

PERCIS III: THE THIRD INTERNATIONAL PERCID FISH SYMPOSIUM

# Percis III

**THE THIRD  
INTERNATIONAL  
PERCID FISH  
SYMPOSIUM**

Madison, Wisconsin, U.S.A.  
July, 2003





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University of Wisconsin, Madison, Wisconsin, U.S.A.

July 20-24, 2003

Terence P. Barry and Jeffrey A. Malison (Editors)

University of Wisconsin Sea Grant Institute

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## Forward

Percis III was held July 20-24, 2003, at the Monona Terrace Convention Center in Madison, WI, USA. Percis III was the successor to two previous symposia, Percis I in Ontario, Canada in 1976, and Percis II in Vaasa, Finland, in 1995. Percis III was an unqualified success: the symposium included more than 180 presentations, given by over 150 registered participants from 30 countries around the world.

Each presenter was invited to prepare a two-page communication of their presentation for publication. Each communication that was received was sent out for external review. Based upon these reviews, 63 communications were accepted for publication, and constitute the bulk of these proceedings.

Percis III was divided into 6 thematic areas: ecology, management, aquaculture, general biology, yellow perch in the Great lakes, and ecology and evolution of darters. At the conclusion of the symposium, organizers and participants were asked to develop a short document describing the current status of each theme (as clarified by the presentations) and outlining key future research needs. Five of these documents are also included in these proceedings.

I would like to thank the following members of the Percis III Steering Committee, and the thematic session organizers, without whose help this symposium would not have been possible: Terence Barry, Ted Batterson, Dominic Baccante, Peter Colby, John Craig, Konrad Dabrowski, Jeffrey Gunderson, Christopher Heyer, Patrick Kestemont, Hannu Lehtonen, Victor Mikeev, Donald Pereira, Kyle Piller, Edward Roseman, and Robert Summerfelt.

Because of the clear importance of these fishes, and the strong interest expressed, preliminary talks have already begun regarding a Percis IV symposium, to be held perhaps in 2009 or 2010.

Sincerely,  
Jeffrey Malison  
Chairman of Percis III

## **Thematic Area Summaries**

### **Percid aquaculture: Current status and future research needs**

*Jeffrey Malison, Patrick Kestemont, and Robert Summerfelt*

### **Ecology and evolution of darters: Current status and future research needs**

*Kyle Piller*

### **Percid ecology: Current status and future research needs**

*Carol Stepien and Edward Roseman*

### **Percid management: Current status and future research needs**

*Edward Roseman*

### **Yellow perch in the Great Lakes: Current status and future research needs**

*Christopher Heyer*

## PERCID AQUACULTURE: CURRENT STATUS AND FUTURE RESEARCH NEEDS

Jeffrey Malison, Patrick Kestemont, and Robert Summerfelt

For many years, the exclusive focus of percid aquaculture had been on the production of walleye (in North America) and pikeperch (in Europe) fingerlings for stocking into natural and impounded waterways. This production continues today. These fingerlings are produced largely by public fish hatcheries, although some commercial culture has begun. The original culture method used was extensive pond culture, and although this method is still widely practiced today, the development of formulated feeds that were nutritionally adequate for walleye fingerlings permitted the use of a tandem method of extensive pond culture followed by intensive tank culture for producing fingerlings to an advanced size (e.g., 100-200 mm). More recently, advances in larval diets and system engineering (e.g., methods to facilitate gas bladder inflation) have led to the development of methods for raising walleye fingerlings entirely in tanks.

Since the early 1980's in the US, and the early 1990's in Europe, a great interest has developed in the commercial culture of yellow perch, and walleye, and Eurasian perch and pikeperch, respectively, as food fish, driven by ever-increasing demand and declining supplies from the wild. In the US, since 1990 a significant number of farms in the US have attempted the commercial culture of yellow perch as food fish, and a smaller number have attempted raising walleye to food size. Some of these businesses failed, others remain in production, and new start-up efforts continue. In Europe, at least one commercial pond-based operation for Eurasian perch exists in Ireland, and several initiatives have emerged in recirculation systems and lake-based cages. At Percis III it became clear that interest is growing in the commercial culture of these species in France, Switzerland, Norway, Sweden and Denmark.

Presently, pond culture or tandem pond/tank culture are the most cost-effective methods for producing yellow perch and walleye fingerlings. Pond culture and recirculation systems appear to be the two most feasible grow-out methods for both species. Recirculation systems offer the benefit of year-round growth, in which yellow perch can be raised from hatch to market size (0.25-0.33 kg) in 12 months, walleye (0.5 – 0.75 kg) in 18 months, and pikeperch (2.0 kg) in 24 months. Ponds or other systems at ambient temperature may prove more cost effective than recirculation systems, however, despite comparatively slower fish growth rates. In the US, a primary need (which is currently being addressed for yellow perch, but not for walleye) is the documentation of production costs for specific system types. Bio-economic data is also needed for the grow-out of Eurasian perch and pikeperch. One significant problem that has developed in the US and is currently restricting the development of yellow perch and walleye aquaculture is an illegal practice of mis-labeling wild-harvest juvenile pikeperch, walleye, or sauger filets as yellow or "lake" perch. These fish are being sold at extremely low prices, and clearly this practice must be halted if the development of commercial percid aquaculture is to continue.

For all of these percid species, the commercial culture of food fish is constrained by economics. Production systems must be developed that can compete with the cost of fish harvested from the wild. Over time, one can reasonably assume that increasing demand and declining supplies will lead to higher costs, making commercial aquaculture more feasible (as is the case with most other wild-harvest seafood products). At the same time, research is needed to develop more efficient production methods and systems.

Both yellow perch and Eurasian perch are marketed at a relatively small size, compared to most other cultured fish species. Accordingly, more fingerlings are needed per unit weight of marketable food, and fingerling costs represent a very high percentage of total production costs for these species. Both of these species also grow slower than most other commercially cultured food fish. Because of these facts, methods to reduce fingerling production costs and improve growth rates are two of the highest priority research areas. For pikeperch, additional major constraints are the high variability in egg and larval quality and the sudden (stress related?) mortalities that occur during grow-out.

Because of the similar biology of yellow perch, Eurasian perch, walleye and pikeperch, advances in aquaculture technology may be applicable across all four species. In this regard, one of the primary values of Percis III was to bring scientists from around the world together to discuss their related research on these different species. Advances in various disciplines, including genetics, nutrition, physiology, endocrinology, and engineering, were described. Specific important advances included: optimization of environmental conditions, better and more cost-effective diets, the use of hybridization to improve growth, methods of controlling reproduction and spawning (including the production of fast-growing monosex female and sterile strains), and beginning efforts at producing domesticated strains for aquaculture. Efforts along all of these lines should continue, but in particular efforts aimed at improving the domestication of these species may be the most important.

## ECOLOGY AND EVOLUTION OF DARTERS: CURRENT STATUS AND FUTURE RESEARCH NEEDS

Kyle Piller

Darters (Subfamily Etheostomatinae) represent one of the most fascinating examples of morphological, behavioral, ecological, and genetic radiation in North America. Darters are one of the most speciose groups of North American freshwater fishes, with over 200 species/subspecies. The high degree of darter diversity is believed to be the result of two factors: adaptation to habitat and sexual selection. As a result, darters are a model group for studies of adaptive radiation and diversification. The eminent ichthyologist and statesman David Starr Jordan (1922) recognized the exceptionality of this group when he stated, "These (darters) we found to be the most fascinating, vivacious, and individual of all river fishes."

Until recently, studies of darter diversity focused on alpha level taxonomy, specifically, describing species and documenting levels of morphological diversity. In the last decade, darter biologists have undertaken phylogenetic studies to examine relationships among species, subgenera, and genera. Interest in darter diversity and systematics has increased dramatically, primarily due to the usage of DNA sequence data. Most studies have relied on mitochondrial DNA, particularly cytochrome b, to address particular evolutionary questions. As a result, we are now beginning to have a clearer understanding of the evolutionary history of this group, and consequently, are re-evaluating darter taxonomy in light of this new data. Future research needs to build on the results from previous studies and should proceed in the direction of multi-gene phylogenies that incorporate multiple nuclear and mtDNA markers. However, one of the unfortunate aspects of systematic and taxonomy studies is the lack of adequate funding sources. At present, the National Science Foundation is the primary funding source for systematic and taxonomic studies. Developing a comprehensive understanding of the diversity and evolutionary history of darters will likely require additional funding sources and collaborative efforts among multiple researchers.

Although darters are relatively unknown to most of society, they represent an important component of riverine ecosystems in the Eastern United States. Darter biologists would argue that particular species of darters (i.e. *Crystallaria asprella*) are some of the most important aquatic species for environmental protection. Darters are important because they are "indicator species" for aquatic environments. When riverine systems are perturbed through human modifications, such as dam construction or channelization, darters are often the first group of organisms to become imperiled, and often extirpated. In fact, one species, the Maryland darter (*Etheostoma sellare*) is already believed to be extinct, prior to understanding its habitat requirements and other aspects of its ecology. We lack comprehensive life-history information for many darters. Additional research is needed to better understand basic aspects of habitat, reproduction, and feeding if we are to conserve darter populations and their respective riverine systems. These types of studies represent an important and often overlooked component of species conservation.

Routine conservation status surveys addressing levels of imperilment in jeopardized darters are necessary for the development of an effective management plan for many species. Although the results from these types of studies are critical for managing and protecting darters, they are often conducted over relatively short periods (1 or 2 years). Documentation of long-term abundance and distributional changes, through multi-year studies or incorporation of museum data, are needed to provide a more comprehensive view of demographic and distributional changes among jeopardized darters.

An equally important aspect of species conservation, but one that is less often pursued, is the incorporation of molecular markers to address levels of genetic diversity within populations. Molecular genetic data routinely are incorporated into the management of salmonids, centrarchids, or other sportfishes, but less often utilized for non-game species including darters. Usage of high-resolution markers including microsatellites or AFLP's, have increased our effectiveness in managing fish populations. Future research should use these types of techniques, as they can provide useful information that can guide re-introduction efforts, monitor gene flow between populations, and document distinct temporal changes in genetic diversity among darters.

Finally, comparing patterns of endangerment of darters and other aquatic groups may shed light on the factors that concurrently have impacted aquatic species. The life-history of mussels, one of the most imperiled groups of organisms in North America, is often tied to population sizes of sympatric species of fishes. Darters serve as glochidial hosts for many species of mussels, particularly in the Interior and Ozark-Ouachita Highland regions, where darter and mussel diversity is greatest. Understanding the relationship between mussel and darter diversities and population sizes may prove to shed light on the mechanisms of endangerment within both the unionid mussels and Etheostomatine darters.



## PERCID ECOLOGY: CURRENT STATUS AND FUTURE RESEARCH NEEDS

Carol A. Stepien and Edward F. Roseman

Ecological investigations of percids are fundamental to preserving this important group, which include economically and ecologically important species, for future generations. The family Percidae comprises about 162 species that live in a variety of lake, river, and stream habitats in North America and Eurasia. Members of the genera *Perca* and *Sander* (the latter was formerly known as *Stizostedion*) in North America and Eurasia are highly prized game fishes, and their anthropogenic exploitation and habitat alterations have impacted their population ecology. The pikeperches are keystone predators in lake and river ecosystems, and their populations regulate species diversity of other aquatic animals. The North American and European yellow perch, *Perca flavescens* and *P. fluviatilis*, are similar ecologically and also are important predators in aquatic systems. Species of *Perca* and *Sander* have been introduced widely outside their native ranges in North America and Europe, usually to augment fisheries. However, some spread of percids to new habitats has been accidental. For example, the Eurasian ruffe *Gymnocephalus cernuus* invaded Lake Superior of the North American Great Lakes in the mid-1980s via ballast water discharge, and has since spread to Lakes Huron and Michigan, raising questions of the need for study of its ecological adaptations as an invasive species. The ruffe is projected to seriously impact populations of the related yellow perch *P. flavescens* if and when it reaches the lower Great Lakes. The darters – especially the species-rich genus *Etheostoma* – are found only in North America, where they have exhibited tremendous adaptive radiation in a great variety of stream and river habitats. They number over 102 species and are very ecologically specialized. Many of them are important indicators of the health of freshwater habitats.

Several studies included in Percis III and in this volume focused on the role of percids as keystone predators in ecosystems. For example, Baccante and Down analyzed walleye *Sander vitreus* diets and growth in British Columbia, located at the western-most limit of its distribution. They found that walleye in British Columbia consume large invertebrates, due to a shortage of smaller fishes – instead of their typical piscivory – with consequential lower growth rates and lower fecundity. The paper by Domer et al. focused on size-dependent predation and prey fish availability in the European yellow perch *Perca fluviatilis* and pikeperch *Sander lucioperca*, addressing competition among percid species and predation dynamics. Haakana et al. examined diet of *P. fluviatilis* in eastern Finland, evaluating predator-prey dynamics and the influence of fishing pressure. Bobyrev provided an overview of quantitative percid ecology in Russia, including population dynamics, growth parameters, mortality rates, life history and reproductive data in relation to habitat, climate, and niche.

Several papers investigated environmental data in relation to stocks of pikeperches. For example, Lappalainen analyzed the state of *S. lucioperca* stocks in Finnish lakes, in relation to environmental data - including turbidity, conductivity and location - as well as other fish species abundances using artificial neural network statistical analyses. Pikeperch stocks in lagoons and estuaries of the southern Baltic Sea region were evaluated by Winkler and Groger in relation to migrations, spawning, life history, population dynamics, and food densities. Populet et al. examined life history characters of *S. lucioperca* in the Mediterranean delta of the Rhone River, in an expansion population area outside of its native range. They analyzed growth, longevity, spawning, sexual maturity, fecundity, and diet. Results suggested differences from areas of their native range - including high growth, early maturity, and shorter life. Stocking of *S. lucioperca* on native *P. fluviatilis* populations and their interspecific competition, diel activity, and diets were examined in Germany by Holder and Mehner. In North America, walleye *S. vitreus* spawning runs in relation to river size and spring maximum daily flow data were analyzed by Eshenroder for 21 rivers in the upper Great Lakes. Recruitment and growth patterns of *S. vitreus* and sauger *S. canadensis* were examined in the lower Wisconsin River, in relation to climate, which appeared to drive recruitment.

Recruitment and life history data were the focus of several papers on *Perca* species, in European and North American habitats. For example, Linlokken examined Eurasian yellow perch *P. fluviatilis* recruitment in 18 small lakes in southeastern Norway, evaluating recruitment and mortality, in relation to air temperatures and acidification. Lozys examined salinity effects on growth of *P. fluviatilis* in the vicinity of the Baltic Sea, Lithuania, in relation to temperature, salinity, and migration patterns in fresh and brackish waters. Mikheev et al. investigated predator avoidance and foraging behavior during migrations by juvenile *P. fluviatilis* in laboratory and field experiments. In North America, Niewinski and Ferreri examined structure and dynamics of an unexploited *P. flavescens* population in Pymatuning Sanctuary in Pennsylvania, using otolith age data and evaluating maturity, fecundity, and annual survival. These data are projected to be useful for comparing unexploited versus exploited populations.

Stock structure data of *Perca* were also the focus of two genetic analyses. Genetic analysis of *P. flavescens* populations in North America by Moyer and Billington used allozyme and mitochondrial DNA RFLPs (restriction fragment length polymorphisms), discerning significant population divergence between western and eastern populations across North America only with allozymes. However, a DNA sequence data analysis by Ford and

Stepien of the mtDNA control region resolved finer-scale structure in spawning populations of *P. flavescens* within Lake Erie, suggesting that the application of multiple genetic approaches is advantageous for addressing stock structure questions.

Population ecology of percids as invasive species was the focus of several papers, in both Eurasian and North American waters. Dgebuadze summarized Eurasian invasions and range expansions by four species, including the pikeperches *S. lucioperca* and *S. volgensis*, yellow perch *P. fluviatilis*, and the ruffe *G. cernuus*. An investigation by Stepien et al. focused on the genetic identification of the Eurasian founding source population for the ruffe *G. cernuus* invasion in the North American Great Lakes as being the Elbe River drainage, as confirmed by both mitochondrial and nuclear DNA sequence analyses.

Perusing the papers in each of the previous Percid volumes (Journal of the Fisheries Research Board of Canada 1977: 34(10) and Annales Zoologici Fennici 1996: 33(3-4)) it becomes evident that percid scientists are on the cutting edge of research and analytical techniques. Following this tradition, papers at Percis III described some innovative state-of-the-science techniques and paradigms including artificial neural network analyses, geographic information systems, sanctuaries, DNA genetic methods, systems modeling, and hydro-acoustics. Many of the papers presented in the Ecology session made use of long-term datasets to explore trends in populations, shifts in community composition, impacts of invasive species, climate change, and anthropogenic disturbances on percid populations and their communities. Some authors referred to or presented results from systems modeling efforts that not only described historical trends, but predicted future population and community dynamics. More importantly, these models identified voids in the knowledge base thus providing direction for future research.

In conclusion, while there may already appear to be a wealth of information on percid ecology, there remains much to be clarified and explored, especially as habitat conditions continue to change and fishing occurs. Some of the themes suggested for future research include the following:

- (1) identifying and measuring the effects of fishing on percid ecology
- (2) exploring the effects of habitat change on population and community dynamics
- (3) expanded use of multivariate and geo-spatial statistical analyses
- (4) continued development of bioenergetic models of growth
- (5) continued assessment of genetic differences among stocks throughout their ranges.

Research efforts should be integrated with fisheries management programs to provide information necessary to complete management objectives as well as assess the effectiveness of the management program.

## PERCID MANAGEMENT: CURRENT STATUS AND FUTURE RESEARCH NEEDS

Edward Roseman

Twenty papers were presented in the Percis III management session. While the authors participating in this session originated from diverse backgrounds and continents, some dominant themes were evident in their presentations suggesting that fisheries managers across the world are addressing similar obstacles and problems. These themes included the use of stocked fish to supplement natural production, impacts of habitat modification and loss (including pollution), and efforts to accurately estimate mortality rates. Also, following recommendations of workgroups from Percis II in 1995, more management agencies are incorporating results from systems modeling to help address complex management issues. Nearly all presenters emphasized the importance of maintaining long-term monitoring studies to provide an information base useful in developing management plans and assessing their effectiveness.

Several papers in the management session addressed issues related to stocking percids as a fisheries enhancement strategy. Papers by Bolotova et al., Jacobson, Wallace, and Kampa et al. discussed the importance of assessing the contribution of stocked percids to fisheries. Schulze et al. and Pierce talked about the impacts stockings of *Zander* species had on fish community and trophic dynamics in lakes. Ruuhijarvi and Salminen presented a paper describing the effect of pikeperch size at stocking on performance and recruitment to the fishery. Stepien et al.'s paper discussed an analysis of genetic hybridization risk posed by stocking into a historic walleye spawning group. Based on the papers in this session, stocking percids to enhance and restore fisheries is a strategy used around the world to achieve management goals and supported by strategies that assess its effectiveness.

Identifying the effects of habitat perturbation on percid fisheries proved to be a dominant theme among papers presented in the management session. Konovalov et al. discussed the impacts of water pollution by heavy metals and other contaminants on percid physiology and pathology in some impacted Russian lakes. Sass presented a paper that detailed the importance of coarse woody structure in littoral zones as refuge for yellow perch in Wisconsin lakes. The need to conduct more research to explore linkages among and between life-history stage-specific habitats was emphasized in the discussion of these papers.

Estimating accurate natural and fishing mortality rates and the use of population parameters as reference points were addressed in several papers in the management session. Papers by Lester and Morgan drew upon knowledge gained from long-term studies conducted in several dozen Ontario lakes to produce a set of criteria for identifying useful biological reference points to assess walleye populations. Hennessy presented a pair of papers describing statistical properties of natural mortality estimates for walleye in northern Wisconsin lakes. A paper by Prchalova discussed gear selectivity and its potential to impact mortality estimates and catch statistics.

Lastly, papers by Knight et al., Salminen et al., and Beard et al. discussed the importance of interagency cooperation and collaboration to produce and carry out effective management plans. These papers, in addition to those mentioned above, emphasized the importance of standardized long-term monitoring programs supplemented by shorter-term research projects to provide the information necessary to formulate effective management plans. These papers also emphasized the importance of assessment programs that monitor the progress and effectiveness of management strategies.

Based on discussions carried out during and after the management session, several research and management issues were highlighted as important for the future of successful percid management and will hopefully be addressed at Percis IV. While none of these can be called "new," they remain important, nonetheless. In no particular order, these include: understanding the role of physical habitat and climate on percid population dynamics, using regulations to effectively control fishing mortality, law enforcement strategies in percid management, multivariate methods to analyze data, genetic considerations in stocking and management, gathering and interpreting stakeholder perceptions of management programs, developing standardized assessment methods, impacts of exotic species on percid populations, role and effects of stocking percids, and improving the exchange of information among scientists around the world. In closing, I would like to thank Roger Knight and Dr. Carol Stepien for helping to moderate the management session and also thank the presenters and co-authors for their excellent contributions.

## YELLOW PERCH IN THE GREAT LAKES: CURRENT STATUS AND FUTURE RESEARCH NEEDS

Christopher Heyer

Yellow perch (*Perca flavescens*) and European perch (*P. fluviatilis*) are an important fishery resource in many parts of the world, both as a food source and as a source of cultural heritage. Globally, declines in yellow and European perch populations have been observed over the past two decades. Declines in perch abundance have been reported in the Baltic (Sweden), the Chesapeake Bay region (US), Lake Erie (US/Canada), Lake St. Claire (Canada), Lake Constance (Germany/Switzerland), Lake Huron (US/Canada), Lake Michigan (US/Canada), and Oneida Lake (US). While percid populations have declined in many areas of the World during similar time periods, their specific causes have varied and in many cases remain undetermined.

In the Baltic, declines in European perch, as well as other species, have been attributed to recruitment failure, though the mechanism or mechanisms responsible for the recent recruitment failures remain unknown. In the Chesapeake Bay region, increased residential and commercial development of several tributary basins and increased coverage by impervious surface is thought to be responsible for decreases in suitable yellow perch habitat. In Lake Erie, yellow perch populations declined during a period of poor recruitment during the late- 1980s through the mid- 1990s, but have since rebounded through sound management practices. The causes of the decline of Lake Erie's perch population are not precisely known, but drastic changes to the lake ecosystem through the introduction of invasive species are thought to have played a major role. The decline of yellow perch in Lake St. Clair has been directly attributed to overfishing. In Lake Constance, the decline of European perch has been attributed to reoligotrophication of the lake, which has favored increased growth but not reproduction. The causes behind the collapse of the yellow perch populations in Lakes Huron and Michigan remain undetermined, but many hypotheses have been put forward. Likely causes of the yellow perch declines in Lake Michigan include increased predation by alewife, offshore transport away from nursery areas, decreased quantity and quality of zooplankton, shifts in the characteristics of the spawning stock, and changes in the ecosystem due to the introduction of invasive species. Recent declines of yellow perch in Oneida Lake have been attributed to increased cormorant predation, which is now a concern in many systems where cormorant populations are booming.

While there is great variation in the causes, or hypothesized causes, for the recently observed declines in yellow and European perch, there are some commonly recurring suspects. With the exception of those systems that can attribute perch population declines to increased predation on adults, there appears to be a common theme of increased mortality during the first summer from the onset of first feeding to the stage of late summer fingerlings. This increased mortality in early-life may be related to increases in water clarity through the introduction of zebra mussels (*Dreissena polymorpha*) and lake reoligotrophication. It has been suggested that reoligotrophication results in decreases in the nutritional quality and species richness of the plankton food web. These changes in the plankton community may result in a shift from pelagic to benthic producing systems and may impact perch development during early-life stages. However, as has been seen in Lake Michigan, the suspected causes for perch declines in one portion of the lake do not appear to be the causes for declines in other portions of the lake.

While much has been learned in many of these systems, much still remains unknown. For example, it is still unclear how many abiotic factors affect recruitment success and yellow and European perch stock-recruitment relationships. Additionally, in many systems little is currently known about the long-term changes in production. There is a need to investigate how the introduction of invasive species and changes in the phosphorous loading and trophic structure of these systems have impacted the quality and quantity of the plankton community. While perch in many of these systems may not be starving, they may not be getting all of the nutrition essential to ensure proper development and successful recruitment. The decline of perch in these systems is not likely attributable to any one cause, but rather to a synergy of many factors. As has become apparent in many current fisheries issues, researchers and managers need to examine the ecosystem as a whole in order to understand and dissect such synergies.

As is the case with all resource management, information about the recent declines of yellow and European perch does not exist in a vacuum. In many cases, the collapse of these populations has prompted tremendous public outcry. While much research has been conducted on these declines and much has been learned, this information often does not get disseminated to the public. There is an increased need for effective and frequent communication with the stakeholders of these resources. A proactive approach to open communication helps to insure public trust in researchers and managers, and may even make tough management decisions easier to accept. This is an essential need if researchers and managers are going to stave off unrealistic management requests by stakeholders.

## HISTORY OF PERCIS

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In the 1960's and 70's an environmentally aware society was concerned that many percid fishes were adversely impacted by man's activities. Thus, two international percid symposiums were held in 1976 and 1995 to obtain a clearer understanding of the effect of man induced stress, primarily overexploitation, habitat degradation, and species interactions on these fishes. The need to understand time lags from the initiation of a process to its consequences became apparent.

Information regarding fish early life history and species interactions was limited and to better predict fish community behavior we needed to know who was doing what to whom, and under what circumstances.

Percis I, held in Ontario, Canada in 1976, was attended by 70 scientists (15 from Europe), published papers from 12 countries and lasted 12 days from September 24th to October 5th. The proceedings were published in *J. Fish. Res. Board Can.* 34:1447-1999, edited by Colby and Wigmore (1977).

The approach was to bring world experts together to address issues and answer specific questions of common concern. Compilation, assimilation, and synthesis of data were accomplished in three phases. Months in advance of Percis I, background papers describing the biology, community characteristics, and habitat requirements of percids were prepared and distributed to participants.

Next, lake-case-history papers were prepared to compile organized blocks of data from long-term studies, to evaluate trend-in-time changes in populations and communities and their response to cultural disturbances. Past habitat alterations and management practices within these fish communities were reviewed as stimulus-response experiments, not with the intent of evaluating the changes or practices, but rather to compare and contrast various community responses to known stimuli.

Phase three involved synthesizing material from the above papers and formulating inferences (preparing synthesis and inference papers) immediately before and during the symposium. Insights into the dynamics and properties of populations and communities were sought by examining the next hierarchical level, community and ecosystem respectively.

The wealth of data and reference material compiled for Percis I, not only was published in the proceedings, but was incorporated in the yellow perch (J.Thorpe, 1978) and walleye (P.J. Colby, R.E. McNicol, and R.A. Ryder, 1979) synopses prepared for the Food and Agricultural Organization of the United Nations, Rome, Italy. Percis I also received

two excellent reviews: One by Edwin L. Cooper, Pennsylvania State University, for the *Transactions of the American Fisheries Society*, Vol.107, No.5, 1978 and the other by Olga A. Popova (A.N. Severtsov Institute of Ecology and Evolution, Moscow) for the *Russian Journal of Ichthyology*, Vol. 18, No.1, 1978.

In the years following Percis I our knowledge of the percid biology, management and culture had greatly expanded making the need for a second symposium evident. Thus, 19 years later Percis II became a reality. The second International Percid Symposium was held in Vaasa, Finland (August 21-25, 1995). The proceedings were published in the *Ann. Zool. Fennici*, 33(3-4): 303-723, and edited by Rask, Van Densen, Lehtonen and Rutherford (1995).

Interestingly, two years earlier at the World Aquaculture Conference held in Torremolinos Spain, May 1993 the European Commission sponsored an international workshop to address the paucity of information and lack of progress in the culture of non-salmonid freshwater fishes. The meeting resulted in the creation of the European Working Group on Aquaculture of Percids (EWAP) to coordinate and communicate their research activities including those aquaculturists working with walleye and yellow perch in North America. Percis II provided the opportunity to hold the first international meeting of this workgroup, as a special session specifically devoted to problems and prospects in percid farming. In addition to Percis II several review papers, including recent papers in percid culture and technology, were published in a special issue of the *J. Appl. Ichthyology* (Vol. 12, 137-200) edited by Kestemont and Dabrowski (1996).

Percis II had three main objectives: 1) to assess the current knowledge of percid biology, 2) to identify priority areas for research on percids, and 3) to increase international collaboration and exchange of ideas among researchers working on percid fishes.

Unlike the first percid symposium, Percis II was more open to presentation requests (89 oral presentations, and 57 poster presentations), hosted more scientists (140) from more countries (17) and was of shorter duration (5 days). Due to time constraints prior to and during the symposium, less emphasis was placed in the preparation of synthesis and inference papers. However, five working groups were convened to discuss and summarize the following areas of primary interests: 1) factors influencing year-class strength, 2) size related feeding patterns, 3) population dynamics of percids, 4) behavior of early life stages, and 5) the role of ruffe in the percid community.



Now in 2003, Percis III is providing an opportunity to include the study of darters, just as Percis II provided an opportunity to bring together percid science and technology. Over the years we have seen progress in cleaning up the aquatic environment and providing new science to manage percid fisheries, yet major problems still exist. Percid culture technology has intensified, and significant progress has occurred. As challenges continue, new and exciting projects are underway. Percis III is the event, at the right place and time, to participate and learn more about this exceptional family of fishes.

## AQUACULTURE

### **Intra-cohort survival and growth characteristics in full- and half-siblings of Eurasian perch *Perca fluviatilis* fry**

*Igor Babiak, Robert S.N.M. Mandiki, Kailahy Ratsinjomanana and Patrick Kestemont*

### **Stress responses of walleye and walleye x sauger hybrids**

*Terence P. Barry, Masako Ochiai, Jeffrey A. Malison and James A. Held*

### **Seasonal variations in fatty acid composition and hepatic status of wild Eurasian perch (*Perca fluviatilis*) during a maturation cycle**

*Gersande Blanchard, Xavier Druart and Patrick Kestemont*

### **Enhancing gas bladder inflation in larval walleye: Comparison of two methods for removing an oily film from the water surface of culture tanks**

*Charles T. Boggs and Robert C. Summerfelt*

### **Variation among stocks of walleye (*Sander vitreus*): Length at hatch and larval development**

*Brian T. Bristow and Robert C. Summerfelt*

### **Dietary lipid studies with yellow perch (*Perca flavescens*)**

*Paul Brown, Deborah Cartwright, Ron Twibell, Anant Bharadwaj and Bruce A. Watkins*

### **Growth of yellow perch exposed to different factors in tanks**

*Terry A. Dick, Dean Jeske, Wenyin Chen and Mingchuan Lu*

### **Biology and control of the Eurasian perch *Perca fluviatilis* reproductive cycle**

*Pascal Fontaine, Hervé Migaud, Jean-Noël Gardeur, Charles Mélard, Neil Wang, Caroline Pereira, Michel Marie and Patrick Kestemont*

### **Semi-intensive larval rearing of pike-perch, *Sander lucioperca***

*Murielle Gielen, Carole Rougeot, Yvan Neus, Brigitte Bezandry and Charles Mélard*

### **Food chain dynamics and diets of larval and post-larval yellow perch in culture ponds**

*Christopher F. Hartleb*

### **Production characteristics of hybrid walleye (*Sander vitreus* female x *S. canadensis* male) reared to food size in ponds**

*James A. Held, Jeffrey A. Malison and Terence P. Barry*

### **Stocking densities and culture environments to habituate walleye fingerlings to formulated feed**

*J. Alan Johnson and James B. Rudacille*

**Experimental diet formulations for intensive culture of walleye fry**

*J. Alan Johnson, Alan Moore and Rick Barrows*

**Feeding and nutrition in European percid fishes – A review**

*Patrick Kestemont, Xueliang Xu, Gersande Blanchard, Charles Mélard, Murielle Gielen, Jean Brun-Bellut and Pascal Fontaine*

**Onset of sex-related dimorphic growth in juvenile hybrid walleye (*Sander vitreus* female x *S. canadensis* male)**

*Jeffrey A. Malison, Alexander B. Head, James A. Held and Terence P. Barry*

**Growth and reproductive development of triploid and shocked and unshocked diploid perch (*Perca flavescens*) reared to adult size under selected environmental conditions**

*Jeffrey A. Malison, James A. Held and Terence P. Barry*

**Effects of exogenous sex steroids and their inhibitors on growth, food intake and endocrine parameters in juvenile Eurasian perch**

*Robert S.N.M. Mandiki, Igor Babiak, Johny M. Bopopi and Patrick Kestemont*

**Hybridization of Eurasian and yellow perch increases growth rate in offspring**

*Robert S.N.M. Mandiki, Jeffrey A. Malison, James A. Held, Carole Rougeot, Gersande Blanchard, Charles Mélard and Patrick Kestemont*

**Genetic growth improvement of *Perca fluviatilis*: A review**

*Charles Mélard, Carole Rougeot, Robert S.N.M. Mandiki, Pascal Fontaine and Patrick Kestemont*

**An estimate of optimal turbidity to maximize survival and growth rate of larval walleye in intensive culture**

*Todd A. Phillips and Robert C. Summerfelt*

**Sex determinism in Eurasian perch, *Perca fluviatilis*: Effect of genetic and environmental factors**

*Carole Rougeot*

**Larval study on pikeperch *Sander lucioperca*: Effects of weaning age and diets (live and formulated) on survival, growth, cannibalism, deformity and stress resistance**

*Xueliang Xu, Jean Maboudou, Ibrahim Imorou Toko and Patrick Kestemont*

## INTRA-COHORT SURVIVAL AND GROWTH CHARACTERISTICS IN FULL- AND HALF-SIBLINGS OF EURASIAN PERCH *Perca fluviatilis* FRY

Igor Babiak, Robert S.N.M. Mandiki, Kailahy Ratsinjomanana and Patrick Kestemont, The University of Namur, Research Unit in Organismic Biology, Rue de Bruxelles 61, B-5000 Namur, Belgium, [patrick.kestemont@fundp.ac.be](mailto:patrick.kestemont@fundp.ac.be)

**Introduction.** Cannibalism frequently appears to be among the main factors that directly regulate stock growth and survival in various aquacultured species including Eurasian perch *Perca fluviatilis* L. (Baras & Jobling 2002). Analysis of growth-survival-cannibalism dynamics in perch larvae has revealed that initial stocking density is an important imposed factor affecting emergence and intensity of cannibalism. Higher stocking densities hamper cannibalism rate in larvae thus resulting in higher survival and not compromising growth whereas in post-larval stages, cannibalism rate is higher in high stocking densities and it lowers survival (Mélard et al. 1996; Baras et al. 2003; Kestemont et al. 2003).

The effects of early live history on further quantitative characteristics of juvenile stocks after restocking (mixing different progenies and changing stocking density) remain unknown. The issue is important for strategy of rearing perch larvae. To approach the problem, a 84-day experiment was conducted starting 16-19 days post-hatch.

**Methods.** Groups of 800 fish were composed of either siblings only (A, B, C) or half-sibs from two or three mothers evenly (A+B, A+C, B+C, A+B+C). Progenies A were significantly bigger on the beginning (day 0), and variation in their weights was significantly higher than in B or C. Fish were reared in 120 L tanks in duplicates or triplicates in a recirculating system under controlled conditions and fed initially *Artemia* nauplii followed by a commercial pelleted diet. Dead fish were removed daily. Truncated individuals were considered as type I cannibalism victims. Fish were weighted on day 0, before setting the experiment. Intermediate weights were conducted on day 19, 42 and 63. On day 84, 100 fish per tank were weighted, and 30 fish per variant were examined for phenotypic sex. All individuals were counted on days 63 and 84, and the difference between the initial number of fish and final number of alive and dead fish was considered as type II cannibalism victims. Coefficients of variation in weight, CV (%) and specific growth rates, SGR (% d<sup>-1</sup>) were calculated for each measurement day. Also, global SGR (SGR<sub>0-84</sub>) was calculated.

**Results.** Increase in average weight was 650-fold in the course of experiment, from 0.007 g (day 0) to 4.56 g (day 84). Average final survival and biomass were the highest in pure progeny C and the lowest in mixed groups A+B+C and A+B (Table I). The effect of variant on intermediate and final weights was highly significant. No effect of variant on intermediate and final CV of weights was observed; final CV were 43.5% on average. Average SGR<sub>0-84</sub> was 7.8 %/d (Table I) and was significantly affected by variant. However, considering intermediate SGR, the effect of variant was significant only in initial SGR from day 0 to 19. No effect of phenotypic sex alone or in interaction with variant on final weights was revealed. Sex ratios in all variants were not different from expected 0.5/0.5. No effect of pure versus mixed progenies on weight, its CV, SGR, cannibalism, survival and biomass was found.

Table I. Survival, biomass and total SGR (mean ± SD) of European perch siblings and half-siblings after 84 days of rearing starting on day 17-19 post-hatch. Progenies A were significantly larger from progenies B and C on the beginning of rearing. Absolute values marked with different superscripts differ from each other.

Variant	Survival (%)	Biomass (g)	Total SGR (%/d)
A	24.6 ± 6.5 <sup>b</sup>	885 ± 290 <sup>a,b</sup>	7.1 ± 0.3 <sup>d</sup>
B	29.5 ± 11.6 <sup>b</sup>	962 ± 286 <sup>a,b</sup>	8.2 ± 0.1 <sup>a</sup>
C	55.3 ± 19.6 <sup>a</sup>	1201 ± 222 <sup>a</sup>	8.1 ± 0.2 <sup>a</sup>
A+B+C	17.9 ± 6.6 <sup>b</sup>	707 ± 177 <sup>b</sup>	8.0 ± 0.1 <sup>a,b</sup>
A+B	18.8 ± 1.1 <sup>b</sup>	763 ± 49 <sup>a,b</sup>	7.7 ± 0.1 <sup>b,c</sup>
A+C	34.9 ± 1.2 <sup>a,b</sup>	1048 ± 82 <sup>a,b</sup>	7.5 ± 0.1 <sup>c,d</sup>
B+C	33.0 ± 18.4 <sup>a,b</sup>	910 ± 308 <sup>a,b</sup>	8.2 ± 0.3 <sup>a</sup>
<b>Average</b>	<b>29.4 ± 14.3</b>	<b>912 ± 241</b>	<b>7.8 ± 0.4</b>

Initial differences in size and size variation affected further growth characteristics: intensity of cannibalism, and resulting survival, biomass and average weights. They did not affect further CV and SGR, except for initial SGR (day 0 to 19).

Total mortality caused by type I cannibalism was 5.1 ± 1.9%. The highest mortalities were in

variants with progenies A: A+C, A+B and pure A (Fig. 1a). Losses caused by type II cannibalism were higher than those caused by the type I cannibalism, on average  $39.0 \pm 13.4\%$ . The effect of variant on type II cannibalism was significant. The highest mortalities were observed in variants A+B+C, A and A+B (Fig. 1b). Dead individuals (truncated and nontruncated) were on average significantly smaller than alive individuals on day 42.

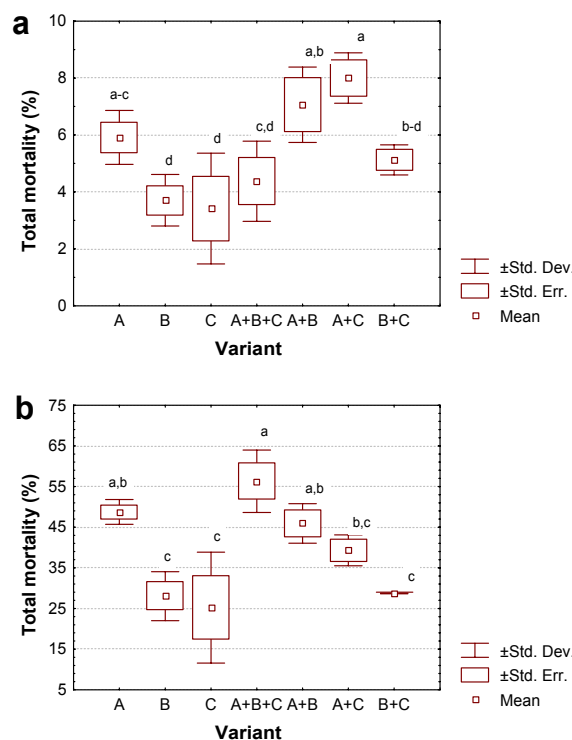


Figure 1. Mortalities in three groups of perch half-siblings reared separately (A, B and C) or in mixed groups (A+B+C, A+B, A+C and B+C) caused by cannibalism. **a**, total type I cannibalism mortality; **b**, total type II cannibalism mortality. Values marked with the same letters did not differ significantly from each other.

There was no significant effect of initial weight ( $W_0$ ) and its CV ( $CV_0$ ) on initial mortalities caused by other than type II cannibalism reasons. Type II cannibalism was significantly and positively affected by  $CV_0$ , but not by  $W_0$ , despite of significant and positive correlation between type II cannibalism and  $W_0$ . In the course of the experiment, correlation of  $W_0$  with intermediate

weights gradually decreased; correlation of initial and final weight was not significant.

Total biomasses on day 63 were not related to weights, whereas significant and negative correlation between final biomasses and average weights on day 84 was found ( $r = -0.65$ ). Those relations resulted from the effect of stocking density (number of fish), which was not yet important on day 63 but was important on final day 84.  $SGR_{0-84}$  were significantly and negatively affected by initial weights but not by initial CV, despite significant and negative correlation between  $CV_0$  and SGR.

**Discussion.** The study shows that early post-hatch history of perch larvae has an important, long-lasting impact on further growth and survival of juvenile forms. Average weight ( $W_0$ ) and variation in weight ( $CV_0$ ) of 16-19 days-old post-larvae perch affect further stock quantitative characteristics through different pathways.  $CV_0$  is responsible, through type II cannibalism, for survival, biomass, and, to some extent, current average weights, whereas  $W_0$  affects SGR and current average weights until hampering effect of overcrowding can appear. Both  $W_0$  and  $CV_0$  result likely from the initial post-hatch stocking density that determines further post-larval and juvenile population dynamics in Eurasian perch under constant, optimal culture conditions.

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## STRESS RESPONSES OF WALLEYE AND WALLEYE x SAUGER HYBRIDS

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**Introduction.** Hybrids of female walleye (*Sander vitreus*) and male sauger (*S. canadensis*, WxS) grow faster and convert feed more efficiently than purebred walleyes when reared under intensive culture conditions. There is great interest among North American aquaculturists in producing food-sized WxS hybrids to supply the needs of retail markets and restaurants (Malison 1990; Siegworth and Summerfelt 1990, 1992).

We postulated that the growth and performance advantages of WxS hybrids over walleyes are related to differences in responsiveness to stress. This idea was suggested by observations that hybrids are much more tolerant of disturbances associated with routine husbandry procedures, such as feeding and tank cleaning, than purebred walleye which are highly excitable and sensitive to noise, shadows, and movements (Malison et al., 1990; Siegworth and Summerfelt 1990, 1992; Held and Malison 1996). The goals of the present investigation were to (1) obtain baseline information on the physiological stress responses of purebred walleye, including determining the effects of time of day on baseline cortisol levels and the effects of acclimation temperature on their responses to acute stress, and (2) compare the physiological stress responses of purebred and hybrid walleye.

**Methods. Fish.** Walleye (271 mm mean total length, TL) were the offspring of wild brood fish collected from Rock Lake, WI. WxS hybrids (262 mm TL) were the progeny of female Rock Lake walleye and male Mississippi River sauger. The fish were held in separate flow-through 220-l circular fiberglass tanks at either  $15 \pm 0.5^\circ\text{C}$  or  $21 \pm 0.5^\circ\text{C}$ . The photoperiod was 12 h light/12 h dark with lights on at 0600 hrs. The fish were fed dry pelleted feed (Ziegler Brothers, Inc., Gardner, PA) at a rate of approximately 1% of body weight per day. Food was withheld 24 h before sampling.

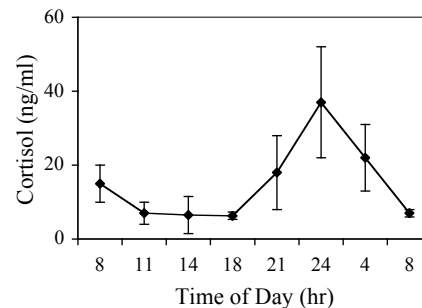
*Acute stress tests, diurnal rhythm, and temperature effect.* Unstressed controls consisted of five fish that were netted from the holding tank, anesthetized in 50 mg/l unbuffered tricaine methanesulfonate (MS-222), and bled via the caudal vasculature. To evaluate the effect of time of day on baseline cortisol levels, five control fish acclimated at  $21^\circ\text{C}$  were sampled every 3-4 hours over a 24-hr period (8 times total). To evaluate the effects of acclimation temperature on the acute stress response, groups of walleye were acclimated for one month at either  $15^\circ\text{C}$  or  $21^\circ\text{C}$  and subjected to the acute stress protocol described below starting at 0900 hrs. The acute stress tests were conducted as follows: fish were netted, held out of the water for one minute, and then randomly divided among seven 110-l tanks. At 7 min, 15 min, 30 min, 1 h, 3 h, 6 h and 24 h

post-handling, all of the fish from one 110-liter tank were netted, anesthetized, and bled. The total length and weight of each fish were recorded.

*Analytical methods.* The blood was allowed to clot for 1 hour, and then centrifuged at  $9000\times g$  for 5 min. The serum was collected and stored at  $-40^\circ\text{C}$  until analysis. Serum cortisol levels were measured with an ELISA validated for use in walleye. Glucose was measured using a diagnostic kit (510-DA, Sigma Chemical Company, St. Louis, MO). Chloride was measured using a Corning (Medfield, MA) model 925 chloride analyzer. All samples were assayed in duplicate.

*Statistics.* All data are presented as mean  $\pm$  SEM. The data were analyzed by analysis of variance, followed by protected least-squares difference tests ( $P < 0.05$ ).

**Results. Diurnal rhythm.** Cortisol concentrations rose significantly from less than 5 ng/ml during the daylight hours, to a peak of over 36 ng/ml at midnight (Fig. 1).



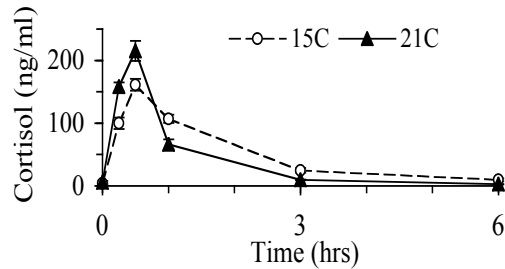
**Fig. 1.** Diurnal changes in baseline serum cortisol levels in purebred walleye.

*Effect of temperature.* At both acclimation temperatures, cortisol rose rapidly from less than 4 ng/ml, to peaks of over 150 ng/ml at 30 min. Cortisol returned to baseline by 3 hr (Fig. 2). Fish acclimated at  $21^\circ\text{C}$ , had higher and faster cortisol responses than fish acclimated at  $15^\circ\text{C}$  (Fig. 2). Significant differences between acclimation temperatures were detected at 15 min, 30 min, 1 hr, and 3 hr post-stress (Fig. 2).

At both acclimation temperatures, baseline glucose levels were approximately 60 mg/dl. At  $15^\circ\text{C}$ , glucose concentrations rose to a peak of  $165 \pm 3$  mg/dl by 15 min, then fell to  $127 \pm 5$  mg/dl by 1hr where they remained steady until 6 hr. At  $21^\circ\text{C}$ , glucose concentrations rose more slowly to a higher peak of  $190 \pm 8$  mg/dl by 1 hr, then fell to  $128 \pm 5$  mg/dl by 3hr, and declined further to  $109 \pm 8$  mg/dl by 6 hr.

Serum chloride levels were  $129 \pm 3$  mEq/L in the  $15^\circ\text{C}$  fish and  $135 \pm 1$  mEq/L in the  $21^\circ\text{C}$

fish. No differences in chloride levels were detected in response to acute stress, or between treatment groups.



**Fig. 2.** Effects of acclimation at 15°C and 21°C on the cortisol stress response in walleye.

*Purebred vs. hybrid.* Cortisol, glucose and chloride did not differ between purebred and hybrid walleye. Cortisol peaked at approximately 200 ng/ml within 15-30 min in both species, and returned to baseline levels by 3 h post-stress (data not shown). In both groups of fish, serum glucose remained elevated through 6 h, and returned to baseline levels by 24 h (data not shown).

**Discussion.** Contrary to our hypothesis, there were no differences in primary or secondary stress responses between hybrid and purebred walleye. We conclude, therefore, that the performance differences between these groups are not related to differences in their ability to respond to an acute handling stressor. There can be a major psychological component to the stress response, and individuals can show robust physiological stress reactions at only the perception of a threat. Given the marked behavioral and performance differences between purebred and hybrid walleyes, and our observations that both groups of fish appear to have the same machinery for responding to stress, we predict that hybridization alters the expression of neuronal pathways in the brain that control the psychological perceptions of stress.

Walleye showed a significant diurnal rhythm in baseline cortisol concentrations. This is a common phenomenon in vertebrates, with cortisol levels generally positively correlated with the activity pattern of the animal. The nighttime rise in cortisol in walleyes probably reflects its normal nocturnal feeding cycle.

Cortisol rose faster and higher, and declined more rapidly, in walleye acclimated at 21°C than it did in fish acclimated at 15°C. Temperature effects on enzymes controlling cortisol

biosynthesis and peripheral metabolism probably explain these results. A reduced stress response may be one explanation for the benefits of handling and transporting walleye at cooler water temperatures. At both temperatures, glucose levels remained elevated longer than cortisol suggesting that hormones besides glucocorticoids (e.g., catecholamines) may be the primary regulators of glucose homeostasis in stressed walleye. Chloride levels did not change significantly in response to acute stress in walleye suggesting that stress-induced osmoregulatory dysfunction may not be as large a problem in walleye husbandry as it is in the culture of salmonids. The stress-induced changes observed in walleye were similar to those reported by Barton and Zitzow (1995).

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## SEASONAL VARIATIONS IN FATTY ACID COMPOSITION AND HEPATIC STATUS OF WILD EURASIAN PERCH (*Perca fluviatilis*) DURING A MATURATION CYCLE

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**Introduction.** At present in aquaculture, the lipid nutrition aspect of aquatic organisms is of main interest. The capacity of some fish species to use high-energy diet to meet optimum growth capacity and enhancing the protein sparing effect is well exploited. However, supply of such high-energy diets to coolwater fish species like *Dicentrarchus labrax* L., *Psetta maxima* L. can be deleterious. The most common effects are the diminution of growth performances and immune defences, the increase of sensitivity to rearing conditions, the accumulation of lipid in tissues and liver, and an increase of mortality rate. It is obvious that the capacity to use high-energy diets differ according to fish species, but the lipid metabolism is also involved in this capacity and mainly influenced by nutritional status and sexual maturation. One of interesting observation is that, according to Diaz (1999), disturbances of lipid metabolism appear when the natural capacity of lipid storage is overpassed. In wild Eurasian perch, it has been observed that energy is mainly stocked in perivisceral tissues and gonads according to season and needs. Females are single spawners with a group-synchronous ovary development and energy needs are greater during vitellogenesis. Indeed, knowledge about liver stocking energy capacities, liver status and metabolism, during a reproduction cycle in the wild is scarce. The main objective of the study was to investigate the lipid content and fatty acid composition of target tissues and the hepatic status of Eurasian perch according to maturation cycle of adult wild fish.

**Methods.** Wild adult females of Eurasian perch were regularly captured from the Meuse river between August 2001 and July 2002. Back from the field, fish were killed with a blow to the head, weighed, dissected to measure the morphological parameters needed to determine the hepatosomatic (HSI) gonadosomatic (GSI) and liposomatic indexes (LSI) (fat around the digestive tract) and sexed. Maturation stages were determined by histological observations of gonads previously fixed in bouin. Samples of liver, gonad and fillet were stored at  $-80^{\circ}\text{C}$  prior to lipid extraction. Total lipid of liver and gonad was extracted with chloroform/methanol (2:1, vol/vol) according to Folch *et al.* (1957), and the total lipid of muscles were extracted with chloroform / methanol / water (2:2:1.8, by vol) according to Bligh and Dyer (1959). The FA of total lipids were converted to methyl esters with  $\text{BF}_3\text{-MeOH}$  and FA separated and

quantified by GC (GC trace, 2000; ThermoQuest, Carlo Erba, Italy) using a 30m X 0.32mm capillary column (FAME-Wax<sup>TM</sup>; Restek Corporation, Bellefonte, PA). For each period, liver samples were fixed to produce electron micrographs. Sixty photographs from 3 females per period (3 x 20) were analysed and lipid droplets (LD), glycogen (Gly), mitochondria (M) and rough endoplasmic reticulum (RER) were quantified by a soft imaging system (AnalySIS).

**Results.** Female GSI was very low (0.67%) during the resting period, from May to late August. It increased then progressively to reach a maximum of 27.8% in April, just before spawning (figure 1). On the other hand, LSI was low (0.46%) during exogenous vitellogenesis (from October to April) but significantly increased during the resting period (up to 1.62%). HSI did not differ significantly during the maturation cycle (1.1%).

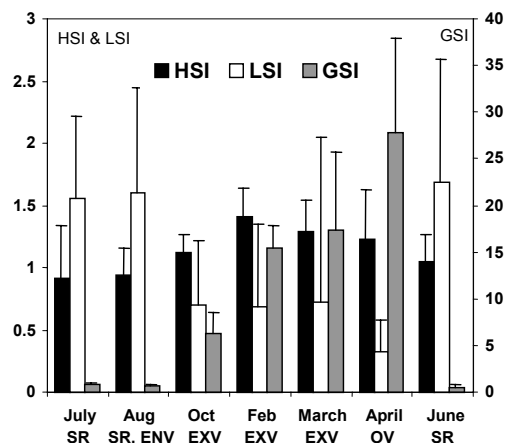


Figure 1. Seasonal variations of gonado- (GSI), hepato- (HSI) and liposomatic indices (LSI) during the reproductive cycle of female Eurasian perch. Maturity stages of ovary: SR: sexual resting; ENV: endogenous vitellogenesis; EXV Exogenous vitellogenesis; OV: Ovulation and Spawning.

In terms of total lipid contents (figure 2), muscles of Eurasian perch never exceeded 0.9%, while ovary displayed a significant decrease just after spawning. The lipid content of liver did not differ significantly along the maturation stage although a slight decrease can be observed until the spawning period. Fatty acid (FA) composition of tissues was relatively stable all year round. In muscle, quantity of n-6 polyunsaturated FA (PUFA) significantly increased



in February, probably due to C18:2 (n-6) augmentation. In liver, content of C20:4 (n-6) (AA) decreased significantly during August. In ovary, content of C22:6 (n-3) (DHA) significantly decreased in June compared to March and April. It has been observed a transfer of C18:2 (n-6) and C18:3 (n-3) from the liver to the gonad and a bioconversion of the FA mainly in DHA.

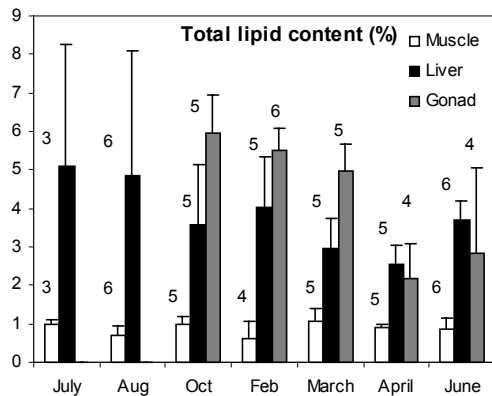


Figure 2. Seasonal variations of total lipid contents (%) in female Eurasian perch muscle, liver and gonad. Upper values indicate the number of fish used. Concerning the liver ultrastructure, the mean area of lipid droplets (area of LD/ number of LD) decreased from October to the spawning period in April ( $0.09$  to  $0.05\mu\text{m}^2$ ) (figure 3) while it increased during the resting period. A decrease in glycogen storage was also noticed during the same period, the area of hepatocytes occupied by glycogen granules ranging from 15% in October to 7.9% in April. At the opposite, RER area increased but not significantly. Mitochondria area increased during the reproductive cycle ( $0.31\mu\text{m}^2$  in August to  $0.83\mu\text{m}^2$  in April) and decreased in June ( $0.48\mu\text{m}^2$ ).

**Discussion.** During the sexual resting period, females accumulated energy as perivisceral fat and, to a lesser extent, into the liver. Size of LD was large and glycogen storage was maximum. Lipid content of ovary was low. A significant decrease of hepatic energy reserve (glycogen and LD) can be attributed to exogenous vitellogenesis. Protein synthesis and energy needs increased during vitellogenesis inducing an increase of RER and mitochondria. Physiological processes are focused to reach the maturation of ovary. In conclusion, general profiles of FA composition of tissues in perch match with the observations of previous researchers (Xu & Kestemont, 2002). Eurasian perch is characterized by a high content of C22:6 (n-3) (DHA) in liver, gonad and muscles (31.3; 22.8; 23.0%, respectively). During a whole annual cycle, the average lipid content of female liver never exceeds 4.3%.

Assuming that muscles represent 65% body weight (BW), the source of lipid in female perch is, in decreasing order of importance, perivisceral fats (0.95% BW), muscles (0.57% BW), gonads (0.30%) and liver (0.05% BW).

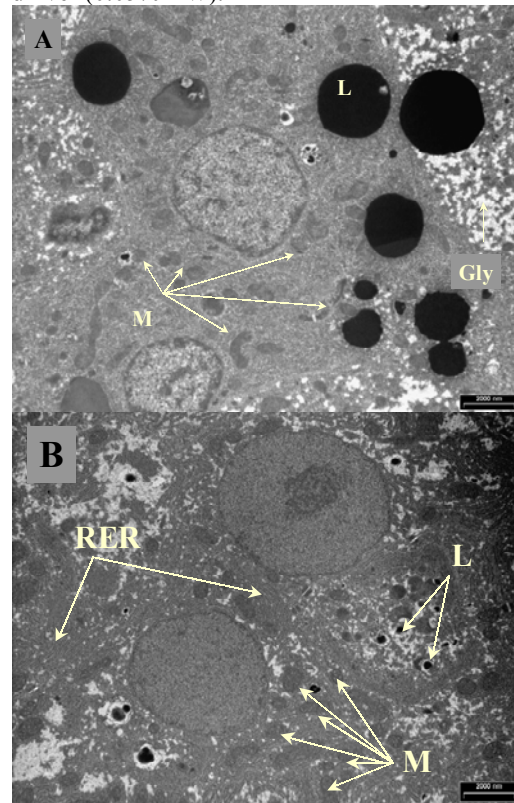


Figure 3. Electron microscopy of liver of female perch at the end of sexual resting period (August, photo A) and at the end of exogenous vitellogenesis (March, photo B).

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## ENHANCING GAS BLADDER INFLATION IN LARVAL WALLEYE: COMPARISON OF TWO METHODS FOR REMOVING AN OILY FILM FROM THE WATER SURFACE OF CULTURE TANKS

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**Introduction.** Larviculture of many freshwater and marine fishes is adversely affected when gas bladder inflation (GBI) cannot be accomplished because an oily layer at the air-water interface prevents the larvae from penetrating the surface to gulp air. Non-inflation of the gas bladder (NGB) was the major limiting factor for intensive larval walleye (*Sander vitreus*) reared on formulated feed until the oily film was removed by impacting the surface with a strong water spray Moore et al. (1994). Chapman et al. (1988) suggested that the oil originates from food and feces, or released from oil globules of dead fish. An air blower-surface trap (Chatain and Ounais-Guschemann 1990) and an air jet-oil skimmer apparatus (Lim 1993) have been used to remove oil from the surface of culture tanks to improve GBI. Van Olst et al. (1990) found that an oil sorbent cloth was ineffective to remove oily film from tanks used for larval culture of striped bass (*Morone saxatilis*). Summerfelt (1991) reported that sorbent cloth did not improve GBI of intensively cultured larval walleye. Moore et al. (1994) reported that larval walleye had substantially greater gas bladder inflation when cultured in tanks with a water surface spray than larvae reared without a spray.

The objective of the present study was to compare the performance of two methods for reducing the thickness of the oil layer on the surface of culture tanks used for larviculture of walleye.

**Methods.** Three tank types were evaluated, each with three replicates: control with no oil removal apparatus (Figure 1A); tank equipped with a surface-spray (Figure 1B); and tank equipped with air jet-oil trap (Figure 1C). The surface spray was oriented at 90° angle to the tank surface and perpendicular to the water flow (Moore et al. 1994). The design of the air blower-surface trap was similar to that described by Chatain and Ounais-Guschemann (1990). An air jet across the water surface pushed the surface film into the trap where oil and floating debris was manually removed with a suction device ("turkey baster"). A glass plate procedure, similar to that used to collect microfilms from the ocean's surface (Harvey and Burzell 1972), was used to collect oil samples from the surface of culture tanks (Boggs and Summerfelt 1996). Oil from the water surface adhered to the glass plate as the plate was submerged perpendicular to the water surface. The plate slowly removed and

then rinsed with trichlorethane (TCE) into a funnel to separate water from the oil-TCE solution (Figure 2).

Oil concentration was quantified by spectrophotometry at 328 nm wavelength. Oil thickness on the surface of the culture tanks was estimated from the ratio of oil volume to surface area of the aquaria. Oil samples were collected from tanks before fish were added to determine if any oil was already present in the system, and when fish were 7, 9, 11, 14, 16, and 18 days posthatch (dph). Two samples were taken from every tank each sampling day and the mean of these two measurements used in the analysis.

Larvae were stocked at 30 fry/L. Water temperature was maintained between 15 and 16°C. Fish were fed Fry Feed Kyowa, B-400 and B-700 in ratios and rates related to fish age: 100% B-400 from 3-5 dph (2.5 g/1000 fry), 75% B-400: 25% B-700 (7.6 g/1000 fry) from 6-12 dph, 50% B-400:50%

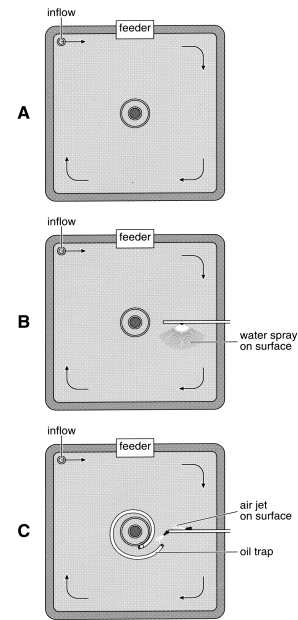


Figure 1. Tank types: A. control; B. surface spray; C. tank with air jet to push oily surface within ring (oil trap).

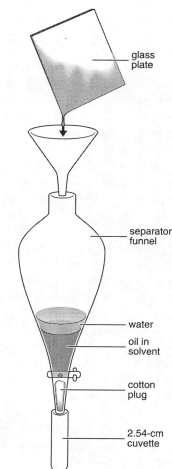


Figure 2. Glass plate oil sampler and funnel to separate water from oil and TCE solvent.

B-700 (7.0 g/1000 fry) from 13-15 dph, and 25% B-400:75% B-700 (8 g/1000 fry) from 16-18 dph. At the end of the experiment, fry in all tanks were counted to determine survival and GBI.

**Results.** Maximum oil layer thickness was in the 7 to 9 day interval and least in the 16 to 18 day interval (Table 1). Differences in oil layer thickness among treatments within intervals were not significant, but within treatments differences between intervals were statistically significant. During the 7 to 9 day interval when most fish inflated their gas bladder, the thickest oil layer occurred in the control group and the smallest thickness in the treatment with the surface spray (Table 1).

Table 1. Mean oil thickness ( $\mu\text{m}$ ) on the water surface before fish were stocked (W/O fish) and at three intervals, and GBI when fish were 19 dph.

Oil thickness	Treatment		
	Control	Spray	Trap
W/O fish	0.114	0.114	0.114
7 to 9 dph	0.404	0.306	0.332
11 to 14 dph	0.168	0.185	0.223
16 to 18 dph	0.176	0.176	0.162
GBI (%)	21.7 <sup>a</sup>	62.3 <sup>b</sup>	41.7 <sup>c</sup>

Oil globule diameter of prolarvae was 0.91 mm at hatching, 0.36 mm by 12 dph, and completely

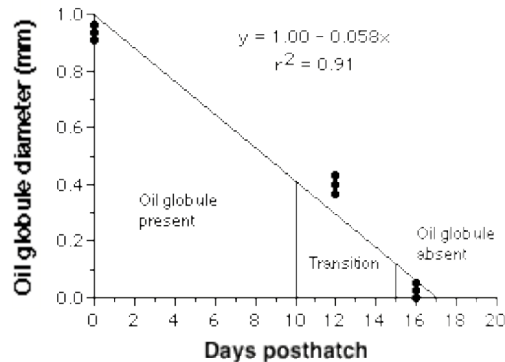


Figure 3. Rate of oil lobule absorption by walleye: data points are means of 30 fish from each treatment.

absorbed by 16 dph (Figure 3). The maximum thickness of the oil layer coincided with an oil globule of 0.4 to 0.55 mm and least after the oil globule was fully absorbed.

Differences in GBI among treatments were highly significant ( $P \leq 0.001\%$ , Duncan's multiple range test); the highest GBI was 62.3% for fish in the spray treatment (Table 1).

**Discussion.** Both water-surface-sprays and blower and trap apparatus enhanced GBI even though oil

thickness was not different between the control and other two treatments. Gas bladder inflation with the surface spray was 20.6% greater than with the air jet-trap apparatus and surface spray had the additional advantage in that it did not require daily effort to manually remove the accumulated oil. Oil layers were significantly thicker during the early stage of fry development when the oil globules were the largest; oil thickness declined as the oil globules were absorbed. Our findings support the supposition by Chapman et al. (1988) that the oil is mainly released from oil globules of the dead larvae.

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## VARIATION AMONG STOCKS OF WALLEYE ( ): LENGTH AT HATCH, AND LARVAL DEVELOPMENT

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**Introduction.** The success achieved in the intensive culture of walleye (*Sander vitreus*) from fry (larvae) to fingerlings has benefited from understanding the rapid biological changes in form and function in larval development. Noninflation of the gas bladder, for many years the major limiting factor in intensive culture of larval walleye occurs in a 6-day interval from 6 to 12 days posthatch, coinciding with yolk sac depletion and initiation of feeding (Marty et al. 1995). In the Iowa stock, the mouth did not open until the third day (47 daily temperature units, DTUs, °C), and the secondary lamellae of the gills first develop when fish are 10 to 12 days posthatch or 163-198 DTUs (Phillips and Summerfelt 1999). Until feeding commences, the yolk sac and oil globule provide energy for activity and growth, and until the secondary lamellae develop, larvae must rely upon cutaneous respiration.

Although some developmental changes in larval walleye have been described for a few stocks, temperature relationships to developmental events have not been compared among stocks. Thus, to fill gaps in information, we compared among progeny of walleye from geographically distinct stocks in Iowa (IA), Kansas (KS), Minnesota, (MN), North Dakota (ND), Ohio (OH) and Wisconsin (WI), egg diameter, length at hatching, and DTUs to complete yolk sac and oil globule absorption, and DTUs to initiate feeding, and start of cannibalism. The OH stock is the only captive broodstock. Since 1975, they were maintained and propagated in ponds at the Ohio Department of Natural Resources, London State Fish Hatchery on a combination of natural and formulated feeds (Nagel 1996). The IA, KS, and ND stocks are in the Missouri River basin, the MN stock in the Hudson Bay drainage basin, and the WI stock the Mississippi River basin.

**Methods.** All stocks were obtained as eyed eggs, then incubated in McDonald hatching jars at 15°C. Average egg diameter of each stock was determined from three samples of eggs measured in a Von Bayer tray 24-hours before hatching commenced. At the peak of hatching, total length, oil globule diameter, and yolk sac length were recorded from 150 fry, and also at 2-days posthatch when they were stocked into the culture tanks. Feeding (BioKyowa B-400) began when fry were 3-d posthatch. The mean culture temperature for the six stocks ranged from 15.9 to 16.9 C; the mean of means was 16.4°C. At 50, 150, and 250 DTUs posthatch and at 21-days post-hatch,

50 fish from each stock were examined for presence of food in the gut, cannibalism, and measurements were made of oil globule diameter, yolk sac and total length. Additional measurements of yolk sac length were taken on at least ten fish per stock per day for calculation of yolk sac absorption. The initiation of cannibalism was determined with daily observations of each tank.

**Results.** Spawning season spanned about 42 days across the region (Table 1); it was strongly correlated with latitude of the fish hatchery (Figure 1). At similar latitude, fish spawned and their eggs hatched at similar dates (e.g., OH and KS, IA and WI, and MN and ND).

Table 1. Mid-point of spawning and hatching date.

Stock	Mid-point	
	Spawn	Hatch
OH	March 25	April 7
KS	March 26	April 7
IA	April 13	May 4
WI	April 20	May 3
MN	May 1	May 25
ND	May 6	May 29

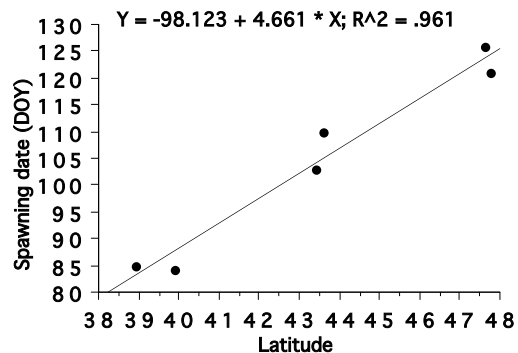


Figure 1. Relationship between mid-point of the spawning season and latitude of the fish hatchery.

Stock differences in length at hatch were statistically significant (Table 2), but the correlation between length at hatching and egg diameter was not statistically significant.

Significant differences occurred among stocks in the DTUs for all developmental events (Table 3). The KS fry were the first to fully absorb the yolk sac (54 DTUs) and the WI stock was the last (80 TU). An overall mean for the six stocks for yolk sac absorption was 68 DTU or about 5 days posthatch.

Table 2. Comparison of egg diameter (mm) and total length (mm) of six stocks of walleye (mean ± SD)

Stock	Egg diameter	Total length at hatch <sup>x</sup>
OH	1.90a ± 0.04	6.9a ± 0.01
KS	1.99a ± 0.02	7.9c ± 0.04
IA	1.93a ± 0.02	7.5b ± 0.06
WI	1.90a ± 0.06	7.9c ± 0.05
MN	1.96a ± 0.04	8.2d ± 0.07
ND	1.94a ± 0.04	6.7e ± 0.08
P - value	0.08	0.0001

<sup>x</sup>Values with letters in common are not significantly different (Fisher's LSD test. P ≥ 0.05).

The oil globule was fully absorbed about 14 days at about 16°C. The oil globule diameter of fry at 150 DTUs that had feed in the gut were significantly larger (P<0.05) than larvae without food in their gut. The WI stock was one of the first to fully absorb the oil globule (205 TU) but was one of the last to begin feeding (137 TU). The initiation of cannibalism ranged from 111 TU for the MN stock to 172 TU for the OH stock

Table 3. DTUs for the completion of yolk sac and oil globule absorption, first feeding, and onset of sibling cannibalism (Cann.).

Stock	Yolk Sac <sup>x</sup>	Oil globule <sup>x</sup>	Initiate feeding <sup>x</sup>	Cann. <sup>x</sup>
OH	73b	251c	167b	172c
KS	54a	226b	129a	125b
IA	70b	188a	120a	114a
WI	80c	205a	137ab	130b
MN	63ab	236b	115a	111a
ND	67b	252c	125a	118ab
Mean	68	226	132	128

<sup>x</sup>See footnote to Table 2.

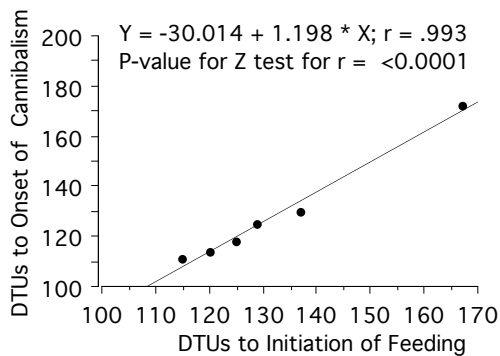


Figure 2. Relationship between DTUs to onset of cannibalism and initiation of first feeding; data represent the mean value for each stock (see Table 3).

The DTUs to the onset of cannibalism was not correlated with the DTUs to yolk sac or oil globule absorption (P value for r < 0.05), but there was a strong relationship between the DTUs to onset of cannibalism and onset of first feeding (Figure 1). There was a gap of about three days between the full absorption of the yolk sac and the initiation of exogenous feeding (Table 4).

Table 4. Comparison of DTUs for larval walleye to complete yolk sac and oil globule absorption, and to commence feeding, gas bladder inflation (GBI), and cannibalism.

Event	McElman and Balon (1979)	LI Mathias (1982)	Present study Mean (6 stocks) (± 95% CI)
Yolk sac	100	100	68 (58 - 77)
Oil globule	N	210	227 (199 - 253)
Feeding	101	104	132 (113 - 152)
Cannibalism	N	114	128 (104 - 152)
GBI	135	N	150 (134 - 165)

**Discussion.** There were significant differences among stocks in all developmental events, which may be genetic or environmental. Larvae that commence feeding had larger oil globules, perhaps providing an energy reserve. Although feeding need not begin until larvae are 3 dph, initiation of feeding was nearly simultaneous with onset of cannibalism; i.e., the first food a larval walleye may be its sibling!

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## DIETARY LIPID STUDIES WITH YELLOW PERCH (*PERCA FLAVESCENS*)

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**Introduction.** The yellow perch is an important food fish in the Great Lakes Region of the US. Total commercial harvest from the Great Lakes was as high as 35.6 million pounds (16.18 million kg) in the later 1960's. However, population levels and commercial harvest have declined significantly since then. Loss of supply coupled with traditional demand stimulated new interest in aquaculture. However, there are no diets formulated for the yellow perch and only a few nutritional requirements have been quantified.

Dietary lipid is an important source of energy, fat-soluble vitamins and fatty acids in fish. We conducted a series of studies designed to evaluate the efficacy of various lipid sources, provide an indication of the essential fatty acid requirement of perch, and evaluate the dynamics of conjugated linoleic acid (CLA). All studies were conducted in a scientifically valid manner. We used all-female fish originating from Lake Mendota and purified diets identified as appropriate in preliminary studies. We fed all fish to satiation and conducted all experiments at  $22 \pm 1$  C.

**Lipid Sources.** In our dietary lipid studies, we incorporated various dietary lipid sources into diets at 6, 12 or 18% and adjusted carbohydrate concentrations to maintain similar gross energy levels. Lipid sources evaluated were menhaden oil, cold-pressed soybean oil, coconut oil, tallow and a 1:1 (wt:wt) mixture of menhaden and soybean oils. The study was designed and analyzed as a 5 x 3 factorial. Weight gain was significantly affected by dietary source and level, but not the interaction of the two main effects. Within each of the single lipid sources, weight gain decreased as dietary lipid source increased from 6 to 18%. However, weight gain of fish fed the combination of menhaden and soybean oils did not exhibit decreased weight gain as dietary lipid concentration increased. Muscle lipid concentrations were low, regardless of dietary treatment. The highest value was 5.9% (dm basis) in fish fed 18% tallow, most values were between 1 and 2%. The EPA (20:5n-3) concentration was 6-9% in fish fed menhaden oil and 4-5.5% in fish fed the combination of menhaden and soybean oils. DHA (22:6n-3)

concentrations were 23-36% in fish fed menhaden oil and 23-28% in fish fed the combination of menhaden and soybean oils. Total n-3 fatty acid concentrations were 28-44% in fish fed various lipid sources and total PUFA concentrations were 32-49%. The typical indicators of essential fatty acid deficiency in fish (fatty liver and increased 18:1n-9 concentrations) were not responsive in this study. Weight gain data suggests that perch may have a requirement for both n-3 and n-6 fatty acids as do chum salmon and common carp. Further, the n-3 and PUFA concentrations of perch muscle are among the highest of any fish.

**CLA.** CLA is an atypical n-6 fatty acid displaying significant health benefits in humans and whole animal benefits in farm animals. It occurs in many geometric configurations and naturally occurs in ruminant meat products. We fed a mixture of CLA isomers to perch and observed significant improvements in weight gain at both 0.5 and 1.0% CLA in the diet. Total CLA concentrations in muscle of perch were 1.19% and 2.60% of fatty acids in fish fed 0.5% and 1.0% CLA, respectively. EPA concentration in perch muscle was 6.3-6.4% and DHA concentrations were 35.1-37.8% in fish fed CLA. Total n-3 fatty acid concentrations were 43-46%. In a second study, various sources of CLA were fed to perch and, based on retention of isomers in liver fatty acids, 18:2(*t*-10,*c*-12) appeared to be the biologically active isomer in perch. CLA isomers first appeared in muscle samples at 14 days after initiation of feeding and were at maximum concentrations at 28 days. Thus, CLA could be fed as a finishing diet during the last 2-4 weeks of the production cycle.

In conclusion, perch appear to require both n-3 and n-6 fatty acids in their diet and regardless of dietary lipid concentrations, perch exhibit relatively low muscle fat concentrations. More importantly, the fatty acid profile of that retained lipid appears to be among the better fatty acid profiles for human consumption, with as much as 45% of fatty acids as n-3s. These facts indicate that perch diets will not be difficult to formulate or manufacture and there are significant marketing opportunities for perch as a health food.

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## GROWTH OF YELLOW PERCH EXPOSED TO DIFFERENT FACTORS IN TANKS

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**Introduction.** As a culture species yellow perch is considered to be slow growing, reach sexual maturity prior to market size, show considerable size variation and are susceptible to non-specific diseases. The variation in size of same-age eurasian perch grown in ponds and tanks is considerable (Kestemont and Melard, 2000) However size sorting techniques suggest that such a strategy may cause a slight deficit in growth of eurasian perch (Melard et al 1996). The objective of the initial growth experiment was to determine if intraspecific interactions might account for some of the variation that is observed in yellow perch collected from the wild and raised in tanks. The second objective was to determine if perch grew differently under ambient light and artificial photoperiods of 16L:8D and if rearing in currents influenced overall growth. The third objective was to determine the optimum density for perch raised in tanks for different genetic lines of yellow perch. The fourth objective was to determine if yellow perch separated into small and large groups had the same growth characteristics.

**Methods.** Yellow perch were raised entirely in tanks. Yellow perch used in these studies were from the following selection program. Selection criteria include an ability to consume particle sizes of 300-500 microns at first feed, live feed for 2-3 weeks, conversion to commercial feeds between 14-21 days after first feed, selection for non-piscivorous fish, low visceral fat and gonad weight at market size < than 5% body weight. Growth of yellow perch was determined for fish with initial weights ranging from of 2 to 3 gms. Perch were raised in square 48 l tanks and in a doughnut shaped circular tank with flow rate of 4 cm/sec at 20°C for a period of 180 days. Perch were fed three times daily to apparent satiation and weighed periodically. Yellow perch were exposed to a photoperiod of 16 hrs light and 8 hrs dark and ambient light ranged from a high of 16 hr to a low of 8 hr of light.

Density experiment 1: Yellow perch were reared at 20°C under ambient light (11-16 hr), fed to apparent satiation for 112 days and perch were individually marked. Perch were raised in groups of 4 (5 replicates), 36 (2 replicates), and individually (36 replicates). Two independent experiments were run. Specific growth rate,

coefficient of variation and percent increase in total biomass was determined.

Density Experiment 2 measured SGR and density over 134 days to determine optimum densities for perch growth. Two lines of perch were tested.

Grading experiment 1. Since the initial study showed little difference among perch raised individually and in groups this experiment was done to determine changes associated with grading. Yellow perch were graded by dividing above and below the initial mean weights of 21 and 25 g and then recording growth over 84 days. Fish were weighed at two-week intervals to determine the proportional increase in biomass and SGR. Fish were fed to apparent satiation and exposed to a 16L:8D light cycle.

**Results.** Table 1 shows that perch raised individually grew slightly slower than perch raised in groups of 4 or 36 individuals

Table 1: Growth of yellow perch singly and in groups of 4 and 36.

No. fish	Group		
	36 (2) <sup>+</sup>	4 (5) <sup>+</sup>	1 (36) <sup>+</sup>
<u>Density (g/l)</u>			
Initial	20	2.5	2.5
Final	42	4	4
<u>Wt (g)</u>			
Initial	22.1	21.4	25.3
	±10.8	±8.4	±11.7
Final	47.2	42.0	50.4
	±15.5	±20.0	±23.6
CV*	55	47	47
<u>+ve growth*</u>			
Initial	75	45	78
Final	100	100	97
% increase in biomass	107	96	94

\* = coefficient of variation; + = number of replicates; \* = % fish with positive growth

Perch grew the same in tanks with current and in square tanks at ambient light (Figure 1). Perch grown at 16:8 photoperiod showed the best growth. Groups of 4 individuals had the lowest initial density (2.5 g/l) and also had the fewest individuals with positive growth during the early stages. At the end of the experiment the percent of individuals with positive growth was similar



for all groups. Groups of 36 produced the highest total % change in biomass and also had the highest coefficient of variation but neither values were markedly different from the other treatment groups.

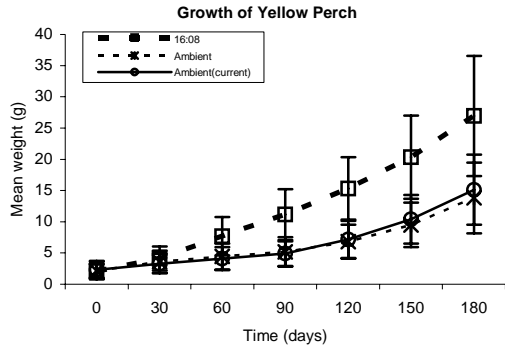


Figure 1. Growth of yellow perch at 16L:8D and ambient light in square and circular tanks.

The SGR and density characteristics of two lines of perch are illustrated in Figures 2 and 3.

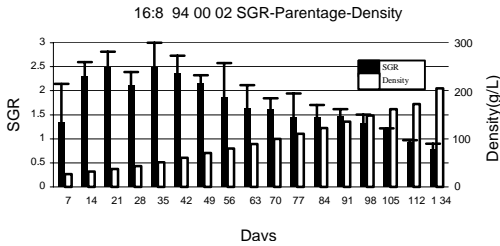


Figure 2. Perch raised at increasing densities for 134 days. Four replicates at each time.

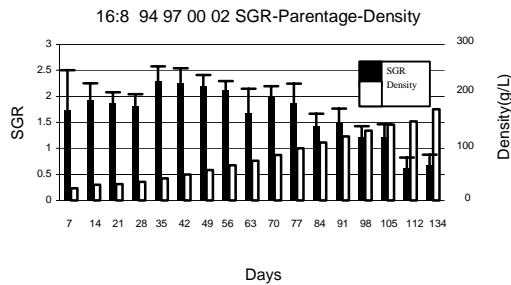


Figure 3. Yellow perch raised at increasing densities. Three replicates at each time.

Figure 1 showed that the SGR of line 1 perch did not decline until density approached 150 g/l. On the other hand line 2 perch (Figure 2) showed a decline in SGR at about 100g/l.

The smaller component of graded perch populations had an increase in total biomass of ~70% while the larger component of perch had a biomass increase of ~ 50 % over 84 days.

**Discussions.** Yellow perch in this study grew best at a light dark cycle of 16:8 and corroborates studies of Huh et al (1976). Jourdan et al (2000) also found that eurasian perch grew better at 18°C and 24°C than at 12°C. Schooling of perch was much more evident in the circular tank with current but growth was similar to that in square tanks. This indicates that while schooling behavior may be more evident in currents it does not confer a growth advantage.

Fish species such as Arctic charr exhibit intraspecific interactions as evidenced by faster growth of the larger, dominant fish which has been interpreted to contribute to size variation in tanks. Perch do not seem to exhibit this phenomenon. The optimum density for yellow perch in this study was between 90 and 140g/l and density appears to be influenced by the genetic background of the perch. Grading results indicate that smaller yellow perch grew somewhat faster suggesting that grading may be beneficial in some situations.

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## BIOLOGY AND CONTROL OF THE EURASIAN PERCH *PERCA FLUVIATILIS* REPRODUCTIVE CYCLE

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**Introduction.** The Eurasian perch, *Perca fluviatilis*, has been identified as a species destined for diversification of inland aquaculture. In Western Europe, the aquaculture development is mainly linked with its intensive rearing in recirculating aquaculture system (R.A.S.). In order to satisfy the market requirements, reproductive cycle must be controlled to obtain out-of-season spawning and produce fingerlings throughout the year. For 8 years, in order to meet this overall objective, different studies (in indoor and outdoor conditions) have been successively conducted.

**Reproductive cycle in natural habitat.** From April 1995 to April 1996, the annual reproductive cycle of male and female Eurasian perch *Perca fluviatilis* (morpho-anatomical and sex steroids changes) was studied at the Departmental Fishfarming Lindre Center (Moselle – France) (Sulistyo et al., 1998, 2000). More recently the testosterone (T), estradiol-17 $\beta$  (E<sub>2</sub>) and 17, 20 $\beta$ -dihydroxy-4-pregnen-3-one (17,20 $\beta$ -P) variations have been measured during the pre-ovulatory period in female Eurasian perch, and the ovarian synthesis of 17,20 $\beta$ -P and 17, 20 $\beta$ , 21-trihydroxy-4-pregnen-3-one (20 $\beta$ -S) has been examined (Migaud et al., 2003a). Results suggest a role for 17,20 $\beta$ -P in the final stages of oocyte development and spawning release. Spawning occurs in early spring over 6-7 weeks (March – April). During this period, the eggs and larvae quality highly fluctuates (Kestemont et al. 1999, Migaud et al., 2001a).

**Environmental control of the reproductive cycle.** The environmental cues of the reproductive cycle were studied to determine the respective effects of the seasonal variations of temperature and photoperiod. Previous work performed in several percids species suggest that temperature would play the major role in the timing of the reproductive cycle, especially final maturation and spawning (Craig, 2000).

Recently, Migaud et al. (2002) have shown in indoor conditions that a long cooling period (6 weeks vs 3 weeks, from 21 to 6°C) allowed a more advanced gonadal development in females, correlated with a higher increase of oocyte diameter and higher plasma levels of testosterone. In the same way, a longer chilling period (5 months vs 3 months, at 6°C) resulted in higher gonadosomatic indexes (GSI), plasma testosterone and protein phosphorus levels. The fish exposed to a cooling period of 6 weeks and a chilling period of 5 months also showed the largest GSI, and highest plasma estradiol and testosterone levels. Finally, at the end of the chilling period, a short water warming period up to 14°C (one month vs two months) resulted in higher rates of mature

females (33-38% vs 7-8%) and spawning (31-33% vs 0%) ( $P < 0.05$ ). Spontaneous out-of-season spawning (17 ribbons) and larvae were obtained for the first time in this species (Migaud et al., 2003b). Relative fecundity was about 100 eggs.g<sup>-1</sup> of female body weight. Five ribbons were fertilized at rates ranging from 5 to 90%. Delayed spawning in Eurasian perch can be induced by temperature manipulations, but treatments tested are not efficient enough because of low female maturational and spawning rates and high variability of fertilization rate (Migaud et al., 2001b).

The effects of photoperiod have been also investigated in further experiments to improve the protocol for inducing out-of-season spawning (Migaud et al., 2001b). Firstly, three photoperiodic regimes were tested in triplicate: continuous photophase, constant daylength set at 16L:8D and natural photoperiod, to determine the effects of photoperiodic regimes on the onset of gonadogenesis in males and females under ambient thermal conditions. This study showed that a continuous photophase, applied to fish from mid-July to October, inhibits the initiation of the perch male and female reproductive cycle (GSI below 2 % and 1% in females and males, respectively). Under a constant daylength regime, a very heterogeneous gonadal development was observed. These results are in accordance with previous studies in which photoperiod was fixed at 12L:12D (Migaud et al., 2002). Under a natural photoperiod regime, gonadal development (GSI above 3 %) was in accordance to that of fish harvested from natural habitat at the same period of the year. Thus, the initiation of gonadogenesis and gametogenesis would need seasonal daylength variations. A 10-month experiment was also carried out to investigate the effects of photoperiodic regimes under ambient temperature on a complete reproductive cycle and spawning quality. Fish were reared in 12 tanks (3000 L, 88 fish/tank, initial weight of 300g, age=2<sup>+</sup>) in an outdoor recirculating system and subjected to 4 photoperiodic regimes in triplicate: continuous photophase, constant daylength (16L:8D) as observed in indoor conditions and natural and simulated natural photoperiod. The results confirmed those obtained in the first experiment and showed effects on egg quality with lower fecundity, fertilization rate and egg size under constant daylength compared to the natural and simulated natural photoperiods. Hatching rate in the natural photoperiod treatment averaged 54 %, whereas it was nil in the simulated natural photoperiod and constant daylength treatments. Light characteristics (spectrum, intensity, daily changes...) appeared to have an effect

on spawning release and egg quality (Migaud et al., 2003c).

More recently, it was demonstrated that variations of the photoperiod conditions during the period preceding the application of inducing photo-thermal programs can completely inhibit the initiation of gonadogenesis and gametogenesis in males and females.

**Broodstock management.** First results have demonstrated the effects of the broodstock intrinsic characteristics and/or management on their fitness to reproduction under controlled conditions. Fish age, spawning time and food composition have an effect on spawning quality. Generally, gamete quality increases with the age of the fish. However the selection of broodstock from a batch of fish reared from the larval stage in R.A.S. should target smaller fish (200-250 g vs 350-400 g) as a significant effect of body weight was observed, with a better gonadal development recorded for smaller broodstock ( $P < 0.05$ , Migaud et al., 2003b). Likewise, broodstock with a higher relative growth rate during the reproductive cycle may have better reproductive performance. That could be related to feeding behavior. Regarding the effect of the quality of broodstock diet, high levels of eicosapentaenoic (EPA) and docosahexaenoic acids (DHA) improve the eggs and larvae quality of Eurasian perch (Abi-Ayad et al., 1997).

**Broodstock mortality.** During the spawning season, Eurasian perch broodstock showed high mortality rates (50-100%). In relation to reproduction and environmental conditions, the physiological (high cortisol levels : 50-110 ng.ml<sup>-1</sup>) and immunological (weakness of the non-specific immune response) status of the broodstock could explain these high mortality rates (Wang et al., 2003).

**Conclusions.** The environmental control of the reproductive cycle is now relatively well understood. The application of artificial conditions allows production of out-of-season spawning. However, further studies are necessary to improve the quality of the reproduction concerning gametes and larvae viability, and broodstock welfare.

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## SEMI-INTENSIVE LARVAL REARING OF PIKE-PERCH, *Stizostedion lucioperca*.

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**Introduction.** In Europe, most of pike-perch (*Stizostedion lucioperca*) production comes from fishing and ponds rearing. Due to good flesh quality and fast growth rate, pike-perch is one of the few candidates for diversification of freshwater fish farming in Europe. Among the fish culture, larvae rearing and weaning are an important and critical period. Two methods are generally used: "intensive" rearing in tanks where larvae receive artificial diets completed with natural food during the first stage of development (*Artemia* nauplii) and "extensive" rearing in ponds where larvae feed on organisms naturally present in the fertilized ponds. A semi-intensive method of rearing in green water fertilized tanks, combining the advantage of natural food and *Artemia* nauplii, has been efficiently developed with Eurasian perch (*Perca fluviatilis*) (Mélard *et al.*, 1996). The aim of this study was to apply and eventually adapt to pike-perch larvae this semi-intensive rearing method.

**Methods.** The experiments were conducted in 10m<sup>2</sup>/6m<sup>3</sup> outdoor tanks. Oxygen concentration was maintained around 8 mg.l<sup>-1</sup> by an air diffuser. To stimulate phyto and zooplacton development naturally present in the water from the river Meuse, the tanks were fertilized at 25°C with pelleted chicken manure (1.5 kg) during 7 days before the introduction of the larvae. Water temperature was maintained by a heat exchanger (supplied with warm water coming from the nuclear power plant of Tihange) and controlled with an automatic regulation system. The larvae originated from the O.V.B. (Netherlands). Fish were 2 days old (post-hatching) at the beginning of the first experiment and 5 days old (post-hatching) for experiment 2. Two days after the beginning of larval rearing, the tanks were 80% covered by a plastic sheet to prevent the growth of filamentous algae. Filamentous algae represent a trap for the young fish and they can also be responsible of oxygen depletion during the night. Temperature and oxygen concentration were checked three times a day. A water renewal with ground water was applied when nitrite and ammonia concentrations (measured three times a week) start to increase. The nitrite and ammonia concentrations were maintained closed to 0.2 mg.l<sup>-1</sup> and 0.5 mg.l<sup>-1</sup> respectively. Larvae first consumed plankton during ± 2 days. Then *Artemia* nauplii were distributed manually five times a day and progressively replaced from day 7 by artificial food which is distributed with an automatic feeder (over a 10 hours period) until the end of the experiment. In practice, experiments were stopped when the fish were closed to 200 mg.

**Results.** Experiment 1. Three different temperatures (17, 20 and 23°C) were tested in 2 replicates with initial stocking density of 6.000 fish.m<sup>-2</sup>. Best growth was obtained at 23°C (21.2%.d<sup>-1</sup>) but the survival rate was low (4.3%) compared to 17°C (19.3%). The number of cannibals was equal at these two temperatures (± 0.3%). The best compromise in terms of growth, cannibalism and survival was obtained at 20°C (growth: 17.7 %.d<sup>-1</sup>, survival: 16.6 % and

cannibalism: 0.1% of the initial number) (figures 1, 2 and 3).

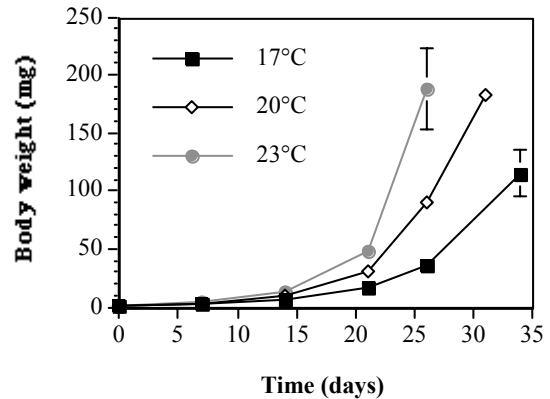


Figure 1. Growth curves (mg) of pike-perch larvae reared at 17, 20 and 23°C in a semi-intensive system (10m<sup>2</sup> tanks, 6000 fish.m<sup>-2</sup>).

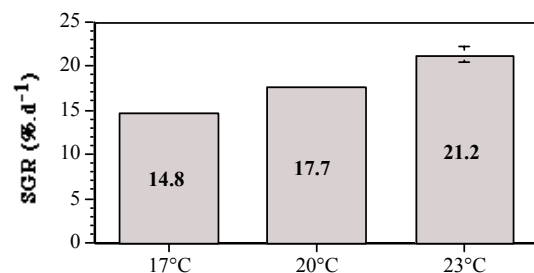


Figure 2. Growth (%.d<sup>-1</sup>) of pike-perch larvae reared at 17, 20 and 23°C in a semi-intensive system (10m<sup>2</sup> tanks, 6000 fish.m<sup>-2</sup>).

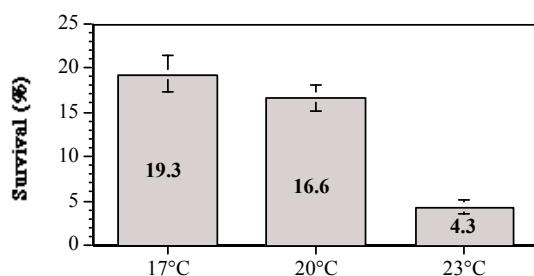


Figure 3. Survival rate (%) of pike-perch larvae reared at 17, 20 and 23°C in a semi-intensive system (10m<sup>2</sup> tanks, 6000 fish.m<sup>-2</sup>).

Experiment 2. Two different initial stocking densities (4.000 and 8.000 fish.m<sup>-2</sup>) were tested in 2 replicates at 20°C. During the first ten days of rearing, the consumption of larvae was checked by analysing the stomach content of ten fish removed from each of the batches (figure 4). Larvae ingested plankton but also *Artemia* nauplii: all fish examined had eaten nauplii at the first day of feeding (day 0). The weaning seemed to take place easily: artificial diet was gradually consumed from the first day of distribution (day 3).

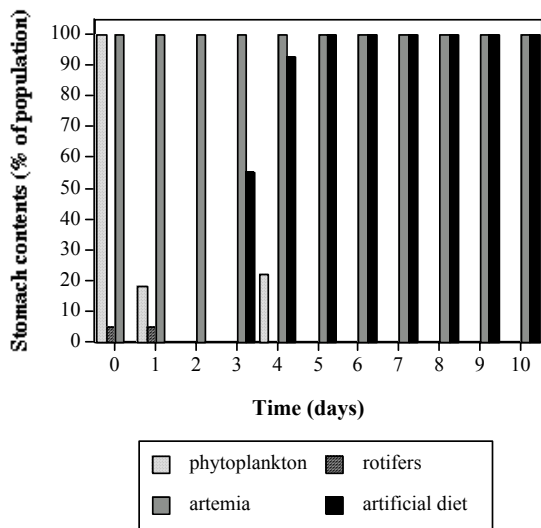


Figure 4. Stomach contents of pike-perch larvae (sampling= 10 fish/tank) reared in semi-intensive system during the starting of exogen feeding period.

We noted the early appearance of "twisted" fishes (lordosis and/or scoliosis) which represented almost 50% of the population one week before the end of the experiment (fig 5). These malformations were related to swim bladder inflation failure (fig 5).

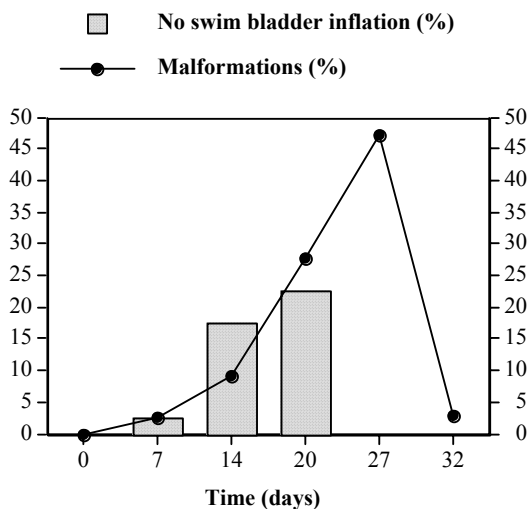


Figure 5. Relationship between no swim bladder inflation (%) and malformations rate (%) in pike-perch larvae reared in semi-intensive system.

The presence of abnormal, weaker and smaller fishes that didn't swim normally could have enhanced cannibalism. This hypothesis was sustained by final body weight: it was higher (mean body weight: 465 mg) than in the first experiment (mean body weight: 183 mg). It was also confirmed by the very low survival rate (0.5 to 3.1%), the high percentage of cannibals (100% of the final population in one batch!) and the decrease of the percentage of twisted fishes at the end of the experiment.

**Discussion.** Semi-intensive system appears suitable for rearing pike-perch larvae and the weaning schedule is appropriate since artificial diet is quickly accepted. Perch survival rate was also negatively correlated to the temperature (Kestemont *et al.*, 1996) and ranged between 18.1 and 38.6% at 20°C depending on the initial stocking density. In walleye (*Stizostedion vitreum*), swim bladder inflation happens normally at 21°C between day 5 and 11 after hatching and non inflation is one of the major problem in culture of many fish larvae, leading to spinal deformities and reduction of survival and growth depression (Marty *et al.*, 1995). On another hand, a study on gilthead sea bream (*Sparus aurata*) showed that deformed larvae are present before the period of swim bladder inflation, meaning that other causes during embryonic development may be implicated like genetic causes and that non-inflation of the swim bladder could be a consequence instead of a cause of lordosis (Andrades *et al.*, 1996). The poor results obtained at the end of the second experiment were probably more related to the initial larvae quality than to the system and the rearing method themselves, even if, both years, the larvae didn't seem to have deformities at the beginning of the experiments.

**Acknowledgements.** This work was supported in part by Electrabel S.A. and the E.C. (contract n°: Q5CR-2001-70594).

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# FOOD CHAIN DYNAMICS AND DIETS OF LARVAL AND POST-LARVAL YELLOW PERCH IN CULTURE PONDS

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**Introduction.** Recent declines in the yellow perch populations in Lake Michigan have prompted state & federal agencies to impose strict harvest limits on yellow perch taken from the lake. Yellow perch aquaculturists have not been able to supply the necessary quantities of perch that consumers demand as a result of the decline in commercial harvest.

Larval yellow perch culture is one of the riskiest phases of fish farming, but can also be one of the most profitable (Ludwig 1999). The successful growth and production of larval and post-larval yellow perch depends on the quantity and type of food available to them in the culture pond. Pond culturing remains the most common culturing method in the U.S., but producers have reported early survival by perch fry to be as low as 11%. This bottleneck in production results in greatly reduced quantities of feed-trained fingerlings.

Bottom-up control in fish culture ponds, through the use of inorganic fertilizer, can influence short-term seasonal changes in the composition of plankton (Morris and Mischke 1999). This can enhance the food chain & ultimately improve growth and survival of yellow perch fry. Nutrient enrichment can alter the abundance and composition of plankton within ponds and result in cascading trophic interactions (Carpenter and Kitchell 1993). Consequently, aquaculturists can better manage culture ponds with appropriately scheduled fertilization times and quantities and with better management in initial stocking density and subsequent grading.

The purpose of this study was to examine the short-term successional changes in phyto- and zooplankton populations that occurred in yellow perch culture ponds as a result of inorganic fertilization. Changes in prey abundance and composition were compared to yellow perch diets to determine prey selection by larval & post-larval yellow perch during the first 10 weeks post-hatch.

**Methods.** From late April to mid-July 2002, water chemistry parameters, including surface water temperature, dissolved oxygen, pH, alkalinity, hardness, nitrogen compounds ( $\text{NH}_3\text{-N}$  and  $\text{NO}_3\text{-N}$ ) and phosphorus ( $\text{PO}_4^{3-}$ ), were measured in yellow perch culture ponds at Willow Creek Aquaculture, LLC, Berlin, WI. From late April to mid-June ponds received weekly treatments of inorganic fertilizer (urea and phosphoric acid) based on transparency (desired secchi depth of 1.5 m). Prolarval yellow perch were stocked into culture ponds on May 3 at a density of 850,000 per quarter-acre. Phytoplankton samples were collected weekly, identified and ranked by abundance. Zooplankton (nanno and net) samples were collected weekly and analyzed for composition and abundance, while yellow perch were collected and measured for growth and diet selection. Regression analysis was used to fit the growth curve

to wet weight and length and used as a predictor of growth during the study.

**Results.** Atypical spring weather with a short warming period in late April, followed by cooler temperatures in May, resulted in slow initial growth by the larval yellow perch (Figures 1 and 2). When water temperature rose above  $21^\circ\text{C}$  in early June, growth rate increased but variation in growth among larval perch also increased.

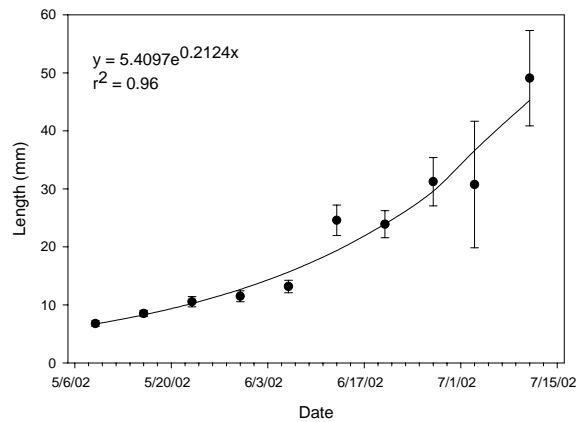


Figure 1. Length of yellow perch from week 1 (7 days old) to time of harvest.

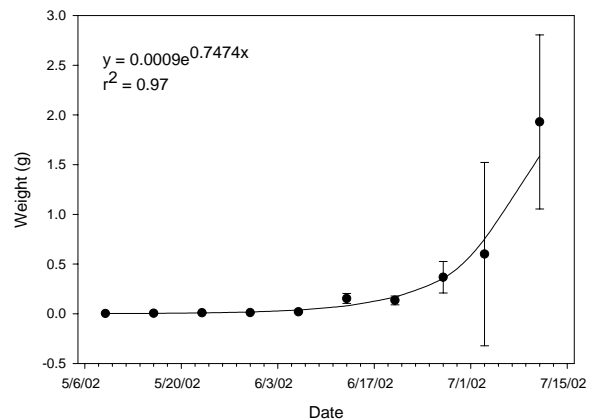


Figure 2. Wet weight of yellow perch from week 1 (7 days old) to time of harvest.

Algal diversity remained high in the ponds during the study, with abundant populations of Chlorophyta (green algae) and Ochrophyta (diatoms) and algal density peaked in mid-June ( $0.027 \text{ mg chlorophyll } a \text{ per m}^3 \text{ pond water}$ ).

Successional changes occurred in both phyto- and zooplankton communities in the culture



ponds. Nanno-plankton succession consisted of nauplii, *Keratella* and abundant free-floating plankton eggs in May; ostracods, *Keratella*, *Kellicottia* and plankton eggs in early June and *Polyarthra*, *Kellicottia*, *Brachionus*, *Notholca* and *Lecane* co-dominating the plankton in July. Net plankton consisted of *Brachionus*, young ostracods, and plankton eggs in late April. Various copepods appeared in early May and were replaced by ostracods, *Bosmina*, and *Keratella* throughout May. *Asplanchna* and *Daphnia* appeared in low densities in mid-May. Ostracods, *Bosmina* and *Keratella* were present in early July, but at low densities.

Larval yellow perch selected plankton eggs, *Keratella*, *Bosmina*, nauplii, and young ostracods in May and continued feeding on similar prey in June (Table 1). Post-larval yellow perch shifted to ostracods and benthic invertebrate larvae in early July. Cannibalism appeared in late June and feed trained yellow perch were observed by early July.

Diet items	Date				
	5/9	5/16	5/23	5/30	6/6
N	50	50	50	50	30
# Empty	0	0	3	3	0
Plankton eggs	1.28	3.20	2.34	42.38	88.77
<i>Brachionus</i>	0.36	0.16		0.16	
<i>Daphnia</i>	0.34	0.10	0.14	0.36	
<i>Keratella</i>		4.00	10.88	63.06	86.90
<i>Kellicottia</i>		0.20	0.58	0.36	
<i>Bosmina</i>	0.54	0.44	0.36	1.64	0.57
Ostracods	0.16	4.76	21.06	34.98	10.47
Copepodite		0.04			
Misc					0.73
Diptera					
Chironomid					
Benthic Inverts					

Diet items	Date				
	6/13	6/20	6/27	7/3	7/11
N	50	50	50	50	50
# Empty	5	27	14	17	5
Plankton eggs					
<i>Brachionus</i>					
<i>Daphnia</i>					
<i>Keratella</i>					
<i>Kellicottia</i>				0.02	
<i>Bosmina</i>		0.04	0.08	0.44	
Ostracods	0.76	0.76	7.58	3.24	1.02
Copepodite					
Misc	0.20	0.30			
Diptera	1.92		0.12	0.10	
Chironomid	0.10	0.02	0.04	0.02	
Benthic Inverts	0.22	0.02		0.10	
Fish parts			X(3)	X(5)	
Fish food		X(1)	X(2)	X(3)	X(41)

Table 1. Weekly diet selection by yellow perch (values = number of organisms per fish; values for fish parts & food = number of fish that contained each item).

**Discussion.** Results show that growth by larval yellow perch is dependent upon water temperature and preferred prey availability. Atypical weather in late spring resulted in slow initial growth, but warmer water temperature in June increased growth. Variation in growth among individual yellow perch increased and may be responsible for the increase in cannibalism. The number of yellow perch with empty stomachs also increased in mid-June and may indicate that suitable prey density was not high enough to support the density of yellow perch in the pond.

Comparison of plankton composition and density with yellow perch diet indicated that yellow perch actively selected ostracods, plankton eggs, *Bosmina*, and young copepods (nauplii and copepodites) during the ten-week culture period. These prey were actively sought by the yellow perch even when they were at low densities in the ponds. Therefore, these prey can be considered favored at certain times during the culture period of May to July.

Fish farmers traditionally rely on water transparency (secchi disk depth) as an indicator of pond fertilization. Results show that transparency was not a good indicator of plankton succession and trophic cascade. Larval yellow perch fed heavily on ostracods, *Bosmina*, & *Keratella*, with little selection for rotifers (*Brachionus* & *Asplanchna*), suggesting that pond management should favor these plankton types.

Based on the results, larval and post-larval yellow perch diets relied heavily on ostracods, but showed a distinct shift from larval perch being planktivorous in late spring & benthivorous by the post-larval period.

**Acknowledgements.** This work was supported in part by the Wisconsin Department of Agriculture, Trade and Consumer Protection, Agricultural Development & Diversification (ADD) Grant Program and the University of Wisconsin-Stevens Point Faculty Development Grant Program. Willow Creek Aquaculture, LLC generously provided use of their culture ponds, yellow perch fry and applied the inorganic fertilizer.

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## PRODUCTION CHARACTERISTICS OF HYBRID WALLEYE (*Sander vitreus* female x *S. canadensis* male) REARED TO FOOD SIZE IN PONDS

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### Introduction

With certain fish species, interspecific crossbreeding has resulted in hybrids having behavioral and growth characteristics better suited for intensive culture than those of purebred fishes. For example, muskellunge (*Esox masquinongy*) x northern pike (*E. lucius*), striped bass (*Morone saxtilis*) x white bass (*M. chrysops*) and plaice (*Pleuronectes platessa*) x flounder (*Platichthys flesus*) hybrids accept formulated feeds more readily and are more easily habituated to intensive culture conditions than their respective parent species. Muskellunge x northern pike, lake trout (*Salvelinus namaycush*) x brook trout (*S. fontinalis*) and striped bass x white bass hybrids grow faster than either parental species, at least during the first few years of life. The improved performance resulting from hybridization is one of the factors responsible for the rapid growth of the hybrid striped bass industry over the past several years.

Natural hybridization between walleye and sauger has been documented and both reciprocal hybrids have been artificially propagated in the laboratory. In-tank growout studies conducted by our laboratory comparing purebred walleye with several geographic crosses of walleye-sauger hybrids concluded that hybrids displayed superior growth and survival as fingerlings, and maintained these desirable characteristics through adulthood.

To date growout studies of hybrid walleye have been confined to tank-based culture. The objective of this study is to document growth rates, gonadal development, and fillet yield of hybrid walleye fingerlings reared to food size in ponds in southern Wisconsin.

### Methods

All fish used in this study were the offspring of wild walleye captured from Rock Lake (Jefferson County, Wisconsin) and wild sauger captured from the Mississippi River at Genoa (Wisconsin). This geographic cross was one of the better performing strains examined in previous growout studies. Hybrid fry were stocked into production ponds, and harvested at 25-30 mm total length (TL). Fry were then placed into 220-L tanks supplied with tempered water, aeration, and internal tank lighting for habituation to formulated feed. Successfully trained walleye fingerlings were reared indoors in tanks for the remainder of the first season. In spring of the second year, age-1 hybrid fingerlings (20-80g) were stocked into 4 ponds at a density of 900 fish/ha.

Two ponds each were fed once daily (at sunset) using either sinking or floating food (Silver Cup, Murray, UT). The study lasted 156 days.

### Results and Discussion

The fish showed an active feeding response throughout the study, except for a 21-day period during which water temperatures were in excess of 27°C. Normally, pond temperatures ranged from 16-26°C. After harvest in mid-October, fish were weighed, measured, identified for sex, and processed as scaled skin-on fillets. No growth differences were found between fish fed sinking or floating food (0.80 vs 0.78 g/day and 0.62 vs 0.57 mm/day, respectively, Fig. 1).

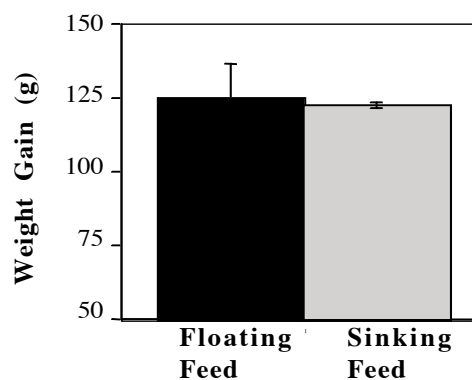


Fig.1. Weight gains of hybrid walleye fed floating and sinking diets. Data represent the mean  $\pm$  SEM of n=20 individuals per treatment.

No growth or fillet yield differences were noted between the sexes (Fig. 2). Fillet yields averaged 46.8%. The lack of size difference between the sexes can be attributed to harvesting the fish at 150-160g, prior to the onset of sex-related dimorphic growth in this species. This agrees with our findings on the onset of dimorphic growth in walleye (size differentiation apparent at 200-250g) presented at this poster session. The relatively high fillet yields were a result of the minimal gonadal development (male GSIs < 1.5% female GSIs < 0.5%) exhibited by the 1+ age fish. Extending the growout into the next season may result in larger fish to market, but may be negatively affected by dimorphic size variation as well as gonadal development. Fish averaged 157g at the end of the study, and scaled skin-on fillets



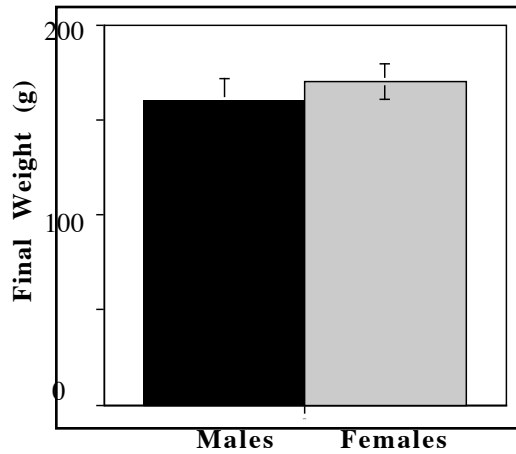


Fig. 2. Final weights of male and female hybrid walleye fed sinking and floating feed. The data represent the mean  $\pm$  SEM of n=20 individuals per sex.

averaged 73.4g/fish. Our findings demonstrate the feasibility of raising age-1 hybrid walleye fingerlings to food size in a single growing season in ponds in southern Wisconsin.

**Acknowledgements.**

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## STOCKING DENSITIES AND CULTURE ENVIRONMENTS TO HABITUATE WALLEYE FINGERLINGS TO FORMULATED FEED

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**Introduction.** The Rathbun Fish Hatchery annually produces 150,000 200-mm walleye (*Stizostedion vitreum*) in a tandem pond and raceway culture method. This technique consists of stocking pond-reared fingerlings into raceways, where habituation to formulated feed takes place. Production of habituated fingerlings can be a limiting factor in the production of larger fish because survival during the habituation period is often low and can be variable. Walleye fingerling habituation may be improved by determining the optimal environment and stocking density to increase production.

It has been shown that modifying the culture environment can improve survival during habituation. Elevating turbidity levels in culture water was found to increase survival of walleye fry and eliminate wall-clinging behavior (Bristow et al. 1996). In addition, Nagel (1996) described a covered raceway with submerged light (CSL) environment that resulted in walleye habituation rates as high as 90%.

The effects of stocking density, turbidity, and CSL on habituation of pond reared walleye fingerlings were evaluated in three separate studies. The purpose of these studies was to determine the optimal stocking density and culture environment for habituating pond-reared walleye fingerlings at Rathbun Fish Hatchery.

**Methods.** The effect of stocking densities of 4.9 and 6.5 fish/L were evaluated in 4,515 L production scale raceways. Fingerling walleye (47.9 mm, 0.64 g) were stocked in three replicate raceways per treatment. Flow rates were initially set at 38 Lpm, and increased up to 76 Lpm to maintain minimum effluent dissolved oxygen (DO) concentration of 5.0 mg/L. On day 30, total biomass was determined and individual lengths and weights were sampled in all raceways.

The effect of elevated turbidity levels on fingerling habituation was evaluated in 1416-L raceways stocked with 3.55 fish/L. A slurry of commercial ball clay (Old Mine #4, K-T Clay Co., Mayfield, KY) was used to increase turbidity levels of the incoming water. Three levels of turbidity were evaluated: low (no added turbidity, 22 nephelometric turbidity units, NTU), medium (50 NTU), and high (87 NTU). The slurry was pumped into three replicate raceways per treatment at ten-minute intervals for the first 14 days of the experiment.

Turbidity was measured twice daily in all tanks for the first 14 days of the experiment.

A production-scale experiment compared habituation rates in a CSL environment to the standard overhead light (OL) environment used at Rathbun Fish Hatchery. Initial stocking density was 6.5 fish/L. Raceways in the CSL treatment were enclosed with black-plastic sheeting to eliminate all external light sources. A low-wattage light was submerged in the middle of the rearing unit which provided 21-25 lux of light at the sidewalls of the CSL raceways. Four raceways in the OL treatment were not covered and received overhead light from windows and fluorescent lights (24 h/day).

All experiments utilized similar culture methods. Pond reared walleye fingerlings (35-40 days old) were confined to the rear two-thirds of the raceway directly under the feeder for the first 14 to 17 days, and allowed the full raceway thereafter. Fingerlings were fed a commercial feed (BioKyowa FFK C-1000, BioKyowa, Inc., Chesterfield, MO) at 10% body weight/day for the first ten days of habituation. The fish were then weaned from BioKyowa to 1.0 mm Walleye Grower 9206 (WG 9206) over a seven-day period, and fed WG 9206 for the remainder of the experiment. Effluent DO, temperature, pH, and ammonia were monitored during these experiments. Statistical significance was determined by t-test for stocking density and CSL evaluations and ANOVA for the turbidity evaluation using a significance level of 0.05.

**Results.** Survival during habituation averaged 57.9% in the low density and 58.0% in the high density treatments (Table 1,  $P=0.987$ ). Cannibalism was 13 and 14% at 4.6 and 6.5 fish/L, respectively ( $P=0.806$ ). More fish were produced per raceway with the initial stocking density of 6.5 fish/L (11,606 fish) than at the lower density (8,695 fish,  $P=0.015$ ). Final lengths and weights were not significantly different among treatments ( $P>0.05$ ). The final density measured on day 30 of the experiment was 1.9 for raceways stocked at the low density to 2.5 fish/L for raceways stocked at the high density ( $P=0.015$ ).

Survival was significantly lower in the raceways receiving low and medium turbidity levels (45% and 43%, respectively), than in tanks at the high turbidity level (53%,  $P=0.005$ ). Cannibalism was significantly lower in the high turbidity treatment (17%) than in either the low (24%) or medium (25%) turbidity

Table 1. Final length, weight and survival of walleye fingerlings at the end of habituation.

	L (mm)	W (g)	Survival (%)
Density (fish/L)			
4.9	64.4	1.75	58.0
6.5	63.0	1.65	58.0
P-value	0.274	0.251	0.987
Turbidity level			
Low	69.3	2.87	45.6
Medium	70.2	2.91	43.2
High	67.6	2.65	53.1
P-value	0.375	0.424	0.005
Light environment			
OL	76.4	3.84	37.3
CSL	80.1	4.53	60.7
P-value	0.259	0.249	0.002

levels ( $P=0.026$ ). Mortality was not different among treatments ( $P=0.872$ ). Initial lengths and weights of walleye were 44.2 mm and 0.52 g. Final length and weight were not significantly different ( $P>0.05$ ). One raceway in the high turbidity treatment was removed from statistical analysis because a feeder malfunctioned repeatedly during the last week of the study, causing the fish to be underfed. The underfeeding resulted in a disease outbreak (*Flexibacter columnaris*), and higher mortality in that raceway than any other in that study.

Fish habituated in the CSL raceways had higher survival rates (60.7%) than fish in the OL raceways (37.3%,  $P=0.0022$ ). Cannibalism was low in both treatments (3.5%). Peak mortality due to starvation occurred on day 12 in the CSL treatment and day 15 for OL. Mortality counts above 1,000 fish/day occurred once in the CSL treatment and five times in the OL treatment. Initial lengths and weights were not different between treatments ( $P>0.05$ ) and averaged 47.7 mm and 0.80 g. Final length and weight were not significantly different among treatments ( $P>0.05$ ). However, growth (g/day) was significantly higher in the CSL treatment (0.147 g/day) than in the OL treatment (0.117 g/day,  $P=0.0385$ ). This experiment was terminated on day 26 because flow rates were at a maximum (150 Lpm) and effluent DO was approaching 5.0 mg/L in the CSL raceways. Final density was 11.99 g/L for the CSL raceways and 6.17 for the OL.

**Discussion.** The density study demonstrates that walleye can be habituated to formulated feed with survival rates of 58% without compromising weight gain, at stocking rates of 6.5 fish/L and flow rates of 38-76 Lpm. At this density, raceways and labor are used efficiently to produce 2.5 habituated fish/L of rearing space at Rathbun Fish Hatchery. Higher stocking densities may be possible in other systems

(14 fish/L, Nagel 1996), but were not evaluated in this study due to water and facility restrictions.

The findings in the turbidity study indicated an increase in habituation survival due to addition of turbidity. This increase in survival was due to a 32% reduction in cannibalism by the addition of 87 NTU of turbidity. The difference in survival between the elevated turbidity levels and no added turbidity treatments may have been more pronounced if the incoming water supply had substantially lower turbidity than 22 NTU.

Practical application of turbidity on a production scale is limited because a large amount of clay (2,250 kg) would be required. However, these findings may help to explain yearly variation in survival during habituation at Rathbun Fish Hatchery.

The evaluation of covered raceways with a submerged light showed a 63% increase in survival compared to overhead lighting. Daily weight gain during the study was also 25% higher for fish habituated in the CSL environment.

There was a marked difference in fish behavior between light environments. Fish reared in CSL raceways swam around the lights continuously, whereas fish in the OL raceways were randomly distributed throughout the raceway. The raceway covers provided a low light environment and prevented overhead motions from disturbing fish. Fish in the OL raceways were disturbed by overhead shadows, which caused the fish to scatter and swim to the opposite end of the raceway.

The improved survival and growth of pond-reared walleye fingerlings during habituation in the CSL environment may be due to reduced chronic stress levels and earlier feed consumption. These conclusions are based on behavioral observations and fish performance during this study. Further research should be conducted to determine the onset of feeding and stress hormone levels in walleye habituated in CSL and OL environments.

**Acknowledgements.** This work was supported by the Federal Aid in Sport Fish Restoration Program, project number F-106-R.

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## EXPERIMENTAL DIET FORMULATIONS FOR INTENSIVE CULTURE OF WALLEYE FRY

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**Introduction.** Significant advancements in fry culture techniques have allowed intensive culture of walleye fry on formulated feeds. In the past, BioKyowa FFK B-series diets (BioKyowa, Inc., Chesterfield, MO) were fed to first feeding walleye fry with success. However, BioKyowa was an expensive diet (\$85/kg) and is no longer available in the United States due to importation restrictions. For fry culture to continue using formulated feeds, an alternative must be found.

In 1997, Rathbun Fish Culture Research Facility began pilot-production scale evaluations of Walleye Starter (WS) diets formulated as alternatives to the BioKyowa FFK B-series diets. Eight feeding trials were conducted evaluating comparative performance of walleye fry fed BioKyowa or one of ten WS diets. One diet, WS 9801, had significantly higher fry survival than BioKyowa. The purpose of this study was to compare the WS 9801 with slight modifications to BioKyowa FFK B series.

**Methods.** The formula for the WS 0201 feed (Table 1) was based on the WS 9801 formulation. The original formulation had to be modified due to unavailability of some of the original ingredients. An enzymatic fishmeal hydrosylate (Neo-pro) and artemia fines were replaced on an isonitrogenous and isocaloric basis with a fish hydrosylate (Sopre-Pesche, France). All other vitamin and mineral additions were kept constant. The WS 0201 diet was processed using the PARA method for the 250 to 400  $\mu$ m size feeds and both the PARA and MES (Micro-Extrusion Spheronization) methods for the 400-700 size. All feeds were dried at ambient temperatures

and sifted to appropriate sizes.

Fry for this study were obtained from adult walleye from Rathbun Lake. Eggs were incubated at 12.2 to 13.9°C and only fry hatched in a 24 h period were used in the diet trial. Fry were enumerated using a fry counter (Model FC2, Jensorter Inc., Bend, OR), and stocked into six 277-L tanks at a rate of 40 fry/L on day 2 posthatch. Each diet was randomly assigned to three tanks of fry.

Water from Rathbun Lake was heated and degassed before pumping to the culture tanks. Water temperature was gradually increased from 13.9°C on day 2 posthatch to 18.4°C on day 4. Water temperature was maintained at 18.4°C for the remainder of the evaluation. Flow rates were 2.0 Lpm from 2-5 days posthatch and increased to 4.0 Lpm on day 8, and 5.0 Lpm on day 19 posthatch.

Tank design was the same as that used by Moore et al. (1994). Surface spray was utilized to reduce oil film build up on the water surface. Clay slurry (Old Mine #4, K-T Clay Co., Mayfield, KY) was added to the culture water before pumping to the tanks. Turbidity in the fry culture tanks ranged from 21 to 31 nephelometric turbidity units (NTU) with a mean of 26.4 NTU. All tanks were curtained with black plastic and illumination was set at a mean of 93 lux. Tank cleaning was performed on a daily basis.

Fry tanks were fed BioKyowa B-400 at 10-minute intervals beginning on day 3 posthatch when mouthparts were becoming fully developed. Beginning on day 4, the daily ration was dispensed from an auger feeder at five-minute intervals for the remainder of the trial. The WS 0201 diet was fed to three tanks beginning on day 5 posthatch. The amount of feed fed was based on grams of feed per 1,000 fry.

Twenty-six fry from each tank were sampled for total length on day 2, 7, 12, 16, 21 posthatch. Samples for final length on day 26 consisted of 52 fry. Total length, presence of feed in the gut (FIG), and gas bladder inflation (GBI) were determined using a dissecting microscope. All fry were hand counted on day 26 posthatch to determine survival. Growth and survival rates were compared with an unpaired *t*-test using a significance level of 0.05.

**Results.** Walleye survival was significantly higher in tanks fed BioKyowa (50.8%) compared to WS 0201 (39.6%) during the 24-day experiment ( $P=0.0261$ ). However, mortality was not different between fry fed the BioKyowa series (38.9%) and WS 0201 (38%,

Table 1. Ingredient composition (g/100g) of Walleye Starter 0201 as fed to walleye fry.

Ingredient	g/100g
Herring	24.3
Egg Solid	20.0
Krill meal	15.0
Cyclopeeze meal	10.0
Liver Meal	10.0
Fish Oil	6.0
Sopre-Pesche	5.0
Wheat Gluten	5.0
Vitamin Premix 30	3.0
Ascorbic Acid	1.0
Pigment	0.5
Trace Mineral Premix	0.1
Inositol	0.1

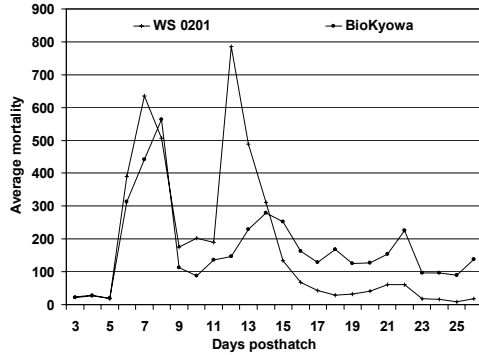


Figure 1. Average daily mortality of walleye fry fed two diets.

P=0.83). Cannibalism, or unaccounted mortality, was higher in tanks fed WS 0201 (21%) compared to those fed BioKyowa (11%, P=0.045).

Daily mortality in BioKyowa and WS tanks began to increase on day 7 posthatch and by day 10 both treatments had declined (Figure 1). However, one tank fed the WS 0201 diet had unusually high mortality for three days starting on day 13, but the cause could not be determined.

Initial length of fry in this study was 8.3 mm. Fry length began to differentiate at day 12 posthatch, with length of fry fed BioKyowa (14.4 mm) exceeding that of WS 0201 (12.8 mm, P<0.0001, Table 2). The percentage of fry with FIG was significantly lower in tanks fed WS 0201 (29.3%) compared to tanks fed BioKyowa (78%, P=0.0017). At the end of the study, fry fed the BioKyowa were, on average, 3.8 mm longer than fry fed WS 0201 diet.

A deformity became apparent in fry fed WS 0201 near the end of the study. About 2% of the fish had an arched back posterior to the head, which caused deformed fish to swim on their side.

**Discussion.** These findings show that walleye fry fed WS 0201 did not perform as well as fry fed BioKyowa B-series diet. Fry fed BioKyowa had better survival and growth compared with WS 0201. Cannibalism was nearly double in the WS fed fry compared to that of BioKyowa fed fry. The effect of ingredients substitutions in the WS diets could not be determined through a direct comparison because of unavailability of some ingredients.

The percentage of fish fed WS 0201 with FIG on day 7 posthatch was 62% lower than the rate of FIG for fish fed BioKyowa. The reduced feed intake may be due to poor palatability of WS 0201 which may have resulted in the higher cannibalism rates observed in tanks fed WS 0201.

Experimental walleye starter diet formulations continue to produce growth problems for larval walleye. Intensive walleye fry culture on formulated diets may be limited without BioKyowa. Unfortunately, this research has not yielded a diet which performed as well as BioKyowa FFK B-series.

**Acknowledgements.** This work was supported by the Federal Aid in Sport Fish Restoration Program, project number F-106-R.

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Table 2. Mean length, gas bladder inflation (GBI), and feed acceptance (feed in gut, FIG) of larval walleye fed two diets.

Performance variable	Diet			P-value
	DPH	BioKyowa	WS 0201	
Length (mm)	7	10.4	10.3	0.5582
	12	14.4	12.8	<0.0001
	16	16.6	14.8	0.0003
	21	21.9	18.8	0.0003
	26	27.2	23.4	0.0011
GBI (%)	7	79.3	88.3	0.2023
	12	100	98.6	0.3739
	16	100	100	
	21	100	100	
	26	100	100	
FIG (%)	7	78.3	29.3	0.0017
	12	97.3	75.7	0.4261
	16	100	100	
	21	93.5	97.4	0.2427
	26	100	100	

## FEEDING AND NUTRITION IN EUROPEAN PERCID FISHES – A REVIEW

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**Introduction.** In Europe, two species belonging to the Percidae family are currently under investigation in aquaculture : the Eurasian perch *Perca fluviatilis* and the pikeperch *Stizostedion* (or *Sander lucioperca*). Despite the fact that both species are highly prized food fish, feeding and nutrition of Eurasian perch and pikeperch are still in their infancy. Indeed, few publications deal with the nutritional requirements of European percid fishes, and most of them focus on Eurasian perch. Short reviews of percid feeding and nutrition have been published by Barrows and Lellis (1996), Brown et al. (1996), Kestemont et al. (1996), Kestemont and Mélard (2000) and Brown and Barrows (2002). The present paper summarises the main nutrition issues related to broodstock management, larval rearing and juvenile on-growing in European percid fishes since the PERCIS II conference held in Vaasa in 1995.

**Broodstock nutrition.** Reproductive performances of Eurasian perch are largely affected by the origin of breeders, wild or captive. Survival of captive females prior to ovulation or after spawning are low, and egg and larval quality are poor, often ranging between 0 and 5%, regardless of spawning period (normal or out-of-season) (Migaud et al., 2003). It has been suggested that gamete quality of Eurasian perch could be improved by improving broodstock nutrition. Performances of breeders held during their entire vitellogenesis period in recirculating aquaculture system under natural profiles of day length and temperature, and fed different formulated diets enriched with vitamin E, vitamin C or HUFA were compared to performances of breeders fed natural food (NF, chironomid larvae and prey fish) or reared in ponds (C). Survival rate of breeders fed NF was significantly higher than in the other groups. Both diet and culture conditions significantly affected performances of Eurasian perch breeders, since fertilisation and hatching rates were maximal in fish reared in ponds, but differences between NF and formulated diets were also significant. The better egg quality of fish fed NF can be related to an improvement in their biochemical composition, namely the level of thyroid hormone (T3) as well as the  $K^+/Mg^{2+}$  and  $K^+/Na^+$  ratios. Total lipid content and fatty acid composition of eggs were, however, not significantly different between treatments.

More research is still needed in order to improve broodstock nutrition and management in captive Eurasian perch breeders to secure high quality eggs

and larvae. To our knowledge, there is no data available regarding the influence of dietary treatment on reproductive performances and the nutritional requirements of pikeperch breeders.

**Larval nutrition.** No specific larval nutrition investigations have been performed recently in Eurasian perch and most research efforts have been paid to improve survival and growth rates, and minimise cannibalism (Fiogbé and Kestemont, 2003, Kestemont et al., 2003). Up to date, Eurasian perch larvae are still fed *Artemia* nauplii until they reach 50 mg b.w., and then can be trained to dry feed usually formulated for marine fish larvae. However, the main pancreatic and intestinal enzymes are efficient from early developmental stages, suggesting that a compound diet could be provided very early to perch larvae (Cuvier-Pères and Kestemont, 2002). Dynamics of total lipids and fatty acids during embryogenesis and early larval development suggest that docosahexaenoic acid (DHA), and to a lesser extend, eicosapentaenoic acid (EPA), play a major role during early life stages of Eurasian perch and must be present at a sufficient level in larval diets to support growth performances (Abi-Ayad et al., 2003). In pikeperch, recent investigations have compared different diets as initial food and determined the optimal weaning time to dry diet. Enrichment of *Artemia* nauplii with vitamin C and HUFA is recommended since it reduces significantly morphological deformities (compared to standard *Artemia* or dry feed) and support high growth rate (Xu et al., this book). It has been also suggested that a formulated feed should be introduced at the day 19 post-hatch in order to avoid some essential nutrients deficiency leading to morphological deformity (Kestemont et al., 2002).

**Nutrition of juveniles and adults.** While requirements of some indispensable amino acids have been determined recently for yellow perch (for review, Brown and Barrows, 2002), there are few published nutritional requirements for European percids. Fiogbé et al. (1996) estimated the protein requirements of Eurasian perch as 36-56 % of the diet, depending on mathematical model chosen, and recommended 40-49% in practical diets. Lipid nutrition is another major concern in Eurasian perch, since high lipid diets usually formulated for salmonids can support rapid growth but are susceptible to impair liver function by excess storage of fat into the hepatocytes. Kestemont et al. (2001)

compared semi-purified diets containing different levels of lipids (6, 12, 18%), with or without added ethoxyquin as antioxidant, and concluded that Eurasian perch juveniles are highly sensitive to oxidised lipid. No significant differences in feed intake and growth were observed between fish fed 12 and 18% dietary lipid, but storage of large lipid droplets, and associated signs of impaired liver function (significant reduction of rough endoplasmic reticulum and mitochondria), was much more severe in fish fed 18% lipid. However, using practical diets containing from 11.7 to 19.3 % lipid, Xu et al. (2001) indicated that 19.3% of dietary fat supported the highest growth, feed efficiency and protein efficiency ratio. These authors also suggested that Eurasian perch possess a high capability to elongate and desaturate DHA from their dietary precursors. The effects of different lipid sources on lipid metabolism and fatty acid composition of Eurasian perch were investigated recently. The results showed that  $\Delta 6$  and  $\Delta 5$  desaturases are highly active in this species. Desaturation enzymes are not specifically favouring n-3 over n-6 acids in perch lipid metabolism, and they are greatly influenced by n-3 and n-6 fatty acid content in the diet (Xu and Kestemont, 2002). There are few results related the influence of feeding and nutrition on quality of perch flesh. Mathis et al. (2003) reported that filleting rate can vary with dietary protein/energy ratio, high energy feed decreasing filleting rate, while sensorial analysis did not reveal any difference between dietary treatments. Feeding and nutrition of pikeperch are poorly documented, but recent studies have investigated the effects of protein, fat and carbohydrate ratio on growth, feed efficiency and nutrient retention in pikeperch fingerlings. Results suggested that the cost-effective P/F/C ratio is 43/10/15. It has been also demonstrated that optimal rearing temperature and feeding frequency for pikeperch fingerling are 28°C with feeding 3 times a day.

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## ONSET OF SEX-RELATED DIMORPHIC GROWTH IN JUVENILE HYBRID WALLEYE (*Sander vitreus* FEMALE x *S. canadensis* MALE)

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**Introduction.** Many fish including percid species such as walleye, sauger (*Sander canadensis*), and yellow perch (*Perca flavescens*), exhibit sexually-related dimorphic growth in which females grow faster than males. Depending on the fish size at which such a growth pattern first becomes apparent, fish culturists stand to gain significantly by using monosex female populations of fish if they are available.

Generally, the onset of sexually-related dimorphic growth in fish does not occur at hatch, but rather in sub-adult fish coincident with key reproductive developmental events, such as the onset of steroidogenesis, oogenesis, or spermatogenesis. In yellow perch, for example, Schott et al. (1978) showed that females began to outgrow males when they reached a total length of about 80-100 mm, the same size at which spermatogenesis and vitellogenesis first begin (Malison et al. 1985).

Several studies to date have shown that hybrid walleye (walleye female x sauger male) have significant potential for commercial aquaculture, because the hybrids grow faster and are more docile than purebreds when reared under intensive culture conditions. The purpose of this study was to document whether sexually-related dimorphic growth occurs in hybrid walleye, and the size at which it first begins.

**Methods.** Hybrid walleye were produced by crossing female walleye from Rock Lake, Jefferson Co., WI, Spirit Lake IA, and the Mississippi River (WI) with male sauger from the Mississippi River. Throughout the study the fish were raised in indoor, flow-through tanks at 21°C and 16L:8D photoperiod, and were fed formulated food. From hatch (April 15) until the fish reached a mean total length of 75 mm (day 110), the fish were raised in four 110-L tanks. At this time, 125 fish were individually PIT-tagged and raised in three 220-L tanks until day 310. Then the fish were transferred into one 750-L tank and one 7,500-L tank at similar densities, where they were raised until day 610. During this time the fish were individually weighed and measured on days 310, 342, 365, 477, and 610. The fish were then necropsied, and sex determinations were made using visual gonadal morphology.

On days 310, 342, 365, 477, and 610, the effects of sex and tank on fish weight and length were analyzed by ANOVA. We used t-tests to compare the sexes for differences in mean weight and length gain during the following periods: day 310-342, day 310-365, day 310-477, and day 310-610. All data were analyzed using  $P < 0.05$ .

**Results.** There were 54 females and 35 males that survived until the end of the study. At no time during the study were there any significant differences between tanks in mean weight or length of the fish. Males and females did not differ in weight, length,

weight gain or length gain until day 477 (Figures 1 and 2). On day 477, females were heavier and longer than males (231 g and 304 mm and vs. 222 g and 295 mm respectively, Figures 1 and 2). These differences in size became greater by day 610.

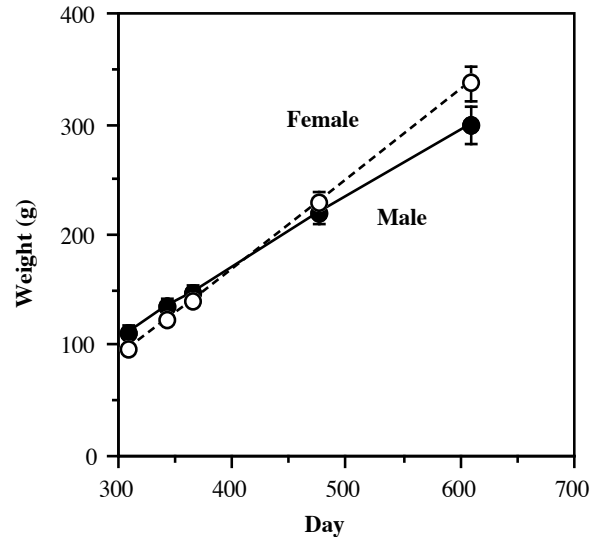


Figure 1. Weight of male and female hybrid walleye reared under intensive culture conditions. Females were heavier than males on days 477 and 610.

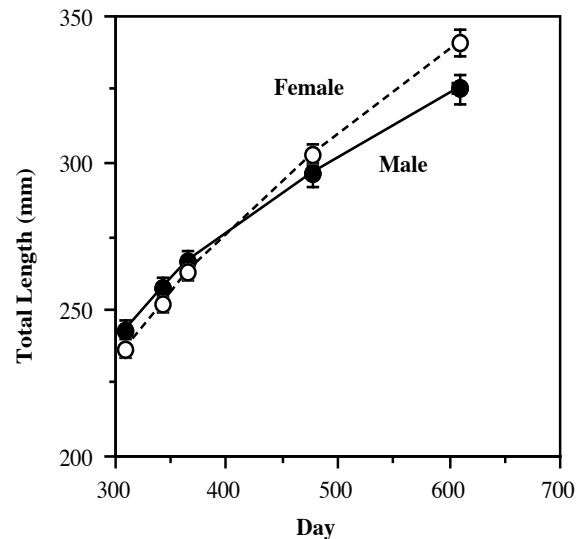


Figure 2. Length of male and female hybrid walleye reared under intensive culture conditions. Females were longer than males on days 477 and 610.

Females and males did not differ significantly in weight or length gain between days 310 to 342 or 310



to 365. Between days 310 to 477, however, females gained significantly more weight and length than males (0.79 g/day and 0.41 mm/day versus 0.66 g/day and 0.32 mm/day, respectively, Figures 3 and 4). These differences in growth became greater during days 310 to 610.

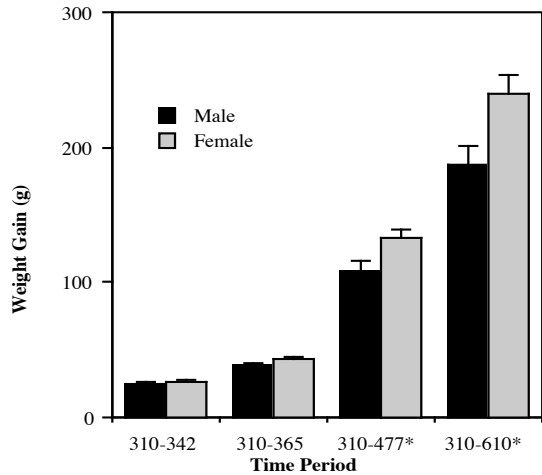


Figure 3. Weight gain of male and female hybrid walleye reared under intensive culture conditions. \* indicates the intervals during which females gained more weight than males.

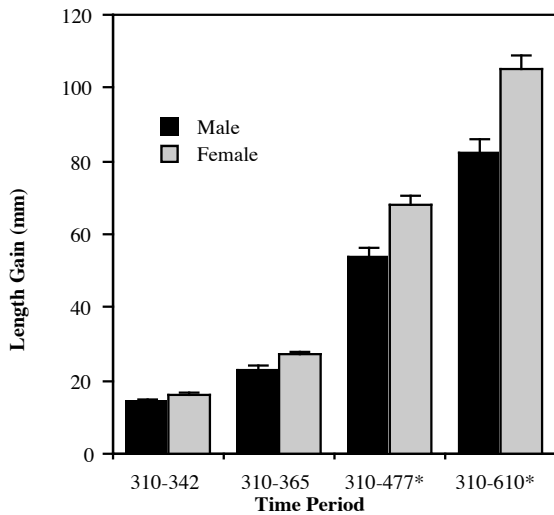


Figure 4. Length gain of male and female hybrid walleye reared under intensive culture conditions. \* indicates the intervals during which females gained more length than males.

**Discussion.** Our findings clearly demonstrate that female hybrid walleyes outgrow males, just as is the case for both parental purebred stocks. Our studies also show that the growth and size differences between females and males become apparent by the time fish reach approximately 200-250 g and 300 mm.

Our studies were conducted with fish raised under constant, near-optimal environmental conditions (21°C and 16L:8D photoperiod). The fish were more than one year old at the time that we were first able to detect sexually-related dimorphic growth. In fish exposed to ambient photothermal conditions (such as fish raised in ponds), some aspects of reproductive development may be stimulated, and sexually-related dimorphic growth may begin in smaller, younger fish.

Based on our results, the use of monosex female populations of hybrid walleye holds a significant potential advantage compared to mixed sex populations for fish culturists raising hybrid walleye to a size greater than approximately 200-250 g and 300 mm.

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# GROWTH AND REPRODUCTIVE DEVELOPMENT OF TRIPLOID AND SHOCKED AND UNSHOCKED DIPLOID PERCH (*Perca flavescens*) REARED TO ADULT SIZE UNDER SELECTED ENVIRONMENTAL CONDITIONS

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**Introduction.** Expansion of the yellow perch aquaculture industry has been constrained by several growth and maturational characteristics of this fish. First, the overall growth potential of perch is limited by its inherent small size and slow growth rate. Second, a considerable reduction in growth rate occurs well before perch attain a market size of 140-160 g. Third, gonadal development can markedly decrease fillet yields (i.e., the percentage of edible flesh) in perch by up to 35%.

These three problems may all be associated with sexual maturation and gonadal development, which begin in perch during the first year of life. The development of methods to sterilize perch by triploidy induction may enhance growth and increase the percentage of edible flesh. This study investigated effects of triploidy induction by heat and hydrostatic pressure shocks on perch reared to adulthood under ambient environmental conditions that simulate pond aquaculture.

**Materials and Methods.** All fish used were the offspring of wild brood fish collected from Lakes Mendota and Cherokee, Dane County, WI. Triploidy was induced by exposing eggs to heat shocks of 28-30°C for a duration of 10-25 min, beginning at 2-5 min post-fertilization, or hydrostatic pressure shocks of 9000 or 11000 psi for a duration of 8 or 12 min, beginning at 5 min post-fertilization. These specific treatments were chosen not to produce the highest possible percentage of triploids, but rather a mixture of triploids and shocked diploids, because both of these groups were needed for these studies.

Batches of heat or pressure shocked embryos containing 30-70% triploids, and unshocked controls, were incubated until hatch and stocked into three separate production ponds and reared for approximately 40 days. The 25-40 mm total length (TL) fingerlings were then harvested and transferred into the laboratory, stocked into separate 750-l flow-through fiberglass tanks, and habituated to intensive culture conditions and formulated feed.

Prior to the initiation of the growth trials, a PIT (Passive Integrated Transponder) tag was implanted into the body cavity of each fish, and the ploidy of individuals was determined by flow cytometry. Each of the five groups of fish were stocked separately into a five 220-l flow through tank under conditions that simulated ambient conditions in ponds and lakes in southern Wisconsin (temperatures varying from 4-21°C on a seasonal basis and tank lighting that mimicked natural day lengths). Fish were hand-fed to

excess (2-5% body weight/day depending on water temperature).

The experiment was terminated in late winter (day 388), at which time the gonads of adult perch are quite developed. At the end of the experiment, blood samples were collected from five randomly selected fish from each treatment group for analyses of serum estradiol-17 $\beta$  (E<sub>2</sub>) and testosterone (T) levels. Hormones were measured using commercially available radioimmunoassay kits validated for use in perch. The fish were filleted and fillet yields were expressed as percentage of body weight. Similarly, the gonads were weighed and gonadosomatic indices (GSIs) were expressed as percentage of body weight.

There were no differences in any measured parameter between heat- and pressure-shocked triploids, or heat and pressure-shocked diploids. Accordingly, these groups were pooled for statistical purposes, the data were analyzed with a 2 x 3 analysis of variance (ANOVA), with the main effects being sex and ploidy (unshocked diploid, shocked triploid, and shocked diploid), followed by pre-planned orthogonal contrasts. Percentage data were arcsine transformed prior to analysis. All results are expressed as mean  $\pm$  standard error of the mean (SEM).

**Results and Discussion.** In general, females grew faster than males regardless of ploidy status (Figure 1). Also, triploids grew faster than shocked diploids, but shocked fish, as a group, grew slower than unshocked diploids. Males had higher fillet yields than females, and triploids had higher fillet yields than diploids. Fillet yields were inversely proportional to GSIs, and reproductive development and function of triploids was reduced compared to diploids (Figure 2).

Our findings show that heat and hydrostatic pressure shocks applied to newly fertilized eggs exert a negative effect on the growth of perch that is independent of ploidy status. Additionally, triploidy will only offer practical improvements to perch aquaculture if the negative effects of shocks can be avoided. Because of the markedly faster growth of females versus males, the use of all-female stocks is a significant advantage for perch culture. Females however, exhibit a significant decline in fillet yield in conjunction with gonadal development. Our findings clearly show that triploid perch of both sexes had approximately 10-20% higher fillet yields compared to diploids.

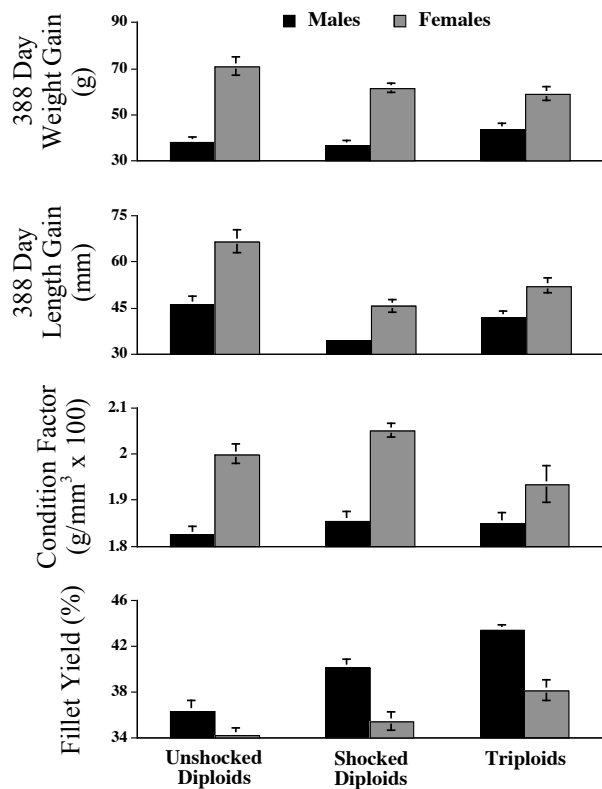


Figure 1. Weight and length gains for a 388-day period, and condition factors and fillet yields of male and female perch reared to adult size under ambient environmental conditions. Data represent the mean  $\pm$  SEM, and N (per treatment) ranged from 14 to 36 for weight and length gains and condition factors, and 5 to 11 for fillet yields.

**Acknowledgements.** These studies have been supported by the University of Wisconsin-Madison College of Agricultural and Life Sciences; the Wisconsin Department of Natural Resources; the University of Wisconsin Sea Grant College Program, National Oceanic and Atmospheric Administration, US Department of Commerce, and the State of Wisconsin (Federal Grant NA46RG0481, Project No. R/BT-8); and the North Central Regional Aquaculture Center under a grant from the United States Department of Agriculture (Federal Grant 89-38500-4319) to Michigan State University (agreement 71-2252I) between Michigan State University and the University of Wisconsin-Madison.

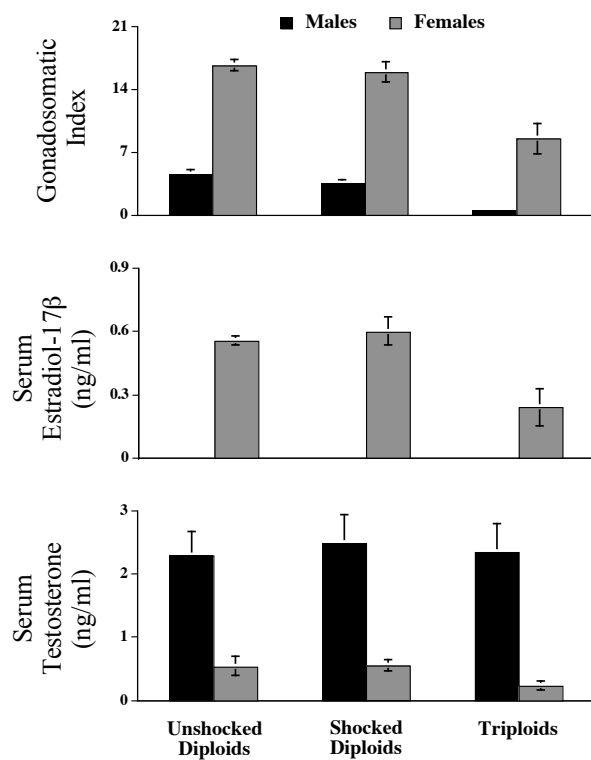


Figure 2. Gonadosomatic indices and serum concentrations of estradiol-17 $\beta$  and testosterone under ambient environmental conditions. Data represent the mean  $\pm$  SEM and N (per treatment) ranged from 4 to 14.

# EFFECTS OF EXOGENOUS SEX STEROIDS AND THEIR INHIBITORS ON GROWTH, FOOD INTAKE AND ENDOCRINE PARAMETERS IN JUVENILE EURASIAN PERCH

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**Introduction.** In Eurasian perch (*Perca fluviatilis*), sex-related growth differences increase at the time close to gonadal maturity in relation to an increase in food intake and high levels of sex steroid secretion (Migaud et al., 2003). Due to a such endocrine increase, it has been hypothesised that sex steroids are involved in the sexual growth dimorphism in fish. Malison et al. (1987) demonstrated that yellow perch growth is stimulated by estrogens and impaired by androgens, but it was also shown that response to sex-steroid hormones is species-related (Donaldson 1987).

In order to characterize the implication of sex steroids in the sexually-related dimorphic growth of Eurasian perch juveniles, we investigated the actions of estradiol-17 $\beta$  (E2) and testosterone (T) on growth and feeding parameters by impairing their effects with selected inhibitors.

**Methods.** Fish were individually tagged (PIT) and the experiment was conducted in a recirculating system (22-23°C) in triplicate tanks of 20 fish (initial body weight, IBW = 32  $\pm$  3 g) each during 90 days. A control (C) feed (TROUVIT T3 – Folia 22) was compared to 5 different diets containing (50 mg/kg diet): tamoxifen, an inhibitor of E2 receptors (IE); flutamide, an inhibitor of androgen receptors (IT); fadrozole, an inhibitor of aromatase enzyme activity (Fa); E2; and T. For each treatment, five fish from an additional tank were sampled on days 4, 15, 29, 64, and 90 for the efficiency of hormone supplementation or inhibition. Each fish was individually weighed on Day 0 (day of hormone treatment), and every 2 weeks. At the end of experiment, blood samples were taken from all fish for hormone and vitellogenin assays. Fish were then sacrificed and sexed. Liver and gonads were removed and weighed to calculate hepatosomatic (HSI) and gonadosomatic (GSI) indices. Individual food intake was calculated by a radiographic method, plasma hormone concentrations were determined by radioimmunoassay, and vitellogenin was measured by indirect endpoints (Ca<sup>++</sup> and alkali-labile-phosphorous = ALP, Verslycke et al., 2002).

**Results.** E2 treatment resulted in significant increase in plasma E2 levels from day 4 to the end of experiment. This treatment decreased plasma T3 levels (Table 1), but increased vitellogenin synthesis, as evidenced by Ca<sup>++</sup> and plasma ALP concentrations (Table 2). T treatment induced significant increase in plasma T levels from day 4 to the end of experiment.

Each inhibitor suppressed significantly its target hormonal secretion, as expected. In addition, Fa treatment induced an increase in plasma T levels. This effect decreased with the time. Endogenous secretion of 11KT was not affected by any treatment.

E2-treatment reduced GSI in both females and males, and Fa increased HSI in both sexes. Other treatments had no significant effects on GSI and HSI (Table 2). T, IT and IE treatments did not significantly affect growth and food intake (Figures 1-3). Growth rate was comparable between Fa and control groups during the first two months of the experiment but an increase was observed in Fa group from day 61 to 90 (Figure 1). Higher growth response was observed only in E2-treated females in relation to higher FI (Figures 2-3). There was a positive significant (P<0.05) correlation (r = 0.40) between growth rate and plasma E2 concentration, while no relation was established with plasma T levels. Feed efficiency was not affected by treatment or sex, values varied between 0.87 and 1.01.

**Table 1:** Plasma levels of E2, T, T3, and 11KT (ng/ml) at the end of experiment

	E2	T	T3	11KT
C	1.2 <sup>b</sup>	2.2 <sup>b</sup>	8.2 <sup>a</sup>	1.1 <sup>a</sup>
IE	0.2 <sup>c</sup>	2.9 <sup>b</sup>	8.3 <sup>a</sup>	1.2 <sup>a</sup>
IT	1.3 <sup>b</sup>	0.9 <sup>c</sup>	8.1 <sup>a</sup>	1.3 <sup>a</sup>
Fa	0.2 <sup>c</sup>	5.8 <sup>b</sup>	8.7 <sup>a</sup>	1.1 <sup>a</sup>
E2	6.5 <sup>a</sup>	1.8 <sup>b</sup>	7.0 <sup>b</sup>	1.2 <sup>a</sup>
T	1.3 <sup>b</sup>	25.1 <sup>a</sup>	8.1 <sup>a</sup>	1.2 <sup>a</sup>

Different letters in column = P < 0.05.

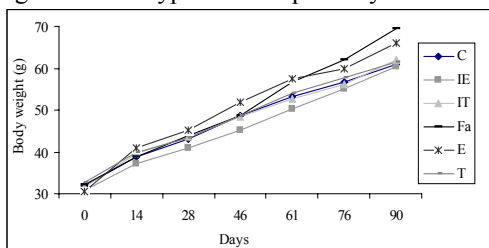
**Table 2:** GSI, HSI, plasma Ca<sup>++</sup> and ALP at the end of experiment

	Ca <sup>++</sup> (mg/ml)	ALP ( $\mu$ g/ml)	GSI (%)	HSI (%)
C	127 <sup>b</sup>	82 <sup>b</sup>	1.92 <sup>a</sup>	1.30 <sup>b</sup>
IE	115 <sup>b</sup>	96 <sup>b</sup>	1.27 <sup>b</sup>	1.43 <sup>b</sup>
IT	153 <sup>b</sup>	96 <sup>b</sup>	1.42 <sup>ab</sup>	1.42 <sup>b</sup>
Fa	152 <sup>b</sup>	104 <sup>b</sup>	1.45 <sup>ab</sup>	1.64 <sup>a</sup>
E2	335 <sup>a</sup>	256 <sup>a</sup>	0.43 <sup>c</sup>	1.28 <sup>b</sup>
T	160 <sup>b</sup>	98 <sup>b</sup>	1.24 <sup>b</sup>	1.32 <sup>b</sup>

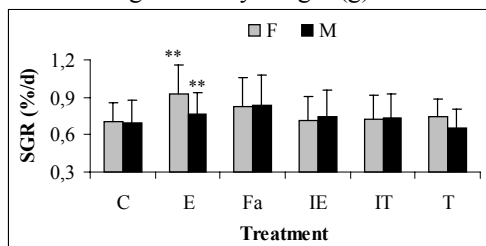
Different letters in column = P < 0.05.

**Discussion.** Doses used in the present study were efficient in sustaining significant increase or decrease in circulating T and E2 levels. Only E2 supplementation and Fa treatment affected morpho-anatomical indices. The increase in endogenous testosterone by Fa has been reported in coho salmon

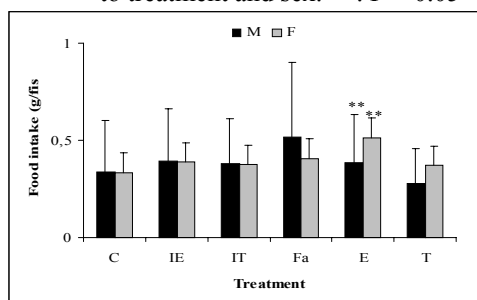
*Oncorhynchus kisutch* (Afonso et al., 1999), and may be related to transient change in the feedback of estrogens on the hypothalamo-pituitary level.



**Figure 1:** Changes in body weight (g) with time.



**Figure 2:** Specific growth rate (SGR %d<sup>-1</sup>) according to treatment and sex. \*\*: P < 0.05



**Figure 3:** Food intake according to treatment and sex. \*\*: P < 0.05

Testosterone supplementation did not affect growth and feeding parameters in any way as previously reported for methyltestosterone in yellow perch juveniles (Malison et al., 1985). This result, and the fact that the reduction in testosterone production by flutamide had no significant effects may indicate that this hormone has no effective anabolic action in juvenile perch. In contrast, estradiol supplementation resulted in high growth rate in relation to high food intake in females not in males. In previous study (Malison et al., 1988), yellow perch females fed to satiation with diet containing E2 gained more weight, consumed more food, and had higher food conversion efficiency in males. Reduction in estradiol production decreased or did not promote growth parameters apart from an increase in growth rate by the aromatase inhibitor fadrozole at the end of experiment.

Therefore, estradiol has an effective action on sexually related dimorphic growth in juvenile Eurasian perch; to some extent, stimulatory in

females but passive in males. The way by which estradiol acts on the growth process is still unclear. E2 may act directly by stimulating anabolic processes, such as protein synthesis as evidenced for vitellogenin in the present study. High levels of E2 may also induce changes in other anabolic hormones, such as thyroid hormones.

**Acknowledgements.** The research was supported by the Belgian National Fond for Scientific Research, contract 2.4568.00 (FNRS).

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## HYBRIDIZATION OF EURASIAN AND YELLOW PERCH INCREASES GROWTH RATE IN OFFSPRING

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**Introduction:** Based on its market value, Eurasian perch *Perca fluviatilis* is attractive species for intensive aquaculture but the intensive culture is strongly limited by a slow growth rate, and thereby a low productivity. Over the 10 last years, considerable information has been obtained on the biology of reproduction and growth dynamics of juveniles in pilot-scale intensive culture (Kestemont and Mélard, 2000, Baras et al., 2003). Until now, perch larvae have been mainly obtained from wild breeders, without any genetic selection that would result in improved survival and growth performances in culture conditions. In other percid fish, improvement of growth rate has been demonstrated by hybridization of walleye *Sander vitreus* and sauger *S. canadensis* (Malison et al., 1990). The objective of the present study was to evaluate hybridization of *Perca fluviatilis* (EP) and *P. flavescens* (YP) in an effort to improve the growth rate of perch juveniles.

**Methods:** Two experiments were conducted in a recirculating system at 22–23°C.

**Experiment 1:** Two types of hybrids (EP females x YP males = HEP, and YP females x EP males = HYP) were produced after an exchange of gametes between the Universities of Namur (Belgium) and Wisconsin-Madison (USA). Semen from several EP or YP males was pooled before dilution (1:4) with an extender (Moore, 1987) and stored in oxygen at 4°C during air freight. Then, the ribbon from YP or EP female was divided into two egg strands and fertilization was made with the two types of semen to avoid maternal effect. For each species, about 7 different strands of eggs were fertilized. Just after fertilization, YP egg strands were stored in oxygen at room temperature, and transferred to Belgium by air freight. For incubation, egg strands were placed in trays in a recirculating flow system under a constant temperature regimen (15 – 17°C) in the indoor facilities of the University of Namur. Eggs hatched at different but relatively close dates: April 27 (YP, HYP), April 28 (HEP), and May 11 (EP), 1998. Larvae were initially reared in 300-l square tanks at 22 – 23°C and fed during the first 17 days with *Artemia* nauplii. Then, larvae were progressively trained to accept artificial dry food (BioMar – Aquastart). During this period, mortality was high for YP and HYP larvae due to their smaller size at

hatching (0.4 mg for YP or HYP vs 0.8 mg for EP or HEP). Consequently, comparison of growth was only made between hybrids and purebred EP until days 137 to 311 after hatching. Experiment began with juveniles of different initial body weight (IBW = 7.4, 9.6, and 7.5 g, respectively for HEP, HYP and EP) but similar biomass (3.2 kg m<sup>-3</sup>) in duplicate or triplicate tanks of 53 or 59 fish each.

**Experiment 2:** Crosses were performed conversely with breeders from the 2 species (EP and YP) on April 30, 2000. Fertilization and incubation were carried out using the same methods as in experiment 1. Due to high mortality of offspring from YP females in the first week after hatching, only EP and HEP larvae and juveniles were compared. Experiment was conducted using similar biomass (3.2 kg m<sup>-3</sup>) of 11543 - 15167 larvae (days 0-40) or 304 juveniles (IBW = 0.12 g, days 41-217) per group. Additionally, 50 juveniles per group were used for sex ratio determination at day 179 after hatching.

**Results:** **Experiment 1:** During the juvenile stage, survival was similar among the 3 fish groups (55, 55 and 54%, respectively for HEP, HYP, and EP). Growth parameters at the end of experiment (day 311) were higher (P<0.05) in both hybrid groups compared to purebreds, however feed efficiency did not significantly differ (Table 1). Weight gain was comparable between Eurasian (HEP) and Yellow (HYP) perch hybrids (456 vs 434 mg fish<sup>-1</sup> d<sup>-1</sup>), and significantly higher than purebreds (EP, 280 mg fish<sup>-1</sup> d<sup>-1</sup>). At the end of experiment, weight gain was 63% higher in hybrid EP juveniles than in purebreds although similar IBW. Growth heterogeneity did not differ among the 3 genotype.

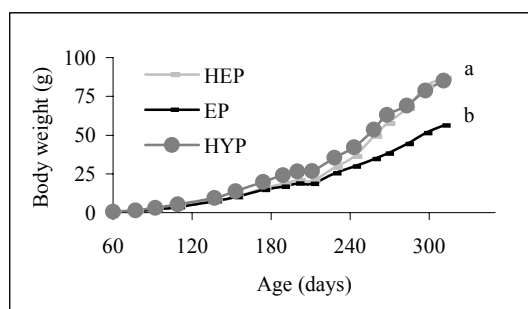
**Experiment 2:** Survival was comparable in hybrid (9%) larvae and purebreds (12%), and increased with the age of fish with higher values in hybrid juveniles than in purebreds (Table 2). Body weight at hatching and at the end of larval period were higher (P<0.05) in hybrid larvae (0.95 and 138 mg) than in purebreds (0.74 and 110 mg). Weight gain was 23% higher in hybrid larvae than in purebreds (3.29 vs 2.68 mg fish<sup>-1</sup> d<sup>-1</sup>). During the juvenile stage, final body weights were higher in hybrid juveniles than in purebreds but not SGR (Table 2). Weight gain was 39% higher in hybrid juveniles than in purebred (125 vs 90 mg fish<sup>-1</sup> d<sup>-1</sup>). Growth heterogeneity was comparable between

hybrid juveniles and purebreds. On day 179 after hatching, the proportion of males was higher than females (65%M, 31%F, 4% steriles,  $P < 0.05$ ), while the purebreds have a 50/50 sex ratio. At that stage, mean body weight was not significantly different between hybrid females ( $14.2 \pm 1.4$  g) and hybrid males ( $15.7 \pm 0.9$  g).

**Table 1:** Growth performance in purebred (EP) and hybrid (HEP, HYP) juveniles from *Perca fluviatilis* (EP) and *P. flavescens* (YP)

	HEP	HYP	EP
FBW, g	$87 \pm 12^a$	$85 \pm 5^a$	$56 \pm 13^b$
CV <sub>FBW</sub>	$31 \pm 5^a$	$24 \pm 1^a$	$31 \pm 6^a$
SGR (%d <sup>-1</sup> )	$1.5 \pm 0.1^b$	$1.3 \pm 0.0^{ab}$	$1.22 \pm 0.2^a$
FE	$0.44 \pm 0.0^a$	$0.43 \pm 0.0^a$	$0.38 \pm 0.1^a$

FBW: final body weight at day 311 after hatching. CV: coefficient of variation. SGR: Specific growth rate. FE: Feed efficiency. Different letters in row =  $P < 0.05$ .



**Figure 1:** Changes in body weight in purebred (EP) and hybrid juveniles (HEP and HYP) from *Perca fluviatilis* (EP) and *P. flavescens* (YP).

**Table 2:** Survival and growth performances in purebred (EP) and hybrid (HEP, HYP) juveniles from *Perca fluviatilis* (EP) and *P. flavescens* (YP)

	HEP	EP
Survival (%)	$90 \pm 7^a$	$63 \pm 9^b$
FBW, g	$22.8 \pm 2.9^a$	$17.3 \pm 2.4^b$
CVf/CVi	$1.20 \pm 0.1^a$	$0.91 \pm 0.1^a$
SGR (%d <sup>-1</sup> )	$2.91 \pm 0.06^a$	$2.86 \pm 0.01^a$

FBW: final body weight at day 217 after hatching. CVf/CVi: Ratio of final and initial coefficient of variation. SGR: Specific growth rate. Different letters in row =  $P < 0.05$ .

**Discussion:** During the two experiments, high mortality was especially encountered for offspring from crossings with yellow perch females in relation to problems of accessibility to feed due to their small size at hatching. Another cause of weakness for yellow perch larvae may be related to an alteration in egg quality due to the transfer of fertilized egg

strands between Madison and Namur. It is worth noting that survival was higher in hybrid juveniles from Eurasian perch females than in purebreds since high mortality is one of the limiting factors in the development of Eurasian perch aquaculture. The better healthy condition of hybrids which increased with the age of fish, compared to purebreds, may be related to heterosis effect. In fact, survival was comparable between hybrid and purebred larvae, but values were 43% higher in hybrid juveniles than purebreds. Also, weight gain was 23% higher in hybrid larvae, and varied between 39 to 63% in juveniles. Preliminary study demonstrated that all-female population and normal population had comparable growth rates during larval and juvenile stages although significant differences were observed during the on-growing stage (Rougeot et al., 2002). Therefore, hybridization is efficient to improve both growth and survival performances of Eurasian perch juveniles. However, further investigations are still warranted to determine the reproductive capacity of hybrids, and to test whether the sex deviation towards high male proportion was related to a male or other genetic factors as it is the case in some mixed-sex populations.

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## GENETIC GROWTH IMPROVEMENT OF *PERCA FLUVIATILIS*: A REVIEW

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**Introduction.** Among the different problems related to Eurasian perch aquaculture, the poor growth rate can be considered as a major limiting factor for the emergence of a commercial activity (Mélard et al., 1996). The production of marketable 80-100 g fish (Swiss market) reared under optimum conditions at a temperature of 23°C in recirculating aquaculture system (R.A.S.) takes at least one year starting from larvae (Figure 1). Under natural temperature regime (cage rearing), the minimal market size is obtained in more than 800 days (Kestemont and Mélard, 2000). Resulting from this poor growth capacity, food conversion ratio (FCR) using high quality diet ranges from 1.0 for 1 to 40 g fish but increases to 1.5 then 2.0 for 80 and 300 g fish, respectively (Mélard et al. 1996).

Due to the slow growth, intensive perch culture is impaired by low production rate (350-400 g m<sup>-3</sup> d<sup>-1</sup>), even at high stocking biomass (60-80 kg m<sup>-3</sup>). High FCR also contribute to reduce the productivity of perch rearing. Together these 2 factors result in high production costs, especially in recirculating aquaculture system and, consequently, low profitability. The emergence of a new market in Belgium, France and Germany for larger fish (350-400 g) also strengthens the necessity to improve growth characteristics of Eurasian perch.

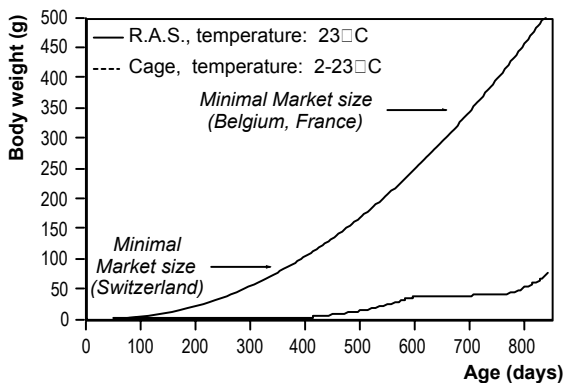


Figure 1. Growth curves of Eurasian perch (Belgian strain; mixed sex populations) reared under intensive conditions at 23°C in R.A.S. and in cage under natural temperature.

Growth rate heterogeneity is another major feature of perch rearing (Figure 2). Fast growing fish (group 3, figure 2) growth twice as fast than slow growing ones (group 1, Figure 2). The high growth rate of some fish, likely having a genetic component, suggest that the possibility to increase growth of Eurasian perch using selective breeding programs exists. Several techniques based on genetic characteristics including strain selection, domestication, all-female populations and

hybridisation have been developed to improve growth rate of Eurasian perch in culture conditions.

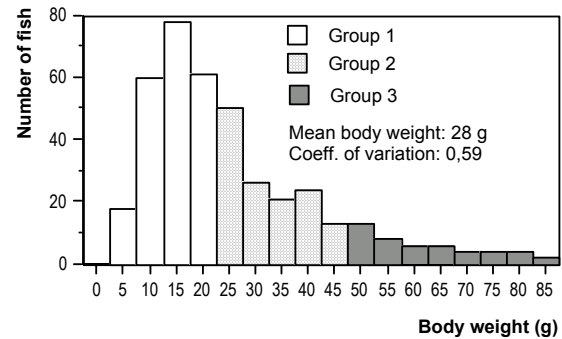


Figure 2. Growth heterogeneity of an Eurasian perch family reared under intensive conditions in R.A.S during 200 days at 23°C.

**Strain selection.** Research conducted on growth of several Eurasian perch wild strains originating from different regions of Europe reared in R.A.S at 23°C suggested marked differences between strains: at day 200 starting from larvae, body weights of Belgian and North-East France strains were 56% and 76% larger respectively than in South-West France and North Italy ones (Figure 3). Starting from 4-5 g fingerlings, survival was also higher (60%) in Belgian and North-East France strains than in South-West France and North Italy ones (Mandiki et al., 2003).

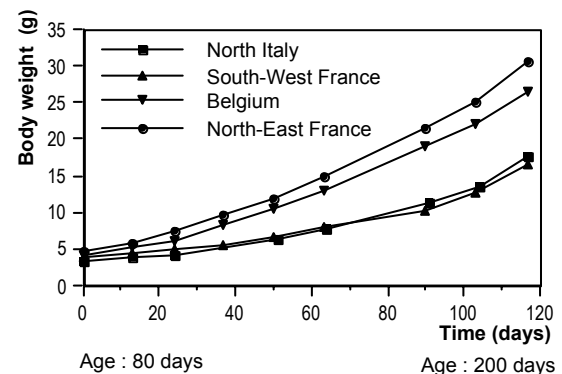


Figure 3. Growth (mean of duplicate) of 4 different strains of Eurasian perch reared under intensive conditions in R.A.S. at 23°C, two progenies / strain.

**Domestication.** It is well established that domestication is beneficial when fitness is positively correlated with desired aquacultural traits like growth rate or eggs and larvae quality. The comparison of growth potential of domesticated progenies (F1 & F2) from captive breeders (no selective breeding program) to wild progenies obtained from wild breeders from the same strain (Belgium, river Meuse)



reared in R.A.S. at 23°C showed a significant growth rate improvement in domesticated fish. At 300 day old, F1 and F2 domesticated fish growth 33% and 72% faster, respectively, than wild fish (Figure 4).

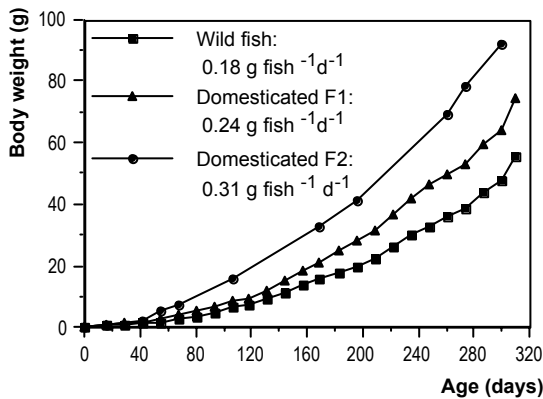


Figure 4. Effect of domestication on growth of Eurasian perch reared in R.A.S at 23°C (Belgian strain; mean of duplicate).

**All-female populations.** Due to the inhibition of sexual maturation under a constant temperature of 23°C (GSI>20% in natural temperature condition) and to a higher intrinsic growth potential, females grow faster than males in intensive conditions. At 400 and 600 days old, growth rates of females are 20% and 80% higher respectively than males. Due to this faster growth rate of females vs males, rearing of all-female populations results in an increase of 35% of growth for marketable fish: the market size of 100 g is obtained in 9 vs 12 months in mixed sex populations (Figure 5). All-female populations can be obtained using sex reversed males breeders (male phenotype, XX genotype; Rougeot et al., 2002).

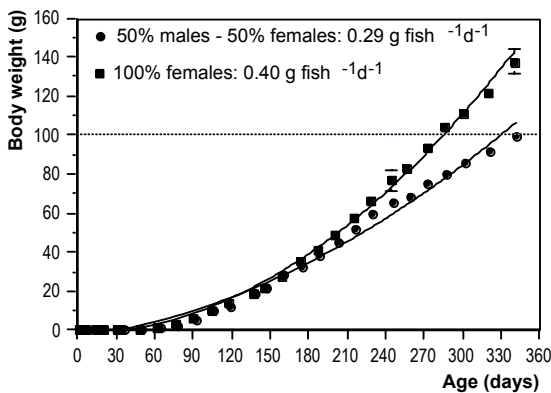


Figure 5. Comparative growth of mixed sex and all-female batches of Eurasian perch reared in R.A.S. at 23°C (Belgian strain; mean of duplicate).

**Hybridisation.** Due to heterosis, hybrids of *P. fluviatilis* female x *P. flavescens* male obtained by artificial fertilisation display an increase of growth performances when compared to purebred *P. fluviatilis*: fish reach a market size of 100 g in 11 months vs 12 months for Eurasian perch (Figure 6, growth rate 42% higher on day 800). The survival rate of hybrids is also 67% higher on day 800.

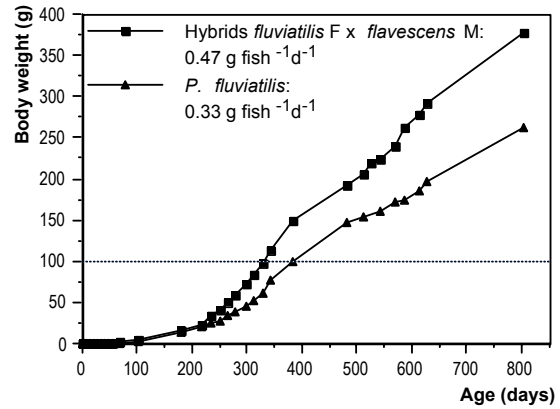


Figure 6. Comparative growth of purebred *P. fluviatilis* and hybrids *P. fluviatilis* female x *P. flavescens* male reared in R.A.S at 23°C (mean of duplicate).

**Conclusion.** The 4 factors mentioned above, alone or in combination, can induce a positive response in the short-term, to enhance the growth of Eurasian perch. An improved growth rate combined with lower FCR should significantly contribute to an increase of productivity and a lowering of production costs of Eurasian perch in intensive culture. Supplementary information is needed about the effects of these 4 factors on growth. A probable family effect on growth should also be evaluated. The identification of the best strain adapted for intensive culture conditions is the first step to start a selection program. In the long run, selective breeding program exploiting the genetic part (additive genetic variance) of the high growth heterogeneity of perch (figure 2) should result in domesticated strains showing higher growth rate. To initiate a directional selection program it will be necessary firstly to establish the heritability of this quantitative trait in Eurasian perch.

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# AN ESTIMATE OF OPTIMAL TURBIDITY TO MAXIMIZE SURVIVAL AND GROWTH RATE OF LARVAL WALLEYE IN INTENSIVE CULTURE

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**Introduction.** Several studies have shown enhanced survival and growth of some species of larval fish in intensive culture by using water with intentionally increased levels of turbidity. It is speculated that turbid water may increase feeding of larval fish by providing a visual contrast of prey items (Boehlert and Morgan 1985; Bristow and Summerfelt 1994), or by illuminating feed particles from the light-scattering effect of turbidity (Bristow and Summerfelt 1994). Bristow et al. (1996) reported 35% survival of larval walleye (*Sander vitreus*) in turbid water (23.8 NTU) compared with 6.6% and 1.9% in clear and blue colored water, respectively. They reported that mean weight of walleye at 21-days posthatch was 270 to 380% greater for fish in turbid (23.8 NTUs) water than in clear or blue colored water (Bristow et al. 1996). The purpose of this study was to determine whether there is an optimal level of turbidity for larval culture of walleye without causing damage to the gills or general fish health.

**Methods.** Larvae were reared for 25 days in 277-L fiberglass tanks from 3- to 28-days posthatch. There were two no-clay controls (0 turbidity) and ten turbidity treatments: 12, 26, 54, 91, 100, 144, 182, 206, 227, and 295 NTUs (mean values for the 25-day exposure). Eyed eggs of walleye were incubated in McDonald hatching jars in our laboratory. Only larvae that hatched within a 24-h interval were used in toxicity tests. Larvae were stocked at 3-days posthatch at a density of 17.9 larvae/L (4,950 larvae/277-L tank). Five fish were sampled every day and observations of the day when the yolk sac and oil globule disappeared were used to describe their larval stage:

Prolarva (1- to 5-days posthatch) - yolk sac and oil globule present; gas bladder has not inflated; gill rakers are present but gill lamellae absent.

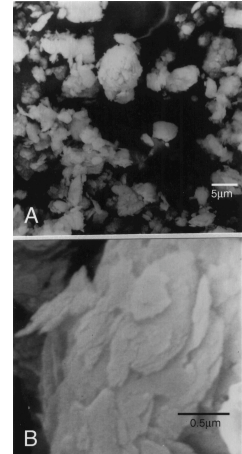
Postlarva I (6- to 14-days posthatch) - yolk sac absent, oil globule present; primary gill filaments

Postlarva II (15- to 21-days posthatch) - oil globule absent, secondary lamellae present (gill respiration developing).

A commercial aluminum-silicate ball clay (Old Mine #4 Kentucky ball clay, Kentucky-Tennessee Clay Company, Mayfield, Kentucky) was used as the source of turbidity. This clay has a specific surface area of  $24.4 \mu\text{m}^2/\mu\text{m}^3$ ; 72% of the particles are  $< 1.0 \mu\text{m}$ . In solution, the particles form amorphous clumps (Figure 1A), which upon higher magnification, reveal a smooth surface that unfolds into thin leaflike layers (Figure 1B).

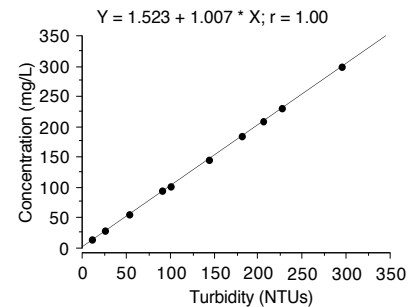
Figure 1. Scanning electron microscope (SEM) photographs of ball clay used in the experiments

- A. 1,000 X (bar =  $5 \mu\text{m}$ )
- B. 20,000 X (bar =  $0.5 \mu\text{m}$ ).



Turbidity (NTU) not clay concentration is essential for intensive culture of larval walleye, but there is a nearly perfect 1:1 linear relationship between NTUs and clay concentration (Figure 2).

Figure 2. Regression of clay concentration (mg/L) on turbidity.



When fish were 28-days posthatch, the gills of 7 fish from each turbidity treatment were excised, fixed, mounted in paraffin blocks, sectioned and stained with hematoxylin and eosin (H & E). Sections of the secondary lamellae on the first and third gill filaments were examined by light microscopy for five pathologies: necrosis, lamellar fusion, epithelial lifting, hyperplasia, and clubbing using the description of these pathologies given by Mallatt (1985). Gills were also examined for the presence of debris. Frequency of occurrence of specific histological changes was calculated as the number of occurrences/100 (i.e., percent) secondary lamellae.

A second degree polynomial was used to describe the relationship between turbidity and fish survival to 28-days posthatch and between turbidity and growth between hatch and 28-days. The Z-test was used to determine probability of the correlation coefficient (r).

**Results.** Survival to 28-days posthatch was less than 0.1% (data points not shown in Figure 3) for fish raised in tanks without clay (i.e., turbidity of <1 NTU), whereas survival ranged from 10.6% at 12 NTUs to 43.3% at 206 NTUs (Figure 3). The correlation coefficient between survival and turbidity was 0.915 (P value for Z test = 0.008).

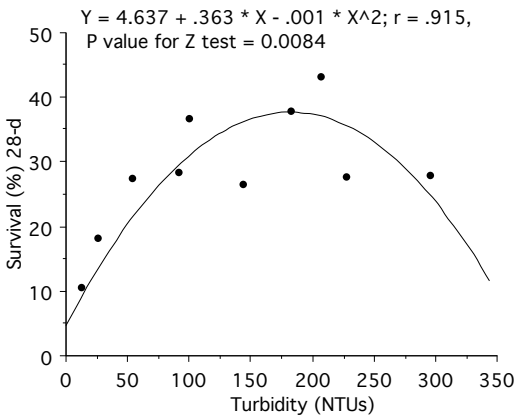


Figure 3. Relationship between fish survival (%) to 28-days posthatch and turbidity (NTU). N = 12 but low survival ( $\leq 0.1\%$ ) in the two tanks without clay (i.e., clear water, <1 NTU) are out of range.

Although the highest survival was at a turbidity of 206 NTUs, the relationship between survival and turbidity was parabolic. Thus, calculated from the quadratic equation fit to the data, (Figure 3) turbidity for maximum survival was 181 NTUs.

The range (Mean  $\pm$  SE) in total length at 28-d posthatch was from  $18.1 \pm 0.33$  mm for fish in the no-clay treatments to  $26.4 \pm 0.41$  mm at 227 NTU. The relationship between growth rate and turbidity was parabolic (Figure 4).

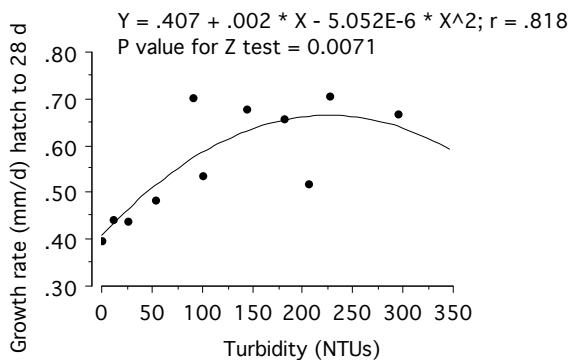


Figure 4. The relationship between growth rate (mm/d) from hatch to mean turbidity (NTU).

No pathologies were observed in tissue sections of gills of 28-day-old walleye cultured in turbid water over a range of turbidities from 12 to 295 NTU. Some debris (25 to 50  $\mu\text{m}$ ) was present between adjacent secondary lamellae in gills of 3 fish from

turbidity treatments 26, 182, and 295 NTUs (Fig. 5). Debris stained with H&E, indicating that it was food not clay.



Figure 5. Gill section with debris between adjacent secondary lamellae.

**Discussion.** The present study corroborates findings by Bristow and Summerfelt (1994) and Bristow et al. (1996), showing that survival and growth of larval walleye during larviculture is enhanced in turbid water by the addition of commercial ball clay. The present study demonstrated that maximum survival is at turbidity levels nearly four times greater than that used previously. Although it has been suggested that the clay fraction of suspended solids in nature may be injurious to fish gills, no adverse effects were observed in this study at clay concentrations as high as 298 mg/L (295 NTUs).

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## SEX DETERMINISM IN EURASIAN PERCH, *Perca fluviatilis*: EFFECT OF GENETIC AND ENVIRONMENTAL FACTORS

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**Introduction.** In fish, sex is genetically (GSD) and/or environmentally (ESD) determined. Besides sex chromosomes (generally XX/XY or ZW/ZZ), autosomal genes are also involved in sex determinism mechanism in fish. Several studies have proven that environmental factors, principally temperature, can influence the sex differentiation mechanism towards males or females.

Only 10 % of fish species display heteromorphic sex chromosomes, and despite the recent research, few sex-specific markers exist in fish. In order to study the different genetic mechanisms involved in genetic sex determinism in fish, hormonal sex inversion, crosses with hormonally sex-reversed breeders, gynogenesis (method of chromosome-set manipulation in which offspring inherited all the female set of chromosomes) or interspecific hybridization are currently used (Devlin and Nagahama, 2002).

The aim of this document is to present a synthesis of study genetic sex determinism (using hormonally sex-reversed breeders, gynogenesis, inter-specific hybridization) and environmental sex determinism study (high temperature) in Eurasian perch.

**Materials and methods.** Exp 1. Hormonally sex-reversed male breeders of Eurasian perch were produced by feeding mixed-sex juveniles (mean body weight (Pm) = 40 to 205 mg) perch populations with diet complemented with exogenous sex steroid  $17\alpha$ -methyltestosterone (40 to 80 mg kg<sup>-1</sup> food) for 30 to 80 days.

Exp. 2. In order to compare some reproductive characteristics of XY males vs XX males we determined the gonadosomatic index (GSI), sperm concentration, sperm motility and plasma levels sex steroids (testosterone - T, estradiol - E<sub>2</sub> and 11keto-testosterone - 11KT) during the reproductive period (1 April - 15 May) for each male genotype. Gonadosomatic index (100 x gonad weight / total body weight) and sperm concentration (estimated by counting spermatozoa in a hemocytometer) were determined in the middle of the spawning period (25 April). Sperm motility was assessed using computer-assisted sperm analysis (CASA) and expressed by the curvilinear velocity (VCL,  $\mu\text{m sec}^{-1}$ ), straight line velocity (VSL,  $\mu\text{m sec}^{-1}$ ), average path velocity (VAP,  $\mu\text{m sec}^{-1}$ ) and percentage of motile sperm (MOT, %). Plasma T, 11KT and E<sub>2</sub> levels were assessed by radioimmunoassay (RIA) at the beginning (6 April), the middle (25 April) and the end (9 May) of the spawning period.

Exp. 3. Mixed-sex and all-female populations of Eurasian perch were artificially produced by fertilizing eggs with sperm from normal XY male (mixed-sex populations) and hormonally sex-reversed XX male (all-female populations) selected

based on gonad morphology (XY males displayed paired testes and XX males displayed a single testis with nodule).

Exp. 4. In order to induce gynogenesis, semen was 10-fold diluted in extender, a solution with Bicine. 10ml of diluted sperm were placed on Petri dishes and placed 5 cm under UV light (254nm, 15 Watts) for 400 seconds. Each spawn was divided into 3 parts and artificially fertilized with sperm : one with non-irradiated sperm (control), the second part with UV-irradiated sperm and heat-shocked (gynogens) and the third part with UV-irradiated sperm and not heat-shocked (haploid). A heat shock of 30°C for 25 minutes was applied beginning at 5 minutes post-fertilization on gynogens batches in order to induce the retention of the second polar body (Rougeot *et al.*, 2003). Ploidy levels was assessed by flow cytometry analysis on 2-days old larvae and sex ratio determined by morphological examination of the gonad.

Exp. 5 Hybrid perch were artificially produced by crossing female Eurasian perch and male yellow perch. Each spawn was divided into 2 parts : one part was fertilized with Eurasian perch sperm (control) and the other part was fertilized with Yellow perch sperm (hybrid). After larval rearing, hybrids and their respective control were transferred into a recirculating aquaculture system (23°C, O<sub>2</sub> > 6ppm) for on-growing during 6 months. When gonads were morphologically differentiated in male and female (6 months old), the sex ratio of the progenies was assessed on 100 random fish from each group.

Exp. 6. In order to test the effect of temperature on sex determinism in Eurasian perch, different batches of undifferentiated juveniles (Pm = 40 mg) were exposed for 30 days to high temperature (29 to 34°C). 33 and 34 °C were lethal in perch (all fish died after one day).

**Results.** Exp. 1. Complete sex reversal (100 % male progenies) was obtained exclusively when the hormonal treatment was applied to fish initially ranging from 40 to 71 mg, regardless the dose and treatment duration. High initial body weight (> 70 mg), high hormonal doses (>80 mg kg<sup>-1</sup>) and long duration (80 days) induced variable proportions of males (70 to 97 %), females (0 to 29 %), ovotestis (0 to 18 %) and undevelopped gonads (0 to 27 %) in the resulting populations (Rougeot *et al.*, 2002).

Exp. 2. Gonadosomatic index and sperm concentration were not significantly ( $p > 0.05$ ) different between the two genotypes (Table 1). None of the four motility parameters were significantly ( $p > 0.05$ ) different between XY and XX males. T, 11KT and E<sub>2</sub> levels increased in the middle of the reproductive season ( $2.70 \pm 0.34$ ;  $3.93 \pm 0.52$  and  $4.25 \pm 0.55$  ng ml<sup>-1</sup>, respectively)

and decreased at the end ( $1.79 \pm 0.27$ ;  $1.89 \pm 0.26$  and  $1.18 \pm 0.24$  ng ml<sup>-1</sup>) but were not significantly different between the 2 genotypes.

	GSI (%)	Sperm density (10 <sup>9</sup> ml <sup>-1</sup> )
XY males	7.6 ± 2.1	32.8 ± 4.3
XX males	7.0 ± 2.4	34.0 ± 3.0

Table 1 : GSI (%) and sperm density (10<sup>9</sup> ml<sup>-1</sup>) of XY and XX males.

Exp. 3. Sex-ratio of progenies resulting from a cross with normal XY male were not significantly ( $p > 0.05$ ) different from a balanced sex ratio in 7 families and were significantly ( $p < 0.05$ ) skewed towards males or females in two families. Sex ratio of all-female populations is significantly ( $p < 0.05$ ) skewed towards females : 97.0 to 100 % (Table 2).

	N	N of fish sexed	Sex ratio (%)		$\chi^2$
			Female	Male	
XY male	11	49-100	32.7-57.9	42.1-67.3	0.0-3.0
	2	100-469	39.3-65.0	35.0-60.7	4.6-11.0*
XX male	5	56-100	100	0	37.3-66.7*
	3	46-100	97.0-98.5	1.5-3.0	39.8-56.7*

Table 2 : Sex ratio of progenies resulting from crosses with XY males and XX males. Values are minimum and maximum. N = number of batches. \* $p < 0.05$ .

Exp. 4. Ploidy were 100 % diploid for the 4 control groups and 2 gynogens groups. The two other gynogens batches displayed 6.7 and 10.0 % triploids fish, suggesting that UV-irradiation was not completed. The control displayed a balanced sex ratio and the 4 gynogens batches are all-female (100 %; Fig.1).

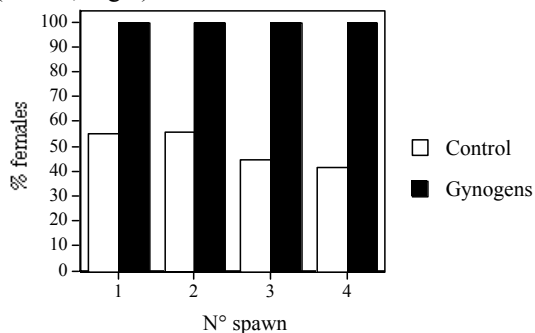


Figure 1. Percentage of females in gynogens group and their respective control.

Exp. 5. Controls displayed a balanced sex ratio and the 2 hybrids batches displayed a significantly ( $p < 0.05$ ) skewed sex ratio towards males (64 and 66%, table 3).

Exp. 6. The sex ratios of all the progenies was not significantly ( $p > 0.5$ ) different from a balanced sex ratio (50 : 50).

	Males (%)	Females (%)	Undeveloped gonads (%)	$\chi^2$
Hybrid 1	64	36	0	3.99*
Control 1	50	50	0	-
Hybrid 2	66	26	8	11.78*
Control 2	50	50	0	-

Table 3 : sex ratio of hybrid progenies between Eurasian perch female and Yellow perch male. \*  $p < 0.05$ .

**Discussion .** The sex ratio obtained in Exp. 3. suggested that genetic sex determinism in Eurasian perch is controlled by homogametic XX sex chromosomes in females. The significantly skewed sex ratio observed in 2 populations resulting from a cross with a normal XY male and males observed in populations where all-female were expected, suggested the action of other genetic sex-determining factors (e.g., autosomal genes). All-female obtained in gynogens batches confirm that Eurasian perch display a female homogamety XX chromosomal system. Nevertheless, as we did not observe any males in progenies, we can not confirm the hypothesis of an autosomal role. Hybrid's sex ratios also suggested the possible effect of an autosomal gene as was suggested for other species as tilapia or carp (see review by Devlin and Nagahama, 2002). A possible role of environment (temperature) on sex determinism in Eurasian perch was not proven.

**Conclusion.** In Eurasian perch, sex is primarily determined by sex chromosomes in which female is the homogametic sex (XX). A role of an autosomal sex determining gene is suggested to explain males arising from crosses with XX males, the two skewed sex ratio observed in normal crosses and in hybrid progenies, but this hypothesis is still not confirmed by mitogynogenesis or high inbred gynogenesis..

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**LARVAL STUDY ON PIKEPERCH *Stizostedion lucioperca*: EFFECTS OF WEANING AGE AND DIETS (LIVE AND FORMULATED) ON SURVIVAL, GROWTH, CANNIBALISM, DEFORMITY AND STRESS RESISTANCE**

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**Introduction.** Experiments on intensive rearing of newly hatched pikeperch fry have not been successful (Ruuhijärvi and Hyvärinen, 1996). Although pikeperch accept both live and formulated diets, both survival and growth are very poor. Therefore, two feeding trials were conducted to study the optimal weaning age and potential formulated feed for pikeperch *Stizostedion lucioperca* larvae. In the first experiment, newly hatched larvae were fed *Artemia* nauplii, then progressively weaned on the day 12, 19 or 26 posthatch with artificial diet. In a second experiment, two commercial fish diets (marine, freshwater) and two live foods (newly hatched *Artemia* nauplii and *Artemia* nauplii enriched with ascorbic acid and highly unsaturated fatty acid HUFA) were investigated in an 18-day trial. Survival, growth, deformity and stress resistance were assessed. The aims of these studies were to determine the optimal weaning age (habituation to dry feed) and suitable commercial feed for pikeperch in relation to survival, deformity and growth at its larval stage.

**Methods.** Experiment 1. Ten thousands pikeperch larvae (10 day post-hatching) were obtained from a commercial fish farm in The Netherlands. After acclimation in well water at 1.5 x 1.5 x 1 m fiberglass tank for 2 days, 12 groups of 120 individuals (mean weight = 3.1 mg) were randomly divided into rectangular plastic tanks (16 L) to provide triplicate of three weaning age treatments (day 12, 19, 26 posthatch) and a control group (feeding *Artemia*). Water temperature was kept at 20-21°C. BioKyowa FFK feed was used as the weaning feed to replace *Artemia* nauplii. Weaning procedures were completed by decreasing the proportion of *Artemia* nauplii while increasing the proportion of dry feed. All groups of larvae were fed every 1.5 h a day. Dead fish were checked for normal and cannibalistic death by microscopy and recorded.

Experiment 2. Both marine (MW1, MW2) and freshwater fish diets FFK, FW2 were used at the day 19 posthatch in comparison to live foods (*Artemia* enriched or non enriched with vitamin C and HUFA). After an 18-day feeding trial, survival, growth, deformity and the ability to resist to stress tests were evaluated. At the end, 20 larvae were selected from each tank and put into 10 L container with 3‰ salinity of artificial seawater for 30 minutes, and survival rate of each group under stress test was calculated. Larvae

were weighed and checked individually for deformity under microscope.

**Results** Experiment 1. The best weight gain and SGR were observed in larvae weaned at day 19 posthatch ( $P < 0.05$ ), which were even better than that of the control group. The lowest weight gain and SGR were found in fish weaned at day 12 posthatch (figure 1). Substantial amount of morphological deformities (11.9-38.6%) were observed in survivors. The highest rate of mandibular or maxillary deformities (37.6%) was found in the control group. Results showed that the formulated feed significantly improved jaw development by lowering the rate of deformation at the weaning age of day 12 (20.7%), day 19 (11.9%) and day 26 (20.7%), respectively (figure 2). The lowest cannibalism was found in larvae weaned at 12 day posthatch.

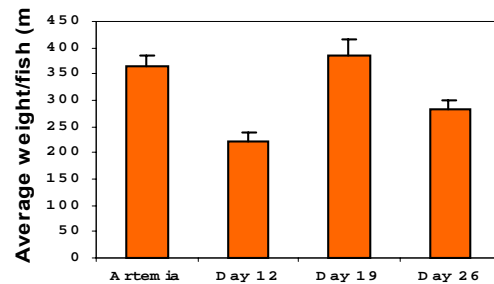


Figure 1. Effect of weaning age on growth of pikeperch larvae.

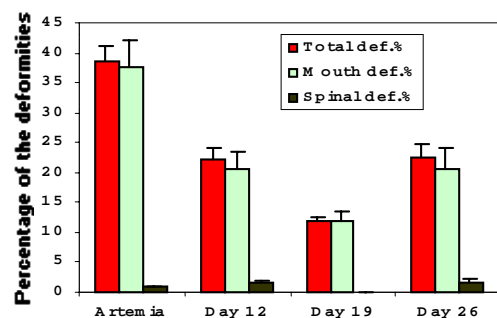


Figure 2. Effect of weaning age on deformity of pikeperch larvae.

Experiment 2. Pikeperch fed live food had significantly better growth than formulated diets, fish fed FW2 diet had significantly better growth than those fed with MW1 and MW2 diets. The best growth was obtained in larvae fed enriched *Artemia* nauplii ( $P < 0.05$ ) with no deformity (scoliosis or lordosis) while high deformity rate was found in larvae fed

marine fish diet (figure 4). Positive correlation ( $r=0.744$ ) was achieved between ascorbic acid content in the diet and larval carcass and reduction of larval deformity. Stress resistance test showed that larvae fed enriched *Artemia* had the best survival rate among all treatment groups.

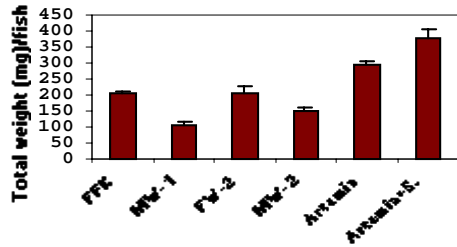


Figure 3. Effect of diet on growth in pikeperch.

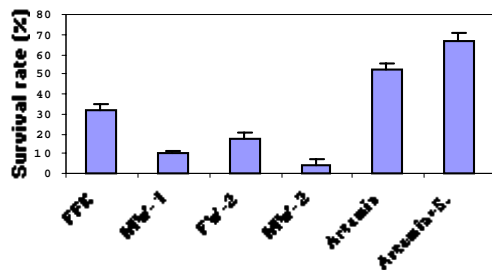


Figure 4. Effect of diet on survival of pikeperch larvae submitted to osmotic shock.

**Discussion.** Experiment 1 showed that significantly high weight gain was found at weaning age of day 19 posthatch and was even higher than those fed *Artemia* nauplii only, indicating that pikeperch at this age probably develop proper digestive capability to digest and absorb multi-nutrients from artificial feed. The lowest weight gain observed at the day 12 posthatch can probably be attributed to the incomplete necessary enzymes development in this early stage. The digestive tract of fish larvae is not achieved at hatching, but undergoes major developmental changes over several weeks (Vu, 1983). This is in agreement with previous work of Kestemont et al. (1995) on the weaning size study with Eurasian perch. High percentage of deformities in maxilla development was observed in the present study. The highest deformity (38.6%) was found in the control group, suggesting that certain essential nutrients might be deficient in *Artemia* nauplii and prolonged feeding *Artemia* nauplii may have adverse result. Results showed that although early weaning (day 12 posthatch) may reduce cannibalism, the growth would be compromised.

Experiment 2 showed that larvae fed FW-2 diet had better growth than those fed diets of MW1 and MW2, and was comparable to fish fed FFK diet, showing that FW-2 may be suitable for pikeperch early feeding. The best growth and none deformity were achieved in fish fed enriched *Artemia* nauplii containing extra vitamin. C and HUFA, suggesting that vitamin C and HUFA may

be essential for fast growing larvae and to prevent scoliosis or lordosis from some essential nutrients deficiency. The results of stress test showed that fish fed FFK diet had better ability to resist osmotic shock compared to fish fed with other formulated diets. However, the best survival rate of larvae was found in fish fed with enriched *Artemia* nauplii, indicating that enriched *Artemia* containing extra vitamin.C and HUFA may also enhance stress resistance in pikeperch larvae. The stress resistance enhancement by vitamin C has also been reported in European sea bass *Dicentrarchus labrax* larvae (Merchie et al., 1995) and walleye, *Stizostedion vitreum* larvae (Kolkovski et al., 2000). In summary, the present results indicate that the optimal weaning age for pikeperch larvae at 20°C is the day 19 posthatch. Enriched *Artemia* nauplii with extra vitamin.C and HUFA would be beneficial for pikeperch larval rearing in terms of survival, growth and normal development. Further investigations are needed on larval nutrition in order to reduce mortality, deformity and cannibalism during this critical period of early development.

#### Acknowledgments.

This study was partially funded by EC CRAFT Project *Lucioperca* Q5CR 2001 70594. J.M. and I.I. Toko were financially supported by the Interuniversity Council of the French Speaking Universities of Belgium (University Co-operation towards Development).

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## **ECOLOGY AND EVOLUTIONARY BIOLOGY OF DARTERS**

**“Spreitzer” vertebrae, a unique character found only in *Ammocrypta* (crystal and sand darters)**

*John Clay Bruner*

**Molecular phylogenetics of Etheostomatinae (*Teleostei*, *Percidae*): Insights from combining cytochrome *b* and 12s ribosomal RNA mitochondrial DNA variation**

*Brian L. Sloss and Neil Billington*



## “SPREITZER” VERTEBRAE, A UNIQUE CHARACTER FOUND ONLY IN *Ammocrypta* (CRYSTAL AND SAND DARTERS)

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**Introduction.** The taxonomic history of darters has witnessed the nominal genera reduced to as few as 1 genus (Gilbert, 1887; Meek, 1893) and increased to as many as 31 genera (Jordan *et al.*, 1930). Bailey and Gosline (1955) reduced darters to the 3 genera *Ammocrypta*, *Percina*, and *Etheostoma*. Most workers followed the 3 genera classification of darters until Simons (1991,1993) resurrected the subgenus *Crystallaria* to generic status, and placed the *Ammocrypta* subgenus within the genus *Etheostoma*. Simon *et al.* (1992), examining characters of protolarvae of darters confirmed Simons' elevation of *Crystallaria*, but found a sister relationship between the genera *Ammocrypta* and *Etheostoma*. Jenkins and Burkhead (1994, pp.852-3) gave 11 reasons for rejecting Simons' hypothesis. Song *et al.* (1998), using mitochondrial cytochrome *b* DNA sequence data, rejected Simons' (1993) hypothesis of relationship between *Ammocrypta* and the *Boleosoma* subgenus within *Etheostoma*, and in a strict consensus found *Crystallaria* and *Ammocrypta* as sisters in their own clade. Shaw *et al.* (1998) using morphological and allozymic data confirmed Simons' (1993) relationship hypothesis. While studying percoid osteology, I discovered a unique type of anterior caudal vertebrae in which the haemal arches are not closed. August Edward Spreitzer (1979, p. 214) was the first to report these vertebrae for *A. pellucida*. In his honor, I have named this type of caudal vertebrae “Spreitzer vertebrae”.

**Methods and Materials.** Specimens used in this study were cleared and stained [C&S] using the method of Taylor and Van Dyke (1985). Dry skeletons [S] examined are from the osteology collections of the University of Alberta Zoology Museum and the Magyar Nemzeti Muzeum (MNH), Budapest, Hungary. Codens of institutions follow Leviton *et al.* (1985).

Forty-four species of percids are used for the analysis. *Perca flavescens* UAMZ 1522 [3C&S], UAMZ 6705-6711 [7S] *P. fluviatilis* UAMZ 6962c [1C&S], UAMZ 6962d [1C&S]. *Percarina demidoffi* UAMZ 6963a [1C&S] UAMZ 6963b [1C&S]. *Gymnocephalus baloni* UAMZ 6930a [1C&S]. *G. cernuus* UAMZ 6789 [1C&S], UAMZ 6790 [1C&S]. *G. schraetser* UAMZ 6784 [1C&S] UAMZ 6933 [1/3,C&S]. *Sander canadensis canadensis* UAMZ 6712 [1S], UAMZ 6715 [1S], UAMZ 6992 [1C&S], UAMZ 6993 [1C&S]. *S. lucioperca* MNH,a

uncatalogued [1S], UAMZ 6796 [1S], UAMZ 6921 [1C&S], UAMZ 6922a [1C&S] *S. vitreus vitreus* UAMZ 5164 [1S], UAMZ 6713 [1S], UAMZ 6990 [1C&S], UAMZ 6991 [1C&S]. *S. volgensis* MNH,a,c, [2C&S]. *Romanichthys valsanicola* UAMZ 6785 [1C&S], UAMZ 6858 [1C&S] *Zingel streber streber* UAMZ 6925a [1C&S], UAMZ 6925b [1C&S]. *Z. zingel* MNH [1S], UAMZ 6926 [1C&S] *Ammocrypta asprella* INHS 74619 [1C&S], INHS 76333 [1C&S]. *Ammocrypta clara* INHS 13390 [2/4,C&S]. *A. pellucida* UAMZ 2502 [2/3,C&S]. *Percina sciera sciera* INHS 16734 [2/4,C&S]. *P. phoxocephala* INHS 63847 [2/4,C&S]. *P. maculata* UAMZ 953 [1C&S], UAMZ 3327 [1C&S]. *P. evides* INHS 68850 [2/4,C&S]. *P. stictogaster* INHS 64075 [1C&S] *P. aurantiaca* UAMZ 6944 [2/4,C&S]. *P. copelandi* INHS 81049 [2/4,C&S] *P. shumardi* INHS 63848 [2/4,C&S], NMC 70-0221 [2/4,C&S]. *P. caprodes semifasciata* UAMZ 5373 [2/23,C&S]. *Etheostoma tuscumbia* UAMZ 6940 [2/4,C&S]. *E. sagitta sagitta* UAMZ 6941 [2/4,C&S]. *E. cinereum* UAMZ 6942 [2/4,C&S]. *E. blennioides* NMC 72-0187 [2/16,C&S]. *E. tetrazonum* INHS 81347 [2/4,C&S]. *E. zonale zonale* INHS 82377 [2/4,C&S]. *E. stigmaeum* INHS 79953 [2/4,C&S]. *E. nigrum* NMC 79-1196 [2/10,C&S]. *E. olmstedii* NMC 87-0224 [2/25,C&S]. *E. vitreum* INHS 74355 [2/4,C&S]. *E. chlorosomum* INHS 17993 [2/4,C&S]. *E. juliae* INHS 75490 [2/4,C&S]. *E. parvipinne* UAMZ 7525 [2/4,C&S]. *E. okaloosae* UF 74516 [2/27,C&S]. *E. edwini* UAMZ 6938 [1/2,C&S], UAMZ 6939 [1/2,C&S]. *E. trisella* UAMZ 6943 [2/4,C&S]. *E. caeruleum* NMC 80-0857 [2/25,C&S]. *E. flabellare* NMC 72-0181 [2/18,C&S]. *E. exile* UAMZ 6852 [1C&S], UAMZ 6853 [1C&S], UAMZ 6854 [1C&S], UAMZ 6855 [1C&S].

**Results.** Of the percids examined, only *Ammocrypta asprella*, *Ammocrypta clara*, and *A. pellucida* had Spreitzer vertebrae. See Figures 1, 2.

**Discussion.** Since Spreitzer vertebrae were found only for *Ammocrypta clara*, *A. pellucida*, and *A. asprella*, I have concluded Spreitzer vertebrae are a generic character defining the genus *Ammocrypta*.

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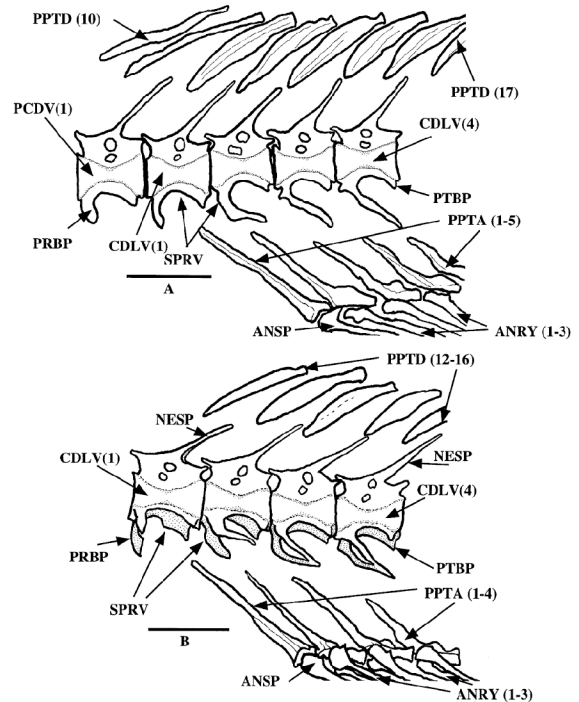
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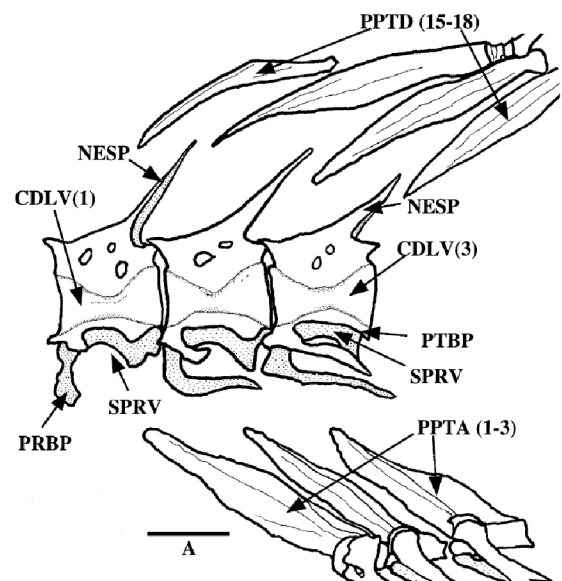
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**Figure 1** Two different left views of *Ammocrypta pellucida*. UAMZ 2502b. Horizontal bar (HB)=1 mm. (A) Lateral view of last precaudal vertebra (PCDV 22), and first four caudal vertebrae (CDLV), dorsal proximal pterygiophores (PPTD) 10-17, and anal proximal pterygiophores (PPTA) 1-5, (B) Ventro-lateral view of the first four CDLV, PPTD 12-16, and PPTA 1-4.



**Figure 2.** Left ventro-lateral views of *Ammocrypta asprella*. HB=1 mm. (A) INHS 76333. View of first three CDLV, PPTD 15-18, and PPTA 1-3, and first anal spine.

# MOLECULAR PHYLOGENETICS OF ETHEOSTOMATINAE (TELEOSTEI, PERCIDAE): INSIGHTS FROM COMBINING CYTOCHROME *b* AND 12S RIBOSOMAL RNA MITOCHONDRIAL DNA VARIATION

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**Introduction.** Phylogenetic relationships within Percidae have long been the topic of debate. Within the family, the vast majority of taxonomic diversity exists within Etheostomatinae (North American darters). Currently, over 150 species of darters in four genera, *Ammocrypta*, *Crystallaria*, *Etheostoma*, and *Percina*, are recognized. These four taxa represent the only percid genera endemic to North America, occurring primarily in the central basin and Atlantic coast drainages.

Evolutionary hypotheses among darters have been complicated by numerous issues within the subfamily including morphological and behavioral convergence, putative rapid speciation events, and evolution of complex breeding strategies. Predominate features of darter evolution are adaptations associated with miniaturization and specialization within the smaller stream habitats (Page 1985). The darter genera are thought to have evolved in response to differing stream environments with *Etheostoma* occupying more lotic portions of stream systems, *Percina* preferentially found in more lentic portions, and *Ammocrypta* and *Crystallaria* found in sand substrates within stream systems (Kuehne and Barbour 1983; Page 1983).

Many questions involving percids center on the uneven distribution of diversity within the family. Why are there so many darters compared to all other percids? Why didn't small, benthic percids found in Eurasia (*Zingel* and *Romanichthys*) experience the same prolific speciation as North American darters? How long did it take the darters to radiate into their present diversity? Many of these questions are hampered by a lack of a well-corroborated phylogenetic hypothesis of darter evolution. Further, the large diversity within the subfamily has confounded taxonomic recognition and nomenclature. Previous efforts to determine a phylogenetic hypothesis of darter genera and subgenera have used morphology, allozymes, reproductive behavior, and mitochondrial DNA (mtDNA) sequence data. Our objective was to develop a phylogenetic hypothesis of North American darters using DNA sequence data from two mitochondrially encoded genes with a focus on generic and subgeneric relations.

**Methods.** Forty-one species representing all four Etheostomatinae genera and 16 of 17 *Etheostoma* subgenera and all 9 *Percina* subgenera were sampled (per Page, 2000; Table 1). Cytochrome *b* (cytb) and 12S rRNA (12S) genes were amplified via the polymerase chain reaction, cloned into a TA-vector, and isolated via standard plasmid miniprep procedures (details available upon request from authors). Cloned DNA was sequenced using commercially available sequencing kits and <sup>35</sup>S-dATP. Autoradiographs were scored manually, aligned using ClustalX, and adjusted based on amino acid translation (cytb) or an inferred percid secondary structure (12S).

Molecular dynamics of each gene were analyzed in

order to estimate phylogenetic relations. Maximum parsimony (MP unweighted and weighted) maximum likelihood (ML), and Bayesian (BAY) analyses were conducted using PAUP\*4.0b10 (Swofford 1998) and MrBayes 2.01 (Huelsenbeck 2000). Details of inference methods are available upon request from the authors. ML and BAY model choice was determined using ModelTest 3.06 (Posada and Crandall 1998). Branch confidence was assessed via bootstrap support values (MP and ML) and posterior probabilities (BAY). Outgroup taxa included representatives of five additional percid (non-darter) genera (Table 1).

**Table 1. Percidae species sampled.**

<i>Ammocrypta beani</i>	<i>Ammocrypta pellucida</i>
<i>Crystallaria asprella</i>	<i>Etheostoma burri</i>
<i>Etheostoma caeruleum</i>	<i>Etheostoma asprigene</i>
<i>Etheostoma tuscumbia</i>	<i>Etheostoma coosae</i>
<i>Etheostoma oophylax</i>	<i>Etheostoma nigrum</i>
<i>Etheostoma vitreum</i>	<i>Etheostoma smithi</i>
<i>Etheostoma kennicotti</i>	<i>Etheostoma blennioides</i>
<i>Etheostoma rafinesquei</i>	<i>Etheostoma gracile</i>
<i>Etheostoma edwini</i>	<i>Etheostoma parvipinne</i>
<i>Etheostoma chlorosoma</i>	<i>Etheostoma stigmaeum</i>
<i>Etheostoma sagitta</i>	<i>Etheostoma variatum</i>
<i>Etheostoma spectabile</i>	<i>Etheostoma punctulatum</i>
<i>Etheostoma proeliare</i>	<i>Etheostoma cinereum</i>
<i>Etheostoma bellum</i>	<i>Etheostoma camurum</i>
<i>Etheostoma aquali</i>	<i>Etheostoma rufilineatum</i>
<i>Percina phoxocephala</i>	<i>Percina oxyrhyncha</i>
<i>Percina maculata</i>	<i>Percina nigrofasciata</i>
<i>Percina ouachitae</i>	<i>Percina copelandi</i>
<i>Percina evides</i>	<i>Percina stictogaster</i>
<i>Percina aurantiaca</i>	<i>Percina macrocephala</i>
<i>Percina caprodes</i>	<i>Gymnocephalus baloni</i>
<i>Sander canadensis</i>	<i>Perca flavescens</i>
<i>Zingel zingel</i>	<i>Romanichthys valsanicola</i>

**Results.** The combination of cytb and 12S yielded 900 variable characters (12S:341, cytb:559) and 639 parsimony informative sites (12S:202, cytb:437). Significant saturation was observed in cytb third codon transitions. We therefore used weighted MP (third codon transitions weighted one-tenth all other substitutions) to account for the apparent saturation. Phylogenetic relations among North American darter taxa sampled in this study are shown in Figure 1. ML, weighted MP, and BAY reported similar topologies but differing levels of nodal support. Numerous stable relationships were consistently resolved and supported. Etheostomatinae is monophyletic with high support values but genus-level relations are ambiguous as shown by the lack of nodal support.

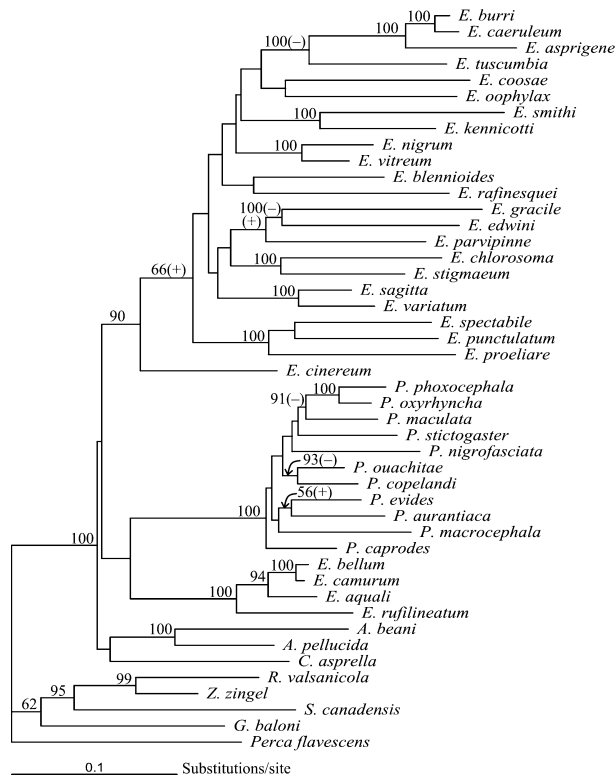


Figure 1. Maximum likelihood recovered phylogram with ML bootstrap values. (+) indicates nodes with higher support (>10%) in weighted parsimony and (-) indicates nodes with lower support.

In the present study, a well-resolved *Nothonotus* failed to resolve with other *Etheostoma* taxa rendering the genus, as currently constructed, paraphyletic. All remaining *Etheostoma* taxa formed a well-supported, monophyletic clade with *E. cinereum* basal within the clade. The two remaining polytypic genera, *Percina* and *Ammocrypta*, were consistently resolved as monophyletic with high support.

Several intrageneric *Etheostoma* relationships were consistently resolved including a partial *Oligocephalus* clade of ((*E. burri*, *E. caeruleum*) *E. asprigene*). The other *Oligocephalus* species (*E. spectabile*) consistently resolved as part of a highly supported three-taxon clade with *E. punctulatum* and *E. proeliare*. The *Catanotus* species *E. smithi* (*E. virgatum* group) and *E. kennicotti* (*E. flabellare* group) were consistently recovered as sister taxa. However, the third included *Catanotus* member (*E. oophylax*; *E. squamiceps* group) failed to resolve with the other members of the subgenus but with low intervening nodal support. *Etheostoma cinereum* consistently resolved basal to all non-*Nothonotus* *Etheostoma* species.

The *Percina* subgenus *Swainia* (*P. phoxocephala* and *P. oxyrhyncha*) was resolved and supported in all analyses. Consistent with the findings of Near (2002), a monophyletic *Alvordius* (*P. maculata* and *P. macrocephala*) was never recovered.

**Discussion.** The combination of *cytb* and 12S data appeared to be informative in addressing several phylogenetic issues within Etheostomatinae including

questions of monophyly/validity for each of the four proposed genera of darters. In terms of genus validity, the only non-resolved issue centers on *Etheostoma*; particularly in regards to the phylogenetic affinity of *Nothonotus*. Song et al. (1998) failed to resolve a monophyletic *Etheostoma* using *cytb* with *E. cinereum* and *E. (Nothonotus) camurum* resolving outside a clade of seven *Etheostoma* species. Likewise, the mtDNA dataset herein failed to resolve *Nothonotus* within a monophyletic *Etheostoma* despite increased taxonomic sampling and number of variable characters over that of Song et al. (1998). The lack of support and relative branch lengths on all intervening nodes suggests rate variation and/or lineage sorting of the mtDNA locus could account for this pattern. Future investigations attempting to elucidate the phylogenetic placement of *Nothonotus* are needed.

Phylogenetic relations among the darter species included in this study were consistent with the previous mtDNA studies of Turner (1997) and Near (2002). The recovery of stable darter relationships are undoubtedly complicated by the large diversity within Etheostomatinae, highly divergent rates of molecular and morphological evolution, and a rapid evolutionary radiation of darter species.

**Acknowledgements.** This work was supported in part by SIUC-ORDA funding and the Fisheries and Illinois Aquaculture Center-SIUC. Samples were provided by Rob Wood (SLU), Michael Hardman (UIUC), Bernie Kuhajda (UAIC), Kate Shaw (UK), Petr Ráb (Czech Republic), and Ed Heist (SIUC). Comments on earlier manuscripts were provided by Greg Moyer and Ryan Frankkowiak. We appreciate the assistance and guidance of Brooks Burr throughout this research.

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## ECOLOGY

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**Pikeperch (*Sander lucioperca*) stocks and fisheries in German southern Baltic lagoons**

*Helmut M. Winkler and Joachim Gröger*

## WALLEYE (*Stizostedion vitreum*) IN BRITISH COLUMBIA: AN EXAMPLE OF HIGH PRODUCTION IN AN INVERTEBRATE-BASED PREY SYSTEM IN THE PEACE REGION

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**Introduction.** Walleye populations in British Columbia (B.C.) represent the western-most limits of the distribution for this species (Scott and Crossman, 1973). Walleye are only native to north-eastern BC within the Peace and Liard river systems, and represent a relatively small component of the diverse provincial fish fauna. Recently, walleye stocked into Lake Roosevelt, Washington, invaded BC waters via the Columbia and Kettle Rivers (MacPhail and Carveth, 1992).

The majority of walleye populations in B.C. are found in rivers of the Peace and Liard watersheds. The only native lacustrine populations in B.C. are found in Maxhamish and Klua lakes (Hopcraft 1993). Walleye have been successfully stocked in Charlie, and Swan lakes, and unsuccessfully into North Cameron lake.

This paper, having provided an overview of the limited walleye distribution in BC, will focus on Charlie Lake. In addition to having the most walleye data available, Charlie Lake is an interesting and unique system. Located 8 kilometres north of Fort St. John, B.C., along the Alaska Highway, it has an unconventional fish stocking history, extremely high nutrient loads, atypical prey composition and a variety of anthropogenic stressors. Despite these conditions, Charlie Lake is an extremely productive walleye system, and it supports angling yields and recreational hours which surpass many others from more southern locales with typical fish communities.

**Methods.** Data for the Peace Region overview came mostly from syntheses by Hopcraft (1993) and Woods Env. Cons. (2003). Information on Charlie Lake walleye came from a number of internal reports and raw data files spanning the time period between 1984 and 1997. During this time period there were 8 creel, 5 index and 3 seine net surveys, plus various other minor sampling events. Creel data was collected from stratified, access point surveys mostly between May and September, and 2 winter surveys. Gill nets were used for intensive index surveys. Ten sites were chosen, representing a diversity of habitats in Charlie Lake. Standard gillnets 2.4 x 91.4 m. with 6 panels ranging from 25.4 to 76.2 mm. mesh size were used. Seining was done at 5 sites with 1.2 x 7.6 m. nets, with 6.4 mm. mesh. Age and length data was collected for all fish that were sampled.

Creel data provided estimates of catch, effort and yield. To show the combined effect of effort and

strong year classes on yield, we calculated an effort-year class index. This index is calculated by multiplying the standardized effort (setting the highest value to 1) by the mean age of the catch.

Fecundity and maturity data came mostly from winter creel surveys, with additional data from creel and index sampling. Although there was sufficient data to estimate fecundity, estimates of maturity rates and mean age to maturity are less reliable because of small sample sizes by age and sex.

Data on food and prey of walleye came from all sampling methods, during the period of 1984 to 1992. Stomach contents were analyzed and reported by general prey group. Here we report the proportion of the sample with various prey items.

**Results.** Longevity of walleye in Charlie Lake is consistent with other populations, 15 to 20 years, however, they do exhibit lower growth rates, early stunting and smaller asymptotic size than what is commonly reported in the literature (Figure 1).

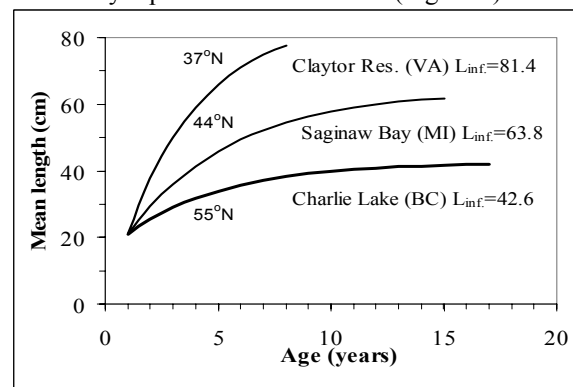


Figure 1. Growth rates of Charlie Lake walleye compared to other, faster-growing populations. (Colby et. al. 1979). Asymptotic size and latitude also shown.

Angling yields and catch rates for walleye in Charlie Lake are high, by any standard. Over a period of 6 years, CUE and yield estimates averaged 0.9 fish/hour and 5.5 kg/ha/yr, respectively (Figure 2). The effort-year class index appears to correlate well with fluctuations in yield estimates (Figure 2). Estimates of effort average 20 rod-hours/ha annually, well above the value of 10, which has been reported by Baccante and Colby (1991) as the point at which fishing quality declines significantly in less productive lakes of northern Ontario.

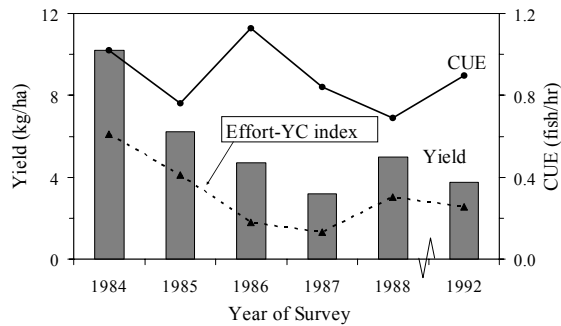


Figure 2. Annual angling yield(kg/ha), catch-per-unit effort (fish/hr) and effort-year class index (no units, same scale as yield) for Charlie Lake walleye, for the period 1984 to 1992.

Stomach content analysis for a sample of 2187 walleye, indicates that, other than empty stomachs, non-fish prey makes up the greatest percentage of occurrence in the sample (Figure 3). The high proportion of empty stomachs could also likely be due to faster digestion and evacuation rates for invertebrate food items, as opposed to fish prey.

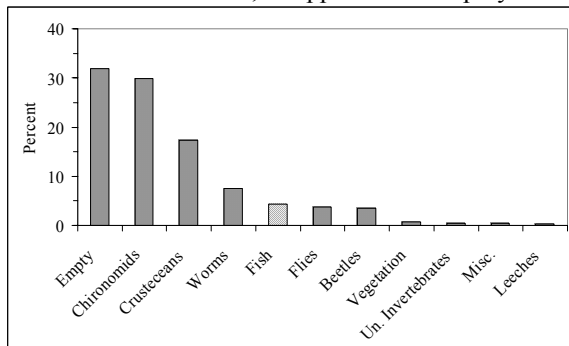


Figure 3. Proportion of a sample of 2187 walleye stomach contents by prey category.

The fecundity of Charlie Lake walleye is well within the range of similar populations, when degree days  $>5^{\circ}\text{C}$  are considered (Figure 4).

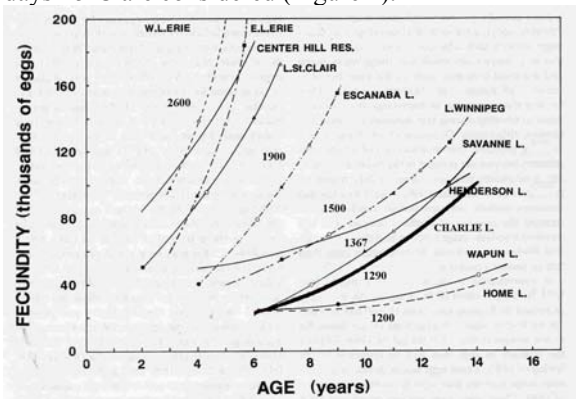


Figure 4. Comparison between Charlie Lake walleye and other populations. Degree-days  $>5^{\circ}\text{C}$  also shown. Additional data from Baccante and Reid (1988).

**Discussion.** Walleye, and a number of other fish species, were introduced in Charlie Lake during the late 1950's, and have since naturalized. Despite the lack of suitable fish prey, the population has flourished, as adult walleye in this lake have efficiently adapted to utilizing planktonic and benthic invertebrates, both abundant in this very eutrophic system.

Lower growth rates and smaller asymptotic sizes are likely due to the relative lack of fish prey in the walleye's diet. Kelso (1972) reported assimilation efficiencies (ratio of weight of food assimilated to weight of food ingested) significantly lower for invertebrates than fish prey.

Charlie Lake supports angling yields and catch rates which consistently exceed expectations based on estimates from current models. This raises an interesting question: can planktivorous and benthivorous walleye populations support higher yields than piscivorous ones?

**Acknowledgements.** We like to thank the numerous people who have contributed to this synthesis through their efforts in the field and data analysis. In particular Ted Euchner and Jay Hammond, former BC Government employees, without whom, most of this valuable data would not exist.

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## QUANTITATIVE ASPECTS OF PERCIDS ECOLOGY: AN OVERVIEW OF RUSSIAN STUDIES.

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**Introduction.** Among percid fishes inhabiting inland water bodies of the former USSR three species are the most abundant and widespread – zander *Sander lucioperca*, European perch *Perca fluviatilis*, and ruffe *Gymnocephalus cernuus*. In Russian scientific publications one can find a great amount of data on their biology and life history. However, there is a surprising lack of studies directed to the data synthesis and interpretation from the general ecological positions. Such studies are needed for better understanding of how complex biological systems like populations and communities function. Below, I give a brief review of Russian key works in the field of percids population dynamics and their role and place in freshwater ecosystems.

**Percids population dynamics.** Perhaps, the most comprehensive model of zander population dynamics among Russian studies is that developed by Kazansky & Koval (1980). It takes into account a variety of factors including environmental conditions, trophic interactions, and fishery operations. The model is intended for zander fishery optimization in Tsymbalsk Reservoir with an emphasis on predator-prey interactions between zander and blue bream, *Abramis ballerus*. The model uses energy units as a currency and traces the consumption of blue bream by zander via weight-at-age description of food requirements. It is assumed that zander are able to feed on other prey as well, among them sprat, gobies, yearlings of different fish species, and benthos, although their biomass is not subdivided into age-groups and given instead as lump quantities. Simulation experiments indicate that inter-annual fluctuations of the zander stock size are caused primarily by changes in recruitment abundance. The recruitment itself is shown to depend on water temperature and water level in May and on drainage area. Kazansky & Koval found out that the largest part of zander annual production (86%) is formed due to consumption of small non-commercial fishes, mainly sprat and gobies. Trophic interactions with other commercial fish species do not have a significant influence on the dynamics of zander population.

While studies on population dynamics of zander are motivated mainly by its commercial value, the interest in dynamics of perch populations stems from its ecological features. Among them two are of great importance. The first is perch ability to occupy different feeding niches consuming plankton, benthos, or being a predator. The second is its indifference to spawning substrate, which makes spawning highly efficient. As a result, perch can be found practically in all boreal water bodies, except anoxic lakes. In many small lakes perch form a single-species fish community, where different size classes function as its different elements.

In single-species perch communities an unusual age composition is sometimes observed – age-group 1+ is almost absent while the relative abundance of

age-group 3+ is extremely high. Menshutkin & Zhakov (1964) have surmised that such a peculiar age distribution could not be stationary and designed a mathematical model that explains the phenomenon. It is based on data obtained in Lake Tulenye (Karelia) by direct counting of perch stock exterminated by applying chemical poison and assumes cannibalism to be a principal feedback mechanism in perch population dynamics. The population trajectory in the phase space is represented by stable limit cycle with the period about 6-8 years. Within the cycle the transition in age distribution occurs, from typical exponentially declining one at low population density to bimodal at high density and back again to exponential. Recruitment is shown to be dependent on planktonic food availability. The latter circumstance imparts great importance to the problem of fry mortality sources. Since there can be two of them (cannibalism and starvation), Menshutkin (1971) used another simulation model to examine their relative significance. The model is size-structured and is built on data from Lake Razdelnoye which is populated by perch only. It couples the dynamics of perch 0-group and zooplankton. The simulations demonstrate that at high density perch fry can deplete their food resource inducing their own mortality due to starvation. After the radical drop in numbers of perch 0-group, zooplankton population recovers. So, food availability appears to be the crucial factor of recruitment formation.

Population dynamics of ruffe attracts much lesser attention because of its low commercial value. Published studies deal mainly with particular aspects of ruffe life history such as growth, longevity, or feeding habits. Data on ruffe stock status or potential for commercial exploitation are limited by catch statistics or fragmentary information on some population parameters. A rare exclusion is the study by Ruzhin & Pavlova (1990) who attempted to use multivariable correlation and regression analyses for predicting percid catches in two water bodies. They assumed that, because of diversified relations within a fish community, the catch of the certain species can be predicted using information on other species catches, and found out that ruffe catches in Gulf of Finland positively correlate with lamprey catches while those in the Ladoga negatively correlate with bream catches. Abiotic factors affecting ruffe catches appear to be water temperature in May (for Lake Ladoga) and water discharges in May and June (for Gulf of Finland). The weak point of the study is a postulate of catch statistics to be an adequate reflection of stock size, which may not always be true.

**Role of percids in aquatic communities and ecosystems succession and functioning.** Attempts to comprehend the functions of percids on a systemic basis are not many in Russian scientific literature. Zhakov (1984) compared the fish species composition in 248 lakes in the Vologda Region (northwest-

ern Russia). He pointed out that the most frequent are lakes with single-species and five-species fish community. Moreover, among the latter ones the majority (66%) contains the same species, namely perch, pike, roach, burbot, and ruffe. Perch is highly adaptive species that can occupy any one of the three niches, feeding on plankton, benthos or fish. The regulatory role, which is executed by cannibalism in single-species perch communities, is transferred in five-species ones to pike and burbot. These predators have different seasonal cycle of activity and spawning substrate requirements, thus being well co-adapted. Roach, feeding primarily on detritus, periphyton and macrophytes, finds its own niche and avoids competition with other species. Finally, ruffe consumes a broad spectrum of benthic organisms and so is able to live in lakes with scarcely developed benthic fauna. The species mentioned form the dominant component of fish communities in boreal lakes. Broadening of species composition is related mainly with water bodies increase in area and in more intensive hydrodynamics. As a result, diverse biotopes emerge which might be inhabited by fishes with more narrow ecological preferences (Zhakov 1984).

Using these data as a starting point, Zhakov (1984) developed an age-structured simulation model of a community composed of 7 fish species (perch, pike, crucian carp, burbot, roach, bream, and ruffe). Different sets of the model parameters correspond to different trophic statuses of a lake. As the simulation results show, the succession process is accompanied by distinct changes in the community structure. When the lake becomes eutrophic, fish productivity increases approximately 1.5 times, mainly through the increase in roach and crucian carp biomass. At the later stages of the succession some species start to disappear from the community, first of them burbot and bream. In acidified environment what remains of the community is only perch and roach.

Complex nature of trophic relationships becomes even more evident when the impact of fishing is introduced into the model. For example, imposing strong fishing pressure on predators as a measure of fish productivity enhancement actually brings about an opposite result – the share of commercially valuable bream in the catches is diminished while the bulk of the catch (70%) turns out to be comprised by roach and perch.

One of the water bodies where system-oriented investigations seem to proceed fairly enough is Lake Syam (Karelia). Ecological processes in the lake have been monitored for 60 years by now, and the data collected have allowed to clarify many questions concerning the ecosystem succession, changes in aquatic community structure, and fisheries optimization. Recently, Kriksunov et al. (2001) designed a steady-state trophic model of the lake ecosystem using ECOPATH IV software. The model takes into account trophic relationships between 17 groups of organisms. One of the model outputs is a matrix of impact coefficients which are the measure of influence exerted by each trophic group on biomass of other groups (Fig. 1).

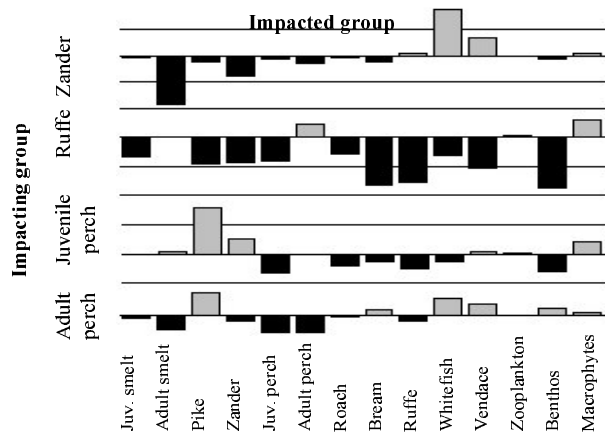


Figure 1. Percid fishes impact on the components of Lake Syam community.

The analysis shows that among percid fishes ruffe is the only species that influences negatively almost all other fishes. Predators (adult perch and zander) play an important role restraining the population growth of smelt, the species that invaded the lake in late 1960s and now forms about 60% of total fish biomass. That leads to their positive influence on the populations of whitefish and vendace, the most valuable species from the fisheries point of view. This conclusion corresponds well with the results obtained by Ladanov (1990) who constructed a matter flow model for the fish community of Lake Belye (the Vologda Region). In his model the presence of predators (pike and zander) turns out to be a beneficial factor for the bream population due to suppression of its competitors for food, first of all ruffe.

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## PERCIDS AS INVADERS IN RUSSIA: A REVIEW

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**Introduction.** Fresh waters of Russia are inhabited by four percid fishes. Two of them are commercially important and two others are game or course species. As a result of intentional introductions, channel and dam construction, overfishing and other kinds of human activities, ranges of percid species altered. The main goals of this review were to update ranges of percids in Russia and adjacent countries, to describe patterns and consequences of percids' invasions, and assess vulnerability of communities to these invasions.

**Methods.** This review is based on the database of about 80 Russian invasive fishes including all available published data since 1763 and unpublished materials on intentional introductions from correspondent institutions. Field observations of fish distribution and assemblages composition in Karelia, and the Volga River basin were also used. Status of reservoir and lake populations of percids was estimated on the basis of long-term studies of downstream fish migrations carried out in the Severtsov Institute of Ecology and Evolution headed by D.S.Pavlov (see Pavlov et al., 1999).

**Results.** The natural ranges of four percid species widening and invading new waters within their ranges during the last 50 years were analyzed.

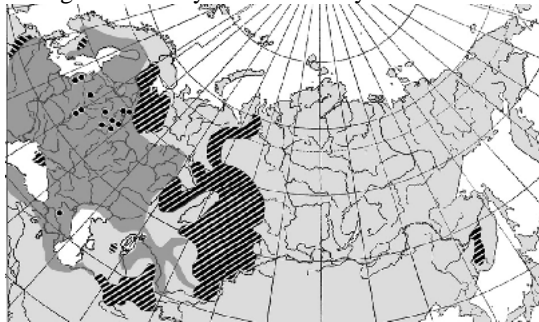


Figure 1. Geographical distribution of the pikeperch (*Stizostedion lucioperca*) in the former USSR. Grey area shows the natural range; striped area, the invasive range; black spots, sites of introduction.

There are two different patterns of percids' invasions in the fresh waters of Russia and adjacent countries. Pikeperch (*S. lucioperca*) and perch (*Perca fluviatilis*) were intentionally introduced, and then spontaneously spreading to new water bodies. Range expansions of Ruffe (*Gymnocephalus cernuus*) and Volga pikeperch (*Stizostedion volgensis*) were connected with accidental introductions.

The invasions of the first type were usually successful. Both pikeperch and perch established

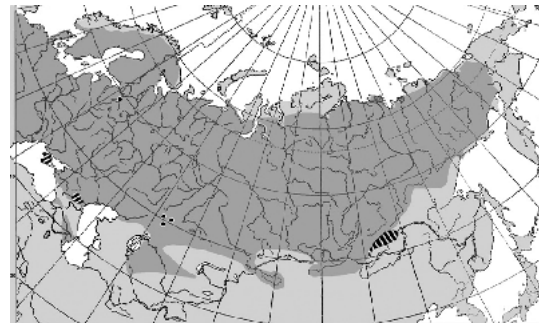


Figure 2. Geographical distribution of the perch (*Perca fluviatilis*) in the former USSR. Denotations as in Figure 1.

many new populations and expanded their ranges to the east of Russia (Figures 1,2). Consequences of the invasion of perch for ecosystems and fishery are usually insignificant or unknown.

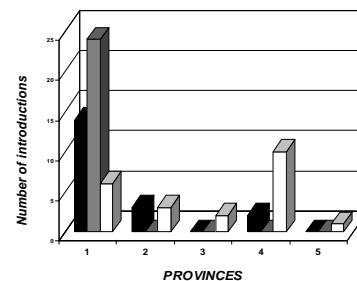


Figure 3. Results of pikeperch introduction to different zoogeographic provinces: 1 – Baltic, 2 – Ponto-Caspian, 3 – Balkhash, 4 – Arctic Ocean, 5 – Amur. Results: unknown – dark, negative – grey, naturalization - white bars.

Well documented intentional introductions of pikeperch within the limits of its natural range demonstrated negative results in the Baltic and Ponto-Caspian provinces (Figure 3). At the same time, pikeperch introduction to the Amur province with extremely rich fish fauna (more than 120 species) was successful.

The situation with introduced pikeperch populations is variable because of fishery and other kinds of human activities. In some new sites pikeperch forms an important part of total fish production. For example, in Vozhe Lake (White Sea basin) pikeperch naturalized and became an important component of the lake ecosystem; no strong competition with aboriginal species was observed (Bolotova et al., 1995). However, in some places (in Balkhash province, for instance) pikeperch suppresses aboriginal species including rare and endangered

endemic fishes like *Schizothorax argentatus*, *Perca schrenki* and Asiatic stone loaches. The main limiting factor of pikeperch populations in reservoirs is mass kill of young fish during down-stream migration. In some reservoirs it exceeds several billion individuals a year.

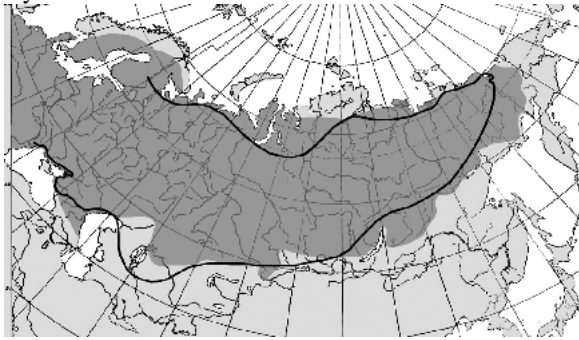


Figure 4. Geographical distribution of the ruffe (*Gymnocephalus cernuus*) within the former USSR. Grey area shows the natural range; solid line shows the former range after L. Berg (1949).

Recent status and trends with ruffe and Volga pikeperch populations may be connected with climate change and human activities.

It seems that the larger present range of ruffe as compared to the range given more than 50 years ago by Berg (1949) is not only the result of better and more numerous recent records. The ruffe widely spread in Western Europe and penetrated to American Great Lakes. In Siberian waters the increase of ruffe abundance was observed during the last decade. Probably, ruffe expansion to the East was due to natural factors. Ruffe have a variety of traits, which allow them to perform successfully in a broad variety of ecological situations and to adapt to fluctuations in both biotic and abiotic factors (Popova, *et al.*, 1998). On the opposite, in many water bodies of the western part of Russia ruffe abundance declines now, probably due to low oxygen concentration, eutrophication and pollution (Lehtonen *et al.*, 1998).

Volga pikeperch abundance decreases because of dam constructions in the greater part of the natural range (Volga River) and increases in the site of invasion (Kuban' River) (Figure 5).

**Discussion.** This review demonstrates significant expansion of percids within Russia and adjacent countries during the last 50 years. The main reasons of percids invasions were intentional and accidental introductions and anthropogenic impact on aboriginal ecosystems. Invasive percids can either destroy aboriginal fish assemblages or stabilize the whole ecosystem. Vulnerability of the communities to percids' invasions depends on the presence of vacant niches, rate of disturbance of aboriginal ecosystems, human impact on invaders (especially in man-made

lakes), and does not depend on aboriginal fish fauna richness.

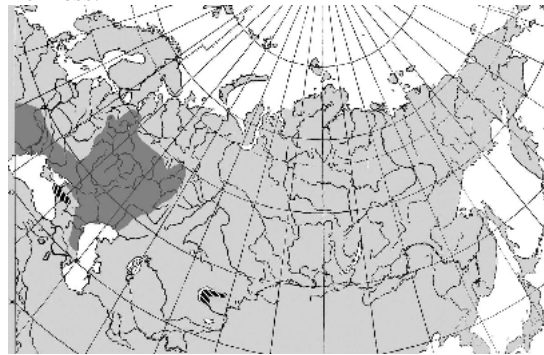


Figure 5. Geographical distribution of the Volga pikeperch (*Stizostedion volgense*) in the former USSR. Grey area shows the natural range; striped area, the invasive range.

The management of established percids populations involves balanced fishery and water flow regulation in reservoirs. More research is needed to elucidate percids' invasions impacts on native ecosystems.

**Acknowledgements.** The study was supported by the Russian Foundation for Basic Research (projects 03-04-49147 and 03-04-48329). I am indebted to Dr. V. Yu. Maslyakov (Inst. of Quarantine, Russia) for his help with database. I also thank Dr. V. N. Mikheev (Severtsov Inst. of Ecology and Evolution, Russian Ac. Sci.) and Dr. S. S. Alekseyev (Koltsov Inst. of Developmental Biology, Russian Ac. Sci.) for helpful comments, including language improvements.

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## SIZE-DEPENDENT PREDATION ON JUVENILE FISH BY PERCH AND PIKEPERCH IN RELATION TO PREY FISH AVAILABILITY

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**Introduction.** Together with one or two other fish species perch *Perca fluviatilis* L. and pikeperch *Sander lucioperca* (L.) constitute the piscivorous fish community in many European temperate lakes. Both species can be very important in controlling the juvenile fish abundance (Dörner et al., 1999) and thus play a vital role in structuring the fish community. The present study focuses on predator-prey relationships between perch, pikeperch and four prey fish species, namely perch, pikeperch, ruffe *Gymnocephalus cernuus* (L.) and roach *Rutilus rutilus* (L.). Data were obtained from the long-term biomanipulated Bautzen Reservoir, Germany. The present paper focuses on the relationship between predator and prey lengths.

**Methods.** Bautzen Reservoir (51° 13' N; 14° 27' E) is situated c. 70 km north east of Dresden, Germany. The reservoir receives high phosphorus loading from the inflow (c. 3.5 g TP m<sup>2</sup> surface area year<sup>-1</sup> in 1997). Biomanipulation of the reservoir started in 1977 (Benndorf et al., 1988). The enhancement of the piscivorous fish stock by stocking in combination with catch restrictions, led to a top-down control of the food web. Consequently, the proportion of piscivores in the total adult fish biomass increased. The fish stock is not dominated by cyprinids, but by percids. Age-0 perch is the dominating planktivore.

Fish were sampled regularly in 1995, 1997 and 1998 using gillnet series (6-100 mm mesh size, 2-4 h, deep and shallow areas, April-Nov., all years), trawls (predatory fish: 10 mm mesh size, 3 hauls per area, sampling speed 1.2 m s<sup>-1</sup>; age-0 fish: 4 mm mesh size, 2 hauls per area, sampling speed 1.4 m s<sup>-1</sup>; May-Aug. 1997/98) and beach seine (May-Aug. 1997/98). Fish were killed immediately after capture and measured for total length ( $L_T$ ) to the nearest 1 mm. Stomach contents were analysed by counting and measuring prey fishes under binocular and compound microscope.

**Results.** Predatory perch age=1 year ranged from 77 to 368 mm  $L_T$  and pikeperch from 70 to 776  $L_T$  (Figure 1). Perch prey fish ranged from 12 to 114 mm  $L_T$  for perch, 17 to 135 mm for pikeperch, 17 to 125 mm  $L_T$  for ruffe and 20 to 118 mm for roach. Pikeperch prey fish ranged from 18 to 202 mm  $L_T$  for perch, 24 to 220 mm for pikeperch, 12 to 165 mm for ruffe and 31 to 215 mm for roach.

Generally, mean prey  $L_T$  of all prey species increased during ontogeny and predator  $L_T$  and mean  $L_T$  of prey fishes were positively and linearly related (Figure 1). Similarly-sized pikeperch fed in

average on larger prey fishes than perch, with the exception of pikeperch of all sizes fed strongly on age-0 perch (Figure 1 a). The proportion of age-0 fishes within the fish community as estimated from the total catch (abundance) from all gillnets and year-class strengths of age-1 roach and perch varied in the 3 years investigated (Table 1).

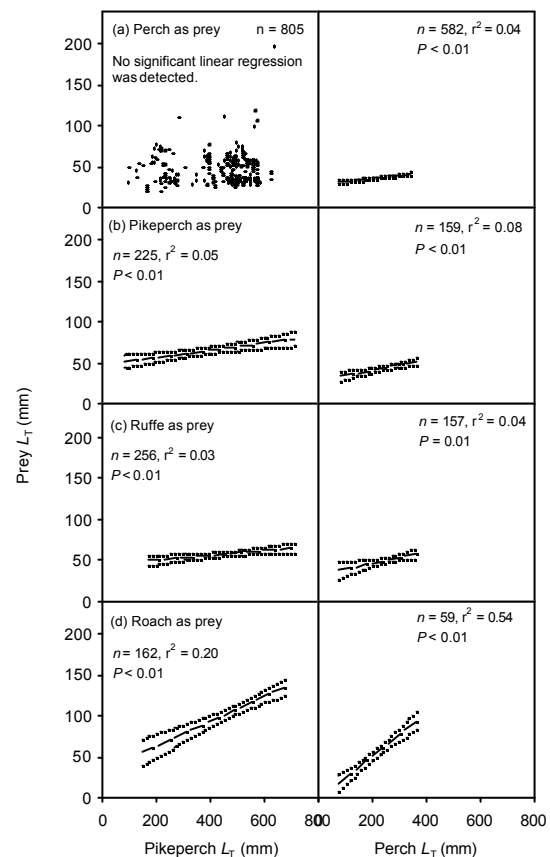


Figure 1. Linear regressions and 95% CI between predator and prey  $L_T$ . The slopes of the regressions were significantly different (ANCOVA, (b):  $F_{4,303} = 6.20$ ,  $P=0.01$ ; (c):  $F_{14,107} = 19.41$ ,  $P<0.01$ ; (d):  $F_{5,410} = 4.78$ ,  $P=0.03$ ). Data for perch [(a), (b) and (d)] were taken from Dörner & Wagner (2003).

**Discussion.** In the present study, size-dependent relationships between perch, pikeperch and their prey fish species in the Bautzen Reservoir were observed. The average prey  $L_T$  of all prey species increased with increasing predator size. But the increase in average sizes of perch, pikeperch and ruffe as prey was less than that of roach. This may be due to three factors: food supply (e.g. the densities, size distribution and habitat use of

different prey species), gape morphology and size-selective feeding of perch and pikeperch.

Summarizing all three years investigated, the age-0 fish abundance was dominated by perch followed by pikeperch, roach and ruffe. Mean sizes of perch prey fishes observed in this study agree well with the mean prey sizes of perch and pikeperch reviewed by Mittelbach & Persson (1998). The authors stated that the fact that piscivorous perch, on average, capture smaller prey than other piscivore species such as pikeperch appears not to be due to size-specific differences in feeding capacity, but rather to differences in the average sizes achieved by the different piscivores in nature. Since mean prey size for pikeperch was significantly bigger than for perch, even though similar-sized pikeperch had smaller gape width (H. Dörner et al., in prep.), a new factor, namely differences in feeding capacity related to existence or non-existence of tusks, could explain the feeding patterns observed in the present study.

Table 1. Proportions of juvenile fish of the total fish stock as based on average CPUE (ind. (100 m<sup>2</sup> net)<sup>-1</sup> hour<sup>-1</sup>). +, o, -: strong, moderate and weak. Data are combined from Kahl *et al.* (2001), Dörner (2002) and Dörner and Wagner (2003).

Prey fish group	1995	1997	1998
Age-0 perch	0.4	29.1	66.9
Age-0 zander	0.6	15.8	1.5
Age-0 ruffe	1.3	6.5	2.9
Age-0 roach	1.3	1.1	12.8
Age=1 ruffe	0.5	1.5	1.5
Age-1 roach	+	o	-
Age-1 perch	+	-	+

In general, mean  $L_T$  of age-0 perch and pikeperch consumed by perch and pikeperch in Bautzen Reservoir are significantly smaller than their cohorts in the lake (Dörner et al., 1999). This might be because small fishes are easier prey than larger fishes because they move proportionally slower. According to Claessen et al. (2002), with a low threshold of the predation 'window', cannibalism should regulate recruitment, resulting in coexistence of many year classes. Minimum and mean sizes of prey fishes observed in the present study were low, indicating a predation-driven type of population dynamics. This is corroborated by the findings of previous studies on perch and pikeperch in the Bautzen Reservoir where it was found that several year classes coexisted (Dörner, 2002), and perch and pikeperch became piscivorous very early in their life span. Pikeperch and age=1 perch fed size- and species-selectively on small perch and pikeperch and age-0 percid abundance was

controlled by predation. The minimum sizes of roach captured by perch and pikeperch were 19 and 31 mm  $L_T$ , also rather low, thus indicating a potential for controlling the age-0 roach cohorts by predation. The relatively strong age-0 roach cohort in 1998 (Table 1), however, was not reflected in the size distribution of roach captured by the perch and pikeperch. In contrast to age-0 perch and pikeperch as prey, no species- or size-selective predation on roach was detected (Dörner, 2002). This was primarily due to spatial separation of the age-0 cohorts of roach and predatory percids. Generally, age-0 roach predominantly use the littoral zones of lakes (Persson et al., 2000) and, therefore, age-1 year perch predominantly inhabiting the littoral zones have been described as the most important predators of age-0 roach in the Bautzen Reservoir (Dörner, 2002). After leaving the littoral zones at age-1, the importance of roach as prey for large (>400 mm  $L_T$ ) pikeperch increased, whereas the importance as prey resource for perch decreased.

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## PERSISTENCE OF UPPER GREAT LAKES WALLEYE (*Sander vitreus*) POPULATIONS IN RELATION TO RIVER FLOW

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**Introduction.** The largest walleye populations in the Great Lakes spawned in more than one location and inhabited large, warm, shallow environments such as the western basin of Lake Erie or Saginaw Bay, but smaller populations were associated with rivers that emptied into near-shore waters close to or bordering the deep basins. These more-isolated populations supported important fisheries, but most are less productive now than in the past and in some instances they are essentially extirpated. Habitat destruction, over-fishing, and introductions have been associated with these losses, but few of these populations were well studied and the exact causes of the depletions are poorly understood (Colby et al. 1991).

Although the historical abundances of many of the isolated-type river populations of walleyes in the Great Lakes were never documented, enough were studied that they can be aggregated as a data set. These populations are similar in that rivers were used for spawning and the larval environment was influenced by the near-shore waters of the deep basins. This similarity in life history among populations provides a means to identify landscape features that may explain why some walleye populations persisted while others did not.

Kitchell et al. (1977) proposed that *Sander* habitat in lakes represents an extension of temperate riverine environments and that the Achilles heel for this genus in large lakes would be their reproductive requirements. Their inferences reflect the idea that *Sander* likely evolved in large rivers, and systems with greater depths and surface areas would impose constraints, especially on conserved traits associated with early life history. My primary interest here is to investigate how one landscape feature, river size, correlates with persistence or non-persistence of upper Great Lakes walleye populations. I also advance a hypothesis regarding why river size would affect persistence of walleye populations.

**Methods.** I selected all of the non-embayment walleye populations from the upper Great Lakes whose histories were reasonably well documented in Colby et al. (1991). These populations were then sorted to those spawning in gauged rivers. I classified these populations as persistent or non-persistent based on Colby et al. (1991). This classification was a value judgment in that individual authors contributing to this volume were not asked to classify their subject populations based on predetermined criteria. Non-persistence as used here indicated low abundance and loss of the fishery without an ensuing partial or full recovery. Likewise, persistence indicated either at least moderate or low levels of abundance followed by some degree of recovery.

Mean daily flows for each river were compiled for the period of record for the entire month of June [<http://waterdata.usgs.gov> or from Ontario Surface Water Data Summary of 1989]. I selected June as the month that best approximates conditions relevant to larval walleyes in the upper lakes. Unpublished data (published data is scarce) indicates that walleye larvae were present in June 1994 in river mouths of Canadian Lake Superior streams (personal communication, J. Kelso, Dept. Fish. Oceans, retired) and in mid May 1990-91 in a northern Lake Michigan river mouth (personal communication, P. Schneeberger, Mich. Dept. Nat. Res.). This study requires only a coarse measure for sizing rivers so alternative measures of river size were not pursued.

**Results.** I identified 21 upper lakes walleye populations whose histories were documented in Colby et al. (1991). Only one of these populations, the Whitefish (located in northern Lake Michigan), did not spawn in a gauged river and was excluded from the analysis. Of the remaining 20 populations, I classified seven as persistent and 13 as non-persistent (Table 1).

Table 1. Walleye population status (P = persistent, NP = non-persistent) and mean June flow (m<sup>3</sup>/s) for the associated spawning river.

River	Great Lake	Walleye Status	June Flow
Bad	Sup	NP	18
Batchawana	Sup	NP	21
Bk. Sturgeon	Sup	NP	46
Goulais	Sup	NP	20
St. Louis	Sup	P	101
Nipigon	Sup	NP	358
Ontonagon	Sup	NP	15
Sturgeon	Sup	NP	12
Taquamenon	Sup	NP	26
Fox	Mich	P	153
Menominee	Mich	P	110
Muskegon	Mich	NP	56
French	Mich	P	157
Magnetawan	Hur	NP	30
Mississagi	Hur	P	146
Moon	Hur	P	11
Notawasaga	Hur	NP	4
Severn	Hur	NP	43
Shawanaga	Hur	NP	1
Spanish	Hur	P	146



The mean June flows for the 20 gauged rivers varied from 358 m<sup>3</sup>/s (Nipigon) to 1 m<sup>3</sup>/s (Shawanaga) (Table 1). All seven walleye populations classified as persistent, except for the Moon, were associated with rivers having June flows exceeding 100 m<sup>3</sup>/s. All 13 populations classified as non-persistent, except for the Nipigon, were associated with rivers having June flows less than 100 m<sup>3</sup>/s and typically less than 50 m<sup>3</sup>/s.

**Discussion.** The persistent walleye populations in this study, except for the Nipigon and Moon, were associated with larger (> 100 m<sup>3</sup>/s) rivers. The Nipigon population, though associated with the largest river in the data, was non-persistent, and the Moon was the only persistent population associated with a small river (11 m<sup>3</sup>/s). The Nipigon River is truly an outlier in the data set and could have been excluded to achieve conformity. It drains Lake Nipigon, the 22<sup>nd</sup> largest lake in the world. Although other rivers in the data set are impounded, none are so dominated by the outflow from an oligotrophic lake. The Moon River population appeared to be recovering in association with stocking near the time that Colby et al. (1991) was published, and to be consistent I classified it as persistent. The recovery, however, was short lived, and the spawning run was at a record low when last sampled in 1995 (personal communication, A. Liskauskas, Ontario Ministry of Natural Resources, Owen Sound).

Several hypotheses for the apparent association between river size and persistence of walleye populations are tenable. First, the larger rivers may have supported more-complex populations that were more resilient to perturbation. Second, the larger rivers may be especially attractive to emigrating walleyes that serve as replacements for those lost to perturbation. Third, and of particular interest here, the larger rivers may provide more thermal habitat for the larval life stage.

This hypothesis of a thermal constraint supposes that optimal temperatures for walleye-egg incubation and larval growth mirror the progression of the spring warming in the ancestral environment (large rivers) of *Sander* and that major deviations from this progression (as expected in the Great Lakes) diminish fitness. Delayed warming of near-shore waters would retard or halt larval growth thereby extending this precarious life stage. If the deep basins of the Great Lakes present a thermal bottleneck for recruitment of walleye larvae, the larger rivers may provide more favorable conditions for larval development in the form of expanded thermal refugia in the lower river and in the vicinity of river mouths.

The separation of persistent and non-persistent walleye populations at a June flow of ~ 100 m<sup>3</sup>/s likely exaggerates the utility of this statistic. A stream that discharges into a protected bay or that has a low gradient at the mouth would tend to provide more thermal habitat for descending walleye larvae than a similar-sized stream that quickly empties into open waters. For example, the Black Sturgeon River, Lake

Superior, empties into a long, narrow, shallow bay, which supported a reef-spawning stock (Ryder 1968), a trait which is otherwise rare in these waters.

The thermal-habitat-limitation hypothesis may explain why upper-lakes walleye stocks isolated from big, warm bays were all relatively small. The long-term commercial catch of walleyes in both Lakes Superior and Michigan approximated only 100 t/yr, and in the North Channel, the basin supporting the biggest river stocks in Lake Huron, yields rarely exceeded 90 t/yr. The inshore waters of the upper lakes likely could support many more juvenile and adult walleyes. Saginaw Bay, Lake Huron, for instance, supported the largest walleye population in the upper lakes (record catch of over 900 t), but juveniles and adults migrated out of the bay in summer (Van Oosten et al. 1946). This distribution indicates that advanced life stages of walleye were not dependent on the bay for feeding, but rather needed its spawning and/or nursery habitat. Spawning habitat should not be limiting outside of Saginaw Bay because numerous rivers and shoals are available in Lake Huron. What the bay provides, apparently, is spawning habitat proximate to large nursery habitats.

The thermal-habitat-limitation concept is intriguing, but it needs more testing before it can be viewed as a strong hypothesis. If river size is indeed important to population persistence, the problem can be approached by comparing inland and Great Lakes populations as regards the smallest rivers that they use for spawning. If walleyes commonly spawn in inland rivers that are much smaller than those having supported spawning runs in exposed regions of the Great Lakes, the existence of a thermal habitat constraint on the productivity of walleye populations in the Great Lakes becomes more attractive.

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# DIET OF PISCIVOROUS PERCH (*Perca fluviatilis* (L.)) IN LAKE HÖYTIÄINEN, EASTERN FINLAND, DURING A LOW-DENSITY STATE OF VENDACE (*Coregonus albula* (L.))

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**Introduction.** Lake Höytiäinen (area 293 km<sup>2</sup>, mean depth 11.8 m, maximum depth 56 m) is an oligotrophic lake in eastern Finland (Fig. 1). Vendace has traditionally been the most important target for commercial fishing. Large variation in year-class strength is typical for vendace stocks, but in Lake Höytiäinen there have been several prolonged vendace recessions. The density of perch population has increased in the 1990's, while the vendace stock has been sparse. A hypothesis has been presented that predation by perch can prevent the recovery of the vendace stock from a low-density state (Auvinen 1994, Helminen and Sarvala 1994, Valkeajärvi and Bagge 1995, Heikinheimo 2001). Intensive fishing of perch was started in 2001 to reduce the density of perch stock and predation pressure on vendace. The diet of perch was studied to find out the effect of perch on recruitment of vendace. In the end of 2002 the total catch of intensive fishing was 40 000 kg of which 81 % consisted of perch.

**Methods.** Our study area (154 km<sup>2</sup>) was the southern part of Lake Höytiäinen (Fig. 1). In this area the number of newly hatched vendace larvae was estimated using a stratified random sampling design (Karjalainen et al. 1998).

The diet sampling was conducted in summer 2001 in two different sampling areas (northern (1) and southern (2)) and in 2002 only in sampling area 1 (Fig. 1). The perch were caught in 2001 using gillnets (mesh sizes 12-35 mm from knot to knot) and in 2002 using fish traps. The sampling interval was 2 hours and the fishing was carried out twenty-four hours once a week in May - June. The water depths in the sampling areas 1 and 2 were 2-10 m and 2-15 m, respectively. Perch larger than 160 mm (total length) were sampled immediately after catching while the smaller were frozen and sampled later in the laboratory. Each fish was first measured for total length to the nearest millimetre and weighed to the nearest gram, and then the stomachs were removed and preserved in 70 % ethanol. The stomach fullness was estimated on a scale of 0-5 and stomach contents were analysed with stereo-microscope. The ingested zooplankton, invertebrates and fish were counted and measured. Sampled perch were divided into five size classes: <100 mm, 101-130 mm, 131-160 mm, 161-190 mm, >190 mm. The dataset included 582 perch in 2001 and 515 in 2002.

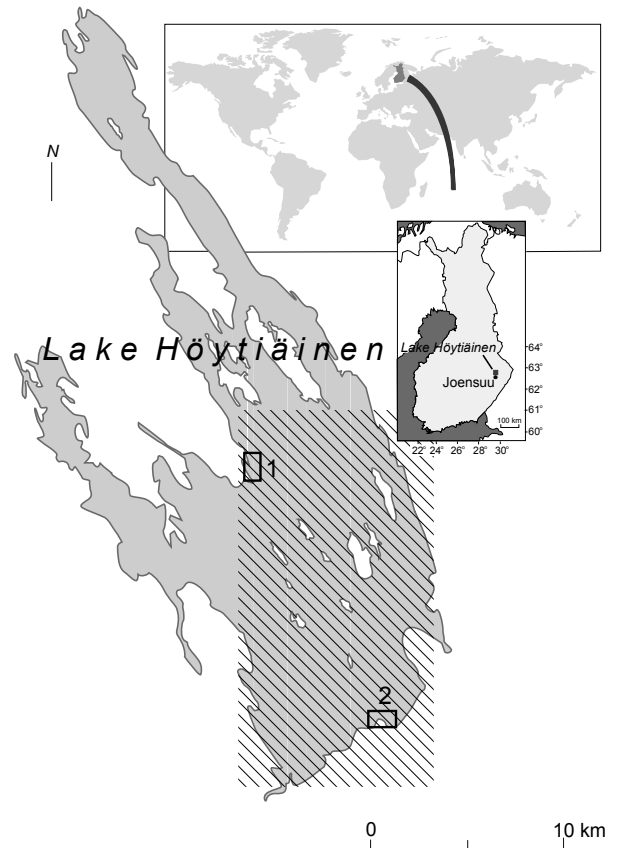


Figure 1. Location of Lake Höytiäinen. Study area and sampling areas 1 and 2 are indicated.

**Results.** In 2001 24% and in 2002 10% of perch were piscivorous. For the perch >161 mm fish was an important food item (Table 1). The smallest piscivorous perch was 82 mm.

Table 1. The proportion of piscivorous perch in different size classes in 2001 and 2002. 1 and 2 represent sampling areas.

Size class	2001		2002
	1	2	1
<100 mm	0%	0%	3%
101-130 mm	4%	4%	1%
131-160 mm	2%	9%	4%
161-190 mm	22%	23%	13%
>190 mm	58%	81%	80%

Perch, ruffe (*Gymnocephalus cernuus*), smelt (*Osmerus eperlanus*) and bullhead (*Cottus gobio*) were the most abundant fish species in the diets of perch in area 1 (Fig. 2). In area 2 vendace larvae and smelt were the most abundant food items. The vendace larvae were eaten by three perch individuals. In sampling area 1 none of the sampled perch had eaten vendace.

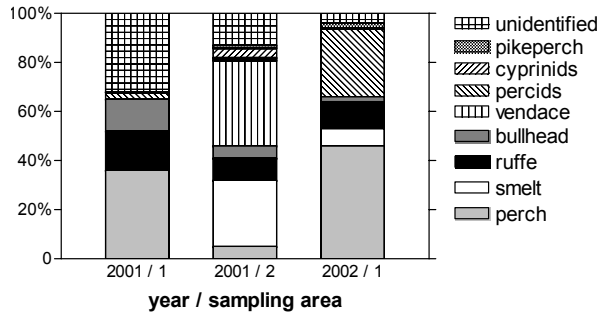


Figure 2. Proportion of fish (by numbers) eaten by perch.

According to larval sampling data collected from different depth zones in Lake Höytiäinen density of vendace larvae were very low or moderate in both sampling years (Table 2).

Table 2. Density of vendace larvae (ind./m<sup>3</sup>) in different depth zones in sampling areas 1 and 2.

depth zone	2001		2002
	1	2	1
0-0.5 m	0	0	0
0.5-1 m	8	1723	122
1-2 m	1	270	7
>2 m	2	120	5

**Discussion.** During a low-density state of vendace, vendace was not an important food item for perch. However, in area 2 where perch predation on vendace was only found, the densities of vendace larvae were clearly higher suggesting that perch can become a remarkable predator on vendace larvae when densities of larvae increase.

All vendace found in stomachs of perch were small larvae (9-10 mm), while the size of eaten perch and smelt ranged from 25 to 105 mm. Energy content of vendace larvae compared to perch or smelt was low and therefore the importance of vendace for perch was marginal.

Due to patchy distribution of vendace larvae and rough estimate of the perch population size in Lake Höytiäinen, it is difficult to estimate the magnitude of perch predation. However perch do not seem to play

a key role in preventing the recovery of vendace stock in Lake Höytiäinen.

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## PIKEPERCH IN FINNISH LAKES: INFORMATION GAINED FROM MAIL SURVEY

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**Introduction.** Pikeperch (*Sander lucioperca* (L.)) is among the most valuable fish species in commercial and recreational fishery in Finland. It occurs naturally in 650 lakes in southern and central Finland, and it has also been introduced to more than 1600 lakes during the recent years (Lappalainen and Tammi 1999). Typical for pikeperch stocks are large annual variations in year-class strengths and yields (Lappalainen 2001). Attempts to stabilize these variations by intensive stockings of 0+ pikeperch have been made, but with varying success (Ruuhijärvi et al. 1996, Sutela and Hyvärinen 2002).

A postal mail survey was accomplished to estimate the state of pikeperch stocks in Finnish lakes (Lappalainen and Malinen 2002). The survey aimed to clarify open questions such as the origin of pikeperch stocks (stocked or natural), number of stockings, fishing regulations in lakes with pikeperch, and the occurrence and abundance of other fish species. In the present study, the fish abundance data from the survey was related to lake specific environmental data using canonical correspondence analysis (CCA). Artificial neural network (ANN) analyses were used to study whether the abundance and occurrence of pikeperch in lakes, and the present state of the pikeperch stocks can be predicted based on other fish species abundance and lake-specific environmental data.

**Methods.** The postal survey was sent to 760 heads of the fishing associations in 1998. Because of incorrect connection in addresses between the heads of the fishing associations and the lakes, only 415 lakes were surveyed twice, and within these the overall return rate was 79%.

Fish abundance data with the 15 most common fish species in the studied lakes ( $n = 97$ ) was related to lake specific environmental data using CCA. The lake specific environmental data was achieved from The Finnish Environment Institute's database. Those lakes with more than 5 measurements of the environmental variables from surface layer ( $< 2$  m) were included to CCA-analysis. To reduce variance in environmental data only variables measured between July 10 and August 20 in 1990-1997 were used in CCA. In CCA, fish data were response variables and environmental data (lake surface area and depth, temperature, oxygen content and %, chlorophyll -a, turbidity, conductivity, pH, color, Secchi disk depth, latitude, COD) were explanatory variables. Of the environmental data, surface area,

lake depth, chlorophyll, turbidity, conductivity, color, and Secchi disk depth were  $\log(x+1)$ -transformed due to their skewed distributions. The significance of the CCA axes was assessed using Monte Carlo permutation test (99 unrestricted permutations) (McCune and Mefford 1999).

Two different data sets were analyzed using ANN (Goodman 1996): basic and test data. The basic data was the same as were used in the CCA (97 lakes, same log-transformations), and the test data was totally independent, i.e. data from different lakes. Prediction in basic data was based on cross-validation of 30% of the data temporarily held out randomly on 20 times, while in the test data the prediction performance was based on weights from basic data.

**Results.** In the CCA, the first two axes explained 22.3% of the total variance in fish abundance data, and the fish abundance – environmental correlations were significant ( $p = 0.01$ ) for both axes. Pikeperch was placed near other common fish species such as burbot, perch, pike, bleak, roach, bream, and ruffe (Figure 1). The pikeperch lakes were characterized by high turbidity, low Secchi disk depth, shallowness, and southern location.

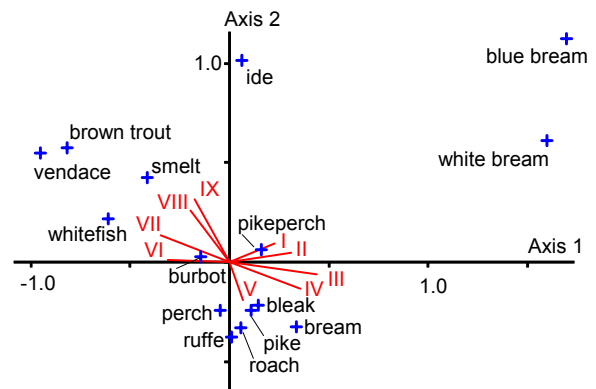


Figure 1. CCA ordination of 97 lakes. Vectors: I = pH, II = conductivity, III = turbidity, IV = chlorophyll, V = COD, VI = latitude, VII = Secchi disk depth, VIII = lake area, and IX = maximum lake depth. Lake markers are excluded, but these were situated evenly within both axes between -1.5 to 1.5.

The ANN analyses showed that the correct classification rates in the basic data were always higher than in the independent test data (Table 1). The extreme classes (I and IV) had higher misclassification rates than the central ones (II and

III) in both data sets (Table 1). The occurrence of pikeperch was clearly more precisely predicted compared to the abundance and the state of the stocks, but here too the non-occurrence had a lower number of correct classifications than the occurrence (Table 1).

Table 1. Pikeperch abundance (Ab.; I = non-occurrence to IV = high), state of stock (State; I = best to IV = totally lost) and occurrence of pikeperch (Occ.; II = non-occurrence and III = occurrence) predicted by environmental (Env) and fish (Fish) data using ANN. E-test indicates independent test data predicted by environmental data and F-test indicates independent test data predicted by fish data. First is the number of correct predictions and second is the total number of observations.

	Pred.	Total	I	II	III	IV
Ab.	Env	52/ 97	1/ 7	21/34	28/43	2/13
	E-test	11/ 24	0/ 3	2/ 7	8/11	1/ 3
	Fish	67/ 97	3/ 7	23/34	34/43	7/13
	F-test	38/117	2/36	16/41	20/31	0/ 9
State	Env	58/ 88	8/15	32/41	18/30	0/ 2
	E-test	9/ 20	0/ 2	8/11	1/ 6	0/ 1
	Fish	76/ 88	13/15	37/41	25/30	1/ 2
	F-test	40/ 88	3/10	18/33	18/37	1/ 8
Occ.	Env	97/ 97		7/ 7	90/90	
	E-test	18/ 24		1/ 3	17/21	
	Fish	97/ 97		7/ 7	90/90	
	F-test	87/117		11/36	76/81	

**Discussion.** The CCA results were in accordance with the earlier findings that the pikeperch lakes are large having high productivity and turbidity (Lehtonen et al. 1984). Besides these, the best pikeperch lakes are situated in southern Finland. Lappalainen and Malinen (2002) showed, based on the same survey as used here, that pikeperch yields decreased towards north in Finland. This was due to both decrease in growth and increase in size-dependent mortality during the first winter (Lappalainen and Malinen 2002). Both were connected to the temperature-dependent growth of 0+ and adult pikeperch (Lappalainen et al. 2000, Lappalainen et al. unpubl.).

The ANN analyses suggested that it is not possible to predict the importance or state of the stocks based on the data used here. One of the reasons for this failure might be that the heads of the fishing associations were overoptimistic of the situation in lakes, which is only understandable after the use of large amount of money on pikeperch stockings. Also the number of extreme classes was low. On the other hand, the occurrence non-occurrence -pattern was more precisely predicted.

Mail surveys have both advantages and disadvantages. The most obvious advantage is that large amount of data can be obtained within a short

period of time with low expenses. Another advantage is that the lakes are evaluated by persons familiar to their waters, even though this estimation might be based on a slight overoptimistic view. The disadvantages here are that the mail survey focused only on pikeperch lakes, so these results can not be expanded beyond the lakes studied. Also the proportions and abundances of fish species with low value can be underestimated in mail surveys such as analyzed here.

**Acknowledgements.** Niilo Helander Foundation financed the study.

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## TEMPERATURE DEPENDENCE OF EURASIAN PERCH (*Perca fluviatilis*) RECRUITMENT

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### Abstract

Eighteen lakes situated in South-Eastern Norway between 60 – 61° northern latitude, were sampled with Nordic survey nets. Relative year-class strength (YCS) of Eurasian perch was calculated, and plotted against mean air temperatures during periods of one to three months during June to September. Positive significant correlations were found in twelve lakes (67 %). Positive, close to significant, correlations were found in three additional lakes, whereas in three of the most acid lakes, there were no correlation. There were no correlations between first-year growth and year-class strength.

**Introduction.** Year-class strength of perch has been related to temperature (Segerstråle 1933, LeCren et al. 1958, Neuman 1976, Karås 1996a), and may be explained by temperature dependent growth, and size dependent survival during first year, which is decisive to cohort strength (Craig 1982, Post 1988, Karås 1996a). This study was conducted on 18 perch populations in southeastern Norway, to analyse year-class strength as a function of summer temperatures.

**Methods.** Eighteen oligotrophic small forest lakes at 60 – 61° northern latitude in South-eastern Norway were sampled once with benthic Nordic survey nets (Appelberg et al. 1995) during 1993 to 2000. Age determination was based on otoliths (Linløkken et al. 1991). Relative year-class strength (YCS) was calculated as:  $YCS = 100\% * (\text{number perch of year-class } x) / (\text{expected number of perch of year-class } x)$ . Expected year-class distribution were calculated by assuming constant recruitment = mortality (M); number of 3+ perch =  $N_3$ , number of 4+ perch =  $N_3 * S^{-M}$ , number of 5+ =  $N_3 * S^{-2M}$ . Mortality was estimated by tagging experiments in six lakes, and the lakes were divided into three groups; eight lakes with allopatric perch and  $M=0,11$ , six lakes with perch coexisting with roach (*Rutilus rutilus*) and pike (*Esox lucius*) with  $M=0,19$ , and the third group with high mortality;  $M=0,40$  in one lake and  $M=0,50$  in three lakes. The low and moderate mortality lakes were sampled in 1993-1995, whereas the high mortality lakes were sampled in 2000. The analysis included five to ten year-classes in each lake and Log(YCS) were plotted on mean air temperatures during periods of one, two and three months within the growth season June-September (mean temperatures ranging 10,5-16,9 °C). First year growth were analysed by opercular bones of adult perch (LeCren 1947).

**Results.** Log(YCS) was significantly, positively correlated to mean air temperature in one, two or three months within the period June-September in twelve of eighteen lakes ( $R^2 = 0,45-0,94$ ,  $p=0,045-0,006$ ). There were significant correlation to June temperatures in two of the lakes, and in those, roach contributed 86–92 % of the catches, compared to 0–65 % in the other lakes. These two lakes also differed from the others by showing high YCS only in 1988, not in 1991. No correlations were found in the three most acid lakes, with mean May pH = 5,03, compared to mean pH = 5,60 for all lakes.

No correlations were found between YCS and precipitation or wind.

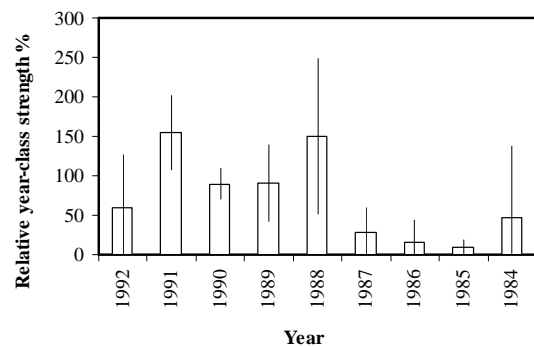


Figure 1. Mean year-class strength of nine populations with positive correlation to July-September air temperature, sampled in 1993 – 1995.

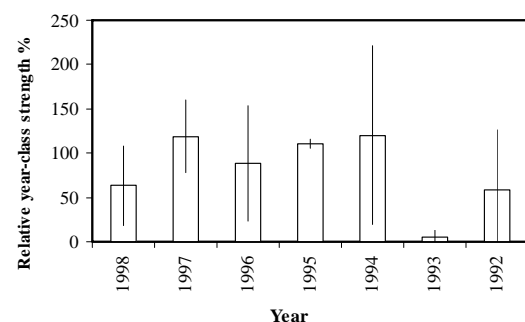


Figure 2. Mean year-class strength of three populations with positive correlation to July-September air temperature, sampled in 2000.

Mean YCS in perch populations with low and moderate mortality and with YCS significantly correlated mean air temperatures of periods within

July-September, showed strong year-classes in 1988 and 1991 (Fig. 1). The mean YCS of the high mortality lakes, with positive correlation to air temperatures within July-September, showed strong year-classes in 1994, 1995 and 1997 and especially weak year-classes in 1993 (Fig. 2). Log(YCS) for all lakes with significant correlation to temperature in periods within July-September were plotted on July-September temperatures (T)(Fig. 3), and following model was achieved:

$$YCS = 0,0087 \times 10^{0,303 \times T}$$

This predicts YCS > 120 % when temperature exceeds 13,7 °C. Mean length after the first year was about 50 mm in all populations, and there were no correlations between growth and year-class strength.

Strong year-classes did not occur in two successive years in any lake, with one exception.

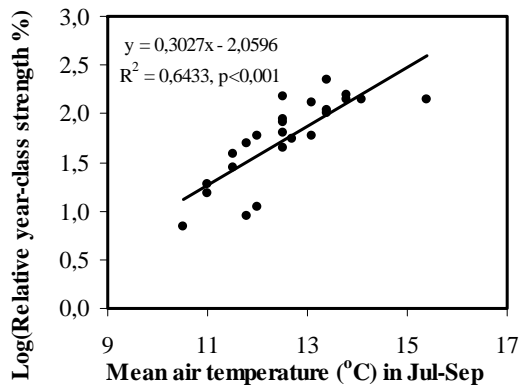


Figure 3. Log(YCS) of all perch populations (10) with YCS significantly correlated to July-September air temperature, sampled in 1993-2000.

### Discussion

The year-class strength variation in this material supports studies from elsewhere in Scandinavia, that temperature probably is the most important regulating factor (Neuman 1976, Karås 1996a). The correlation of a single lake might be coincidental, but not the correlations in the pooled samples showing synchrony and highly significantly correlations. Temperature decides first year growth and condition, and in turn the survival during first year (Post 1988, Pereira et al. 1995, Karås 1996a). Survival demands a minimum length, about 50 mm (Karås 1996b), and year-class strength will depend on how many specimens achieve this size during growth season. This is probably more pronounced in high latitude lakes, with relatively low temperatures, short growth season, and moderate perch densities in low diversity systems. This moderate the impacts from both intraspecific and interspecific interactions. Nevertheless, the absence of a strong 1991 year-

class in the two lakes with highest roach abundance, indicates an impact from interspecific interactions. Acidification may alter effects from temperature, by reducing hatching success in summers of relatively high temperatures.

The model of YCS as a function of temperature is of course valid only within a limited temperature range, not above 15-16 °C. Above this, temperature may be of minor importance, which probably is the case in perch populations on lower latitudes. A study in Netherlands (Willemsen 1977), showed no correlation between YCS and temperature.

**Acknowledgements.** This work was supported in part by Hedmark College and Directorate for Nature Management. Per Arne Holt Seeland was an excellent collaborator in field work.

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## ADVANTAGES OF PERCH (*Perca fluviatilis*) SEASONAL MIGRATIONS TO BRACKISH WATERS.

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**Introduction.** Perch (*Perca fluviatilis*) are known as seasonally migrating fish species in southern part of the Baltic Sea. Perch inhabit brackish coastal waters of the southern Baltic in summer time, while they usually winter in the freshwater lagoons. The objective of the study was to explain experimentally perch spring migration behaviour while they migrate from the freshwater Curonian Lagoon to the brackish Baltic Sea, Lithuania, and to prove a cause of their backward migration to the Lagoon in the autumn.

**Methods. Field study.** Material for the perch *in situ* growth study was collected during 1998 – 2000, in September when growth in length and accumulation of energy resources reached the yearly maximum. The growth study focused on perch individuals of 1997-year class, since this generation dominated in both water bodies: individuals of the other age groups were scarce. All perch were weighed ( $\pm 1.0$  g) and measured (total length  $L$ ,  $\pm 0.5$  cm). Condition factor (CF) and fatness coefficient ( $K_F$ ) were calculated as follows (Bagenal & Tesch, 1978; Bukelskis & Kublickas, 1988):  $CF = W/L^3 \times 100$ , where  $W$ , body weight in grams,  $L$ , total length in cm and  $K_F = w/W \times 100$ , where  $w$ , weight of fat on the intestines, in grams,  $W$ , body weight, in grams. Since differences in the growth rate of perch for the same age group is considerable, the parameters were calculated for the same length, but different age perch individuals. Both sexes were combined in calculations. Fat content ( $C_F$ ) in muscle tissues was expressed as a percentage of wet weight. Perch age was estimated from growth zones of opercular bones. Only females were aged. For statistical analysis *t*-tests was used.

**Experimental study of growth.** To evaluate the effect of salinity on perch growth, a survey of perch YOY growth under different salinity conditions was conducted. The first experiment was performed at “high temperature” range (mean water temperature 19.2) and the second - at “low temperature” range (mean water temperature 12.4). Available laboratory facilities restricted the experiment to YOY providing sufficient density of fish for statistical analysis. Perch YOY were collected by seine netting at Ventė cape, a coastal area in the eastern part of the Curonian Lagoon (55°21' N, 21°12' E) in August 2001 and 2002. After 5 days acclimatisation in fresh water, fish were randomly divided into 15 experimental groups. Each group comprised 10 fish, which were reared in identical 100-l glass aquaria under continuous aeration. The influence of salinity on the perch growth was studied under certain three experimental salinity conditions: five aquaria contained water at 5 ppt, five at 2 ppt and five contained fresh water. The duration of the experiment in “high temperature” range was three weeks, while the duration of the experiment in “low temperature” range was six weeks. Water temperature was ambient in all aquaria and during the experimental period, fluctuated from 24.9 to 16.0°C in “high temperature” range, while in

“low temperature” range - from 14.1 to 11.7°C. All fish were provided with the same quantity of live *Chironomus* spp. larvae, weighed with accuracy of 0.01 g. To ensure similar food consumption between replicates, each new portion of food was introduced immediately following consumption of the previous ration. Total weight ( $\pm 0.01$  g, after excess water removed) for each replicate was measured prior to the beginning of the experiment and after each week. To assess differences in growth under different treatments, the weight increments of perch YOY groups of each replicate were analysed using Tukey honest significant difference test.

**Results.** Perch start to migrate from the Curonian Lagoon after wintering and spawning. Field observations demonstrated better growth in length and condition (Fig. 2, 3) in the sea despite lower water temperature (Fig 1).

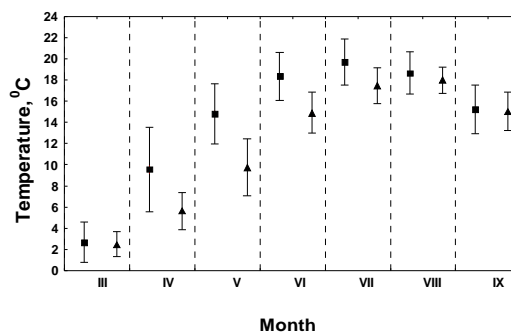


Figure 1. Water temperatures in the Curonian Lagoon (■) and the Baltic Sea (▲) during March – September 1998–2000 (vertical bars represent 1 SD).

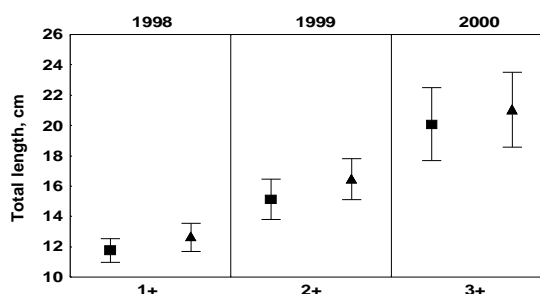


Figure 2. The total length of perch of 1997 year class in the Curonian Lagoon (■) and the Baltic Sea (▲) during September of 1998–2000 (vertical bars represent 1 SD) (Ložys 2001).

The results of the experiment in “high temperature” range demonstrated the significant affect of salinity on YOY perch growth at both 5 and 2 ppt salinity conditions (Fig. 4) (Ložys, *in press*). Differences in growth between 2 and 5 ppt salinity replicates were insignificant. Salinity affect was insignificant at the “low temperature” range (Fig. 5).



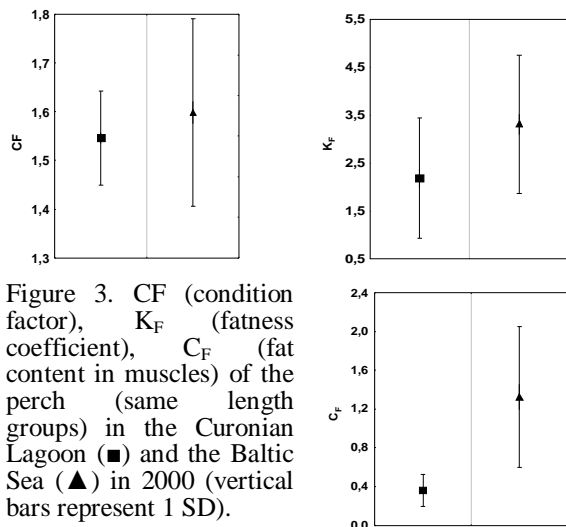


Figure 3. CF (condition factor),  $K_F$  (fatness coefficient),  $C_F$  (fat content in muscles) of the perch (same length groups) in the Curonian Lagoon (■) and the Baltic Sea (▲) in 2000 (vertical bars represent 1 SD).

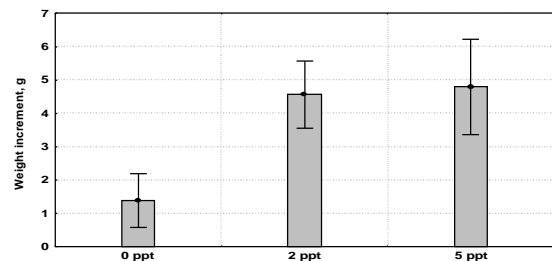


Figure 4. Total weight increment of perch YOY in brackish and fresh water in "high temperature" range (Tukey HSD test: 5 ppt vs. fresh water,  $P=0.001$ ; 2 ppt vs. fresh water,  $P=0.002$ ; 5 ppt vs. 2 ppt,  $P=0.95$ ).

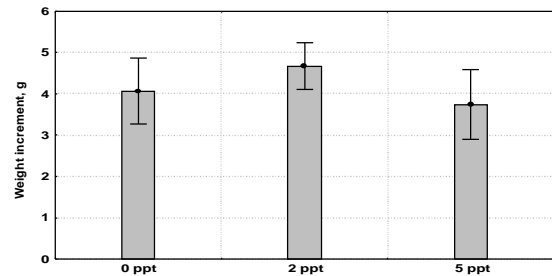


Figure 5. Total weight increment of perch YOY in brackish and fresh water in "low temperature" range (Tukey HSD test: 5 ppt vs. fresh water,  $P=0.78$ ; 2 ppt vs. fresh water,  $P=0.44$ ; 5 ppt vs. 2 ppt,  $P=0.17$ ).

**Discussion.** Available information suggests that feeding conditions in the Curonian Lagoon are better than in the coastal waters (Repečka et al., 1996; Ložys, unpubl. data). Despite that, part of perch population migrates from the Curonian Lagoon to the Baltic Sea in spring. In mid September, when water temperature drop to 12-13°C, intensive perch migration back to the lagoon starts. Study *in situ* demonstrates beneficial effect of perch summer in the brackish coastal waters. Consequently it was hypothesized that water salinity could beneficially effect perch in the sea.

To test the hypothesis of the salinity influence, YOY perch were reared under equal feeding conditions and temperatures, at 5 and 2 ppt salinity regimes and freshwater as control. The first experiment was performed at 16-22°C (mean water temperature 19.2) and the second - at 9-14°C (mean water temperature 12.4) range. The results of the experiment in "high temperature" range demonstrated the significant beneficial affect of salinity on YOY perch growth at both 5 and 2 ppt salinity conditions (Fig. 4) (Ložys, *in press*). The beneficial effect of salinity on perch growth, most likely, is manifested only under salinities close to the internal osmotic pressure in fish. However, the affect was insignificant at the lower temperature range (Fig. 5). Hence it is evident that temperature plays also significant role in salinity affect on perch growth.

According to the results of the first experiment, migration to the sea could be interpreted as a result of the beneficial salinity affect on the perch growth. The second finding allows stating that after water temperature decreases, the salinity affect becomes insignificant, and migration to the protected from the stormy winds lagoon starts. However, the obtained results requires further studies to understand mechanisms of water salinity effect on perch.

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## RECRUITMENT PATTERNS OF WALLEYE AND SAUGER IN THE LOWER WISCONSIN RIVER

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**Introduction.** The lower Wisconsin River supports an important sport fishery for walleye (*Stizostedion vitreum*) and sauger (*S. canadense*) (Rasmussen et al. 1994). Fishery exploitation is high and perhaps as a consequence walleye and sauger populations have relatively small adult stocks, a low mean age, and fast individual growth rates (Lyons and Welke 1996). Variation in recruitment is high, and year-class strength strongly influences angling success. Since 1987, I have assessed walleye and sauger reproductive success in the upper part of the lower Wisconsin River with the goal of better understanding patterns and causes of recruitment variation. This paper summarizes my findings.

**Methods.** The Wisconsin River is the largest river within Wisconsin, with a length of 676 km, a basin area of 31,800 km<sup>2</sup>, and a mean annual flow of 292 m<sup>3</sup>/sec (Lyons 2004). The lower river is defined as the 149-km reach from the Prairie du Sac Dam (a barrier to upstream fish movement) downstream to the mouth at the Mississippi River. The dam tailwater has a deep (>10 m) pool with extensive gravel and cobble substrates, but otherwise the lower river has a wide (> 400 m), shallow (< 1 m mean depth), braided channel with shifting sand substrate. Tagging studies indicate that the majority of walleye and sauger in the upper half of the lower river migrate to the tailwater by October. They overwinter there until spawning and dispersing downstream in April (Rasmussen et al. 1994). The tailwater is also a primary habitat for age-0 walleye and sauger in the upper part of the lower river.

Angler harvest regulations for walleye and sauger varied over the course of the study. Walleye had no size limit from well before 1987 through 1989, a 381-mm total length limit from 1990-2001, and a 457-mm total length limit in 2002. Sauger had no size limit from well before 1987 through 1993 and a 381-mm total length limit from 1994-2002. There was no closed season on either species and the bag limit was five walleye and sauger in aggregate throughout the study period.

From 1987-2002, I conducted annual electrofishing surveys of walleye and sauger in the tailwater in late October. Three 1-km shoreline stations were sampled each night with a pulsed-DC boom shocker with two netters, and surveys were conducted one to three nights per year, an approach that provided an accurate index of relative abundance and size/age structure (Lyons and Welke 1996). All captured walleye and sauger were measured for total

length. A previously developed age-length key was used to determine age. Catch rates were expressed for each species as number per night per age group. Age-specific catch and growth rates were correlated with each other and with measures of river temperature and flow using multiple linear regression in order to identify factors influencing year-class success. Daily flow data were taken from the U.S. Geological Survey Muscoda gage, 79 km downstream from the dam. The Prairie du Sac Dam had a gage from 1946-1953 and flows at the dam were 92% of those at Muscoda ( $r^2=0.96$ ). Daily air temperatures were taken from the University of Wisconsin Arlington Experimental Farm, 30 km east of the dam. During 1983-1990 daily mean water temperatures at the dam during the growing season (April-October) were tightly correlated with daily mean air temperatures ( $r^2>0.90$ ) and usually within 3°C of each other. For flow and temperature I calculated monthly means and standard deviations for April through October and a mean and standard deviation for the entire growing season.

**Results and Discussion.** Abundances of walleye and sauger age classes varied substantially among years, but patterns of variation differed between the species. Nightly mean catches of age-0 walleye ranged from 8.9 in 2000 to 140.0 in 1987, a 16-fold difference. Age-1 catches varied by a factor of nearly 10 (8.3 in 2001, 79.4 in 2002) and age-2 catches by a factor of 12 (2.2 in 1988, 26.9 in 1999). Age-0 walleye catch was positively related to age-1 catch the following year ( $r=0.57$ ,  $p=0.02$ ) but not to age-2 catch two years later. However, age-1 catch was marginally positively related to age-2 catch the following year ( $r=0.47$ ,  $p=0.075$ ). This indicates that walleye year-class strength was not always fully set by the end of the first growing season and could be modified during the next two years. Age-0 sauger catches ranged from 0.28 in 2002 to 28 in 1999, a 100-fold difference. Age-1 catches varied by a factor of over 250 (0.1 in 1991, 26.8 in 1987) but age-2 catches only by a factor of 15 (1.1 in 1996, 16.9 in 2002). Age-0 sauger catch was positively related to age-1 catch the following year ( $r=0.65$ ,  $p=0.009$ ) and to age-2 catch two years later ( $r=0.61$ ,  $p=0.02$ ). These results suggest that sauger year-class strengths were largely set by the end of the first growing season, but that differences in year-class strength could be reduced between age-1 and age-2.

Walleye and sauger growth also varied among years but was consistently fast relative to other

populations in Wisconsin. Annual mean total length of age-0 walleye in late October ranged from 183-236 mm with a grand mean of 208 mm. At the end of their third growing season, just prior to maturity, walleye averaged about 400 mm. Statewide averages for walleye after their first and third growing seasons are 157 and 315 mm (Wisconsin Department of Natural Resources, unpublished data). Annual mean total length of age-0 sauger in late October ranged from 165-211mm with a grand mean of 182 mm. Sauger averaged about 350 mm at the end of their third growing season, just prior to maturity. Statewide averages for sauger after their first and third growing seasons are 167 and 325 mm.

Temperature was the best predictor of age-0 abundance for both walleye and sauger, and the best year classes were produced in years with warm stable temperatures. Age-0 walleye catches were positively related to April mean temperature (the month of spawning) and negatively to standard deviations of June and September temperatures ( $R^2=0.75$ ,  $p=0.0002$ ). Age-0 sauger catches were positively related to July mean temperature and negatively to the standard deviations of growing season and May temperatures ( $R^2=0.72$ ,  $p=0.0012$ ). Annual variation in age-0 catch was not explained by spawning stock (age-3 and older catch), abundance of age-1 and age-2 fish, fluctuations in river flow, nor variation in age-0 walleye and sauger growth.

Temperature and river flow explained significant variation in age-0 walleye and sauger growth, and the fastest growth occurred in years with warm stable temperatures and stable river flows. Age-0 walleye growth was positively related to August mean temperature and negatively to standard deviations in August temperatures and May flows ( $R^2=0.80$ ,  $p=0.002$ ). Age-0 sauger growth was positively related to August mean temperature and negatively to standard deviations in August temperatures and growing season flows ( $R^2=0.78$ ,  $p=0.0003$ ). Age-0 walleye and sauger growth was positively correlated ( $r=0.59$ ,  $p=0.016$ ), but abundances of older age classes of walleye and sauger did not explain variation in age-0 growth for either species.

Overall, results indicate that temperature is a better predictor of walleye and sauger reproductive success and growth in the lower Wisconsin River than spawning stock or river flows. Studies from other waters in the region have yielded similar results. In Navigation Pool 13 of the Mississippi River, 265 km downstream of the Prairie du Sac Dam, October age-0 walleye and sauger abundances were positively related to the rate of water temperature increase in late April and early May but not to flow attributes (Pitlo 2002). In Escanaba Lake, Wisconsin, fall age-0 walleye density was negatively

related to the standard deviation of May water temperature and growth was positively related to June mean temperature, but neither age-0 walleye density nor growth was correlated with densities of older walleyes (Serns 1982).

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## AN INTERPLAY BETWEEN FORAGING AND ANTIPREDATOR BEHAVIOR IN 0+ PERCH (*Perca fluviatilis*) AT THE DEMERSAL PHASE

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**Introduction.** When 0+ perch migrate from the open waters to the shore, they face new, structured habitats, often with cruising (larger perch) and ambush (pike) predators. Both novelty of surroundings and predation risk may enhance vigilance and modify fish foraging. Piscivore-induced shifts of prey fish between habitats have received much more attention than within habitats (food patches) changes of behavior. A trade-off between foraging and defense within food patches may be assessed as a change in total food intake (Fraser, Huntingford 1986) or prey size selectivity (Godin 1990). Our main questions were: a) what predator-associated cues, visual or olfactory, cause more pronounced feeding response in 0+ perch? b) does habituation to a novel situation influence their foraging? Roach (*Rutilus rutilus*) are living in similar habitats as perch. They compete with perch for planktonic prey and face the same challenges. We studied the same responses in 0+ roach.

**Methods.** Perch and roach were obtained by artificial fertilization of eggs from wild fish from Lake Mondsee (Austria). The fish were kept in flow-through tanks at  $20 \pm 1^\circ\text{C}$  and 16L:8D photoperiod. They were raised on a diet of live brine shrimp nauplii, lake zooplankton and *Daphnia magna*. Pike (*Esox lucius*) juveniles (15-18 cm TL) from the same lake were used as predators. Feeding tests were run with groups of 3 fish, either perch (mean  $\pm$  SD  $36.5 \pm 3.5$  mm TL) or roach ( $33.8 \pm 3.4$  mm TL) in 10 l glass aquaria at  $20 \pm 1^\circ\text{C}$ , and 400 (day light) or 2 (twilight) lux. Fish prestarved for 20 hrs were provided with 50 large ( $2.9 \pm 0.28$  mm) and 100 small ( $1.2 \pm 0.25$  mm) *D. magna* and allowed to feed for 15 min. Dry weight (DW) of individual perch and ingested daphnia was calculated from length-weight regressions. Feeding response of the fish (intake rate and prey size selectivity) to novelty of the environment (transfer from flow-through tanks to test aquaria) was assessed on days 1, 3, and 5. Impacts of predator-induced cues (pike odor, visual contact with pike, both cues presented together) on fish feeding were tested with fish acclimatized to test aquaria for 5-6 days. Ten replicates were always used in both experiments and controls. Mann-Whitney test (MW) or Kruskal-Wallis ANOVA (KW) were used for statistical comparisons.

**Results.** Increase in intake of large (KW,  $p < 0.01$ ), and decrease in intake of small prey ( $p < 0.001$ ) were observed during habituation of perch to novel surroundings (Figure 1).

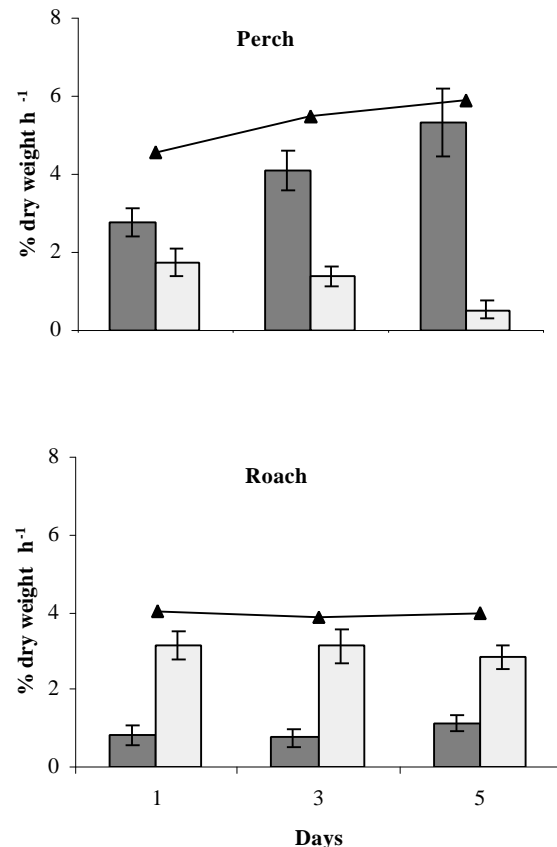


Figure 1. Specific intake rate of large (dark) and small (light bars) *D. magna* at 400 lux. Triangles indicate total consumption.

There was no significant changes in intake of either large ( $p=0.875$ ) or small prey ( $p=0.798$ ) by roach. Total intake by perch increased ( $p=0.007$ ), but did not change in roach ( $p=0.812$ ) (Figure 1). Perch fed more intensively upon large prey at twilight than at day (MW,  $p < 0.0001$ ); intake of small prey was not affected by light.

Pike odor did not affect total intake nor the ratio between large and small prey eaten in perch nor roach at 400 lux (Figure 2). However, at 2 lux, pike odor inhibited intake by perch (MW,  $p=0.01$ ).

Visual contact with pike at 400 lux inhibited intake in both perch ( $p < 0.01$ ) and roach ( $p < 0.01$ ). Visual contact together with pike odor affected perch feeding even stronger ( $p < 0.001$ ), but not roach.

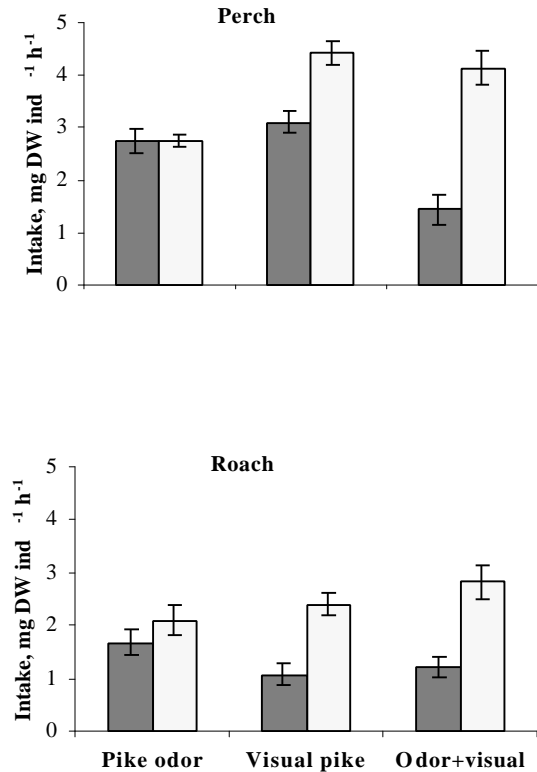


Figure 2. Predator induced cues affect total intake rate of perch and roach at 400 lux. Trial: dark, control: light bars.

Predator-induced cues inhibited intake of large prey more than that of small prey in perch (MW,  $p = 0.04$ ).

**Discussion.** Perch responded to pike-induced cues, novelty of surroundings, and high illumination, decreasing total food intake and proportion of large (costly in terms of handling time) prey in the diet. Surprisingly, pike odor did not affect intake at high illumination, but at twilight. Visual cues caused pronounced changes in feeding of both perch and roach. Chemical cues seem less reliable at day light than visual ones and could not be of much use at detection and orientation (Webster, Weissburg 2001). It is probably too costly for hungry fish to respond to such an uncertain threat by lowering food intake. However, pike odor combined with visual cues made 0+ perch even more cautious when feeding. Feeding of 0+ roach was not further decreased when pike odor was provided together with visual contact.

Roach has a higher capacity than perch to avoid predators due to the higher swimming and group cohesion capacities as well as ability to make evasive jumps (Christensen, Persson 1993). When transferred into novel surroundings, 0+ roach quickly habituated and attained a steady level of food intake and selectivity. Perch gradually habituated to novel surroundings with no refuges, increasing consumption of large prey. Perch use hiding and often associate with macrophytes while foraging and avoiding threat (Eklov, Persson 1995). Opposite to roach, perch respond to predators by decreasing activity and oxygen consumption (Huuskonen, Karjalainen 1997). Predator-induced stress caused a decrease of foraging of perch to a larger extent than that of roach. Young perch at the demersal phase can compromise between foraging and vigilance adjusting food intake and prey size selection to predation threat.

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## A SURVEY OF GENETIC VARIATION AMONG YELLOW PERCH (*Perca flavescens*) POPULATIONS DETERMINED FROM ALLOZYME AND MITOCHONDRIAL DNA DATA

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**Introduction.** The issue of stock conservation has received considerable attention from geneticists and fisheries managers. The trend in fisheries management is to conserve as much intraspecific variation as possible in order to protect adaptive gene complexes. Yellow perch (*Perca flavescens*) are an important recreational and commercial resource, and conserving stock structure among natural populations of *P. flavescens* is an essential element in any sound management program aimed at ensuring high-quality yellow perch fisheries in North America. Todd and Hatcher (1993) provided evidence for stock structure among *P. flavescens* populations based on patterns of allozyme variation. In contrast, Billington (1996) showed no evidence for stock structure in *P. flavescens* using whole molecule mtDNA RFLP data. To address this conflict, we expand on previous allozyme and mtDNA studies by surveying a broader range and a larger sample size of *P. flavescens* throughout North America.

**Methods.** Specimens of *P. flavescens* (N=241) were collected from 14 locations throughout North America (Table 1). Protein polymorphisms (allozymes) in *P. flavescens* populations were examined using horizontal starch gel electrophoresis. Alleles from 10 enzyme systems (EST, MDH, ADH, G6PDH, G3PDH, IDDH, LDH, GPI, PGM, and SOD), representing 14 loci, were separated using a tris-maleate buffer system (see Moyer, 1998 for details).

Mitochondrial DNA variation of *P. flavescens* populations was screened using eight restriction enzymes known to reveal polymorphisms in *P. flavescens* (*Apa* I, *Ava* I, *Hind* III, *Nci* I, *Nco* I, *Sca* I, *Sst* I, and *Stu* I; Billington, 1996). Isolation and digestion of mtDNA followed the procedures of Billington and Hebert (1988). Fragments from total genomic DNA isolates were analyzed using the Southern Blot procedure described by Richard (1994).

**Results.** Allozyme analysis of *P. flavescens*: We initially screened four populations (Table 1) using 10 enzyme systems representing 14 presumptive loci. Five presumptive loci (*ADH-1\**, *GPI-1\**, *LDH-1\**, *MDH-1\**, and *PGM-2\**) were polymorphic for these four populations. Subsequently, further analyses relied on these five polymorphic loci. We failed to resolve discernable allozyme patterns at the ADH and

PGM for Lake Simcoe, Lake Erie, and Oneida Lake populations, and therefore excluded these populations from subsequent analyses. Mean heterozygosity was less in the Mississippi River Drainage (MRD) populations (0.000-0.010) compared to the greater values (0.099-0.269) observed in the Atlantic Ocean Drainage (AOD) populations (Table 1). Four of the five surveyed loci (*ADH-1\**, *GPI-1\**, *LDH-1\**, and *PGM-2\**) were polymorphic (95% criterion). All polymorphic loci were in Hardy-Weinburg equilibrium except *GPI-1\** (NC and PA populations), and *PGM-2\** (MD population). There was significant heterogeneity ( $\chi^2 = 226.38$ ; df = 20;  $p \leq 0.001$ ) between pooled MRD populations (WI, IN, and IA) and AOD populations (DE, MD, ME NC, PA and ONT) at *GPI-1\**. Genetic variability at *PGM-2\** also showed significant ( $\chi^2 = 595.96$ ; df = 36;  $p \leq 0.001$ ) heterogeneity when pooled MRD populations were compared with AOD populations.

Table 1. Localities and sample sizes (N) surveyed in this study. Mean heterozygosity (H) values for each population are based on values from five presumptive allozyme loci. MtDNA nucleon diversity (Nei and Tajima, 1981) for each population is indicated by *h*. Values not reported are due to poor resolution. An asterisk denotes populations initially screened for allozyme analyses.

Drainage	Location	N	H	<i>h</i>
Mississippi River	Whorton Lake, WI	12	0.000	0.000
	Grassy Lake, WI*	20	0.010	0.000
	Trout Lake, WI	17	0.000	0.143
	Spirit Lake, IA	23	0.000	0.091
	Crooked Lake, IN	10	0.000	0.154
Atlantic Ocean	Lake Huron, Ontario	12	0.000	0.182
	Lake Simcoe, Ontario	11	----	0.378
	Lake Erie, Ontario	22	----	0.481
	Oneida Lake, NY	11	----	0.000
	Tioga River, PA*	24	0.099	0.245
	Perquimans River, NC*	14	0.157	----
	Lake George, ME*	30	0.117	----
	Nantikoke River, DE	23	0.269	----
	Choptank River, MD	12	0.241	0.495

Mitochondrial DNA analysis of *P. flavescens*: Fourteen different mtDNA haplotypes were identified from nine *P. flavescens* populations (DE, ME, and NC populations were excluded due to resolution problems). Mean haplotype diversity estimates for MRD populations were low (0.000-0.182) (Table 1) with most populations fixed for the most common haplotype. In comparison, AOD populations

exhibited higher mean haplotype diversity values (0.245-0.495) (Table 1). Pairwise comparisons between all populations revealed significant heterogeneity between *P. flavescens* populations ( $\chi^2 = 254.88$ ;  $df = 130$ ;  $p < 0.001$ ); however, this test was not significant when the MD population was excluded ( $\chi^2 = 107.91$ ;  $df = 108$ ;  $p = 0.498$ ).

#### Discussion.

Todd and Hatcher (1993) proposed separate Pleistocene glacial refugia as a hypothesis for the observed allozyme variation between MRD and AOD populations of *P. flavescens*. Significant differences in our estimates of nucleotide and haplotype diversity between pooled MRD and AOD support the finding of separate stocks.

The nearly complete loss of nucleotide diversity and decreased haplotype diversity in MRD populations (in comparison to AOD populations) suggest that MRD populations underwent a more severe bottleneck than the AOD populations. However, potential secondary contact of refugial lineages, translocation, or selection could also contribute to these observed patterns of diversity. Haplotypic and allelic distributional data (see Billington, 1996; Moyer, 1998) show that although secondary contact may have occurred (see below), much of the allelic and haplotypic diversity is found in putative non contact populations (e.g., Delaware, North Carolina, and Maryland). These findings indicate that increases in allelic/haplotypic diversity due to historical secondary contact are not contributing to these observed patterns. Whether selection or translocation is attributing to increases/decreases in diversity remains unclear and should be further explored.

In contrast to Billington (1996), significant differences in our estimates of mtDNA haplotype diversity between pooled MRD and AOD further support Todd and Hatcher's (1993) findings. The discrepancy in results can be explained by the increased sample size of our study. Unfortunately, we could not obtain data for the three southern most AOC populations, but perch from Maryland have a preponderance of haplotype 13 (Moyer, 1998), which is different from all other populations except the Pennsylvania population. This haplotype may represent a unique haplotype that corresponds to the AOC refugium, and analysis of populations from south-eastern United States may provide more evidence of an Atlantic coastal refugium haplotype.

We also provide genetic support for a post-glacial outlet (contact zone) between the two refugia. Evidence for this observation is found in the Tioga River (Pennsylvania) population, which is a tributary of the east branch of Susquehanna River. This

population shares alleles (*GPI-1\** and *PGM-2\**) and haplotypes (1 and 13) from both the Atlantic and Mississippian refugia (Moyer, 1998), which indicates that contact may have occurred between MRD and AOD refugia. During the Pleistocene, the Genesee River, which flows into the MRD, flowed south into the AOD (Hocutt et al., 1986). Therefore, a post-glacial outlet may have occurred between the Allegheny River (MRD) and the Susquehanna River (AOD) via the Genesee River. Further evidence supporting this hypothesis was reported by Hocutt et al. (1986) who concluded that the native fauna from the Susquehanna River had elements from the northern Mississippi Basin due to secondary contact from post-glacial outlets during the Pleistocene.

Allozyme data indicate significant stock structure between MRD and AOD *P. flavescens* populations. Management initiatives for *P. flavescens* should strive to conserve the genetic integrity of these stocks. Moreover, we suggest that contact between glacial refugia may have occurred, presumably during the Pleistocene.

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## STRUCTURE AND DYNAMICS OF AN UNEXPLOITED YELLOW PERCH POPULATION

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**Introduction.** The yellow perch (*Perca flavescens*) is one of the most popular sport and commercial fishes in North America. In the Great Lakes, for example, 36% of over 2 million anglers who fished in 1996 targeted yellow perch (USDOI 1997). Although a wealth of information has been published about yellow perch, little is known about unexploited yellow perch populations. In general, studies of unexploited populations are prized rarities in fishery literature (Ricker 1979). Studies of unexploited populations can provide fisheries managers and researchers with baseline information with which to compare data from exploited fish populations. The unique opportunity to examine an unexploited population of yellow perch exists in the Pymatuning Sanctuary, Crawford County, Pennsylvania. The Pennsylvania Fish and Boat Commission (PFBC) manages the Sanctuary primarily as a valuable source of walleye (*Stizostedion vitreum*) broodstock, thus the Sanctuary is closed to all fishing activities. Our goal was to describe the structure and dynamics of the unexploited yellow perch population in the Pymatuning Sanctuary.

**Methods.** Yellow perch were collected in the Pymatuning Sanctuary during 1997 and 1998 using trap nets and boat electrofishing gear. Three hard structures (scales, otoliths, and dorsal fin spines) were used to determine the age of yellow perch. Scales, dorsal fin spines, and sagittal otoliths were removed from 107 yellow perch; the three structures were prepared and examined by two readers (Niewinski and Ferreri 1999).

In October 1997, 178 yellow perch were collected using electrofishing gear to determine age at first maturity. Fish were euthanized using an overdose of MS-222, dissected in the laboratory, and the gonads were examined. Fish were determined to be mature or immature based on the condition of the gonads as described by Treasurer and Holliday (1981). Ages were assigned using scales and sex-specific age at first maturity was determined. Mean length at maturity for males and females was also calculated.

From March 20-29, 1998, immediately prior to the yellow perch spawning season, we collected 198 female yellow perch using four Pennsylvania-style trap nets to estimate absolute fecundity. Each fish was measured (total length in mm), weighed (nearest g), and scales were collected for age determination. Ripe females were euthanized using an overdose of

MS-222. To estimate fecundity, the ovaries were removed and weighed after removing excess water by blotting on a piece of filter paper. One-gram sections were removed from the anterior, middle, and posterior parts of the ovaries from each fish. To estimate fecundity, the numbers of eggs in the one-gram sections were counted and the total was extrapolated to the total weight of the ovary. The mean number of eggs and the range of eggs produced for fish in each 25-mm length group were also estimated.

Instantaneous total mortality ( $Z$ ) was estimated for the entire population as well as for males and females separately from the slope of the descending limb of the catch curve (Ricker 1975). Only age groups in which five or more fish were collected were included in the regression. The 95% confidence intervals were calculated using the standard error of the slope.

**Results.** Of the three structures evaluated for estimating ages of yellow perch in the Pymatuning Sanctuary, we found otoliths to be the most precise. Ages assigned by two independent readers using otoliths agreed 96% of the time. Paired t-tests indicated no significant differences between the ages assigned by two readers using each structure ( $P > 0.05$ ). Using otolith ages as a benchmark, ages assigned using dorsal fin spines were more precise ( $CV = 5.21\%$ ) than ages assigned using scales ( $CV = 9.91\%$ ). Otoliths were the best structure to use for determining yellow perch age as evidenced by high reader agreement. However, we found that scales could be used to adequately describe the age structure of yellow perch populations (Niewinski and Ferreri 1999).

The age and size structures of this unexploited yellow perch population were markedly different between males and females collected in the spring on the spawning grounds (Figure 1). Most males collected were between one and three years of age and between 90 and 150 mm total length, while most females were three to five years of age and between 280 and 360 mm long.

Most male yellow perch (70.5%) were mature by age 1 and all (100%) by age 2. In contrast, a few (3.8%) female yellow perch were mature at age 1; with most (62.9%) becoming mature by age 2 and all (100%) mature by age 3. Most males were mature at a mean total length of 82 mm, while most females were mature at a mean total length of 152 mm. The



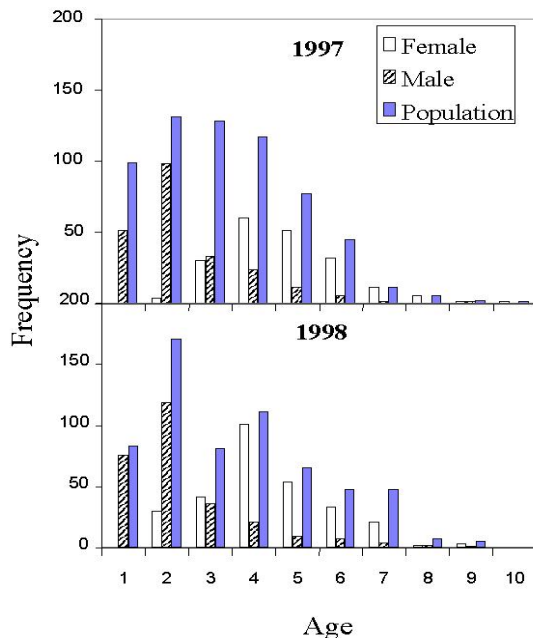


Figure 1. Age frequency of yellow perch collected from the Pymatuning Sanctuary in the Spring of 1997 and 1998. Population includes all males, females, and those yellow perch designated as unknown sex.

length interval at which 100% of the male yellow perch were mature was 101-125 mm and the length interval at which 100% of the females were mature was 201-225 mm. The total number of eggs produced per female yellow perch ranged from 443 in a 126-mm, age 2 female to 104,268 in a 351-mm, age 7 female. The mean number of eggs per fish increased with fish size (length or weight). Using simple linear regression, we determined that fish weight and wet ovary weight were the two best predictors of fecundity (Table 1).

Table 1. Simple linear regression equations and  $R^2$  values for predicting total fecundity using fish weight, total length, ovary weight, and age for yellow perch collected in Pymatuning Sanctuary, Spring 1998.

Variable	Equation	$R^2$
Fish weight (g)	$F = -1415 + 122 \text{ Wt.}$	0.95
Fish length (mm)	$F = -66980 + 399 \text{ L.}$	0.86
Ovary weight (g)	$F = 4542 + 408 \text{ Ov. wt.}$	0.95
Age	$F = -25542 + 14555 \text{ Age}$	0.75

Annual survival for the sample population was 0.51 in 1997 (0.56 for males and 0.47 for females) and 0.59 in 1998 (0.57 for males and 0.62 for females). Overlap in the 95% confidence intervals on

sex-specific survival rates indicated that male and female yellow perch survival was similar both within years and between years.

**Discussion.** The current management of the Pymatuning Sanctuary, as a source of warmwater broodstock for Pennsylvania, provided the unique opportunity to evaluate the structure and dynamics of an unexploited yellow perch population. In general, we found that yellow perch in the Pymatuning Sanctuary are larger and older, compared to exploited populations where many of the larger individuals have been removed through fishing. In comparison to other yellow perch populations, males and females in the Pymatuning Sanctuary reached maturity approximately one year earlier with 100% of males becoming mature at age 2 and 100% of females becoming mature at age 3. Absolute fecundity determined for this population was within the range of yellow perch fecundity found in other studies. As expected, annual survival was higher for this yellow perch population than for those experiencing some level of fishing pressure. With these data now available, fishery managers can compare unexploited with exploited yellow perch populations to determine how fishing pressure may influence the structure and dynamics of these populations.

**Acknowledgments.** Funding for this project was provided by the School of Forest Resources at The Pennsylvania State University. We thank J. Harvey, C. Billingsley, and F. Johns, PA Fish and Boat Commission for their on-site support, S. Tonsor at The University of Pittsburgh's Pymatuning Laboratory of Ecology for providing housing and laboratory space, and P. Kocovsky and M. Krumrine for their help in the field.

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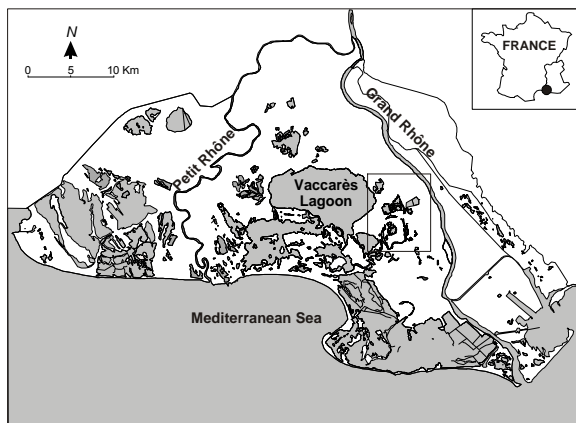
## LIFE HISTORY TRAITS OF THE PIKEPERCH *Sander lucioperca* (L.) IN THE SOUTHERN OUTSKIRT OF ITS DISTRIBUTION AREA

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**Introduction.** In 1948 the pikeperch colonised the sandy Vaccarès lagoon, in the Mediterranean delta of the Rhône River (Goubier 1972). Very few data are available about the life history traits of pikeperch in the southern part of its distribution area. Yet, such information is crucial for the species management. We investigated growth, maturity, fecundity and the diet of one of the Rhône delta population.

**Methods.** The study area was located in the Rhône delta (Fig. 1), southern France (43°34 N, 4°34 E). The Fumemorte canal collects water from a complex canal network spreading over 68 km<sup>2</sup>. It was shallow (1 m), around 14 m wide and flowed into the brackish Vaccarès lagoon. The salinity in the canal varied from 0.1 g l<sup>-1</sup> in summer to 5 g l<sup>-1</sup> in winter depending mainly on the agricultural activities. The water remained highly turbid all over the year.



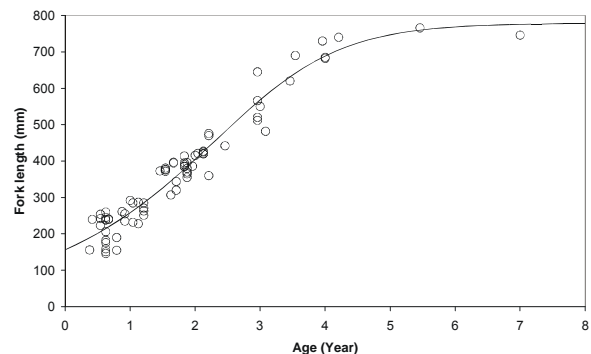
**Figure 1.** The Rhône delta (the Camargue). The rectangle delimites the Fumemorte basin.

Age readings were performed on scales and otoliths of 30 males and 46 females captured from 2000 to 2002. The growth curve was fitted using the Schnute (1981) model which includes numerous historical models as special cases and the fitting was processed by non-linear regression based on the least squared errors. Sexual cycle was determined by monitoring the Gonadosomatic Index (i.e. weight of ovaries\*100/total weight). Length at first maturity was considered as the length at which 50% of the individuals were mature using a logistic regression. Both sexual cycle and maturity were studied using pikeperch collected since 1982 (more than 300 fish). The fecundity was measured on 17 females captured

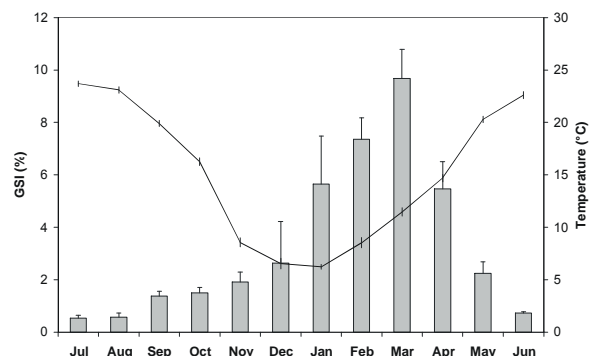
between January and March 2000 and was estimated by weighting 500 eggs to the nearest 1/10 mg in a tarred water volume. As the weight of the eggs changed among month, its relation with the fork length was tested using a covariance analyse where the length was the covariable and the month the fixed factor. Diet analysis was performed on 194 pikeperch caught between 1982 and 2002. The occurrence of each prey was registered.

**Results.** No growth difference between sexes was observed (ANCOVA,  $F_1=1.28$ ,  $p=0.26$ ). Richards growth model was the best to fit pikeperch growth in the Fumemorte canal, both sexes pooled (Fig. 2;  $n=76$ ,  $r^2=0.94$ ;  $p<0.001$ ). The estimated fork length at 1 year was 258mm, 2: 404mm, 3: 568mm, 4: 689mm and 5 years: 747mm. The estimated  $L_{inf}$  was 779mm.

The spawning occurred from mid-March to late April, at a temperature of 12°C-15°C (Fig. 3). A sexual rest occurred in summer and the ovaries maturation took place from September to March.

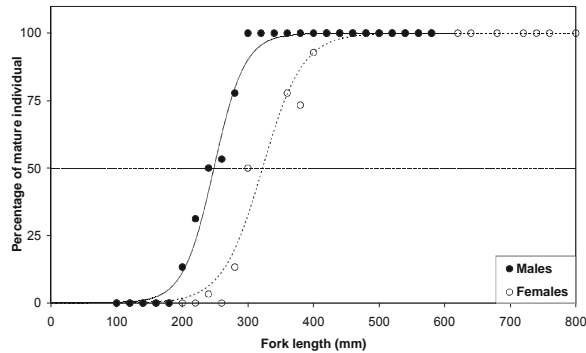


**Figure 2.** Growth of the pikeperch fitted according to the Richard growth model.



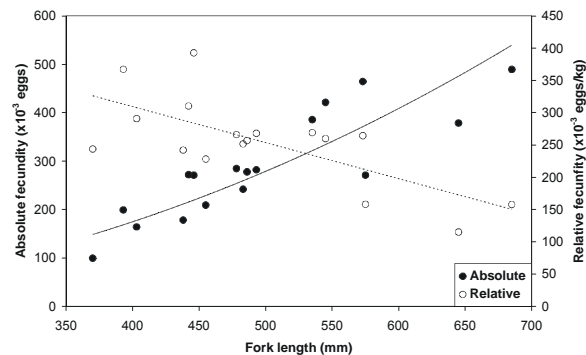
**Figure 3.** Monthly mean ( $\pm$  S.E.) Gonadosomatic Index development (bars) and monthly mean ( $\pm$  S.E.) temperature between 1988 and 2000 (solid line).

Fifty percent of the males reached their sexual maturity at 246mm (11 months) and 50% of the female at 322mm (18 months) (Fig. 4). The smallest mature male and female were 215mm and 242mm long respectively.



**Figure 4.** Length at first maturity of the male (solid line) and the female pikeperch (broken line).

The mean relative fecundity was 255412 ( $\pm 16710$ ) eggs/kg. The absolute fecundity increased significantly with the fork length according to a power function ( $n=17$ ,  $r^2=0.77$ ,  $p<0.001$ ), while the relative fecundity decreased significantly according to a linear function ( $n=17$ ,  $r^2=0.46$ ,  $p=0.002$ ) (Fig. 5). The egg weight ( $n=17$ , mean=0.53mg  $\pm$  0.06) increased significantly with the fork length (ANCOVA,  $F_1=9.8$ ,  $p=0.008$ ).



**Figure 5.** Regression of absolute (solid line) and relative fecundity (broken line) on the fork length.

On 194 stomachs investigated, 107 were full and 89.7%, 11.2% and 2.8% contained fish, crustacean and other preys, respectively. Among the 64 stomachs displaying identifiable species 58% contained *Atherina boyeri*, 19% shrimp and 14% *Mugil* spp. Other species as *Lepomis gibbosus*, *Carassius gibelio*, *Alburnus alburnus*, *Abramis* spp. and *Pseudorasbora parva* were also found. No cannibalism was observed.

**Discussion.** The growth of the pikeperch in the Fumemorte canal was one of the fastest observed for this species. This might be due to the geographical

location: summer water temperatures at this latitude are close to the pikeperch physiological optimum (i.e. 27°C, Hokanson 1977). Thus 0+ become piscivorous early which speeds up their growth. The age at first maturity was also among the earliest reported but the usual difference between males and females was still observed. As for growth, the acquisition of the sexual maturity probably depended on the latitude: earlier maturity is related to fastest growth rate at lower latitudes (Lappalainen et al. 2003). The power function fitting the absolute fecundity and length was congruent with an early sexual maturity (Zivkov & Petrova 1993). Smaller females had a greater relative fecundity which was seldom observed for this species (Lappalainen et al. 2003). This may be due to the short lifespan of the pikeperch in the Fumemorte canal bringing the females to express their full fecundity potential at their youngest age. However, older females displayed heaviest eggs: this is commonly observed for teleost fish. Further data on fecundity and egg size would be necessary to confirm these results. In the Fumemorte canal, adult pikeperch fed on fish but also on shrimp. Sandsmelt and mullet were only abundant in winter. Nevertheless, other species abundant all over the year also provide suitable preys. This fact associated with the low density of pikeperch could explain why no cannibalism occurred. Environmental conditions in the Rhône delta bring the pikeperch to adapt its life history traits thereby proving its plasticity.

**Acknowledgements.** Great thanks to P. Contournet for the sampling and to J. Lappalainen and P. Irz for their valuable comments.

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## IMPACT OF ZANDER STOCKING ON PERCH AND PIKE IN A MESOTROPHIC LAKE.

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**Introduction** Top down control of pelagic food webs was assumed to be strongest in mesotrophic lakes but empirical evidence to support this assumption is rare. To compare the interaction intensity within pelagic food webs in a mesotrophic lake before and after manipulation of the piscivorous level, the pelagic and night active species zander (*Sander lucioperca* (L.)) was additionally stocked into a lake inhabited by perch (*Perca fluviatilis* L.) and pike (*Esox lucius* L.). By comparison of feeding pressure and habitat choice of fish in the period before (1997/98) and after zander stocking (2001/02), the response of ecosystem structure was investigated. In this work first results of the influence of zander introduction on the ecology of the perch and pike populations is presented.

**Methods.** Mesotrophic Lake Großer Vätersee (12 ha, max. depth 11.5 m) is situated in north eastern Germany. In 1997/98, roach (*Rutilus rutilus* (L.)) and perch were the dominant non-predatory species (Haertel *et al.* 2002). Predatory fish were pike and large perch. Population estimates from mark-recapture surveys in 1998 for pike and perch were 156 kg and 96 kg, respectively. Fish were caught by electric fishing in both periods and with gill nets in the with-zander period. Mesh sizes used were 25, 32, 40 and 50 mm. Nets were set at day, twilight and night and different depths. In both periods stomach contents were obtained by stomach flushing. Prey biomass was recalculated from stomach remains. To double the biomass of piscivorous fish and to introduce a pelagic and night active predator, 719 (182 kg) and 301 (100 kg) age-2 zander (mean total length  $31 \pm 4$  cm standard deviation) were stocked in spring 2001 and 2002, respectively.

**Results.** During the zander-free period it was found that pike were mainly restricted to the littoral zone throughout the whole day. Perch were mainly found in the pelagic area during day and were inactive during night. From 45 perch caught during daytime, 88% were caught in the pelagic zone. After stocking with zander, pike still inhabited the littoral zone. Results from gill net catches showed that pike were most active during day but catch per unit effort (CPUE) was low (Figure 1). No pike were caught at night. After stocking with zander, CPUE of perch was highest during day and no perch were caught at night. CPUE were similar for all depths during daytime indicating that perch were evenly distributed in all

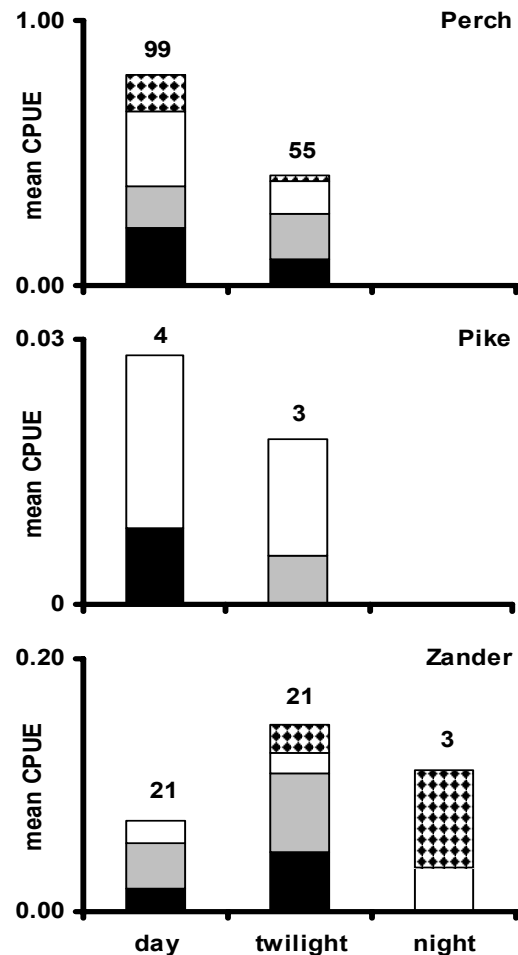


Figure 1. CPUE (numbers) in gill nets set at different depths of perch, pike and zander in Lake Großer Vätersee in 2002. ▣ surface, □ 3 m, ◻ 6 m, ■ 8 m. Figures above columns indicate fishes caught. Please notice differences in y-axes scale.

habitats. During twilight, CPUE in the surface net was low. CPUE of zander was highest during twilight and zander were also caught at night. During twilight CPUE was generally highest at depths more distant from the shoreline.

Stomach contents of perch (wet weight) was dominated by roach and *Orconectes limosus* during the zander-free period (Figure 2), whereas perch was rarely eaten. In response to zander stocking, there was a shift in prey dominance of piscivorous perch

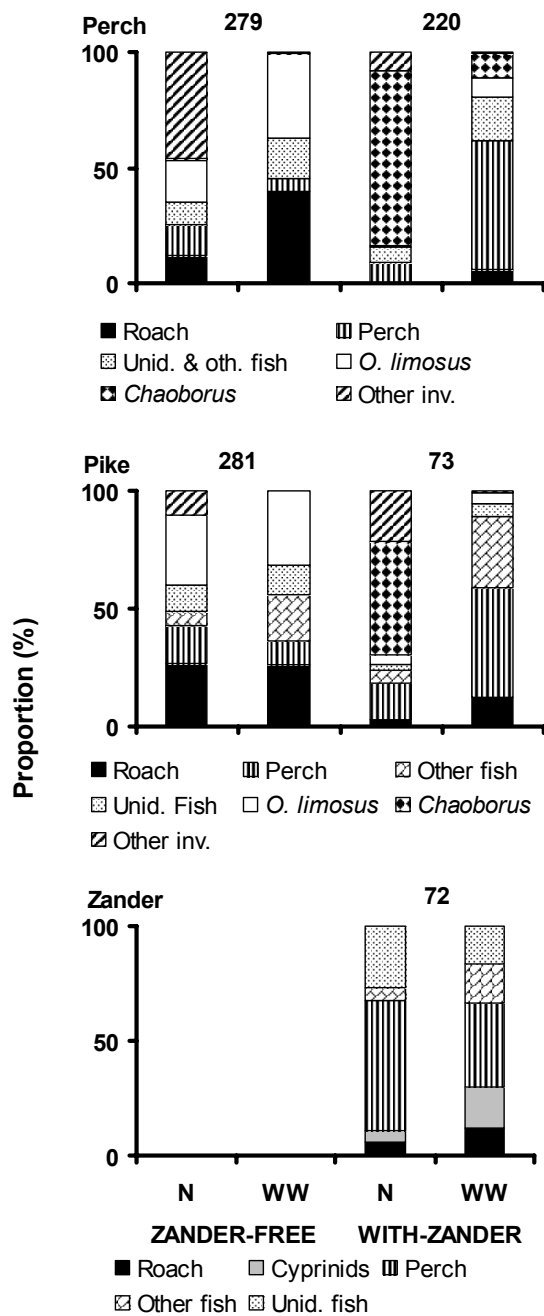


Figure 2. Composition of stomach contents by numbers (N) and by wet weight (WW) for 'zander-free' and 'with-zander period'. Unid.= unidentified; Oth.= other. Inv.= invertebrates. Figures above columns indicate numbers of stomachs analysed.

towards strong cannibalism on YOY perch. In addition, *O. limosus* was largely replaced by *Chaoborus*.

Pike fed mainly on roach and other fish species except for perch and *O. limosus* during the zander-free period. In contrast, during the with-zander pe-

riod, dominant prey were perch and other fish species. Zander fed mainly on perch and cyprinids.

**Discussion.** In the present study, clear changes in habitat choice of perch and in the diet of perch and pike have been observed in response to stocking with a night-active pelagic predator. In contrast, no changes in pike activity and habitat choice became visible. This may support the assumption that competition by introduced zander was stronger on the pelagic piscivorous perch than on the more littoral living pike.

Diet composition of pike and perch showed a decrease in the proportion of roach and *O. limosus* and an increase in perch and *Chaoborus*. The antagonistic shift between roach and perch may reflect a change in habitat choice of roach. Whereas roach were exclusively caught in the littoral zone during the zander-free period at daytime, at night more than 90% of roach were caught in the pelagic zone (Haertel *et al.* 2002). A different image was found during the period after zander stocking (Dörner, unpublished data). In those years, roach showed a less clear diel pattern of habitat choice and was found both in the pelagic and the littoral zone during night. During day, however, roach was still caught at high proportions in the littoral zone. Much lower pelagic CPUE of roach in this period as compared to 1997 and 1998 is caused by a behavioural response of the roach population as abundance of roach has not severely altered between both periods. This indicates that behaviour of roach was altered by the nightly activity of zander in the pelagic. Furthermore, a simulation with an individual-based model revealed that roach consumed pelagic plankton prey to a much lower extent if diel migrations were stopped (Hölker *et al.* 2002) which is expected to impact substantially the whole pelagic food web. The trophic changes in response to zander stocking will be analysed by means of a bioenergetic model and mark recapture data to address whether the trophic interactions are indeed strongest at meso-trophic conditions.

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## RISK ANALYSIS AND GENETIC IDENTITY OF THE EURASIAN SOURCE POPULATION FOR THE RUFFE (*Gymnocephalus cernuus*) INVASION IN THE GREAT LAKES

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**Introduction.** Risk analysis methodology, coupled with the genetic characterization of invasive and potential source populations, may allow scientists and managers to predict the spread patterns and successes of nonindigenous species invasions. In this study, we compare nuclear and mitochondrial DNA sequence data from potential source populations in relation to the original colonization and spread sites for the Eurasian ruffe *Gymnocephalus cernuus*. The ruffe colonized the western Lake Superior region of the North American Great Lakes (Fig. 1) during the mid-1980s, after its accidental introduction via shipping ballast water discharge from one or more unknown Eurasian source populations. The ruffe is now an abundant nearshore benthic fish in western Lake Superior. During the early 1990s, it spread rapidly eastward along Lake Superior's southern shore and since then slowed in range progression, contrary to predictions by some fishery scientists. Shipping traffic also was the likely vector for the ruffe's 1992 introduction 300 km ne to Thunder Bay Harbor, Canada as well as its 1995 establishment in Lake Huron at Thunder Bay River, near Alpena, MI (site 11, Fig. 1). In 2002, it appeared in Little Bay de Noc of Lake Michigan near Escanaba, MI (site 12, Fig. 1).

The potential North American range of the ruffe originally was predicted to extend from the Great Plains to the eastern seaboard and north into Canada (Busiahn 1993). Its widespread Eurasian range led scientists to predict that the ruffe would quickly colonize the lower Great Lakes and potentially outcompete the yellow perch *Perca flavescens*. International efforts have focused on preventing new ballast water introductions and the Ruffe Control Program has sought to stem its spread. Here we analyze the ruffe's genetic characters in native and invasive populations in Eurasia and North America, based on nuclear DNA sequences of the LdhA6 intron and the mitochondrial DNA control region, in relation to risk analysis predictions and its spread patterns.

**Methods.** Ruffe were sampled from seven Eurasian population sites (Fig. 2), including: the Danube River at Gabčíkovo, Slovakia (site 1, N=13), the Morava River, Czech Republic (site 2, N=8), the Elbe River near Magdeburg, Germany (site 3, N=11), Bassenthwaite Lake, United Kingdom (an invasive location; site 4, N=12), Loch Lomond, Scotland (another invasive location; site 5, N=12), St.

Petersburg, Russia (site 6, N=15), and the Ob' River at Novosibirsk, Siberia, Russia (site 7, N=12).

Collections from North America included three sites off Lake Superior, representing the initial North American introduction (Fig. 1): the St. Louis River, MN (site 8, N=4), Superior Harbor, WI (site 9, N=12), and the Amnicon River, WI (site 10, N=10). Individuals also were examined from the Thunder Bay River, a tributary of Lake Huron at Alpena, MI (site 11, N=6), as well as from Little Bay de Noc in Lake Michigan at Green Bay, WI (Site 12, N=3).

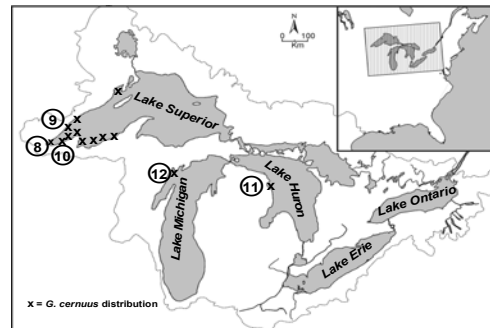


Figure 1. North American range of the ruffe (X), with numbered collection sites in circles.

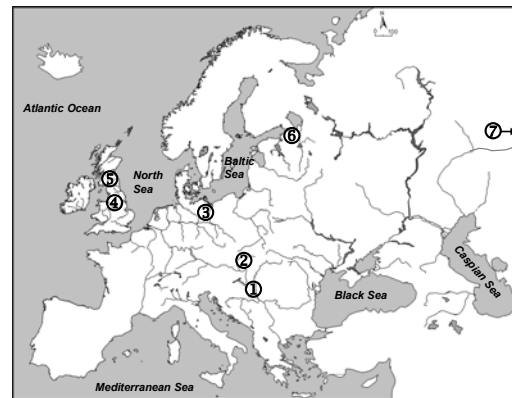


Figure 2. Eurasian collection sites for ruffe.

Methodology for DNA extraction, PCR amplification, and DNA sequencing of the mtDNA control region followed Stepien et al. (1998). Procedure for the sixth intron of the nuclear muscle-type lactate dehydrogenase A (LdhA6) locus followed Quattro and Jones (1999). Sequences were

run either manually (Stepien et al. 1998) or on a Beckman-Coulter CEQ 8000 capillary autosequencer separately in both directions. Data analysis of relationships among haplotypes included neighbor-joining trees in the programs Mega 2.1 using Kimura 2-parameter genetic distances and maximum parsimony using the branch-and-bound algorithm in PAUP\*, each with 1000 bootstrap replications. Distributions of haplotypes among sites and genetic divergences were analyzed with the programs AMOVA in Arlequin 2.1 and Genepop.

**Results.** The mtDNA control region of ruffe and its congeners comprised 1,024 bp. Sequences were deposited in GenBank as Accession Numbers AF025355-62. Ruffe had 5 different haplotypes (A-E), and all population sites contained only a single type - except for the Ob' River, which had two (D and E) (Fig. 3). All samples from the Great Lakes were haplotype A, matching ruffe from the Danube, Morava, and Elbe Rivers. Haplotypes from western and central Europe (A and B) were widely diverged from those in northern Eurasia (C, D, and E).

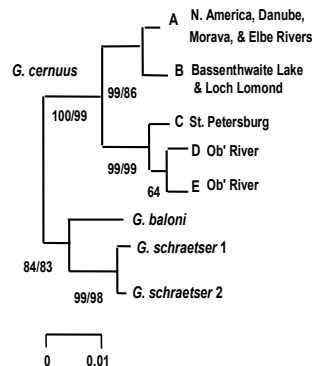


Figure 3. Neighbor-Joining and maximum parsimony tree of relationships among mtDNA haplotypes, with 1000 bootstrap replications.

The nuclear DNA LdhA6 intron for ruffe and its congeners comprised 198 bp and were deposited as Accession numbers AY034781-3 in GenBank. This nuclear intron was significantly more variable than mtDNA, having 16 different haplotypes. Each sampling location housed 3-7 LdhA6 haplotypes. Three haplotypes occurred in the North American Great Lakes, and did not significantly differ in their representation among those sites. The Elbe River also contained only 3 haplotypes identical to those in the Great Lakes, in statistically similar frequencies. One haplotype was only found in North America (24% of samples) and the Elbe River (27%). Samples from other Eurasian sites significantly differed from those in the Great Lakes and the Elbe River.

**Discussion.** The genetic composition of the nonindigenous introduction of ruffe in the Great Lakes matches that from the Elbe River drainage region in nw Europe (which empties into the Baltic and North Seas) for both nuclear and mitochondrial DNA sequences. All later colonization areas in the Great Lakes appear to stem from the original introduction in the St. Louis River region of Lake Superior. There thus appears to have been a single colonization source for the introduction, from the vicinity of the Elbe River. Ports on the Elbe River increasingly opened to shipping traffic with North America preceding the 1990 reunification of Germany, coinciding with the time of the anthropogenic introduction of the ruffe. This population may be better pre-adapted to the temperatures and other environmental conditions in the upper Great Lakes, and less well suited to habitats in the lower Great Lakes – which should be further analyzed. As in our genetic studies of the dreissenid mussel and round and tubenose goby invasions in the Great Lakes, the new ruffe population has a similar level of genetic variation to the founding population, indicating that a large number of individuals were introduced and there was no apparent “founder effect”. Risk analyses suggest that founding success may increase with introduction of large numbers of individuals representing the “normal” amount of genetic variation in native populations. Relatively slow spread may be due to the introduction of a single source population and ballast control efforts.

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## AN ANALYSIS OF GENETIC RISK TO A NATIVE SPAWNING STOCK OF WALLEYE *Sander vitreus* DUE TO STOCKING IN CATTARAUGUS CREEK

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**Introduction.** Prior to the last 3 years, a substantial native spring spawning run of walleye *Sander vitreus* (*Stizostedion vitreum*) was unknown in Cattaraugus Creek – an eastern Lake Erie basin tributary whose mouth is near a native walleye spawning ground in Van Buren Bay – due to the remote location of these grounds belonging to the Seneca Nation. Believing that there was no native walleye run but that the habitat was suitable, the New York Department of Environmental Conservation (NYDEC) stocked Cattaraugus Creek with about 2.2 million 1-3 day-old fry and 44,000 fingerlings from Maumee River (western Lake Erie) run origin hatchery fish per year from 1995-2000. Genetic data from our laboratory showed that walleye spawning in Lake Erie tributaries and reefs are genetically divergent, suggesting spawning site philopatry- i.e., return to natal areas (Stepien and Faber 1998). The NYDEC then discovered a substantial native stock return in Cattaraugus Creek, estimated as 2000-4000 individuals. The present study tests the degree of genetic diversity and divergence of the original spawning stock, using older walleye in comparison to the nearby spawning group in Van Buren Bay. We then compared the genetic composition of the older fish with younger individuals (age 2-4), which are unknowns that may represent either stocked individuals and/or the offspring of the original individuals.

**Methods.** Fin clips from spring spawning run walleye were collected by Ohio Division of Wildlife from the Maumee River (the source for the hatchery stock), the Sandusky River. NYDEC collected spawning run walleye from Cattaraugus Creek in the eastern basin of Lake Erie (including older individuals, ranging from 7 to 20 years old by otolith rings) and younger individuals. We compared 25 old (pre-stocking) versus 20 young (stocked and non-stocked individuals). We also compared a nearby population (Van Buren Bay) and the stocking source population (Maumee River).

We analyzed sequence from entire 1200 bp of the mtDNA control region in comparison with our data base of 400 walleye from the Great Lakes. DNA was extracted and purified with a Quiaquick kit. The entire mtDNA control region was PCR amplified following Stepien and Faber (1998). PCR products were purified using an Exosap kit and sequenced separately in both directions for verification on a

Beckman CEQ 8000 capillary autosequencer. We analyzed sequence from entire 1200 bp of the mtDNA control region in comparison with our data base of 400 walleye from the Great Lakes.

Neighbor joining trees and maximum parsimony analysis of relationships among haplotypes, including comparison to sauger *S. canadense* were constructed with MEGA2 and PAUP\*, and support for relationships was compared with 1000 bootstrap replications. Hierarchical analysis of variance using AMOVA in Arlequin examined divergence among spawning sites and population groups.

**Results.** AMOVA hierarchical  $F_{ST}$  analyses showed significant differences among all spawning sites tested in Lake Erie (including those shown in Table 1 and Fig. 1). Results revealed that the original spawning population in Cattaraugus Creek is very genetically diverse, with many unique haplotypes and significantly diverged from the other spawning sites tested (Fig. 1 and Table 1). However, there was no significant difference between the genetic compositions of Cattaraugus Creek older versus younger individuals.

**Discussion.** The native Cattaraugus Creek spawning stock is very genetically diverse and should be maintained. It is likely that the history of exploitation pressure in this spawning habitat area has been light, leading to the preservation of high genetic variability to date. The genetic composition of the native Cattaraugus Creek population is very different from the nearby population spawning in Van Buren Bay. Recent spring returns in Catt Creek are not significantly genetically divergent from the older returns. There is no indication that stocking efforts significantly influenced the native Cattaraugus Creek walleye group.

**Acknowledgements.** This study was supported by the NOAA Ohio Sea Grant Program, the Lake Erie Protection Fund, and the CSU Risk Analysis Program. We also thank K. Kayle, R. Knight, and E. Roseman, for specimens. E. Whippo-Cline, M. Tumeo, J. Reutter, and J. Busch provided logistic support.

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## Neighbor-Joining Tree of relationships among mtDNA control region haplotypes (MEGA 2003)

**St=** Lake St. Clair, MI  
**M=** Maumee River, OH  
**S=** Sandusky River, OH  
**G=** Grand River, OH  
**V=** Van Buren Bay, NY  
**O=** Grand River, Ontario  
**C=** Cattaraugus Creek, NY

*Note: Many unique Cattaraugus Creek haplotypes, widely distributed throughout the tree. This spawning population is very genetically diverse.*

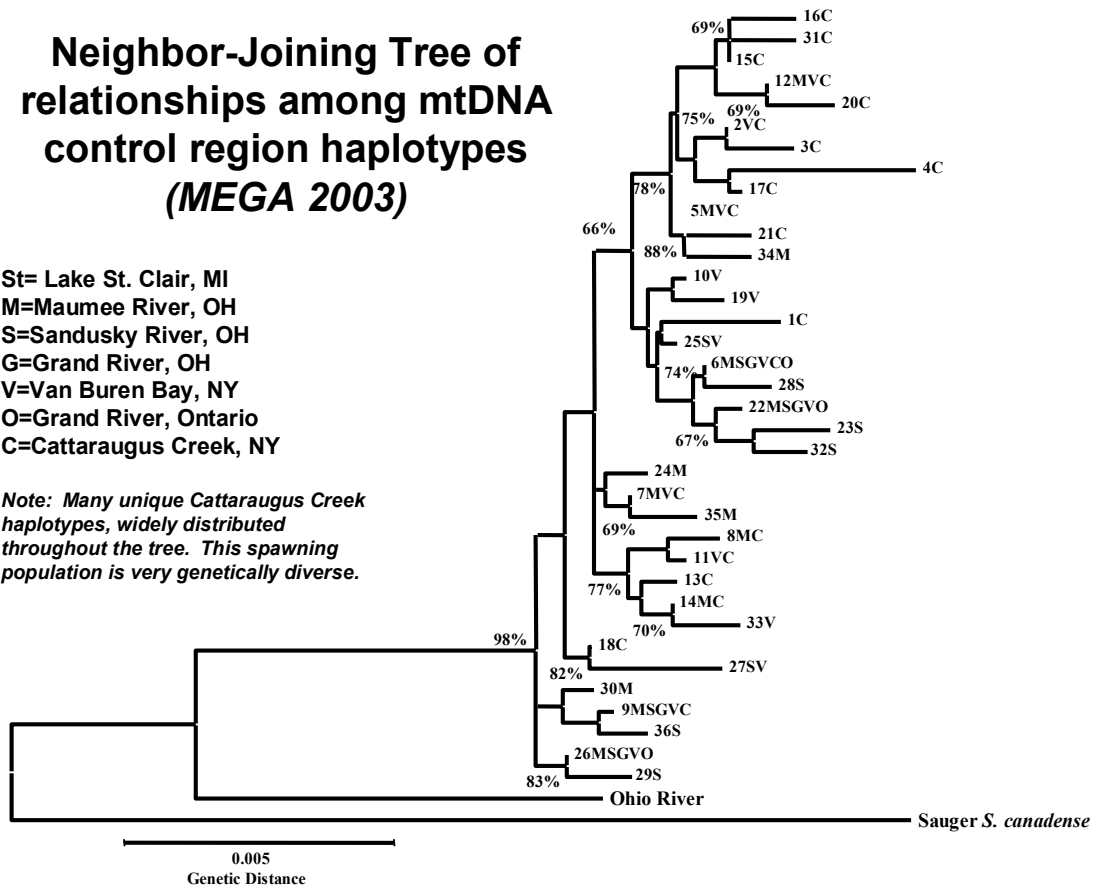


Fig. 1. (above). Neighbor-Joining tree of relationships among mtDNA control region haplotypes of walleye from spawning sites in Lake Erie based on 400 individuals analyzed (Mega 2.1). Numbers at nodes represent support from 1000 bootstrap replications. A unique type from the Ohio River (Stepien and Faber 1998) and its sister species, the sauger *S. canadense* are shown at the base of the tree, for comparison. Nodes with relatively high bootstrap support also were supported by maximum parsimony analyses in PAUP\*.

Table 1. (below) Distribution of mtDNA control region haplotypes among Lake Erie spawning sites examined.

Haplotype	2	5	6	7	8	9	12	14	11	22	26	Unique Catt. Creek	Unique Van Buren	Unique Maumee River
Catt. Creek Old	3 14.2%	1 4.8%	2 9.5%	1 4.8%	1 4.8%	2 9.5%	1 4.8%	1 4.8%	---	---	---	9 42.7%	---	---
Catt. Creek Young	1 5.6%	4 22.2%	---	2 11.1%	2 11.1%	1 5.6%	1 5.6%	---	4 22.2%	---	---	3 16.6%	---	---
Van Buren Bay	1 1.7%	4 6.7%	20 33.3%	2 3.3%	---	7 11.6%	---	---	3 5%	4 6.7%	13 21.6%	---	6 10.0%	---
Maumee River	---	14 23%	12 19.6%	3 4.9%	1 1.6%	4 6.6%	1 1.6%	2 3.3%	---	8 13.1%	11 18.1%	---	---	5 8.2%



## LONG-TERM TRENDS IN THE TIMING OF THE SPAWNING SEASON OF EURASIAN PERCH (*Perca fluviatilis*) IN THE NORTH BASIN OF WINDERMERE, U.K.

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**Introduction.** As in many fish taxa, the seasonal timing of spawning in percids is controlled by a number of exogenous factors including photoperiod, substrate conditions, water level and velocity, social interactions and, particularly, water temperature (Craig 2000). Indeed, many studies in Europe and North America have demonstrated significant effects of annual variations in lake temperature on spawning in *Perca* species in particular.

Given this established dependency on temperature, there is a clear potential for percid spawning time to be impacted by climate change. However, assessment of such hypothesised impacts requires appropriate environmental and population datasets of long duration. To date, among lake fishes such analyses have been performed only for an esocid (pike, *Esox lucius*) and a cyprinid (common bream, *Abramis brama*) in Lake Peipsi, Estonia, where the beginning of spawning was found to have advanced by 6 and 8 days, respectively, between 1952 and 1996 (Ahas 1999).

Many physical, chemical and biological features of Windermere, U.K., where a major component of the fish community is the percid Eurasian perch (*Perca fluviatilis*), have been intensively studied since the early 1930s, resulting in an extensive array of datasets very suited to addressing issues of climate change. The objectives of this study were to use two of these datasets to determine if there has been any long-term trend in the seasonal timing of spawning by perch in this lake, and if so to investigate if such change can be related to water temperature.

**Methods.** Windermere (54° 22' N, 2° 56' W; surface area 14.8 km<sup>2</sup>; maximum depth c. 64 m) is elongate in shape and composed of north and south basins separated by a narrow area of shallows. While the south basin has been subjected to considerable eutrophication, the north basin has shown only slight elevations in nutrient levels since the 1940s (CEH Windermere, unpublished data). Perch is the dominant littoral species throughout the lake, although its population dynamics in the two basins are discrete (see Le Cren 2001).

Inshore surface water temperature was recorded c. daily from 1933 to the present and used to calculate an annual mean from 1946 to 2002 and a mean for weeks 1 to 15 of the year from 1946 to 2003. Perch were trapped annually for a period of at least 6 weeks on a number of spawning grounds in both basins of the lake from 1946 to the present. Traps were lifted at 1 week intervals and all catches were enumerated, measured and sexed. Further sampling and processing details are given in Le Cren (2001).

For the present analysis, only trap data from the single north basin site of Green Tuft (National Grid Reference NY 374 019) were used in order to avoid the south basin complications of eutrophication. In

addition, only data from a 6 week period during each year were used in the present analyses. Such data most commonly ran over weeks 17 to 22 (30 years) or from weeks 18 to 23 (20 years), or less frequently from weeks 16 to 21 in 1985 and 1997 to 2003 (8 years). These data were used to calculate for each year the week of the peak catch of perch and the week by which 50% of that year's total perch catch had been recorded. The latter parameter provides a more stable description of the timing of spawning each year and was so subjected to statistical evaluation including regression on the mean temperature of weeks 1 to 15, i.e. the period before spawning.

The above analysis is potentially complicated by changes in spawning time arising from demographic changes within the perch population since 1946, during which time length frequency distributions, sex ratios, disease prevalence and population abundance have changed dramatically (Le Cren 2001; CEH Windermere, unpublished data). In an attempt to reduce the impact of such variations, the above analyses were repeated for only mature male perch in the size range of 100 to 150 mm total length.

**Results.** Over the period from 1946 to 2002, the mean annual temperature of Windermere showed considerable variation but also a clear increase (Figure 1). The latter was evident from the late 1980s onwards, resulting, for example, in the mean annual temperature of 11.31° C (SE 0.18° C) in the 1990s being significantly higher than that of 10.36° C (SE 0.19° C) in the 1950s (*t* test; *t* = 3.66, *df*=18, *p*<0.01).

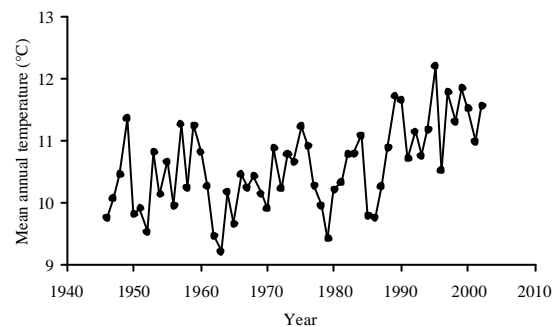


Figure 1. Mean annual water temperature from 1946 to 2002 of Windermere, U.K.

Long-term patterns in the timing of perch spawning as indicated by both week of peak catch and week of 50% catch largely mirrored that of mean annual temperature, with both parameters advancing earlier in the year and again with an apparent step change during the late 1980s (Figure 2). Assessing these changes for the week of 50% catch simply by

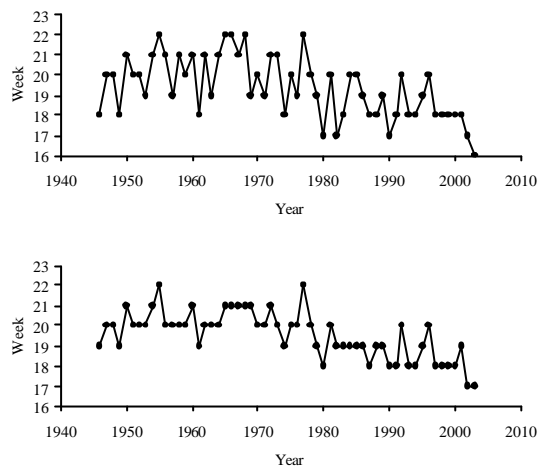


Figure 2. Week of the year of the peak perch catch (upper) and week of the year by which 50% of that year's total perch catch was reached from 1946 to 2003. For both time series, mean values for the first half of the datasets are significantly greater than those for the second halves (see text).

breaking the dataset into two halves, the mean of 20.24 weeks (SE 0.14 weeks) for 1946 to 1974 was significantly greater than that of 18.83 weeks (SE 0.20 weeks) for 1975 to 2003 (t test;  $t = 5.85$ ,  $df=50$ ,  $p<0.001$ ). Figures for the 1950s and 1990s were 20.40 weeks (SE 0.22 weeks) and 18.50 weeks (SE 0.27 weeks) respectively, i.e. an advance of 1.9 weeks or 13 days. For only mature male perch in the size range of 100 to 150 mm total length, the corresponding statistics were a mean of 19.83 weeks (SE 0.15 weeks) for 1946 to 1974 which was significantly greater than that of 18.52 weeks (SE 0.18 weeks) for 1975 to 2003 (t test;  $t = 5.54$ ,  $df=54$ ,  $p<0.001$ ). Figures for such males in the 1950s and 1990s were 20.10 weeks (SE 0.28 weeks) and 18.40 weeks (SE 0.31 weeks) respectively, i.e. an advance of 1.7 weeks or 12 days.

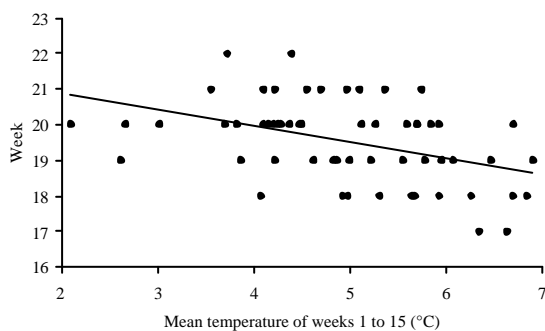


Figure 3. Mean temperature of weeks 1 to 15 of the year and the week by which 50% of that year's total perch catch was reached from 1946 to 2003 (ANOVA,  $r^2=0.186$ ,  $F_{1,56}=12.809$ ,  $p<0.001$ ).

Finally, there was a significant negative relationship between the mean temperature of weeks 1 to 15 and the week of 50% catch over the period

from 1946 to 2003, although it explained only 18.6% of the variation observed in the latter parameter (Figure 3). For mature males in the size range of 100 to 150 mm total length, the corresponding regression statistics were similar (ANOVA,  $r^2=0.208$ ,  $F_{1,56}=14.733$ ,  $p<0.001$ ).

**Discussion.** There has been a clear long-term trend in the timing of perch spawning in the north basin of Windermere over the period from 1946 to 2003, with all descriptors displaying a significant shift towards earlier spawning. In addition, the observed trend appears to be a step function with a transition in the 1980s, rather than a simple linear function. The observed magnitude of this shift of 12 days is greater than those of 6 and 8 days reported by Ahas (1999) for pike and common bream, respectively, although it must be noted that the present study was of greater considerably greater duration (1946 to 2003 compared with 1952 to 1996).

Inverse correspondence between the observed patterns in mean annual temperature and perch spawning time were notable, but clearly the former cannot be the actual driver of the latter because spawning is completed during the first half of each year. However, the present initial analysis also demonstrated that 18.6% of the observed variation in spawning time can be explained simply by the mean temperature during the period of the year before spawning. Given that the rate of temperature change, rather than simply the absolute temperature, has also been shown to be an important determinant of perch spawning time (Craig 2000), it is remarkable that the simple approach adopted here was able to reveal a significant relationship of moderate explanatory power. Examination of relationships between the timing of perch spawning and the rate of temperature increase in Windermere during the early weeks of the year is a high priority of future work, as is extension of the present analysis to data from perch spawning grounds in the south basin of the lake. The implications of the observed advances in spawning time for perch recruitment also remain to be addressed.

**Acknowledgements.** Thanks to many colleagues, past and present, for their help in the field and laboratory. We are also grateful to the Freshwater Biological Association for their joint stewardship of these invaluable data. This work was funded by the Natural Environment Research Council.

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## COEXISTENCE OF THE EURASIAN PERCH (*Perca fluviatilis*) AND AN INTRODUCED POPULATION OF RUFFE (*Gymnocephalus cernuus*): AN 11 YEAR STUDY

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**Introduction.** Competitive interactions between Eurasian perch (*Perca fluviatilis*) and ruffe (*Gymnocephalus cernuus*) have been the subject of a number of experimental studies in the laboratory and field (e.g. Bergman & Greenberg 1994), although relevant long-term observations of population dynamics are notably lacking. The need for such population studies has increased in recent years due to the accidental introduction of ruffe to new water bodies in its native Europe and in North America, with consequent concerns over impacts on native fish communities.

A number of such introductions have occurred in water bodies holding native perch populations in the U.K., probably as a result of anglers live-baiting for pike (*Esox lucius*), including the first recording of the ruffe in Bassenthwaite Lake in north-west England in 1991 (Winfield et al. 1996). This lake, from which removal fisheries are absent, has been subject to extensive monitoring since 1990, making it a particularly appropriate site for the investigation of the impact of introduced ruffe on perch, although the situation is complicated by the fact that the cyprinids roach (*Rutilus rutilus*) and dace (*Leuciscus leuciscus*) also have been recently introduced.

The objectives of this study were to examine the population biology of perch in Bassenthwaite Lake for any changes since the first recording of ruffe in 1991, and if such changes exist to investigate if there is any evidence that they are the result of competitive interactions between these two species.

**Methods.** The fish community of the culturally eutrophic Bassenthwaite Lake (54° 39' N, 3° 13' W; surface area 528 ha; maximum depth c. 19 m; mean depth c. 5 m) was first assessed by autumnal overnight survey gill netting at 2 sites in 1991 and has subsequently been monitored using this technique at these and three additional sites from 1995 to 2002. Community composition by numbers and species catch-per-unit-efforts (number of individuals per net per night) were calculated for major species at a single inshore site (National Grid Reference NY 216 284) which had been consistently sampled throughout the study. All fish sampled in this way were subsequently identified, measured, weighed and a stratified sub-sample aged using the opercular bone. Fish from all sites were used to produce length frequency distributions and fitted von Bertalanffy growth curves, although only those for perch are presented here.

In addition, the diet compositions of perch, ruffe and roach sampled by gill nets in May, July and August 1991 and June, July and August 1995 were determined by numerical and frequency of occurrence methods.

**Results.** Over the study period, perch comprised between 26% and 77% of the fish community by numbers (Figure 1), while ruffe increased in relative

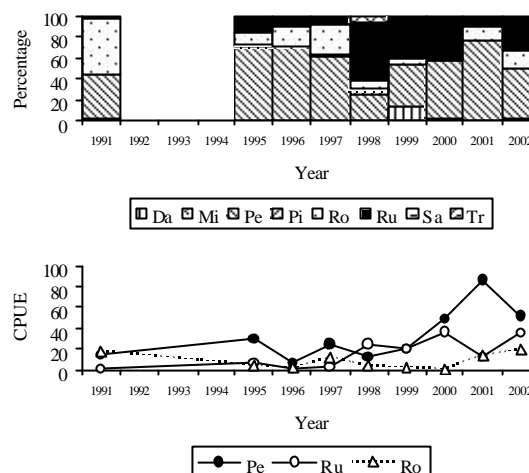


Figure 1. Percentage composition (by numbers, total sample size 316 individuals) of the fish community and the catch-per-unit-effort (CPUE, number of fish per night per net) of the major fish species at one inshore site in 1991 and 1995 to 2002. Abbreviations are as follows: Da, dace; Mi, minnow *Phoxinus phoxinus*; Pe, perch; Pi, pike; Ro, roach; Ru, ruffe; Sa, Atlantic salmon (*Salmo salar*); Tr, brown trout (*Salmo trutta*).

abundance from 2% on their first detection in 1991 to 33% in 2002. The relative abundance of roach declined from 53% to 18% over the same period, with all other species consistently comprising no more than 16% in total. Dace were first detected at this inshore site in 1999, when they comprised 14% of the community. The catch-per-unit effort of perch and ruffe increased over the study period, while that of roach showed no consistent trend.

The length frequency distribution of perch showed a great increase in diversity between 1991, when it was extremely truncated with few individuals in excess of 170 mm, and 2002 by which time a series of discrete length classes was present and individuals in excess of 250 mm were common (Figure 2).

Growth curves (Figure 3) revealed that the restricted perch length frequency distribution in 1991 was the result of extremely poor growth, which subsequently increased greatly in rate and ultimate length to recover to the level previously recorded in 1986 by Mubamba (1989). Growth rate and ultimate length peaked in the late 1990s, whereas perch sampled in 2002 showed the greatest longevity.

The diet of perch (46 to 163 mm, n=73) was dominated by *Daphnia*, with some *Asellus* and chironomid larvae and pupae. In contrast, ruffe diet (56 to 144 mm, n=70) was dominated by chironomid larvae, with some chironomid pupae, *Daphnia*,

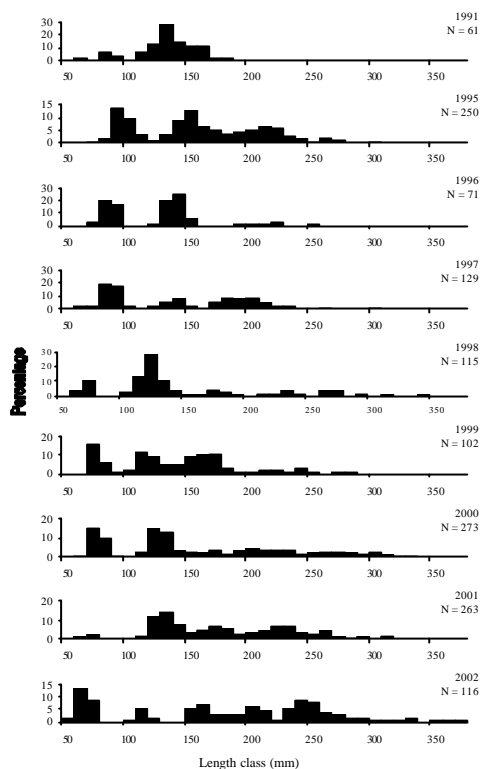


Figure 2. Length frequency distributions (total sample size 1380 individuals) of perch from all sites in 1991 and 1995 to 2002.

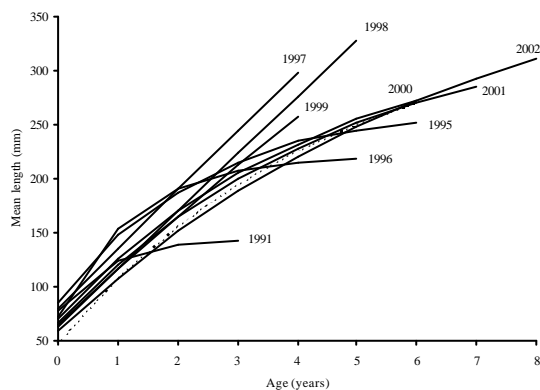


Figure 3. Growth curves (solid lines) of perch from all sites in 1991 and 1995 to 2002. The growth curve in 1986 (data from Mubamba (1989)) is shown as a broken line.

*Asellus* and other benthos. The diet of roach (75 to 338 mm, n=33) was dominated by *Daphnia*, with some chironomid larvae and filamentous algae.

**Discussion.** The fish community of Bassenthwaite Lake is now far removed from its original composition due to introductions of ruffe, roach and dace, followed by their population expansions to the extent that introduced species account for up to 62% of the inshore fish community.

The environment of Bassenthwaite Lake has also changed over the study period. Between 1991 and 2002, the mean annual water temperature increased significantly ( $r^2=0.387$ ,  $n=12$ ,  $p<0.05$ ; CEH Windermere, unpublished data) and Seechi depth showed a decreasing but non-significant trend ( $r^2=0.208$ ,  $n=12$ ,  $p>0.10$ ; CEH Windermere, unpublished data). The competitive balance between perch and ruffe is known to be strongly influenced by environmental factors such that the observed trends in the abiotic and biotic environment of Bassenthwaite Lake are likely to have favoured perch over ruffe. However, the changes were relatively modest in extent and so are unlikely to have been exclusively responsible for the observed dramatic increases in perch relative and absolute abundances, growth rate and length diversity.

These changes in perch population biology clearly show no signs of adverse impacts by the introduced ruffe population through competition or any other means. Thus, the two percids are able to coexist in Bassenthwaite Lake even though the latter species now accounts for up to 53% of the inshore fish community. Moreover, the low diet overlap observed between the two species also refutes a competition hypothesis. In contrast, diet overlap was very high between perch and introduced roach due to common consumption of *Daphnia*. Competition for cladoceran prey between the latter two species under eutrophic conditions often results in depressed perch populations. It is suggested that such a situation existed in Bassenthwaite Lake at the start of the present study period, resulting in a depressed growth rate and truncated length distribution of perch. During the later 1990s, competitive pressure from roach may have been reduced, allowing the recovery of the perch to conditions shown in 1986 before the significant development of introduced populations. The immediate mechanism for this hypothesized reduction in competitive pressure may have been a series of years of very poor or no roach recruitment (CEH Windermere, unpublished data), although the reason for this observed recruitment failure is unknown.

**Acknowledgements.** Thanks to many colleagues, past and present, for their help in the field and for giving access to unpublished environmental data. Components of this work were funded by the Natural Environment Research Council, Environment Agency, United Utilities and English Nature.

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## PIKEPERCH (*Sander lucioperca*) STOCKS AND FISHERIES IN GERMAN SOUTHERN BALTIC LAGOONS

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**Introduction.** Pikeperch (*Sander lucioperca*) has always been one of the most important commercial fish species in lagoons and estuaries of the southern German Baltic Sea where five larger more or less separated populations exist (Stettin Lagoon, Peene River Estuary, Darss-Zingst Bodden Chain, Jasmund Bodden, Lower Warnow River) (Winkler and Thieme 1978). Differences in these populations are induced mainly by different feeding conditions, and thus are specifically linked to life history traits such as growth, body condition, fertility (Winkler 1991). Growth differences lead to various patterns in the age structure of the related populations.

The populations from the Stettin Lagoon and the Peene River estuary are more or less permanently mixed. These two populations show the fastest growth and also have the highest body condition as these are usually not restricted by food supply. Low salinities in adjacent offshore Baltic Sea waters (< 10 PSU) allow some young of the year and older fish to feed offshore, leading them from shallower lagoons and estuaries to deeper areas of the open Baltic Sea. The other three stocks are more or less separated from each other by intermediate waters with higher salinity (> 10 PSU), functioning as a migration barrier. Consequently, these populations are strongly influenced by local situations such as food shortages as they are not able to exploit additional food resources outside their more or less enclosed brackish home waters. Nevertheless, from the commercial perspective the highest population densities, and hence the highest catches per ha, arise from these three

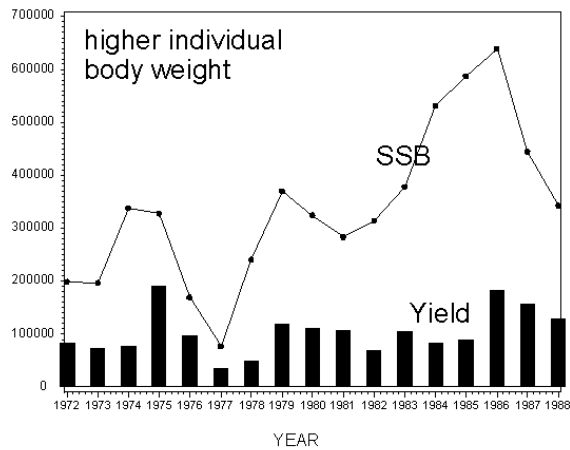
ecologically isolated populations. Here, we report on a study of the population structure and dynamics of the largest of the three isolated pikeperch population to be found in the Darss-Zingst Bodden chain.

**Methods.** We started our investigations in the 1970s. Thus, the population structure, migration pattern, growth, and feeding conditions have been studied for more than 30 years. The population data (length-age compositions, length-weight relationships) were collected from commercial landings usually in spring and fall. Age has been determined from scales. Here, we present preliminary results of a Pope's plain virtual population analysis method (VPA) in order to estimate the fishing mortalities (F) and stock size (N) from a subset of the commercial landings data of the years 1972 to 1989. By using these parameters we further derived the recruitment (R) at age 2, the spawning stock biomass (SSB), the exploitation rate (catch in kg divided by SSB), and the yield per recruit. In order to initialize the VPA we estimated the natural mortality (M) beforehand, and derived terminal F values from a shorter period of 5 years. The model was run assuming either higher or lower individual body weights to illustrate the effect of interannual variations in the length-weight relationship.

**Results and Discussion.** The estimated spawning stock biomass and the commercial catch in numbers are shown in Figure 1. The average population of adult pikeperch ranges between 3 (1977) and 28.7 (1983) individuals per ha. F varies between 0.224 in 1985 and 2.788 in 1980 and the yield per recruit (average of age classes 3-7) between

0.022 and 0.5. Recruitment (in numbers per age class 2) fluctuates widely (Figure 2). Recruitment has a negative correlation with SSB (lagged by one year). Thus, the years with rich recruitment correspond to years of low SSB values (Figure 2).

Yield, SSB (ages 3-7) in kg



Yield, SSB (ages 3-7) in kg

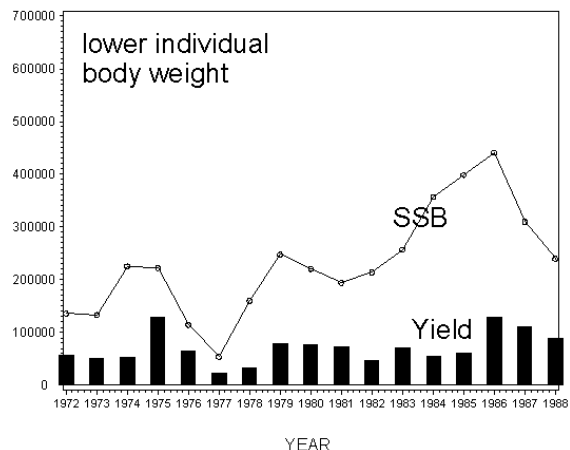


Figure 1. Yield (commercial catch in kg) and estimated spawning stock biomass (SSB, for higher and lower body weights).

This indicates a density-dependent feedback-mechanism between recruits and adults possibly triggered by cannibalism (and indirectly by food shortage). This agrees with investigations of the feeding ecology of pike perch in this lagoon (Winkler 1989, 1991) where high cannibalism rates were observed in some years.

The exploitation rate for age 3-7 varies between 13% and 55%. A negative trend of the exploitation rate was observed. In relation to corresponding F values the catch increases to a maximum, near  $F = 1.0$ . Higher fishing mortalities do not lead to higher exploitation rates. We have planned to incorporate the commercial landings data for 1990 to 2000 into the analysis. Furthermore, we will create an ecosystem-dependent survey index by which the commercial landings can be calibrated. Our future perspective is to finalize all calculations by using the ADAPT algorithm (advanced stochastic VPA) instead of the plain (deterministic) VPA.

Recruitment (age class 2 in numbers)

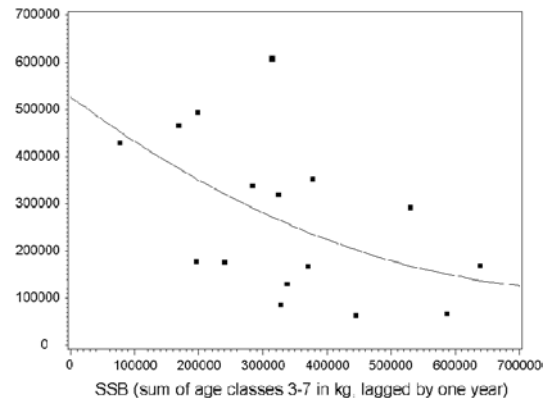


Figure 2. Estimated recruitment and spawning stock biomass. Recruitment =  $526543,2 - 1.003752 \times SSB_{t-1} + 6.191E-7 \times SSB_{t-1}^2$

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## **GENERAL BIOLOGY**

### **Hybridization between sauger and walleye in Lewis and Clark Lake, South Dakota, determined by protein electrophoresis**

*Neil Billington, Rachael N. Koigi, Brian D. S. Graeb and David W. Willis*

### **Influence of temperature and depth on spawning site selection of pikeperch (*Sander lucioperca*) in the Helsinki Sea area**

*Erkki Fontell, Hannu Lehtonen and Jyrki Lappalainen*

### **Trophic feeding of yellow perch using food habits, stable isotopes and parasites**

*Michael W. Johnson, Ray Hesslein and Terry A. Dick*

### **Ontogenetic patterns and interspecific variability in external morphology of three sympatric *Gymnocephalus* species**

*Vladimír Kováč and Stanislav Katina*

### **Distribution of young-of-the-year percids in European reservoirs**

*Josef Matena, Martin Cech, Vladislav Drastík, Jaroslava Frouzová, Michal Kratochvíl, Jan Kubecka, Jiri Peterka and Mojmir Vasek*

### **Histopathological changes during pikeperch *Sander lucioperca* swim bladder development**

*Teresa Ostaszewska*

## HYBRIDIZATION BETWEEN SAUGER AND WALLEYE IN LEWIS AND CLARK LAKE, SOUTH DAKOTA, DETERMINED BY PROTEIN ELECTROPHORESIS.

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**Introduction.** Sauger (*Sander canadensis*) and walleye (*S. vitreus*) are two extensively managed North American percid fishes. These two species can hybridize naturally (Nelson and Walburg 1977; Trautman 1981) and their F<sub>1</sub> hybrids can produce F<sub>2</sub> hybrids and also backcross to both parental species (Hearn 1986). Several external morphological characteristics distinguish sauger from walleye (Trautman 1981). First generation (F<sub>1</sub>) hybrids tend to be intermediate for these characteristics, but often express features of both parental species (Trautman 1981). Backcrosses of F<sub>1</sub> hybrids to either of the parental species are often more difficult to detect by morphological criteria because they tend to resemble one of the parental species. Therefore, it can be difficult to separate hybrids from their parental species by morphological criteria, especially if backcrossing has occurred.

One method for detecting hybrid fishes is by genetic screening if diagnostic loci have been identified between the species involved. Sauger and walleye show fixed allelic differences at four protein coding loci: *mMDH-1\** for malate dehydrogenase and *PGM-1\** for phosphoglucosmutase from muscle, and *ALAT\** for alanine aminotransferase and *IDDH\** for L-iditol 2-dehydrogenase from liver (Billington et al. 1990; Van Zee et al. 1996; Fiss et al. 1997). Two additional loci, *sMDH-3\** and *PROT-3\** (general muscle protein), are informative in sauger (polymorphic in walleye, but fixed for one allele in sauger) (Billington et al. 1990) and one additional locus *SOD\** (superoxide dismutase) is informative in walleye (polymorphic in sauger, but fixed for one allele in walleye). By using these loci, it is possible to screen electrophoretically North American *Sander* samples to confirm specific identification, detect F<sub>1</sub> hybrids (which will be heterozygous at all of the diagnostic loci), and multi-generation hybrids or backcrossed individuals (often collectively referred to as F<sub>x</sub> hybrids). Backcrossed individuals will be heterozygous at a portion of the diagnostic loci, with the remaining loci being homozygous; the direction of backcrossing can be determined by the alleles that are homozygous.

Numerous studies have now reported the occurrence of natural sauger-walleye hybrids, introgression between the two species, and difficulties in using morphological characters to discriminate walleye, sauger, and their hybrids

(Flammang and Willis 1993; Ward and Berry 1995; White and Schell 1995; Van Zee et al. 1996; Billington et al. 1997; Fiss et al. 1997). In this paper, we examine hybridization and introgression between sauger and walleye in Lewis and Clark Lake, a main-stem reservoir on the Missouri River in South Dakota, and compare the reliability of morphological versus genetic analysis for identification of hybrids.

**Methods.** A total of 467 *Sander* specimens were collected from Lewis and Clark Lake, South Dakota, by experimental multiple-mesh gillnets (six-panel, 13-51mm bar mesh range) 17-19 September 2002, and identified to species by morphology. Muscle and liver samples (approximately 1 g) were excised from each fish and placed into numbered 1.5-ml microcentrifuge tubes along with 400 µl of distilled water and kept on ice until frozen. All samples were stored at -20°C until they were sent frozen, via overnight express, to Troy State University, where they remained in frozen storage until they were screened by protein electrophoresis.

Electrophoretic analysis was conducted on cellulose acetate gels. Samples were electrophoresed for 20 min at 200 V using a continuous 1X tris-glycine buffer, pH = 8.5 (Billington et al. 1990; Van Zee et al. 1996). Gels could be scored after 2-15 minutes of staining for the diagnostic sauger and walleye alleles; patterns at *ALAT\** were visualized with UV light. Walleye, sauger, and saugeye (their F<sub>1</sub> hybrid) allele mobility references were included on the gels.

**Results.** Based on morphological examination, 236 fish were identified as walleye and 231 as sauger, with three of the fish identified as walleye and one fish identified as a sauger recorded as putative hybrids. Genetic analysis revealed that 144 (61%) fish identified as walleye by morphology were confirmed as walleye and 211 (91%) fish identified by morphology as sauger were confirmed as sauger. A total of 91 (39%) fish identified as walleye by morphology possessed sauger alleles, of these, seven were F<sub>1</sub> hybrids, 52 were backcrosses to walleye, 18 were possible multi-generation hybrids, one was a backcross to sauger, and 13 were genetically sauger. A total of 20 (9%) fish identified as sauger by morphology possessed walleye alleles, of which one was an F<sub>1</sub> hybrid, 16 were backcrosses to sauger, two were possible multi-generation hybrids, and one was a backcross to walleye. Of the three fish identified as



putative walleye or hybrids, two were identified as backcrosses to walleye, while the third was a walleye. The single fish identified as a putative sauger or hybrid was identified as an F<sub>1</sub> hybrid by genetic analysis. Overall, 111 (24%) of the 467 fish examined possessed alleles of the other species and 109 (23%) fish were misidentified by morphological examination.

**Discussion.** Extensive hybridization and introgression between sauger and walleye was clearly documented in Lewis and Clark Lake, with 24% of the fish containing alleles of the other species. This compares to 10% of fish (mainly sauger) identified as hybrids in a previous electrophoretic study on Lewis and Clark Lake (Van Zee et al. 1996), and 10% of fish identified as hybrids by morphology alone (Nelson and Walburg 1977). Saugeye have never been stocked into Lewis and Clark Lake. Sauger and walleye have recruited naturally since impoundment (1955), with supplemental walleye stocking with fish from Lake Oahe, further upstream, occurring prior to 1991. Morphology was clearly unreliable compared to protein electrophoresis for identification of sauger, walleye, and their hybrids in this study. In particular, hybrids were grossly underestimated by morphology. A much higher (39%) proportion of fish identified as walleye had sauger alleles in them than fish identified as sauger by morphology contained walleye alleles (9%). This included seven fish identified as walleye by morphology that were F<sub>1</sub> hybrids and 13 fish that were pure sauger by electrophoresis. However, fish identification in the field was difficult due to the degraded nature of some of the fish. Three of the four samples that were identified as putative hybrids based on morphology were confirmed as hybrids (two backcrosses and one F<sub>1</sub> hybrid), but one putative hybrid turned out to be a walleye by electrophoresis.

Fisheries managers must be aware that this and other studies (Flammang and Willis 1993; Ward and Berry 1995; White and Schell 1995; Van Zee et al. 1996; Billington et al. 1997; Fiss et al. 1997) have shown that morphological examination is unreliable for separating walleye, sauger, and their hybrids compared to protein electrophoresis. This has important implications for management agencies that use wild fish for brood stock for supplemental stocking programs. In order to maintain the genetic integrity of the fish produced, especially if they are to be stocked into other water bodies, it is essential that potential brood fish of both *Sander* species be screened by protein electrophoresis prior to them being spawned, when they co-occur, or in drainages where hybrid saugeye have been stocked. Fortunately, the South Dakota Department of Game, Fish and Parks do not use sauger or walleye from Lewis and Clark Lake as a source of brood fish.

**Acknowledgements.** We thank John Lott, Jason Sorensen, Cliff Stone, and Gerry Wickstrom for assistance with data collection, and Freeman White and Debra Porter for assistance with protein electrophoresis. The South Dakota Department of Game, Fish and Parks through Federal Aid in Sport Fish Restoration Project F-15-R, Study 1594, provided partial funding for this study.

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## INFLUENCE OF TEMPERATURE AND DEPTH ON SPAWNING SITE SELECTION OF PIKEPERCH (*Sander lucioperca* (L.)) IN THE HELSINKI SEA AREA

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**Introduction.** The spawning of pikeperch in the Gulf of Finland generally takes place in late May-June (Erm 1976, Lehtonen et al. 1996, Lappalainen et al. 2003). Successful reproduction and development of larvae and juveniles occur almost entirely in sheltered archipelagoes and bays (Lehtonen et al. 1996). In these parts of the Baltic Sea suitable low salinities and temperatures are found. To be able to reproduce and form viable populations, pikeperch depend on areas where water warms up early in the spring/summer.

Before spawning the males build nests with a diameter of about 0.5 m and at depth of 5-10 cm situated on the sandy grounds. The highly sticky eggs are laid in 3-4 layers on twigs, roots or aquatic plants (Virbickas et al. 1974). However, females can lay their eggs also on stones and other hard substrates, for example, on artificial spawning substrates. Typical to pikeperch both in the Baltic Sea and lakes is that males guard the eggs until hatching. The purpose here was to study the dependence of pikeperch spawning on temperature, depth and location in the western Helsinki sea area by using artificial spawning nests.

**Methods.** The study area was situated in the western Helsinki sea area. The bottom consists mainly of clay and the water is very turbid.

Altogether 276 nests were set on potential spawning areas. Nests were made of 80-100 cm long spruce twigs which were tied with wire to a brick. Each nest consisted of 3 twigs and the total coverage of a nest was thus about 0.5 m<sup>2</sup>. Nests were set in rows by fastening them to a line at intervals of 10 m. The study area was divided into squares (500 x 500 m) and a set of nests was set into every second nest.

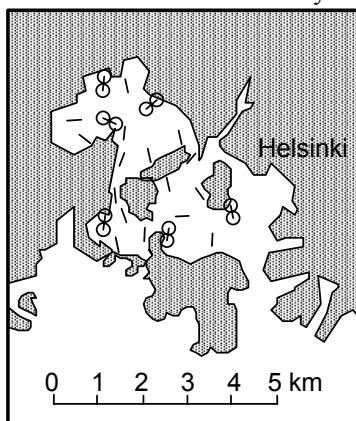


Figure 1. Location of nest sets. Sets with eggs are marked with circles.

Nests were examined weekly between 26 May and 29 June 1999. The coverage of pikeperch eggs was estimated as percentage and depth, temperature and salinity were measured over each spawning nest.

**Results.** The first observations of pikeperch eggs were made in late May at the depth of 4.9-5.5 m and at a temperature of 6.2°C (Table 1). However, the bulk of eggs were laid on spruce twigs at the depths of 2-3 m and at temperatures between 13-19°C. Salinity varied in spawning sites between 4.0-5.9 ppt. Altogether pikeperch eggs were found on 12 nests and on 6 nest rows (Figures 1 and 2). Spawning sites were located in compact areas in different parts of the study area and when eggs were found usually also the neighboring nests were used. Only in one case solitary nest was spawned. The spawning continued through late June (Table 1).

Table 1. Date, water temperature, depth zone and salinity when pikeperch eggs were found.

Date	Bottom °C	Surface °C	Depth zone m	Salinity ppt
28 May	6.2	12.6	4-6	5.9
1 June	13.6	14.2	2-3	5.6
14 June	20.9	22.0	1-2	4.0
14 June	20.7	21.8	2-3	4.1
14 June	21.2	21.5	2-3	4.2
15 June	18.9	21.3	1-2	4.6
22 June	19.1	20.5	2-3	5.1

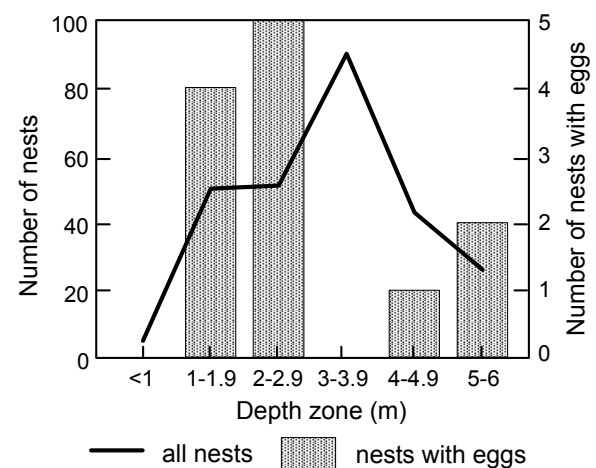


Figure 2. Depth distribution of all spawning nests and the numbers of nests with pikeperch eggs.

**Discussion.** Our findings demonstrate that pikeperch spawn only in some restricted areas. This is supported by the fact that pikeperch eggs were not found in 16 out of 23 net sets and that in the same set eggs were found also in neighboring nests.

Summer 1999 was exceptionally warm and rainless. These kind of summers are known to favor pikeperch reproduction (Lehtonen and Lappalainen 1995, Lappalainen and Lehtonen 1995). Only 4.5 % of the spawning nests were used which also supports the hypothesis of limited spawning areas. Similar results have been found also the Swedish Lake Vänern (Puke 1952) and Danish Lake Bygholm (Jepsen et al. 1999).

Pikeperch spawning time is determined primarily on the basis of water temperature and indirectly also by weather conditions (Sonesten 1991). Normally spawning starts at the temperatures 10-14°C (Virbickas et al. 1974, Gaygalas and Gyarulaitis 1974, Lappalainen 2001). During warm springs the onset of spawning is earlier than during cold ones (Salminen et al. 1992). First pikeperch eggs were found in exceptionally cold (6.2°C) and deep (4.9-5.5 m) water. This was colder than the lowest temperature where the normal development of embryos is possible (8°C) (Muntyan 1967).

According to egg findings the spawning period was between 28 May and 22 June in 1999. However, eggs appeared to the same nest row always concurrently which refers to short spawning period in one spawning site although timing of spawning may differ several weeks between closely situated different sites.

Most eggs were found at the depths of 1-3 m. Deepest spawners spawned in 4.9-5.5 m in cold and saline (5.9 ppt) water. Both temperature and salinity were unfavorable for normal development of embryos. Olifan (1945) mentions that the maximal salinity for survival of pikeperch larvae is 4.75 ppt. Salinities below that were found only in the innermost areas. It is therefore possible that most productive spawning sites are situated there.

**Acknowledgements.** This work was financially supported by the Helsinki Fishing District.

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# TROPHIC FEEDING OF YELLOW PERCH USING FOOD HABITS, STABLE ISOTOPES AND PARASITES

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**Introduction.** Yellow perch are generalist predators capable of shifting trophic status depending on the complexity of the local aquatic community (Craig 2000). Much is known about perch biology and host-parasite relationships (Craig 2000 and Johnson and Dick 2001). Consequently perch are an ideal model species to compare its trophic status in aquatic systems of differing community composition and to explore links between stable isotopes and parasite fauna.

Food items recovered from fish stomachs give a glimpse of food consumption over a very short time frame while parasitic endohelminths can indicate what a fish has eaten at least annually and occasionally longer. On the other hand, stable isotopes have been used to infer what a fish has eaten for longer periods of time and, as a consequence, identify its trophic status. The objective was to determine if fish dietary information, the presence of parasite species transmitted through food and stable isotopes could be correlated and thus more accurately predict trophic status than fish size or age.

**Methods.** Four Canadian Shield Lakes in northwestern Ontario for this study, based on the fish community and their physical features. Yellow perch were collected using gillnets, trap nets and electrofishing throughout the open water season over a two year period. Lengths and weights were recorded and age determined from otoliths. Food items were recorded and complete necropsies for all parasite species were done on all perch. Individual perch were chosen for stable isotopes analyses based on dietary and parasitological information. A sample of muscle tissue was removed from each fish, dried at 45 °C and powdered with mortar and pestle of which 2 mgs were added to tin foil capsules. Samples were analyzed for  $d^{13}C$  and  $d^{15}N$  isotopic concentrations with a dual inlet ratio mass spectrophotometer. Perch were separated into four length classes (< 60mm, 61-80mm, 81-100, >100), five age classes (0+, 1+, 2+, 3+, and >4+) and three diet or parasite intermediate host categories (zooplankton, benthos and fish). MANOVAS were used to identify significant relationships among perch length, age, diet, parasite fauna and stable isotope ratios.

**Results.** A total of 1842 perch were collected across all size and age classes. Parasites recovered from perch were *Glugea*, *Ichthyophthirius*, *Apophallus*, *Diplostomum*, *Posthodiplostomum*, *Clinostomum*,

*Eustrongylides*, *Raphidascaris*, *Spinitectus*, *Crepidostomum*, *Bunodera*, *Echinorhynchus*, *Pomphorhynchus*, *Proteocephalus*, *Bothriocephalus*, *Urocleidus*, and *Piscicola*. Major food items included Cladocera, Copepoda, Diptera, Trichoptera, Ephemeroptera, Odonata, Cambaridae, Amphipoda and fish.

Both the  $d^{15}N$  and  $d^{13}C$  differed among lakes (Figure 1). As perch size (Figure 2) and age increased there was a trend towards less negative  $d^{13}C$  values but no distinct separation of  $d^{15}N$  values.

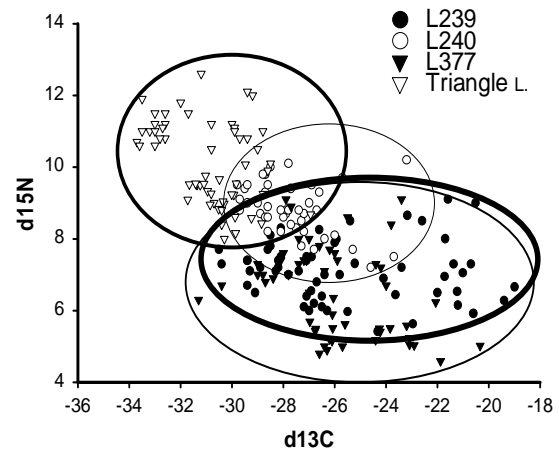


Figure 1. Range (identified by boundaries) of carbon ( $d^{13}C$ ) and nitrogen ( $d^{15}N$ ) isotope ratios of yellow perch in four Canadian Shield lakes.

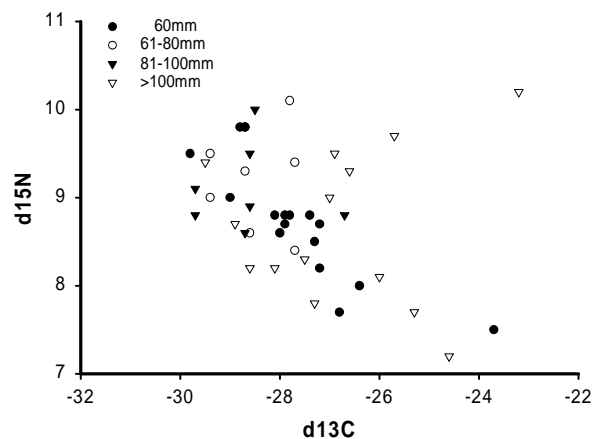


Figure 2. Range of carbon ( $d^{13}C$ ) and nitrogen ( $d^{15}N$ ) isotope ratios of L240 yellow perch separated into four fish size classes.

When apparent trophic position was considered, based on observed diets, there was a greater distinction between both C and N isotopic values (Figure 3). There was a trend to more positive  $d^{15}N$  and  $d^{13}C$  as perch shifted from zooplankton to benthos and then to fish. When perch were categorized by apparent trophic position based on the intermediate host sources for their parasite fauna there was the clearest distinction between isotopic ratios (Figure 4).

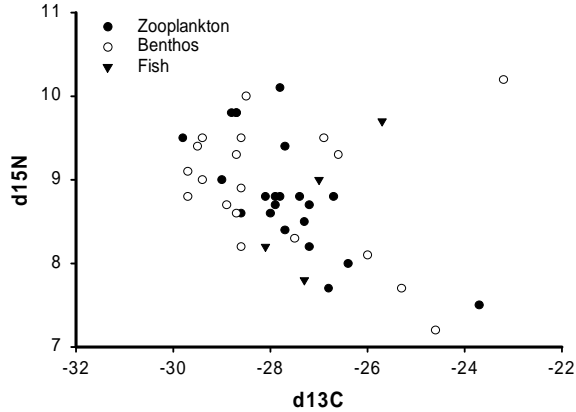


Figure 3. Range of carbon ( $d^{13}C$ ) and nitrogen ( $d^{15}N$ ) isotope ratios of L240 yellow perch as categorized by fish diet.

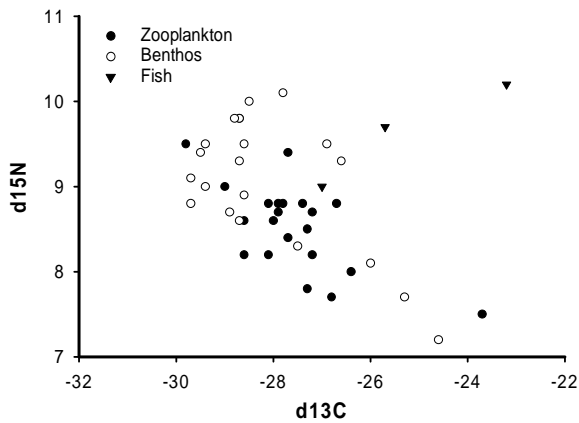


Figure 4. Range of carbon ( $d^{13}C$ ) and nitrogen ( $d^{15}N$ ) isotope ratios of L240 yellow perch as categorized by parasite fauna (grouped by intermediate host type).

**Discussion.** Differing  $d^{13}C$  values relate to differing contributions of various primary producers to the food chain. The fewer significant correlations

between parasites and C ratios suggest that parasites may not be useful predictors of important primary producers in a food chain. Moreover, this study shows that an average N or C isotopic ratio obtained from a small sample of perch does not accurately identify the trophic relationship of individual perch even when they are of similar size and age. Keough et al (1996) found that nitrogen isotopic ratio of young-of-the-year perch indicated zooplanktivory and as perch size increased the ratio shifted to indicate benthivory and finally piscivory. The same trend was observed here with increasing perch size but there were individuals in each size and age class that did not have nitrogen isotopic ratios typical of that group. Some of the largest individuals apparently remained zooplanktivorous as indicated by stable isotopes and their parasite infracommunities. While perch are known to have a generalist diet, some individuals in our study populations may be more specialized in their feeding patterns. Benthivorous perch were the most difficult to correctly place in their original categories by discriminant analysis of host size, age and diet and parasite intermediate hosts. Nevertheless, certain patterns emerged. For example, perch infected with amphipod-derived parasites tended to have more negative  $d^{13}C$  and more positive  $d^{15}N$  values than those infected with large benthic insect-derived parasites. We believe that benthic invertebrates that consume settled pelagic algae or detritus, such as amphipods, affect the  $d^{13}C$  ratios and will be useful discriminators for trophic status. By combining parasite/isotope studies of a few representative fish species of an aquatic system we can make useful predictions about trophic category of individuals regardless of fish size. Further, this approach will be helpful in constructing aquatic food webs.

**Acknowledgements.** This work was supported through operating grants to T. Dick from the Natural Science and Engineering Research Council of Canada and the Department of Fisheries and Oceans, Government of Canada.

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## ONTOGENETIC PATTERNS AND INTERSPECIFIC VARIABILITY IN EXTERNAL MORPHOLOGY OF THREE SYMPATRIC *Gymnocephalus* SPECIES

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**Introduction.** Three of four species of the genus *Gymnocephalus* occur in the River Danube: ruff (*G. cernuus*), Balon's ruff (*G. baloni*) and yellow pike (*G. schraetser*). Differences in their ecological requirements are few as all three species share: similar diets, many of the same habitats, and similar early developmental patterns and life history traits (Kováč 1994). The genus *Gymnocephalus* is supposed to have originated in the River Paleodanube (Holčík & Hensel 1974) and, with sympatric speciation, represents excellent material for studies of both ontogenetic and phylogenetic trajectories. The present paper aims to analyse the external shape of these *Gymnocephalus* species from an ontogenetic point of view, including interspecific comparison, and subsequently two previously published hypothetical models of speciation within the genus (Holčík & Hensel 1974, Kováč 1994) are revised.

**Material and Methods.** In total, 117 specimens of *G. cernuus* (GC), 89 specimens of *G. baloni* (GB), and 154 specimens of *G. schraetser* (GS) were collected from various locations in Slovakia's stretch of the River Danube between the village of Radvaň nad Dunajom and the Devínske side-arm (rkm 1749 to 1880). The material was preserved in a 10% formalin solution.

Ontogenetic patterns in the three species were examined using both distance-based and geometrical (Bookstein coordinates-based) measurements (Katina & Kováč 2003) taken using image analysis based on digital photographs: 26 morphometric characters plus standard length (SL), as well as 17 landmarks (Fig. 1). The characters measured were transformed to a unit size, i.e. referred to SL. With the distance-based measurements, triple-regression analysis was used to test the null hypothesis that development of body proportions is isometric (linear regression) and not gradually allometric (quadratic regression; first alternative hypothesis) or abrupt (split-linear regression; second alternative hypothesis), the latter reflecting ontogenetic thresholds and/or transitions (see Kováč et al. 1999 for details).

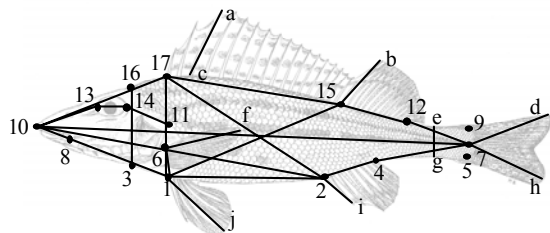


Figure 1. Schematic illustration of the landmarks (1 to 17) and distance-based measurements (see also Table 1) taken from three *Gymnocephalus* species from the Danube in Slovakia.

Table 1. Best regression models for ontogenetic variability of 26 morphometric characters (lm = landmarks) in ruffe (GC), Balon's ruffe (GB) and yellow pike (GS). P = pectoral fin, V = ventral fin, A = anal fin, D = dorsal fin, L = linear, isometric growth; Q = quadratic, allometric growth; S = split linear, isometric growth with abrupt change.

n° character	lm	GC	GB	GS
1 head length	10-11	L	L	L
2 preorbital distance	10-13	L	L	Q
3 eye diameter	13-14	Q	L	Q
4 postorbital distance	14-11	Q	L	Q
5 head depth	16-3	Q	Q	Q
6 predorsal distance	10-17	L	L	Q
7 preventral distance	10-1	Q	Q	L
8 preanal distance	10-2	S	Q	Q
9 postdorsal distance	12-7	Q	L	L
10 P – V distance	6-1	S	Q	L
11 V – A distance	1-2	Q	L	Q
12 D1 – A distance	17-2	S	L	Q
13 V – D2 distance	1-15	L	L	Q
14 body depth	17-1	S	L	Q
15 ang. caudal ped. length	4-7	L	L	Q
16 minimum body depth	e-g	Q	L	L
17 dorsal fin 1 length	17-15	L	L	Q
18 dorsal fin 2 length	15-12	Q	L	L
19 anal fin length	2-4	L	L	L
20 pectoral fin length	6-f	L	Q	L
21 ventral fin length	1-j	L	Q	L
22 caudal lobe sup. length	7-d	L	L	L
23 caudal lobe inf. length	7-h	L	L	L
24 3 <sup>rd</sup> or 4 <sup>th</sup> D spine length	c-a	L	L	S
25 dorsal 1 <sup>st</sup> soft ray length	15-b	L	Q	L
26 anal 1 <sup>st</sup> ray length	2-i	L	L	Q

For geometrical (Bookstein coordinates) analysis, specimens were divided into size groups identified by seeking for the lowest possible within-group variability. New program routines in S-PLUS (Dryden & Mardia 1999) modified by Katina (Katina & Kováč 2003) for geometrical analysis were used. Both local and global shape differences (affine and non-affine transformations) were evaluated using infinite-window thin-plate splines (TPS, elastic splines) with  $L_2$  roughness penalty, as well as partial warps (PW). For visualization, TPS and PW grids were created (Fig. 2). The shape differences were also tested using Goodall tests (see Katina & Kováč 2003 for details on the geometrical analysis used).

**Results.** SL of GC, GB and GS specimens ranged from 37.1 to 133.7, from 43.0 to 135.1, and from 41.0 to 202.9 mm, respectively. In GC, 14 characters grew isometrically (best described by linear regression), 8 characters allometrically (quadratic regressions), and the remaining four characters isometrically up to a



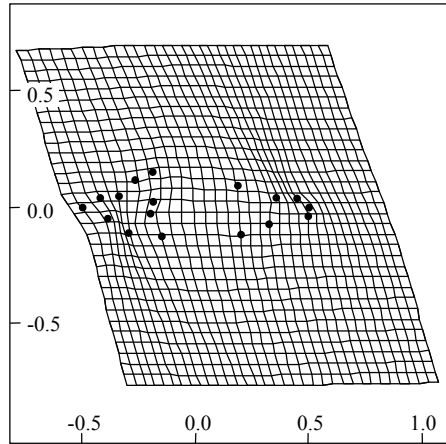


Figure 2. TPS grid for ruffe – illustrative example of shape differences between size groups SG 1 and 4.

certain interval of SL (66.7-86.6 mm) when changed to grow allometrically and then isometrically, again (Table 1). In *GB*, 19 characters grew isometrically and 7 characters allometrically, whereas in *GS*, only 12 characters were found to grow isometrically, as 13 characters grew allometrically and one character showed isometric growth with abrupt allometry occurring at a specific SL, followed by isometric growth (Table 1).

In the geometrical analyses, 4 size groups (SG) in each species were identified following the lowest possible within-group variability (Table 2). As for the ontogenetic variability, in *GC*, TPS and PW grids revealed considerable differences between SG1 and SG3, SG1 and SG4, and SG2 and SG3, though the Goodall tests were statistically significant only between SG1 and SG4 ( $P < 0.01$ ). In *GB*, no significant differences among the SGs were found. In *GS*, the Goodall tests showed significant differences between SG1 and all the remaining SGs ( $P < 0.01$ ), as well as between SG2 and SG3 ( $P < 0.01$ ), however, TPS and PW grids indicated only little ontogenetic variability in this species.

Table 2. Size groups (SG) identified in the three *Gymnocephalus* species by the geometrical analysis.

SG	GC	n	GB	n	GS	n
1	<55	25	<60	11	<60	26
2	55.0-79.9	55	60.0-99.9	37	60.0-99.9	55
3	80.0-99.9	22	100.0-119.9	31	100.0-119.9	18
4	>100	15	>120	19	>120	49

Interspecific differences among the three species appeared statistically significant within all the SGs ( $p < 0.01$ ). However, visualization in TPS and PW grids revealed that *GC* and *GB* differed little from each other in SG1 and SG2, whereas the difference in SG3+4 was evident. An opposite pattern was found between *GC* and *GS*, as well as between *GB* and *GS* – the differences in SGs 1 and 2 were bigger than those in SG3+4.

**Discussion.** Abrupt changes in otherwise isometric growth of morphometric characters may indicate thresholds in ontogeny of fish (Kováč et al. 1999). However, this can be true only if the changes occur in several morphometric characters simultaneously (within a certain interval of SL), and if such a shift in external shape is associated with other, especially ecological, physiological and/or behavioral changes. This was not the case in any of the three *Gymnocephalus* species studied. Therefore, it appears that in ruffe, Balon's ruffe and yellow pope, morphometric characters do not aid in the identification of ontogenetic thresholds.

Nevertheless, in *GC*, the four characters (preanal, P-V and D1-A distances, and body depth) with an abrupt change in their isometric growth indicate that the external shape of this species undergoes some remodelling between 66.7 and 86.6 mm SL, which is also supported by the geometrical analysis (changes between SG2 and SG3).

Most of the morphometric characters did not grow isometrically in all three species. Therefore, any inter-population and/or interspecific comparisons based on data sets that ignore size of the specimens studied, may be strongly biased by ontogenetic variability and should be avoided.

Little ontogenetic variability in *GS* corroborates with the concept that the subgenus *Gymnocephalus* (contains *GS* and *G. acerinus*) evolved precociously to the subgenus *Acerina* (*GC* and *GB*) and underwent juvenilization (Kováč 1994). This is also supported by the greater differences between the *Acerina* and *Gymnocephalus* subgenera in earlier (1,2) rather than advanced size groups (3,4). However, owing to great similarity in external morphology of *GC* and *GB*, phylogenetic relationships within subgenus *Acerina* are uncertain and models of its speciation (Holčík & Hensel 1974, Kováč 1994) remain hypothetical.

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## DISTRIBUTION OF YOUNG-OF-THE-YEAR PERCIDS IN EUROPEAN RESERVOIRS

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**Introduction.** Besides the cyprinids, perciform fish are the most successful in colonizing European reservoirs. This paper summarizes numerous published and unpublished information on perch (*Perca fluviatilis*), pike perch (*Sander lucioperca*) and ruffe (*Gymnocephalus cernuus*) distribution and behavior during the first year of life. The emphasis is given on the aspects of biology not mentioned in Urho (1996) and Craig (2000).

**Methods.** Open water of five Czech reservoirs was sampled by ichthyoplankton towed nets (Wanzenböck et al., 1997; May-July), by 3\*3 m frame trawl (August-September) and by the SIMRAD EY 500 split-beam echosounder. Littoral regions were sampled using fry beach seine (10 m long, mesh size 1\*1.35 mm). All samplings were performed either during day time or during 24 hours. All fish were counted and measured to the nearest 0.5 mm. The results from three non-stratified drinking water reservoirs in the Meuse estuary, the Netherlands (Kubečka et al., 1998) are used for comparison.

**Results and Discussion.** *1. Spawning, hatching and embryonic period.* The trigger of perch spawning is the onset of thermal stratification when the surface temperature reaches 8°C (second half of April). The spawning is one continuous event lasting about one month with most activity at depth strata corresponding to 8-12°C (Pivnička and Švátora, 2001). Pikeperch and ruffe spawn slightly later. Especially the spawning of ruffe can be prolonged during May to July. The spawning of pikeperch is usually considered as a single event, but the appearance of very small (15-25 mm) fry in August amongst contemporaries 50-150 mm long may indicate portional spawning in Dutch reservoirs.

*2. Pelagic larval period.* Marine origin of percids predetermined pelagic phase in the life cycle.

*2.1. Surface-confined period.* Larvae of perch and pikeperch are positively phototactic. They leave spawning grounds, enter open water and inhabit surface layers during the day (Fig. 1) for week or two (length 5-10 mm, end of May). Unpublished acoustic studies show that in this period schooling aggregations are missing (randomly distributed ichthyoplankton). This period seems to be present in all studies compared and the larvae seem to avoid littoral.

*2.2. Period of more diverse distribution.* In subsequent period, social contacts and schooling develops gradually, the behavior of larvae splits in several modes:

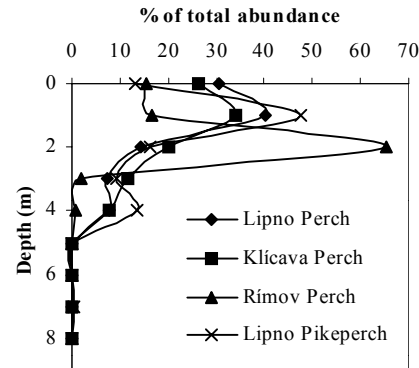


Figure 1. Vertical distribution of percid fry during surface-confined period (end of May, day time).

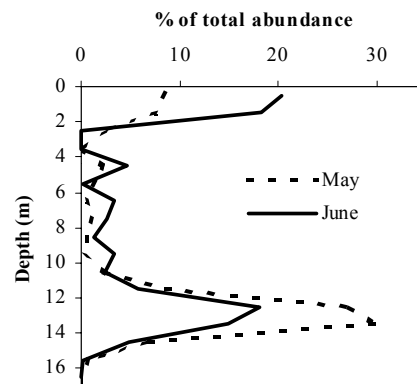


Figure 2. Vertical distribution of percid fry during the period of bimodal distribution (day time, 0700-1900).

a) Surface distribution like in 2.1. This type of distribution is often reported in the literature, but it was never encountered during our studies when all types of habitats were sampled. Such references have to be treated with caution, as they may be result of undersampling of deep pelagics. Pavlov et al. (1988) show preference of pikeperch to the surface layers.

b) Bimodal vertical distribution with epi- and bathypelagic perciform fry (Fig. 2). This type is typical for deep stratified reservoirs. The cohort of all three species splits into differently behaving groups: Epipelagic fry (EPF), which spends the whole 24 hours in upper 4 meters together with the fry of cyprinids and Bathypelagic fry (BPF) spending the day in hypolimnion at depths 10-20 m with no measurable light. No cyprinids are present in BPF. BPF formate 2-3 m thick scattering layer, which can be followed by the echosounders. In the evening, these fish migrate to



the surface and join the EPF. Most our observations show significantly smaller average size of BPF. Diurnal vertical migration of BPF may be a good way to reduce fish predation and metabolic costs, but living in cold dark waters results in slower growth rate and smaller sizes compared with EPF (Fig.3). The formation of scattering layers is a very interesting phenomenon observed in Řimov, Slapy and Orlik reservoirs and it was possible to investigate distribution of BPF along the longitudinal axis of the reservoirs till August.

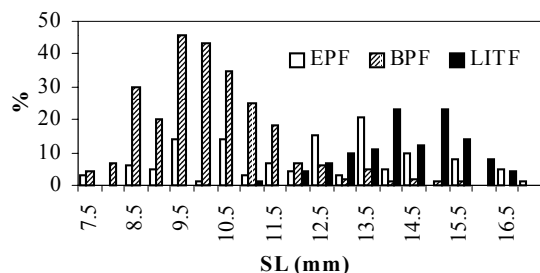


Figure 3. Length-frequency distribution of perch fry. LITF stands for littoral fry.

c) Bathypelagic and demersal distribution. In some well-mixed reservoirs, Lipno, Konakovskoye (Boitsov, 1980), most perciform larvae seem to spend the day close to the bottom rising into whole water column during the sunset. Direct sampling during the day is difficult, but the whole rising sequence can be observed by the echosounder. The distribution of ruffe in a Bulgarian reservoir (Pavlov et al., 1988) is of this type.

d) Littoral distribution. Irrespective of pelagic distribution type, some perch and ruffe older larvae always switch to the littoral way of life. This switch seems to be much less expressed in pikeperch which prefer to stay offshore in reservoirs during the whole first year of life. In the littoral habitat, percoid fry join the inshore community usually dominated by cyprinids. It is often believed in the literature that all perch fry move inshore, but fair sampling of all habitats show that inshore habitat is not the most important for percoid larvae and fry. The biggest individuals seem to be using this habitat (Fig. 3).

3. *Juvenile period.* Most percids enter this period during June leaving thus definitely ichthyoplanktonic way of life. In stratified reservoirs, littoral and BPF perciforms are usually present. EPF is composed mainly by cyprinids. Schooling as an antipredation mechanism is very characteristic for day distribution of perch fry which dominate BPF. BPF tend to live less deeply than during larval period: 4-10 m. Ruffe becomes demersal and is usually absent in pelagic trawl catches. Pikeperch fry stays in pelagic and deep bottom habitats. Fry density culminates usually in the

tributary region; the proportion of perch is higher in more lacustrine parts of the reservoir (Vašek et al. 2002). Autumnal and winter distribution is not known except of the fact that during mild weather, littoral fry stay inshore till December. Very distinct pattern of juvenile percoid distribution was found in Dutch reservoirs (Fig.4).

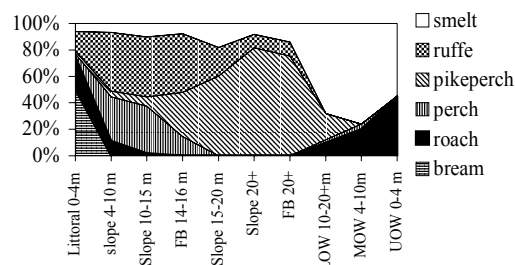


Figure 4. Fry composition in different habitats of Dutch reservoirs, idealized from 9 surveys.

Percid fish dominate in nearbottom habitats. At depths 4-16 m, ruffe and perch are the most important. At deeper habitats, their dominance is replaced by pikeperch. Littoral is dominated by cyprinids; upper (UOW) and middle (MOW) open water by roach (*R. rutilus*) and smelt (*O. eperlanus*).

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## HISTOPATHOLOGICAL CHANGES DURING PIKEPERCH *Sander lucioperca* SWIM BLADDER DEVELOPMENT

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**Introduction.** Low efficiency of intensive rearing of pike-perch and walleye larvae is related to low survival during metamorphosis (Moore et al. 1994). Failure of swim bladder inflation is main cause of high larval mortality until the 20 day post hatching (Barrows et al. 1993). The larvae without inflated swim bladder show swimming difficulties, therefore they spend more energy for prey capture, and locomotion. Such larvae show low survival, especially after transfer into natural waters. The aim of present study was to identify and describe pathological changes during swim bladder development in pike-perch, *Sander lucioperca*, and to investigate the effects of abiotic factors on its development rate.

**Methods.** The study was carried out in the Division of Ichthyobiology and Fisheries of the Warsaw Agricultural University. Newly hatched pike-perch larvae were used in the experiment, placed in the glass 20 dm<sup>3</sup> aquaria with water recirculation, 500 fish in each. Larval development took place at three temperatures: 16°C, 18°C or 20°C (±0.5°C). Each temperature group included six replicates with aeration, and another six without aeration. Beginning from the fourth day post hatching all fish were fed twice a day with *Artemia salina* nauplii, *ad libitum*. Ten fish from each experimental group were sampled daily, from hatching to the 20 day of life and preserved for histological examination. The fish were anesthetized with MS 222, and fixed in buffered formaldehyde and Bouin solution, and then subjected to standard histological procedure. The preparations were stained with hematoxylin and eosin.

**Results.** First pathological changes in the swim bladder were observed between the 11 and 15 day from hatching (at various water temperatures). At early swim bladder development stages the changes included hypertrophy of gas gland secretory epithelium, which resulted in a decrease in swim bladder lumen. At later larval stages, progressive anomalies in swim bladder and pneumatic duct were observed, accompanied by malformation of rete mirabilis and gas gland, while the bladder remained noninflated. Moreover, bacterial infection occurred. Pathologically hypertrophic epithelium occluding swim bladder lumen consisted of cells of various shape and size, most of them showed considerably hypertrophic cytoplasm with light vacuoles or granules. Among large hypertrophic cells, small

cubical ones, macrophages and blood vessels were also visible.

The noninflated swim bladders were smaller than correctly developed ones in pike-perch larvae at the same age (Fig. 1 a, b).

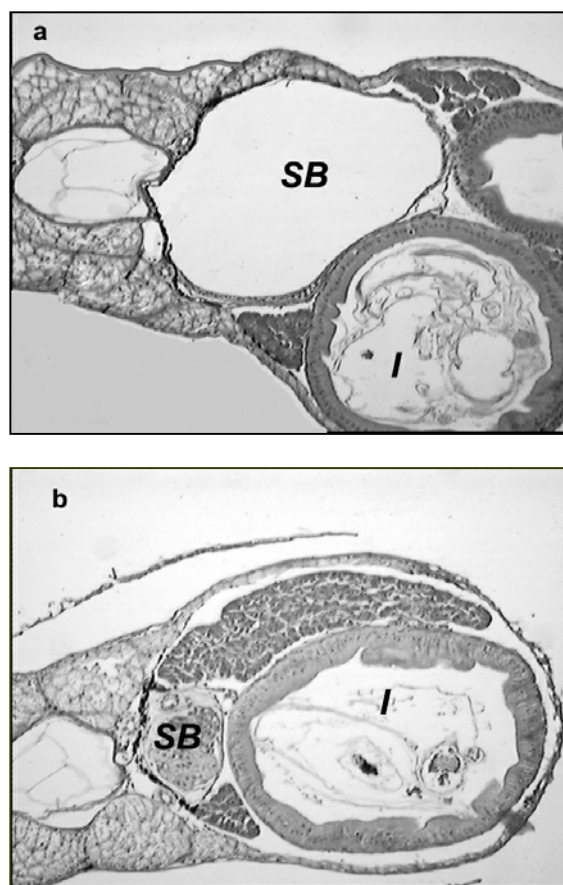


Figure 1 a, b. The thirteenth day post hatching. Cross-section. a) larva with correctly inflated swim bladder (SB). b) larva with pathologically changed swim bladder. Intestine (I). (H-E) x 25.

During the experiments, increased mortality was observed in all experimental groups after 200<sup>o</sup>D (degree-days), at the time of development of first intestinal loop, stomach and pylorus.

In all flow-through tanks, irrespectively to the temperature, fish survival was higher comparing to the aerated ones (Table 1).

Experimental factors Water temperature (°C)	Survival on the 20 day (%)	Total body length on the 20 day (mm)		Pathological changes in swim bladder (% of larvae)	Mass mortality (day)
		Noninflated bladder	Inflated bladder		
	$\bar{x} \pm s.e.$	$\bar{x} \pm s.e.$	$\bar{x} \pm s.e.$	$\bar{x} \pm s.e.$	
Flow 16 Aeration 16	18.60±0.70 15.60±0.58	10.10±0.39 09.79±0.19	11.44±0.34 10.01±0.18	18±0.73 19±0.82	14-15
Flow 18 Aeration 18	46.50±1.81 36.30±1.72	13.54±0.26 13.17±0.17	14.71±0.15 14.81±0.15	27.5±0.92 28.0±1.06	12-13
Flow 20 Aeration 20	28.60±1.54 27.40±0.97	14.07±0.19 13.33±0.28	16.63±0.08 14.35±0.18	46.0±1.32 52.5±1.23	10-11

Table 1. Summary of the observations on pike-perch larval development.

The pike-perch larvae with noninflated swim bladders were significantly smaller than those with correctly developed bladders (Table 1).

At lower temperatures, the number of larvae showing swim bladder anomalies was considerably lower. The highest frequency of histopathological swim bladder changes occurred at 20°C (Table 1).

**Discussion.** The results of histological examination indicate that high mortality of pike-perch larvae might have been related to swim bladder inflation disturbances. The observations revealed swim bladder inflammation (*aerocystitis*), and necrosis of secretory epithelium. Swim bladder development anomalies were observed also by other authors. According to Bennett et al. (1987), 4 days old larvae of *Morone saxatilis* showed swim bladder fibrosis and its progressive degradation, in 7 days old larvae entire swim bladder chamber was filled with fibrous tissue. Marty et al. (1995) reported that swim bladder inflammation occurred in *Sander vitreus* larvae at the very beginning of its inflation. The moment of inflammation development observed in the present study and described by other authors (Marty et al. 1995) indicates that bacteria may be introduced into the bladder together with the air.

According to Kindschi and MacConnell (1989), water aeration did not result in an increase in number of *Sander vitreus* larvae with inflated swim bladder.

Also in the present study no positive effect of aeration swim bladder inflation was observed.

Statistically significant effect of swim bladder inflation on total body length was observed. The

larvae showing swim bladder anomalies were shorter comparing to those in which the bladder was correctly developed.

Increased mortality of pike-perch larvae observed after 200°C was related to morphogenetic translocation of internal organs during stomach and pylorus development. Digestive tract development makes swim bladder inflation difficult. If it is not inflated before the stomach development (9-15 day of life, at various water temperatures), its inflation may become impossible. Increased mortality of *Sander lucioperca* larvae between 200°C and 300°C was observed also by Mani-Ponset et al. (1994).

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## **MANAGEMENT**

### **Contribution of stocked walleyes (*Sander vitreus*) to the statewide harvest in Minnesota**

*Peter C. Jacobson*

### **Biological reference points for management of walleye (*Sander vitreus*) fisheries**

*Nigel P. Lester and George Morgan*

### **Application of biological reference points to evaluate the status of walleye (*Sander vitreus*) in Ontario**

*George Morgan, Nigel Lester and Todd Morris*

### **Effects of walleye stocking on the fish community of Lake Thirteen**

*Rodney B. Pierce*

### **Are percid fish overestimated by gillnet sampling?**

*Marie Prchalová and Jan Kubecka*

### **The effect of stocking size on survival of fingerling pikeperch (*Sander lucioperca*)**

*Jukka Ruuhijärvi and Matti Salminen*

### **Management of Lake Lohjanjärvi pikeperch (*Sander lucioperca*) – A fading success?**

*Matti Salminen and Jukka Ruuhijärvi*

### **Monitoring hatchery use of spawning walleye in Lake Diefenbaker, Saskatchewan (Canada)**

*Robert G. Wallace, Ronald E. Jensen and Kevin M. Murphy*

## CONTRIBUTION OF STOCKED WALLEYES (*Sander vitreus*) TO THE STATEWIDE HARVEST IN MINNESOTA

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**Introduction.** Many lakes in Minnesota have excellent spawning habitat that sustain abundant walleye (*Sander vitreus*) populations without stocking. Other lakes lack suitable habitat for good natural reproduction and are stocked with walleye fry or fingerlings. The Minnesota Department of Natural Resources (DNR) walleye stocking program is one of the largest walleye stocking programs in North America and is one of its most visible activities. The magnitude and visibility of the program have led to high, and possibly, unrealistic expectations of the benefits of walleye stocking by the angling public in Minnesota. The purpose of this analysis was to estimate the contribution of stocking to the total number of walleyes harvested statewide.

**Methods.** Minnesota DNR Fisheries Managers assigned lakes managed for walleyes into five categories of walleye natural reproduction capabilities (1-known to be adequate, 2-suspected to be adequate, 3-suspected to be inadequate, 4-known to be inadequate, 5-nonexistent; adequate defined as capable of sustaining an abundant walleye population). Some lakes (mostly unmanaged for walleyes) were not categorized, but were included in this analysis if standard Minnesota DNR netting assessments detected presence of walleyes. The ten largest lakes in the state represented a separate category. Natural reproduction is excellent in all ten lakes, although Lake Vermillion is stocked annually with fry because it is an egg source for the hatchery program (Minnesota DNR policy) and Upper Red Lake is temporarily being stocked with fry for rehabilitation purposes (and is closed to harvest).

Indices of walleye abundance were estimated from gillnet catch per effort (CPE) from 7,463 standard Minnesota DNR assessments from 1970 through 2000. Stocked CPE's were defined as CPE's from lakes that had at least one stocking from 1 to 6 years before the assessment (age distributions from all assessments indicated that 90% of the walleyes captured were from 1 to 6 years old). Unstocked CPE's were defined as CPE's from lakes that had no stocking in the 1 to 6 years before the lake survey. The relative contribution of stocked fish was estimated by assuming that the mean unstocked CPE for each natural reproduction category was the

baseline level of abundance due to natural reproduction. Any increase that mean stocked CPE's had over mean unstocked CPE's was assumed to be the result of stocking for each category.

Mean annual harvest of walleyes within each category was calculated from creel surveys conducted on 387 Minnesota lakes from 1970 through 2000 (data described in Cook and Younk 1998). Annual harvests were calculated using open water harvest data (the time period of most creel surveys) and then adding 14% for winter harvest (the mean percent winter walleye harvest from lakes with both open water and winter creel surveys). Unfortunately, few creel surveys were conducted on unstocked lakes in some of the natural reproduction categories. Therefore, harvests were partitioned into stocked and naturally reproduced components using the relative stocking contribution calculated from gillnet assessments for each natural reproduction category by solving the equations:

$$H_{a,i} = P_{u,i} H_{u,i} + P_{s,i} H_{s,i}$$

$$H_{s,i} = H_{u,i} + S_i H_{s,i}$$

where,  $H_{a,i}$  = mean annual harvest (number/ha) from all lakes in natural reproduction category  $i$ ,  $H_{u,i}$  = mean annual harvest (number/ha) from unstocked lakes in natural reproduction category  $i$ ,  $H_{s,i}$  = mean annual harvest (number/ha) from stocked lakes in natural resource category  $i$ ,  $P_{u,i}$  = proportion of hectares not stocked in category  $i$ , and  $P_{s,i}$  = proportion of hectares stocked in category  $i$ , and  $S_i$  is the contribution (proportion) that stocking made to the gillnet CPE for natural resource category  $i$ .

Solution:

$$H_{u,i} = \frac{H_{a,i}}{\frac{P_{s,i}}{1 - S_i} + P_{u,i}}$$

and

$$H_{s,i} = \frac{H_{u,i}}{1 - S_i}$$

Mean annual harvest for the ten large lakes was calculated from yields and hectares presented in

Table 1. Mean walleye gillnet CPE's in standard assessments from 1970 through 2000, percent stocked contribution, and mean annual walleye harvest by natural reproduction category and stocking status.

Category	Stocked CPE	Unstocked CPE	Stocking Contribution	Percent of Hectares Stocked	Harvest (number/ha)		
					All Lakes	Stocked Lakes	Unstocked Lakes
1	8.62 (468)	8.91 (513)	-3.4%	5.3%	4.42 (96)	4.29	4.43
2	8.97 (678)	7.53 (99)	16.1%	87.4%	5.83 (65)	5.95	4.99
3	7.64 (1231)	4.71 (136)	38.4%	94.4%	3.99 (85)	4.08	2.51
4	6.38 (1045)	3.35 (170)	47.5%	83.0%	3.07 (46)	3.34	1.76
5	5.14 (1341)	2.35 (252)	54.2%	82.4%	4.08 (66)	4.51	2.06
NC	3.6 (457)	2.9 (1073)	19.3%	9.9%	0.75 (29)	0.90	0.73
Large Lakes	-	-	0.0%	10.7%	3.16	-	3.16

Table 2. Estimated number of stocked and naturally reproduced walleyes annually harvested statewide from Minnesota lakes by natural reproduction category.

Category	Currently Stocked Lakes				Currently Unstocked Lakes				Total Harvest
	Lakes	Hectares	Harvest (number)		Lakes	Hectares	Harvest (number)		
			Stocked	Naturally Reproduced			Stocked	Naturally Reproduced	
1	8	8,051	-	35,672	220	144,058	0	638,281	673,953
2	102	56,183	53,779	280,569	41	8,104	0	40,470	374,818
3	230	106,359	166,583	267,411	36	6,350	0	15,966	449,959
4	189	58,893	93,438	103,391	81	12,023	0	21,108	217,937
5	290	59,712	145,949	123,280	140	12,762	0	26,348	295,576
NC	98	13,102	2,286	9,558	1077	119,564	0	87,224	99,068
Large Lakes	2	35,853	-	113,353	8	299,614	0	947,260	1,060,613
Totals	919	338,153	462,035	933,233	1,603	602,477	0	1,776,656	3,171,924

Minnesota DNR (1997) and were assumed to originate entirely from natural reproduction. Total statewide harvests for each category were then calculated from the hectares and mean annual harvest data.

**Results.** Walleye abundance was directly related to the amount of natural reproduction in a lake (Table 1). Lakes with the best natural reproduction (Natural Reproduction Categories 1 and 2) had the highest gillnet CPE's. Walleye abundance progressively declined through Natural Reproduction Categories 3, 4, and 5. Walleye stocking had the largest impact in the lakes with the poorest reproduction. The percent contribution increased progressively from a slight negative contribution in Natural Reproduction Category 1 to over 50% in Natural Reproduction Category 5. The relatively small amount that stocking contributes to the unclassified lakes (19.3%) may be due to the relatively light stocking densities that these unimportant lakes (for walleyes) receive.

As with abundances, mean annual harvests of walleyes (Table 1) were largest in the lakes with the best natural reproduction (Natural Reproduction Categories 1 and 2). The values ranged from 0.75 walleyes harvested per hectare in lakes without Natural Reproduction Category assignments to 5.83 walleyes harvested per hectare in Natural Reproduction Category 2. The partitioned harvests (stocked and unstocked lakes) generally tracked the stocking contribution estimates from the gillnet assessments.

A total of 919 lakes, with over 338,000 hectares, are currently stocked with walleyes in Minnesota (Table 2). A total of 263 lakes, with over 600,000 hectares, are not stocked because they have good natural reproduction of walleyes (Natural Reproduction Category 1 and 2, and the unstocked large lakes). An estimated 3.2 million walleyes were harvested annually throughout the state. Naturally reproduced fish accounted for an estimated 85% (2.7 million fish) of the statewide walleye harvest, while stocked walleyes accounted for only 15% (462,035 fish) of the harvest (Table 2). Even in stocked lakes, more walleyes were harvested that originated from natural reproduction than from stocking (933,233 fish vs. 462,035 fish). The harvest of walleyes from the ten largest lakes in the state comprised the largest

component of the statewide annual harvest (over 1 million fish). The annual harvest of walleyes in other unstocked good natural reproduction lakes (Natural Reproduction Categories 1 and 2) was also large (678,751 fish).

**Discussion.** The trend of declining stocking contribution with increasing natural reproduction is consistent with Li et al. (1996), who concluded that walleye stocking was ineffective in good natural reproduction lakes and more effective in poor natural reproduction lakes. The result is also consistent with Moyle (1950), who was one of the first to conclude that walleye fishing in Minnesota depends on naturally reproduced fish, and who also made the oft repeated (Laarman 1978) recommendation that walleye stocking not be used to supplement natural reproduction.

The importance of naturally reproduced walleyes to the state's walleye fishery should be emphasized to the angling public. Although stocking can make a significant contribution on some lakes (especially lakes with poor natural reproduction), the vast majority of walleyes caught in Minnesota are naturally reproduced. Protection of natural walleye spawning habitats should warrant as much public and agency attention as stocking, and probably more.

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## BIOLOGICAL REFERENCE POINTS FOR MANAGEMENT OF WALLEYE (*Sander vitreus*) FISHERIES

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**Introduction.** Walleye (*Sander vitreus*), the most popular sport fish in Ontario, are known to inhabit approximately 4000 lakes in the province. Management of this dispersed fishery is difficult because it is not economically feasible to monitor each lake. A practical alternative is a sampling approach in which data from a statistical sample of lakes are used to evaluate the state of the resource and decide whether a change in fishing regulations is needed to protect walleye from over-exploitation (Lester et al. 2003). This judgement requires that indicators from each lake be compared to reference values that specify the maximum (or minimum) level that must be sustained to safeguard the long-term productivity of a stock. These reference values, known as Biological Reference Points (BRP), are expected to vary among lakes depending on environmental characteristics that affect walleye carrying capacity and maximum intrinsic rate of increase. This paper describes a method of establishing *MSY*-based reference levels of total mortality rate and stock biomass for walleye. These reference points are interpreted as upper (mortality) and lower (biomass) limits.

**Methods.** We used the classical Graham-Schaefer model of surplus production (Quinn and Deriso 1999) as a basis for calculating reference points. This model implies that as fishing mortality rate ( $F$ ) increases from zero, the equilibrium biomass ( $B$ ) of a stock decreases linearly, starting at  $B_\infty$  (i.e., carrying capacity) and reaching zero when  $F = F_{ext}$  (i.e., maximum intrinsic rate of increase). Because yield equals  $F * B$ , this relationship produces a dome shaped yield curve with a maximum sustainable yield (*MSY*) described as

$$MSY = F_{msy} B_{msy},$$

where  $F_{msy} = F_{ext}/2$  and  $B_{msy} = B_\infty/2$ .

To estimate  $F_{ext}$  we used a life history based model (Lester and Shuter in prep.) that assumes density-dependent growth and an optimum reproductive schedule (i.e., the age of maturation and the investment in egg production maximizes net reproductive rate). That model predicts the relationship between  $F_{ext}$ ,  $M$  (natural mortality rate) and the degree of growth compensation ( $h_1/h_0$ ) is:

$$\frac{F_{ext}}{M} = \left( \frac{h_1}{h_0} \right)^{4/3} e^{\frac{F_{ext} L_c}{3h_1}} - 1$$

where  $h_0$  is growth rate (cm/yr) of the unexploited population ( $F = 0$ ),  $h_1$  is growth rate of heavily exploited population (i.e.,  $F = F_{ext}$ ),  $L_c$  is the size of a fish when it is recruited into the fishery. This model also implied, for walleye,  $M = h_0/(20 + 0.4h_0)$ . Observed variation in growth rate, combined with results from bioenergetics models, implied that  $h_0$  is higher in warmer climates:  $h_0 = 5.63 (G - 0.7)^{0.67}$ , where  $G$  is growing degree days above  $5^\circ\text{C} \times 10^{-3}$ , and that maximum growth rate ( $h_1$ ) is approximately 2.5 times the unexploited rate. Assuming  $h_1/h_0 = 2.5$  and  $L_c = 30$  cm, we calculated  $M$  and  $F_{ext}$  for climatic conditions that span the province of Ontario. A reference point for total mortality rate was then calculated as:  $Z_{msy} = M + F_{ext}/2$ .

We calculated the expected walleye biomass at *MSY* as  $B_{msy} = MSY/F_{msy}$ , in which *MSY* was calculated from an empirical formula (Lester et al. 2002):

$$MSY = \frac{1.70 H^{0.93} TDS^{0.42} G^{1.86}}{Area}$$

where *TDS* is total dissolved solids (mg/l) and  $H$  is average daily thermal-optical habitat area available for walleye during the summer (ha).  $H$  is calculated as

$$H = Area p_T z_{rel} e^{-4.2 z_{rel}}$$

where  $p_T$  is area of the lake shallower than the thermocline,  $z_{rel}$  is relative Secchi depth:

$$z_{rel} = \frac{z_{sec}}{z_{max} (1 - e^{-s})}, \quad z_{max} \text{ is effective maximum}$$

depth (i.e., maximum depth of the lake or depth of the thermocline if the lake is thermally stratified) and  $s$  is a basin shape parameter typically having a value near 1.

**Results.** Our model indicates that  $F_{msy}$  is approximately 1.6 times  $M$  when the growth compensation ratio is 2.5, implying that  $Z_{msy}$  is approximately 2.6 times  $M$  (Figure 1). Across a climatic gradient of 1000 to 2400 GDD,  $M$  ranges from 0.12 to 0.34 and  $Z_{msy}$  ranges from 0.34 to 0.85. The implied exploitation rate at *MSY* ranges from 20% to 40%.

Biomass at *MSY* depends on water clarity relative to lake depth, as well as nutrient levels. Examples in Figure 2 illustrate that  $B_{msy}$  is very sensitive to water clarity, reaching maximum values

when Secchi depth is in the range of 1 to 3 m. The amplitude of this relationship depends on  $TDS$  and, in thermally stratified lakes, the proportion of lake area above the thermocline.

**Discussion.** Methods described here allow the calculation of Biological Reference Points from easily measured lake parameters (GDD, Secchi depth, surface area, maximum depth, mean depth, and  $TDS$ ). Reference points calculated for individual lakes have large uncertainty associated with them. This uncertainty, combined with error in estimating stock biomass and mortality rate, implies that diagnosis of stock status on individual lakes is limited. This uncertainty is a lesser problem when reference points are used to evaluate the status of a group of lakes, rather than an individual lake. An example of their application in evaluating the status of walleye lakes in Ontario is given by another paper in this volume (Morgan et al. 2003).

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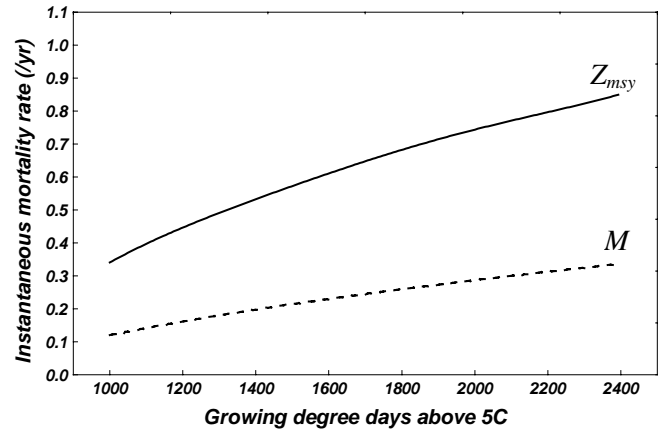


Figure 1. Estimated  $M$  and  $Z_{msy}$  as a function of climate, assuming  $h_1/h_0 = 2.5$  and  $L_c = 30$  cm.

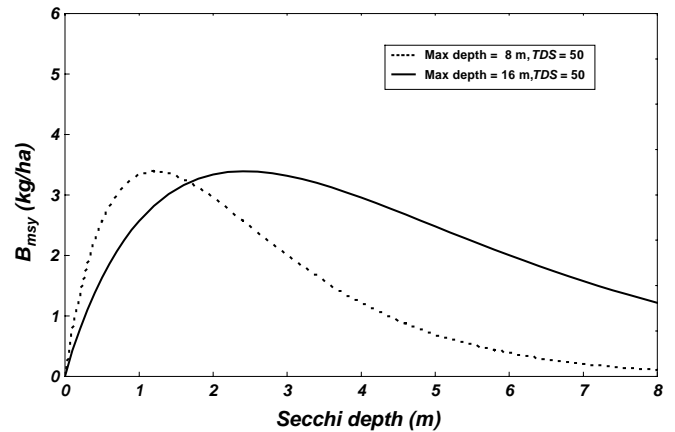


Figure 2. Estimated  $B_{msy}$  as a function of Secchi depth, assuming  $TDS = 50$  mg/l,  $L_c = 30$  cm and 2 values of maximum depth (8 m and 16 m).



## APPLICATION OF BIOLOGICAL REFERENCE POINTS TO EVALUATE THE STATUS OF WALLEYE (*Sander vitreus*) IN ONTARIO

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**Introduction.** Ontario contains more than 4,000 walleye (*Sander vitreus*) lakes scattered over 1,000,000 square kilometres. Inland lakes vary in size from under 2 hectares to over 150,000 hectares. Historically data were collected on very few of these lakes using a variety of methods and throughout the year making it difficult to compare between lakes or over time. In 1993, Ontario began testing a fall walleye index netting (FWIN) method that was developed in Quebec. After a slight modification, the FWIN method is now the recommended provincial index netting standard. To evaluate the status of Ontario's walleye resource we compared the 1993 to 2001 FWIN data to maximum sustainable yield biological reference points for exploitable stock biomass and total adult mortality rate.

**Methods.** Walleye populations were sampled using the FWIN standard (Morgan 2002). The sampling window for the FWIN protocol generally begins in late summer to early fall when surface water temperatures (at 0.5m depth) have begun to cool to less than 15°C and ends when it reaches 10°C (late fall). During this period walleye are more evenly distributed throughout the water column and the catch rate may be more comparable from year-to-year and lake-to-lake. The sampling gear is a gill net composed of eight 7.6m long by 1.8m deep panels of clear monofilament. The panels are arranged in increasing order of mesh size: 25, 38, 51, 64, 76, 102, 127, and 152mm (stretched mesh). The panels are sewn in order with no spacers. Nets are set at a randomly determined site for one day and one night only and then moved to the next site. The gear is set perpendicular from the shore, starting at a depth of 2.0m. The offshore end of the net is in less than 15.0m of water. The sampling effort is stratified into two depth categories: 2 to 5m and 5 to 15m. The small (25mm) and large (152mm) mesh ends of the gill nets are alternated on a daily basis so that half of the efforts have the small mesh to shore and half have the large mesh to shore. Fish are killed over the 24 hour period that the net is in the water at a particular site. Sampling effort is determined by surface area or until 200 to 300 walleye samples are obtained, whichever comes first. All walleye captured were biologically sampled for fork length (mm), total length (mm), wet weight (g), gonad weight (g), and visceral fat (g). Sex and maturity was determined by internal examination of the gonads (Duffy et al. 2000). Fecundity was estimated from mature ovaries collected and preserved in 70% ethanol. Scale, spines, and otoliths were collected for age determination.

To evaluate the status of walleye populations in Ontario, FWIN results from approximately 400 water

bodies sampled between 1993 and 2001 were compared to maximum sustainable yield biological reference points (BRP). Walleye relative abundance, biomass, and mortality estimates were derived for each water body after correcting for gear selectivity. The exploitable stock biomass BRP was compared to the observed FWIN  $\text{kg}\cdot\text{net}^{-1}$  for walleye  $\geq 300\text{mm}$  total length. The total adult mortality BRP was compared to female age 5+ Robson-Chapman mortality estimates (Robson and Chapman 1961). The ratios of abundance and mortality BRP-to-FWIN estimate were  $\log_{10}$  transformed. Individual ratio observations were pooled to determine the 80% prediction interval ellipse for the entire data set.

**Results.** Results from this extensive provincial survey program indicate that Ontario's walleye populations appeared to be healthy (Figure 1). Most lakes sampled in Ontario had high abundance BRP values and low mortality BRP values.

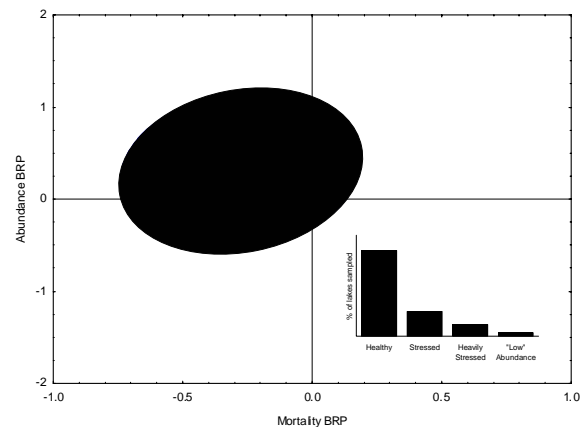


Figure 1. Status of Ontario walleye populations sampled using the fall walleye index netting standard 1993 to 2001 (80% prediction interval ellipse). Inset graphic (histogram) shows proportion of lakes by status classification (Healthy = high abundance and low adult mortality, Stressed = high abundance and high adult mortality, Heavily Stressed = low abundance and high adult mortality, and "Low" Abundance = low abundance and low adult mortality).

However, at the regional level there was a significant trend. The proportion of healthy populations declined from the northwest (NW region) to the northeast (NE region) to the south central region (SC region) (Figure 2).

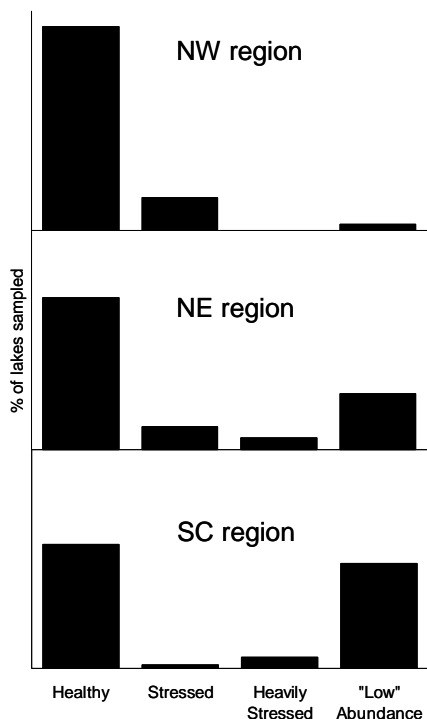


Figure 2. Classification of walleye population status by region (Healthy = high abundance and low adult mortality, Stressed = high abundance and high adult mortality, Heavily Stressed = low abundance and high adult mortality, and "Low" Abundance = low abundance and low adult mortality).

**Discussion.** Ontario's walleye resource appears to be healthy as defined by BRP for abundance and adult mortality. This result is somewhat surprising considering that the majority of the lakes that were sampled were issue lakes (i.e., identified by Ontario Ministry of Natural Resources staff to be sampled because of local users complaints over the status of their individual walleye population). Only the south central region was sampled using a stratified random design. Lakes were stratified by surface area, transparency, productivity, and climate. From this framework a 25% random sample was drawn and all lakes were netted in the fall of 2001. Based upon this sample, the walleye resource in the south central region appears to be in the worst shape.

The decline in the proportion of healthy populations from the northwest region through to the northeast region to the south central region is similar to the pattern in resident angler license holders. In the northwest region (where walleye populations were mostly healthy) there are approximately 50,000 resident anglers. There are 4 times as many anglers (200,000 license holders) in the northeast region where there are a lower proportion of healthy populations and more low abundance populations. Compared to the northwest region there are 15 times as many anglers (750,000 license holders) in the south central region. Healthy walleye populations

were found in one-half of the lakes sampled in 2001 and over 40% were classified as low abundance. The relationship between population health and the number of licensed resident anglers suggests that exploitation pressure may be a major factor limiting population growth.

This study clearly demonstrates the importance of extensive databases derived from surveys using standard sampling methodologies and appropriate sampling frameworks. Fisheries managers can use this information on overall resource status to evaluate current management actions and propose future changes. Walleye populations in Ontario generally appear healthy but stricter harvest controls may need to be implemented in the south-central region to protect currently healthy populations and rebuild low abundance populations.

**Acknowledgements.** Our thanks to the many dedicated Ontario Ministry of Natural Resources field staff who worked long and difficult hours to collect the data. The analysis was supported in part by the Ontario Ministry of Natural Resources and the Cooperative Freshwater Ecology Unit, Laurentian University.

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## EFFECTS OF WALLEYE STOCKING ON THE FISH COMMUNITY OF LAKE THIRTEEN

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**Introduction.** Walleye *Sander vitreus* stocking has historically been a major component of the fisheries management program in Minnesota and elsewhere. The popularity of walleye stocking as a management tool has led to increases in stocking with little regard for fish community dynamics. In this study, fish community responses to discontinued walleye stocking were monitored in a north-central Minnesota lake that previously had a consistent history of fry stocking.

**Methods.** Lake Thirteen is a 222 ha lake with a maximum depth of 17 m. Fish population assessments by gill netting, trap netting, and electrofishing during 1986-2002 tracked changes in relative abundance, size structure, and growth rates of fish in response to discontinued walleye stocking during 1989-1996. Walleye fry stocking was resumed in 1997. Supplementary information was collected on fish diets and habitat use. A linear growth model (Weisberg and Frie 1987; Weisberg 1993) that partitioned variation in scale growth into age effects and year (environmental) effects was used to examine the influences of interannual temperature changes and fish densities on year effects. The Wisconsin bioenergetics model of fish growth (Hanson et al. 1997), using physiological parameters developed for walleye (Kitchell et al. 1977; Madon and Culver 1993), was used to model walleye consumption of yellow perch *Perca flavescens*.

**Results.** Large changes occurred in size structure and relative abundance of walleye. The effect of discontinued stocking was to decrease the abundance of younger age classes of walleye in the lake, and walleye were re-established when fry stocking was resumed. An unusually large 1988 year class had large effects on the size structure of the walleye population as the year class grew older, and density-dependent growth was evident for walleye. Mean backcalculated total length at age three was 260 mm (SE=3) for the dense 1988 year class, but after stocking was resumed, age three fish were 327 mm (SE=5).

Natural variation in recruitment was a predominant theme among the other fish species. The northern pike *Esox lucius* population was characterized by variable recruitment that was apparently not linked to walleye stocking, water levels, or yellow perch densities. Largemouth

bass *Micropterus salmoides* and pumpkinseed *Lepomis gibbosus* populations also had variable recruitment, with the two coldest summers (1985 and 1992) corresponding to the two weakest year classes for both species. Summer temperatures (mean of June-August temperatures each year) and relative abundance of largemouth bass (electrofishing catch/effort) accounted for much of the variation in year effects from the linear growth model for largemouth bass ( $R^2=0.62$ ;  $P=0.002$ ;  $df=2,13$ ;  $F=10.77$ ). For pumpkinseed, summer temperatures and relative abundance of their primary predator (largemouth bass) also explained much of the variation in year effects from the growth model ( $R^2=0.83$ ;  $P<0.001$ ;  $df=2,13$ ;  $F=30.73$ ). Largemouth bass habitat use overlapped with walleye, and their diets overlapped primarily in their use of yellow perch, dipterans, and ephemeropterans.

The yellow perch population was initially typified by abundant large fish and a broad range of age classes. During the study, large changes were observed that coincided with changes in the walleye population. Electrofishing catches, which tended to select for smaller yellow perch than gill-net catches, showed increasing numbers of small fish after walleye stocking was discontinued in 1989, and catch rates of small yellow perch peaked just prior to resumption of walleye stocking in 1997 (Figure 1). Numbers of small yellow perch were reduced again following resumption of walleye stocking. Gill-net catches indicated a decline in abundance of large, older yellow perch throughout the study. Growth rates of yellow perch were density dependent and not related to summer temperatures. Year effects from the linear growth model showed a significant negative relationship with electrofishing catch rates for yellow perch ( $R^2=0.58$ ;  $P=0.001$ ;  $df=1,13$ ;  $F=17.93$ ). Slowest growth rates were for yellow perch year classes produced during 1991-1997 (mean backcalculated total length at age 3 of 104-126 mm for each year, with SE of 2-4 mm). Fastest growth rates were for year classes produced during 1983-1990 and 1998-1999 (mean backcalculated length at age 3 of 133-159 mm for each year, with SE of 3-10 mm).

Bioenergetics modeling projected large annual differences in consumption of yellow perch by walleye. Consumption of small ( $\leq 125$

mm) yellow perch was negligible in 1995-1996 (573 – 1,240 kg/yr) when small walleye were not present, compared to earlier (1987-1988) and later (2000, 2002) years of walleye stocking when consumption of small yellow perch was estimated to be 79,103 – 255,251 kg/yr. Consumption of large (>125 mm) yellow perch was projected to be greatest during 1995-1996 (824,880 – 1,008,496 kg/yr) when the walleye population consisted almost exclusively of large fish from the 1988 year class. Consumption of large yellow perch was lowest during 2000 and 2002 (57,305 – 290,003 kg/yr) when there were relatively low numbers of both large walleye and large yellow perch.

**Discussion.** Walleye predation played a large role in structuring the yellow perch population in Lake Thirteen. When stocking was discontinued, reduced predation on small yellow perch allowed their numbers to expand, and led to reduced growth rates of yellow perch. When stocking was resumed, walleye predation reversed the trend by reducing numbers of small yellow perch and improving their growth rates. Bioenergetics modeling confirmed walleye predation as a plausible explanation for changes in the yellow perch population. All of the trends in relative abundance of small yellow perch were explained by walleye feeding rates and changes in the size structure of the walleye population.

Variable recruitment, intraspecific competition for food, and interannual climate changes all helped confound analyses of other changes in fish community structure. Summer water temperatures affected growth and recruitment of centrarchid species in the lake. Intraspecific competition was evident among fish species, and was intense enough to restrict growth rates of walleye, yellow perch and largemouth bass. Given the range of food habits for these species (Pierce and Tomcko 1998), a variety of food resources must have been limiting in Lake Thirteen. Competitive effects of walleye stocking on largemouth bass were not documented, even though food and habitat use for the two species overlapped considerably.

In summary, yellow perch was the species most sensitive to changes in the walleye population, and the dynamics observed during this study are relevant to the ecological roles of both percids. These results illustrate how predator sizes can mediate structural changes in a prey population.

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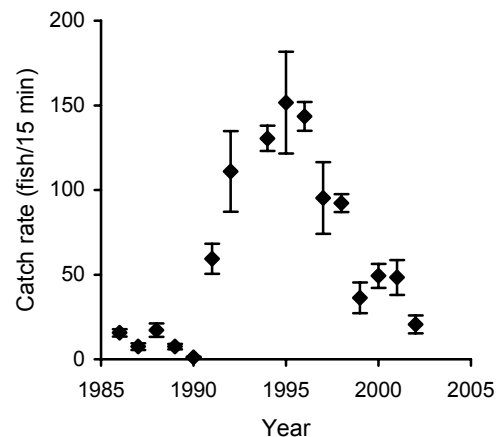


Figure 1. Electrofishing catch rates ( $\pm$ SE) for yellow perch during 1986-2002 in Lake Thirteen.

## ARE PERCID FISH OVERESTIMATED BY GILLNET SAMPLING?

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**Introduction.** Common percid fish – perch (*Perca fluviatilis*), pikeperch (*Stizostedion lucioperca*) and ruffe (*Gymnocephalus cernuus*) – possess a structured body surface and have a relatively firm body structure (Kipling, 1963). This, together with a potential difference in activity, may result in higher probability of capture and retention in gillnets comparing with smooth bodied fish like cyprinids or salmonids. Due to this, percid fish can be overestimated by gillnets.

To verify potential bias, we compared fish species composition based on catches with gillnets and a different fishing gear. As a reference gear, shore seines at the same time and site was used.

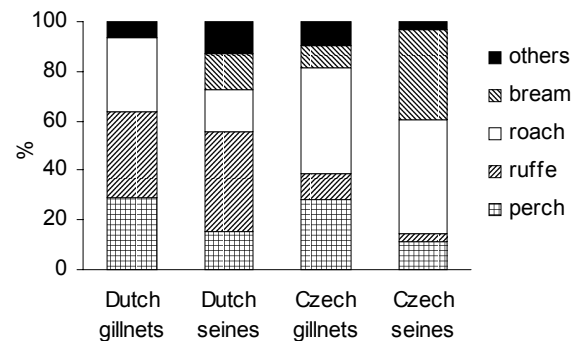
**Methods.** Suitable data for observing potential overestimation of percid fish were taken from three Dutch water-supply reservoirs (De Gijster, Honderd en Dertig and Petrusplaat) and two Czech reservoirs (Řimov and Staviště) during 1998 – 2002.

Nordic multimesh benthic gillnets were used for the studies. Sets included 13 different mesh sizes – 6, 8, 10, 12.5, 16, 19.5, 24, 29, 35, 43, 55, 70 and 90 mm (knot to knot). Each panel was 1.5 m high and 25 m long. Benthic gillnets were set for 12 hours overnight in the littoral in the depth 2 – 3 m. Hauls with 50 m shore seines with mesh size 10 mm (knot to knot) were carried out during the same night and on the place as close to the gillnets as possible to not disturb fish.

Absolute numbers of caught fish from both gears were converted to a ratio of number of percids to the sum of numbers of percids and cyprinids. Cyprinids created major part of abundance in selected reservoirs and they represent a close group considering the morphology. This ratio was tested with multifactor analysis of variance (MANOVA, p-level of 0.05) after arcsin transformation. An overestimation index of percids from gillnets was determined as a ratio of the proportion in gillnets / proportion in seine. Values above 1 mean overestimation and values below 1 signify underestimation of percids by gillnets.

**Results.** Percids (perch, pikeperch, ruffe) and cyprinid fishes (mainly roach *Rutilus rutilus*, common bream *Abramis brama* and bleak *Alburnus alburnus*) comprised 90 – 100% of both gillnet and seine catches in all reservoirs (Fig. 1). The rest of catches were represented by a sporadic catch of pike (*Esox lucius*), trout (*Salmo trutta*), eel (*Anguilla anguilla*) and smelt (*Osmerus eperlanus*; in Dutch reservoirs only). We compared 26 couples of ratios of

the number of percids to the sum of percids and cyprinids – 10 from Dutch reservoirs, 15 from the Řimov reservoir and one from the Staviště reservoir. A higher proportion of percid fish in gillnets was found in 77% of cases. Statistical analysis showed significant differences between proportions of percids



from two compared fishing gears (p-level 0.0142).

**Figure 1.** Average species composition from gillnets and seines in Dutch and Czech reservoirs.

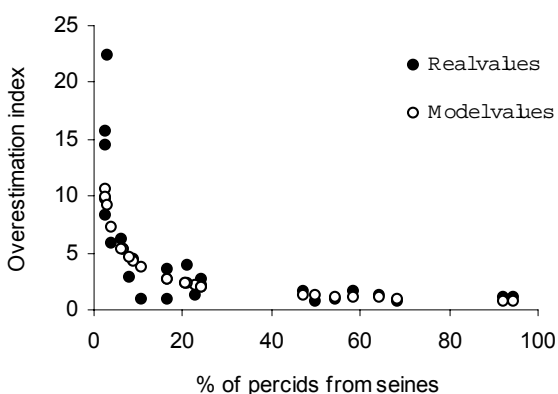
In individual catches, the overestimation index varied between 0.7 and 16. Table 1 shows the weighted average of the overestimation index for total number of percids and for particular perciform species. With only one exception – ruffe in Dutch reservoirs perciform species were overestimated by gillnets. The highest overestimations were gained for ruffe and perch in Czech reservoirs and for pikeperch from Dutch reservoirs.

Overestimation index of percids was found to be adversely related to the proportion of percids in the community from the reference catch (Fig 2). In high percid densities, the overestimation index cannot be high by definition. This may partly explain higher values of overestimation indexes in Czech reservoirs (Table 1). After log-transformation, the relationship in Figure 2 can be described by linear function ( $\text{Log } y = -0.74 \text{ Log } x + 1.33$ ;  $R^2 0.75$ ) and has a hyperbolic course similar for all three perciform species.

**Discussion.** The catchability of fish by gillnets is affected by factors, which are related either to the characteristics of the net or of the fish (Reis & Pawson, 1999). Many works were oriented to the significance of nets parameters (Kurkilahti, 1999), but less attention was paid to the fish attributes.

**Table 1.** Average overestimation index (OI) and proportion in catch (%) for total number of percids and for particular perciform species.

Reservoirs	Dutch	Czech	Both
<b>Percids total: OI</b>	<b>1.17</b>	<b>2.60</b>	<b>1.63</b>
% in gillnets	66	43	52
% in seines	56	17	32
<b>Perch: OI</b>	<b>1.91</b>	<b>2.62</b>	<b>2.28</b>
% in gillnets	29	28	29
% in seines	15	11	13
<b>Pikeperch: OI</b>	<b>2.50</b>	<b>1.44</b>	<b>1.60</b>
% in gillnets	2	4	3
% in seines	1	3	2
<b>Ruffe: OI</b>	<b>0.86</b>	<b>3.53</b>	<b>1.16</b>
% in gillnets	35	11	20
% in seines	40	3	17



**Figure 2.** Dependence of value of overestimation index on proportion of percids in reference community.

Overestimation index of percids varied a lot between two groups of reservoirs. No obvious similarity for the same species or the same reservoir was found. The results suggest that the patterns of gillnet overestimation of percids are more complicated than simple mechanical selectivity. The highest difference was found with ruffe. It is interesting, that ruffe was slightly underestimated by gillnets in Dutch reservoirs, while it was very much selected in the Czech reservoirs. Significant proportion of more active perch in Dutch reservoirs may be responsible for the discrepancy. Another explanation would be habitat selection of ruffe and ability of fishing gears to cover microhabitats. On the flat concrete bottom and shores of Dutch reservoirs, the effectiveness of gillnets and seine nets could be comparable. Contrary to this, the Czech reservoirs have natural beaches, where the benthic gillnets can follow the roughness of the bottom, whereas hauls with seine nets over such a bottom leave many gaps

to escape. We should also consider selectivity of seining due to physical obstructions and various ecology of species (Parsley et al., 1989; Pierce et al., 1990). Two types of reservoirs differed in species proportions and many aspects of fish biology (Kubečka et al., 1998) and the patterns of net selectivity may differ between them.

The results showed that the positive overestimation of percids by gillnets and higher probability of capture usually take place in reservoir surveys. Selectivity of gillnets is complicated by both mechanical and behavioral aspects of fish capture as well as by the fish community structure. However, multimesh gillnet is a very robust and frequently used sampling gear and in many cases it is the only method capable of fair sampling of all habitats of the reservoir. Also due to constancy of this gear, the long time gillnet data are highly valuable. Therefore, we believe that correcting the selective gillnet catch by a sound correction factor is a challenging task worth intensive investigation. Future studies should include more detailed analysis of the capture mechanism, more extensive catch statistics, and experiments with gillnet selectivity in tailored fish communities.

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## THE EFFECT OF STOCKING SIZE ON SURVIVAL OF FINGERLING PIKEPERCH (*Sander lucioperca*)

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**Introduction.** Stocking one-summer-old fingerlings is a popular method to increase recruitment of pikeperch (*Sander lucioperca*) in Finnish lakes. During last decade, 8-10 million pikeperch fingerlings have been stocked in Finnish lakes every year. Most of the stockings are made in lakes having a self-sustaining pikeperch population.

Pikeperch fingerlings reared in natural food ponds are usually smaller than natural fingerlings of same latitudes in the end of their first summer (Ruuhijärvi et al. 1996, Ruuhijärvi and Hyvärinen 1996). Large size at the end of the first growing season is known to improve the survival of pikeperch through their first winter (Buijse and Houthuijzen 1992, Lappalainen et al. 2000).

The pikeperch catches obtained by stocking pond-reared fingerlings have been very variable and in most of the lakes they have not covered the stocking costs (Ruuhijärvi et al. 1996). The objective of this study was to find out how much the survival of stocked pikeperch could be improved by stocking fingerlings with size equal to the natural ones. The contribution of stocked large and small fingerlings to pikeperch recruitment was studied in a lake having a self-sustaining pikeperch population.

**Methods.** In the study area, the Enonselkä basin (2 600 ha, 61°00'N, 25°30'E) in the eutrophic Lake Vesijärvi (11 000 ha) biomanipulation by mass removal of cyprinids was successfully performed in 1989-1993 (Horppila and Peltonen 1994). Pikeperch was introduced to the lake in 1984-91 by stocking fingerlings and first strong natural year-class was born in 1992 (Peltonen et al. 1999). High fishing mortality of juvenile pikeperch due to extensive use of 35-45 mm (bar length) gillnets kept the pikeperch stock at unsatisfactory low level. In 1997, gillnets of mesh sizes 22-49 mm (bar length) were forbidden (Suoraniemi et al. 2000). This fishing restriction, together with the 40 cm minimum size limit, made the Enonselkä basin a suitable environment for this pikeperch stocking study.

Two size groups, "conventional" (71-73 mm TL) corresponding the average size of pond-reared fingerlings and "large" (88-96 mm TL) corresponding the average size of wild fingerlings were stocked marked in September in 3 successive years, 1997-1999. Pikeperch fry used in the study originated from wild spawners from Vanajavesi watercourse, southern Finland and were of same origin as the established stock of Lake Vesijärvi. Two size groups of fingerlings were raised in two ponds using different stocking densities. The pond used for rearing conventional fingerlings was stocked with 20 000 fry/ha and the pond for large fingerlings with

10 000 fry/ha in the beginning of June. Ponds were harvested in September and the fingerlings were transported to Evo Fisheries Research Station. Fingerlings were marked with hot branding (Saura 1996) and transported and stocked from shore to Enonselkä the day after marking. Water temperature during pond harvest, marking and stockings was 10 – 14°C. Extra mortality caused by marking was estimated by keeping 200 fingerlings of each marking batch in 1 m<sup>2</sup> tanks for one month. Stocking numbers (Table 1) were adjusted with the average survival of each group of fingerlings. The number of fingerlings in different stocking groups varied from 27000-47000 (average 37000), and the total annual stocking density from 25 - 33 fingerlings/ha.

Samples of 2+ and 3+ pikeperch, not yet recruited to fishery, of year-classes 1997-99 were collected with 25, 30, 35, 45 and 55 mm (bar length) gillnets in October after the growing season in 1999-2002 and in May before the growing season in 2000. Brand-marks and age, determined of scales, were used to identify wild fish and fish belonging to different stocking groups. The number of recoveries (Table 2) (in relation to numbers stocked) was then used as an index for survival in each group.

We considered possible to detect a 30 % departure from intended 50:50 stocking ratio of conventional and large fingerlings at the significance level  $\alpha=0.05$  and power  $1-\beta=0.90$  (Elrod and Frank 1990) (Table 1), which required with the true (adjusted) stocking ratios 103, 151 and 132 recaptures of the year-classes 1997, -98 and -99 respectively. The likelihood ratio ( $G^2$ ) test was applied to test for differences in the recapture rates for conventional and large fingerlings.

Table 1. Stockings of conventional and large pikeperch fingerlings and the estimated need of recaptures.

year-class		1997	1998	1999
conventional	no. stocked	50000	50000	38000
	control survival %	75.6	75.4	95
	adjusted no. st.	38000	38000	36000
	mean length mm	73	71	73
	mean weight g	2.3	2.4	2.9
large	no. stocked	30000	49000	52000
	control survival %	90.3	95.5	73.3
	adjusted no. st.	27000	47000	38000
	mean length mm	88	90	96
	mean weight g	4.1	4.7	6.2
need of recaptures		103	151	132

Table 2. Samples of 2+ and 3+ pikeperch of the two stocking groups and wild fish collected from the Enonselkä basin in years 1999-2002, and the statistical analyses of the results ( $G^2$ - test).

year-class	group	Oct 99-May 00	Oct-00	Oct-01	Oct-02	total	independence	Goodness of fit
97	conventional	19	8			27	3.338, p>0.05	13.97 p<0.05
	large	43	42			85		
	wild	85	26			111		
98	conventional		9	5		14	0.022, p>0.05	186.1, p<0.05
	large		241	123		364		
	wild		53	10		63		
99	conventional			18	21	39	0.789, p>0.05	49.46, p<0.05
	large			86	137	223		
	wild			66	87	153		

**Results.** The numbers of young pikeperch of the two stocking groups and wild fish in the samples collected from the Enonselkä basin in years 1999-2002 are shown in Table 2. The survival rate of the large fingerlings in relation to the stocking numbers was in year-class 1997 4.4, in year-class 1998 21 and in year-class 1999 5.4 times higher than the survival rate of conventional fingerlings. The number of samples of every year-class was sufficient for statistical analyses. The distribution of recaptures over sampling years was homogenous between conventional and large fingerlings at the 5 % risk level (Table 2,  $G^2$  -test of independence). In each year-class the difference of survival of conventional and large fingerlings was statistically significant (Table 2, goodness of fit). The results show, that larger stocking size at the end of first growing season improved the survival of pikeperch fingerlings. Most of the pikeperch recruits in year-classes 1997-99 were of stocked origin in the Enonselkä basin. The natural recruitment also had a remarkable contribution to pikeperch stock in these year-classes.

**Discussion.** Results of this experiment confirm that the common observation of better survival of larger fingerlings in natural pikeperch populations in various habitats, e.g. Lake IJssel (Buijse and Houthuijzen 1992) and Pärnu Bay in the Baltic Sea (Lappalainen et al. 2000), is valid for stocked fingerlings in Finnish lakes also. In the Enonselkä basin the improvement of survival was good enough to cover the 2-3 times higher production costs of larger fingerlings. The production of large pikeperch fingerlings is, however, risky and requires a productive pond with rich zoobenthos food supply and a warm and long growing season. Another way to improve survival of stocked pikeperch fingerlings might be to stock them in July-August during the growing season. The growth of pikeperch fry is often faster in ponds than in lakes in June, but retards later in the summer because shortage of suitable sized food. Sutela and Hyvärinen (2002) showed that pikeperch fingerlings stocked to Lake Oulujärvi in the beginning of August were able to predate on fish fry and grew faster than wild or in the rearing pond left fingerlings in late summer. The pikeperch stocking practices in Finland need reconsidering. One way or another the reared fingerlings should grow larger before the fall. Stocking small fingerlings in

the end of growing season is in most cases not feasible.

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## MANAGEMENT OF LAKE LOHJANJÄRVI PIKEPERCH (*Sander lucioperca*) – A FADING SUCCESS?

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**Introduction.** Pikeperch is one of the most important fish species in Lake Lohjanjärvi (89 km<sup>2</sup>), Southern Finland. In 1980-2001, pikeperch yield varied from 4000-21000 kg, of which ca. 90% was taken by gillnets. The no. of gill-netters varied from 300-700, each having a license for 1-4 nets. Trolling accounted for ca. 10% of the yield. Catch was mainly used for household needs, but some fishermen also sold fish.

Most gill-netters fished with small gear (length \* height 30 m \* <2 m) near the shoreline in the summer, targeting on pikeperch and a number of other species (e.g. *Esox lucius*, *Perca fluviatilis*, *Coregonus lavaretus*). In the two deeper basins (>30 m, Karjalohjanselkä, Isoselkä), special pikeperch nets (60 m \* ≥10 m) were used, mainly set in mid-water. This fishery, which took place in September-December and, after icing, again in January-April, accounted for the most part of the pikeperch catch.

Lehtonen and Miina (1988) reported high fishing mortality and a low age at recruitment (4-6 yrs) for Lake Lohjanjärvi pikeperch. Growth over-fishing was regarded as evident and recruitment over-fishing as possible. A larger gill-net mesh size (50-55 mm) and a larger minimum landing size (MLS, 40-42 cm TL) were thus suggested, in order to increase the age at recruitment to 5-6 years.

On this recommendation, the local fishing authority decided in 1992 to raise the minimum bar length of all large (height > 2 m) gillnets from 45 to 50 mm, and MLS from 37 to 40 cm. In addition, YOY pikeperch were stocked in 1991-95. The aim was to increase and stabilize pikeperch catches. In this study we assess whether these goals were achieved.

**Methods.** All YOY pikeperch stocked were marked using hot branding (Saura 1996) (Table I).

Table I. Stocking of YOY-pikeperch

	Year 1991	Year 1992	Year 1993	Year 1994	Year 1995	All
No. of fish	14800	20000	40800	41300	40000	156900
Ind./ha	1,6	2,2	4,4	4,5	4,3	16,9
Size, mm	84	77	73/87	92	87	

Catch samples and CPUE data from pikeperch nets were obtained from 3-6 bookkeeping fishermen in autumn/winter seasons 1993-2001. Catch and effort were recorded by fishing occasion. Marks were checked and standard scale samples were taken for age determination. Comparable older catch samples were available from the scale archives of the FGFRI.

Total gear-specific fishing efforts, catches of different fish species, and pikeperch CPUE in all nets were assessed using mailed fishing surveys. Two surveys were performed for this study (1996, 2000), five by local water authorities (1981, 1983, 1990, 1994, 1998). Samples were drawn from the local

registers of licensed fishermen. Catch data were also obtained from two nation-wide surveys (Leinonen et al. 1998; Anna-Liisa Toivonen, pers. com.).

**Results.** In the Isoselkä basin, fishing effort dropped markedly between 1990 and 1994 (Fig 1), partly due to the reluctance of fishermen to invest in new 50 mm nets. In Karjalohjanselkä, where 50 mm nets were to some extent used, effort remained first at the previous level. Later a decreasing trend became evident also here, probably indicating a deeper change in fishing habits.

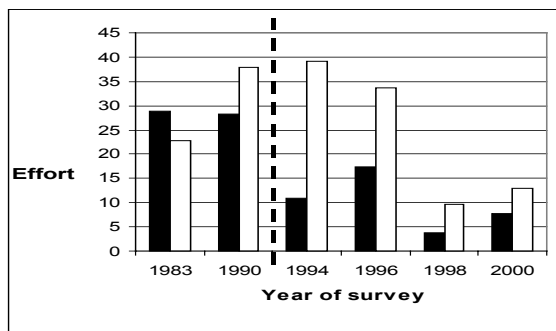


Fig 1. Gillnet fishing effort (1000 net-days), as estimated from fishing surveys. Black columns: Isoselkä. White columns: Karjalohjanselkä.

After the implementation of the larger mesh size, the average catch size of pikeperch in nets increased from 600-700 to 900-1000 g. However, no clear change was observed in the age structure of the catch (Table II), due to the large overall variability in year-class strength and the coinciding increase in pikeperch growth rates (Fig 2).

Table II. Catch age-structure in pikeperch gillnets (45 mm mesh until 1991/92, then 50 mm mesh). The most abundant age group is in bold type.

Season	Age-group								Total	n
	1+/2	2+/3	3+/4	4+/5	5+/6	6+/7	7+/8	>8		
1979/80	16,2	1,9	5,7	<b>39,0</b>	20,0	11,4	2,9	2,9	100,0	105
1980/81	12,3	27,9	3,9	7,1	<b>42,2</b>	5,2	1,3		100,0	154
1981/82	1,4	<b>50,6</b>	20,5	2,8	5,6	18,5	0,6		100,0	356
1982/83		7,7	14,2	21,9	7,1	11,2	<b>35,5</b>	2,4	100,0	169
1985/86	0,9	1,9	14,2	<b>42,5</b>	34,0	5,7	0,9		100,0	106
1991/92			<b>92,0</b>	0,9	3,6	1,8	0,9	0,9	100,0	112
1993/94		7,3	10,4	6,3	<b>71,9</b>	1,0		3,1	100,0	96
1994/95		1,9	<b>51,5</b>	37,9	2,9	5,8			100,0	103
1995/96	0,8	1,6	9,1	<b>77,8</b>	8,3	1,0	1,2		100,0	492
1996/97	0,9	14,5	25,5	<b>28,2</b>	28,2	1,8		0,9	100,0	220
1997/98	0,3	2,4	<b>75,0</b>	13,5	6,8	1,2	0,6	0,3	100,0	340
1998/99	0,5	2,2	22,9	<b>67,7</b>	4,7	1,0	0,7	0,2	100,0	402
1999/00	0,4	4,6	<b>52,1</b>	36,6	6,3	0,0			100,0	284
2000/01	2,4	3,2	24,6	28,6	<b>35,7</b>	5,6			100,0	126

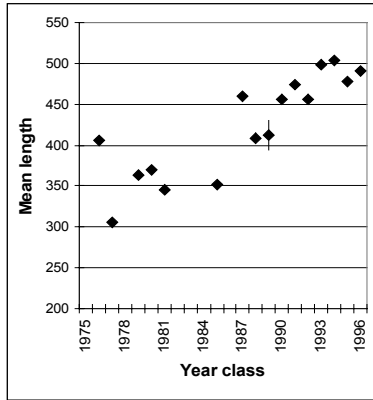


Fig 2. Pikeperch mean length (mm) at age 5

Stocking contributed significantly to the recruitment of pikeperch in year-classes 1991-1995 (Table III). Contribution to fishery peaked in 1998, when 60% of catches consisted of marked fish.

Due to insufficient historical data, trends in pikeperch CPUE cannot be properly assessed in relation to the new fishing regulations. The observed increase in CPUE in 1996-2001 (Fig 3) was largely attributable to stocking, although the larger average catch size probably also contributed positively.

Despite increasing CPUE in pikeperch nets, neither increase nor stabilizing could be observed in the total catches of pikeperch in 1996-2001 (Fig 3). The positive impacts of management were counteracted by the decreasing popularity of gill-net fishing.

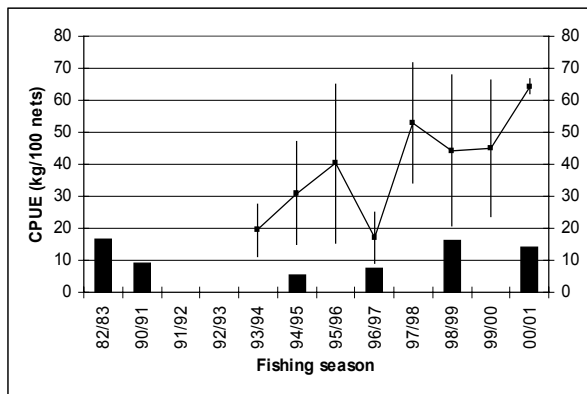


Fig 3. Pikeperch CPUE in all nets (columns: estimated from fishing surveys), and in pikeperch nets (line). The former refer to entire years (1983, 1990 etc), the latter to fishing seasons (Sept.-April).

**Discussion.** Our results are another example of uncertainties related to fisheries management decisions. Larger gill-net mesh size and MLS created a good basis for more sustainable exploitation of Lake Lohjanjärvi pikeperch, but the anticipated positive impacts on total catches didn't come true due to the unexpected decrease in fishing effort.

Management measures taken in 1992 (50 mm mesh, 40 cm MLS) were based on slower growth

than the present one. Given the present fast growth, larger catches per recruit and higher CPUEs could probably be expected by applying 55 mm mesh and 42-45 cm MLS. Uncertainties and implementation risks related to such a decision may, however, be too big.

Releases of YOY-pikeperch contributed markedly to pikeperch catches and fisheries, and were probably a success also in economic terms.

Fig 4. Total catches of pikeperch, as estimated from fishing surveys. Black columns: local surveys; white columns: nation-wide surveys.

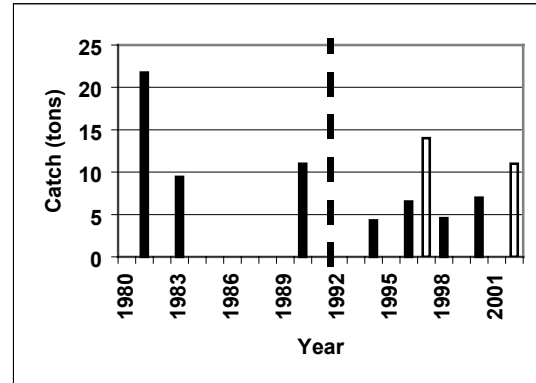


Table III. No. of marked fish in catch samples by year-class (A, YCL), and by sampling year (B).

A	YCL	YCL	YCL	YCL	YCL	All
	1991	1992	1993	1994	1995	
No. of fish	476	144	157	799	331	1907
Marked	20	47	113	497	224	901
%	4,2	32,6	72,0	62,2	67,7	47,2
B	Year	Year	Year	Year	Year	Year
	1995	1996	1997	1998	1999	2000
No. of fish	316	355	353	474	305	488
Marked	26	64	199	284	168	161
%	8,2	18,0	56,4	59,9	55,1	33,0

**Acknowledgements.** We thank Karl Sundman for the scale analysis, Sakari Kuikka for comments on the manuscript, and Pekka Ilmarinen, Esko Manninen, Pentti Nikander, Mikko Raunio, Seppo Sundström, and Pekka Sjögren for co-operation in collecting data.

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## MONITORING HATCHERY USE OF SPAWNING WALLEYE IN LAKE DIEFENBAKER, SASKATCHEWAN (CANADA)

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**Introduction.** Saskatchewan is a prairie province with most of its human population residing in the southern agricultural region. Many lakes in this area are shallow and mesotrophic or eutrophic, summers are often sunny and dry and winters long, and watercourses are fragmented by barriers.

Walleye (*Sander vitreus*, formerly *Stizostedion vitreum*) fry are stocked annually to mitigate winterkill and supplement natural recruitment. Since 1950, several spawning populations have been used to obtain eggs for stocking over 50 lakes annually.

Since 1991, the walleye that spawn in Coteau Bay of Lake Diefenbaker have been the sole source of 60 to 100 million eggs annually for this program. An assessment of the sustainability of hatchery operations seemed advisable.

Lake Diefenbaker was impounded in 1967 for hydro-electric, irrigation, and recreational use. It is 222 km long and has an area of 43,000 ha. About 1/4 of the lake is deeper than 30 m and the maximum is 59 m (Royer 1972). Winter draw-downs range up to 11 m. Coteau Bay is adjacent to Gardiner Dam, about 4 km long, and a maximum of 15 m deep.

After initial stocking of several fish species, angling increased slowly and moved from northern pike (*Esox lucius*) to walleye. The lake now ranks first or second in recent angler surveys (Joerissen and Brickley 1998).

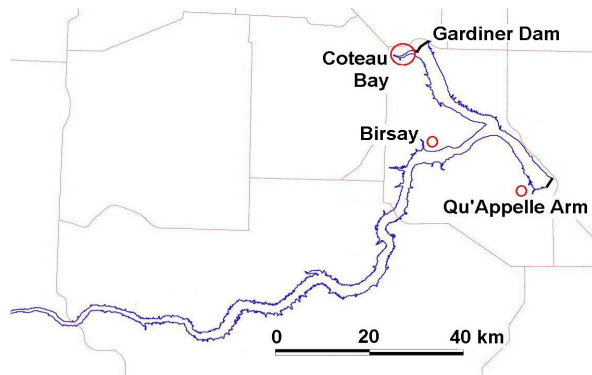


Figure 1. Lake Diefenbaker showing Coteau Bay (large circle) and two other sites (small circles).

**Methods.** Fish culture station (FCS) staff used trapnets to catch fish in late April to early May, collected eggs from ripe females, held others in pens up to 3 days for ripening, and shipped eggs to the hatchery. They monitored indices annually from 1991: numbers of walleye and other species, numbers

of female and male walleye, average eggs obtained per female, and % hatch. Fishing efforts, waterlevels, and water temperatures were recorded.

Initially, only walleye caught during hatchery operations in Coteau Bay were examined. Later, assessment crews trapnetted at two other sites: Qu'Appelle Arm (Aikto and Fordes creeks) and Birsay area (Hitchcock and Sage bays).

Assessment covered four main topics, from microscale to ecosystem-wide:

(1) FCS monitoring and additional indices of egg quality (as 'egg dry mass') and stress from handling (by 'lymphocystis' rates). Samples of eggs were expressed, frozen, and two replicates of 30 eggs were counted, dried 24 hours at 60C, and weighed.

(2) Sizes and age compositions at several sites. Ageing of dorsal spines was done for sub-samples and applied to length compositions.

(3) Abundance of spawners at each site. Serially numbered tags were used for daily estimates ('within year' by Jolly-Seber) and batch tags for seasonal ('year-to-year' by Petersen). These required analyses of length of stay during spawning, tag-loss from double-tagging, mortality and recruitment, and homing.

(4) Movements of walleye after spawning based on reports by anglers. Mixing of spawners among sites was assessed by staff to detect any net inflow into Coteau Bay from other sites. The 3 sites are 40 to 60 km from each other, and chosen to be within the observed range.

**Results.** Time series of FCS indices showed some variations and auto-correlations among years (all non-significant at  $p=0.05$ ). Linear regressions showed no significant trends, and only one index was low in any year: % females in 2000 reached the lower 95% prediction limit for single observations. Some of the FCS indices are not easily standardized because staff adjust their fishing to maintain catches while ensuring proper care of the fish and eggs. Lower waterlevels in some years also increase catches noticeably, further confounding the situation.

Each year, staff examined 3,000 to 5,000 walleye at Coteau Bay and 100 to 900 at each of the other sites.

'Egg dry mass' averaged about 0.9 mg for 115 females, in line with data from Coteau Bay in 1997 and other populations. 'Lymphocystis' occurred on significantly more walleye at Coteau Bay than other sites (10% versus 3%). Rates reached 15% in females that were handled for both hatchery and tagging operations. Preliminary data from serial# tags suggest that the effects of different kinds of tags may vary.

Sizes of females ranged from 35 to 80 cm long and males 25 to 70 cm. Sizes, ages, and mortality rates were very similar at most sites.

Sex and site	Ages (years)	Mortality (annual)
Females		
Coteau Bay	6 to 20	19 %
Qu'Appelle	6 to 18	17 %
Birsay	6 to 19	17 %
Males		
Coteau Bay	5 to 19	27 %
Qu'Appelle	5 to 11	38 %
Birsay	5 to 15	28 %

Daily mark-recapture estimates of abundance usually fluctuated and had wide confidence limits, if any. Estimates were not possible at Coteau Bay since most walleye were temporarily removed during penning. Recaptures at Qu'Appelle sites indicated stays averaged only 2 days and may suggest 'staging' in the open lake. About 9 % of fish tagged at Birsay in 2001 were recaptured at Coteau or Qu'Appelle sites within the same spawning season, implying considerable transience. Fish tagged farther inside the Birsay bays in 2002 showed greater residency during spawning season.

Walleye abundances confirm that Coteau Bay is a major spawning site. Numbers of walleye averaged 15,800, comprised of 5,000 females and 10,000 males. Numbers were about 2,300 in the Qu'Appelle area and 2,100 in the Birsay area, based on year-to-year recaptures.

Anglers reported over 300 walleye from Coteau Bay were recaptured between May and December in the initial 3 years. Some walleye were 100 km up the lake by July and the furthest were 145 km along by September. This reflects both walleye movements and seasonal angler patterns. Some walleye remained in Coteau Bay all summer and longer.

Spawning walleye tended to return to the site used the previous spring. About 95 % returned to Coteau Bay and 91 % to Qu'Appelle sites, but only 65 % to Birsay sites in 2002. This means about 800 walleye arrived for the first time in Coteau Bay and about 800 walleye departed from Coteau for the other two areas. Data for 2003 should show if Birsay 'residents' tend to further reduce any inflow into Coteau Bay.

**Discussion.** Monitoring indices in place since 1991 suggest there are few, if any, concerns. Nonetheless, some indices need long periods to detect problems within the natural variability of walleye populations and may lag behind early effects.

Similar concerns about impacts from a similar longterm use of another spawning run in Saskatchewan showed changes, but a generally healthy population (Mathias *et al.* 1985).

Hatchery operations collected eggs from 480 to 920 females annually, and not all of the eggs in each fish. Actual usage is about 14 % of the 750 million eggs that could be collected, based on the total abundance of females in Coteau Bay. Continued stocking of fry into Coteau Bay may alleviate any residual concerns.

Several of the initial recommendations are in place, even as the study concludes. Egg collections have been fine-tuned to better reflect natural abundance each year, rather than demands for fry. Monitoring continues and more detailed indices (e.g. egg dry mass) are planned periodically. Lymphocystis rates require further analysis of the effects of tagging and periodic updates.

Spawning populations in Coteau Bay, Qu'Appelle Arm, and Birsay areas all show good size and age compositions and acceptably low mortality rates.

The population in Coteau Bay does not appear to be sustained by net inflows from other populations. Some mixing of spawners occurs between sites within the known range of walleye movements in Lake Diefenbaker. If spawners at all 12 to 20 known spawning sites behave similarly (given their relative distances from Coteau Bay), the balanced mixing into and out of this major site would remain.

Many aspects of walleye populations in Lake Diefenbaker are unknown and will likely remain so: identification and suitability of most spawning sites, total abundance of walleye in the lake, and genetics of the original riverine *versus* stocked fish and any sub-populations.

The effects of fishing harvests, catch-and-release angling, year-class variability, and past escapes of large numbers of fish from aquaculture facilities on walleye and other species may need examination. Meanwhile, habitat conditions in this reservoir continue to evolve.

**Acknowledgements.** Staff at the Fish Culture Station monitored operations from 1991 to present. Many staff and volunteers from the EcoRegion and Branch worked every spring on the lake. Tournament organizers for Elbow Wildlife Federation, Riverhurst Recreation Board, and Kyle Lions Club provided access to anglers, and enforcement staff summarized reports from anglers. Students and staff rechecked tag numbers and other data, aged fish, and reviewed drafts. Funding came from Branch and EcoRegion budgets and the provincial Fish and Wildlife Development Fund.

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## **YELLOW PERCH RECOVERY AND MANAGEMENT**

### **Collapse of the yellow perch fishery in Les Cheneaux Islands, Lake Huron and possible causes**

*David G. Fielder*

### **Genetic variation and spawning population structure in Lake Erie yellow perch, *Perca flavescens*: A comparison with a Maine population**

*Alexander M. Ford and Carol A. Stepien*

### **Recruitment failure of perch populations in the Baltic**

*Lars Ljunggren, Peter Karås, Magnus Appelberg and Alfred Sandström*

### **Another yellow perch population decline in the 1990s: The Lake St. Pierre case study, St. Lawrence River, Quebec**

*Yves Mailhot and Pierre Dumont*

## COLLAPSE OF THE YELLOW PERCH FISHERY IN LES CHENEAX ISLANDS, LAKE HURON AND POSSIBLE CAUSES

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**Introduction.** The Les Cheneaux Islands region of Lake Huron is an archipelago along the south shore of Michigan's upper peninsula. The area provides about 2,023 hectares of pristine coolwater habitat situated in a series of channels and embayments. The region has long been famous for its yellow perch (*Perca flavescens*) sport fishery dating back to the early 1900s.

Quantifiable estimates of harvest and harvest rate are available from only a series of years when creel surveys were in place. Harvest has been estimated from these surveys to be as high as 389,000 yellow perch in a single open-water fishing season (Lucchesi 1988). During the 1980s, there was concern of the possibility of over harvest and a 178 mm minimum length limit was instituted in 1988. The yellow perch fishery remained relatively stable through the mid 1990s, and then abruptly declined to a near total collapse in 2000 (Figure 1).

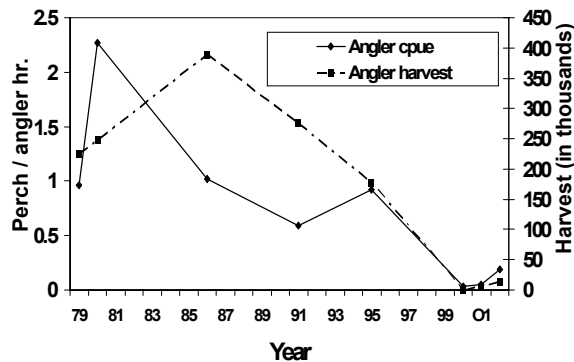


Figure 1. Yellow perch harvest and angler catch-per-unit-effort (CPUE) for the Les Cheneaux Islands, Lake Huron, 1979-2002. Harvest estimates adjusted for aerial pressure count method.

The objective of this Communication is to identify possible explanations for the collapse.

**Methods.** Since 1969, the Michigan Department of Natural Resources has conducted an annual assessment of the fish community in the Les Cheneaux Islands via gill netting with graded-mesh nets. The gill net mesh sizes ranged from 38.1 mm to 152.4-mm stretch-measure mesh. Two such nets were fished overnight in three stations each October. Catch was identified, measured for total length, round weight, sexed, and aged.

Trends in abundance were examined by comparing mean catch-per-unit-effort (CPUE) with

one effort unit being one net lift. Total annual mortality rate was determined by the Robson-Chapman method. Trends in recruitment were examined by comparing mean CPUE of age-2 yellow perch over time. Age-2 perch were believed to be the first age completely vulnerable to the sampling gear. Trends in abundance of double-crested cormorants (*Phalacrocorax auritus*) were examined based on nest counts performed by various researchers since 1980.

**Results and Discussion.** Mean annual catch rate of yellow perch in survey nets declined in 1985 but remained relatively stable (Figure 2) despite the collapse in the fishery. Change of one station location in the assessment survey beginning in 1985 partly accounts for the change in mean catch rate beginning that same year. On the whole, trends in abundance based on survey catch rate did not reflect trends in the fishery. Closer examination of patterns of catch in the survey, however, indicated that the vast majority of the catch in recent years came from one location (Muskellunge Bay) while yellow perch became rare in the eastern most station (Hessel Bay). In addition, much of the survey catch was comprised of fish less than the minimum length limit and thus were not available to the fishery. Local fishery managers generally regarded the collapse in the fishery to be genuine and not just an artifact of some change in fishing preference.

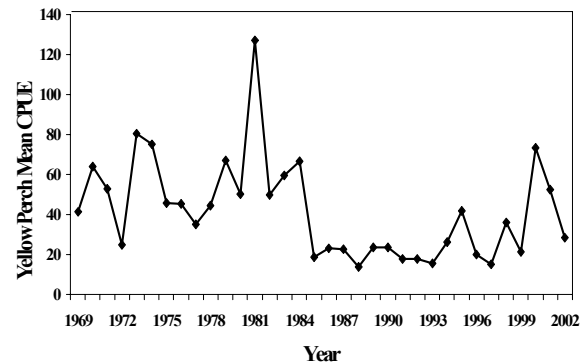


Figure 2. Mean yellow perch catch-per-unit-of-effort (CPUE) in survey nets from the Les Cheneaux Island, 1969 – 2002.

Recruitment of yellow perch during this time was examined based on mean CPUE of age-2 fish in the survey catch (Figure 3). Reliable age data were not available for every year of the survey since 1969, but remaining years did provide some indication of



recruitment trends. This series suggests that annual recruitment has continued during the decline and collapse of the fishery. Despite the collapse in angler harvest and fishing pressure, total annual mortality rate of yellow perch remained high, ranging from 67% to 78% from 1997 through 2002. Mean age of perch has also declined from 4.5 years in 1997 to 1.5 years in 2002.

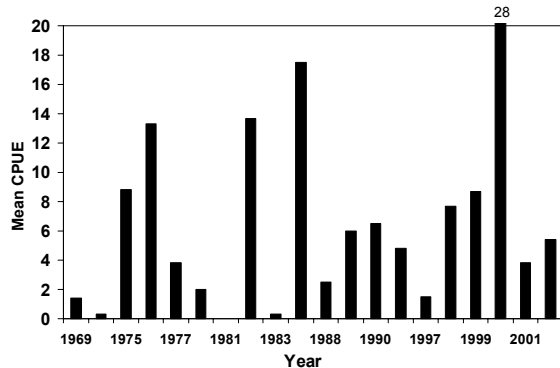


Figure 3. Trends in yellow perch recruitment in the Les Cheneaux Islands based on mean CPUE of age-2 fish for 20 years between 1969 and 2002. Graphed years are limited to those for which reliable age data existed.

Concurrent with the decline and collapse of the fishery and the loss of perch in certain areas of the Les Cheneaux Islands, was the proliferation of cormorant nesting in the area. Trends in nest numbers indicated a near exponential increase in usage during the early 1990s (Figure 4).

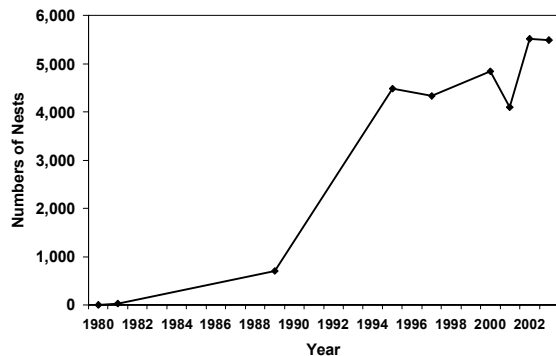


Figure 4. Numbers of cormorant nests in the Les Cheneaux Islands vicinity 1980 - 2003.

Maruca (1997) examined feeding habits of cormorants in the Les Cheneaux Islands in 1995 and confirmed that yellow perch are part of their regular diet. However, that study also concluded that the overall impact was generally low because of the then relatively high abundance of perch and because their predation was buffered for much of the year by

abundant alewives (*Alosa pseudoharengus*). Alewives, however, were scarce in the late 1990s (James Johnson, Michigan DNR, Personal communication) raising the question of whether cormorant predation on perch may have been greater than measured by Maruca (1997). The timing of the rise in the cormorant population coincides closely with the collapse of the yellow perch fishery and such a predation scenario would account for the continued high total annual mortality rate and decline in mean age.

These data indicate that the collapse of the fishery and range contraction of perch were caused at least in part by the predatory effects of cormorants. It is not entirely clear, however, whether trends in recruitment also contributed. Better recruitment indices will be necessary to fully answer what function (if any) trends in recruitment play in the suppression of the perch population.

A contributory or competing explanation is that heavy angler harvest through the 1980s and early 1990s reduced the yellow perch population to a point where the fishery was vulnerable to collapse with the addition of the predatory effects of cormorants. Under this scenario, cormorant predation would then account alone or principally for the ongoing suppression of the population, once initially reduced to low levels and contracted in range.

Additional research is needed to better quantify the exact role of cormorant predation in the collapse and suppression of the yellow perch fishery and contraction in range of the population in the Les Cheneaux Islands. However, in the absence of other explanations, it is compelling to conclude that cormorant predation is at least part of the explanation.

**Acknowledgements.** Much of the survey work was funded by the Sport Fish Restoration Program. Contributing either data or manuscript review were Dale Trexel (Univ. of Minnesota), of the Michigan DNR; Gerald Rakoczy, James Johnson, and the Lake Huron Basin Team.

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## GENETIC VARIATION AND SPAWNING POPULATION STRUCTURE IN LAKE ERIE YELLOW PERCH, *Perca flavescens*: A COMPARISON WITH A MAINE POPULATION

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**Introduction.** Yellow perch, *Perca flavescens*, recolonized the newly formed Great Lakes system about 10,000 years ago from three proposed glacial refugia. Previous genetic investigations discerned differences among groups of Great Lakes fishes related to differential colonization from the glacial refugia – with Lake Erie populations largely comprising Mississippi refugium descendants (especially in the western and central basins) and some from the Atlantic refugium in the east. Allozyme and mtDNA RFLP genetic studies of yellow perch in Lake Erie found low genetic variability, which may be related to historically low variability in the Mississippi refugium populations (Todd and Hatcher 1993, Billington 1993).

Populations of yellow perch in Lake Erie have been rebounding after declining in the late 1980s. At the request of the Lake Erie Yellow Perch Task Force, the objective of the present study is to analyze the genetic stock structure and variability of yellow perch in Lake Erie. We also are comparing the data to several outgroup population areas of their range, including the other Great Lakes. This investigation analyzes the entire mtDNA control region (912 bp) of 118 yellow perch from spawning locations spanning Lake Erie (Fig.1), and makes comparisons with a native outgroup population from south-central Maine. **Methods.** Fin clip tissue samples were collected from 16 spawning locations around Lake Erie (Fig. 1), including the western, central, and eastern basins.

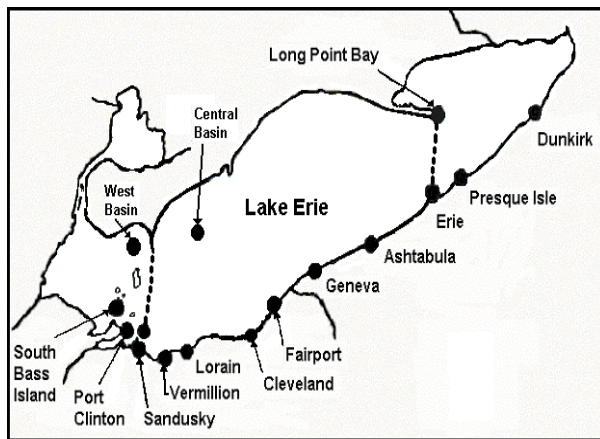


Figure 1. Lake Erie sample sites for yellow perch.

Maine samples were from Searsmont. DNA was extracted and purified with a Quiaquick kit. The entire

mtDNA control region was PCR amplified following Stepien and Faber (1998). PCR products were purified using an Exosap kit and sequenced separately in both directions for verification on a Beckman CEQ 8000 capillary autosequencer.

The proportion of polymorphic nucleotides ( $p_n$ ), as well as haplotypic diversity ( $h$ ) and nucleotide diversity ( $\pi$ ) were calculated. Neighbor joining trees and maximum parsimony analysis of relationships among haplotypes, including comparison to the European yellow perch *P. fluviatilis* were constructed with MEGA2 and PAUP\*, and support for relationships was compared with 1000 bootstrap replications. Hierarchical analysis of variance using AMOVA in Arlequin examined divergence among spawning sites and population groups.

**Results.** Ten mtDNA control region haplotypes were identified to date in Lake Erie, and 3 others in Maine (Fig. 2). Gene diversity in Maine was 0.57 +/- 0.12 s.e. and 0.37 +/- 0.06 in Lake Erie. Haplotypic diversity was 0.71 +/- 0.20 and 0.33 +/- 0.03, respectively. Nucleotide diversity was 0.67 +/- 0.03 for Maine and 0.39 +/- 0.03 for Lake Erie.

No haplotypes were shared between Lake Erie and Maine, and those from Maine formed a clade distinguished by 5 synapomorphies in the neighbor-joining (NJ) and maximum parsimony (MP) consensus tree. The data revealed a significant difference between the Maine and Lake Erie populations, equivalent to 62.8% of the variation in AMOVA (Analysis of Molecular Variance) comparisons in Arlequin and an  $F_{ST} = 0.66$ ,  $p < 0.00001$ , and a very great genetic divergence.

Haplotype #2 was located basally in the tree (Fig. 2) to all other *P. flavescens* haplotypes, including those from Maine, and was the sister type to all other *P. flavescens*. The frequency of #2 was greatest in western Lake Erie, and decreased from west to east. Two haplotypes were unique to the central basin and 5 to the eastern basin. The western basin was dominated by 3 shared haplotypes, but no unique ones to date. Haplotype #1 was widely distributed across Lake Erie, comprising about 80% of the samples. Haplotype #3 was relatively common in the west, less common in the central basin, and absent from the eastern basin.

AMOVA hierarchical  $F_{ST}$  analyses showed that pairwise divergences among some spawning site populations were significant (e.g., those with larger



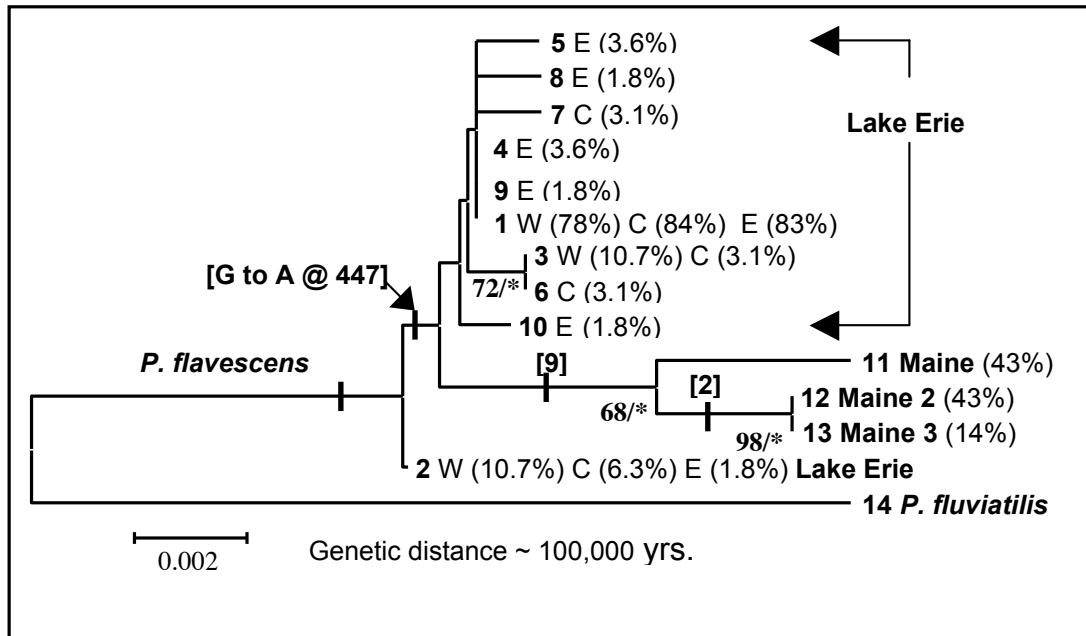


Figure 2. NJ (MEGA 2.0) tree of yellow perch mtDNA from Lake Erie and Maine with comparison to *P. fluviatilis*. Genetic distance is calibrated using 2%/my clock (Stepien and Faber 1998). Numbers in parentheses are haplotype frequencies. W = West Basin, C = Central Basin, and E = East Basin. Numbers with “/\*” are bootstrap values congruent with the most-parsimonious maximum parsimony consensus tree (PAUP\*).

sample sizes at present), comprising about 3% of the variance overall.

**Discussion.** MtDNA control region sequence haplotypes revealed greater genetic diversity in Lake Erie than was found in analyses of allozymes (Todd and Hatcher 1993) and mtDNA RFLPs (Billington 1993). However, our data show that Lake Erie is dominated by a single mtDNA control region haplotype (#1), which comprises about 80% of the population in all basins. We discerned greater genetic variation within the Maine population.

Lake Erie populations of yellow perch have lower levels of genetic diversity overall than do walleye (Stepien and Faber 1998, Stepien and Taylor, in progress), which may be due to their “boom and bust” history in Lake Erie in comparison to the Maine population. However, since European yellow perch *P. fluviatilis* display similarly low levels of genetic diversity in allozymes and the mtDNA control region in comparison to *Stizostedion* - and both *Perca* are similar in levels to their sister genus *Gymnocephalus* (Stepien et al. 1998) - some of this low genetic diversity may reflect the phylogenetic history of these genera.

MtDNA control region sequences reveal higher genetic variation than was previously discerned, as well as significant population divergences among spawning sites for yellow perch in Lake Erie (e.g., those with larger sample sizes at present), which

suggests spawning site philopatry and differential colonization patterns stemming from glacial refugia.

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## RECRUITMENT FAILURE OF PERCH POPULATIONS IN THE BALTIC

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**Introduction.** In the Baltic, perch (*Perca fluviatilis* L.) is of great importance for recreational and commercial fishery. In recent years decreasing catches and recruitment failures have been reported for the coastal stocks of perch (Fig 1), but also pike (*Esox lucius*), in several areas around the Baltic (Skora 1992; 1996; Andersson *et al.* 2000; Lehtonen *et al.* 2000; Bylund *et al.* 2001; Almesjö & Hansson 2002; Karås *et al.* (unpublished); Nilsson *et al.* (unpublished). Since there is still no clear evidence to the causes of the observed recruitment failures, the Swedish National Board of Fisheries together with the Swedish Environmental Protection Agency gathered scientists from around the Baltic from different disciplines to a workshop held in Öregrund, Sweden in October 22-23, 2002. This paper is a summary of earlier studies and the outcome of that workshop.

**The nature of the problem.** Catch statistics from Poland and the island of Gotland in Sweden indicates decreasing stocks at least since the 1970's. Inquiries in Sweden report similar time scale for other coastal areas. Finnish inquiries also point to the fact that there have been problems in their coastal waters of a similar nature on a long-time scale. Test fishing's from e.g. the Kalmar Sound show that abundance's of mainly pike and perch have reached very low levels during the 1990's, and sampling of juveniles in late summer indicates an almost complete recruitment failure of these species in the area. Common for all affected areas is that they are relatively exposed and located close to the main basin of the Baltic. Experiments and field studies showed that there was no increased mortality during embryonic life stages and the larvae of perch and pike survived until exogenous feeding. The conclusion from these studies was that: **i)** There is no indication of direct toxic effects related to water quality during the most sensitive stages. **ii)** There is no indication of indirect toxic effects through the parental fish. **iii)** There is a good quality of the larvae with no immediate links to the reproduction disturbances of Baltic salmon (Bengtsson *et al.*), i.e. the "M74 syndrome". **iv)** The problem is most likely related to increased mortality between onset of feeding and late summer juveniles. However, the possibility that low spawning biomass is partly a cause of the problem, or at least affects the recovery, could not be ruled out.

**Potential causes.** Several possible causes to the observed problems have been suggested. Based on present knowledge, the most possible ones are listed and briefly discussed below. The causes may differ between areas and several mechanisms may interact.

-Habitat changes. For many of the freshwater species in the Baltic, the best recruitment areas are

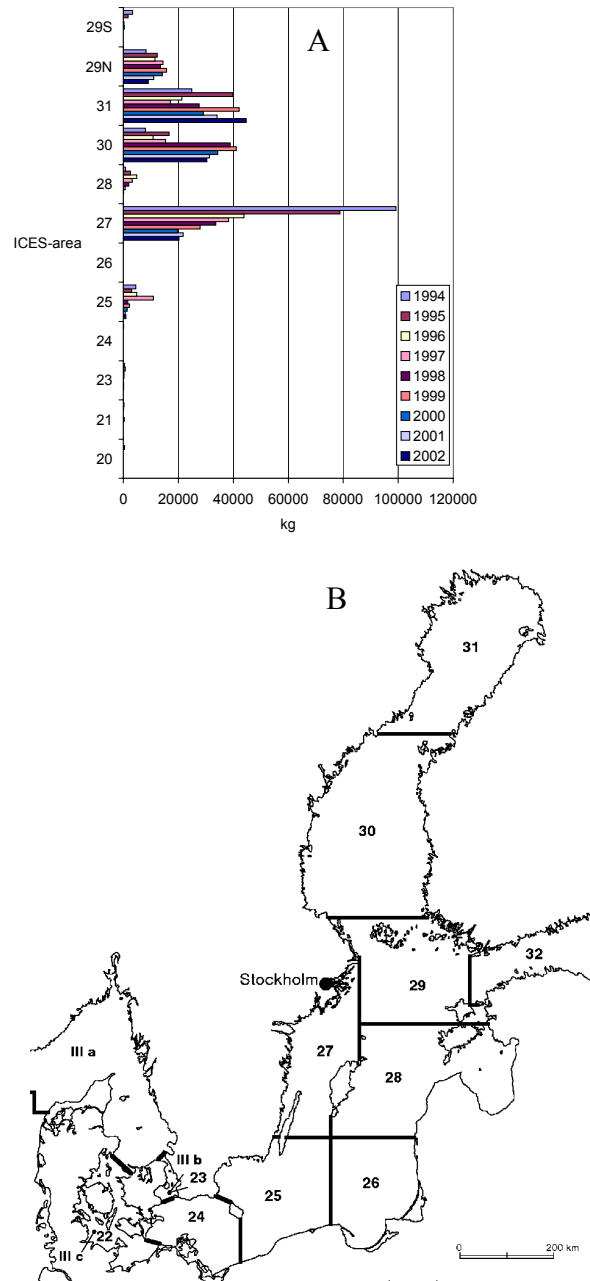


Figure 1. A) Official commercial landings of perch from Swedish coastal fishery divided in ICES areas. (To get the total landings including recreational fishing and non-commercial net fishing those numbers should be multiplied by approximately a factor 10.) B) Map of the Baltic with the corresponding ICES areas.

situated in freshwaters, estuaries and sheltered archipelagos. Unfortunately, due to human impact over a long period, many of these habitats have been lost or degraded. These disturbances are caused by direct habitat destruction and/or related to activities within agriculture, forestry, industry and settlements. Obstacles in migration routes are also common. The losses of those key recruitment areas can make the fish populations more sensitive to environmental changes in sub-optimal recruitment areas. Simultaneous with the decline in fish stocks, the general opinion is that there has been an increased growth of filamentous algae and changes in the macrophyte community. These changes seem to be most pronounced in sub-optimal recruitment areas that are more exposed to the open sea. The reason for this development may be related to both nutrient load and changes in climate (e.g. warm/wet and ice-free winters and changes in the hydrodynamic regime). In the Kalmar sound, there has been a pronounced increase in secchi-disc depth during the 1990's, indicating a switch from pelagic to benthic primary production. Changes of the abundance and species composition of macrophytes and filamentous algae has the potential to affect fish recruitment through several mechanisms such as: **i)** Reduced quality and quantity of spawning substrates. **ii)** Reduced quality in the microhabitat for eggs and larvae (e.g. oxygen-, pH- and ammonia levels). **iii)** Reduced quality and quantity of shelter for young fish. **vi)** Favoured habitat for predators such as sticklebacks.

-Food availability. The experimental and field data from affected areas indicate that the quantity and/or quality of available food for fish larvae is a potential reason for the recruitment failure. The effects of changes in quantity, quality and timing of available prey could affect the recruitment by: **i)** Direct mortality through starving of first feeding larvae. **ii)** Indirect stage specific mortality caused by reduced growth rate.

-Predation and fishing. Studies from the Kalmar Sound area shows that stickleback can be a serious predator on the eggs and larvae of pike. Perch is less likely to be affected since sticklebacks do not feed on the egg-strands and the larvae disperse pelagically. Herring and sprat has been suggested to be potential predators on larvae. There is, however, no data regarding overlap in time and space. Predation from birds on juvenile and adult fish could be a potential threat. Thus, in the Kalmar Sound large colonies of cormorants have built up during the 1990's. There are, however, no such large colonies in other affected areas (e.g. Åland and the Archipelago Sea) to explain recruitment disturbances there. Predation and fishing could affect recruitment of perch and pike through: **i)** Predation on eggs and young life-stages from e.g. sticklebacks. **ii)** Low density of spawning stock biomass.

-Toxic substances. Anthropogenically derived toxins are a potential threat, but the pattern of the problems (e.g. habitats in the outer archipelago) indicate that

land sources is not the reason. Further, studies performed so far, do not indicate toxic effects on eggs and larvae. Red and brown filamentous macroalgae and cyanobacteria have the potential to produce harmful substances, e.g. naturally produced halogenated polyphenolic compounds that could affect eggs and/or larvae. For the filamentous brown algae there is an overlap in time between the maximum occurrence of the algae and fish recruitment.

-Diseases and parasites. This could be a potential cause, but current knowledge is very limited.

**Acknowledgements.** Thanks to all participants of the workshop and everyone that in some way have contributed to the investigations this paper is based on.

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## ANOTHER YELLOW PERCH POPULATION DECLINE IN THE 1990s : THE LAKE ST. PIERRE CASE STUDY, ST. LAWRENCE RIVER, QUEBEC

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**Introduction.** Yellow perch sport and commercial catch in Lake St. Pierre, a shallow 36 000 ha enlargement of the St. Lawrence River, increased between the late 1970s and the 1990s. Total annual catch was estimated at about 300 t in 1986 (declared commercial fishing, 220 t; sport fishing, 80 t). This perch population is heavily exploited : growth rates and fecundity are high; age at sexual maturity is low; annual total mortality has been consistently high since 1978 and was estimated at 77 % (natural mortality: 25 %) between 1986 and 1991 while it was only 35 % at the same period in Lake St. Louis, another freshwater enlargement of the river 100 km upstream where there is no commercial fishery (Dumont, 1996). In the mid 1990s, Gu nette *et al.* (1994) predicted that population failure would happen if consecutive low year-classes were produced without reducing fishing effort and catch, using Thompson and Bell yield per recruit model and virtual population analyses based on data from yearly commercial catch sampling.

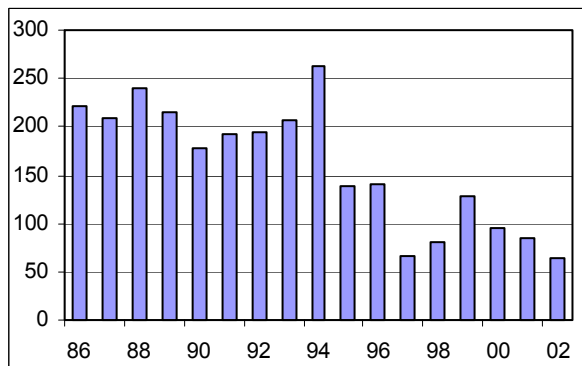


Figure 1. Declared annual commercial catch (t) of yellow perch in Lake St. Pierre between 1986 and 2002.

Between 1994 and 1996, the total annual declared commercial catch decreased from 262 t to 140 t (Figure 1). In 1996, a management plan was designed to reduce by 12 % the total annual mortality rate. A 165 mm minimum legal length was imposed for sport and commercial fisheries; sport fishermen were allowed a 50 fish bag limit and could no longer sell their catch; commercial fishermen were limited to only one helper. In 1997 and 1998, the annual declared commercial catch decreased again to 67 t and 80 t. Over and under declarations naturally occur in voluntary commercial catch reports but we think that the importance of the decrease reported between 1994 and 1998, combined to the contents of the discussions we had with the fishermen during this

period, indicate the correct order of magnitude of the population failure since no management changes occurred. After 1999, they can no longer represent the abundance of the resource since the fishing effort was reduced. In order to evaluate the efficiency of the management plan, we realized a four consecutive years (1997-2000) survey of the perch population to determine if the total annual mortality rate had changed.

**Methods.** Since over 8 years old perch proved to be rare in the past studies, we designed our protocol to sample adequately the most abundant segment of the population in order to produce sex-separated catch curves between ages 2 and 7. We used the results of a 1995 experimental gill-net sampling of the Lake St. Pierre where a set of two experimental multimesh gill-nets (mesh sizes 1, 1.5, 2, 2.5, 3, 4, 5 and 6 inches stretched mesh) had been fishing for 24 hrs at 94 stations. In order to optimize the results for older than age 2 perch, we excluded the 1 inch mesh size and kept 1.5 to 3 inch mesh. We then choose the stations with the most significant perch catch per effort well spread all over the perch habitat after we made sure the length structure of the perch from the selected stations and the rest of them was the same. The final length of the mesh panels (50 ft) was chosen according to the results of simulations to determine the number of perch needed to sample at a 95 % probability level all the present age groups and to reduce the confidence interval of the distribution of the simulated mortality rates.

The sampling took place at 27 stations. The samples were corrected for gill-net size selectivity and encounter probability as proposed by Kraft and Johnson (1992) and Spangler and Collins (1992) in order to represent more accurately the size and age structure of the perch population. The total annual mortality was estimated by Ricker's catch curve and Robson and Chapman methods with the corrected numbers of perch at age for males and females. The samples for both sides of the lake were grouped to allow the temporal comparison with the 1986-1991 period.

**Results.** Table 1 presents the total instantaneous mortality rates ( $Z$ ), calculated for each sex and year by both methods as well as a mean  $Z$  for the four years period, included to minimize the ever-present impact of the year-class strength variation on the estimation of this parameter. The overall global mean  $Z$  (1.402) corresponds to a total annual mortality rate ( $A$ ) of 75 % which cannot be considered as different from the 77 % 1986-91 period mortality rate.

**Discussion.** Our results show that the 1996 management plan failed to reduce the total annual mortality rate over the whole period studied. The year 2000 lower values could theoretically result from

Table 1 Annual and mean instantaneous mortality rate of males and females lake St. Pierre yellow perch for the 1997-2000 period, calculated with Ricker's catch curves and Robson and Chapman methods.

Year	Z Males	Z Females	Mean Z	Mean A
Catch Curves				
1997	1.133	1.185		
1998	1.600	1.496		
1999	1.460	1.489		
2000	1.233	1.215		
Mean	1.356	1.346	1.351	74%
Robson and Chapman				
1997	1.132	1.347		
1998	1.899	1.700		
1999	1.582	1.989		
2000	0.964	1.007		
Mean	1.394	1.511	1.452	77%
<b>Global mean from both methods</b>			<b>1.402</b>	<b>75%</b>

a positive effect of the management plan but we believe that they are rather due to the unusual abundance of the strong 1995 year class at age 5.

Due to the very high annual mortality rate maintained since at least the 1970s, this perch population was reputedly fragile. It is our opinion that the population failure was due to the persistence of a high level of exploitation during a 10 year period (1988-1998) where only two strong year-classes that could support the fishery were produced (Figure 2). Furthermore, within this period of time, the demand for Lake St-Pierre perch increased considerably due to the many Great Lakes commercial and sport catch restrictions.

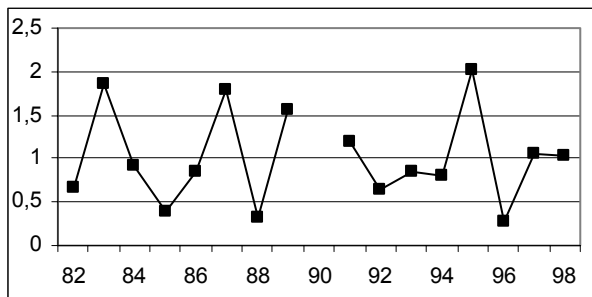


Figure 2. Lake St. Pierre's yellow perch year-class strength variation between 1982 and 1998. Note that the 2 periods are separated and that the second corresponds to a lower abundance level.

The original management plan included delaying the springtime opening of the commercial fishing season to protect half of the spawning activity but it was not implemented. Commercial fishing is still permitted throughout the whole spawning period and the springtime catch represents between 51% and 75% of the annual commercial declared catch. We think that the restrictions of the 1996 management plan did not have a significant impact since the most

effective measure, a restriction of the catch during the spawning period, had been removed. Belore et al (2003) clearly showed that a reduction of the catch during the spawning period resulted in a significant increase of the population level and a major reduction of different perch populations total mortality rate in Lake Erie. A recent independent expert report (Magnan 2002) confirmed that the lake St. Pierre yellow perch population was exploited to the limit of the sustainable yield, that data on the resource abundance and catch are necessary to try to manage this population at such a high level of exploitation and that it is necessary to at least partially restrain fishing during the spawning season.

A more restrictive management plan has been enforced since 2000. The number of fishing days and the total allowed commercial gear were reduced in April during the spawning period. Yellow perch minimum legal length since 1997 (165 mm) has also been changed to 190 mm.

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