Industry, which was charged with enforcing animal importation regulations. Currently, the Veterinary Services, Organisms and Vectors Permitting Unit of the Animal and Plant Health Inspection Service (APHIS) regulates the importation into the United States and interstate transportation of organisms and vectors of pathogens of livestock and poultry. Given the importance of animal production industries to the U.S. economy, potential vectors of pathogens of livestock and poultry are extensively regulated. Imported wildlife (principally mammals), for hunting, display, or other uses, also pose similar risks of introducing new pathogens to domestic livestock (Pavlin et al., 2009), a risk that has been recognized and is regulated, at least as far as known pathogens are concerned.

Risks to wildlife from animal introductions were recognized somewhat later. While most attention in this area has also been focused on pathogens associated with fish, mammals, and birds, the accidental movement of pathogens in imported frogs (Muths et al., 2003; Adams et al., 2017), salamanders (Martel et al., 2014), and crawfish (Cammà et al., 2010; Aquiloni et al., 2011) illustrates the potential harm to native biodiversity of introduced pathogens of other groups. Currently, this risk is partly regulated through listing of some species as “injurious wildlife” under certain provisions of the Lacey Act (discussed in Group 5). For a summary of the intent, powers and process of listing non-native species as “injurious wildlife” under the Lacey Act and associated statutes, see USFWS (2020a), and for the criteria for listing see USFWS (2020b). These acts provide the agency with the ability to list as “injurious wildlife” vertebrate species and some groups of invertebrates (mollusks and crustaceans, but not insects), but do not provide any authority over plant introductions.

Risks of deliberately imported herbivorous insects were not considered before the 1920s because, for the most part, there were none. But about 1920, in Australia, damage from invasive cacti was so severe that such herbivorous insect importations were systematically pursued. While not the first effort to use insects to reduce invasive plant densities, the control of invasive *Opuntia* cacti in New South Wales, Australia, was the first large, state-sponsored, successful effort (Wilson, 1960). During the implementation of this project, concern that the deliberately imported plant-feeding insects might damage crops or other economically important plants led to the creation of legal controls on such importations. Regulations were adopted under plant protection acts (such as the Plant Quarantine Act, 1912 in the United States) requiring laboratory testing to show that the insects being imported would not harm economically important plants. While the regulatory mandate begun in the 1920s was to ensure that crops and economic plants would not be affected by deliberately imported plant-feeding insects, by the late 1960s that goal had been broadened to include assessment of potential risks to non-economic, native plants. This larger task was done by estimating the fundamental host range of the proposed agents, rather than just checking lists of economically important species for possible feeding (Julien and White, 1997).

A main theme of this review is the gradual expansion of social recognition of different types of risks and the uneven application of regulatory processes to control them. Here, we define six risk categories that should be considered before approving the introduction of any new species (Table 1): (1) direct attack on non-target species*; (2) potential of an imported species (usually a plant) to vector pest insects or mites, or, for imported animals, ticks; (3) potential of an imported species to vector pathogens able to infect non-target plants or animals; (4) potential for imported plants or animals to damage crops; (5) potential for an imported plant or animal to change native habitats or ecosystems; and (6) potential for a new species to reduce the density of native species by changing food webs.

While the above risks now seem reasonable and fairly comprehensive, they were recognized gradually over time as experience with damage caused by various types of imported species accrued. As awareness grew, additional regulations or programs were adopted to prevent recurrence of newly recognized risks.

However, regulations to reduce these risks were not applied comprehensively across species imported for different purposes, but rather were frequently developed to apply only to a particular type of species importation, to control the risk in one specific context. The contention of this review is, therefore, that a uniform, defined risk-review process should be developed and used in the future for assessment of all species use-groups as discussed here, rather than the ad hoc, historical patchwork that now exists. In a U.S. context, this is sometimes referred to as having an "Organic Act" covering an issue as a whole, rather than many separate acts addressing pieces of the problem. Currently in the United States, we have no such Organic Act addressing the risks potentially posed by new species importations.

In this review, first we show that different species use-groups (species imported for a particular purpose) have historically been, and still are, regulated in the United States with strikingly different levels of rigor. Second, we show that this difference in regulatory rigor is not justified, which in theory it might be if some species "use-groups" were intrinsically free of certain types of risks, but which we show is not the case. We review the 17 purposes we have recognized for novel species introductions ("species-use groups") and consider, for each species use-group, if the six risks we have identified above are regulated, partly regulated, not regulated, or not applicable.

*Throughout this publication, "non-target species" refers to species native to the United States as well as species not native to the United States that were introduced intentionally and are still considered desirable.

GROUP #1: FORESTRY, FORAGE, AND FODDER PLANTS

HISTORY OF U.S. INTRODUCTIONS OF FORESTRY, FORAGE, OR FODDER PLANTS

This group includes plants used in forestry, or for forage or fodder, or for certain other economic reasons such as erosion control or stabilization of areas of sand or mud. In North America, the abundance of desirable soft woods for lumber and hardwood trees suitable for many purposes led to domination of the forestry sector by native species, with few non-native trees being imported for production in plantations (and those that were, being of only limited acreage). Hawaii, in contrast, made extensive use of exotic trees for reforestation of denuded, eroding lands, including plantations of pines and eucalyptus (Woodcock, 2003; Fischer et al., 2009). In the Southern Hemisphere, a similar paucity of native softwoods suitable for use as building lumber led to large-scale planting of exotic trees (often *Pinus* spp.), especially in Australia, New Zealand, Chile, and South Africa (Gilmour, 1946; Scott, 1960). In many warmer regions of the world (e.g., central Africa), exotic eucalyptus species have been widely grown in plantations (e.g., in the Congo [Istas, 1954]). Due to a lower need for exotic forestry plantations, the United States has had relatively few problems with exotic forestry tree species invading and naturalizing in native forests. Most pest trees in natural areas in the United States, such as tree of heaven (*Ailanthus altissima* [Mill.] Swingle) and Norway maple (*Acer platanoides* L.), were introduced not for forestry, but rather as ornamentals.

In contrast to problems with novel species used for forestry, the United States has a significant history of introduction of exotic forage grasses (e.g., buffel grass [*Cenchrus ciliaris* L.] and Lehmann lovegrass [*Eragrostis lehmanniana* Nees]) in attempts to improve grazing, especially in several western states, where introduced grasses now dominate large areas and have had dramatic ecological consequences (buffel grass [**Fig. 1;** Sands et al., 2009; Olsson et al., 2012; Lyons et al., 2013] and Lehmann lovegrass [McDonald and McPherson, 2011; Lindsay et al., 2011]). Similarly, in Hawaii, exotic pasture grasses were deliberately introduced (Whitney et al., 1939), and some exotic grasses have had large effects on native grasslands, often changing the fire cycle to the detriment of native species (e.g., *Paspalum conjugatum* P.J. Bergius [Ainsworth and Kauffman, 2010]). In contrast, relatively few woody plants have been introduced in the continental United States for use as fodder for cattle or goats, although exotic species of mesquite (*Prosopis* spp.) and the nitrogen-fixing shrub *Leucaena leucocephala* (Lam.) de Wit, both excellent sources of high-protein cattle fodder in dry tropical areas, are examples of damaging introductions made for this purpose in areas such as Hawaii and Guam (Egler, 1947; Cronk and Fuller, 1995; Gallaher and Merlin, 2010). Finally, several plants introduced to vegetate mud flats (e.g., *Spartina alterniflora* Loisel. in San Francisco Bay, California [Ayres et

Banner Photos. Plants intentionally introduced to the U.S. and used for forestry, fodder, or forage that have since caused ecological damage include (from left to right) Tasmanian blue gum, *Eucalyptus globulus* Labill. (Forest & Kim Starr, Starr Environmental); timothy, *Phleum pratense* L. (John M. Randall, The Nature Conservancy, Bugood.org); kudzu, *Pueraria montana* (Lour.) Merr. (Scott Ehardt, Wikipedia.org); white leadtree, *Leucaena leucocephala* (Lam.) de Wit (William M. Ciesla, Forest Health Management International, Bugwood.org); Lehmann lovegrass, *Eragrostis lehmanniana* Nees (John Ruter, University of Georgia, Bugwood.org); and hairy vetch, *Vicia villosa* Roth (John D. Byrd, Mississippi State University, Bugwood.org).

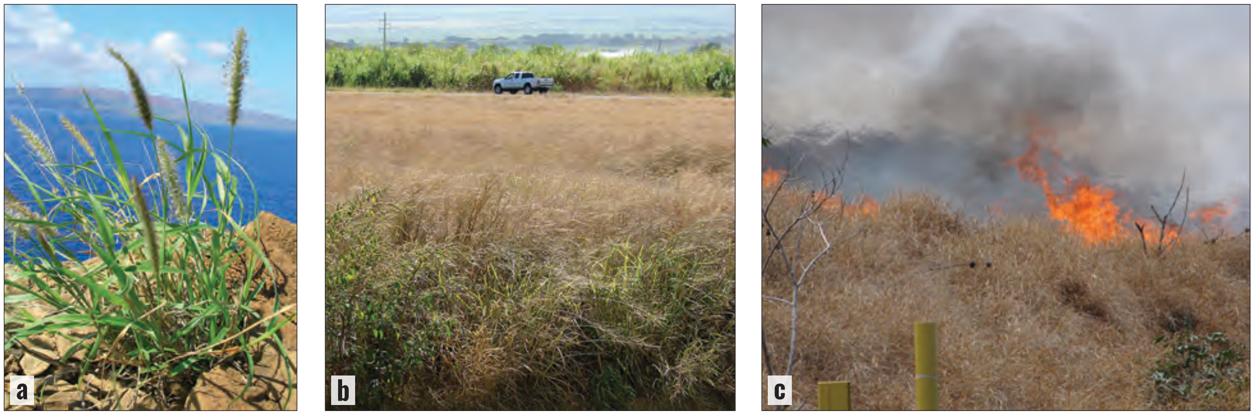


Figure 1. Buffel grass, *Cenchrus ciliaris* L. (a), was intentionally planted to improve grazing, but quickly spread in many western states (b), dramatically altering ecosystems and promoting hot, rapidly-moving fires (c). (Photos: Forest & Kim Starr, Starr Environmental)

al., 2004]) or to reduce soil erosion (e.g., kudzu, *Pueraria montana* (Lour.) Merr. [Rowalt, 1937]) have had damaging effects over large or ecologically important areas (Van Driesche et al., 2002).

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

Historically, unrestricted movement of plants, timber, and other plant-products from overseas locations into the eastern United States and Canada led to the accidental introduction of a great many plant pests. Some accidentally introduced pest insects and plant pathogens were highly destructive of native trees, such as the browntail moth, *Euproctis chrysorrhoea* (L.); winter moth, *Operophtera brumata* (L.); chestnut blight, *Cryphonectria parasitica* (Murrill) Barr; and beech scale, *Cryptococcus fagisuga* Lindinger (Van Driesche and Reardon, 2014). Simultaneously, introduced species of scales, mealybugs, whiteflies, and other insects affected crops (Nechols et al., 1995). Therefore, the Plant Quarantine Act of 1912 was passed, regulating the importation and movement of nursery stock and other plants and plant products within the United States to control the dissemination of injurious plant pests and diseases. The goal of this Act was to deal with this influx of plant pests, newly recognized in this period. Plants themselves were not viewed under this Act as potential pests in this period, merely potential vectors of plant pests. The mechanism created to reduce this risk was the use of inspections of plants entering the United States, to detect and exclude infested or infected plants vectoring such pests. To date, the regulatory mission concerning imported plants has remained largely unchanged from its original purpose. Under U.S. law, nearly all plant species themselves are assumed to be benign and acceptable for importation. Relatively recently, a small number of plants have been identified whose importation is prohibited without a prior risk review, a process called NAPPRA ("not authorized pending pest risk analysis"). There are two types of NAPPRA lists. The goal of the first is the prevention of the introduction of pests attacking plants (NAPPRA, 2019a). The list consists of species (or genera) of plants that may not be imported from various countries because their movement would pose a risk of importing a known pest insect or pathogen. The second NAPPRA list addresses a new risk: the plants themselves. The plants on list two (for first three rounds, 79 species out of the quarter million species of existing plants) have been identified as likely weeds of crops, forests, or other natural areas (NAPPRA, 2019b). The burden of risk identification remains with the government rather than the person or group making the importation. Thus, the current posture of the U.S. government with regard to plant importations is that "For taxa of plants for planting whose importation is not specifically restricted or prohibited in the regulations [NAPPRA listing as mentioned above], the only risk mitigation requirements are that the shipments enter the United States through a Federal plant inspection station, be accompanied by a phytosanitary certificate and a permit, and be sampled and visually inspected for quarantine pests." That is, any plant not on the NAPPRA lists may legally be imported for planting, provided it is not obviously diseased or infested with insects.

RISK-REGULATION PROFILE FOR FORESTRY, FORAGE, AND FODDER PLANTS

Risk 1: Direct attack on non-target species

Direct attack on non-target plants is not applicable for most groups of imported plants, excepting only a few parasitic species.

Risk 2: Potential to harbor pest insects, mites, or nematodes

Extensive measures are in place to prevent the inadvertent introduction of pest insects, mites, or nematodes in or on imported plants. Risk reduction activities include (1) inspections of imported material at U.S. ports of entry, (2) inspections of plants at foreign production sites, and (3) prohibition of importation of certain plants from countries where pests occur that might accompany imported plants of the prohibited genus or species (NAPPRA, 2019a). For example, to forestall the importation of the citrus longhorned borer, *Anoplophora chinensis* (Forster) (Cerambycidae), it is forbidden to import *Acacia* species, except as seeds, cut flowers, or "greenery" (parts incapable of concealing live stages of the insect in question), from any country except for Canada. Similarly, to forestall the accidental importation of the plant-parasitic nematode *Bursaphelenchus cocophilus* (Cobb) Baujard, the importation of plants in eight genera (*Acrocomia, Astrocaryum, Attalea, Bactris, Euterpe, Mauritia, Oenocarpus,* and *Roystonea*) is prohibited from all countries, except as seeds, cut flowers, or greenery (plant parts incapable of vectoring live stages of the nematode). New specific prohibitions are published periodically by the U.S. Animal and Plant Health Inspection Service (APHIS) under NAPPRA. The same process is used to reduce the risk of introduction of plant pathogens (see Risk 3 below). Note, however, that while NAPPRA-listed species have been flagged as requiring review, they may still be imported after a risk analysis if the agency chooses. Also, this black-listing approach has been applied to only a tiny fraction of existing plant species, leaving most plants unreviewed.

Risk 3: Potential to vector pathogens to non-target plants

To make the accidental introduction of plant pathogens on imported plants less likely (through partial regulation), a similar approach is used to restrict movement of plants likely to harbor such pathogens. Detection of diseased plants at points of entry would result in rejection of a plant shipment. However, plants may either be infected but not yet show symptoms or may harbor organisms to which they are tolerant (and relatively symptom-free) but which can undergo host range expansion onto susceptible hosts in new regions of the world following importation of their host plants. For example, *Phytophthora ramorum* Werres et al., the causal agent of sudden oak death, kills several tree species but was introduced by the nursery industry on three genera of shrubs that are not themselves strongly affected by the pathogen (Hüberli et al., 2008; Poucke et al., 2012).

To lower the risk of introducing pathogens, importation of some plants is prohibited from countries where specific pathogens are known to occur and be associated with particular groups of plants (NAPPRA, 2019a). NAPPRA lists are of prohibited plant species (or genera) x plant part(s) x country combinations, whose prohibition is intended to forestall importation of certain plant pests or pathogens. For example, to reduce the risk of importation of the alder pathogen *Phytophthora alni* Brasier & S.A. Kirk, the importation of any species of *Alnus* (excepting only the importation of seed) is prohibited from all countries except Canada.

Risk 4: Potential to become pests in crops

Some plant species have been identified by APHIS in the United States as having the potential to become weeds in U.S. crops or natural areas, based not on testing, but rather on literature records. These species are on a short

NAPPRA black list (31 species in 2013 and 22 more in 2017), and their introduction is prohibited pending review (therefore, this risk is partly regulated; NAPPRA, 2019b). These species are pests of crops or natural areas (or both) in their native ranges, or in previously invaded areas. However, many plants not on such lists still have an undetermined potential to become invasive pests of agriculture, forestry, or natural areas.

Risk 5: Potential to degrade native habitats or ecosystems

Many deliberately imported plant species have become pests of natural areas (Foxcroft et al., 2013). New plant importations in the United States are not routinely tested for this risk, nor is their importation prohibited unless the species happens to be one of the few species whose literature records have been reviewed and placed on the prohibited lists (79 species) mentioned above as posing a risk of becoming crop weeds (NAPPRA, 2019b). These species are black-listed based on literature records that show the species are pests of crops or natural areas (or both) in their native ranges, or in previously invaded areas. For example, the grass *Acroceras zizanioides* (Kunth) Dandy is one such NAPPRA-listed species that is recorded as "flourishing in semi-aquatic and forest environments in Africa, Asia, and tropical America. It occurs in both disturbed and undisturbed soils, in forests and throughout the interior and coastal savannas, and would seem well adapted to be a significant threat to wetlands and forest in any tropical regions of the United States." Another such example is silky hakea, *Hakea sericea* Schrad. & J.C. Wendl., an introduced tree in South Africa that is now widely invasive there in dry natural areas (Fugler, 1982).

The NAPPRA listing process has two shortcomings. First, the number of species placed on the list is less than 0.1% of all plant taxa, leaving 99.9% of plant species unreviewed, even based solely on literature. Second, the listing process is triggered by plants being weeds in either their native ranges or previously invaded areas. However, many plants that are not weeds in their native ranges have potential to increase in density and become pests in new regions either due to separation from the natural enemies that suppress their densities in their native range (Blossey and Kamil, 1996) or other mechanisms (Enders and Jeschke, 2018). The whole field of plant management through natural enemy importation (weed biocontrol) is based on the repeated occurrence of such introduction-induced plant explosions (Van Driesche et al., 2008).

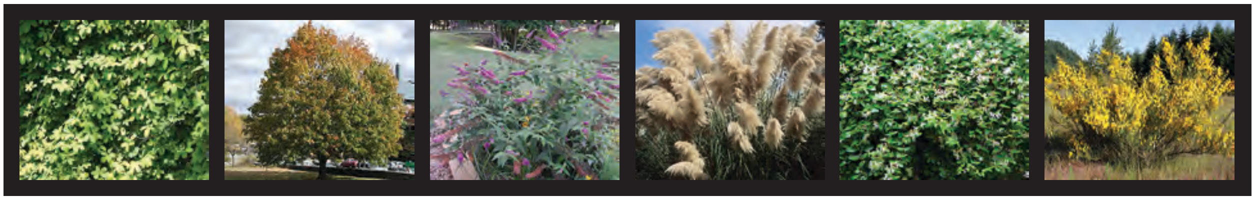
Currently in the United States, the burden of proof concerning the potential risk of importation of particular plants rests on the government, which must show that the importation of a particular plant is not safe, rather than requiring the importer to show that it is safe. This situation is reminiscent of the commercialization of chemicals for use as pesticides before the 1947 Federal Insecticide, Fungicide, and Rodenticide Act, whose passage inverted a similar presumption of safety, placing the burden on the manufacturer to prove safety before being permitted to sell a chemical as a pesticide product (implemented through a new requirement for product registration [Aspelin, 2003]).

Risk 6: Potential to reduce density of native species by changing food webs

Invasive plants that dominate habitats or change them structurally are very likely to also affect non-target species through changes to native food webs (e.g., Pritekel et al., 2006; Lowe et al., 2008). However, it is difficult to predict the direction (harmful versus beneficial) and intensity of such effects, and this risk is not assessed for new plant introductions in the United States.

SUMMARY OF RISK REGULATION FOR FORESTRY, FORAGE, OR FODDER PLANTS

For forestry, forage, and fodder plants, Risk 1 (direct attack) is not relevant, while Risks 2 and 3 (vectoring pests or pathogens) have been the core regulatory focus of concern since the beginning of controls on plant importations in the United States more than a century ago. Insect invasions, however, are much easier to detect than invasions of previously unrecognized pathogens in asymptomatic hosts, making Risk 3 only partially regulated. Regulation of Risks 4 and 5 (plants being weeds or damaging natural habitats) has begun, but only for a few NAPPRA-listed species. Risk 6 (impacts of plants on food webs) remains unregulated. Overall, the burden of proof to show a proposed plant introduction is unsafe remains with the government, not the importer.



GROUP #2: ORNAMENTAL PLANTS

HISTORY OF U.S. INTRODUCTIONS OF ORNAMENTAL PLANTS

In North America, as in Europe, the importation of ornamental plants for their beauty or other desired qualities has long been a popular and commercially important activity (Cunningham, 1990; Wulf, 2010), and such importations have been the source of most plant invasions (Reichard and White, 2001). The desire of people to have new and unusual plants in their private estates (**Fig. 2**) has long created a market demand, which led to the development of a nursery industry to satisfy such interest. Before approximately 1400, plants were moved slowly over land between areas, which forced many introductions to be based on the use of seed. As European ships began to more thoroughly explore the world in the 15th century, transit times were greatly reduced, and trade routes were used to import goods, including live plants. European interest in plants from China was especially strong in the 18th and 19th centuries (Cox, 1961). Once new plant species entered the nursery trade in Europe, they were moved widely among countries with suitable climates, especially to regions of the world that Europeans had colonized (Crosby, 2003). In many regards, the importation of plants as ornamentals was very similar to the introduction of plants for forestry, forage, or fodder. But two differences are worth mentioning. First, the number of plants potentially considered desirable for importation as ornamentals is greater by orders of magnitude. Secondly, the development of a worldwide commercial industry centered on making such plant translocations created a large and effective mechanism for plant movement, with a strong and sustained motive for doing so on a continuing basis. This industry then provided a political constituency for plant importations, lobbying for lenient terms of importation.

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

Historically, unrestricted movement of imported plants, including ornamentals from overseas locations into the eastern United States, led to the accidental introduction of many plant pests. Some of these introduced insects and plant pathogens became forest or garden pests (e.g., for pests in U.S. forests, see Van Driesche and Reardon, 2014). This risk was reduced by the same act (Plant Quarantine Act, 1912) mentioned above, which restricted the introduction of plants, including ornamentals, into the United States by requiring plant inspections. The regulatory status of this group of novel species is the same as described above for Forestry,

Banner Photos. Plants intentionally introduced to the U.S. as ornamentals that have since caused ecological damage include (from left to right) chocolate vine, *Akebia quinata* (Houtt.) Decne. (Chris Evans, University of Illinois); Norway maple, *Acer platanoides* L. (Leslie J. Mehrhoff, University of Connecticut); butterfly bush, *Buddleja davidii* Franch. (Leslie J. Mehrhoff, University of Connecticut); pampas grass, *Cortaderia selloana* (Schult. & Schult.f.) Asch. & Graebn. (John Ruter, University of Georgia); Japanese honeysuckle, *Lonicera japonica* Thunb. (Chris Evans, University of Illinois); and Scotch broom, *Cytisus scoparius* (L.) Link (Eric Coombs, Oregon Department of Agriculture) (all images from Bugwood.org).

Forage, and Fodder plants. The most significant difference between ornamentals as a group and those plants imported for use in forestry or as forage or fodder, is that ornamentals provide a much larger pool of new plant species for importation and an industry (horticulture) eager to obtain and sell them to private, individual users at millions of locations, which provide many points of introduction into natural habitats.

SUMMARY OF RISK REGULATION FOR ORNAMENTALS

For plants sold as ornamentals, Risk 1 (direct attack) is not relevant. Risks 2 and 3 (vectoring pests or pathogens) have been the core regulatory focus since the beginning of control a century ago and, in principle, are regulated. However, the sheer diversity of the taxa involved makes it difficult to recognize and control these risks effectively through inspection. Furthermore, insect invasions are much easier to detect than invasions of previously unrecognized pathogens in asymptomatic hosts, making Risk 3 only partially regulated. Risks 4 and 5 (plants being weeds or damaging natural habitats) have begun to be regulated, but only for a few NAPPRA species, with risk evaluation remaining the obligation of the government, not the importer. Many ornamental plants imported for use in gardens are not invasive due to lack of competitiveness, being dependent on weeding and fertilization by homeowners. However, some groups of plants (vines [Gordon et al., 2017], ground covers, and grasses [Overholt and Franck, 2017]) may have higher potential for invasion and cause greater damage to natural ecosystems than other growth forms (Phillips et al., 2010). Risk 6 (impacts of ornamental plants on food webs) remains unregulated, but clearly exists (e.g., Burghardt et al., 2010; Carvalheiro et al., 2010; Hladyz et al., 2011; Wang et al., 2013).

Figure 2. Water hyacinth, *Pontederia* (formerly *Eichhornia*) *crassipes* (Mart.) Solms (a), was intentionally introduced as an aquatic ornamental (b), but escaped ponds and was also intentionally dumped with aquaria contents. It has since become one of the worst aquatic invaders in the world (c). (Photos: a. Shaun Winterton, California Department of Food and Agriculture; b. Leslie J. Mehrhoff, University of Connecticut; c. James R. Holland) (all images from Bugwood.org)

GROUP #3: CROP PLANTS

HISTORY OF U.S. INTRODUCTIONS OF CROP PLANTS

Plants grown as crops in agricultural fields are often less competitive than wild plants due to human-selection for traits desired by farmers. Some crops species, however, can be invasive (Pasiecznik and Jaenicke, 2009; Quinn et al., 2015). Examples of crops that have become invasive include (1) watercress (*Nasturtium officinale* W.T. Aiton) in Massachusetts (U.S.) (Van Driesche, pers. obs.), (2) water spinach (*Ipomoea aquatica* Forssk.) in Florida, California, and Hawaii (U.S.) (Austin, 2007; USDA NRCS, 2015); (3) blackberries (*Rubus niveus* Thunb.) in the Galápagos (Rentería et al., 2012); and (4) strawberry guava (*Psidium cattleianum* Sabine) in Hawaii (**Fig. 3**; Patel, 2012) and Lord Howe Island (Australia) (Bower, 2016). Our intent here is not to review crops as invasive plants, but only to make the point that it can happen, and therefore that the potential risks of new crops should be reviewed before introduction of new species not already in the country.

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

In general, the importation and growing of exotic plants as food crops has been seen as having few risks (except as vectors of pests or pathogens), and such plant introductions have not been prevented or restricted, with only a few exceptions where the plant was perceived to have potential to become a weed (i.e., water spinach in rice in Texas, where personal cultivation is banned at the state level).

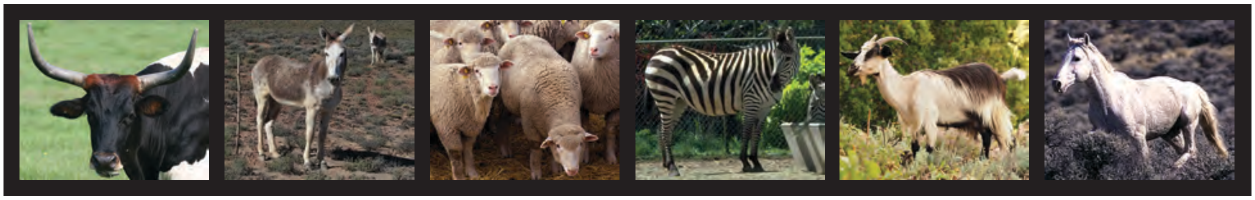
SUMMARY OF RISK REGULATION FOR CROPS

For plants grown as food crops, Risk 1 (direct attack on non-target species) is not relevant. Risks 2 and 3 (vectoring pests or pathogens) are regulated under the Plant Quarantine Act, 1912, as is true for all plant introductions. Insect invasions, however, are much easier to detect than invasions of previously unrecognized pathogens in asymptomatic hosts, making Risk 3 only partially regulated. Compared to ornamentals, the numbers of plants used as food crops is small, well established, and stable. Risks 4 and 5 (plants being agricultural weeds or damaging to natural habitats) in theory might be regulated by designating a species as a NAPPRA species, but this has never been done for a crop plant. Risk 6 (impacts of crop plants on food

Banner Photos. Crop species introduced to the U.S. that have since become invasive, causing ecological damage include (from left to right) species of blackberry, *Rubus* spp. (Gerald Holmes, California Polytechnic State University at San Luis Obispo, Bugwood.org); watercress, *Nasturtium officinale* W.T. Aiton (Zack Abbey, iNaturalist.org); water spinach, *Ipomoea aquatica* Forssk. (Eric in SF); common St. Johnswort, *Hypericum perforatum* L. (Ohio State University Weed Lab, Bugwood.org); hardy kiwi, *Actinidia arguta* (Siebold & Zucc.) Planch. ex Miq. (Onidiras, iNaturalist.org); and spearmint, *Mentha spicata* L. (Modestcowboy, iNaturalist.org).

Figure 3. Strawberry guava, *Psidium cattleianum* Sabine (a), was intentionally introduced to Hawaii for its fruit, but quickly escaped. It readily forms dense, impenetrable thickets (b) and large monocultures (as seen from above, c) that displace native species and serve as refuges for fruits flies that are serious pests to agriculture. (Photos: Forest & Kim Starr, Starr Environmental)

webs) could occur (as surely must be the case for strawberry guava in Hawaii) but no requirements exist to forecast and consider such risks when new crop plants are first imported.



GROUP #4: TERRESTRIAL MAMMALS FOR RANCHING OR VIEWING

HISTORY OF U.S. INTRODUCTIONS OF TERRESTRIAL MAMMALS FOR RANCHING OR VIEWING

There is overlap between the introduction of exotic vertebrates for ranching or viewing and for use as pets. The former tends to be larger species, dominated by mammals, while pets may be large or small and span a wider taxonomic range. Exotic vertebrate animals (usually mammals but also birds and reptiles) held on ranches may be used for trophy hunting or viewing by tourists ("wildlife parks") in large fenced enclosures. The most common exotic mammals held on U.S. ranches are species of Bovidae (cattle and antelope), Cervidae (deer), or Equidae (horses and zebras) (Land.com, 2019). Ranches sell excess animals to other ranches or private individuals (Fernandez, 2017). Since fenced enclosures are not highly secure, animals can and do occasionally escape, leading in some cases to the establishment of populations of exotic animals in natural areas. Russian wild boar (*Sus scrofa* L.; **Fig. 4**), now widely established as feral animals in several states, were introduced through this mechanism (Waithman et al., 1999).

Legal restrictions on the possession of exotic vertebrates vary by state (for details for all 50 states see Born Free USA [2020]). Examples of some states' requirements follow, with categories defined as (1) "B" = ban on private ownership of exotic animals; (2) "B*" = ban on private ownership of those exotic animals on a prohibited list; (3) "L" = requirement for the owner of the exotic animal to obtain a license or permit or to register the animal with state or local authorities to privately possess the animal; and (4) "N" = states that do not require a license or permit to possess the animal, but may regulate some aspects (i.e., entry permit, veterinary certificate, etc.).

Category B: Summary of California Law

It is unlawful for persons to possess wild animals unless the animal was in possession prior to January 1992. Wild animals include, but are not limited to "the following [groups]: Primates; Marsupialia; Insectivora (shrews); Chiroptera (bats); Carnivora (non-domestic dog and cats); Proboscidea (elephants); Perissodactyla (zebras, horses, rhinos); Reptilia (crocodiles, cobras, coral snakes, pit vipers, snapping turtles, alligators); etc." (CAL. CODE REGS. Tit. 14, §671 and §671.1).

Categories B* and L: Summary of Florida Law

It is unlawful for a person to possess any Class I Wildlife unless the animal was in possession prior to August 1, 1980. Class I Wildlife includes, but is not limited, to the following: chimpanzees, gorillas,

Banner Photos. Exotic species introduced for ranching and viewing in North America sometimes escape and cause ecological and economical damage, including (from left to right) cows, *Bos taurus* L. (Johnny N. Dell, Bugwood.org); donkeys, *Equus africanus asinus* L. (Tony Rebelo, iNaturalist.org); domestic sheep, *Ovis aries* L. (Keith Weller, Wikipedia.org); zebras, *Equus* spp. (Howard F. Schwartz, Colorado State University, Bugwood.org); domestic goats, *Capra hircus aegagrus* Erxleben (Jakob Fahr, iNaturalist.org); and horses, *Equus ferus caballus* L. (Terry Spivey, USDA Forest Service, Bugwood.org).

Figure 4. Russian wild boar, *Sus scrofa* L. (a), were intentionally introduced to North America as food animals and for hunting, but subsequently escaped. Feral populations do extensive damage to native vegetation and agricultural crops (b,c), reduce water quality, destroy nests of ground-nesting species, kill fawns and young livestock, and can transmit diseases to domestic pigs and humans. (Photos: a. Dushenkov, iNaturalist.org; b,c. Sasa Kunovac, Bugwood.org)

orangutans, baboons, leopards, jaguars, tigers, lions, bears, elephants, crocodiles, etc. Persons may possess Class II Wildlife if he or she obtains a permit from the Fish & Wildlife Conservation Commission. Class II Wildlife includes, but is not limited to, the following: howler and guereza monkeys, macaques, cougars, bobcats, cheetahs, ocelots, servals, coyotes, wolves, hyenas, alligators, etc. For all other wildlife in personal possession not defined as Class I or II Wildlife, owners must obtain a no-cost permit. In addition, Florida has promulgated regulations governing possession of Class II and III animals (caging requirements, etc.). In 2010, Florida passed state regulations prohibiting the importation, sale, use, and release of non-native species. The regulations include a ban on capturing, keeping, possessing, transporting or exhibiting venomous reptiles or reptiles of concern, including listed python species; the green anaconda, *Eunectes murinus* (L.); the Nile monitor, *Varanus niloticus* (L.), and other reptiles designated by the commission as a conditional or prohibited species. Persons who hold pre-July 1, 2010 permits for these species may legally possess the species for the remainder of the reptile's life. Traveling wildlife exhibitors who are licensed or registered under the United States Animal Welfare Act and licensed zoos are exempted (FLA. ADMIN. CODE ANN. r. §68A-6.002, §68A-6.0021, and §68A-6.0022. FL ST. §379.231-2 [nonnative animals]).

Category N: Summary of North Carolina Law

A county or city may by ordinance regulate, restrict, or prohibit the possession of dangerous animals. In addition, an entry permit from the State Veterinarian is required before importing into the state a skunk, fox, raccoon, ringtail, bobcat, North or South American feline, coyote, marten, or brushtail possum (N.C. SESS. LAWS §153A-131 and §160A-187; N.C. ADMIN. CODE tit. 2, r. 52B.0212).

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

Three potential problems were recognized in relation to the keeping of wild animals, and in each case local (state, county, or city) regulations, rather than federal regulations, were deemed sufficient. (1) Greatest public awareness has focused on the potential for captive wild animals to harm people. Controls enacted in the regulations of many states have, therefore, often been drafted to prevent animals like bears or lions from hurting people who may accidentally come into contact with them where they are housed or should they escape. These regulations may apply to private menageries or animal collections, or to individuals keeping one or more such animals as pets. (2) A second problem of concern to some groups has been the potential for cruelty to animals kept under poor conditions. (3) A third and more ecological concern is that animal pathogens might be introduced through the importation of infected animals that could affect domestic animals or wildlife in the same general taxonomic group. To control this risk, veterinary certificates are required in some states (but not others) to prevent the introduction of known wildlife diseases, including rabies (a viral disease caused by *Rabies lyssavirus*) and other diseases that are transmissible to people. Unknown pathogens, however, are not controlled by this approach. Also, the lack of this being a requirement in all states allows opportunity for animals that are infected but not visibly ill to be imported to states where veterinary inspections are not required, with subsequent uncontrollable spread of the pathogen if it establishes in a wild population of a related species.

A fourth problem, the risk of exotic introduced animals themselves becoming pests in natural areas, has not been identified specifically as a risk. This risk is, however, controlled in some states (e.g., Alaska) if the state has a blanket prohibition against wildlife importations by private parties. In the lower 48 states, the patchwork of the presence and absence of such controls across different states leaves the country as a whole at risk of exotic animals establishing in the wild in one or more states with weak or no regulations, with the animal then spreading naturally or being spread by enthusiasts to other states. This is the scenario by which the Russian wild boar gained entrance and spread over a wide region in the United States (Le Stegeman, 1938; Wood and Lynn, 1977; Howe et al., 1981). More generally, on islands and in countries such as New Zealand, introductions of exotic animals such as deer for ranching or hunting have frequently led to establishment of damaging populations (e.g., New Zealand Department of Conservation, 2020).

SUMMARY OF RISK REGULATION FOR TERRESTRIAL MAMMALS USED FOR RANCHING OR VIEWING

For exotic vertebrate animals introduced for ranching, enclosed hunting, or viewing, Risk 1 (direct attack on non-target species) is relevant for introduced herbivores, but not regulated. Examples include various species of deer that have become established in other countries (Fraser et al., 2003). For predatory animals, direct attack on native prey is also an unregulated risk (Drummond and Leonard, 2010; Bytheway and Banks, 2019). Risks 2 and 3 (vectoring pests like ticks or bacterial or viral pathogens) are regulated in principle. However, this risk is addressed by states, and requirements for veterinary inspections of animals entering the country vary considerably among states. Risks 4 and 5 (the exotic animals damaging natural habitats or their component species) is unregulated. Risk 6 (impacts on native food webs by exotic animals established in natural areas) is unregulated, but the impacts of European boar populations have received some study (Wood and Lynn, 1977; Howe et al., 1981).

GROUP #5: FISH USED FOR AQUACULTURE

HISTORY OF U.S. INTRODUCTIONS OF FISH USED FOR AQUACULTURE

At least 673 fish species have been introduced in the United States and its territories, including introductions that failed (Witmer and Fuller, 2011). A small number of these fish introductions were accidental (as ballast contaminants), but most were deliberate introductions. Intentional introductions were made either for sport (e.g., trout and salmon [Salmonidae spp.] and bass [*Micropterus* spp.]) or, the majority, were introduced for use as pets (tropical fish) or use as bait fish (Fuller, 2003; see also Groups 10 [sport] and 11 [pets] later in this publication). Only a few species were introduced as a food source (e.g., common carp [*Cyprinus carpio* L.] and tilapia [*Oreochromis* spp.]). The list of all introduced fishes is dominated by two orders, the Cypriniformes and Perciformes, which together make up some 400 introduced species (Fuller, 2003, as discussed in Witmer and Fuller, 2011). See also the list of introduced fish compiled by the U.S. Fish and Wildlife Service (USFWS) (USGS, 2019a). Many of these introduced fish species have provided important food and sport resources or economic gains for the pet trade, and many do not cause large adverse effects. However, others have become pests through spread of fish diseases, predation or competition with native fish, or by causing habitat degradation or food web changes.

Intentional fish introductions have been a mixture of authorized and unauthorized actions, in varying proportions (e.g., in California, Moyle [1976]). For example, blue tilapia, *Oreochromis aureus* (Steindachner), and other species of tilapia native to Africa were introduced to the United States as a food source or as sport fish and escaped from aquaculture facilities. In natural waters, blue tilapia consume native aquatic vegetation and compete with native fish (Fuller et al., 1999).

Aquaculture production in North America began with state and federal efforts to enhance sport fishing opportunities through rearing and release of reared fish into wild waters, including various species of native and introduced trout and catfish (FAO, 2019a). Rearing of trout in the United States has largely been done to restock depleted or degraded rivers, and only a small proportion of trout produced via aquaculture have been reared for sale to consumers. In the United States, aquaculture production of fish for consumption has been dominated by channel catfish, *Ictalurus punctatus* (Rafinesque), a native fish that is widely reared in ponds in the southeastern United States. In 2008, this species constituted 81% of the 287,132 tons of finfish produced in the United States. A second species, Atlantic salmon (*Salmo salar* L.), began to be produced in the 1970s in North America using ocean net pens in the Pacific Northwest, a region in which Atlantic salmon is not native. In 2008, 17,000 tons of Atlantic salmon were produced, valued at 45 million dollars. In general, five types of fish have dominated aquaculture in the United States (catfish, trout, salmon, tilapia,

Banner Photos. Exotic fish species introduced for aquaculture in North America sometimes escape and cause ecological and economical damage, including (left to right) blue tilapia, *Oreochromis aureus* (Steindachner) (Enriqueperez, iNaturalist.org); common carp, *Cyprinus carpio* L. (Dezidor, Wikipedia.org); bighead carp, *Hypophthalmichthys nobilis* (J. Richardson) (South Dakota Game, Fish and Parks, Bugwood.org); walking catfish, *Clarias batrachus* (L.) (J.D. Willson, iNaturalist.org); banded tilapia, *Tilapia sparrmanii* Smith (Rob Palmer, iNaturalist.org); and Asian swamp eel, *Monopterus albus* (Zuiew) (Maggiekuo, iNaturalist.org).

and hybrid striped bass). These fish are native in some parts of the United States where they are produced, but exotic in others. In addition, fish aquaculture facilities produce bait fish and ornamental fish. The latter is discussed in Group 11 (pets) (Centers for Epidemiology & Animal Health, 1995).

The search for new species of fish to farm continues. For example, University of Florida researchers are examining the rearing of South American pirarucu (*Arapaima* spp.) in ponds in southern Florida (Hill and Lawson, 2015). It is known that these large fish (up to 200 lbs or 91 kg) can prey on other fish and would do so if they got into the wild waters (Buck, 2016).

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

Two key risks have long been known to potentially be associated with fish introductions: (1) fish vectoring pathogens that cause disease in fish or humans (such as whirling disease and hemorrhagic septicemia), and (2) the potential for exotic fish to damage native fisheries through competition, hybridization, predation, or habitat degradation (USGS, 2019b). For example, whirling disease, which affects trout and salmon, is caused by the non-native pathogen *Myxobolus cerebralis* Hofer, a myxozoan parasite first introduced into the United States in 1958. This parasite can be spread to wild fish by stocking of infected fish (**Fig. 5**). By 2008, this parasite had reached Alaska, where it now threatens native fish (Arsan and Bartholomew, 2008). Introduced fish can also pose health risks to humans. For example, Asian swamp eels, *Monopterus albus* (Zuiew), are commonly eaten in Asia, either from wild-caught or farmed sources. However, this eel can vector parasitic nematodes (*Gnathostoma* spp.) that cause tissue damage or even death in people (Cole et al., 2014). Wild populations of this eel, introduced casually for human consumption, are now established in Florida, Georgia, New Jersey, and Hawaii (USGS, 2019b), and wild swamp eels are infected with the parasitic nematode (Cole et al., 2014).

In response to risks posed by invasive and otherwise harmful wildlife, the USFWS, under the injurious wildlife provisions of the Lacey Act (18 U.S.C. 42 as amended), a law passed in 1900, has the authority to list animal species as "injurious" and to date has listed 408 species of fish. The entry of listed species into the United States is prohibited, except by permit for certain purposes. Of these listed species, over half (228) are salmonids that pose a risk of disease transmission to other salmon and trout populations, as well as other fish. Of these listed fish, 122 are walking catfish (Clariidae), and 44 are species of snakeheads (Channidae). The other 14 species are not clustered in particular groups. This black list covers 1.3% of the world's fish species (approximately 32,500), or 2.7% of its freshwater species (app. 15,000) (Nelson, 2006; IUCN, 2019). No regulatory prohibition on importation exists for the remaining 97–99% of fish species.

RISK-REGULATION PROFILE FOR FISH USED FOR AQUACULTURE

Risk 1: Direct attack on non-target species

It is well known and generally accepted that introduced predatory fish will prey on native invertebrates and fish. Similarly, introduced herbivorous fish will consume native plants. Fish introductions are not prohibited based on the potential for such ordinary direct effects on native species unless the impacts are severe or the affected species themselves are rare or endangered, or ecologically or economically important. The general prohibition of the introduction of snakehead fish (Channidae) is based on their ability to harm native or established fisheries, such as largemouth bass (*Micropterus salmoides* (Lacépède); Love and Newhard, 2012). New introductions, such as pirarucu (*Arapaima* spp.) for production in ponds in Florida, have the potential to harm populations of non-target native fish, but this risk is assumed to not exist, as fish are reared in ponds rather than wild waters. However, while it is known that many fish, previously introduced for rearing in outdoor ponds, later escaped or were deliberately moved into wild waters by individuals who valued the fish, this risk in not given credence when evaluating such introductions.

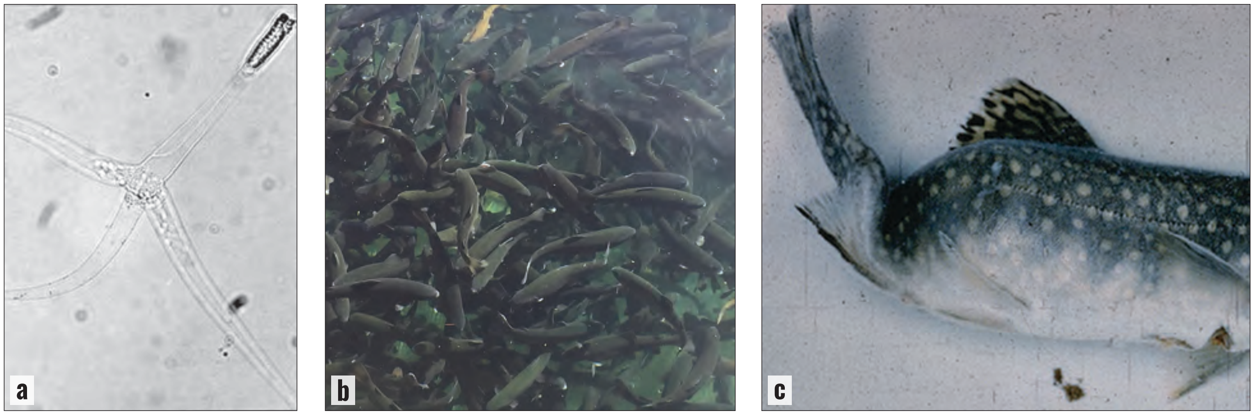


Figure 5. Whirling disease is caused by the non-native pathogen *Myxobolus cerebralis* Hofer (a). It is often carried by farmed salmon and trout (b) and can infect wild populations following the wild stocking of infected fish. This disease causes skeletal deformation (c) and neurological damage and has a juvenile mortality rate of up to 90% in infected populations. (Photos: a. USGS; b. aeafa17, iNaturalist.org; c. Dr. Thomas L. Wellborn, Jr. and USFWS)

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

This risk is not applicable to fish introductions if nematodes are taken to mean plant-infesting species. Parasitic nematodes of animals are considered below.

Risk 3: Potential to vector parasites or pathogens to non-target fish

The potential for new fish species to introduce parasites or pathogens able to infect native or economically important fish has been recognized, and some efforts have been made to limit spread of known pathogens by restricting further introductions or spread of problem species from infected sources of production. However, there is no requirement to investigate the potential of a first-time fish introduction to pose such a problem, provided that the fish is not on the list of prohibited species under the Lacey Act (18 U.S.C. 42).

Risk 4: Potential to become pests in crops

This risk is generally not applicable to fish used in aquaculture.

Risk 5: Potential to degrade native habitats or ecosystems

In Canada, studies have shown that the bottom-feeding habit of common carp can cause degradation of aquatic ecosystems, causing a shift from clear, macrophyte-dominated water to a turbid phytoplankton-dominated state at levels of under 600 kg of carp per ha (Badiou and Goldsborough, 2015). In Mexico, carp aquaculture has been observed to reduce water quality and native species abundance (Tapia and Zambrano, 2003).

Risk 6: Potential to reduce density of native species by changing food webs

The potential for new fish species to strongly affect native fish communities through changes in food webs has been amply demonstrated by the documented changes in Lake Victoria in East Africa following the deliberate introduction of Nile perch, *Lates niloticus* (L.), which led to the complete collapse and reorganization of the lake's ecosystems and apparent extinctions of many endemic fish species (Goldschmidt, 1996; Welz, 2017). While the purpose of this particular introduction was to create a new fishery rather than for aquaculture, it establishes the point that new fish establishments can pose such risks. This, coupled with the fact that species reared in ponds frequently escape during flooding or through the action of people, highlights the risk from new-species aquaculture operations.

SUMMARY OF RISK REGULATION FOR FISH FOR AQUACULTURE

As with other vertebrates, the release of new species of fish potentially poses serious risk of direct attack on non-target species (Risk 1), which is only partially regulated, and spread of pathogens (Risk 3), which is more fully regulated. There is also risk of damage to aquatic habitats (Risk 5) and impacts on food webs (Risk 6), but these concerns are not regulated. The approach used to minimize these risks in the United States has been to create a small (408 species) list of fish species whose introduction into the United States, or transport between listed jurisdictions, is prohibited (except by permit for certain purposes). For species not placed on the prohibited list, importation remains unrestricted. The risk most often regulated to date has been the possible spread of pathogens to native fish.

GROUP #6: COMMERCIALLY PRODUCED INVERTEBRATES

HISTORY OF U.S. INTRODUCTIONS OF COMMERCIALLY PRODUCED INVERTEBRATES

Non-native invertebrates commercially produced in the United States, or directly imported live from foreign sources, include species of oysters, mussels, clams, edible land snails, earthworms, and crayfish. In some cases, the species being produced may be grown in cages or isolated ponds (from which escape is sometimes possible), and in others, the species are reared in nets, cages or on surfaces in natural water bodies, from which dispersal is highly likely.

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

Risks known to follow, or potentially follow, commercial rearing of invertebrates have included (1) damage to commercial crops or horticultural plants (e.g., land snails), (2) transmission of pathogens to native congeners in natural habitats (e.g., pathogens of oysters and, in Europe, crayfish), (3) introduction of associated undesirable species (e.g., oyster predators), (4) displacement of native species from their habitats (e.g., oysters and crayfish, both in Europe), and (5) spread of vertebrate animal disease (e.g., earthworms).

Damage to commercial crops or horticultural plants (land snails)

Land snails of the species consumed by people are generalist herbivores that eat many crop and horticultural plants. Escaped populations of such land snails can and do become crop pests. The brown garden snail, *Cornu aspersum* (Müller) (= *Helix aspersa*), is being produced on Long Island, New York, at a private farm licensed to do so by the U.S. Department of Agriculture (Wilson, 2018). This same snail has become established in the wild in California, where it is now a garden and horticulture pest (Stearns, 1900; UCANR, 2019).

Transmission of pathogens to native congeners in natural habitats (pathogens of oysters)

Introduction of non-native oysters for aquaculture is a potential vectoring mechanism for pathogens affecting related native oysters (Ruesink et al., 2005). There are two confirmed such cases of pathogen transfer to wild oyster populations. The protozoan *Haplosporidium nelsoni* (MSX) was first noted on the East Coast of the United States in Delaware Bay in 1957, but it is now widespread along the Atlantic and Caribbean coasts,

Banner Photos. Many commercially-produced invertebrates have established outside of containment and/or were introduced infected with parasites and other pest species, causing ecological and economical damage, including (from left to right) the red swamp crayfish, *Procambarus clarkii* (Girard) (Edoswalt, iNaturalist.org); the brown garden snail, *Cornu aspersum* (Müller) (Gerardo, iNaturalist.org); the oyster *Magallana angulata* (Lamarck) (Jan Johan ter Poorten, Wikipedia.org); the European nightcrawler, *Dendrobaena veneta* (Michaelsen) (Trevor Reid, Wikipedia.org); the giant African snail, *Achatina fulica* (Suzannevf, iNaturalist.org); and the common yabby, *Cherax destructor* (Adam Yates, iNaturalist.org).

where it infects the U.S. native eastern oyster, *Crassostrea virginica* (Gmelin). MSX was likely introduced to the East Coast through importation of infected Pacific oysters (*Crassostrea gigas* Thunberg) from California, which themselves had become infected with this Asian protozoan due to an earlier importation of oysters from Japan to California (Burreson et al., 2000). Similarly, *Bonamia ostreae* Pichot et al. was moved from its native range in the United States into Europe, where it causes mortality in wild populations of the native European oyster *Ostrea edulis* L. (Chew, 1990).

Introduction of associated undesirable species (e.g., oyster predators)

Movement of exotic oyster spat into the United States, before imposition of controls and domestic spat production, led to the introduction and establishment of predators and competitors of oysters and clams in native habitats in the United States. In the early to mid-1900s, transfers of *C. virginica* from the U.S. East Coast to the U.S. West Coast resulted in the introduction of the slipper shell *Crepidula fornicata* (L.) (an oyster competitor) and the predaceous oyster drill *Urosalpinx cinerea* (Say) (National Research Council, 2004a) (**Fig. 6**). Also, in the early to mid-1900s, introduction of *C. gigas* to the U.S. and Canadian West Coast and to Western Europe resulted in the establishment of the Japanese oyster drill, *Ocinebrellus inornatus* (Récluz) (Barber, 1997; National Research Council, 2004a).

Figure 6. In the early to mid-1900s, transfers of *Crassostrea virginica* (Gmelin) (a) from the U.S. East Coast to the U.S. West Coast resulted in the introduction of *Crepidula fornicata* (L.) (b; an oyster competitor) and *Urosalpinx cinerea* (Say) (c top left; a predaceous oyster drill). (Photos: a. Andrew C, Wikipedia.org; b. Ken-ichi Ueda, iNaturalist.org; c. Sjplante, iNaturalist.org)

Displacement of similar native species from their habitats (in Europe, oysters and crayfish)

There are no known examples in the United States of competitive displacement of native U.S. oysters or crayfish by introductions of exotic species in these groups. However, in principle, this can happen and has happened in other countries, as discussed here for illustration of the issue. In France, introduction of the exotic oyster *Magallana angulata* (Lamarck) in approximately 1868 displaced the native oyster *O. edulis*; by 1870, the native species was gone from some stretches of the French coast (Ruesink et al., 2005). In Europe, several species of North American crayfish have been introduced, with damaging effects on native crayfish due to direct competition and to the spread of an associated pathogen. In particular, the American species *Procambarus clarkii* (Girard) (the red swamp crayfish, which is the dominant crayfish used in aquaculture in the United States and which is also used in aquaculture in Italy [FAO, 2019b]) and *Pacifastacus leniusculus* (Dana) are responsible for a wide range of harmful impacts on native crayfish populations in Europe (Savini et al., 2010). *Procambarus clarkii* and the rusty crayfish, *Faxonius rusticus* (Girard), (both indigenous to parts of the United States) are being spread into parts of the United States where they are not native through use as bait (a form of aquaculture), with impacts on local native species (Kilian et al., 2009; O'Shaughnessey and Keller, 2019).

Spread of vertebrate animal disease (earthworms or pathogens able to attack native insects)

Because earthworms contain soil in their guts, worms raised and sold as live fish bait have the potential to transport vertebrate pathogens, including the pathogen causing foot and mouth disease, a critical disease of cattle and other livestock. Consequently, the importation of any species of earthworms from countries other than Canada requires submission to the U.S. Animal and Plant Health Inspection Service (APHIS) of a PPQ 526 permit application. The sole exception is for the European nightcrawler, *Dendrobaena veneta* (Michaelsen) (also known as *Eisenia hortensis*), provided it is imported from a European country that APHIS agrees is free of foot-and-mouth disease (USDA APHIS, 2019b). If permits are issued for other species of earthworms or from other locations, rearing of worms on artificial diets is required to free their guts of soil contamination. It is important to note that this procedure is not aimed at preventing invasions of new species of earthworms, but rather the prevention of worms being a vector for foot and mouth disease. Because exotic earthworm change soil structure and processes, particularly in areas in North America naturally devoid of earthworms, their own ecological effects (not just their potential to vector pathogens) are important and should be considered in the regulation of the group (Hendrix and Bohlen, 2002). No regulations, however, currently address this issue.

Several insect species are commercially reared and sold for a mixed set of reasons, including pollination (*Bombus* spp.) and as pet food (*Tenebrio* spp. and *Gryllus* spp.), among others. These colonies have the potential to spread pathogens between countries and infect native insects in the same genus or family where they are introduced for use (e.g., Goulson, 2010) or become invasive themselves.

RISK-REGULATION PROFILE FOR COMMERCIALLY-REARED INVERTEBRATES

Risk 1: Direct attack on non-target species

Not applicable.

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

Not applicable.

Risk 3: Potential to vector predators or pathogens

Importation of spat of foreign species of oysters into the United States for rearing in wild waters led to the introduction of both predators (e.g., oyster drill) and pathogens (e.g., MSX). To prevent more such introductions, production of oyster spat in state-owned hatcheries replaced importation of foreign material. More recently, sterile triploid native oysters have been developed that grow faster and show some resistance to key pathogens. Triploid native oysters now dominate the aquaculture industry in Virginia (Kobell, 2015). However, the non-farmed oyster population remains suppressed by pathogens and lack of suitable substrate for settling of spat.

Risk 4: Potential to become pests in crops

To mitigate the risk of farmed snails escaping and establishing in the wild, snail farming is regulated by federal regulations and, in some areas, by state statutes. The U.S. Department of Agriculture (USDA) requires snail-rearing facilities to conform to certain specifications. The USDA allows interstate shipment of live snails, provided the importing state approves the shipment. However, federal statutes prohibit interstate movement or importation into the United States of snails in the genus *Achatina,* e.g., *Achatina fulica* (Férussac), the giant African snail (USDA, 2019). Based on this regulatory position, it is likely that importation of other edible snails (apart from *Achatina* species) would not be prohibited, although rearing facilities would have to meet certain specifications to reduce the likelihood of escape.

Risk 5: Potential to degrade native habitats or ecosystems

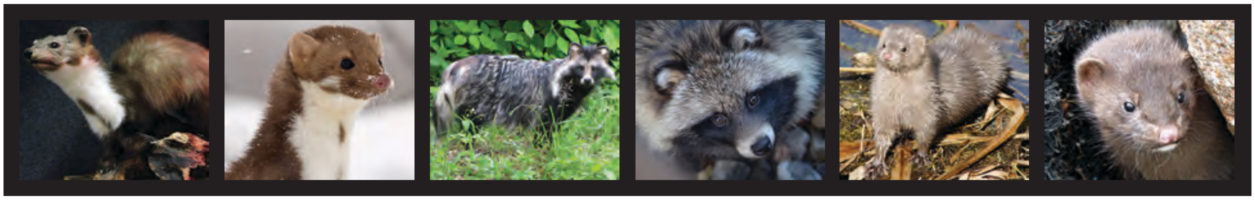
Under the injurious wildlife provisions of the Lacey Act, which has authority over mollusks and crustaceans (but not insects), eight species of invertebrates have been prohibited from importation, including some that can affect habitats: (1) mitten crabs (*Eriocheir* spp.), which pose human health risks and can damage banks and levees (Cohen and Weinstein, 2001; see the listing at 54 FR 22286, 23 May 23 1989), (2) quagga and zebra mussels (*Dreissena bugensis* Andrusov and *Dreissena polymorpha* (Pallas) (note: these two mussels are already established in the wild in the United States), and (3) the crayfish known as the common yabby (*Cherax destructor* Clark) (USFWS, 2019a).

Risk 6: Potential to reduce density of native species by changing food webs

While this risk certainly exists, it is not at this time reviewed or part of the regulatory process.

SUMMARY OF RISK REGULATION FOR COMMERCIALLY PRODUCED INVERTEBRATES

This group covers a wide variety of organisms, although most are aquatic. The main risks that have been regulated to date relate to the spread of pathogens (by oysters, worms). Some attention under the Lacey Act has been given to protection of wildlife habitats through a short black list. Finally, the Plant Quarantine Act (1912) has been used to regulate land snails due to their status as direct plant pests. In general, this is a significantly under-regulated group, with actions currently being guided by a patchwork of laws at several levels (state, federal, and international) that influence introductions but do not act directly to review and control them (e.g., for oysters and other marine invertebrates, see National Research Council, 2004b). A tool for assessing the likely degree of risk for the introduction of new species for marine aquaculture has been developed that emphasizes four components of impact: probability of establishment, rate of spread, degree of direct impact on ecosystems, and ability to vector a pathogen (Gollasch et al., 2003).



GROUP #7: PREDATORY MAMMALS FARMED FOR FUR

HISTORY OF U.S. INTRODUCTIONS OF PREDATORY MAMMALS FARMED FOR FUR

The fur-rearing industry in the United States relies heavily on the American mink, *Neovison vison* (Schreber), which likely has reduced interest in the importation of foreign species. At least one truly predatory mammalian furbearer has been introduced to the United States for fur farming—the stone marten, *Martes foina* (Erxleben). It subsequently established feral populations in Wisconsin (Frederickson, 2007). The omnivorous raccoon dog, *Nyctereutes procyonoides* (Gray), is another species that was imported into the United States to be reared for fur production. However, this species, which is native to Russia, was listed as "injurious wildlife" by the U.S. Fish and Wildlife Service before it could escape into the environment. Its use in the industry was then discontinued.

In general terms, the injurious wildlife provisions of the Lacey Act prohibit the importation of wild mammals that are on a short black list that includes (1) fruit bats in the genus *Pteropus*; (2) any mongoose or meerkat in the genera *Atilax, Cynictis, Helogale, Herpestes, Ichneumia, Mungos,* or *Suricata*; (3) any *Oryctolagus* species of European rabbit; (4) any species of Indian wild dog, red dog, or any species of *Cuon*; (5) any species of multimammate rat or mouse of the genus *Mastomys*; (6) the raccoon dog, *N. procyonoides*; and (7) the brushtail possum, *Trichosurus vulpecula* (Kerr). These "injurious wildlife" species may, however, be imported with a permit for scientific, medical, educational, and zoological purposes.

Any other live wild mammal may be imported without a permit unless another law applies (USFWS, 2019a). While releases of "non-injurious" wildlife into the wild require approval of the relevant state's wildlife conservation agency in the intended area of release, such approval is not required for importation for use of captive animals for production of fur. While law prohibits the return of any live member of an exotic species of wildlife back into the wild in the United States (50 CFR 12.34), importation of such species still poses a risk that escape into the wild may occur. This potential is well illustrated by experience in the United Kingdom, where the American mink was introduced to be farmed in captivity (**Fig. 7**). Subsequently, animals escaped or were liberated and populations became established, with severe ecological impacts on the northern water vole, *Arvicola amphibius* (L.), which in the United Kingdom has declined by over 90%, largely due to mink predation (Rushton et al., 2000; Macdonald and Harrington, 2003).

In the United States and other countries, most operations rearing predatory furbearers produce fox or mink, species that are native to North America. If an exotic predatory furbearer were desired by this industry in the future, nothing in the injurious wildlife section of the Lacey Act or other federal laws would prohibit its importation into captivity, provided the species was not protected under statutes due to its rare

Banner Photos. Two predatory mammals have been introduced to the U.S. to be farmed for fur: the stone marten, *Martes foina* (Erxleben) (photos 1, 2), which has since established in the wild, and the raccoon dog, *Nyctereutes procyonoides* (Gray) (photos 3, 4), which was listed as "injurious" and its use discontinued before it could escape into the wild. The U.S. fur-rearing industry now relies heavily on the American mink, *Neovison vison* (Schreber) (photos 5, 6). (Photos: 1. Gg. Any; 2. Bohuš Čičel; 3. Karlakas; 4. Bernd Schwabe; 5. Wojciech Uszak; 6. Jonn Leffmann) (all photos Wikipedia.org)

Figure 7. The predatory American mink, *Neovison vison* (Schreber) (a), was introduced to Europe where it was farmed for its fur (b). Mink escaped captivity in the U.K., where they have had severe ecological impacts. (Photos: a. Jared Gorrell, iNaturalist.org; b. Vadeve, Wikipedia.org)

or endangered status and it was legally collected or obtained. Also, any such predatory mammal could be released if one state gave its approval. From one such state, spread to the species' ecological limits would then follow, covering any number of states.

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

No problems have occurred in North America that have forced the development of regulations specific to the rearing of predatory furbearers; however, impacts of American mink in the United Kingdom show the potential for such problems.

RISK-REGULATION PROFILE FOR PREDATORS FARMED FOR FUR

Risk 1: Direct attack on non-target species

While no impacts on non-target species have occurred in the United States, harm to the northern water vole in the United Kingdom from introduced mink shows the potential for such impacts (Rushton et al., 2000; Macdonald and Harrington, 2003).

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

This risk might occur, but exotic mammals are inspected for health and the presence of ectoparasites such as ticks before being allowed into the country.

Risk 3: Potential to vector pathogens to non-target animals

This risk might occur, but exotic mammals are inspected for health, and sick animals would be excluded.

Risk 4: Potential to become pests in crops

This risk would depend on the biology of the introduced species, but it seems less likely for predatory mammals than herbivorous or omnivorous species.

Risk 5: Potential to degrade native habitats or ecosystems

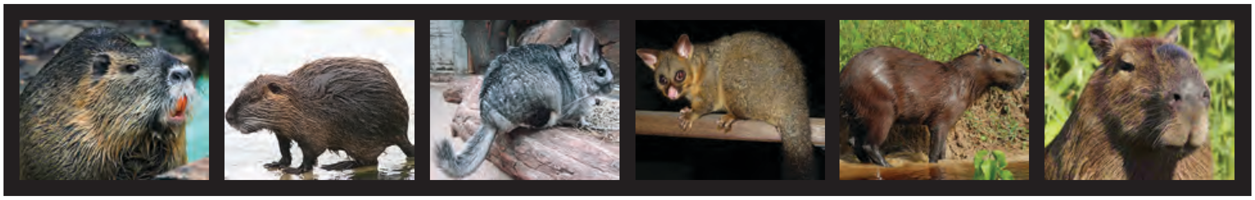
Potential exists for impacts on habitats if key herbivore species' densities were depressed by the predator.

Risk 6: Potential to reduce density of native species by changing food webs

In theory, this risk may occur, but there are no examples in the United States.

SUMMARY OF RISK REGULATION FOR PREDATORY FURBEARERS

Direct attack on non-target species (Risk 1) could occur if an exotic predator were imported, escaped, established, and preyed heavily on a particular native species. Importation of exotic predators for fur farming could also pose risks of introducing new ectoparasites (Risk 2) or pathogens (Risk 3) able to infest or infect native species, but both should be controlled by animal inspections at the time of importation. Risk 4 (crop damage) is not applicable for predatory furbearers, while Risk 5 (habitat destruction) and Risk 6 (impacts through food web changes) exist in principle and are unregulated; however, there are no known examples in the United States.



GROUP #8: HERBIVOROUS MAMMALS FARMED FOR FUR

HISTORY OF U.S. INTRODUCTIONS OF HERBIVOROUS MAMMALS FARMED FOR FUR

Two non-native herbivorous furbearers have been introduced into the United States to be farmed for fur: nutria, *Myocastor coypus* (Molina), and the long-tailed chinchilla, *Chinchilla lanigera* Bennett. The capybara, *Hydrochoerus hydrochaeris* (L.), is a third species that is sometimes farmed for fur, but it was likely brought into the United States as a pet and is potentially established. Of the 92 species of mammals classified as injurious wildlife under the Lacey Act, only three listed species are herbivores that could be farmed for fur (for remarks on the omnivorous raccoon dog, see the previous section on predatory mammals): (1) European rabbit, *Oryctolagus cuniculus* (L.); (2) European hare, *Lepus europaeus* Pallus; and (3) the Australian brushtail possum, *Trichosurus vulpecula* (Kerr). Of these, *T. vulpecula* was introduced into New Zealand for fur farming and became a highly damaging forest pest (Atkinson and Cameron, 1993). Based on the exploding population of brushtail possums in New Zealand, this species' importation into the United States was prohibited under the injurious wildlife provisions of the Lacey Act as a proactive measure before it could become established (USFWS, 2002).

In general terms, the Lacey Act prohibits the importation of wild mammals that are on a short black list described in the previous section on predatory mammals farmed for fur. Any wild mammal not listed as "injurious wildlife," however, may be imported without a permit for scientific, medical, educational, exhibition, propagation, or other legitimate purposes. While release into the wild of such "non-injurious" wildlife requires approval of the state wildlife conservation agency in the intended area of release, this is not required for importation of captive animals for production of fur. Such importations, however, pose a risk for subsequent release into the wild due to escape from rearing farms, release by animal rights activists, or release following failure of farming operations.

Of species used for fur farming in other countries that have not yet been introduced and established in the United States, the omnivorous Asiatic raccoon dog, *Nyctereutes procyonoides* (Gray), stands out as a high-risk species. While this species' diet includes animals (insects, rodents, amphibians, birds, fish, reptiles, mollusks) and carrion, it also consumes fruits, nuts, and berries, and it can be a crop pest. The risk of this species to the environment is obvious from experience in Europe, where its introduction into Latvia by the USSR led to its spread over much of Europe, from Finland to France, causing various impacts to wildlife (Kauhala and Kowalczyk, 2011; Dahl and Åhlén, 2019; Wikipedia, 2019a). For this reason, the USFWS listed the raccoon dog as injurious in 1983 before it could become established in the wild (USFWS, 1982), and it has remained absent from the wild in the United States.

Banner Photos. Only a few herbivorous mammals have been introduced to the U.S. to be farmed for fur, including nutria, *Myocastor coypus* (Molina) (photos 1,2); long-tailed chinchilla, *Chinchilla lanigera* Bennett (photo 3); Australian brushtail possum, *Trichosurus vulpecula* (Kerr) (photo 4); and capybara, *Hydrochoerus hydrochaeris* (L.) (photos 5, 6). (Photos: 1. Timo Sack, Wikipedia.org; 2. Philippe Amelant, Wikipedia.org; 3. Guérin Nicolas, Wikipedia.org; 4. Christopher Watson, Wikipedia.org; 5. Paul Donahue, iNaturalist.org; 6. Douglas Trent, iNaturalist.org)

Figure 8. Nutria, *Myocastor coypus* (Molina) (a), were introduced to the United States to be farmed for their fur. Animals escaped captivity and have since caused extensive ecological and economical damage, as evidenced here (b) with the girdling of native bald cypress trees, *Taxodium distichum* var. *imbricarium* (Nutt.) Croom. (Photos: a. Royal Tyler, Bugwood.org; b. Gerald J. Lenhard, Louisiana State University, Bugwood.org)

Nutria

Of the herbivorous furbearers that have invaded the United States, nutria (**Fig. 8a**) are a major environmental pest, subject to control efforts in various habitats, including attempted eradication in California (CDFW, 2019). Nutria cause both ecological damage to the marshes they invade and economic damage to water-distribution systems. Ecological damage is caused by consumption and disturbance of marsh vegetation. Nutria feeding destroys approximately 10 times more vegetation than is actually eaten (**Fig. 8b**). Reduction of marsh vegetative cover leads to loss of soil and disappearance of marshland (CDFW, 2019). Economic damage results from burrowing. Nutria dens and burrows can be several meters deep and up to 50 m long, often leading to streambank erosion, increased sedimentation, levee failures, and roadbed collapses (CDFW, 2019). Nutria have also caused severe damage to the marshes of southern Louisiana (Taylor and Grace, 1995) and the wetlands of Chesapeake Bay, both areas to which the nutria were introduced for fur farming in the 1930s or 1940s (Wikipedia, 2019b).

Chinchilla

The long-tailed chinchilla (*C. lanigera*) are endangered in their native range in the South American Andes, and while the species has been introduced to the United States, it has not become established there.

Capybara

Capybara (*H. hydrochaeris*) are farmed for their meat and hides in various countries. Sightings have occurred in Florida and one sighting in Mississippi, but these animals may have come from the release of animals held as pets (Benson, 2019).

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

All animals farmed for fur are mammals, and the perceived risks of herbivorous or omnivorous species used in this way are similar to those for mammals introduced for other purposes, with regulatory focus on the risk of introducing pathogens able to spread to other species of importance to people. Farming of fur-bearing herbivores does not use dangerous mammals capable of injuring people (such as bears or big cats) so that has not been an area of concern. The potential impact on native species, ecosystems, or the environment of herbivorous or omnivorous mammals imported for rearing for fur production has been addressed by the U.S. Fish and Wildlife Service principally in the two cases of the Australian bush possum and the Asian raccoon dog, whose introductions were prohibited to protect the environment.

RISK-REGULATION PROFILE FOR HERBIVOROUS MAMMALS FARMED FOR FUR

Risk 1: Direct attack on non-target species

Native plants are consumed by nutria, but since this animal is a generalist herbivore, its impacts are not usually focused on rare species, although impacts on rare species may occur in some circumstances (in Italy, Prigioni et al., 2005).

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

Exotic mammals are inspected for health and the presence of ectoparasites such as ticks before being allowed into the country.

Risk 3: Potential to vector pathogens to non-target animals

This risk is a serious concern that is addressed by requirements for veterinary inspections to determine the health of imported animals.

Risk 4: Potential to become pests in crops

Some potential does exist for herbivorous furbearers to damage crops, but no clear examples exist for the United States, except indirectly for nutria, which can damage crops by degrading the physical integrity of irrigation canals.

Risk 5: Potential to degrade native habitats or ecosystems

There is a clear risk of habitat degradation, as illustrated by the impact of nutria on freshwater marshes.

Risk 6: Potential to reduce density of native species by changing food webs

In theory, this risk may occur, but there are no examples in the United States.

SUMMARY OF RISK REGULATION FOR HERBIVOROUS MAMMALS FARMED FOR FUR

In the United States, nutria is the only example of an herbivorous mammal imported for fur farming escaping and causing harm in the wild. However, the brushtail possum in New Zealand is another important example. Taken together, these two examples suggest that the risks posed by species in this group include direct consumption of native plants (Risk 1), habitat destruction (Risk 5), and potentially crop damage (Risk 4) and food web changes (Risk 6). All four of these risks are unregulated. Ectoparasites (Risk 2) and pathogens (Risk 3) might be inadvertently introduced along with exotic mammals, but should be controlled by animal inspections at the time of importation.

GROUP #9: BIRDS AND MAMMALS FOR HUNTING

HISTORY OF U.S. INTRODUCTIONS OF BIRDS AND MAMMALS FOR HUNTING

Birds

Relatively few birds have been introduced into the United States for hunting, with most introductions being for use as pets. This outcome may be due to the prohibition, from 1900 to 1948 by an early version of the Lacey Act, of wild bird importations, with the exception of caged birds. Since 1948, the injurious wildlife section of the Lacey Act has prohibited the importation of certain wild birds, forming a short black list that currently includes four species: (1) the "pink starling," *Sturnus roseus* (L.); (2) the dioch, *Quelea quelea* (L.); (3) the Java sparrow, *Lonchura oryzivora* (L.); and (4) the red-whiskered bulbul, *Pycnonotus jocosus* (L.). Unless prohibited by the Convention on International Trade in Endangered Species (CITES) or other foreign laws, any species of wild birds not listed as "injurious wildlife" may be imported without a permit for scientific, medical, educational, exhibition, or propagation purposes. Release of any such imported birds into the wild may occur with the approval of the relevant state wildlife conservation agency having jurisdiction over the area of release.

Before 1900, some game bird introductions were made by private individuals. The ring-neck pheasant, *Phasianus colchicus* L., was first introduced privately into Oregon from China in 1881 (Oldham, 2008). It was subsequently spread by state fish and game agencies to nearly all other states. It has established especially well in northern, grain-producing states and become an abundant species much appreciated by hunters, stimulating fish and game agencies to consider other possible introductions. The chukar partridge, *Alectoris chukar* (Gray), was introduced into the United States in 1893 by W. O. Blaisdell of Illinois who brought in five pairs of chukars from Karachi, India (Cottam et al., 1940; Christensen, 1970). Following this initial introduction, a majority of the U.S. states and Canadian provinces made releases of this bird. It established throughout the Great Basin between the Cascade/Sierra Mountains and the Rocky Mountains, with a distribution from southern California to Canada. Similarly, the gray partridge, *Perdix perdix* (L.), which was first introduced about 1900, was further spread by state agencies and now has a distribution in the northern United States that stretches from Washington to Wisconsin (Carroll, 1993). The Himalayan snowcock, *Tetraogallus himalayensis* G.R. Gray, was first introduced into the United States in 1963 by the Nevada state agency responsible for fish and game into the high alpine areas of Nevada's Ruby Mountains; it successfully established, but without further spread (Christensen, 1998).

These introductions share a common set of beliefs and a common mechanism. The underlying belief is that new species for hunting are a pure benefit, with no risks or negative side effects. Early releases were

Banner Photos. Only a few species of birds and mammals have been introduced to the United States for hunting in the wild; however, many more have been introduced into containment for hunting purposes. Species introduced include (from left to right) the ring-neck pheasant, *Phasianus colchicus* L. (Chung-Yen); Russian wild boar, *Sus scrofa* L. (Eric Graham); chukar partridge, *Alectoris chukar* (Gray) (Yael Orgad); gray partridge, *Perdix perdix* (L.) (Admss); Sahara oryx, *Oryx dammah* (Cretzschmar) (Sara Hollerich Giles); and Himalayan snowcock, *Tetraogallus himalayensis* G.R. Gray (Cnarraway) (all photos iNaturalist.org).

Figure 9. Sika deer, *Cervus nippon* Temminck (a), were intentionally introduced from Asia into the wild in North America and elsewhere for hunting. Populations have since increased, causing damage to crops (b) and forests, and reducing forage (c) for domestic livestock and native ungulates (Feldhamer and Demarais, 2009). (Photos: a. Yan Vincent; b. Chris Moody; c. Anna; all iNaturalist.org)

done privately by individuals with this belief, but later introductions (such as much of the spread of chukar and the entire Himalayan snowcock program) were done by state agencies charged with protecting game and increasing opportunities for hunting. The introduction of Himalayan snowcock, specifically, was guided by the belief that high alpine habitats in Nevada had an "empty niche" in the sense that there was no suitable, huntable, native game bird there.

Mammals

(See previous section on mammals imported as furbearers for general information on the restrictions of the "injurious wildlife" section of the Lacey Act on the importation of mammals). Efforts to increase huntable exotic animals other than birds occurred in two different ways in the United States: (1) releases of new species into the wild to create self-sustaining, spreading populations, as was done for the Russian wild boar *Sus scrofa* L. and other species (**Fig. 9**); and (2) creating fenced populations of diverse exotic mammals for hunting, from which the animals are not expected to escape or establish breeding populations outside of the fenced area.

(1) Release of new species into the wild

In the 1900s (in California in 1925 and again in 1950 [Waithman et al., 1999]), the Eurasian or Russian wild boar was introduced to the United States for sport hunting. It has since spread rapidly and caused great economic and environmental damage (Snow et al., 2017), leading to a formal U.S. Department of Agriculture (USDA) swine suppression program (USDA APHIS, 2019a). See **Fig. 4** (Group 4) for images and additional information.

(2) Creating fenced populations of exotic mammals subject to hunting

A wide range of exotic ungulates, goats, and other mammals are held in large, outdoor fenced areas. Stock is bred on site and sold to other parties. It is estimated that more than 1,000 captive-mammal hunting operations are operating in at least two dozen states, with the greatest concentration in Texas. No federal law bans the practice, and only about half of the states have policies that ban or restrict this type of animal importation. While escape is not intended, there is potential for caged animals to escape during extreme weather events or civil disruptions if fences are breached.

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

Importation of living individuals of wildlife into the United States for any purpose, including use for hunting, is subject to restrictions that have as their primary purposes (1) the prevention of the introduction of pathogens and (2) the protection of animals that were not legally collected in their country of origin or whose commercial exploitation is prohibited under international agreements protecting rare or over-exploited species (e.g., CITES) (USDA APHIS, 2019c).

Risk of pathogen introduction

Because of the risk that bird introductions pose for moving pathogens (e.g., the Highly Pathogenic Avian Influenza [H5N1 virus]), for all sources except Canada, the USDA quarantines birds for 30 days in special USDA animal importation facilities to screen for infected individuals. The Center for Disease Control prohibits the importation of African rodents due to their potential to vector the monkeypox virus. This virus did occur in a shipment of giant Gambian rats (*Cricetomys gambianus* Waterhouse) that were imported into the United States by the pet trade.

Species protected under CITES

Species that are protected under CITES require permits to move protected animals from one country to another, and importation may be subject to permit requirements or restrictions. Commercial and recreational use of such species is prohibited.

RISK-REGULATION PROFILE FOR BIRDS AND MAMMALS FOR HUNTING

Risk 1: Direct attack on non-target species

Exotic birds likely eat native insects, and exotic herbivorous mammals eat native plants. These events are not seen as posing risks unless impacts occur on rare or endangered native species.

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

Exotic animals are inspected for health and the presence of ectoparasites such as ticks before being allowed into the country.

Risk 3: Potential to vector pathogens to non-target animals

This risk is a significant concern, especially for birds, but also for some mammals, and is a key focus of regulation of this type of importation.

Risk 4: Potential to become pests in crops

Some species, such as wild boar, destroy crops through foraging and rooting.

Risk 5: Potential to degrade native habitats or ecosystems

Extreme risk for some species, as demonstrated by Russian wild boar.

Risk 6: Potential to reduce density of native species by changing food webs

Theoretically, this is a risk, and potentially one of considerable importance. Some consideration is now given to not placing native species in direct competition with a similar exotic species. For example, whitetail deer, *Odocoileus virginianus* (Zimmermann), are not being considered for introduction to California because they would compete with native deer.

SUMMARY OF RISK REGULATION FOR BIRDS AND MAMMALS FOR HUNTING

Regulations address the risk that pathogens (Risk 3) or ectoparasites (Risk 2) might be inadvertently introduced along with exotic birds or mammals, but no regulations examine the ecological effects of the introduced species themselves, either through feeding (Risk 1), changing native habitats (Risk 5) or food webs (Risk 6), should they by intent or accident establish wild populations, with the caveat that any species can be reviewed for listing as "injurious wildlife" for any or all of these criteria under the relevant sections of the Lacey Act. Exotic game held in fenced areas are treated as if fencing prevents escape completely, which in the long run is likely not to be the case. The potential for introduced sport species to become agriculture pests (Risk 4) is illustrated by Russian wild boar, whose rooting and feeding can destroy fields of some crops.

GROUP #10: EXOTIC FISH FOR SPORT OR COMMERCIAL FISHING

HISTORY OF U.S. INTRODUCTIONS OF FISH FOR SPORT OR COMMERCIAL FISHING

Fish have been introduced into the United States both privately and by government agencies since the 1840s for many reasons, including (1) use for aquaculture to grow fish for consumption (5 spp.); (2) fish for control of weeds or mosquitoes (8 spp.); (3) medical uses (1 sp.); (4) ornamental fish reared for the aquarium pet trade (134 spp.); (5) private introduction of food or sport fish (9 spp.); (6) food or sport fish released into wild waters by government agencies (26 spp.); and (7) introductions whose reasons and circumstances of introduction are historical and unknown (12 spp.) (USGS, 2019a). Separate from these are an even larger number of translocations of fish native to parts of the United States into areas outside their natural range, which biologically is the same as an exotic introduction (e.g., movement of smallmouth bass [*Micropterus dolomieu* Lacépède] from Lake Champlain to California [Moyle, 1976]). However, these movements are not federally regulated and not considered here.

Of the 195 species of exotic introduced fish listed above (USGS, 2019a), most were introduced as species to be sold as ornamental fish for ponds or aquaria—fish that later either escaped from outdoor rearing ponds (often during flooding) or were released by customers when the fish became too large for their tanks. That group of fish introductions is discussed in a later section on the pet trade. Here we focus on the fish introduced into wild waters for food or sport, which includes five species released historically before the era of government involvement (e.g., common carp, *Cyprinus carpio* L.), nine that were released illegally by private persons in more modern times (e.g., species of snakehead fish [Channidae]), and 26 whose releases were sponsored by government agencies, e.g., the Ohrid trout, *Salmo letnica* (Karaman). These releases were concentrated in two periods, the first being seven introductions by the U.S. Fish Commission between 1865 and 1885 (**Fig. 10**), and the second being 15 species released by state fish and game departments or other agencies between 1950 and 1980. After 1980, the practice seems to have died out, with only two additional releases of exotic fish sourced directly from outside the United States, *Lates mariae* Steindachner and *Sander lucioperca* (L.) (USGS, 2019a). However, such releases are still federally allowed if states wish to make introductions. Also, exotic species that were previously introduced into the United States continued to be released into new states via interstate transfers long after the original introduction, including (1) tench, *Tinca tinca* (L.), from 1884 in Nebraska to 1999 in Vermont; (2) tiger trout, hybrid of *Salmo trutta* L. x *Salvelinus fontinalis* (Mitchill), from 1950 in Minnesota to 2017 in Idaho; (3) blue tilapia, *Oreochromis aureus* (Steindachner), from 1961 in Florida to 2017 in Ohio; and (4) silver

Banner Photos. Many exotic fish species have been introduced or redistributed by federal or state agencies or private individuals for the purposes of sport fishing. Several have had severe impacts on native ecosystems. Introduced or redistributed species include (from left to right) northern snakehead, *Channa argus* (Cantor) (Pmk00001); Ohrid trout, *Salmo letnica* (Karaman) (Albinfo, Wikipedia.org); bigeye lates, *Lates mariae* Steindachner (Oliver Drescher, iNaturalist.org); tench, *Tinca tinca* (L.) (Matt Gorton, iNaturalist.org); tiger trout, hybrid of *Salmo trutta* L. x *Salvelinus fontinalis* (Mitchill) (Wasatch_hunter, iNaturalist.org); and silver carp, *Hypophthalmichthys molitrix* (Valenciennes) (H.T.Cheng, iNaturalist.org).

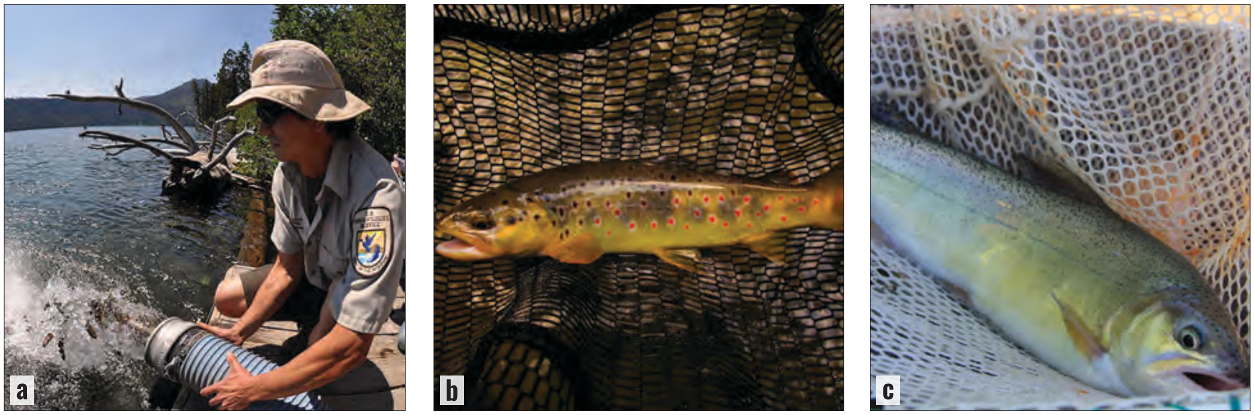


Figure 10. Stocking of fish into lakes and rivers (a) has occurred in the U.S. since at least 1865. Introducing exotic species, such as German trout, *Salmo trutta* L. (b), as well as native rainbow trout, *Oncorhynchus mykiss* (Walbaum), to areas where they previously didn't occur has had harmful effects on some native fish species due to predation, introduction of disease, competition and hybridization with threatened species such as the Gila trout, *Oncorhynchus gilae* (Miller). (Photos: a. Pacific Southwest Region USFWS; b. David_Taylor, iNaturalist.org; c. Melanie Dabovich, USFWS)

carp, *Hypophthalmichthys molitrix* (Valenciennes), from 1972 in Puerto Rico and Arizona to 2012 in Ohio and Oklahoma (USGS, 2019a).

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

Early in the history of exotic fish introductions or the mixing of fish faunas regionally within the United States, no risks were perceived; the general attitude was one of trial and error to see how local fisheries could be "enhanced" by adding fishable, edible species favored in other regions of the United States or other countries. The Lacey Act (18 U.S.C. 42) checked such movement to a degree, allowing undesirable species to be designated as "injurious wildlife" and therefore making their movement into the United States or between named jurisdictions subject to regulations. Such listings occurred because the listed non-native species were expected to cause harm to people, agriculture, horticulture, forestry, or wildlife in the United States. Listing under this law in some cases targeted an already-introduced species of injurious fish (to limit further spread) and their relatives, or additional species believed by the agency to be potentially damaging based on experience in other countries. The Lacey Act's requirements for the importation of fish (USFWS, 2019b) include (1) the importer must file a written declaration of importation; (2) the release of imported live fish into wild waters is prohibited, unless authorized by the State wildlife conservation agency having jurisdiction over the area, (3) the importation of fish species found on the agency's list of "injurious wildlife" is prohibited (see below for listed fish); (4) the movement of salmonoids is regulated for the purpose of preventing the spread of pathogens, especially the *Oncorhynchus masou* virus and viruses causing viral hemorrhagic septicemia, infectious hematopoietic necrosis, and infectious pancreatic necrosis. Screening for these viruses is required. Also, live fish eggs of foreign origin must be disinfected following procedures specified in the regulation.

There are 408 fish on the list of "injurious wildlife" (USFWS, 2019a), including 6 carp (Cyprinidae, of which 3 are already in the U.S.): bighead carp, *Hypophthalmichthys nobilis* (J. Richardson) (in 26 states); black carp, *Mylopharyngodon piceus* (J. Richardson) (in 9 states); crucian carp, *Carassius carassius* (L.) (not in the U.S.); largescale silver carp, *Hypophthalmichthys harmandi* Sauvage (not in the U.S.); Prussian carp, *Carassius gibelio* (Bloch) (not in the U.S.); and silver carp, *H. molitrix* (in 15 states and Puerto Rico); 122 walking catfish (Clariidae), of which *Clarias batrachus* (L.) is established in Florida; wels catfish, *Silurus glanis* L. (not in the U.S.); Eurasian minnow, *Phoxinus phoxinus* (L.) (not in the U.S.); stone moroko, *Pseudorasbora parva* Temminck & Schlegel (not in the U.S.); European perch, *Perca fluviatilis* L. (not in the U.S.); Nile perch, *Lates niloticus* (L.) (formerly in Texas; current status not clear); roach, *Rutilus rutilus* (L.) (not in the

U.S.); 228 salmonids (Salmonidae) (due to the risk of pathogen introductions); Amur sleeper, *Perccottus glenii* Dybowski (not in the U.S.); 44 snakeheads (Channidae) (4 species in the U.S.); and the zander, *S. lucioperca* (already in the U.S.).

In addition, Ecological Risk Screening Summaries have been created by the U.S. Fish and Wildlife Service to quickly identify the level of invasion risk (high, uncertain, low) of species of fish (and other vertebrates, invertebrates, and plants) (USFWS, 2020c) as a way to rank species for decision-making, but this characterization has no force of regulation.

RISK-REGULATION PROFILE FOR FISH RELEASED FOR SPORT OR COMMERCIAL FISHING

Risk 1: Direct attack on non-target species

This risk is recognized and regulated in some cases (e.g., snakeheads and some others) by placing certain species on the list of fish designated under the Lacey Act as "injurious wildlife." However, most exotic fish consume many species of non-target fish, plants, amphibians, or insects, and those risks are generally not of concern to regulators.

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

Not applicable.

Risk 3: Potential to vector pathogens to non-target fish

A definite and significant risk for fish introductions to spread pathogens is well recognized for salmonids, and provisions in the Lacey Act exist to control this risk. However, the requirement is specific for this fish group. Control of fish introductions to prevent invasion of pathogens associated with other fish families (e.g., cyprinid herpesvirus 3 [CyHV-3] in carp [McColl et al., 2016]) could be addressed under the injurious wildlife section of the Lacey Act; however, the U.S. Fish and Wildlife Service does not have the authority to directly regulate the pathogens themselves.

Risk 4: Potential to become pests in crops

Not applicable.

Risk 5: Potential to degrade native habitats or ecosystems

This is a recognized but unregulated risk. Carp, by virtue of how they feed, are known to reduce water clarity, destroy native macrophytes, and promote algal growth (e.g., Tapia and Zambrano, 2003; Badiou and Goldsborough, 2015).

Risk 6: Potential to reduce density of native species by changing food webs

This risk certainly exists potentially, but has not been regulated. Each introduction would have to be studied to assess the significance of this risk.

SUMMARY OF RISK REGULATION FOR FISH RELEASED FOR FISHING

In summary, the risk of direct attack on non-target species (Risk 1) is regulated for some predatory fish that attack valuable existing fish species, but not for fish that only prey on native plants or insects, unless this affects at-risk species or ecosystems. Also, fish importations are regulated at the federal level for the purpose of limiting the spread of pathogens (Risk 3) that can affect salmonoids by including many salmonoids on a black list of species under the Lacey Act; however, other groups of fish pathogens are not addressed. Risks to habitats (Risk 5) and native food webs (Risk 6) clearly exist but are largely ignored, with the exception of placing some species of carp (the group that to date has caused the greatest degradation of habitat) on the Lacey Act black list. However, for fish species that are not black listed, no pre-introduction review is required, and any state may introduce into wild waters any species it wishes to release. Risk 2 (vectoring pests such as insects or nematodes) and Risk 4 (damaging crops) are generally not applicable.

GROUP #11: ANIMALS SOLD AS PETS

HISTORY OF U.S. INTRODUCTIONS OF ANIMALS SOLD AS PETS

For vertebrates, the pet trade is a large and increasing pathway for establishment of exotic species, and it is the dominant pathway for reptiles and amphibians (Kraus, 2009; Lockwood et al., 2019). Of the 140 non-native species in these latter two groups that have been introduced into Florida, 85% came in through the pet trade (Krysko et al., 2011). The U.S. market for tank marine fish is the largest in the world, with annual imports of over 11 million individual fish, including 2,300 species from 125 families (Rhyne et al., 2012, 2017). The number of freshwater fish species imported for the aquarium trade (worldwide) is at least ten times as large as the number of marine species (Livengood et al., 2014). In North America, of the many species of freshwater fish imported by the aquarium trade, at least 100 have been released in wild water bodies and 40 are known to be established (Rixon et al., 2005). Increasingly, insects are also being imported for sale as pets (Thomas, 1995).

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

Under the Lacey Act (18 U.S.C. 42), a small number of pet species that are associated with pathogens, are known crop pests, or are known environmental pests have been placed on the list of "injurious wildlife" (USFWS, 2019a).

(1) Pathogens

Some pet species are on the Lacey Act list of "injurious wildlife" because they are associated with pathogens able to infect wildlife, such as 20 genera of European salamanders, which are listed because they can potentially vector the chytrid fungus *Batrachochytrium salamandrivorans* Martel et al., which would threaten U.S. native salamanders.

(2) Crop pests

The four cage birds listed under the Lacey Act are all important crop pests in their native ranges.

Banner Photos. The pet trade is an increasing pathway for exotic species introductions in the United States. Many species introduced in this manner have escaped containment or were intentionally released into the wild where they have since established and caused ecological harm, including (from left to right) the red lionfish, *Pterois volitans* (L.) (Sarah-sydneydives); bearded dragon, *Pogona vitticeps* (Ahl) (John Sullivan); Nile monitor lizard, *Varanus niloticus* (L.) (Copper); monk parakeet, *Myiopsitta monachus* (Boddaert) (Donata Jonuškienė); green iguana, *Iguana iguana* (L.) (Daniel Onea); and rhesus macaque, *Macaca mulatta* (Zimmermann) (Dr. Vijay Anand Ismavel MS MCh) (all photos iNaturalist.org).

(3) Environmental pests

Some pet species known to become invasive environmental pests are also black listed, including (a) walking catfish, (b) yabby crayfish, (c) Chinese mitten crabs, and (d) certain large constrictor snakes (anacondas and pythons) related to snakes that have already established as environmental pests in Florida.

Insects sold as pets are regulated if "they might be a crop pest, or a biocontrol agent, or affect a biocontrol agent" (Robert Pfannenstiel, USDA, APHIS, pers. comm.). Other species of insects imported as pets are not regulated.

RISK-REGULATION PROFILE FOR EXOTIC SPECIES SOLD AS PETS

Risk 1: Direct attack on non-target species

Regulations do not require any consistent attempt to discover (before importation) if a risk of attack on non-target species might be posed by species proposed for importation as pets. In a few cases in which such a risk is well recognized (e.g., pythons in Florida), or where the U.S. Fish and Wildlife Service has evaluated the risk of harm for species not yet established in the United States, some species have been listed as "injurious wildlife."

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

Exotic animals are inspected for health and the presence of ectoparasites such as ticks before being allowed into the country.

Risk 3: Potential to vector pathogens to humans or wildlife

Some groups have been identified as potential sources of human or wildlife pathogens and have been put on the Lacey Act black list. However, no systematic effort is made before importation to determine the level of threat from this risk posed by new species being imported for use as pets.

Risk 4: Potential to become pests in crops

A few birds that are well known crop pests have been prohibited, but this risk is not consistently evaluated before new species are introduced in the United States. Rather, the risk is only controlled if the species already has a history of being a crop pest elsewhere, which could cause the USFWS to list it as "injurious wildlife." This process, however, allows unrecognized pests to be introduced without evaluation.

Risk 5: Potential to degrade native habitats or ecosystems

A few crustaceans have been listed as "injurious wildlife" because they pose risk to native habitats, but this risk is not consistently evaluated before new species are introduced in the United States. Rather, the risk is only controlled if the species already has a history of degrading native habitats or ecosystems elsewhere, which could cause the USFWS to list it as "injurious wildlife." This process, however, allows unrecognized pests to be introduced without evaluation.

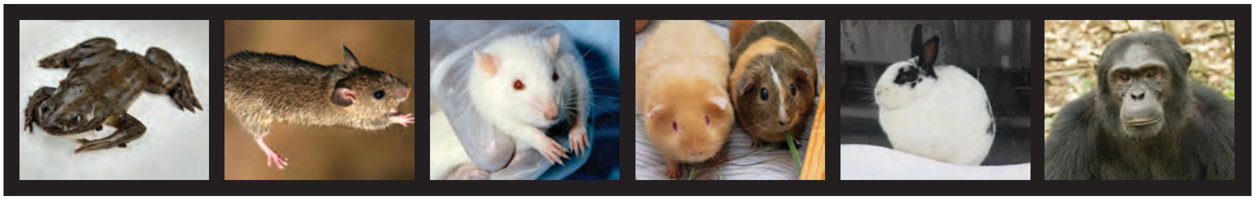
Risk 6: Potential to reduce density of native species by changing food webs

This risk is addressed if a species is chosen for review for potential listing as "injurious wildlife." However, this risk is not consistently evaluated before introduction of all new species in the United States. Rather, the risk is only addressed if the species already has a history of changing food webs elsewhere. In the absence of such a history, species can be introduced without evaluation that turn out to cause such damage in the United States.

Figure 11. The Burmese python, *Python bivittatus* (Kuhl) (a), was introduced to the U.S. via the pet trade and established populations in the Everglades after it escaped or was intentionally released. Pythons are currently destroying populations of native birds and mammals, such as the native Virginia opossum, *Didelphis virginiana* Kerr (b), which is shown partially digested in a dissected python (c). Extensive predation on opossums and other nest-feeding mammals has disrupted food webs by increasing the nesting success of turtles (Willson, 2017). (Photos: a. J.D. Willson, iNaturalist.org; b. David Cappaert, Bugwood.org; c. Lori Oberhofer, National Park Service, Bugwood.org)

SUMMARY OF RISK REGULATION FOR ANIMALS SOLD AS PETS

In summary, pets are assumed to be risk free unless a particular species or its relatives have previously been determined to be harmful and consequently been placed on the "injurious wildlife" list of the Lacey Act. No evaluation of the potential risks of individual new species (ones not on the Lacey Act "injurious wildlife" list) is required before importation. Risk of direct attack on non-target species (Risk 1) is not regulated, unless the species has been listed as "injurious wildlife." Such listing has occurred for some snakes, such as the Burmese python *Python bivittatus* (Kuhl), which is well documented as causing dramatic damage to native species' populations (**Fig. 11**; Dorcas et al., 2012; Sovie et al., 2016), as well as seven other pythons and anacondas. The risks that some pet species pose as vectors of pathogens of wildlife are well known, and the sale of some such species is prohibited (e.g., salamanders able to transmit the salamander chytrid fungus) (Risk 3). Ectoparasites (Risk 2) might be inadvertently introduced along with exotic pets, but should be controlled by animal inspections at the time of importation. Similarly, four bird species have been prohibited under the Lacey Act because they are well known crop pests (Risk 4). Potential to degrade native habitats (Risk 5) is known for some crustaceans, and some species are listed under the Lacey Act, but this risk is not evaluated for non-listed species before their introduction. Effects of introduced pets on food webs (Risk 6) clearly exist but are largely ignored.



GROUP #12: ANIMALS INTRODUCED FOR MEDICAL USES

HISTORY OF U.S. INTRODUCTIONS OF ANIMALS FOR MEDICAL USES

Live animals have been used in medicine for various reasons, including testing and as models of human diseases. No particular protocols govern importation for this use, and the implicit assumption is that such animals live and die in captivity. However, this pathway provides opportunities for unauthorized releases similar to those from the pet trade. Such medical-use animals may, under some circumstances, be released by people involved in the animals' care or final disposal. Such releases may result in the animals becoming established as invasive species. Also, some medical-use species have the potential to move their pathogens to new geographical locations. Under modern standards, laboratory animals are bred in controlled colonies and disposed of after use, limiting both of these concerns. So, for example, even though multimammate rodents such as *Mastomys* spp. are hosts for viruses that can infect people (e.g. the Lassa virus [Lecompte et al., 2006]), the rodent *Mastomys coucha* (Smith), which is used as a model species (Vinzón et al., 2014), is derived from laboratory colonies. However, in the past, wild collected animals were used in some cases. For example, in the 1930s, Shapiro and Zwarenstein (1935) developed a test for human pregnancy based on injecting a woman's urine into a female of the African clawed frog, *Xenopus laevis* Daudin. If the frog laid eggs, the woman was pregnant. This simple test was widely used for about 30 years, and, during this period, wild-collected African clawed frogs were distributed around the world. Although *X. laevis* is no longer used for pregnancy tests, the species' eggs and embryos are still a popular model system in medical research (Wallingford et al., 2010; Harland and Grainger, 2011). Releases of *X. laevis* have resulted in established wild populations in at least four continents (Measey et al. 2012; **Fig. 12**), partly due to medical use and partly through sale as pets.

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

Few risks have been formally associated with the use of live animals in medical research or practice, apart from the use of rare species in Chinese and other medicines, for which the Convention on International Trade in Endangered Species (CITES) is the intended control mechanism. Here we focus on species that are not rare, endangered, or illegally obtained. One risk is that such species may pose risks of introduction of pathogens, and indeed some species are precisely imported because they host pathogens that make them

Banner Photos. Several species used in the medical industry have escaped captivity or potentially can do so and establish wild populations, such as the African clawed frog, *Xenopus laevis* Daudin (left image, Erestor, iNaturalist.org). Other species frequently used in the medical industry include (from left to right) mice, *Mastomys coucha* (Smith) (_3foxes iNaturalist.org); rats, *Rattus norvegicus domestica* (Berkenhout) (Janet Stephens); guinea pigs, *Cavia porcellus* (L.) (Sandos, Wikipedia.org); rabbits, *Oryctolagus cuniculus domesticus* (L.) (Jameson Nagle); and chimpanzees, *Pan troglodytes* (Blumenbach) (Scott Bowers, iNaturalist.org).

Figure 12. The African clawed frog, *Xenopus laevis* Daudin (a), has been widely used in the medical industry. It has established wild populations in at least four continents, partly due to medical use and partly through sale as pets. Introduced populations prey upon and compete with native species, make water bodies turbid, provide a novel food source to both native (b) and non-native predators, and can potentially vector the chytrid fungus *Batrachochytrium dendrobatidis* Longcore, Pessier & D.K. Nichols (Somma, 2019; Global Invasive Species Database, 2020a). (Photos: a. Alex Rebelo; b. Mickey Long; both iNaturalist.org)

useful model systems for studying related pathogens affecting people (e.g., the rodent *M. coucha*, which is used as a model species [Vinzón et al., 2014]). Presumably, modern rules for housing animal colonies, the need for control of the animals' environment to make them useful in research, and rules for disposal of medical waste should prevent this being an accidental pathway for pathogen introduction. However, the pathway may remain open if non-hazardous animals (such as *X. laevis* frogs) that are surplus to needs and are directed to be euthanized are instead released into the wild by employees who do not wish to kill animals.

RISK-REGULATION PROFILE FOR ANIMALS INTRODUCED FOR MEDICAL USES

Risk 1: Direct attack on non-target species

In California, *Xenopus laevis*—released either from medical colonies or by owners of individuals held as pets—consumes native invertebrates; native frogs (all life stages); western toads, *Anaxyrus boreas* (Baird and Girard); arroyo chubs, *Gila orcuttii* C.H. Eigenmann & R.S. Eigenmann; the endangered tidewater goby, *Eucyclogobius newberryi* (Girard); and locally endangered three-spined sticklebacks (*Gasterosteus aculeatus* L.) (McCoid and Fritts, 1980; Lafferty and Page, 1997; Stebbins, 2003; Stebbins and McGinnis, 2012; Dodd, 2013).

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

Not applicable.

Risk 3: Potential to vector pathogens to non-target species

This risk is possible, but is presumably controlled by "good practices" in research laboratories.

Risk 4: Potential to become pests in crops

Not applicable.

Risk 5: Potential to degrade native habitats or ecosystems

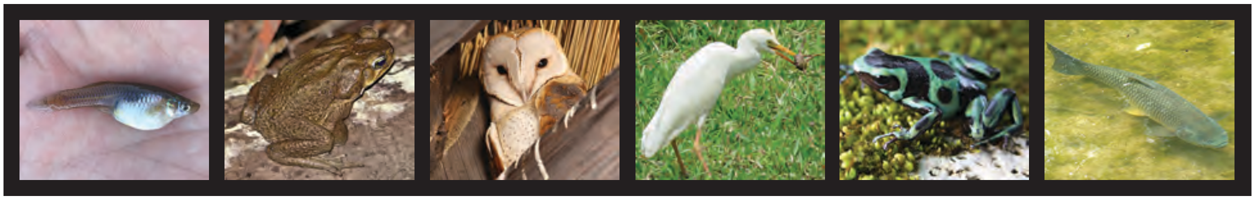
In theory, this risk may occur, but there are no examples in the United States.

Risk 6: Potential to reduce density of native species by changing food webs

In theory, this risk may occur, but there are no examples in the United States.

SUMMARY OF RISK REGULATION FOR ANIMALS INTRODUCED FOR MEDICAL USES

This pathway needs to be studied to understand the scope of exposure it poses by determining the range of species held in research colonies or imported live for immediate use, noting in particular if specimens come from the wild or from rearing facilities. Training on risks to the environment of unauthorized releases for employees of facilities holding such species should be required and disposal records maintained. The greatest risk may be the spread of pathogens (Risk 3), which may be self-regulated by the medical establishment, provided animals are in fact not released into the wild after being used. Risk of harm to non-target species (Risk 1) has been demonstrated in California by the introduction of the African clawed frog, but is not regulated. Risk of harm to native habitats (Risk 5) or food webs (Risk 6) exist in principle and are unregulated; however, there are no known examples in the United States. Risks of vectoring insects (Risk 2) or being crop pests (Risk 4) do not seem to apply.



GROUP #13: VERTEBRATES FOR PEST CONTROL

HISTORY OF U.S. INTRODUCTIONS OF VERTEBRATES FOR PEST CONTROL

The kinds of species that people have tried to use to reduce pests have evolved over the centuries. The earliest and most familiar predators used in this way were mammals, the group with which people are most familiar. Since remote historical times, cats have been used to lower rodent numbers around houses and barns. In the 18th and 19th centuries (pre-1900), familiarity with predatory vertebrates led European plantation owners and farmers in certain areas (e.g., New Zealand, Caribbean islands, Hawaii) to try to use predatory vertebrates to reduce populations of rodents and other pests. Introductions of vertebrates in this period of history were made by private individuals and were neither sanctioned nor prohibited by governments, although governments began to play a role by the end of the 19th century. During the period that preceded governmental oversight, some generalist vertebrate predators, such as species of mongoose, stoats, and insectivorous birds, were released in Hawaii and other locations. These introductions were generally ineffective against their targets and often caused important ecological damage (Davis et al., 1976).

Because pre-1900 private introductions of species for control of rodents or other pests—e.g., the mongoose *Herpestes javanicus* (É. Geoffroy Saint-Hilairein) released in Hawaii in 1883—caused significant damage to native vertebrate wildlife (**Fig. 13**), the territory of Hawaii enacted legal controls in 1903 intended to prevent the unplanned introduction of new potentially damaging species and ensure the proper use of biological control agents (Funasaki et al., 1988). A few terrestrial vertebrates were introduced after 1900, including the cane toad—*Rhinella marina* (L.)—and the poison dart frog *Dendrobates auratus* (Girard) in 1932, the barn owl, *Tyto alba* (Scopoli), in 1958, and the cattle egret, *Bubulcus ibis* (L.), in 1959 (Funasaki et al., 1988). In general, however, the introduction of terrestrial vertebrates (mammals, birds, amphibians) for biological control ended in the United States (including Hawaii) by about 1960.

In contrast, the use of exotic fish for biological control continued longer—for example, guppies, *Poecilia reticulata* Peters; and western mosquito fish, *Gambusia affinis* (Baird & Girard), for mosquito control and grass carp, *Ctenopharyngodon idella* (Valenciennes), for aquatic weed control (USGS, 2019a). To some extent, this occurred because introduced fish were more effective against their target pests than were terrestrial predaceous vertebrates, and their risks were harder to detect or more acceptable to the public. Indeed, exotic fish that consumed mosquito larvae were encouraged as a safer replacement for pesticides. The harm these introduced fish caused to native top-feeding minnows through competition or hybridization became clear, at least to fish biologists, by the 1980s (e.g., Courtenay and Meffe, 1989). The use

Banner Photos. Though no longer practiced in the U.S., the introduction of vertebrates for pest control often had severe ecological impacts from non-target predation, competition, altering food webs, disease introduction, and more. Predaceous vertebrates introduced for pest control include (from left to right) the western mosquito fish, *Gambusia affinis* (Baird & Girard) (Corey Lange); cane toad, *Rhinella marina* (L.) (Antonio Rodríguez Arduengo); barn owl, *Tyto alba* (Scopoli) (Mikael Bauer); cattle egret, *Bubulcus ibis* (L.) (Jhon Velasquez); the poison dart frog *Dendrobates auratus* (Girard) (Noah Morales); and grass carp, *Ctenopharyngodon idella* (Valenciennes) (Vsvogelaar) (all photos iNaturalist.org).

Figure 13. The Javan mongoose, *Herpestes javanicus* (a), has been introduced to many islands worldwide for control of rats and snakes. Native oceanic island fauna, which typically evolved in the absence of predatory mammals, proved particularly susceptible to mongoose predation (b). Several native mammals, birds, reptiles, and amphibians around the world have declined or gone extinct following Javan mongoose introductions (Global Invasive Species Database, 2020b). (Photos: a. J.M.Garg, Wikipedia.org; b. Вых Пыхманн, Wikipedia.org)

of grass carp for weed suppression in ponds continued at least as late as 1992 (first release in Pennsylvania) (USGS, 2019a). In addition, the black carp—*Mylopharyngodon piceus* (J. Richardson)—was used not only as a food fish, but also for control of the yellow flatworm, *Clinostomum margaritum* (Rudolphi), which is a pest in aquaculture fish ponds (Nico and Neilson, 2019). Black carp is now established in many states (Nico and Neilson, 2019).

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

The principal risk associated with introduced terrestrial vertebrates for animal control was indiscriminate predation on native birds and mammals. An associated economic risk was that most introduced terrestrial vertebrates also failed to control their target pests. For introduced mosquito-feeding fish, impacts on native fish—through competition or hybridization—were not fully appreciated until the 1980s. For introduced plant-feeding fish, destruction of native macrophytes, greater water turbidity, and low aquatic insect biodiversity in ponds or canals were outcomes that took even longer to be recognized as problems.

RISK-REGULATION PROFILE FOR VERTEBRATES USED FOR BIOCONTROL

Risk 1: Direct attack on non-target species

Damage to populations of native vertebrates (birds, mammals, amphibians) is the main harm associated with terrestrial predaceous vertebrates introduced on islands for pest control. The earliest, clearest example was the impact of the Javan mongoose in the Caribbean islands (e.g., Pimentel, 1955 [Puerto Rico]; Seaman and Randall, 1962 [Virgin Islands]).

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

Exotic animals are inspected for health and the presence of ectoparasites such as ticks before being allowed into the country.

Risk 3: Potential to vector pathogens to non-target animals

This risk likely exists for vertebrates used for pest control, as it does with vertebrates introduced for any reason, including for use as pets or for hunting or fishing.

Risk 4: Potential to become pests in crops

Not applicable.

Risk 5: Potential to degrade native habitats or ecosystems

This risk can occur. For example, see the previously mentioned impact of feeding of carp species on pond habitats through destruction of macrophytes. However, this risk would now be considered before any new vertebrate introduction, and the potential agents would be rejected.

Risk 6: Potential to reduce density of native species by changing food webs

This risk can occur. In Australia, the harm to native marsupial predators that consume introduced cane toads is well documented (Jolly et al., 2015). However, this risk would now be considered before any new vertebrate introduction, and the potential agents would be rejected.

SUMMARY OF RISK REGULATION FOR VERTEBRATES USED FOR PEST CONTROL

In summary, risk of direct attack on non-target species by vertebrates used for pest control (Risk 1) is a serious problem (e.g., Pimentel, 1955; Seaman and Randall, 1962). Damaging effects on habitats (Risk 5) are known for herbivorous fish used for aquatic plant suppression. Effects on food webs (Risk 6) occurred in Australia when native marsupials were poisoned by toxins after eating cane toads (Jolly et al., 2015). Because of issues with all three risks, releases of vertebrates for pest control (apart from the use of fish) was ended in the United States nearly 60 years ago. Ectoparasites (Risk 2) and pathogens (Risk 3) might be inadvertently introduced along with exotic mammals, but should be controlled by animal inspections at the time of importation. Risk 4 (damaging crops) is not applicable.

GROUP #14: PARASITOIDS FOR INSECT BIOLOGICAL CONTROL

HISTORY OF U.S. INTRODUCTIONS OF PARASITOIDS FOR INSECT BIOLOGICAL CONTROL

Parasitoids are insects that develop at the expense of other insects and are key components of all terrestrial ecosystems, being largely responsible for restraining herbivorous insects from devastating plants. Consequently, they are key tools useful in correcting some pest invasions damaging to either crop plants or plants in native ecosystems. Insect biocontrol began in the United States in the 1880s with the introduction of agents, including one parasitoid, a tachinid fly, to control a new invasive scale that was devastating the young California citrus industry (Caltagirone and Doutt, 1989). In contrast, plant biological control (see Group 16) using herbivorous insects or plant pathogens to control invasive plants began later in the 1920s in the continental United States. While plant biocontrol agents in the U.S. were regulated under the Plant Quarantine Act (1912) as being potentially a risk to plants, this law did not apply to insect biocontrol agents, which did not have any potential to be direct plant pests. Rather, the introduction of agents for classical biological control of insects and mites in the United States is guided by several laws or executive orders: the Plant Quarantine Act (1912), the Federal Plant Pest Act (1957), the Plant Protection Act (PPA, 2000), and Executive Order 13112 (1999) for invasive species.

The Plant Protection Act (2000) provided the first legal definition in the United States of a biological control agent. Authority over the introduction of new species of biological control agents is vested in the Plant Protection & Quarantine section of the USDA Agricultural Plant Health Inspection Service (APHIS), and this agency is responsible for issuing permits for the importation and release of natural enemies used as biological control agents, following a review of each proposed agent's risk. Initial permits allow researchers to import live natural enemies into approved U.S. quarantine facilities, where their host ranges are further investigated. Subsequently, following review of a proposed agent's potential risks, a second permit is required from APHIS for the release of the species from quarantine and its interstate movement. Before 1993, the permitting of parasitoids and predators was automatic because they did not pose any risk to plants, which was the risk regulated by the Plant Quarantine Act (1912). Later, the Plant Protection Act (2000) provided APHIS with explicit authority to regulate parasitoids and predatory insects when used as biological control agents, and that Act also charged APHIS with facilitating the use of biological control agents in solving invasive species problems. In summary, the approach used by APHIS is neither a black list (as done under the 18 U.S.C. 42 section of the Lacey Act for vertebrate introductions or by USDA under NAPPRA) nor a white list of pre-

Banner Photos. Many parasitoids with narrow host ranges have been introduced as biocontrol agents in North America for control of key pests of vineyards, forage crops, vegetables, ornamentals, and fruit and forest trees, including (from left to right) *Cosmocomoidea ashmeadi* (Girault) (Hymenoptera: Mymaridae) (Ron Matsumoto, iNaturalist.org); *Peristenus digoneutis* Loan (Hymenoptera: Braconidae) (Scott Bauer, USDA Agricultural Research Service, Bugwood.org); *Cotesia rubecula* (Marshall) (Hymenoptera: Braconidae) (David Cappaert, Bugwood.org); *Anagyrus kamali* Moursi (Hymenoptera: Encyrtidae) (Jeffrey W. Lotz, Florida Department of Agriculture and Consumer Services, Bugwood.org); *Spathius galinae* Belokobylskij & Strazanac (Hymenoptera: Braconidae) (USDA ARS); and *Lathrolestes thomsoni* Reshchikov (Hymenoptera: Ichneumonidae) (Anna Soper, Bugwood.org).

approved species, but rather an individual review of risk for each new species proposed for its first introduction to the United States. This is the highest level of regulatory review for any group of new species' introductions.

Host range estimates are the heart of parasitoid risk assessments done by APHIS as they address the major presumed potential risk—direct attack on non-target species (see **Box 1** for example). Host range estimates entail both compilation of known host records from published literature and new data from quarantine laboratory testing against species that are taxonomically or ecologically close to the target pest and are found in the United States. Such work is done in quarantine laboratories, working with colonies of the parasitoid or predator, exposing selected test species to the agents for oviposition (or predation in the case of predatory insects) and then measuring agent development in any non-target species accepted for oviposition. Quarantine studies do not address the filter of host finding, which in nature acts strongly to shape realized host ranges, but which is logistically difficult to measure in a laboratory setting. However, surveys in the native range provide information on the realized field host range where all filters on host range operate.

In North America since 1985, 208 releases (geographic area x species of agent) of parasitoids (170 distinct species of parasitoids) have been made, where a "release" is the first release of a new parasitoid species in a particular geographic area within "North America" (defined as Canada, Mexico, the continental United States, Hawaii, Guam, Puerto Rico, the Northern Mariana Islands, and the U.S. Virgin Islands) (Van Driesche et al., 2018). Of these, 112 (54%) "species x geographic area combinations" have led to parasitoids establishing in the wild as intended. Of those, 57 (51% of those establishing) have contributed to reduction of densities of the pest they were released against.

Box 1. Risk assessments for three parasitoids imported to suppress emerald ash borer (*Agrilus planipennis* Fairmaire, Coleoptera: Buprestidae) (Van Driesche and Reardon, 2015).

***Oobius agrili* Zhang & Huang (Hymenoptera: Encyrtidae).** In laboratory no-choice tests with *O. agrili*, there were no attacks on moth eggs or eggs of long-horned borers (Coleoptera: Cerambycidae). Attacks did occur on eggs of other similar-sized *Agrilus* species, including the bronze birch borer, *Agrilus anxius* Gory; the two-lined chestnut borer, *Agrilus bilineatus* (Weber); and red-necked cane borer, *Agrilus ruficollis* (Fabricius). There were no attacks on *Agrilus* species with dissimilar-sized eggs, including *A. cyanescens* (Ratzeburg), *A. egenus* Gory, and *A. subcinctus* Gory. In choice tests, *O. agrili* showed a preference for emerald ash borer eggs. These data (Bauer and Liu, 2007; Federal Register, 2007; Gould et al., 2015) show that the laboratory host range is limited to *Agrilus* species with similar-sized eggs as *A. planapennis*. As none of these occur in ash trees, the field host range is predicted to be narrower than these laboratory findings.

***Tetrastichus planipennisi* Yang (Hymenoptera: Eulophidae).** In laboratory no-choice tests with *T. planipennisi,* there were no attacks on three species in two other orders (two moths and one hymenopteran sawfly), five species of long-horned borers, or eight species of other buprestids (five in *Agrilus* and three in *Chrysobothris*). These data (Liu and Bauer, 2007; Federal Register, 2007; Gould et al., 2015) suggest that the laboratory host range of *T. planipennisi* is limited to the target species.

***Spathius galinae* Belokobylskij & Strazanac (Hymenoptera: Braconidae).** In laboratory no-choice tests with *S. galinae*, there were no attacks on two borers in two other orders (one moth, one sawfly) and no attacks on eight borers in other (non-buprestid) beetle families. There were no attacks on four species of *Agrilus* or one of *Chrysobothris*. Attack did occur on one *Agrilus* species (*Agrilus auroguttatus* Schaeffer), an invasive pest of oaks in California. These data (Federal Register, 2015; Gould et al., 2015; Duan et al., 2015) suggest that the laboratory host range of *S. galinae* includes the target pest and the invasive pest species *A. auroguttatus*. However, the latter is not a suitable field host because the species of oaks it infests have bark too thick for *S. galinae* to penetrate.

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

The initial risk that led to governmental regulation of biological control agent introductions was the same as the Plant Quarantine Act of 1912, namely that introduced insects might feed on crops or other economically important crops. Logically, this risk had no application to introductions of parasitoids, which do not attack plants. Later, the concern developed in certain circles (Howarth, 1991) that introduced parasitoids might damage populations of native insects, and this potential risk is the principal focus of current regulation of new species of introduced parasitoids.

The belief that some biocontrol agents could become invasive pests damaging native species or ecosystems was first effectively raised by Howarth (1991), who outlined evidence for significant non-target impacts from some species historically used as biological control agents. This assessment, however, included vertebrate introductions, some made as far back as the 1700s by private individuals rather than by government scientists after biological control developed as a science (post 1920s). A popular narrative has been promoted that biological control agents are particularly dangerous (Simberloff and Stilling, 1996; Simberloff, 2012). This stems in part from how biocontrol agents are described, being intended to attack and kill their target pest species. This labeling has shaped the public's sense that the group poses high risks. However, this perception is different from the public's view of similar events in other groups of introduced species with different labeling. For example, while an introduced fish and an introduced parasitoid may both feed on and thus kill native insects, only for the introduced parasitoid is this considered a problem. The fact that introduced fish will eat native insects is considered normal and simply accepted. A key failing in public understanding of the issue is that it does not separate impacts at the level of effects on individuals (feeding or parasitism on some individuals of a prey or host species) from population-level impacts that lead to population declines. Finally, because insects in general are less familiar to people than vertebrates, much public thinking about the risks to non-target species from biocontrol introductions was driven by a few examples that became highly popularized. Four cases have shaped public perception of risk to native insects from introduced biocontrol agents targeting pest insects: (1) two predaceous coccinellid beetles, *Harmonia axyridis* (Pallas) and *Coccinella septempunctata* L. (Harmon et al., 2007; Losey et al., 2007) (discussed in the following section) and (2) two parasitoids, the tachinid flies *Compsilura concinnata* (Meigen) (Boettner et al., 2000) and *Bessa remota* (Aldrich) (Kuris, 2003; Hoddle, 2006; **Fig. 14**).

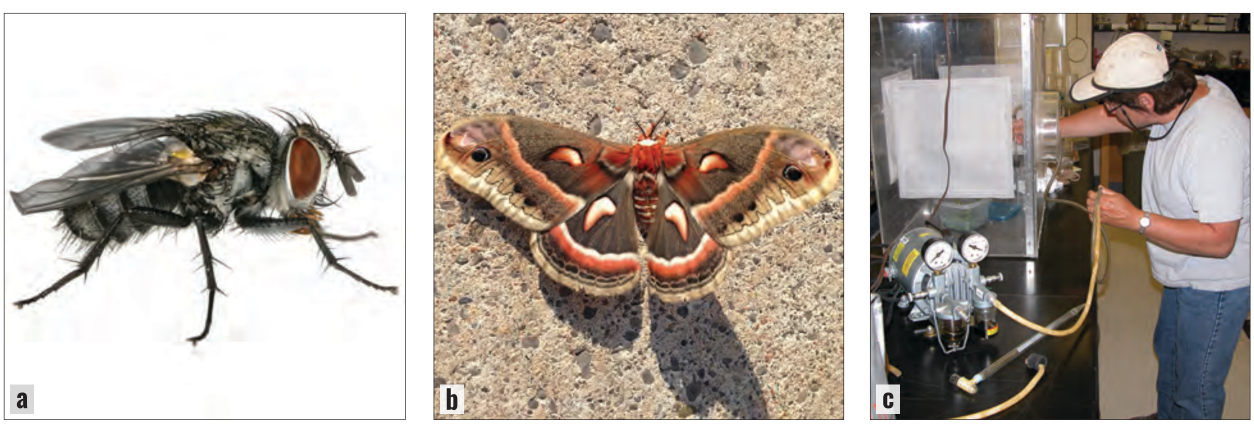


Figure 14. *Compsilura concinnata* (Meigen) (Diptera: Tachinidae) (a) was introduced to North America in 1906 for control of the invasive gypsy moth, *Lymantria dispar* (L.), and browntail moth, *Euproctis chrysorrhoea* (L.). While *C. concinnata* had significant impacts on browntail moth, its impact on gypsy moth was smaller. Importantly, its naturally wide host range led to frequent attacks on native non-target species, including *Hyalophora cecropia* L. (Lepidoptera: Saturniidae) and other giant silk moths (b) (Elkinton and Boettner, 2012). Though this introduction occurred over 100 years ago, decades before biological control developed as a science, the negative attention this introduction garnered demonstrated the importance of introducing only agents with narrow host ranges. Today, rigorous field and laboratory host range testing (c) is required before a new parasitoid can be introduced to North America. (Photos: a. Joyce Gross, Bugwood.org; b. Hayleyreynolds, iNaturalist.org; c. Sharlene E. Sing, USDA FS RMRS)

Because the above four cases are highly publicized and discussed, they are believed by most of the general public to be "typical." This poster-child generalization has led to gross overestimation of risk. Reviews of non-target impacts of releases of parasitoids or predatory insects and mites (van Lenteren et al., 2006; Van Driesche and Hoddle, 2017) suggest that, to the contrary, the risk from parasitoids is very small. From 1880 to 2000, approximately 5,000 species x country releases of parasitoids were made worldwide, as reported in the database BIOCAT (van Lenteren et al., 2006). Of these releases, only 17 of the 5,000 records (0.34%) have been reported to have harmed non-target native insect populations.

RISK-REGULATION PROFILE FOR PARASITOIDS USED FOR INSECT BIOLOGICAL CONTROL

Risk 1: Direct attack on non-target species

This risk is the focal concern for evaluation of parasitoid introductions. A highly developed evaluation system has been created (Van Driesche and Hoddle, 1997; Van Driesche and Reardon, 2004) and is routinely applied to each species of parasitoid proposed for introduction before it is approved for release.

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

The only such risk would be from hyperparasitoids that attack the beneficial parasitoids being introduced. These unwanted species are routinely and efficiently eliminated in quarantine (e.g., Hoddle et al., 2013).

Risk 3: Potential to vector pathogens to non-target plants

This risk has not been demonstrated for parasitoids. However, theoretically, it might occur if a parasitoid's host vectored a plant pathogen that itself was able to be spread mechanically as a surface contaminate. In such cases, a parasitoid might pick up the pathogen on its ovipositor and move it to a second host during a subsequent oviposition. Greening disease of citrus was a high-risk pathogen in Florida before the pathogen's eventual introduction there on live plants. Before the pathogen's invasion, there was concern that parasitoids of the citrus psyllid (*Diaphorina citri* Kuwayama—the vector of the pathogen), which were being imported for suppression of the vector, might inadvertently introduce the pathogen. To prevent such an eventuality, parasitoids in quarantine were screened for DNA of the pathogen (*Liberobacter asiaticum* Jagoueix et al.) before parasitoids were released. No pathogen DNA was found, and releases were able to be made safely (Hoy et al., 2001). Other than this, there are no known examples of this risk being associated with parasitoids.

Risk 4: Potential to become pests in crops

Not applicable.

Risk 5: Potential to degrade native habitats or ecosystems

This risk is regulated if it can be foreseen. In some cases, parasitoids improve habitats if they control invasive pests that damage the habitat (e.g., wax scales in Queensland rain forest [Waterhouse and Sands, 2001; Van Driesche et al., 2010]). Conversely, if parasitoids are used to suppress an insect attacking an invasive plant that damages the habitat, then successful biocontrol of the pest insect could be construed as damaging to habitat (e.g., biocontrol of exotic scales [*Pulvinaria* spp.] attacking exotic ice plants [*Carpobrotus* spp.] in California dunes [Tassan et al., 1982; Magnoli et al., 2013]). Good vs. bad impact may depend on social values placed on introduced plants.

Risk 6: Potential to reduce density of native species by changing food webs

Harmful effects on native food webs are possible from introductions of parasitoids, and one mechanism for food web effects is termed "apparent competition" in which the introduced parasitoid, in addition to attacking the target pest, attacks related native species. For example, the parasitoid *Cotesia glomerata* (L.) (Hymenoptera: Braconidae), introduced to North America in the 1880s to control the imported cabbage worm, *Pieris rapae* (L.) (Lepidoptera: Pieridae), caused the decline of the native butterfly *Pieris oleracea* (Harris) in Massachusetts (Benson et al., 2003). Interestingly, this effect was later reversed by *P. oleracea*'s use of a non-native host plant (Herlihy et al., 2014) and the displacement of *C. glomerata* as the dominant parasitoid of *P. rapae* in crops by *Cotesia rubecula* (Marshall), another introduced biocontrol agent that was more specialized, attacking only *P. rapae* (Herlihy et al., 2012).

However, it is also possible to obtain large beneficial impacts on native food webs from parasitoid introductions if the pest for which the parasitoid is being introduced is distorting native food webs to the detriment of native species. In Queensland, Australia, for example, biological control of two invasive wax scales attacking crops (*Ceroplastes destructor* Newstead and *Ceroplastes rubens* Maskell; Hemiptera: Coccidae) also reduced the densities of invasive ants foraging on the scales' honeydew on native plants. Invasive ants and the scales together reduced health and quality of forest plants for larvae of native lycaenid butterflies, such as *Hypochrysops miskini* (Waterhouse) and *Pseudodipsas cephenes* Hewitson. Reduction of the scales' density by the introduced parasitoids led to fewer invasive ants, improved host plant quality for the butterfly larvae, and allowed native ants needed as symbiotic partners for the butterflies' larvae to return (Waterhouse and Sands, 2001; Van Driesche et al., 2010).

Similarly, on Christmas Island (property of Australia) in the Indian Ocean, the parasitoid *Tachardiaephagus somervilli* (Howard) (Hymenoptera: Encyrtidae) is being introduced to suppress the invasive scale *Tachardina aurantiaca* (Cockerell) (Hemiptera: Kerriidae) (Ong et al., 2017). The larger purpose is to reduce the supply of honeydew this abundant scale provides to the invasive yellow crazy ant, *Anoplolepis gracilipes* (F. Smith) (Hymenoptera: Formicidae), which is decimating populations of the local red land crab, *Gecarcoidea natalis* (Pocock), through direct attack and poisoning (O'Dowd et al., 2003). The crab itself is both a world-renowned biodiversity phenomenon and the island's principal tourist attraction, as well as an engineering species controlling forest structure on the island (Green et al. 1997).

SUMMARY OF RISK REGULATION FOR PARASITOIDS FOR INSECT BIOLOGICAL CONTROL

In summary, direct attack on non-target species by parasitoids (Risk 1) is a possible risk, but it is highly regulated by studying the host ranges of new parasitoids in quarantine laboratories before permission is given for their release. Risk 2 (vectoring pests such as insects or nematodes) is only applicable in the case of hyperparasitoids that attack the parasitoid itself. These are excluded during quarantine evaluation. Risk 3 (spreading plant pathogens) has not been observed, and Risk 4 (damaging crops) is not applicable due to basic biology of the species. Damage to habitats (Risk 5) may occur indirectly if the introduced parasitoids control an invasive species that affects the health of habitat-shaping plants. If the plants are native, then such insect control would be ecologically positive, but if the plants themselves are invasive, then control of their pests would be ecologically negative. Effects on food webs (Risk 6) may be either negative, as when native herbivores are affected through apparent competition, or positive, as when biological control of an invasive insect leads to improvement in the health of important native plants or animals.

GROUP #15: PREDATORY INSECTS AND MITES FOR BIOLOGICAL CONTROL

HISTORY OF U.S. INTRODUCTIONS OF PREDATORY INSECTS AND MITES FOR BIOLOGICAL CONTROL

In the United States, the first dramatically successful use of biological control, which saved the young California citrus industry from collapse in 1888, was based on the use of the ladybird beetle *Novius* (formerly *Rodolia*) *cardinalis* (Mulsant) (Coleoptera: Coccinellidae) (Caltagirone and Doutt, 1989). As a consequence, many other ladybirds were introduced against various other pests in the ensuing decades, with the hope that they too would control various pests. Most of these other coccinellids failed to establish, and few had any useful impact on their target pests (Caltagirone and Doutt, 1989). Unknown at the time was the fact that *N. cardinalis* is a highly specialized predator of scales in the genus *Icerya*, while most of the other introduced ladybirds have wide diets. Over time, the advantages of the greater dietary specialization found in parasitoids caused biocontrol introductions to shift away from predators. Practitioners only occasionally imported some of the more specialized predators, such as *Laricobius nigrinus* Fender (Coleoptera: Derodontidae) released against the hemlock woolly adelgid, *Adelges tsugae* Annand (Hemiptera: Adelgidae) (Mausel et al., 2010), especially if the target pest had no parasitoids. In the past 35 years in North America, only 27 species of predatory insects have been introduced (Van Driesche et al., 2018). Apart from this difference in diet breadth, regulation of predatory arthropod introductions for biocontrol has been identical to that applied in the case of parasitoids, as described in the previous section, Group #14.

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

Early regulation of predaceous insects used as biological control agents had the same legal basis as parasitoids (Plant Quarantine Act, 1912). Because most predatory insects do not feed on plants (apart from some mirid bugs, which have not been imported), this law was only loosely applicable. Later, the concern that introduced predators might damage populations of native insects became the main focus of regulation. While no cases are known of introduced predatory insects directly harming populations of native, non-target, non-pest insects through their feeding behaviors, two introduced (or perhaps, as has been suggested, just naturally

Banner Photos. Though not as frequently used as parasitoids, several species of predatory insects have been introduced to the U.S. for control of pest insects and mites attacking citrus and ornamental plants, to protect native hemlocks in forests, and to control aphids and whiteflies in crops, including (from left to right) *Novius* (formerly *Rodolia*) *cardinalis* (Mulsant) (Coleoptera: Coccinellidae) (Division of Plant Industry, Florida Department of Agriculture and Consumer Services, Bugwood.org); *Laricobius nigrinus* Fender (Coleoptera: Derodontidae; native to the Pacific Northwest) (Ashley Lamb, Virginia Polytechnic Institute and State University, Bugwood.org); *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) (Russ Ottens, University of Georgia, Bugwood.org); *Chilocorus kuwanae* Silvestri (Coleoptera: Coccinellidae) (Tom Murray, Bugwood.org); *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae) (Budak, iNaturalist.org); and *Curinus coeruleus* (Mulsant) (Coleoptera: Coccinellidae) (Isis Meri Medri, iNaturalist.org).

Figure 15. The Asian ladybird beetle *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) (a) was introduced to the United States for biological control of aphid pests on pecans (b). Though highly effective in managing some pest aphids, this species often receives negative public attention because of its tendency to overwinter in large masses in and around structures and dwellings (c). Though competition, it has also contributed to population reductions of native ladybird beetles that also feed on invasive crop aphids. (Photos: a. Ryzhkov Oleg; b. Keene Haywood; c. Curtis Eckerman) (all photos iNaturalist.org)

invasive) coccinellid beetles—*Harmonia axyridis* (Pallas) (**Fig. 15**) and *Coccinella septempunctata* L.—reduced populations of some native coccinellids by reducing the abundance of various invasive aphids used by native ladybirds as prey in crop fields (Harmon et al., 2007; Losey et al., 2007). Other than these two species, no other introductions of predatory insects in the United States have created any problems for the public that have led to regulation.

RISK-REGULATION PROFILE FOR PREDATORY INSECTS AND MITES USED FOR BIOLOGICAL CONTROL

Risk 1: Direct attack on non-target species

While all predatory insects must on occasion include non-target insects in their diet, ladybird beetles introduced as biocontrol agents have not been reported to cause population-level effects on non-target aphids through prey consumption. Some introduced ladybird species have been observed feeding on some aphid species of interest, e.g., the woolly alder aphid *Prociphilus* (formerly *Paraprociphilus*) *tesselatus* (Fitch) (Hemiptera: Aphididae). This aphid is a required prey for one butterfly and some lacewings. Two introduced ladybird beetles, *H. axyridis* (Butin et al., 2004) and *Propylea quatuordecimpunctata* (L.) (Wheeler, 1990), have been noted feeding on this aphid, in laboratory studies and field observations, respectively. However, no effect on field densities of this aphid have been reported.

This lack of concern is similar to how the public views the consumption of native insects by introduced fish, namely "yes it exists, but is not a problem." Nevertheless, consumption of non-target insects in quarantine screening tests is now sufficient for the Animal and Plant Health Inspection Service to deny permission for a predator's introduction. For example, the Thailand-native *Phaenochilus kashaya* Giorgi & Vandenberg (Coleoptera: Coccinellidae) is a predator of the cycad scale, *Aulacaspis yasumatsui* Takagi (Hemiptera: Diaspididae), an invasive scale that kills and threatens populations of native cycads in Guam. *Phaenochilus kashaya* was denied any possibility of introduction into the United States because it was not sufficiently limited in its diet range (Ron Cave, University of Florida, pers. comm.).

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

Any hyperparasitoids of the beneficial predaceous insects would be eliminated when the colony was held in quarantine for testing.

Risk 3: Potential to vector pathogens to non-target plants

Populations for introductions are screened for fungal or microsporidian pathogens, and laboratory colonies are cleared of pathogens before introduction.

Risk 4: Potential to become pests in crops

Some predatory insects have potential to be minor crop pests. The ladybeetle *H. axyridis* has become a minor pest of wine vineyards because even relatively low numbers of beetles mixed with grapes can impart an off taste to the wine (Linder et al., 2009). Also, plant feeding/predaceous mirids are used in greenhouses for pest control in Europe. Should they be proposed for introduction for use in the United States in the future, their possible effects on crops would have to be assessed. Risks of this type are recognized and regulated in the United States.

Risk 5: Potential to degrade native habitats or ecosystems

This risk is regulated, but no clear examples of such effects are known from introduced predatory insects.

Risk 6: Potential to reduce density of native species by changing food webs

Two important, well documented examples of effects on native insects (native ladybirds) exist in the United States, namely *H. axyridis* and *C. septempunctata*, whose reduction of populations of various aphids (mostly invasive species in crops) have also reduced the density of some native ladybirds in crops, especially *Adalia bipunctata* (L.) and *Coccinella novemnotata* Herbst (Wheeler and Hoebeke, 1995; Elliott et al., 1996; Turnock et al., 2003; Harmon et al., 2007; Fothergill and Tindall, 2010).

SUMMARY OF RISK REGULATION FOR PREDATORY INSECTS AND MITES FOR BIOLOGICAL CONTROL

In summary, direct attack on nontarget species by predaceous insects used as biocontrol agents (Risk 1) is possible, although no clear examples exist of such predation causing population changes in prey. This risk is, however, highly regulated by study of the prey ranges of new predators in quarantine laboratories before permission is given for their release. Risk 2 (vectoring pests such as insects or nematodes) and Risk 3 (spreading pathogens to native species) are generally not applicable to predatory insect introductions but are within the scope of regulated risks. Risk 4 (becoming crop pests) is regulated and some examples of real risk of this type exist, including the effect mentioned above of *H. axyridis* on the taste of wine. Also, some predaceous mirids used in greenhouse biocontrol in Europe also feed on crop plants. Should this type of predator be proposed for introduction in the future, possible effects on crops would have to be evaluated. Effects of predatory insects on habitats (Risk 5) are unknown but regulated. Effects on food webs of predatory insects used for biocontrol (Risk 6) have occurred in the case of two coccinellids that greatly reduced pest aphids that were also used as prey by native coccinellids, which then became rare.

GROUP #16: INSECTS AND MITES FOR WEED BIOLOGICAL CONTROL

HISTORY OF U.S. INTRODUCTIONS OF INSECTS AND MITES FOR WEED BIOLOGICAL CONTROL

Historically, plant-feeding insects introduced for control of unwanted plants seemed rather too close to pest insects attacking crops in the popular and governmental minds. As a consequence, host-range testing was required from the beginning of such importations (in the 1940s in the continental United States), and introductions were regulated under the Plant Quarantine Act (1912) to protect crops or horticultural plants, largely by screening lists of locally important crops. By the mid-1980s, the proposed idea of introducing weed biocontrol agents against pestiferous native plants had become controversial in the United States (DeLoach, 1985; Pemberton, 1985), and the idea of targeting native plants was abandoned before any significant application (apart from one project in Hawaii in the 1960s against false puncture vine, *Tribulus cistoides* L.). In the 1970s, the first Endangered Species Act (1973) was passed in the United States, with the goal of protecting rare or threatened native species, including plants. In this same time period, the goal of ensuring that introduced plant biocontrol agents would not damage economic plants was expanded to protect native plants. While rare plants received special attention in testing, the goal was to protect all native plants from any significant population-level damage. This caused the testing protocol applied to candidate agents to shift from being just an exclusionary exercise (providing evidence of lack of attack on a small list of particular crops) to estimating the boundaries of the agent's host range so as to be predictive of risk for untested species. This was achieved by testing plants at various taxonomic distances from the target weed, using the centrifugal method of Wapshere (1974). Improvements in the science of host range estimation continued to be made, with increased focus on the role of preference among accepted plants and the role of attractants causing foraging adults to seek out specific plant species for oviposition (Briese, 2005).

Administratively, petitions for the release of weed biocontrol agents in the United States are reviewed by an inter-agency committee known as the Technical Advisory Group (TAG), which after its review makes a recommendation to the Animal and Plant Health Inspection Service (APHIS) concerning the advisability of releasing a proposed agent (Cofrancesco and Shearer, 2004). The TAG committee has representatives

Banner Photos. As of 2020, approximately 190 species of insects and mites have been introduced to the United States (including Hawaii) as biological control agents of weeds. Many have led to spectacular success against their target weeds, without causing population-level impacts to any non-target species, including (from left to right) *Chrysolina quadrigemina* (Suffrian) (Coleoptera: Chrysomelidae) (Cheryl Moorehead, Bugwood.org); *Mecinus janthiniformis* Toševski & Caldara (Coleoptera: Curculionidae) (Gary Chang, iNaturalist.org); *Galerucella calmariensis* (L.) (Coleoptera: Chrysomelidae) (Mark Schwarzländer, University of Idaho, Bugwood.org); *Longitarsus jacobaeae* (Waterhouse) (Coleoptera: Chrysomelidae) (USDA ARS European Biological Control Laboratory, Bugwood.org); *Lilioceris cheni* Gressitt & Kimoto (Coleoptera: Chrysomelidae) (Leslie J. Mehrhoff, University of Connecticut, Bugwood.org); and *Oxyops vitiosa* Pascoe (Coleoptera: Curculionidae) (Gary Buckingham, USDA ARS, Bugwood.org). The agents listed and pictured have wholly or partially suppressed invasive populations of the target weeds (from left to right) common St. Johnswort, *Hypericum perforatum* L.; Dalmatian toadflax, *Linaria dalmatica* (L.) Mill.; purple loosestrife, *Lythrum salicaria* L.; tansy ragwort, *Jacobaea vulgaris* Gaertn.; air potato, *Dioscorea bulbifera* L.; and melaleuca, *Melaleuca quinquenervia* (Cav.) S.T. Blake.

from the following federal agencies, countries, and organizations: (1) Canada, Agriculture and Agri-Food Canada, (2) Mexico, SAGARPA-SENASIA-DGSV, (3) National Plant Board, (4) Army Corps of Engineers in the U.S. Department of Defense, (5) U.S. Environmental Protection Agency, (6) U.S. Department of Agriculture (USDA) Agricultural Research Service, (7) APHIS, (8) USDA Forest Service, (9) USDA National Institute of Food and Agriculture, (10) USDA Natural Resources Conservation Service, (11) U.S. Department of Interior (USDI), Bureau of Indian Affairs, (12) USDI Bureau of Land Management, (13) USDI Bureau of Reclamation, (14) USDI Fish and Wildlife Service, (15) USDI National Park Service, (16) USDI, U.S. Geological Survey, and (17) the Weed Science Society of North America.

Through consultation, the TAG committee makes recommendations on target suitability and non-target species for use in quarantine testing, and comments on the advisability of issuance of a release permit. A reviewer's manual defines the requirements for petitions, petitioners, and reviewers (Cofrancesco and Shearer, 2004; USDA APHIS, 2019d).

Presence on the TAG committee of representatives from Canada and Mexico provide opportunities for concerns of those countries related to new weed biocontrol agents to be raised. Following positive recommendations from the TAG, APHIS then prepares a "Biological Assessment (BA)" that is shared with the Fish and Wildlife Service for the Section 7 Endangered Species Act consultation. If USFWS find sufficient data to show safety of the agent in regards to Threatened and Endangered Species and they concur with the proposed release, USFWS provides a "Letter of Concurrence" to that effect. APHIS then prepares an Environmental Assessment document and shares that with Native American tribes in areas within the range of the target plant as a "Tribal Consultation." APHIS then submits the release petition for publication in the Federal Register for public comments. The agency then responds to public comments and reaches its decision, which, if positive, is called a FONSI (Finding of No Significant Impact). This procedure is the most rigorous review process for any group of new species being imported into the United States.

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

The principal risk for which new weed biocontrol agents are assessed is the possibility of direct attack on non-target species, including crops, horticultural plants, or native plants. Exotic plants used as ornamentals are not considered protected if they are of limited economic importance. No other risks have been identified for weed biocontrol agents, but some potential exists for effects on habitat structure or food webs are theoretically possible.

RISK-REGULATION PROFILE FOR INSECTS AND MITES FOR WEED BIOLOGICAL CONTROL

Risk 1: Direct attack on non-target species

The review process for weed biocontrol agents (Wapshere, 1974) is primarily focused on evaluating risk to non-target plants. Of the approximately 465 arthropod species that have been introduced as biocontrol agents at the world level (Winston et al., 2020), only two species seem to have the potential to cause population-level impacts on native non-target species: the cactus-feeding moth *Cactoblastis cactorum* Berg (Lepidoptera: Pyralidae) (**Fig. 16**; Stiling et al., 2004; Pemberton and Liu, 2007) and the thistle-feeding weevil *Rhinocyllus conicus* Fröelich (Coleoptera: Curculionidae) (Louda, 1998; Louda et al. 2005). Of these, only *R. conicus* was introduced intentionally to the United States.

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

Parasitic insects, mites, or nematodes attacking candidate weed biocontrol agents are eliminated during quarantine.

Figure 16. *Cactoblastis cactorum* Berg (Lepidoptera: Pyralidae) (a) is a biological control agent highly effective at controlling weedy *Opuntia* cactus species in numerous countries worldwide (b). In the 1950s and 60s, it was introduced to several islands in the Caribbean. It subsequently spread naturally and via the nursery trade throughout the Caribbean and to the southeastern United States, where it has attacked native *Opuntia* species and prompted a sterile moth breeding and eradication program. Though only two arthropod species used for weed biocontrol worldwide (out of 465) have had population-level impacts on non-target species, the concern of weed biocontrol agents damaging crops and native species led to stringent field and laboratory host-testing requirements (c). This review process is the most rigorous for any group of new species being imported into the United States. (Photos: a. Jeffrey W. Lotz, Florida Department of Agriculture and Consumer Services, Bugwood.org; b. Christine Sydes, iNaturalist.org; c. Fritzi Grevstad, Oregon State University)

Risk 3: Potential to vector pathogens to non-target plants

Plant pathogens of concern can be detected as pathogen DNA inside weed biocontrol agents during quarantine and, if present, eliminated from agent colonies by destroying groups of affected individuals.

Risk 4: Potential to become pests in crops

Crop species that are potentially suitable for agent feeding are included in tests for evaluation of host range, and agents are rejected if they have potential to feed on crops (e.g., Cristofaro et al., 2013).

Risk 5: Potential to degrade native habitats or ecosystems

Habitats produced by native plants would not be affected because feeding on native plants by biocontrol agents is nil to incidental. However, habitats created by invasive plants may be affected if the pest weed is suppressed. Speculatively, two scenarios might exist in which this direct, desired effect might indirectly damage native species. The first is when a second invader in the habitat expands to fill the space opened up by control of the target pest. This outcome would be damaging if the second pest were worse than the first.

A second scenario that may be of concern in some cases occurs when the habitat created by the targeted invasive plant has some valuable features, which might be lost if the invasive plant was suppressed by biological control agents. To some extent this is the case for invasive saltcedars (*Tamarix* spp.) in the southwestern United States, which provide poor but accepted nesting habitat for the endangered southwestern willow flycatcher, *Empidonax traillii* ssp. *extimus* Phillips. The risk expected by some was that saltcedar reduction would occur rapidly enough to lower the rate of nesting success for this bird. However, restoration of native willow and cottonwood, if properly executed and well timed, provides higher quality habitat that can more than offset loss of saltcedar as nesting sites (Dudley and Bean, 2012).

Risk 6: Potential to reduce density of native species by changing food webs

No real example is known, but a theoretical one is provided. The native butterfly *Pieris oleracea* (Harris) (Lepidoptera: Pieridae) was reduced to low levels in Massachusetts by parasitism of the braconid parasitoid

Cotesia glomerata (L.) (Hymenoptera: Braconidae), which was introduced into North America in the 1880s to control the imported cabbage worm, *Pieris rapae* (L.) (Lepidoptera: Pieridae) (Benson et al., 2003). Currently the native butterfly's population is recovering in the western part of Massachusetts due to two factors. First, the impact of *C. glomerata* on *P. oleracea* has been greatly reduced by the introduction of *Cotesia rubecula* (Marshall) (Hymenoptera: Braconidae), a second, more specialized parasitoid of *P. rapae* made in 1988. This more specialized parasitoid has drastically reduced the number of *P. rapae* that are available for *C. glomerata* to use as hosts, reducing that parasitoid's spillover onto *P. oleracea* (Herlihy et al., 2012, 2014). However, another critical factor driving this recovery has also been the invasion of cuckoo flower, *Cardamine pratensis* L., which provides a high quality, full-season host plant for *P. oleracea* in open wet meadows, supporting up to four generations of the butterfly per year (Herlihy et al., 2014). Theoretically, if the importance of cuckoo flower to *P. oleracea* were unknown and if a successful weed biocontrol program were mounted against the invasive plant, the introduction of the weed biocontrol agents would slow or prevent the recovery of the native butterfly.

SUMMARY OF RISK REGULATION FOR INSECTS AND MITES FOR WEED BIOLOGICAL CONTROL

Of the six possible risks associated with novel species introductions for plant biocontrol, Risk 2 (vectoring unwanted insects or nematodes) and Risk 3 (vectoring pathogens) could occur, but in practice can be eliminated effectively by screening of weed biocontrol agents for parasitoids, pathogens, or misidentified similar herbivorous species in quarantine. Risk 1 (attack on native species) and Risk 4 (attack on crops) overlap and both are tightly regulated. These risks are effectively prevented by host range testing in quarantine before agents are introduced. This approach has been highly successful since it was adopted in the United States in the 1940s. Risk 5 (unwanted effects on habitats) might occur if the targeted invasive plant species itself created habitats with some desired attributes. In such a context, the benefits the invasive target weed might would have to be determined and weighed against the weed's harm before proceeding. Finally, the risk of effects mediated through food webs (Risk 6) would, in a similar way, have to be recognized by field studies of the invasive plant's biology and ecology to determine if any species strongly benefited from it as a host plant.

GROUP #17: PATHOGENS FOR WEED OR INSECT BIOLOGICAL CONTROL

HISTORY OF U.S. INTRODUCTIONS OF PATHOGENS FOR WEED OR INSECT BIOLOGICAL CONTROL

In the United States, pathogens have been introduced against both insect pests and weeds. Insect and plant pathogens have different regulatory histories in the United States, and insect pathogens have been regulated under a number of laws.

Against weeds

Plant pathogens have been regulated in a consistent manner, with all groups of plant pathogens being evaluated in the same general way over the whole period of use historically. Twelve species of plant pathogens have been released in the United States, including Hawaii, as classical biocontrol agents (two nematodes and 10 fungi) (Winston et al., 2020). No plant viruses, bacteria, or microsporidia (now considered fungi) have been intentionally introduced. The regulatory process applied to plant pathogens has been the same as that applied for insects used for weed biocontrol, as described in Group 16, with early introductions being regulated under the Plant Quarantine Act (1912) and, more recently, under the Plant Protection Act (2000).

Against insects

Pathogens introduced as classical biocontrol agents of insects and mites include species of nematodes, viruses, microsporidia (now considered fungi), bacteria, and fungi (Hajek et al., 2016). The regulation of these agents was different from that used for plant pathogens, inasmuch as the U.S. Environmental Protection Agency (EPA) treated most insect microbial agents as pesticides subject to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and later laws regulating pesticides, even when used as classical biocontrol agents rather than as formulated products (**Fig. 17**). Insect pathogenic nematodes, however, were not regulated in this manner by EPA, but rather treated as augmentative biocontrol insects and mites under the oversight of the U.S. Animal and Plant Health Inspection Service (APHIS). In contrast to nematodes, microbial agents and fungi directed against insects were reviewed under rules designed for the regulation of chemical pesticides

Banner Photos. Several pathogens have been released against weeds and insects in the United States. None of these introduced species have caused population-level impacts to non-target species (Hajek et al., 2007; Winston et al., 2020). Weed biocontrol pathogens include (from left to right) *Puccinia carduorum* Jacky (Pucciniales) (Loke T. Kok, Virginia Polytechnic Institute and State University, Bugwood.org); *Puccinia chondrillina* Bubák & Syd. (Pucciniales) (Gary L. Piper, Washington State University, Bugwood.org); and *Puccinia jaceae* var. *solstitialis* (Pucciniales) Savile (Eric Coombs, Oregon Department of Agriculture, Bugwood.org) released, respectively, against musk thistle (*Carduus nutans* L.), rush skeletonweed (*Chondrilla juncea* L.), and yellow starthistle (*Centaurea solstitialis* L.). Insect biocontrol pathogens include *Metarhizium anisopliae* (Metschn.) Sorokīn (Hypocreales) (Sunnetchan, iNaturalist.org); *Beauveria bassiana* (Bals.-Criv.) Vuill. (Hypocreales) (David Whyte, iNaturalist.org); and *Entomophaga maimaiga* Humber, Shimazu, & R.S. Soper (Entomophthorales) (Steven Katovich, Bugwood.org). The first two are species with worldwide distributions used as biorational pesticides, and the final species is an introduced agent against gypsy moth, *Lymantria dispar* (L.).

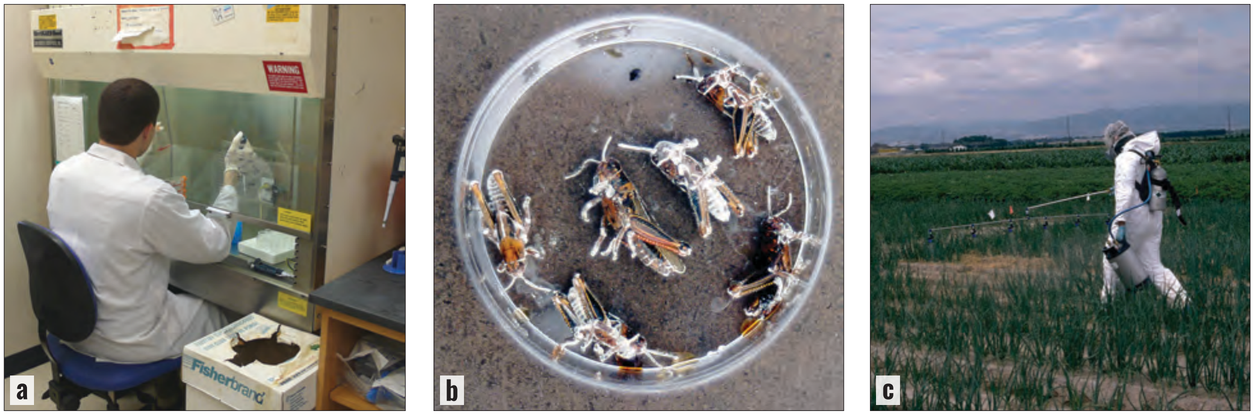


Figure 17. Potential weed and insect biocontrol pathogens are subject to stringent field and laboratory host-testing requirements (a) before approval for their use in the United States. The fungus *Beauveria bassiana* (Bals.-Criv.) Vuill. (Hypocreales), a cosmopolitan species affecting many pest insects (b), is commercially available in many formulations that can be applied in a similar fashion as pesticides (c). (Photos: a. Tim Vickers, Wikipedia.org; b. USDA ARS, Wikipedia.org; c. Howard F. Schwartz, Colorado State University, Bugwood.org)

until 2000, when the North American Plant Protection Organization (NAPPO) endorsed a standard similar to that of its European counterpart (European and Mediterranean Plant Protection Organization [EPPO, 2000]), based on the FAO Code of Conduct (FAO/IPPC, 1996). APHIS then provided instructions on how to petition for the release of non-native entomopathogens and insect parasitic nematodes for biological control (as discussed in Hajek et al., 2007).

Hajek et al. (2007) notes that 37 species of viruses, bacteria, fungi, microsporidia, or oomycetes and eight species of nematodes had been introduced to one or more countries for insect biocontrol, with fungi being the most frequently released group, followed by viruses and nematodes. Other groups have rarely been used. The species most frequently employed (at the world level) have been the *Oryctes rhinoceros* nudivirus, the fungi *Metarhizium anisopliae* (Metschn.) Sorokīn (Hypocreales) and *Entomophaga maimaiga* Humber, Shimazu, & R.S. Soper (Entomophthorales), and the nematodes *Romanomermis culicivorax* Ross & Smith (Mermithida) and *Deladenus siricidicola* Bedding (Tylenchida).

REGULATION OF RISKS: WHAT WERE THE PERCEIVED PROBLEMS?

Plant pathogens

The risk that is the focus of regulation for pathogens used for weed biocontrol is potential for infection of plants other than the target weed. None of the other risks are applicable to weed biocontrol pathogens.

Insect pathogens

Entomopathogens may pose direct risks to native non-target insects related to the target pest (e.g., Lockwood, 1993). Hajek et al. (2007), however, found no documented cases in the literature of substantial mortality to a non-target species caused by an introduced insect pathogen. None of the other risks are applicable to insect biocontrol pathogens.

RISK-REGULATION PROFILE FOR PATHOGENS USED FOR WEED OR INSECT BIOCONTROL

Risk 1: Direct attack on non-target species

This is the principal risk of concern for pathogens used for weed biocontrol, and new agents must have narrow host ranges that do not threaten populations of native plants. This risk is also the principal regulatory focus for pathogens used for insect biocontrol; their host ranges, however, are broader, however, and many species used as biorational pesticides are native or cosmopolitan species.

Risk 2: Potential to vector pest insects, mites, ticks, or nematodes

Not applicable.

Risk 3: Potential to vector pathogens to non-target plants

Not applicable.

Risk 4: Potential to become pests in crops

Weed biocontrol pathogens might, potentially, be able to infest crop plants and so this is a regulated risk. For insect pathogens, however, there is no biological possibility for attack on plants (also some species can act as beneficial endosymbionts in plants) and so this risk is not applicable.

Risk 5: Potential to degrade native habitats or ecosystems

There are no known examples of this risk for this group.

Risk 6: Potential to reduce density of native species by changing food webs

There are no known examples of this risk for this group.

SUMMARY OF RISK REGULATION FOR PATHOGENS USED FOR WEED OR INSECT BIOCONTROL

Plant pathogens

The concern that introduced plant pathogens might harm populations of native plants (Risk 1) or crops (Risk 4) through direct attack has been the primary focus of regulatory review. Risk 2 (vectoring insects) and Risk 3 (vectoring plant pathogens) are not applicable. Risk 5 (effects on habitats) and Risk 6 (effects on food webs) are regulated, but there are no known examples.

Insect pathogens

Before 2000, newly introduced pathogens were regulated in the United States using the same criteria as chemical pesticides (except for nematodes, which were exempt). After 2000, the concern that introduced insect pathogens might harm populations of native insects through direct attack (Risk 1) has been the primary focus of regulatory review. Risk 2 (vectoring insects), Risk 3 (vectoring plant pathogens), and Risk 4 (becoming crop pests) are not applicable. Risk 5 (effects on habitats) and Risk 6 (effects on food webs) are regulated, but there are no known examples.

CREATING A UNIFORM, RISK-BASED SYSTEM FOR ALL GROUPS OF ORGANISMS

THE PAST: AN AD HOC COLLECTION OF NARROWLY FOCUSED REGULATIONS

The current rules used to evaluate requests to introduce new species into the United States have no cross-group, unifying standards, but are rather an ad hoc collection of narrow rules designed for particular problems at various points of U.S. history. This ad hoc nature of current regulations creates a highly variable level of regulation (**Fig. 18**), with some groups such as biological control agents being more stringently regulated than other groups such as horticultural plant introductions or species used in the pet trade (**Fig. 19**). The current situation arose because no attempt was ever made to react to the larger problem of how to reduce risks across the board for new species introductions. Rather, each sector was seen in isolation, and its most obvious problems were the drivers shaping the legislative response, often to the neglect of other, less obvious risks. Also, for many groups, the organisms that were being introduced were historically accepted as "good" without review. In such cases, the risks being regulated were not the species themselves, but rather the chance that these "good" organisms would act as vectors for hitchhiking pests. This is most clear in the 1912 Plant Quarantine Act, which was not intended to regulate threats posed by new plants becoming pests (since the free introduction of new plants was seen as completely good), but rather to prevent those plant introductions from transporting pest insects or plant pathogens. Much the same sort of thinking has gone into control of other sectors. In aquaculture, for example, the exotic oyster was not seen as the problem; rather, the possibility of it bringing in another oyster pathogen was the risk to control. In many sectors, therefore, little thought was given to the possibility of the introduced species themselves becoming damaging pests. A noticeable exception to the above scenario was the ban on the importation of any new species of birds or mammals (under a previous version of the Lacey Act) from 1900 until 1948, when the ban was lifted and applied only to species classified by the government as "injurious."

For some sectors, the Lacey Act (18 U.S.C. 42) provides some measure of regulation. However, the Lacey Act's regulator power, based on designation of species as "injurious wildlife," has several important limitations, including (1) no authority over plants or any invertebrates except for mollusks and crustaceans; (2) the use of black lists (= species listed as "injurious wildlife") as the main regulatory tool; and (3) no authority to require prior review of proposed introductions of species not already on the black list. This approach is similar to the status of chemicals used as pesticides before the 1947 Act regulating pesticides (the Federal Insecticide, Fungicide, and Rodenticide Act [FIFRA]). Before the 1947 Act, the federal government bore the burden of proving that a chemical proposed for use as a pesticide was dangerous. After FIFRA, the burden of proof shifted from the government (black list approach) to the company proposing the use of a new compound as a pesticide (a prior-review, data-based system). With respect to the introduction of new plant and animal species, the United States' current regulatory position is similar to that used to control pesticides before 1947, where the burden of proof to identify harmful species is on the federal government, with the single exception of species whose reason for introduction is biological control of invasive pests—all

GROUP	RISK 1 NON-TARGET ATTACKS	RISK 2 VECTOR INSECTS, MITES, TICKS	RISK 3 VECTOR PATHOGENS	RISK 4 DAMAGE CROPS	RISK 5 DEGRADE HABITATS	RISK 6 CHANGE FOOD WEBS
#1 FORESTRY, FORAGE, OR FODDER PLANTS	Not Applicable	Regulated	Partially Regulated	Partially Regulated	Partially Regulated	Not Regulated
#2 ORNAMENTAL PLANTS	Not Applicable	Regulated	Partially Regulated	Partially Regulated	Partially Regulated	Not Regulated
#3 CROP PLANTS	Not Applicable	Regulated	Partially Regulated	Partially Regulated	Partially Regulated	Not Regulated
#4 TERRESTRIAL MAMMALS FOR RANCHING OR VIEWING	Not Regulated	Regulated	Regulated	Not Regulated	Not Regulated	Not Regulated
#5 FISH USED FOR AQUACULTURE	Partially Regulated	Not Applicable	Regulated	Not Applicable	Not Regulated	Not Regulated
#6 COMMERCIALLY PRODUCED INVERTEBRATES	Not Applicable	Not Applicable	Partially Regulated	Partially Regulated	Partially Regulated	Not Regulated
#7 PREDATORY MAMMALS FARMED FOR FUR	Not Regulated	Regulated	Regulated	Not Applicable	Not Regulated	Not Regulated
#8 HERBIVOROUS MAMMALS FARMED FOR FUR	Not Regulated	Regulated	Regulated	Not Regulated	Not Regulated	Not Regulated
#9 BIRDS AND MAMMALS FOR HUNTING	Not Regulated	Regulated	Regulated	Not Regulated	Not Regulated	Not Regulated
#10 FISH FOR SPORT OR COMMERCIAL FISHING	Partially Regulated	Not Applicable	Partially Regulated	Not Applicable	Not Regulated	Not Regulated
#11 ANIMALS SOLD AS PETS	Not Regulated	Regulated	Partially Regulated	Partially Regulated	Partially Regulated	Not Regulated
#12 ANIMALS INTRODUCED FOR MEDICAL USES	Not Regulated	Not Applicable	Not Regulated	Not Applicable	Not Regulated	Not Regulated
#13 VERTEBRATES USED FOR PEST CONTROL	Regulated	Regulated	Regulated	Not Applicable	Regulated	Regulated
#14 PARASITOIDS FOR INSECT BIOCONTROL	Regulated	Regulated	Regulated	Not Applicable	Regulated	Regulated
#15 PREDATORY INSECTS AND MITES FOR BIOCONTROL	Regulated	Regulated	Regulated	Regulated	Regulated	Regulated
#16 INSECTS OR MITES FOR WEED BIOCONTROL	Regulated	Regulated	Regulated	Regulated	Regulated	Regulated
#17 PATHOGENS FOR WEED OR INSECT BIOCONTROL	Regulated	Not Applicable	Not Applicable	Regulated	Regulated	Regulated

Figure 18. Summary of degree of regulation for 17 groups (purpose of introduction) versus six risks. Biological control agents, groups 13 to 17, in boxed portion of figure.

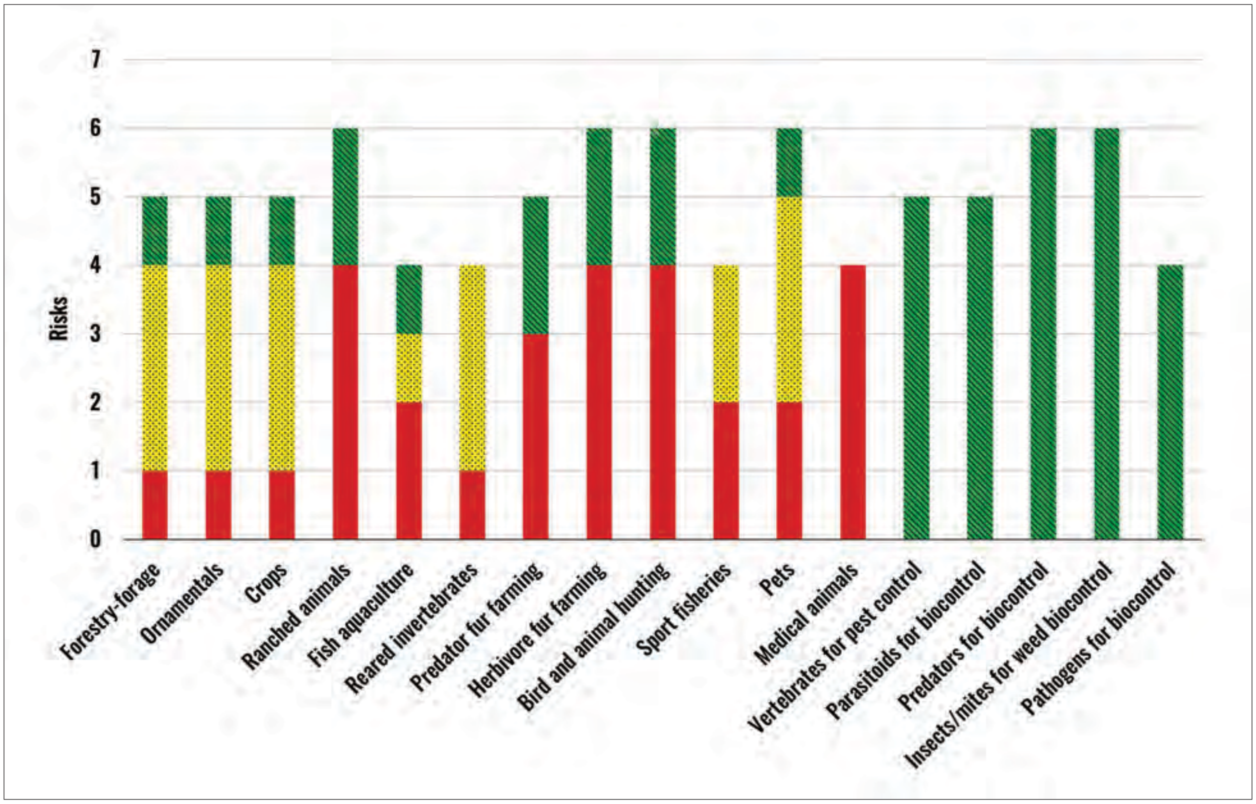


Figure 19. Number of risks that are regulated (green striped), partially regulated (yellow dotted), or not regulated (red) for each of the 17 categories of novel species, under U.S. law (risks judged "not applicable" make up the remainder in each group).

of which require pre-release review. For those organisms, a prior-review, data-based system has been in place since the 1940s for weed biological control agents, since 1993 for parasitoids and predatory insects, and since 2000 for insect pathogens, with regulation of each sector of biocontrol addressing over time a progressively more comprehensive suite of risks.

In this section, we consider the need for a harmonized system in which all new species introductions would follow a pre-introduction, data-driven review process. It also seems reasonable that species being considered for introduction would be judged based on their attributes, not on the reason for which they are being introduced. This influence of the reason for a species introduction on its regulation is similar to differences in U.S. law between regulation of chemicals used as pesticides ("to kill pests") versus chemicals used for industrial applications ("to do many things"), with the latter group often being equally as toxic, but nevertheless held to lower standards under a different law (Toxic Substances Control Act, 1976). Currently, biological control agents are equated with pesticides and are held to higher standards than other species, which can be as or more damaging. In addition, for all species, it would seem valuable to consider the benefits of the introduction. Currently, benefits are the principal item considered for non-biological control agents ("it is good to eat"; "it will boost aquaculture"; "it will provide excellent sport fishing or hunting"; "it will be highly profitable to sell"). The benefits of a biocontrol agent potentially controlling a pest are taken into account during the agent's review; however, far more emphasis is placed on the potential for the agent to have negative impacts on people, plants, animals, soil, water, and other elements of the environment.

Furthermore, adoption of a uniform, defined risk-review process would force some assumptions to be considered—assumptions that we consider faulty but which have been allowed to go unchallenged. For example, new species of fish are imported virtually daily for the aquarium trade, and potential risks of these species escaping and becoming damaging are not reviewed because the fish are not initially being released into the environment. However, the assumption of non-release is amply refuted by the documentation of end-users routinely releasing unwanted, oversized fish too big for home aquaria rather than killing them (Simberloff et al., 1997; USGS, 2019a).

ARGUMENTS FOR RETAINING THE PRESENT U.S. SYSTEM (SPECIAL RULES FOR SPECIAL GROUPS)

Argument #1. Some groups do not cause invasions and hence can be lightly regulated.

One might argue that a universal set of standards for new species introductions is not needed because only some types of introductions are the source of new, damaging invaders. If so, then the implied expectation would be that the groups serving as the strongest sources of new invaders would be the most strongly regulated. Examination of one such list ("100 of the World's Worst Invasive Alien Species" [Global Invasive Species Database, 2014]) found that 63 of the 100 were deliberately introduced. The rank order of importance as sources for deliberately introduced species on this list (**Fig. 20**) was (1) ornamental plants (38%), (2) forestry/forage/fodder plants (14.3%), (3) the pet trade (14.3%), (4) predaceous vertebrates historically used for biocontrol (7.9%), (5) animals and birds for hunting (6.3%), (6) fish for fisheries or sport fishing (6.3%), (7) fish for aquaculture (3.2%), (8) crops (3.2%), and (9) herbivores for fur production (3.2%). These sources accounted for 61 of the 63 deliberately introduced pests on this list (two species not fitting any category). The types of agents used in the last 50 years for biocontrol (i.e., parasitoids for biocontrol of insects or insects and pathogens as agents for weed biocontrol) each had zero species listed (**Fig. 20**). While one might argue that any list's choices would be subjective, this distribution shows that deliberate introductions that create new important pests come from a wide range of groups, topped by ornamental plants, pet species, and vertebrate

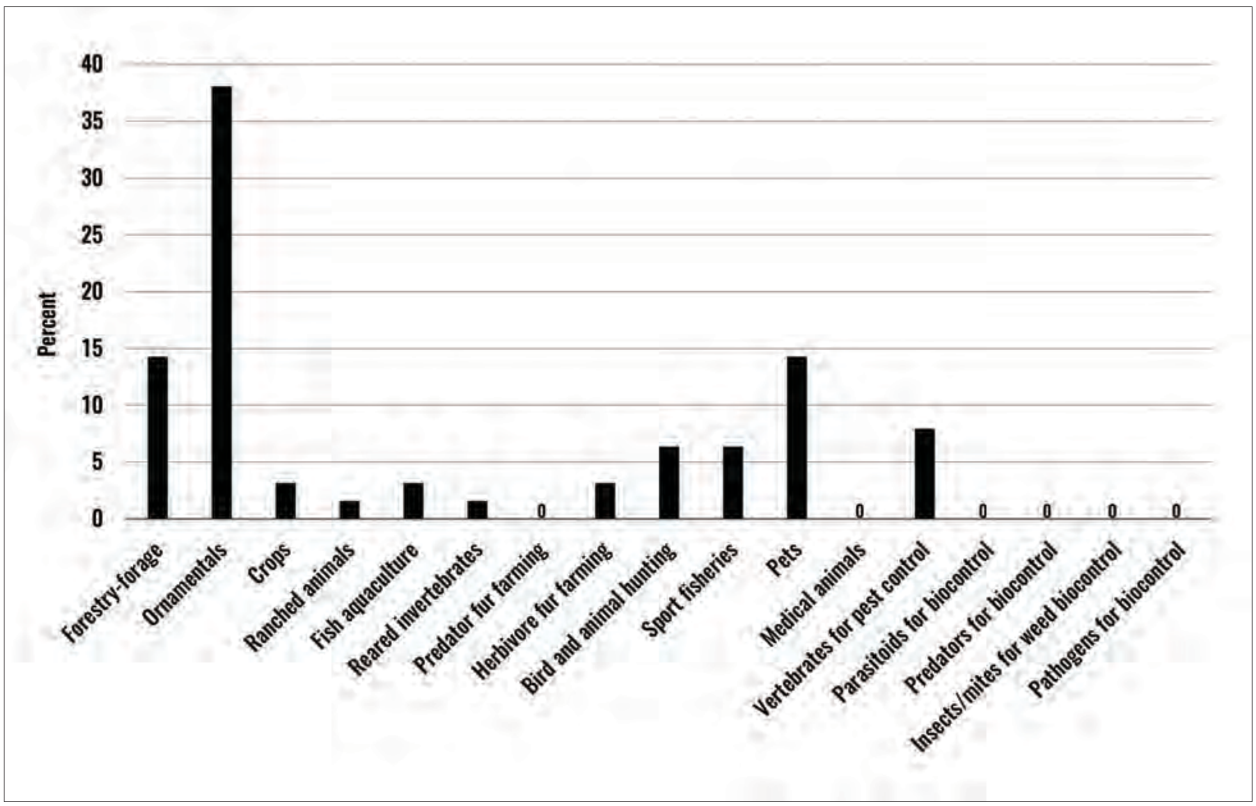


Figure 20. Percentage of deliberately introduced species (n = 63) from list "100 of the World's Worst Invasive Alien Species" (Global Invasive Species Database, 2014) divided by intended use.

animals. This distribution provides no support, rather the contrary, for under-regulating new introductions in these groups.

Argument #2. Some groups are too economically important to restrict their importation.

This argument is an economic argument, not an ecological one. Nevertheless, it also is not supported by facts. Fish importations, for example, have caused damage far in excess of the benefits from the pet and aquaculture industries, and so allowing species in these groups to be introduced freely is not justified economically. This argument might hold in some sectors and some regions, such as the introduction of softwood lumber species to the Southern Hemisphere, where economic and social benefits were enormous and the damage to date has been moderate. If this is the justification for the regulator posture of a country, then it should be explicitly stated as such and supported by financial assessments. Because many species have some economic benefits, the analyses must quantify how great the benefits are and who receives them, versus the damage done by a sector's introductions. For example, it may be easier to justify fish introductions for aquaculture (with significant social benefits) than introductions by the pet industry (with the only economic benefits being to private industry and minor aesthetic benefits to consumers).

Argument #3. Public support does not exist for a new system.

It is likely not an accident that New Zealand and Hawaii, regions that have suffered the most from previous ill-considered species introductions, have the most rigorous policies for new species introductions. For the continental United States, this level of recognition and aversion of invasions is not present; most concern is focused retrospectively on remediation of the effects of bad introductions that have already occurred, rather than on policies that might reduce the chances of new, high-impact introductions. However, opportunities exist to increase public understanding of this problem. One important obstacle is that among the many sectors making species introductions, different groups are perceived independently. Public views are often based on impressions about benefits, limited information about harm (often less easy to see), and images produced by mass media about particular cases, which then become the face of introductions for particular sectors (e.g., Strong, 1997).

ARGUMENTS FOR CREATING A NEW, RISK-BASED SYSTEM, APPLIED EVENLY TO ALL SPECIES GROUPS

The basic argument for a new, risk-based system with parity among all the sectors introducing new species is that this is the only rational way to adjust the intensity of restrictions and the volume of regulatory effort in accordance with the real need. If each sector is regulated based on how much the public (or other smaller groups of people such as commercial interests, biological scientists, or ecologists who dislike biocontrol, etc.) like or dislike an activity, then regulatory rigor will depend on politics, not risk. In the United States, the current regulatory system is highly political. The risks that are perceived and accepted or, conversely, required to be regulated, are the product of politics, not science. However, getting to a better system from the current one would be a formidable task. The authors of this publication are under no illusions about the feasibility of such a change in the near or even medium term. However, by re-framing the conversation as an examination of risks that exist versus risks that the U.S. has chosen to regulate, we hope to increase public understanding of a new potential regulatory framework for evaluating risks of new species introductions, based on their traits, not their purpose.

REFERENCES

Adams, A. J., S. J. Kupferberg, M. Q. Wilber, A. P. Pessier, M. Grefsrud, S. Bobzien, V. T. Vredenburg, and C. J. Briggs. 2017. Extreme drought, host density, sex, and bullfrogs influence fungal pathogen infection in a declining lotic amphibian. *Ecosphere* 8(3): e01740.

Ainsworth, A. and J. B. Kauffman. 2010. Interactions of fire and nonnative species across an elevation/plant community gradient in Hawaii Volcanoes National Park. *Biotropica* 42(6): 647–655.

Albins, M. A. and M. A. Hixon. 2008. Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral-reef fishes. *Marine Ecology, Progress Series* 367: 233–238.

Al-Rwahnih, M., J. Karlik, A. Diaz-Lara, K. Ong, D. Mollov, D. Haviland, and D. Golino. 2019. First report of rose rosette virus associated with rose rosette disease affecting roses in California. *Plant Disease* 103(2): 380.

Aquiloni, L., M. P. Martín, F. Gherardi, and J. Diéguez-Uribeondo. 2011. The North American crayfish *Procambarus clarkii* is the carrier of the oomycete *Aphanomyces astaci* in Italy. *Biological Invasions* 13: 359–367.

Arsan, E. L. and J. L. Bartholomew. 2008. Potential for dissemination of the nonnative salmonid parasite *Myxobolus cerebralis* in Alaska. *Journal of Aquatic Animal Health* 20(3): 136–149.

Aspelin, A. L. 2003. *Pesticide Usage in the United States: Trends during the 20th Century.* CIPM Technical Bulletin 105. Center for Integrated Pest Management, North Carolina State University, Raleigh, North Carolina, USA.

Atkinson, I. A. E. and E. K. Cameron. 1993. Human influence on the terrestrial biota and biotic communities of New Zealand. *Trends in Ecology & Evolution* 8: 447–451.

Austin, D. F. 2007. Water spinach (*Ipomoea aquatica*, Convolvulaceae): a food gone wild. *Ethnobotany Research and Applications* 5: 123–146.

Ayres, D. R., D. L. Smith, K. Zaremba, S. Klohr, and D. R. Strong. 2004. Spread of exotic cordgrasses and hybrids (*Spartina* sp.) in the tidal marshes of San Francisco Bay, California, USA. *Biological Invasions* 6: 221–231.

Badiou, P. H. J. and L. G. Goldsborough. 2015. Ecological impacts of an exotic benthivorous fish, the common carp (*Cyprinus carpio* L.), on water quality, sedimentation, and submerged macrophyte biomass in wetland mesocosms. *Hydrobiologia* 755: 107–121.

Balch, R. E. 1943. European Spruce Sawfly in 1942. Report of the Department of Lands and Forests, Nova Scotia, 1942. Halifax, Nova Scotia, pp. 90–93.

Barber, B. J. 1997. Impacts of bivalve introductions on marine ecosystems: a review. *Bulletin of National Research Institute of Aquaculture* 3 (supplement): 141–153.

Bartholomew, J. W. and P. W. Reno. 2002. The history and dissemination of whirling disease. *American Fisheries Society Symposium* 26: 1–22.

Bauer, L. S. and H-P. Liu. 2007. *Oobius agrili* (Hymenoptera: Encyrtidae), a solitary egg parasitoid of emerald ash borer from China, pp. 63–64. *In*: Mastro, V., D. Lance, R. Reardon, and G. Parra (compilers). *Proceedings of the 2006 Emerald Ash Borer and Asian Longhorned Beetle Research and Development Review Meeting, Cincinnati, Ohio*. FHTET-2007-04. USDA Forest Service, Morgantown, West Virginia, USA. http://www.nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_bauer_002.pdf.

Benson, A. J. 2019. *Hydrochoerus hydrochaeris* (Linnaeus, 1766): U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, Florida, USA. Revision Date: 6/3/2013. Accessed 16 October 2019 at https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=2587.

Benson, J., R. G. Van Driesche, A. Pasquale, and J. Elkinton. 2003. Introduced braconid parasitoids and range reduction of a native butterfly in New England. *Biological Control* 28: 197–213.

Blossey, B. and J. Kamil. 1996. What determines the increased competitive ability of invasive non-indigenous plants? pp. 3–9. *In*: Moran, V. C. and J. H. Hoffmann (eds.). *Proceedings of the 9th International Symposium on Biological Control of Weeds, Stellenbosch, South Africa, 19–26 January 1996.* University of Cape Town, Rondebosch, South Africa.

Boettner, G. H., J. S. Elkinton, and C. J. Boettner. 2000. Effects of a biological control introduction on three nontarget native species of saturniid moths. *Conservation Biology* 14: 1798–1806.

Born Free USA. 2020. Animals in Captivity: Summary of State Laws Relating to Private Possession of Exotic Animals. Accessed 1 March 2020 at https://www.bornfreeusa.org/campaigns/animals-in-captivity/summary-state-laws-exotic-animals/.

Bower, S. M. 2016. Breaking Bad—10 years into a projected 30-year weed eradication program on world heritage listed Lord Howe Island, pp. 201–208. *In*: Randall, R., S. Lloyd, and C. Borger (eds.). *20th Australasian Weeds*

Conference, Perth, Western Australia, 11–15 September 2016. Weeds Society of Western Australia, Perth, Australia.

Briese, D. T. 2005. Translating host-specificity test results into the real world: the need to harmonize the yin and yang of current testing procedures. *Biological Control* 35: 208–214.

Bruland, G. F., C. A. Browning, and C. I. Evensen. 2010. Effects of feral pigs (*Sus scrofa*) on watershed health in Hawai'i: a literature review and preliminary results on runoff and erosion, pp. 251–278. *In*: Roumasset, J. A., K. M. Burnett, and A. M. Balisacan (eds.). *Sustainability Science for Watershed Landscapes.* Institute of Southeast Asian Studies, Singapore.

Buck, B. 2016. Florida researchers weigh risk of arapaima for fishery farms in state. Farm Progress. https://www.farmprogress.com/peanuts/florida-researchers-weigh-risk-arapaima-fishery-farms-state.

Bumbeer, J., R. M. da Rocha, H. Bornatowski, M. de C. Robert, and C. Ainsworth. 2018. Predicting impacts of lionfish (*Pterois volitans*) invasion in a coastal ecosystem of southern Brazil. *Biological Invasions* 20: 1257–1274.

Burghardt, K. T., D. W. Tallamy, C. Philips, and K. J. Shropshire. 2010. Non-native plants reduce abundance, richness, and host specialization in lepidopteran communities. *Ecosphere* 1(5): article #11.

Burreson, E. M., N. A. Stokes, and C. S. Friedman. 2000. Increased virulence in an introduced pathogen: *Haplosporidium nelsoni* (MSX) in the eastern oyster *Crassostrea virginica*. *Journal of Aquatic Animal Health* 12: 1–8.

Butin, E. E., N. P. Havill, N. P., J. S. Elkinton, and M. E. Montgomery. 2004. Feeding preference of three lady beetle predators of the hemlock woolly adelgid (Homoptera: Adelgidae). *Journal of Economic Entomology* 97: 1635–1641.

Bytheway, J. P. and P. B. Banks. 2019. Overcoming prey naiveté: free-living marsupials develop recognition and effective behavioral responses to alien predators in Australia. *Global Change Biology* 25(5): 1685–1695.

Caltagirone, L. E. and R.L. Doutt. 1989. The history of the vedalia beetle importation to California and its impact on development of biological control. *Annual Review of Entomology* 34: 1–16.

Cammà, C., N. Ferri, D. Zezza, M. Marcacci, A. Paolini, L. Ricchiuti, and R. Lelli. 2010. Confirmation of crayfish plague in Italy: detection of *Aphanomyces astaci* in white clawed crayfish. *Diseases of Aquatic Organisms* 89(3): 265–268.

Carnegie, R. B., I. Arzul, and D. Bushek. 2016. Managing marine mollusk diseases in the context of regional and international commerce: policy issues and emerging concerns. *Philosophical Transactions of the Royal Society, London, Series B, Biological Science* 371: 1689.

Carroll, J. P. 1993. Gray Partridge (*Perdix perdix*), version 2.0. *In*: Poole, A. F. and F. B. Gill (eds.). *The Birds of North America.* Cornell Lab of Ornithology, Ithaca, New York, USA. DOI: 10.2173/bna.58.

Carvalheiro, L. G., Y. M. Buckley, and J. Memmott. 2010. Diet breadth influences how the impact of invasive plants is propagated through food webs. *Ecology* 91(4): 1063–1074.

CDFW. 2019. California Department of Fish and Wildlife. Discovery of invasive nutria in California. Accessed 31 December 2019 at https://www.wildlife.ca.gov/Conservation/Invasives/Species/Nutria/Infestation.

Center, T. D., M. P. Hill, H. Cordo, and M. H. Julien. 2002. Waterhyacinth, pp. 41–64. *In*: R. Van Driesche, B. Blossey, and M. Hoddle, S. Lyon, and R. Reardon (eds.). *Biological Control of Invasion Plants in the Eastern United States.* FHTET-2002-04. USDA Forest Service, Morgantown, West Virginia, USA.

Centers for Epidemiology & Animal Health. 1995. Overview of Aquaculture in the United States. USDA, APHIS, Fort Collins, Colorado, USA.

Chew, K. 1990. Global bivalve shellfish introductions. *World Aquaculture* 21: 9–22.

Christensen, G. C. 1970. The Chukar Partridge: Its Introductions, Life History and Management. Nevada Fish and Game Department Biological Bulletin No. 4. Reno, Nevada, USA.

Christensen, G. C. 1998. Himalayan Snowcock (*Tetraogallus himalayensis*), version 2.0. *In*: Poole, A. F. and F. B. Gill (eds.). *The Birds of North America.* Cornell Lab of Ornithology, Ithaca, New York, USA. DOI: 10.2173/bna.328.

Cofrancesco, A. F., Jr. and J. F. Shearer. 2004. Technical advisory group for biological control agents of weeds, pp. 38–41. *In*: Coombs, E. M., J. K. Clark, G. L. Piper, and A. F. Cofrancesco A.F., Jr. (eds.). *Biological Control of Invasive Plants in the United States.* Oregon State University Press, Corvallis, Oregon, USA.

Cohen, A. N. and A. Weinstein. 2001. The Potential Distribution of Chinese Mitten Crabs (*Eriocheir sinensis*) in Selected Waters of the Western United States with U.S. Bureau of Reclamation Facilities. Tracy Fish Collection Facilities Studies, Vol. 21. U.S. Bureau of Reclamation, Mid-Pacific Region and the Technical Service Center. https://www.usbr.gov/mp/TFFIP/docs/tracy-reports/tracy-rpt-vol-21-potential-distrib-chinese-mitten-crabs.pdf.

Cole, R. A., A. Choudhury, L. G. Nico, and K. M. Griffin. 2014. *Gnathostoma* spp. in live Asian swamp eels (*Monopterus* spp.) from food markets and wild populations, United States. *Emerging Infectious Diseases* 20(4): 634–642.

Cottam, C., A. L. Nelson, and L. W. Saylor. 1940. The Chukar and Hungarian partridges in America. U.S. Fish and Wildlife Service, Washington D.C., USA.

Courtenay, W.R. and G. K. Meffe. 1989. Small fishes in strange places: a review of introduced poeciliids, pp. 319–331. *In*: G.K. Meffe and F.F. Snelson, Jr. (eds.). *Ecology and Evolution of Livebearing Fishes (Poeciliidae)*. Prentice Hall, Englewood Cliffs, New Jersey, USA.

Cox, E. H. M. 1961. *Plant Hunting in China: A History of Botanical Exploration in China and the Tibetan Marches.* Oldbourne Book Co. Ltd, London, UK.

Cristofaro, M., A. de Biase, and L. Smith. 2013. Field release of a prospective biological control agent of weeds, *Ceratapion basicorne*, to evaluate potential risk to a nontarget crop. *Biological Control* 64: 305–314.

Cronk, Q. C. B. and J. L. Fuller. 1995. *Plant Invaders: The Threat to Natural Ecosystems*. Chapman & Hall, London, UK.

Crosby, A. W. 2003. Old World plants and animals in the New World, pp. 64–121. *In*: *The Columbian Exchange, Biological and Cultural Consequences of 1492.* Praeger Publishing, Westport, Connecticut, USA.

Cunningham, I. S. 1990. Collecting landscape plants in eastern Asia. *Diversity* 6(3–4): 22–23.

Dahl, F. and P. A. Åhlén. 2019. Nest predation by raccoon dog *Nyctereutes procyonoides* in the archipelago of northern Sweden. *Biological Invasions* 21: 743–755.

Davis, D. E., K. Meyers, and J. B. Hoy. 1976. Biological control among vertebrates, pp. 501–519. *In*: Huffaker, C. B. and P. S. Messenger (eds.). *Theory and Practice of Biological Control.* Academic Press, New York, USA.

DeLoach, C. J. 1985. Conflicts of interest over beneficial and undesirable aspects of mesquite (*Prosopis* spp.) in the United States as related to biological control, pp. 301–340. *In:* Delfosse, E. S. (ed.). *Proceedings of the 6th International Symposium on Biological Control of Weeds, Vancouver, Canada 19–25 August 1984.* Agriculture Canada, Ottawa, Ontario, CAN.

Dodd, C. K., Jr. 2013. *Frogs of the United States and Canada, Vol. 1 & 2.* The Johns Hopkins University Press, Baltimore, USA.

Dorcas, M. E., J. D. Willson, R. N. Reed, R. W. Snow, M. R. Rochford, M. A. Miller, W. E. Meshaka, Jr., P. T. Andreadis, F. J. Mazzotti, C. M. Romagosa, and K. M. Hart. 2012. Severe mammal declines coincide with proliferation of invasive Burmese pythons in Everglades National Park. *Proceedings of the National Academy of Sciences of the United States of America* 109(7): 2418–2422.

Dowling, T. E. and M. R. Childs. 1992. Impact of hybridization on a threatened trout of the southwestern United States. *Conservation Biology* 6: 355–364.

Drummond, B. A. and M. L. Leonard. 2010. Reproductive consequences of nest site use in fork-tailed storm petrels in the Aleutian Islands, Alaska: potential lasting effects of an introduced predator. *Avian Conservation and Ecology* 5(2): Article # 4. DOI: 10.5751/ACE-00414-050204.

Duan, J. J., J. R. Gould, and R. W. Fuester. 2015. Evaluation of the host specificity of *Spathius galinae* (Hymenoptera: Braconidae), a larval parasitoid of the emerald ash borer (Coleoptera: Buprestidae) in Northeast Asia. *Biological Control* 89: 91–97.

Dudley, T. L. and D. W. Bean. 2012. Tamarisk biocontrol, endangered species risk and resolution of conflict through riparian restoration. *Biological Control* 57: 331–347.

Egler, F. E. 1947. Arid southeast Oahu vegetation, Hawaii. *Ecological Monographs* 17(4): 383–435.

Elkinton, J. S. and G. H. Boettner. 2012. Benefits and harm caused by the introduced generalist tachinid, *Compsilura concinnata*, in North America. *BioControl* 57: 277–288.

Elliott, N., R. Kieckhefer, and W. Kauffman. 1996. Effects of an invading coccinellid on native coccinellids in an agricultural landscape. *Oecologia* 105(4): 537–544.

Endangered Species Act. 1973. An act to provide for the conservation of endangered and threatened species of fish, wildlife, and plants, and for other purposes. Public Law 93-205, 16 U.S.C. pp. 1531–1544. https://www.fws.gov/endangered/esa-library/pdf/ESAall.pdf.

Enders, M. and J. M. Jeschke. 2018. A network of invasion hypotheses, pp. 49–59. *In*: Jeschke, J. M. and T. Heger (eds.). *Invasion Biology: Hypotheses and Evidence.* CAB International, Wallingford, UK.

Englund, R. A. and D. A. Polhemus. 2001. Evaluating the effects of introduced rainbow trout (*Oncorhynchus mykiss*) on native stream insects on Kauai Island, Hawaii. *Journal of Insect Conservation* 5: 265–281.

EPPO. 2000. EPPO standards, import and release of exotic biological control agents. PM 6/2(1) English. European and Mediterranean Plant Protection Organization, Paris, France.

Executive Order 13112. 1999. Invasive species. Federal Register 64(25). http://www.gpo.gov/fdsys/pkg/FR-1999-02-08/pdf/99-3184.pdf.

FAO. 2019a. Food and Agriculture Organization of the United Nations. Fisheries and Aquaculture Department, National Aquaculture Sector Overview: United States of America. http://www.fao.org/fishery/countrysector/naso_usa/en#tcN70044.

FAO. 2019b. Food and Agriculture Organization of the United Nations. Fisheries and Aquaculture Department, National Aquaculture Sector Overview: Italy. http://www.fao.org/fishery/countrysector/naso_italy/en.

FAO/IPPC. 1996. Food and Agriculture Organization, International Plant Protection Convention. Code of conduct for the import and release of exotic biological control agents. ISPM No.3, IPPC Secretariat, FAO, Rome, Italy.

Federal Plant Pest Act. 1957. An Act to facilitate the regulation, control, and eradication of plant pests. 7 U.S.C. §§ 150aa-150jj.

Federal Register. 2007. Availability of an environmental assessment for the proposed release of three parasitoids for the biological control of the emerald ash borer (*Agrilus planipennis*) in the continental United States. Federal Register 72: 28947–28948 [Docket No. APHIS-2007-0060]. https://www.govinfo.gov/content/pkg/FR-2007-05-23/pdf/E7-9895.pdf.

Federal Register. 2015. Availability of an environmental assessment for the biological control of emerald ash borer Federal Register 80(29): 7827 [Docket No. APHIS–2014–0094]. https://www.govinfo.gov/content/pkg/FR-2015-02-12/pdf/2015-02914.pdf.

Feldhamer, G. A. and S. Demarais. 2009. Free-ranging and confined sika deer in North America: current status, biology and management. *In*: McCullough, D. R., S. Takatsuki, and K. Kaji (eds). Sika Deer: Biology and Management of Native and Introduced Populations. International Springer, Chiyoda-ku, Tokyo, Japan.

Fernandez, M. 2017. Blood and beauty on a Texas exotic-game ranch. *New York Times* 19 October 2017. https://www.nytimes.com/2017/10/19/us/exotic-hunting-texas-ranch.html.

Fischer, L. K., M. von der Lippe, and I. Kowarik. 2009. Tree invasion in managed tropical forests facilitates endemic species. *Journal of Biogeography* 36(12): 2251–2263.

Fothergill, K. and K. V. Tindall. 2010. Lady beetle (Coleoptera: Coccinellidae: Coccinellinae) occurrences in southeastern Missouri agricultural systems: differences between 1966 and present. *Coleopterists Bulletin* 64(4): 379–382.

Foxcroft, L. C., P. Pyšek, D. M. Richardson, and P. Genovesi (eds). 2013. *Plant Invasions in Protected Areas: Patterns, Problems, and Challenges.* Springer, Dordrecht, Holland.

Fraser, K. W., J. P. Parkes, and C. Thomson. 2003. Management of new deer populations in Northland and Taranaki. Science for Conservation No. 212. Landcare Research, Department of Conservation, Wellington, New Zealand.

Frederickson, B. 2007. Untitled fact sheet of Wisconsin Department of Natural Resources on occurrence of beech or stone marten in Wisconsin. https://dnr.wi.gov/topic/invasives/documents/classification/lr_stonemarten.pdf.

Fugler, S. R. 1982. Infestations of three Australian *Hakea* species in South Africa and their control. *South African Forestry Journal* 120: 63–68.

Fuller, P. 2003. Freshwater aquatic vertebrate introductions in the United States: patterns and pathways, pp. 123–151. *In*: Ruiz, G. and J. Carlton (eds.). *Invasive Species: Vectors and Management Strategies.* Island Press, Washington, D.C., USA.

Fuller, P., L. Nico, and J. Williams. 1999. Nonindigenous fishes introduced into inland waters of the United States. Special publication #27. American Fisheries Society, Bethesda, Maryland, USA.

Funasaki, G. Y., P-Y. Lai, L. M. Nakahara, J. W. Beardsley, and A. K. Ota. 1988. A review of biological control introductions in Hawaii: 1890 to 1985. *Proceedings, Hawaiian Entomological Society* 28: 105–160.

Gallaher, T. and M. Merlin. 2010. Biology and Impacts of Pacific Island Invasive Species. 6. *Prosopis pallida* and *Prosopis juliflora* (Algarroba, Mesquite, Kiawe) (Fabaceae). *Pacific Science* 64(4) :489–526.

Geiger, W., P. Alcorlo, A. Baltanás, and C. Montes. 2005. Impact of an introduced Crustacean on the trophic webs of Mediterranean wetlands. *Biological Invasions* 7: 49–73.

Gilmour, J. D. 1946. The exotic forests of Chile. *B.C. Lumberman* 30(5): 89–90.

Global Invasive Species Database. 2014. 100 of the World's Worst Invasive Alien Species. Accessed 5 September 2018 at https://en.wikipedia.org/wiki/100_of_the_World%27s_Worst_Invasive_Alien_Species.

Global Invasive Species Database. 2020a. *Xenopus laevis* (amphibian). Accessed 4 April 2020 at http://issg.org/database/species/impact_info.asp?si=150&fr=1&sts=&lang=EN.

Global Invasive Species Database. 2020b. *Herpestes javanicus*. Accessed 4 April 2020 at http://www.iucngisd.org/gisd/species.php?sc=86.

Goldschmidt, T. 1996. *Darwin's Dreampond: Drama in Lake Victoria*. MIT Press, Boston, Massachusetts, USA.

Gollasch, S., S. Carlberg, and M. M. Hansen (eds.). 2003. *ICES Code of Practice on the Introductions and Transfers of Marine Organisms.* International Council for Exploration of the Sea. Copenhagen, Denmark.

Gordon, D. R., D. Lieurance, and S. L. Flory. 2017. Predicted versus actual invasiveness of climbing vines in Florida. *Biological Invasions* 19: 2375–2384.

Gould, J. R., L. S. Bauer, J. J. Duan, D. Williams, and H. Liu. 2015. History of emerald ash borer biological control, pp. 83–95. *In*: Van Driesche, R. G. and R. C. Reardon (eds.). 2015. *Biology and Control of Emerald Ash Borer.* FHTET-2014-09. USDA Forest Service, Morgantown, West Virginia, USA. (see page 87). https://www.fs.fed.us/foresthealth/technology/pdfs/FHTET-2014-09_Biology_Control_EAB.pdf.

Goulson, D. 2010. Impacts of non-native bumblebees in Western Europe and North America. *Applied Entomology and Zoology* 45: 7–12.

Green, P. T., D. J. O'Dowd, and P. S. Lake. 1997. Control of seedling recruitment by land crabs in rain forest on a remote oceanic island. *Ecology* 78(8): 2474–2486.

Hajek, A. E., M. L. McManus, and I. Delalibera, Jr. 2007. A review of introductions of pathogens and nematodes for classical biological control of insects and mites. *Biological Control* 41: 1–13.

Hajek, A. E., S. Gardescu, and I. Delalibera, Jr. 2016. *Classical Biological Control of Insects and Mites: A Worldwide Catalogue of Pathogen and Nematode Introductions.* FHTET-2016-06. USDA Forest Service, Morgantown, West Virginia, USA. http://bugwoodcloud.org/resource/pdf/BiocontrolCatalog.pdf.

Hamon, A. B. and V. Salguero. 1987. *Bemisia tabaci*, sweet potato whitefly, in Florida (Homoptera: Aleyrodidae: Aleyrodinae). Entomology Circular #292. Division of Plant Industry, Florida Department of Agriculture and Consumer Services, Florida, USA.

Harland, R. M. and R. M. Grainger. 2011. *Xenopus* research: metamorphosed by genetics and genomics. *Trends in Genetics* 27(12): 507–515. DOI: 10.1016/j.tig.2011.08.003.

Harmon, J. P., E. Stephens, and J. Losey. 2007. The decline of native coccinellids (Coleoptera: Coccinellidae) in the United States and Canada. *Journal of Insect Conservation* 11: 85–94.

Hendrix, P. F. and P. J. Bohlen. 2002. Exotic earthworm invasions in North America: Ecological and policy implications: Expanding global commerce may be increasing the likelihood of exotic earthworm invasions, which could have negative implications for soil processes, other animal and plant species, and importation of certain pathogens. *BioScience* 52(9): 801–811. DOI: 10.1641/0006-3568(2002)052[0801:EEIINA]2.0.CO;2.

Herlihy, M. V., R. G. Van Driesche, M. R. Abney, J. Brodeur, A. B. Bryant, R. A. Casagrande, D. A. Delaney, T. E. Elkner, S. J. Fleischer, R. L. Groves, D. S. Gruner, J. P. Harmon, G. E. Heimpel, K. Hemady, T.P. Kuhar, C. M. Maund, A. M. Shelton, A. J. Seaman, M. Skinner, R. Weinzierl, K. V. Yeargan, and Z. Szendrei. 2012. Distribution of *Cotesia rubecula* (Hymenoptera: Braconidae) and its displacement of *Cotesia glomerata* in eastern North America. *Florida Entomologist* 95: 461–467.

Herlihy, M. V., R. G. Van Driesche, and D. L. Wagner. 2014. Persistence in Massachusetts of the veined white butterfly due to use of the invasive form of cuckoo flower. *Biological Invasions* 16: 2713–2724.

Hill, J. E. and K. M. Lawson. 2015. Risk screening of arapaima, a new species proposed for aquaculture in Florida. *North American Journal of Fisheries Management* 35(5): 885–894. DOI: 10.1080/02755947.2015.1064835.

Hladyz, S., K. Åbjörnsson, P. S. Giller, and G. Woodward. 2011. Impacts of an aggressive riparian invader on community structure and ecosystem functioning in stream food webs. *Journal of Applied Ecology* 48(2): 443–452.

Hoddle, M. 2006. Historical review of control programs for *Levuana iridescens* (Lepidoptera: Zygaenidae) in Fiji and examination of possible extinction of this moth by *Bessa remota* (Diptera: Tachinidae). Pacific Science 60: 439–453.

Hoddle, C. D., M. S. Hoddle, and S. V. Triapitsyn. 2013. *Marietta leopardina* (Hymenoptera: Aphelinidae) and *Aprostocetus* (*Aprostocetus*) sp. (Hymenoptera: Eulophidae) are obligate hyperparasitoids of *Tamarixia radiata* (Eulophidae) and *Diaphorencyrtus aligarhensis* (Hymenoptera: Encyrtidae). *Florida Entomologist* 96: 643–646.

Howarth, F.G. 1991. Environmental impacts of classical biological control. *Annual Review of Entomology* 36: 485–509.

Howe, T. D., F. J. Singer, and B. B. Ackerman. 1981. Forage relationships of European wild boar invading northern hardwood forest. *Journal of Wildlife Management* 45(3): 748–754.

Hoy, M. A., A. Jeyaprakash, and R. Nguyen. 2001. Long PCR is a sensitive method for detecting *Liberobacter asiaticum* in parasitoids undergoing risk assessment in quarantine. *Biological Control* 22: 278–287.

Hüberli, D., B. Lutzy, B. Voss, M. Calver, M. Ormsby, and M. Garbelotto. 2008. Susceptibility of New Zealand flora to *Phytophthora ramorum* and pathogen sporulation potential: an approach based on the precautionary principle. *Australasian Plant Pathology* 37: 615–625.

Istas, J. R. 1954. The importance of biometry in the analysis of the raw materials for a possible paper pulp industry in the Belgian Congo. / Belang van de biométrie in het onderzoek van grondstoffen voor een Kongolese pulpnijverheid. *Bulletin Agricole du Congo Belge* 45: 1249–1276.

IUCN. 2019. IUCN Freshwater Fish Specialist Group. Accessed 31 December 2019 at https://www.iucnffsg.org/freshwater-fishes/freshwater-fish-diversity/.

Jolly, C. J., R. Shine, R. and M. J. Greenlees. 2015. The impact of invasive cane toads on native wildlife in southern Australia. *Ecology and Evolution* 5: 3879–3894.

Julien, M. and G. White. 1997. *Biological Control of Weeds: Theory and Practical Application.* ACIAR Monograph Series No. 49. Australian Centre for International Agricultural Research (ACIAR), Canberra, Australia.

Jussila, J., A. Vrezec, J. Makkonen, R. Kortet, and H. Kokko. 2016. Invasive crayfish and their invasive diseases in Europe with the focus on the virulence evolution of the crayfish plague, pp. 183–211. *In*: Canning-Clode, J. (ed.). *Biological Invasions in Changing Ecosystems: Vectors, Ecological Impacts, Management and Predictions.* De Gruyter, online publisher.

Kauhala, K. and R. Kowalczyk. 2011. Invasion of the raccoon dog, *Nyctereutes procyonoides*, in Europe: history of colonization, features behind its success, and threats to native fauna. *Current Zoology* 57(5): 584–598.

Kilian, J. V., J. Frentress, R. J. Klauda, A. J. Becker, and S. A. Stranko. 2009. The invasion of *Procambarus clarkii* (Decapoda: Cambaridae) into Maryland streams following its introduction in outdoor aquaculture ponds. *Northeastern Naturalist* 16(4): 655–663.

Kobell, R. 2015. A remarkable recovery for the oysters of Chesapeake Bay. *Yale Environment 360* 14 May 2015. https://e360.yale.edu/features/a-remarkable-recovery-for-the-oysters-of-chesapeake-bay.

Kraus, F. 2009. Alien Reptiles and Amphibians: A Scientific Compendium and Analysis. Springer, Basel, Switzerland.

Krysko, K. L., J. P. Burgess, M. R. Rochford, C. R. Gillette, D. Cueva, K. M. Enge, L. A. Somma, J. L. Stabile, D. C. Smith, J. A. Wasilewski, G. N. Kieckhefer Iii, M. C. Granatosky, and S. V. Nielsen. 2011. Verified non-indigenous amphibians and reptiles in Florida from 1863 through 2010: outlining the invasion process and identifying invasion pathways and stages. *Zootaxa* 3028: 1–64.

Kuris, A.M. 2003. Did biological control cause extinction of the coconut moth, *Levuana iridescens*, in Fiji? *Biological Invasions* 5: 133–141.

Land.com. 2019. Exotic animals for your ranch. Land Magazines, September 23, 2015. Accessed 31 December at https://www.land.com/owning/wildlife/ranch-raising-exotic-animals/.

Lafferty, K. D., and C. J. Page. 1997. Predation on the endangered tidewater goby, *Eucyclogobius newberryi*, by the introduced African clawed frog, *Xenopus laevis*, with notes on the frog's parasites. *Copeia* 1997(3): 589–592.

Lecompte, E., E. Fichet-Calvet, S. Daffis, K. Koulémou, O. Sylla, F. Kourouma, A. Doré, B. Soropogui, V. Aniskin, B. Allali, S. K. Kan, A. Lalis, L. Koivogui, S. Günther, C. Denys, and J. ter Meulen. 2006. *Mastomys natalensis* and Lassa Fever, West Africa. *Emerging Infectious Diseases* 12(12): 1971–1974. DOI: 10.3201/eid1212.060812.

Le Stegeman, R. C. 1938. The European wild boar in the Cherokee National Forest, Tennessee. *Journal of Mammalogy* 19: 279–290.

Linder, C., F. Lorenzini, and P. Kehrli. 2009. Potential impact of processed *Harmonia axyridis* on the taste of 'Chasselas' and 'Pinot noir' wines. *Vitis* 48(2): 101–102.

Lindsay, D. L., P. Bailey, R. F. Lance, R. F., M. J. Clifford, R. Delph, and N. S. Cobb. 2011. Effects of a nonnative, invasive lovegrass on *Agave palmeri* distribution, abundance, and insect pollinator communities. *Biodiversity and Conservation* 20: 3251–3266.

Liu, H-P. and L. S. Bauer. 2007. *Tetrastichus planipennisi* (Hymenoptera: Eulophidae), a gregarious larval endoparasitoid of emerald ash borer from China, pp. 61–62. *In*: Mastro, V., D. Lance, R. Reardon, and G. Parra (compilers). 2006. *Emerald Ash Borer and Asian Long-Horned Beetle.* Research and Development Review Meeting, Cincinnati, Ohio. FHTET-2007-04. USDA Forest Service, Morgantown, West Virginia, USA. http://nrs.fs.fed.us/pubs/9566.

Livengood, E. J., N. Funicelli, and N. A. Chapman. 2014. The applicability of the U.S. law enforcement management system (LEMIS) database for the protection and management of ornamental fish. *AACL Bioflux* 7: 268– 275.

Lockwood, J. A. 1993. Environmental issues involved in biological control of rangeland grasshoppers (Orthoptera: Acrididae) with exotic agents. *Environmental Entomology* 22: 503–518.

Lockwood, J. L., D. J. Welbourne, C. M. Romagosa, P. Cassey, N. E. Mandrak, A. Strecker, B. Leung, O. C. Stringham, B. Udell, D. J Episcopio-Sturgeon, M. F. Tlusty, J. Sinclair, M. R. Springborn, E. F. Pienaar, A. L. Rhyne, and R. Keller. 2019. When pets become pests: the role of the exotic pet trade in producing invasive vertebrate animals. *Frontiers in Ecology and the Environment* 17: 323–330. DOI: 10.1002/fee.2059.

Losey, J. E., J. E. Perlman, and E. R. Hoebeke. 2007. Citizen scientist rediscovers rare nine-spotted lady beetle, *Coccinella novemnotata*, in eastern North America. *Journal of Insect Conservation* 11: 415–417.
Louda, S. M. 1998. Population growth of *Rhinocyllus conicus* (Coleoptera: Curculionidae) on two species of native thistles in prairie. *Environmental Entomology* 27: 834–841.
Louda, S. M., T. A. Rand, A. E. Arnett, A. S. McClay, K. Shea, and A. K. McEachern. 2005. Evaluation of ecological risk to populations of a threatened plant from an invasive biological control insect. *Ecological Applications* 15: 234–249.
Love, J. W. and J. J. Newhard. 2012. Will the expansion of northern snakehead negatively affect the fishery for largemouth bass in the Potomac River (Chesapeake Bay)? *North American Journal of Fisheries Management* 32: 859–868.
Lowe, S. R., D. J. Woodford, D. N. Impson, and J. A. Day. 2008. The impact of invasive fish and invasive riparian plants on the invertebrate fauna of the Rondegat River, Cape Floristic Region, South Africa. African Journal of Aquatic Science 33: 51–62.
Lyons, K. G., B. G. Maldonado-Leal, and G. Owen. 2013. Community and ecosystem effects of buffelgrass (*Pennisetum ciliare*) and nitrogen deposition. *Invasive Plant Science and Management* 6(1): 65–78.
Macdonald, D. W. and L. A. Harrington. 2003. The American mink: the triumph and tragedy of adaptation out of context. *New Zealand Journal of Zoology* 30(4): 421–441.
Magnoli, S. M., A. R. Kleinhesselink, and J. H. Cushman. 2013. Responses to invasion and invader removal differ between native and exotic plant groups in a coastal dune. *Oecologia* 173: 1521–1530.
Marler, T. E. and J. H. Lawrence. 2012. Demography of *Cycas micronesica* on Guam following introduction of the armoured scale *Aulacaspis yasumatsui*. *Journal of Tropical Ecology* 28: 233–242.
Martel, A., M. Blooi, C. Adriaensen, P. van Rooij, W. Beukema, M. C. Fisher, R. Farrer, B. R. Schmidt, U. Tobler, K. Goka, K. R. Lips, C. Muletz, K. R. Zamudio, J. Bosch, S. Lötters, E. Wombwell, T. W. J. Garner, A. A. Cunningham, A. Spitzen-van der Sluijs, S. Salvidio, R. Ducatelle, K. Nishikawa, T. T. Nguyen, J. E. Kolby, I. van Bocxlaer, F. Bossuyt, F. (et al). 2014. Recent introduction of a chytrid fungus endangers Western Palearctic salamanders. *Science (Washington)* 346(6209): 630–631.
Mausel, D. L., S. M. Salom, L. T. Kok, and G. A. Davis. 2010. Establishment of the hemlock woolly adelgid predator, *Laricobius nigrinus* (Coleoptera: Derodontidae), in the eastern United States. *Environmental Entomology* 39: 440–448.
McCoid, M. J., and T. H. Fritts. 1980. Notes on the diet of a feral population of *Xenopus laevis* (Pipidae) in California. *Southwestern Naturalist* 25: 272–275.
McColl, K. A., A. Sunarto, and E. C. Holmes. 2016. *Cyprinid herpesvirus* 3 and its evolutionary future as a biological control agent for carp in Australia. *Virology Journal* 13(206): (8 December 2016).
McDonald, C. J. and G. R. McPherson. 2011. Absence of a grass/fire cycle in a semiarid grassland: response to prescribed fire and grazing. *Rangeland Ecology & Management* 64: 384–393.
Measey, G. J., D. Rödder, S. L. Green, R. Kobayashi, F. Lillo, G. Lobos, R. Rebelo, R. and J. M. Thirion. 2012. Ongoing invasions of the African clawed frog, *Xenopus laevis*: a global review. *Biological Invasions* 14(11): 2255–2270.
Moerkens, R., E. Berckmoes, V. van Damme, N. Ortega-Parra, I. Hanssen, M. Wuytack, L. Wittemans, H. Casteels, L. Tirry, P. de Clercq, and R. de Vis. 2016. High population densities of *Macrolophus pygmaeus* on tomato plants can cause economic fruit damage: interaction with Pepino mosaic virus? *Pest Management Science* 72: 1350–1358.
Moore, J. D., C. I. Juhasz, T. T. Robbins, and E. D. Grosholz. 2007. The introduced sabellid polychaete *Terebrasabella heterouncinata* in California: transmission, methods of control and survey for presence in native gastropod populations. *Journal of Shellfish Research* 26: 869–876.
Moyle, P. B. 1976. Fish introductions in California: History and impact on native fishes. *Biological Conservation* 9: 101–118.
Muths, E., P. S. Corn, A. P. Pessier, and D. E. Green. 2003. Evidence for disease-related amphibian decline in Colorado. *Biological Conservation* 110: 357–365.
NAPPRA. 2019a. [List of plants likely to facilitate the introduction of certain pests]. Accessed 31 December at https://www.aphis.usda.gov/import_export/plants/plant_imports/Q37/nappra/downloads/HostsofQuarantinePests.pdf.
NAPPRA. 2019b. [List of plants likely to become weeds]. Accessed 31 December 2019
Round 1: Final, Effective 20 May 2013. https://www.aphis.usda.gov/import_export/plants/plant_imports/Q37/nappra/downloads/QuarantinePestPlants.pdf.
Round 2: Final, Effective 19 June 2017. https://www.aphis.usda.gov/import_export/plants/plant_imports/Q37/nappra/downloads/quarantine-pest-plants-round2.pdf.

Round 3: Proposed 25 November 2019 https://www.aphis.usda.gov/import_export/plants/plant_imports/Q37/nappra/downloads/proposed-quarantine-pest-plants-round-3.pdf.

National Research Council. 2004a. Nonnative Oysters in the Chesapeake Bay. The National Academies Press, Washington, D.C., USA.

National Research Council. 2004b. Chapter 8: Regulatory Framework for Managing Proposed Introductions. *In: Nonnative Oysters in the Chesapeake Bay*. The National Academies Press, Washington, D.C., USA.

Nechols, J. R., L. A. Andres, J. W. Beardsley, R. D. Goeden, and C. G. Jackson (eds.). 1995. *Biological Control in the Western United States, Accomplishments and Benefits of Regional Project W-84, 1964–1989*. Publication 3361 of the University of California, Division of Agriculture and Natural Resources, Oakland, California, USA.

Nelson, J. S. 2006. *Fishes of the World. Fourth Edition.* John Wiley & Sons, New York, USA.

New Zealand Department of Conservation. 2020. Deer. Accessed 31 March 2020 at https://www.doc.govt.nz/nature/pests-and-threats/animal-pests/deer/.

Nico, L. G. and M. E. Neilson. 2019. *Mylopharyngodon piceus* (Richardson, 1846): U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL. Revision Date 1 October 2019. Accessed 11 May 2020 at https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=573.

Nyström, P., O. Svensson, B. Lardner, C. Brönmark, and W. Granéli, W. 2001.The influence of multiple introduced predators on a littoral pond community. *Ecology* 82: 1023–1039.

O'Dowd, D. J., P. T. Green, and P. S. Lake. 2003. Invasional 'meltdown' on an oceanic island. *Ecology Letters* 6 (9): 812–817.

O'Hanlon, S. J., A. Rieux, R. A. Farrer, G. M. Rosa, B. Waldman, A. Bataille, T. A. Kosch, K. A. Murray, B. Brankovics, M. Fumagalli, M. D. Martin, N. Wales, M. Alvarado-Rybak, K. A. Bates, L. Berger, S. Böll, L. Brookes, F. Clare, E. A. Courtois, A. A. Cunningham, T. M. Doherty-Bone, Pria Ghosh; D. J. Gower, W. E. Hintz, J. Höglund, T. S. Jenkinson (et al). 2018. Recent Asian origin of chytrid fungi causing global amphibian declines. *Science* 360(6389): 621–627.

Oldham, K. 2008. The first ring-necked pheasants introduced into the United States arrive at Port Townsend on March 13, 1881. HistoryLink.org Essay 8444.

Olsson, A. D., J. Betancourt, M. P. McClaran, and S. E. Marsh. 2012. Sonoran Desert ecosystem transformation by a C4 grass without the grass/fire cycle. *Diversity and Distributions* 18: 10–21.

Ong, S. P., D. J. O'Dowd, T. Detto, & P. T. Green. 2017. Introduction of *Tachardiaephagus somervilli*, an encyrtid parasitoid, for the indirect biological control of an invasive ant on Christmas Island, pp. 118–120. *In*: Mason, P. G., D. R. Gillespie, & C. Vincent. (eds.) *Proceedings of the 5th international symposium on biological control of arthropods, Langkawi, Malaysia, September 11–15, 2017.* CABI, Wallingford, UK.

O'Shaughnessey, E. M. and R. P Keller. 2019. When invaders collide: competition, aggression, and predators affect outcomes in overlapping populations of red swamp (*Procambarus clarkii*) and rusty (*Faxonius rusticus*) crayfishes. *Biological Invasions* 21: 3671–3683.

Overholt, W. A. and A. R. Franck. 2017. The invasive legacy of forage grass introductions into Florida. *Natural Areas Journal* 37(2): 254–264.

Pasiecznik, N. and H. Jaenicke. 2009. Underutilized crops and invasive species—understanding the links. *Acta Horticulturae* 806(2): 587–594.

Patel, S. 2012. Exotic tropical plant *Psidium cattleianum*: a review on prospects and threats. *Reviews in Environmental Science and Bio/Technology* 11(3): 243–248.

Pavlin, B. I., L. M. Schloegel, and P. Daszak. 2009. Risk of importing zoonotic diseases through wildlife trade, United States. *Emerging Infectious Diseases* 15(11): 1721–1726. DOI: 10.3201/eid1511.090467.

Pemberton, R. W. 1985. Native weeds as candidates for biological control research, pp. 869-877. *In:* Delfosse, E. S. (ed.). *Proceedings of the 6th International Symposium on Biological Control of Weeds, Vancouver, Canada 19–25 August 1984.* Agriculture Canada, Ottawa, Ontario, CAN.

Pemberton, R.W. and H. Liu. 2007. Control and persistence of native *Opuntia* on Nevis and St. Kitts 50 years after the introduction of *Cactoblastis cactorum*. *Biological Control* 41: 272–282.

Phillips, M. L., B. R. Murray, M. R. Leishman, and R. Ingram, R. 2010. The naturalization to invasion transition: are there introduction-history correlates of invasiveness in exotic plants of Australia? *Austral Ecology* 35(6): 695–703.

Pickering, G., J. Lin, R. Riesen, A. Reynolds, I. Brindle, and G. Soleas. 2004. Influence of *Harmonia axyridis* on the sensory properties of white and red wine. *American Journal of Enology and Viticulture* 55(2): 153–159.

Pilliod, D. S. and C. R. Peterson. 2001. Local and landscape effects of introduced trout on amphibians in historically fishless watersheds. *Ecosystems* 4: 322–333.

Pimentel, D. 1955. Biology of the Indian mongoose in Puerto Rico. *Journal of Mammalogy* 36: 62–68.

Plant Protection Act (PPA). 2000. 7 USC 7702. 114 STAT. 438 Public Law 106–224—June 20, 2000. http://www.aphis.usda.gov/plant_health/plant_pest_info/weeds/downloads/PPAText.pdf.

Plant Quarantine Act (PQA). 1912. An act to regulate the importation of nursery stock and other plants and plant products; to enable the Secretary of Agriculture to establish and maintain quarantine districts for plant diseases and insect pests; to permit and regulate the movement of fruits, plants, and vegetables, therefrom, and for other purposes. 20 Aug 1912. 7 U.S.C. pp. 154–167. https://babel.hathitrust.org/cgi/pt?id=loc.ark:/13960/t51g1603m&view=1up&seq=3.

Pope, K. L., J. M. Garwood, H. H. Welsh, Jr., and S. P. Lawler. 2008. Evidence of indirect impacts of introduced trout on native amphibians via facilitation of a shared predator. *Biological Conservation* 141: 1321–1331.

Poucke, K. van, S. Franceschini, J. F. Webber, A. Vercauteren, J. A. Turner, A. R. McCracken, K. Heungens, and C. M. Brasier. 2012. Discovery of a fourth evolutionary lineage of *Phytophthora ramorum*: EU2. Fungal Biology 116(11): 1178–1191.

Prigioni, C., A. Balestrieri, and L. Remonti. 2005. Food habits of the coypu, *Myocastor coypus*, and its impact on aquatic vegetation in a freshwater habitat of NW Italy. *Folia Zoologica* 54(3): 269–277.

Pritekel, C., A. Whittemore-Olson, N. Snow, and J. C. Moore. 2006. Impacts from invasive plant species and their control on the plant community and belowground ecosystem at Rocky Mountain National Park, USA. *Applied Soil Ecology* 32: 132–141.

Purcell, M. F. and J. A. Goolsby. 2005. Herbivorous insects associated with the paperbark *Melaleuca quinquenervia* and its allies: VI. Pergidae (Hymenoptera). *Australian Entomologist* 32: 37–48.

Quinn, L. D., E. C. Scott, A. B. Endres, J. N. Barney, T. B. Voigt, and J. McCubbins. 2015. Resolving regulatory uncertainty: legislative language for potentially invasive bioenergy feedstocks. *GCB Bioenergy* 7(5): 909–915.

Reichard, S. H. and P. White. 2001. Horticulture as a pathway of invasive plant introductions in the United States. *BioScience* 51(2): 103–113.

Rentería, J. L., M. R. Gardener, F. D. Panetta, R. Atkinson, and M. J. Crawley. 2012. Possible impacts of the invasive plant *Rubus niveus* on the native vegetation of the Scalesia forest in the Galapagos Islands. *PLoS ONE* 7(10): e48106.

Rhyne, A. L., M. F. Tlusty, P. J. Schofield, L. Kaufman, J. A. Morris Jr, and A. W. Bruckner. 2012. Revealing the appetite of the marine aquarium fish trade: The volume and biodiversity of fish imported into the United States. Plos/One https://doi.org/10.1371/journal.pone.0035808.

Rhyne, A. L., M. F. Tlusty, J. T. Szczebak, and R. J. Holmberg. 2017. Expanding our understanding of the trade in marine aquarium animals. *PeerJ* 5: e2949.

Rixon, C. A. M., I. C. Duggan, N. M. N. Bergeron, A. Ricciardi, and H. J. Macisaac 2005. Invasion risks posed by the aquarium trade and live fish markets on the Laurentian Great Lakes. *Biodiversity and Conservation* 14: 1365– 1381.

Rowalt, E. M. 1937. Soil defense in the Piedmont. Farmers' Bulletin No. 1767. United States Department of Agriculture.

Ruesink, J. L., H. S. Lenihan, A. C. Trimble, K. W. Heiman, F. Micheli, J. E. Byers, and M. C. Kay. 2005. Introduction of non-native oysters: ecosystem effects and restoration implications. *Annual Review of Ecology, Evolution and Systematics* 36: 643–689. DOI: 10.1146/annurev.ecolsys.36.102003.152638.

Rushton, S. P., G. W. Barreto, R. M. Cormack, D. W. MacDonald, and R. Fuller. 2000. Modeling the effects of mink and habitat fragmentation on the water vole. *Journal of Applied Ecology* 37: 475–490.

Sancho, G., P. R. Kingsley-Smith, J. A. Morris, C. A. Toline, V. McDonough, and S. M. Doty. 2018. Invasive lionfish (*Pterois volitans/miles*) feeding ecology in Biscayne National Park, Florida, USA. *Biological Invasions* 20(9): 2343–2361.

Sands, J. P., L. A. Brennan, F. Hernández, W. P. Kuvlesky, Jr., J. F. Gallagher, D. C. Ruthven, III, and J. E. Pittman, III. 2009. Impacts of buffelgrass (*Pennisetum ciliare*) on a forb community in south Texas. *Invasive Plant Science and Management* 2(2): 130–140.

Savini, D., A. Occhipinti-Ambrogi, A. Marchini, E. Tricarico, F. Gherardi, S. Olenin, and S. Gollasch. 2010. The top 27 animal alien species introduced into Europe for aquaculture and related activities. *Journal of Applied Ichthyology* 26(s2): 1–7.

Scott, C. W. 1960. *Pinus radiata*. FAO Forestry & Forest Products Studies No. 14. 328 pp.

Seaman, G. A. and J. E. Randall. 1962. The mongoose as a predator in the Virgin Islands. *Journal of Mammalogy* 43: 544–546.

Shapiro, H. A. and H. Zwarenstein. 1935. A test for the early diagnosis of pregnancy on the South African clawed toad, *Xenopus laevis*. *South African Medical Journal* 9: 202–205.

Simberloff, D. 2012. Risks of biological control for conservation purposes. *BioControl* 57: 263–276. DOI: 10.1007/s10526-011-9392-4.

Simberloff, D. and P. Stilling. 1996. Risks of species introduced for biological control. *Biological Conservation* 71(1–2): 185–192. DOI: 10.1016/0006-3207(96)00027-4.

Simberloff, D., D.C. Schmitz, and T. C. Brown. 1997. *Strangers in Paradise : Impact and Management of Nonindigenous Species in Florida*. Island Press, Washington, D.C., USA.

Snow, N. P., M. A. Jarzyna, and K. C. VerCauteren. 2017. Interpreting and predicting the spread of invasive wild pigs. *Journal of Applied Ecology* 54: 2022–2032.

Somma, L. A. 2019. *Xenopus laevis* (Daudin, 1802): U.S. Geological Survey, Nonindigenous Aquatic Species Database, Gainesville, FL. Revision Date 18 April 2019. Accessed 11 May 2020 at https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=67.

Sovie, A. R., R. A. McCleery, R. J. Fletcher, and K. M. Hart. 2016. Invasive pythons, not anthropogenic stressors, explain the distribution of a keystone species. *Biological Invasions* 18: 3309–3318.

Stearns, R. E. C. 1900. Exotic Mollusca in California. *Science* 11(278): 655–659.

Stebbins, R. C. 2003. *A Field Guide to Western Reptiles and Amphibians, 3rd Ed.* Houghton Mifflin Company, Boston, USA.

Stebbins, R.C., and S. M. McGinnis. 2012. *Field Guide to the Amphibians and Reptiles of California, Revised Ed.* University of California Press, Berkeley and Los Angeles, USA.

Stiling, P., D. Moon, and D. Gordon. 2004. Endangered cactus restoration: mitigating the non-target effects of a biological control agent (*Cactoblastis cactorum*) in Florida. *Restoration Ecology* 12: 605–610.

Strong, D. R. 1997. Fear no weevil? *Science* 277 (5329): 1058–1059. DOI: 10.1126/science.277.5329.1058.

Tamaru, C. S., H. Ako, H., and C. C. T. Tamaru. 2006. Control of the apple snail, *Pomacea canaliculata*, in Hawai'i: challenge or opportunity? pp. 459–473. *In*: Joshi, R. C. and L. S. Sebastian (eds.). *Global Advances in Ecology and Management of Golden Apple Snails.* Philippine Rice Research Institute (PhilRice), Los Baños, Philippines.

Tapia, M. and L. Zambrano. 2003. From aquaculture goals to real social and ecological impacts: carp introduction in rural Central Mexico. *Ambio* 32(4): 252–257.

Tassan, R. L., K. S. Hagen, and D. V. Cassidy. 1982. Imported natural enemies established against ice plant scales in California. *California Agriculture* 36(9/10): 16–17.

Taylor, K. L. and J. B. Grace. 1995. The effects of vertebrate herbivory on plant community structure in the coastal marshes of the Pearl River, Louisiana, USA. *Wetlands* 15(1): 68–73.

Thomas, M. C. 1995. Invertebrate pets and the Florida Department of Agriculture and Consumer Services. *Florida Entomologist* 78: 39–44.

Toxic Substances Control Act. 1976. 15 U.S.C. §2601 et seq. https://www.epa.gov/laws-regulations/summary-toxic-substances-control-act.

Turnock, W. J., I. L. Wise, and F. O. Matheson. 2003. Abundance of some native coccinellines (Coleoptera: Coccinellidae) before and after the appearance of *Coccinella septempunctata*. *The Canadian Entomologist* 135: 391–404.

UCANR. 2019. University of California. California Snails and Slugs: Brown garden snail. Accessed 31 December 2019 at https://ucanr.edu/sites/CalSnailsandSlugs/Californias_Pest_Snails_and_Slugs/Brown_Garden_Snail/.

USDA. 2019. Alternative Farming Systems Information Center. Snails: Permits and Restrictions. Accessed 31 December at https://www.nal.usda.gov/afsic/snails#snailpermit.

USDA APHIS. 2019a. Swine Damage. APHIS National Feral Swine Damage Management Program. Accessed 31 December 2019 at https://www.aphis.usda.gov/aphis/resources/pests-diseases/feral-swine/feral-swine-program; Feral Swine Damage Accessed 31 December 2019 at https://www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/operational-activities/feral-swine/feral-swine-damage.

USDA APHIS. 2019b. Earthworms. Accessed 31 December at https://www.aphis.usda.gov/aphis/ourfocus/planthealth/import-information/permits/plant-pests/SA_Earthworms.

USDA APHIS. 2019c. Bringing Pets and Wildlife into the United States: Licensing and Health Requirements. Accessed 31 December at https://www.cbp.gov/sites/default/files/assets/documents/2016-Aug/pets-wildlife-unitedstates.pdf.

USDA APHIS. 2019d. Technical Advisory Group for Biological Control of Weeds Manual, Interim Edition. 04-2016 Int. Ed. Rev, 11/2019. Animal and Plant Health Inspection Service, United States Department of Agriculture. https://www.aphis.usda.gov/import_export/plants/manuals/domestic/downloads/tag-bcaw_manual.pdf.

USDA NRCS. 2015. *Ipomoea aquatica* Forssk, swamp morning-glory. The PLANTS Database. National Plant Data Team, Greensboro, NC, USA. Accessed 31 December 2015 at http://plants.usda.gov.

USDA NRCS. 2020. Introduced, Invasive, and Noxious Plants. Federal Noxious Weeds. Accessed 31 March 2020 at https://plants.usda.gov/java/noxious?rptType=Federal.

USFWS. 1982. Importation or shipment of injurious wildlife: raccoon dog. Federal Register vol. 47, No. 242.

USFWS. 2002. Injurious wildlife; brushtail [possum] (*Trichosurus vulpecula*) (18 U.S.C. 42; 50 CFR 16). Federal Register vol. 67, No. 112.

USFWS. 2019a. Summary of species currently listed as injurious wildlife under the Lacey Act (18 U.S.C. 42). See 50 CFR §16 for regulations regarding Injurious Wildlife. Accessed 31 December 2019 at https://www.fws.gov/injuriouswildlife/pdf_files/Current_Listed_IW.pdf.

USFWS. 2019b. [Regulations for Importation of live fish into the United States]. Accessed 31 December 2019 at https://www.ecfr.gov/cgi-bin/text-idx?SID=8ff536e53acc4a218ab0f04191d57c02&mc=true&node=se50.1.16_113&rgn=div8.

USFWS. 2020a. Injurious wildlife: a summary of the injurious provisions of the Lacey Act (18 U.S.C. 42; 50 CFR 16). Accessed 25 April 2020 at https://www.fws.gov/injuriouswildlife/pdf_files/InjuriousWildlifeFactSheet2017.pdf.

USFWS. 2020b. U.S. Fish & Wildlife Service Lacey Act evaluation criteria. Accessed 25 April 2020 at https://www.fws.gov/fisheries/ANS/pdf_files/Lacey_Act_Eval_Criteria_%20FINAL.pdf.

USFWS. 2020c. Fish and Aquatic Conservation. Ecological Risk Screening Summaries—High Risk. Accessed 31 March 2020 at https://www.fws.gov/fisheries/ANS/species_erss.html.

USGS. 2019a. NAS—Nonindigenous Aquatic Species. Fish. Accessed 31 December 2019 at https://nas.er.usgs.gov/queries/SpeciesList.aspx?Group=Fishes.

USGS. 2019b. Invasive Species Program: Invasive fish. Accessed 31 December 2019 at https://www.usgs.gov/ecosystems/invasive-species-program/science/invasive-fish?qt-science_center_objects=0#qt-science_center_objects.

Van Driesche, R. G. and M. Hoddle. 1997. Should arthropod parasitoids and predators be subject to host range testing when used as biological control agents? *Agriculture and Human Values* 14: 211–226.

Van Driesche, R. and M. Hoddle. 2017. *A Review of Nontarget Effects of Insect Biological Control Agents: Concepts and Examples.* FHTET-2016-02. USDA Forest Service, Morgantown, West Virginia, USA. http://bugwoodcloud.org/resource/pdf/nontarget.pdf.

Van Driesche, R. G. and R. Reardon (eds.). 2004. *Assessing Host Ranges of Parasitoids and Predators Used for Classical Biological Control: A Guide to Best Practice.* FHTET-04-03. USDA Forest Service, Morgantown, West Virginia, USA.

Van Driesche, R. G. and R. Reardon (eds.). 2014. *The Use of Classical Biological Control to Preserve Forests in North America.* FHTET-2013-02. USDA Forest Service, Morgantown, West Virginia, USA. https://www.fs.fed.us/foresthealth/technology/pdfs/FHTET-2013-2.pdf.

Van Driesche, R. G. and R. C. Reardon (eds.). 2015. *Biology and Control of Emerald Ash Borer.* FHTET-2014-09. USDA Forest Service, Morgantown, West Virginia, USA. https://www.fs.fed.us/foresthealth/technology/pdfs/FHTET-2014-09_Biology_Control_EAB.pdf.

Van Driesche, R. G. and R. C. Reardon (eds.). 2017. *Suppressing Over-Abundant Invasive Plants and Insects in Natural Areas by Use of Their Specialized Natural Enemies.* FHTET-2017-02. USDA Forest Service, Morgantown, West Virginia, USA. https://bugwoodcloud.org/resource/pdf/Biocontrol_Natural_Areas_FHTET-2017-02.pdf.

Van Driesche, R., B. Blossey, M. Hoddle, S. Lyon, and R. Reardon (eds.). 2002. *Biological Control of Invasive Plants in the Eastern United States.* FHTET-2002-04. USDA Forest Service, Morgantown, West Virginia, USA. https://www.fs.fed.us/foresthealth/technology/pdfs/BiocontrolsOfInvasivePlants02_04.pdf.

Van Driesche, R. G., M. S. Hoddle, and T. Center. 2008. *Control of Pests and Weeds by Natural Enemies.* Blackwell, Boston, MA, USA.

Van Driesche, R. G. et al. (48 other authors). 2010. Classical biological control for the protection of native ecosystems. *Biological Control* 54: S1–S33.

Van Driesche, R., M. J. W. Cock, R. L. Winston, R. Reardon, and R. D. Weeks, Jr. 2018. *Catalog of Species Introduced into Canada, Mexico, the USA, or USA Overseas Territories or Classical Biological Control of Arthropods, 1985–2018.* FHAAST-2018-09. USDA Forest Service, Morgantown, West Virginia, USA. https://www.fs.fed.us/foresthealth/technology/pdfs/FHAAST-2018-09_Catalog_Bio_Control_Arthropods.pdf.

van Lenteren, J. C., J. Bale, F. Bigler, H. M. T. Hokkanen and A. J. M. Loomans. 2006. Assessing risks of releasing exotic biological control agents of arthropod pests. *Annual Review of Entomology* 51: 609–634.

Vinzón, S. E., I. Braspenning-Wesch, M. Müller, E. K. Geissler, I. Nindl, H.J. Gröne, K. Schäfer, and F. Rösl. 2014. Protective vaccination against papillomavirus-induced skin tumors under immunocompetent and immunosuppressive conditions: a preclinical study using a natural outbred animal model. *PLoS Pathogens* 10(2): e1003924. DOI: 10.1371/journal.ppat.1003924.

Vogler, W. and A. Lindsay. 2002. The impact of the rust fungus *Maravalia cryptostegiae* on three rubber vine (*Cryptostegia grandiflora*) populations in tropical Queensland, pp. 180–182. *In*: Jacob, H. S., J. Dodd, and J. H. Moore (eds.). *13th Australian Weeds Conference: Weeds "threats now and forever?", Perth, Western Australia, 8–13 September 2002.* Plant Protection Society of Western Australia Inc, Victoria Park, Perth, Australia.

Waithman, J. D., R. A. Sweitzer, D. Van Vuren, J. D. Drew, A. J. Brinkhaus, I. A. Gardner, and W. M. Boyce. 1999. Range expansion, population sizes, and management of wild pigs in California. *Journal of Wildlife Management* 63: 298–308.

Wallingford, J. B., K. J. Liu, Y. Zheng. 2010. Xenopus. *Current Biology* 20(6): R263–264.

Wang, S-K., Q-A. Sheng, T-J. Chu, B. Li, J-K. Chen, and J-H. Wu. 2013. Impact of invasive plants on food webs and pathways. *Biodiversity Science* 21(3): 249–259.

Wapshere, A. J. 1974. A strategy for evaluating the safety of organisms for biological weed control. *Annals of Applied Biology* 77: 201–211.

Ward, D. L. and R. Morton-Starner. 2015. Effects of water temperature and fish size on predation vulnerability of juvenile humpback chub to rainbow trout and brown trout. *Transactions of the American Fisheries Society* 144: 1184–1191.

Waterhouse, D. F. and D. P. A. Sands. 2001. *Classical Biological Control of Arthropods in Australia.* Australian Centre for International Agricultural Research, Canberra, Australia.

Wehr, N. H., S. C. Hess, C. M. Litton. 2018. Biology and impacts of Pacific Islands invasive species. 14. *Sus scrofa*, the feral pig (Artiodactyla: Suidae). *Pacific Science* 72(2): 177–198.

Welz, A. 2017. How aquaculture is threatening the native fish species of Africa. *Yale Environment 360* 30 October 2017. https://e360.yale.edu/features/how-aquaculture-is-threatening-the-native-fish-species-of-africa.

Wheeler, A. G., Jr. 1990. *Propylea quatuordecimpunctata*: additional US records of an adventive lady beetle (Coleoptera: Coccinellidae). *Entomological News* 101(3): 164–166.

Wheeler, A. G., Jr. and E. R. Hoebeke. 1995. *Coccinella novemnotata* in northeastern North America: histological occurrence and current status (Coleoptera: Coccinellidae). *Proceedings of the Entomological Society of Washington* 97(3): 701–716.

Whitney, L. D., E. Y. Hosaka, and J. C. Ripperton. 1939. Grasses of the Hawaiian Ranges. Bulletin No. 82, Hawaii Agricultural Experiment Station, University of Hawaii. Honolulu, Hawaii.

Wikipedia. 2019a. Raccoon dog. Accessed 31 December at https://en.wikipedia.org/wiki/Raccoon_dog.

Wikipedia. 2019b. Coypu. Accessed 31 December at https://en.wikipedia.org/wiki/Coypu.

Willson, J.D. 2017. Indirect effects of invasive Burmese pythons on ecosystems in southern Florida. *Journal of Applied Ecology* 54(4) 1251–1258.

Wilson, F. 1960. *A Review of the Biological Control of Insects and Weeds in Australia and Australian New Guinea.* Commonwealth Agricultural Bureaux Technical Communication No. 1. Lamport Gilbert and Company, Reading, U.K.

Wilson, J. 2018. At an American escargot farm, growth proceeds at a snail's pace. Washington Post 17 July 2018. https://www.washingtonpost.com/lifestyle/food/at-an-american-escargot-farm-growth-proceeds-at-a-snails-pace/2018/07/13/3104b02c-8556-11e8-8f6c-46cb43e3f306_story.html.

Winston, R. L., M. Schwarzländer, H. L. Hinz, M. D. Day, M. J. W. Cock, and M. H. Julien (eds). 2020. *Biological Control of Weeds: A World Catalogue of Agents and Their Target Weeds.* Based on FHTET-2014-04. USDA Forest Service, Morgantown, West Virginia, USA. Accessed 31 March 2020 at https://www.ibiocontrol.org/catalog/.

Witmer, G. W. and P. L. Fuller. 2011. Vertebrate species introductions in the United States and its Territories. Current *Zoology* 57(5): 559–567.

Wood, G. W. and T. E. Lynn, Jr. 1977. Wild hogs in southern forests. *Southern Journal of Applied Forestry* 1(2): 12–17.

Woodcock, D. 2003. To restore the watersheds: early twentieth-century tree planting in Hawai'i. *Annals of the Association of American Geographers* 93: (3): 624–626.

Wulf, A. 2010. *The Brother Gardeners: Botany, Empire and the Birth of an Obsession.* Penguin, Random House Pub., New York.