13th International Symposium on the Biology and Management of Coregonid Fishes

September 10-15, 2017

Bayfield, Wisconsin USA
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Program

Sunday Evening, September 10

4:00 - 7:00  Participant Check-in at Business Center
6:00 - 9:00  Welcome Reception on roof of Bayfield Inn

Monday, September 11

7:30-8:30  Check-in at Business Center | Speakers Load Presentations on Computer and Poster Session in Bayfield Pavilion
8:30 - 9:00  Opening Ceremony by Red Cliff Tribal Member | Welcome from Mayor of Bayfield and Red Cliff Tribal Chairperson
9:00 - 9:30  Invited Speaker - The Role of Coregonids in Local Peoples Culture and Traditions on the Torne River - The Border River between Finland and Sweden  Markku Vaaraniemi
9:30 - 9:45  The Role of Adikameg in Ojibwa Reserved Fishing Rights  William Mattes
9:45 - 10:00  A Management Framework for North American Coregonine Ciscoes  Andrew Muir
10:00 - 10:30  Morning Break | Poster Session
10:30 - 10:45  Minnesota's Cisco Fishery: Managing for Sustainability of a Multi-Jurisdiction Commercial Fishery  Cory Goldsworthy
10:45 - 11:00  Stakeholder Views of Management and Decision-Support Tools to Integrate Climate Change into Great Lakes Lake Whitefish Management  Abigail Lynch
11:00 - 11:15  Value Chains for Lake Whitefish (Coregonus clupeaformis) in the Laurentian Great Lakes  So-Jung Youn
11:15 - 11:30  Status of Cisco (Coregonus artedi) Morphotypes in Lake Huron, 1917-2016  Randy Eshenroder
11:30 - 11:45  Summer Ascending Whitefish in the River Tornionjoki – A Target of Manifold Interreg-study  Erkki Jokikokko
11:45 - 12:00  Role of Lake Whitefish Compensatory Mechanisms in Fisheries Sustainability  William Taylor
12:00 - 1:30  Lunch Break
1:30 - 1:45  GSI% of Pelagic Whitefish (Coregonus lavaretus) in Upper Lake Constance Decreased Drastically: Effect of Non-native Invasive Stickleback (Gasterosteus aculeatus)  Roland Roesch
1:45 - 2:00  Bythotrephes Invasion Alters Lake Herring Biomagnification Rates  Michael Rennie
2:00 - 2:15  Impacts of Emerging Ecological and Fishery Stressors on Lake Superior Ecosystem and Coregonid Population Dynamics  Bryan Matthias
2:15 - 2:30  Climate Change and Clarity Trends Influence Thermal Habitat for Coldwater Fishes in Inland Lakes  Gretchen Hansen
2:30 - 2:45  The Influence of Land Use Disturbance on Cisco (Coregonus artedi) Population Characteristics in Minnesota  Tyler Ahrenstorff
2:45 - 3:00  Cestode Infection in a Polymorphic Whitefish Population  Odd Terje Sandlund
3:00 - 3:15  Population-level Effects of Food Web Changes on Bloater (Coregonus hoyi) Age Composition and Growth Across their Contemporary Geographic Range  Timothy O'Brien

3:15 - 3:45  Afternoon Break | Poster Session

3:45 - 4:00  Trophic Ecology of (Coregonus hoyi) in Lakes Michigan and Huron  David Bunnell

4:00 - 4:15  Effects of Cisco on Walleye Growth Trajectories in Northern Wisconsin Lakes  Greg Sass

4:15 - 4:30  Adaptation and Habitat Selection During the Migration of a Coregonid, Broad Whitefish, (Coregonus nasus Pallas)  Ross Tallman

6:00 - 9:00  Dinner and Show at Big Top Chautauqua

**Tuesday, September 12**

7:30 - 8:30  Speakers Load Presentations onto Computer | Poster Session

8:30 - 9:00  Invited Speaker – Role of Coregonids in Ecosystem Functioning and Services in a Changing World  Kimmo Kahilainen

9:00 - 9:15  Effect of Mysis on Feeding Efficiency of Blackfin Cisco and Lake Whitefish via Feeding Structure Comparison.  Allan Bell

9:15 - 9:30  Seasonal Changes in Partial, Reverse Diel Vertical Migrations of Cisco (Coregonus artedi)  Thomas Hrabik

9:30 - 9:45  Retrospective Analysis of Growth and Predatory Demand by Cisco (Coregonus artedi) in Western Lake Superior  Ian Harding

9:45 - 10:00  An Examination of Life History Attributes and Food Web Interactions of Unexploited Lake Whitefish in the Presence of Invasive Rainbow Smelt  Courtney Taylor

10:00 - 10:30  Morning Break | Poster Session

10:30 - 10:45  Diversity of Ciscoes in Lake Superior: More than Koelz Envisioned?  Owen Gorman

10:45 - 11:00  Continued Spawning and Larval Production of Lake Whitefish in the Detroit River  Robin DeBruyne

11:00 - 11:15  Export of Pelagic Lake Whitefish Larvae from the Detroit River  Ed Roseman

11:15 - 11:30  Lake Whitefish Early Life History in Western Basin Lake Erie  Zachary Amidon

11:30 - 11:45  Effect of photoperiod on Cisco (Coregonus artedi) Egg Development  Taylor Stewart

11:45 - 12:00  Winter Severity and Survival of Larval and Age-1 Ciscoes (Coregonus artedi, C. hoyi, C. kiyi) in Lake Superior  Mark Vinson

12:00 - 1:30  Lunch Break

1:30 - 1:45  Suitability of Different Whitefish Strains from Upper Lake Constance for Aquaculture Purposes  Susanne Goebel

1:45 - 2:00  Lipid Composition of Baikal Whitefish Aquaculture  Olga Glyzina
2:00 - 2:15 Moving a Step Forward in Intensive Maraena Whitefish Aquaculture - The Influence of Temperature and Different Live Feed Periods on Growth and Survival of \((\text{Coregonus maraena})\) Larvae

Peter Luft

2:15 - 2:30 Initiating Nelma \((\text{Stenodus leucichthys nelma})\) Farming for Food in Finland

Petri Heinimaa

2:30 - 2:45 Induction of Free Flowing Gametes by Injection of Luteinizing Hormone Releasing Hormone Analog in Hatchery-Reared Bloaters

Trevor Pitcher

2:45 - 3:00 Impact of Sound Pollution on Auditory Epithelium of Baikal Coregonid Fish in Natural Habitat and Aquaculture

Yulia Sapozhnikova

3:00 - 3:15 Core Microbiotas of the Larvae of Coregonid Fishes and Their F1 Hybrids

Natalia Belkova

3:15 - 3:45 Break | Poster Session

3:45 - 4:00 Common Garden Experiments for Coregonidae: Study of Reticulate Evolution, Biodiversity Conservation, Aquaculture

Lyubov Sukhanova

4:00 - 4:15 Incorporation of Otolith Morphometry and Environmental Determinants into Stock Discrimination of Phenotypically Subarctic Lake Whitefish Stocks

Xinhua Zhu

4:15 - 4:30 Cisco Body Morphology, Relative Weight Redundancy, and Oxythermal Habitat Relationships in Wisconsin Inland Lakes, U. S.

Timothy Parks

6:00 - 8:00 Research Vessel Tour at Bayfield Marina | Tour of Northern Aquaculture Demonstration Facility

Wednesday, September 13

7:30 - 8:30 Speakers Load Presentations on Computer | Poster Session

8:30 - 9:00 Invited Speaker - The Recent Evolution of Coregonus Lineages: An Illustrative Digest

Julie Turgeon

9:00 - 9:15 Parallel Expression of Trophic-Mediated Morphologies: A Key to Evolution?

Louise Chavarie

9:15 - 9:30 Genetic Stock Structure of Lake Herring and Bloaters Across the Upper Great Lakes

Kim Scribner

9:30 - 9:45 The Story of the Whitefish \((\text{Coregonus lavaretus})\) Inhabiting the Bay of Puck, the Southern Baltic

Anna Wąs-Barcz

9:45 - 10:00 Historic and Contemporary Genetic Diversity of Lake Erie Cisco

Wendylee Stott

10:00 - 10:30 Morning Break | Poster Session

10:30 - 10:45 Population Genetics Analyses of Inconnu \((\text{Stenodus leucichthys})\) Populations: Implications for Fisheries Management in Great Slave Lake, Northwest Territories

Lauren Wiens

10:45 - 11:00 Transcriptomics Identifies Genes Associated with Phenotypic Differences among Great Lakes Ciscoes \((\text{Coregonus} \text{ spp.})\)

Trevor Krabbenhoft

11:00 - 11:15 Developing a Rapture Panel to Investigate Genetic Diversity in Cisco Across the Great Lakes Region

Wesley Larson

11:15 - 11:30 Algonquin Park is a Landscape of Coregonine Diversity

Mark Ridgway
11:30 - 11:45 Morphological Assessment of Contemporary Cisco Populations in Lake Michigan and their Relationship to Historic Forms  Kyle Broadway

2:00 - 5:00 Boat Cruise in Apostle Islands

Thursday, September 14

7:30 - 8:30 Speakers Load Presentations onto Computer | Poster Session

8:30 - 9:00 Invited Speaker - Rearing and stocking of Coregonids: A Comparison of Current Aquaculture Practices in Eurasia and North America  Josef Wanzenböck

9:00 - 9:15 Development of Culture Practices and Captive Broodstocks for (Coregonus hoyi) to Support Bi-national Efforts to Restore the Species to Lake Ontario  Kevin Loftus

9:15 - 9:30 Collecting Viable Deep-water Cisco Gametes from Lake Michigan for Propagation - Lessons Learned  Roger Gordon

9:30 - 9:45 An Overview of Lake Herring (Coregonus artedi) Culture and Rearing at the University of Wisconsin - Stevens Point Northern Aquaculture Demonstration Facility  Gregory Fischer

9:45 - 10:00 Feasibility of Using Native Lake Michigan Cisco as Parental Stock for Hatchery-Based Restoration  Kris Dey

10:00 - 10:30 Morning Break | Poster Session

10:30 - 10:45 Post-stocking Behaviour, Habitat use, and Survival of Hatchery-reared Bloater (Coregonus hoyi) in Lake Ontario using Acoustic Telemetry  Natalie Klinard

10:45 - 11:00 Historical Habitat uses by Ciscoes (Coregonus artedi) in Lake Michigan  Yu-Chun Kao

11:00 - 11:15 Characterizing Spawning and Nursery Habitat of Great Lakes Cisco (Coregonus artedi) and Applications to Areas Targeted for Restoration  Matthew Paufve

11:15 - 11:30 Dispersion of Larval Vendace Around Potential Nursery Areas  Juha Karjalainen

11:30 - 11:45 From Side Scan Sonar to Egg Pumping – Quantifying Spawning Habitat of Anadromous Whitefish in a Constructed River  Lari Veneranta

11:45 - 12:00 Vertical Habitat use of Lake Whitefish in a Small Canadian Shield lake: Insights from Acoustic Telemetry  Andrew Chapelsky

12:00 - 1:30 Lunch Break

1:30 - 1:45 Restoration of Whitefish Population in Lake Bourget: An Historical Analysis  Chloé Goulon

1:45 - 2:00 Lake Whitefish Re-colonization in Wisconsin’s Green Bay Tributaries  Scott Hansen

2:00 - 2:15 Cisco Restoration in Lake Ontario  Ellen George

2:15 - 2:30 From Hoyi to Hybrida: Spatial Patterns in Bloater-like Fishes of the Upper Great Lakes  David Warner
Total Mercury Concentrations in Liver, Muscle and Scales of European Whitefish (*Coregonus Lavaretus* (L.)) in a Subarctic Lake – Assessing the Factors Driving Year-Round Variation

Short-term Survival of Lake Whitefish Following Surgical Implantation of Acoustic Transmitters using Two Forms of Anesthesia

Movement Patterns of Lake Whitefish in Lake Erie

Proposals for 14th International Coregonid Symposium

Discuss Published Proceedings for this (13th) Symposium

Final Celebration at Blue Vista Orchard

**Friday, September 15**

Speakers Load Presentations onto Computer

Invited Speaker - Stock Assessment Modeling and its use in Management, with Examples Emphasizing Lake Whitefish in the Upper Great Lakes

A Comparison of Size and Age Structured Assessment Models Applied to a Cisco Stock in Thunder Bay, Ontario.

Can Recruitment Rates of Contemporary Cisco Stocks Support Historical Levels of Yield in Lake Superior?

A Permafrost Thaw Slump’s Effect on Selawik River Inconnu Recruitment

Development of a Collaborative Beach-seine Based Recruitment Index for Lake Whitefish (*Coregonus clupeaformis*) in Shoreline Nursery Habitats of the Great Lakes

Morning Break

Stock Monitoring Tools for Commercial Vendace (*Coregonus albula* (L.)) Fisheries Management Decision Makers

Long Term and Targeted Surveys Inform Lake Ontario Cisco Dynamics

Cisco Population Characteristics in Wisconsin Lakes


Can Lake Whitefish Abundance be Estimated with a Hydroacoustic Survey?
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The Role of Adikameg in Ojibwa Reserved Fishing Rights

William Mattes

Great Lakes Indian Fish and Wildlife Commission, USA

Email: bmattes@glifwc.org

Land cession treaties were signed between the United States Government and the Ojibwa tribes living around Lake Superior between 1836 and 1854. In return for their land, the Ojibwa reserved the right to hunt, fish, and gather throughout the ceded territory, including fishing for Adikameg (Coregonus clupeaformis) in Gichigami (Lake Superior). As fish populations began to decline in the lake due to increasing exploitation, habitat destruction and invasive species, the states began to develop regulatory programs and to enforce their laws against the Ojibwa. Starting in the 1970s, tribal members and tribal governments began challenging the authority of the states to apply their resource regulations against tribal members fishing in ceded waters. In some instances, after the existence of the rights was reaffirmed, further litigation followed to establish the scope of state regulation, the adequacy of tribal regulations, and how the resources should be allocated. In other cases, further litigation did not follow and the parties chose to negotiate regulations and allocation issues on a periodic basis. Thus, in the Ojibwa ceded territories, coordinated or cooperative management arrangements are normally founded in Court decisions reaffirming treaty-reserved rights but each arrangement differs in various ways.
A Management Framework for North American Coregonine Ciscoes

Andrew Muir

Great Lakes Fishery Commission, USA

Email: amuir@glfc.org

Co-authors: R. L. Eshenroder, J. Turgeon, C.R. Bronte, N. E. Mandrak, and J.D. Reist

The coregonine ciscoes of North America are phenotypically and ecologically diverse with multiple deep- and shallow-water forms occurring sympatrically across their range. Their taxonomy remains unresolved—forms in the Laurentian Great Lakes and a northwestern assemblage were formally described and named yet, elsewhere, considered variants of a presumed ancestor, Coregonus artedi. The ciscoes provide important ecosystem services; via vertical and horizontal migrations they assimilate energy and nutrients across a wide range of environmental conditions making them important trophic integrators. They are also primary forage for top predators, such as Lake Trout Salvelinus namaycush and Burbot Lota lota. A complete loss of three deep-water forms from the Great Lakes and the loss of additional forms from individual lakes, represents a considerable departure from historical ecosystem function. Ciscoes do not fit easily into the current framework for resource management, which is broadly based on a ‘biological species’ concept. We support a previous argument that C. artedi be recognized as the sole taxon for Great Lakes ciscoes and that unique forms, whether reproductively isolated or not, be recognized as ‘evolutionary significant units.’ Regardless of taxonomy, a conservation and management framework that focuses on restoring functional food web ecology is advocated.
Minnesota's Cisco Fishery: Managing for Sustainability of a Multi-Jurisdiction Commercial Fishery

Cory Goldsworthy

Minnesota Department of Natural Resources, USA

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Since 2008, the Minnesota Department of Natural Resources (MNDNR) has used hydroacoustic derived spawning stock biomass estimates to set total-allowable-catch quotas for the November Cisco roe fishery. The evolution of management techniques including hydroacoustic survey design and year-class monitoring has largely been based on a better understanding of Cisco population dynamics through increased research efforts of collaborating agencies. This presentation will highlight the techniques MNDNR uses to manage it's Cisco fishery in an attempt to ensure sustainability of the resource and assess whether sustainability can be achieved given current population dynamics and existing harvest rules.
Stakeholder Views of Management and Decision-Support Tools to Integrate Climate Change into Great Lakes Lake Whitefish Management

Abigail Lynch

U. S. Geological Survey, National Climate Change and Wildlife Science Center, USA

Email: ajlynch@usgs.gov

Co-authors: William W. Taylor and Aaron M. McCright

Decision-support tools can aid decision making by systematically incorporating information, accounting for uncertainties, and facilitating evaluation between alternatives. Without user buy-in, however, decision support tools can fail to influence decision-making processes. We surveyed fishery researchers, managers, and fishers affiliated with the Lake Whitefish Coregonus clupeaformis fishery in the 1836 Treaty Waters of Lakes Huron, Michigan, and Superior to assess opinions of current and future management needs to identify barriers to, and opportunities for, developing a decision-support tool based on Lake Whitefish recruitment projections with climate change. Approximately 64% of 39 respondents were satisfied with current management, and nearly 85% agreed that science was well integrated into management programs. While decision support tools can facilitate science integration into management, respondents suggest that they face significant implementation barriers, including lack of political will to change management and perceived uncertainty in decision support outputs. Recommendations from this survey can inform development of decision-support tools for fishery management in the Great Lakes and other regions.
Value Chains for Lake Whitefish (*Coregonus clupeaformis*) in the Laurentian Great Lakes

So-Jung Youn

Michigan State University, USA

Email: younsoju@msu.edu

Co-authors: William W. Taylor and Ron Kinnunen

Lake whitefish (*Coregonus clupeaformis*) are an important commercial fishery in the Laurentian Great Lakes. Little information is known, however, regarding the nature and dynamics of the value chains for lake whitefish in this region. Value chains describe the process by which fish go from the water to human food consumption and the added value that accrues to the product during each stage of this process. Value chains for whitefish sold under the “Legends of the Lake” brand and whitefish that are not part of this brand will be compared in order to investigate the benefits and drawbacks of having such a label. “Legends of the Lake” is a brand created by a cooperative of commercial whitefish fishers and processors in the upper Great Lakes region in order to rebrand whitefish as a premium product, which would increase the value of whitefish products, and create relationships with local restaurants to ensure steady market demand and stable prices for whitefish throughout the year. Understanding the value chains for whitefish will provide insight into ways to strengthen the whitefish value chain and increase the economic values of whitefish for producers and consumers.
Status of Cisco (*Coregonus artedi*) Morphotypes in Lake Huron, 1917-2016

Randy Eshenroder

Great Lakes Fishery Commission, USA

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Co-authors: Chris Olds, Yu-Chun Kao, Jason Smith, Chris Davis, David Bunnell, and Andrew Muir

What was formerly recognized as one species within a species flock indigenous to the Great Lakes, Cisco (*Coregonus artedi*) is now recognized as a group of morphotypes that inhabited the pelagia of each Great Lake. In Lake Huron, two morphotypes, typical *artedi*, a widespread dominant, and *manitoulinus*, reported only from the North Channel in one location, were described based on samples collected in 1917. Typical *artedi* was erroneously reported widespread in recent times but, based on sampling in 2002-2016, appears to be extirpated from the lake’s main basin and the North Channel, while at least one small population remains in Georgian Bay. *Manitoulinus* is relatively unchanged morphologically from 1917 and remains locally abundant where originally described. A previously undescribed morphotype, here called false *albus* to distinguish it from *albus* of Lake Erie, is abundant in northern waters of the main basin and the North Channel. It was recognized as a distinct, although variable, morphotype in 2015, even though it long supported fisheries. The near loss of typical *artedi* and recent severe population declines of two introduced planktivores, Rainbow Smelt (*Osmerus mordax*) and Alewife (*Alosa pseudoharengus*), has created interest in reintroduction of a typical *artedi* morphotype.
Summer Ascending Whitefish in the River Tornionjoki – A Target of Manifold Interreg-study

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Long time statistics indicate a decreasing trend in a traditional dip net catch of summer ascending whitefish in the river Tornionjoki, the border river between Finland and Sweden. The ascend also starts in early August, which is about a month later than before and the mean size of whitefish has decreased. In a three year study that started in late 2015 we focus on reasons behind the stock development with a manifold study approach, considering also the culture and traditions around the whitefish and its fishing in the river Tornionjoki. Whitefish on spawning migration are tagged with radio transmitters and t-anchor tags to find out their potential spawning areas and where they are caught. Newly hatched alizarin tagged larvae are stocked in the river and captured with dip nets and smolt screws and the proportions of marked and wild larvae are used to estimate the natural production. Based on the telemetry results in October the potential spawning areas are explored with a side scan sonar and egg pumping and the actual spawning bottoms are identified and classified. Elementary analysis of whitefish otoliths together with t-anchor tag returns allow to evaluate the areas with the highest fishing pressure.
Role of Lake Whitefish Compensatory Mechanisms in Fisheries Sustainability

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Lake whitefish (*Coregonus clupeaformis*) provide an important economic commercial fishery resource in the upper Laurentian Great Lakes. They are also an excellent indicator species of environmental change as they have a great deal of compensatory scope related to their life history and production dynamics, which has allowed them to successfully respond to the changing ecological and social conditions that have significantly altered the Great Lakes. For instance, over the past century, Northern Lake Huron and Michigan have undergone extensive changes to the environment, fishing efforts, and management practices, which have directly or indirectly influenced mortality and growth rates of lake whitefish. One of the most substantial and well-documented changes was the invasion and proliferation of the sea lamprey (*Petromyzon marinus*) and implementation of sea lamprey control practices. To determine how lake whitefish have been able to responded to environmental changes, we are going to measure the compensatory reserve of lake whitefish during fluctuations in sea lamprey abundance. Changes in lake whitefish growth, survival, and reproduction within the pre-sea lamprey, sea lamprey dominant, and current time periods will be evaluated using a life table approach. Determining the compensatory reserves and its associated biological processes of lake whitefish in the upper Laurentian Great Lakes will help fisheries managers evaluate the sustainability of these stocks and predict their ability to survive new adversities such as alterations in trophic levels, the invasion by new species, and climate change.
GSI% of Pelagic Whitefish (*Coregonus lavaretus*) in Upper Lake Constance Decreased Drastically: Effect of Non-native Invasive Stickleback (*Gasterosteus aculeatus*)

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Upper Lake Constance (ULC) has undergone intensive re-oligotrophication in recent years and P-concentration is back at pre-eutrophication levels since about 2010. Fisheries yield followed these changes. Non-native invasive stickleback (*Gasterosteus aculeatus*) invaded the pelagic zone of ULC about 2013. In autumn 2014 the pelagic fish community consisted of about 80 % stickleback in number and >20% in biomass. Since 1991 each year from July/August until spawning in late autumn of at minimum 20 female whitefish per sampling also GSI% (gonad weight/body weight x 100) is recorded monthly. Here GSI% of pelagic whitefish before (up to 2012) and with stickleback in ULC (2013-2016) are compared. Effect on pelagic whitefish was dramatic: Maximum GSI% immediately before spawning had steadily decreased from about 25% in 1991 to just above 20 % in 2014. However, in 2015 throughout the year mean GSI% values have been the lowest recorded since the beginning of the monitoring. In 2016 GSI% slightly recovered. This drastic decrease of GSI% in 2015 is not explainable by re-oligotrophication, it is presumably caused by competition for food of stickleback with whitefish. In parallel, professional fisheries yield in 2015 was the lowest since the beginning of the statistics in 1910.
Bythotrephes Invasion Alters Lake Herring Biomagnification Rates

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*Bythotrephes longimanus* have invaded numerous inland lakes in North America, many of which are stratified and support offshore fishes like the Lake Herring (*Coregonus artedi*). While evaluations based on changes in zooplankton community composition following *Bythotrephes* invasion predict an increase in Lake Herring mercury concentrations, this has not been observed across a broad range of lakes. Here, we compare temporal changes Lake Herring biomagnification factors (relationships between Lake Herring Hg and isotopes δ15N) from a number of invaded and non-invaded lakes over similar time periods. Our results show that biomagnification factors after *Bythotrephes* invasion either changed direction (from positive to negative relationships) or decreased in elevation relative to those prior to invasion. No such pattern was observed in reference lakes. This reduction in Lake Herring Hg associated with increased δ15N suggests that growth efficiency of Lake Herring has increased, potentially due to reduced handling time feeding on *Bythotrephes*, which are larger and more spatially aggregated compared to native zooplankton species. These findings highlight the potential importance of foraging energetics over and above shifts in trophic position in dictating fish contaminant concentrations.
Impacts of Emerging Ecological and Fishery Stressors on Lake Superior Ecosystem and Coregonid Population Dynamics

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Lake Superior is unique among the Laurentian Great Lakes in that it has ecological communities dominated by native species in both nearshore and offshore areas. However, the Lake Superior ecosystem is undergoing significant changes to both nearshore and offshore food webs, including Coregonid population declines. These changes are likely affecting ecosystem functions, trophic dynamics, and fishery yields. The objective of this study was to use EcoPath with EcoSim to explore how the declines in Corregonid populations influence Lake Superior ecosystem dynamics. The secondary objective was to assess how the Lake Superior ecosystem changes as a result of climate change (through changes in consumption rates), implications of increased Lake Cisco and Lake Whitefish harvest, and impacts of increased Lake Trout harvest. We focus on the population responses of the Corregonid community including Lake Cisco *Coregonus artedi*, Lake Whitefish *C. clupeaformis*, Bloater *C. hoyi*, and Kiyi *C. kiyi*. In addition, we assess the dynamics of 1) predator populations and 2) non-native competitor, Rainbow Smelt *Osmerus mordax*, populations in response to changes in the native prey fish communities.
Climate Change and Clarity Trends Influence Thermal Habitat for Coldwater Fishes in Inland Lakes

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Inland waters are warming, with consequences for fisheries management. We aggregated millions of temperature observations and developed mechanistic lake temperature models for over 10,000 lakes in Minnesota, Wisconsin, and Michigan to examine broad-scale trends and among-lake diversity in warming rates. For all lakes, daily temperature profiles were simulated for 1979-2015 using the General Lake Model. Future temperatures were predicted for the mid- and late 21st century by driving these lake models with downscaled climate drivers from the RCP8.5 worst-case emissions scenario based on six global circulation models. Warming rates in the contemporary period vary substantially among lakes, depths, and seasons. Preliminary results suggest that inland lakes nearest the Great Lakes are warming fastest, although the mechanism behind this pattern is unknown. Future simulations predict continued warming through the 21st century. Lake size, water clarity, and depth influence the sensitivity of lakes to climate change. For example, a 1% annual decrease in water clarity is sufficient to offset the effects of climate change on whole-lake temperatures for many lakes. Conversely, a 1% annual increase in water clarity can more than double warming rates. Understanding heterogeneous lake responses to climate can identify resilient lakes and enable prioritization of climate adaptation efforts.
The Influence of Land Use Disturbance on Cisco (*Coregonus artedi*) Population Characteristics in Minnesota

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Understanding how Cisco (*Coregonus artedi*) populations respond to anthropogenic disturbance is fundamental to understanding how future disturbance may influence Cisco populations, pelagic food-webs, and management decisions. We used vertical gillnets and hydroacoustics to evaluate how Cisco relative weight, average size, and catch-per-unit-effort varied across a range of lakes (N=50) with differing amounts of disturbance (e.g., total phosphorous). Cisco relative weight and average size was positively correlated with disturbance measures, while catch-per-unit-effort was negatively correlated. Mitigating future land use disturbance and maintaining water quality, for example through the protection of forests surrounding Cisco lakes, is imperative for supporting populations of abundant Cisco of an adequate size for predator consumption.
Cestode Infection in a Polymorphic Whitefish Population

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Infection by *Diphyllobothrium* spp. and *Triaenophorus crassus* in the polymorphic whitefish (*Coregonus lavaretus* s.l.) stock in Lake Femunden, Norway, was monitored during 1988-2005. Almost all individuals of D-, R- and S-whitefish were infected by *Diphyllobothrium*, with prevalence varying between 89 and 100% during the sampling period, and with no significant difference between the morphs. The number of cysts per host varied over time, but with the highest mean intensity in R-whitefish. In all morphs, intensity of *Diphyllobothrium* increased with fish age, with the most rapid increase in young age groups. In D-whitefish, infection intensity appeared to stabilize from an age of approx. 5 years, while in R-whitefish, infection intensity continued increasing up to 15-17 years. The prevalence of *T. crassus* in adult fish varied between years: between 5-43% in D-whitefish, between 0-56% in R-whitefish, and between 14-56% in S-whitefish. *T. crassus* prevalence increased significantly with age in all whitefish morphs, but with mean values significantly higher in S-whitefish than in D-whitefish. The mean intensity index for *T. crassus* was at 1.5-1.6 larvae per fish in all three morphs. The patterns of cestode infection are discussed in relation to the known diet and habitat of the three whitefish morphs.
Population-level Effects of Food Web Changes on Bloater Coregonus hoyi Age Composition and Growth Across their Contemporary Geographic Range

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Contemporary populations of Coregonus hoyi are found in lakes Michigan, Huron, Superior, and Nipigon, which distinguishes this species as the most widespread deepwater coregonine in the Great Lakes. Across the geographic range of C. hoyi, lower food web changes such as nutrient reduction, declining benthic and zooplankton prey species, and dreissenid mussel invasion have varied from extensive in lakes Michigan and Huron to minimal in lakes Superior and Nipigon. Because C. hoyi is an important planktivore that shuttles energy from the lower food web to higher trophic levels, food web changes that impact their growth may impinge on predator populations. In this paper, we compared length-at-age and population growth rates of C. hoyi across their present range in lakes Huron, Michigan, Superior, and Nipigon. We place our findings in the context of lower food web changes to evaluate the indirect effect that these changes may have on deepwater cisco populations. Our findings will inform management and reintroduction of C. hoyi in Lake Ontario and continued management of commercial fisheries for C. hoyi in other Great Lakes by providing information on population age structure and food web effects on growth across a gradient of ecosystem disruption.
Trophic Ecology of *Coregonus hoyi* in Lakes Michigan and Huron

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Among the deepwater cisco assemblages in Lakes Michigan (LM) and Huron (LH), *Coregonus hoyi* (bloater) was a relatively small-sized, nearshore form. In contemporary times, it is the only remaining deepwater cisco in LM and has shifted to occupy deeper, offshore waters. In LH, it has been hypothesized to have hybridized with other forms based on morphology, but it remains a dominant offshore planktivore. We compared the trophic ecology of *C. hoyi* in these two lakes using diet analyses and stable isotopes from 2010 (LM) and 2012 (LH). Diets revealed yearling and older bloater from LM consume mostly mysids, whereas those from LH consumed mostly mysids in spring, chironomids in summer, and *Bythotrephes* in autumn. Isotopically, *C. hoyi* shared the same niche with at least four other fish species in each lake, although bloater in LH occupied a wider range of isotopic carbon (suggestive of more allochthous carbon sources). Although there appear to be subtle trophic differences between *C. hoyi* in these two lakes, those differences were not as large trophic differences between lakes for other species (i.e., sculpins, alewife, round goby). Hence the contemporary *C. hoyi* form may occupy a relatively stable trophic position among other ongoing food-web changes.
Effects of Cisco on Walleye Growth Trajectories in Northern Wisconsin Lakes

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Understanding population dynamics among co-occurring fishes is important for informing regional fisheries management policies. We conducted a statewide assessment of cisco *Coregonus artedi* in inland lakes of Wisconsin to better understand the status of this coldwater forage fish. We then used Wisconsin walleye *Sander vitreus* data (2005–2014) to test for the influence of cisco and several abiotic and biotic variables on walleye growth potential. We used data from both monitoring programs to compare walleye growth trajectories (sex-specific $L_\infty$, $K$, time to minimum length limits ($T$)) among lakes where cisco were present, no longer detected, and have never been present. Female walleye reached greatest asymptotic lengths in lakes with Cisco present, compared to those with cisco no longer detected or those that have never had cisco. Female walleye early growth was positively correlated with growing degree days and Secchi depth. Male Walleye early growth was positively correlated with Secchi depth. Time to minimum length limits ($T_{381\text{mm}}$, $T_{457\text{mm}}$) for walleye were reached most rapidly in lakes where ciscoes were not detected. Because extirpations of cisco are expanding northward due to environmental and land use change, conservation efforts may be important for maintaining maximum walleye growth potential in lakes where cisco remain.
Adaptation and Habitat Selection During the Migration of an Coregonid, Broad Whitefish, Coregonus nasus (Pallas)

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Broad Whitefish are an anadromous Arctic fish species in the Mackenzie River Valley, N.W.T. that undergo extensive spawning migrations to spawning grounds located on tributaries of the Mackenzie River, like the Arctic Red River. These spawning migrations occur annually between mid-October and early November as demonstrated with catch-per-unit-effort. The maturity stage development of Broad Whitefish can be predicted by using the variables by gonad-weight and timing of migration for both female and male Broad Whitefish; however, male Broad Whitefish maturity stage also requires the variable abundance for prediction. At the time of Broad Whitefish migration the river environment has slow flowing water as documented by current profiles. The water velocity speeds present in the river at the time of migration are not a barrier to Broad Whitefish migration as Broad Whitefish can swim against water velocities 4 to 10 times higher. This research contributes important life history, migrating characteristic and swimming ability information to the knowledge of Broad Whitefish in the Mackenzie River System.
Effect of Mysis on Feeding Efficiency of Blackfin Cisco and Lake Whitefish via Feeding Structure Comparison

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Blackfin Cisco, a species once endemic in the Laurentian Great Lakes, was discovered in four lakes during fish community surveys conducted in northern Algonquin Park. The lakes are situated in a drainage outflow of glacial Lake Algonquin within an elevation threshold associated with *Mysis diluviana* - a result of inundation by glacial Lake Algonquin. Blackfin Cisco feeding structures are highly differentiated from other coregonines in Algonquin Park. Blackfin Cisco display an elevated gill raker count (50-66), and, via size allometry, greater gill raker length over Lake Whitefish (*C. clupeaformis*) and Lake Cisco (*C. artedi*). Having more numerous and longer gill rakers suggests a premium is placed on Blackfin feeding efficiency. We hypothesize that Mysis reduce planktonic food web size structure resulting in selection for higher feeding efficiency for coregonines. Evidence for this Mysis hypothesis is detected in Lake Whitefish residing in Mysis lakes. Lake Whitefish have longer gill rakers in Mysis systems than in Chaoborous systems after accounting for allometric effects of body size. The results of this study have provided valuable insight into the little-known feeding ecology of Blackfin, as well as revealed an effect of Mysis on two Coregonid species.
Seasonal Changes in Partial, Reverse Diel Vertical Migrations of Cisco *Coregonus artedi*

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We intensively studied a population of cisco (*Coregonus artedi*) in a deep, oligotrophic lake across the range of seasons. The objectives of this study were to (1) document changes in partial, reverse diel vertical migrations (DVM) patterns of cisco *Coregonus artedi* in Ten Mile Lake, MN, U.S.A., throughout the year and (2) evaluate the mechanisms that may cause shifts in migration behavior. Results indicated that *C. artedi* remained deep in the water column during the day and night of the spring and autumn, which was related to a low risk, low reward strategy. During summer, a partial migration revealed a portion of the population remained deeper according to the low risk, low reward strategy, while the other portion performed a more extensive high risk, high reward reverse DVM. In winter, *C. artedi* did not migrate because there were only low risk, low reward conditions present at all depths. The extensive partial, reverse DVM during summer probably increased the growth potential of *C. artedi*, helping individuals survive in a lake with low zooplankton prey resources.
Retrospective Analysis of Growth and Predatory Demand by Cisco (*Coregonus artedi*) in Western Lake Superior

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Cisco (*Coregonus artedi*) are an abundant and important planktivorous fish in Lake Superior that link secondary production to top level predators and support a viable commercial fishery in multiple states and a province. Lake Superior’s food-web has changed in recent decades, but it is unknown how cisco have responded to these changes. Growth histories of cisco from western Lake Superior from 1984-2013 were reconstructed to explore how cisco have responded to changes in their density, climate change, and the invasion of spiny waterflea (*Bythotrephes longimanus*). We also used bioenergetics modeling and concurrent estimates of calanoid copepod standing stock and production to estimate the current supply-demand relationship for this important prey resource of cisco in Lake Superior. Cisco growth rates have been stable over the 25-year period analyzed in this study despite a 10-fold difference in commercial CPUE, a 1.7-fold difference in cumulative-degree-days, and the invasion by spiny waterflea. Calanoid copepod production exceeded cisco consumption during the 2015 growing season, but may limit foraging by cisco over winter. Our findings suggest that cisco growth rates have been resilient to changes in Lake Superior and that winter food-web dynamics may be important for cisco production in Lake Superior.
An Examination of Life History Attributes and Food Web Interactions of Unexploited Lake Whitefish in the Presence of Invasive Rainbow Smelt

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Populations of Lake Whitefish in Algonquin Provincial Park, Ontario, are unexploited and live in lakes with either Mysis or Chaoborus as the major planktonic predator undergoing diel vertical migration. Some lakes have recently been invaded by Rainbow Smelt. Competition in the fry and juvenile stages could potentially result in differing growth and maturity attributes among lakes. Influences of Rainbow Smelt on life history parameters of Lake Whitefish will be examined, including whether a Mysis or Chaoborous food web structure can account for differences. Isotopic analysis will be used to investigate potential food web relationships between Lake Whitefish and Rainbow Smelt during various life stages and in the presence of Mysis or Chaoborous. We will examine pre-maturation growth using back-calculations from a large set of otoliths collected during gill-netting surveys. Providing information regarding life history variation in unexploited Lake Whitefish populations will be valuable generally but also with respect to an invading fish such as smelt and the role of planktonic food web structures.
Diversity of Ciscoes in Lake Superior: More than Koelz Envisioned?

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The recent publication of “Ciscoes (Coregonus, subgenus Leuchichthys) of the Laurentian Great Lakes and Lake Nipigon” has brought to light the diversity of ciscoes in the Great Lakes. We have been studying the ciscoes of Lake Superior for more than 15 years and have catalogued a diversity of 9 forms other than artedi. Since 2012 we have conducted detailed examinations of more than 1000 ciscoes from age groups of 1 year to > 10 years and from all regions of Lake Superior. Most specimens were photographed; measured according to Koelz’s morphological characters and counts; dissected for determination of sex, condition and diet; and age structures, gill rakers and muscle samples were removed for further analysis. The goals of the study are to develop a diagnostic key for field identification of ciscoes, determine the accuracy of those field identifications following detailed laboratory examination, and describe the diversity of cisco forms in regard to habitat and geographic region. We will use multivariate ordination tools to explore the range of morphological variation in Lake Superior ciscoes and determine whether distinct forms exist and can be identified in the field, how morphology changes with ontogeny, and if forms are associated with habitat and geographic region.
Continued Spawning and Larval Production of Lake Whitefish in the Detroit River

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Historic reports designate the lower Detroit River as a once prolific spawning area for lake whitefish with large numbers of fish caught in the fall with seines from islands and nearshore areas. Spawning runs of lake whitefish into the Detroit River almost disappeared by 1920 due to overfishing and habitat degradation resulting from the construction of the Amherstburg and Livingstone channels in 1911. In fall 2005, scientists documented the successful reproduction of lake whitefish in the Detroit River and subsequent annual surveys have shown continued spawning and larval drift into Lake Erie. Fall surveys show that spawning occurs throughout the river, with highest egg catches in deep (>8 m) waters with flows >0.8 m/sec over hard substrates. Larvae emerge in early spring, with peak densities in the middle of April. Most larvae enter western Lake Erie as sac-fry and mix with other spawning stocks’ larvae. Currently, the Lake Erie population is suffering from a lack of recruitment, and investigations are underway to determine the role of early life history stages in determining year-class strength and to estimate the contribution of various stocks to the overall population.
Export of Pelagic Lake Whitefish Larvae from the Detroit River

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The St. Clair-Detroit River System is located in the heart of the North American Laurentian Great Lakes, connecting lakes Huron and Erie, and providing spawning habitat for many fishes. Lake whitefish reproduction has been measured using egg and larval surveys for the past 12 years. However, quantitative estimates of contributions from spawning in the system to the Lake Erie population have not been determined. We used long-term biological sampling and physical habitat surveys to characterize egg deposition and larval drift patterns and a Bayesian approach to quantify larval export from the Detroit River. Egg deposition of lake whitefish occurred throughout the river, including recently constructed reefs restoration habitats. Larval export from the Detroit River into Lake Erie varied across years, and spatially among the multiple navigational channels in the lower Detroit River. Total annual export of lake whitefish larvae ranged from 28.8 million in 2010 to 83.4 million in 2011. Given the widespread spawning, large numbers of larvae produced, and continued system-wide water quality and aquatic habitat improvements; the Detroit River can provide valuable habitat and added resilience to the Lake Erie population in the face of recent poor recruitment from other sources.
Lake Whitefish Early Life History in Western Basin Lake Erie

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Lake Whitefish (*Coregonus clupeaformis*) commercial catches have declined in Lake Erie and a strong year class has not been produced since 2003, reflecting a trend in poor recruitment. Variation in egg and larval survival is suspected to be a major source of Lake Whitefish recruitment variability. To investigate the role of early life history stages on recruitment, we sampled Lake Whitefish eggs on 6 western basin reefs and 5 Maumee Bay dredge spoil mounds in 2016 and 2017. Larvae were sampled from 1994-1998 and again in 2017. Gillnets were set to assess potential egg predators. In fall 2016, viable eggs were collected at all sampling locations, with highest CPUEs near the mid-lake reef complex. During February 2017, no viable eggs were collected at sites in Maumee Bay. Larval distributions from 1994 to 1998 show highest densities near the southern shore. Lake Whitefish eggs were found in the stomachs of all Channel Catfish (*Ictalurus punctatus*) and White Perch (*Morone americana*) collected. A lack of ice cover on Lake Erie increases Lake Whitefish egg exposure to severe wind events, likely contributing to low egg survival and larval abundance.
Effect of photoperiod on cisco (*Coregonus artedi*) egg development

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Cisco in the Laurentian Great Lakes exhibit boom-or-bust population dynamics and may be particularly vulnerable to climate change. Cisco spawn in the fall and eggs develop over the winter with hatching occurring soon after ice-out. Water temperature and ice cover, however, are changing in the Great Lakes. Such changes may influence the quantity and quality of light penetration to the lake bed and thus may potentially impact the phenology and development rate of cisco eggs via photosensitive organs (e.g., retina and pineal organ). Developmental response of cisco eggs to changing winter light regimes may impact life history characteristics, and thus synchrony with spring algae and zooplankton blooms. We conducted a pilot laboratory experiment to test the effect of photoperiod on egg development and hatching of cisco at 2–3°C over the 2016-2017 winter. Fertilized eggs were exposed to three light treatments: continuous and seasonal diel photoperiod of high-intensity white (full-spectrum) light and continuous darkness. We hypothesized that exposure to continuous light accelerates development resulting in earlier hatching, larger larvae, and smaller yolk-sac area at hatch than eggs incubated under a diel light cycle or no light.
Winter Severity and survival of Larval and Age-1 Ciscoes (Coregonus artedi, C. hoyi, C. kiyi) in Lake Superior

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The quest to understand recruitment variability and identify the critical period for larval and first-year survival of coregonid species has motivated much research. Lake Superior cisco recruitment has declined over the past 30 years coincident with a decrease in ice cover and increase in spring water temperatures. This association between winter severity and cisco survival to age-1 is intriguing but the link is poorly understood. To investigate this possible relationship and to identify the life stage most critical to survival to age-1, we collected larval ciscoes from hatching to 3 months of age and at age-1 the following spring from 2014-2017. We related larval survival and growth and age-1 survival to winter and spring limnological conditions. Larval survival and growth was highest in years with less ice cover and warmer spring water temperatures. Conversely, survival of fish to age-1 was highest during the winter with the most ice cover and coldest spring water temperatures. We propose that cisco survival to age-1 is controlled by a number of environmental factors, some of which are related directly or indirectly to ice cover.
Suitability of Different Whitefish Strains from Upper Lake Constance for Aquaculture Purposes

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Decreasing fisheries yields of whitefish in Upper Lake Constance have prompted efforts for local coregonid aquaculture. The aim of this study was to assess the performance of three local wild forms (*Coregonus macrophthalmus*, *Coregonus arenicolus* and *Coregonus wartmanii*) in comparison with an aquaculture-adapted strain of *C. lavaretus* from Finland (JALO strain) under common aquaculture conditions. Larvae were raised from eggs over 100-day periods under standardized feeding conditions with commercial pellet diet, considering survival and growth as performance indicators. Egg diameter of *C. arenicolus* was significantly larger compared to the other two local species, resulting in larger larvae with better growth and survival compared to *C. wartmanii*. Larvae from *C. macrophthalmus* showed growth and survival rates comparable to *C. arenicolus* only if they were offspring from large females. At similar survival as in *C. arenicolus*, eggs from the JALO strain were significantly larger and the offspring showed significantly better growth rates compared to the three coregonid forms from Lake Constance, indicating that offspring of wild coregonids are less adapted to aquaculture conditions. Still, rearing of *C. arenicolus* and offspring of large *C. macrophthalmus* appears promising, particularly if an optimized breeding program capable of further increasing growth can be realized.
Lipid Composition of Baikal Whitefish Aquaculture

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The content of total lipids and fatty acids was for the first time compared in muscles and liver of Baikal omul, lacustrine whitefish, lacustrine-riverine whitefish, and their hybrids raised under equal conditions from artificially fertilized eggs in the Experimental Freshwater Aquarium Complex for Baikal Hydrobionts. We analyzed fatty acid composition of white muscles and liver of fish aquaculture kept in the tap water. The pool of fatty acids (FA) of whitefish tissues consists of bioactive polyunsaturated fatty acids, including 20:5 ω3 and 22:6 ω3, the main components for energy metabolism. These parameters were 1.5-2 times lower in the fish kept in the tap water. To determine patterns of FA distribution in different fish tissues, we processed the data using multivariant statistical analysis and the software Sirius 7.0 (Pattern Recognition Systems). Statistic differences in the content of ω3 fatty acids were recorded in muscles and liver of various Baikal whitefish species. The data obtained provided insight into adaptation mechanisms of the lipid composition in whitefish to the environmental changes. Biochemical studies of whitefish hybrids helped investigate specific features of growth and development of fish and offer new aquacultures with high level of unsaturated fatty acids of the ω3 group.
Moving a Step Forward in Intensive Maraena Whitefish Aquaculture - The Influence of Temperature and Different Live Feed Periods on Growth and Survival of Coregonus maraena larvae

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Wild Maraena whitefish, Coregonus maraena (Bloch, 1779), is despite of stocking programs listed vulnerable. So a need for aquaculture production rises. Intensive aquaculture in RAS is lacking efficient protocols especially for the weaning of the larvae. In this 34-day-experiment the offspring of wild fish was used. All treatments were stocked in triplicate with 500 larvae per tank (18 ind./l). Feeding started 4 days post hatch. The Maraena whitefish larvae were weaned at three different temperatures (16 °C, 18 °C, 20 °C). A first group got pure live feed (freshly hatched Artemia sp. nauplii) for ten days, a 1:1-mixture of live and dry feed for three days, a second group got as long as 13 days the live and dry feed mixture and a third group directly got dry feed at all three temperatures resulting in nine groups. Survival was highest in the pure dry feed groups and lowest in the pure live feed groups. In contrast to growth, which was highest in the live feed groups and lowest in the dry feed group. Higher Temperature increased growth in the live feed groups but had no effect on survival in all groups. These results will enhance the weaning of Coregonus maraena in recirculation aquaculture.
Initiating Nelma (*Stenodus leucichthys nelma*) Farming for Food in Finland

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Nelma *Stenodus leucichthys nelma* farming was initiated in Finland in 2010. The first generation was subject to examine the suitability of nelma to Finnish rearing conditions in flow-through and recycling systems. Also the comparison the features of nelma to whitefish from the national breeding programme were studied. Nelma proved to be a suitable species for food fish production in the Finnish conditions. However, as the growth is slower than for whitefish it requires multiyear growing to achieve such marketable size where it would make the farming profitable. The nelma broodstock for future was established from the imported material and individually tagged fishes were analyzed for microsatellite DNA. The information was used to choose the mating pairs to create the families for the new broodstock generation. Nelma’s features as food were evaluated in comparison to whitefish and was found highly valued by processors and end users. As nelma is an alien species in Finland it is not allowed to escape to wild and at present only RAS farms are allowed to rear nelma. Development on suitable techniques to create sterile nelma is critical to be able to rear nelma in flow-through and net cage farms.
Induction of Free Flowing Gametes by Injection of Luteinizing Hormone Releasing Hormone Analog in Hatchery-Reared Bloaters

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Animals raised in captivity typically exhibit reproductive dysfunction of varying degrees ranging from diminished to absent reproduction. This observation holds true for the bloater (Coregonus hoyi); a deepwater cisco extirpated from Lake Ontario. Efforts to rear bloaters in captivity have met with complications including the absence of egg expression in females and asynchronous gamete expression between sexes. As such, we examined whether the injection of an exogenous hormone (LHRHa) could induce gamete expression in both males and females. Overall, the exogenous hormone injections were effective at inducing the gamete expression of females, more so than males.
Impact of Sound Pollution on Auditory Epithelium of Baikal Coregonid Fish in Natural Habitat and Aquaculture

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We studied morphological and functional characteristics of the affected and unaffected by intense sound hearing epithelium in Baikal coregonids living under different environmental conditions. The sensory epithelium was analyzed with the help of scanning, transmission and confocal imaging techniques. The EthoStudio soft- and hardware complex was used for studying behavioral response. We observed local epithelium damages, e.g. sticking stereocilia, vacuolization and round shape gaps with a diameter of 0.85 to 5.1 microns equal to the area of the apical surface of sensory cells. The acoustic impact included not only mechanical damage to the sensory epithelium, causing temporary hearing loss, but also behavior disorder in fish depending on the acoustic signal intensity. For example, we recorded fundamental differences in depth preferences, swimming direction and speed of the affected and unaffected fish. Our work demonstrates that fish are very sensitive to environmental changes, thus making them adapt at all structural levels: both at the cell and organism level and at the level of populations and species. This work was performed at the Experimental Freshwater Aquarium Complex for Baikal Hydrobionts with the support of the State Project VI.50.1.4 (N 0345-2016-0002).
Core Microbiotas of the Larvae of Coregonid fishes and their F1 Hybrids

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The formation of a microbiome of digestive tract of fish starts with larvae hatching. Artificial fertilization of coregonids, conducted in the “Freshwater Aquarium Complex” of LIN SB RAS, allows to investigate both fundamental and applied topics, one of which is the formation of the gut microbiota of fish from the earliest stages of their ontogenetic development. Artificial fertilization was carried out for Baikal omul Coregonus migratorius Georgi and peled Coregonus peled (Gmelin). Non-feeding larvae of omul, peled and their F1 hybrids were used in the experiment. The core microbiotas of all larvae types was presented by Proteobacteria, Actinobacteria, Firmicutes, and Bacteroidetes. Additionally Verrucomicrobia were detected by real-time PCR, which content was 3 to 10 time less then main bacterial phyla. Representatives of Candidatus Saccharibacteria and Deferrribacteres were detected in individual samples, while Spirochaetes, Synergistetes and Fusobacteria were not detected by the group-specific PCR. Metagenomic analysis revealed a similarity in the core microbiome of coregonid fishes as well as their F1 hybrids. Investigation of the colonization of the intestine by beneficial microorganisms and the development of a healthy organ – gut microbiome – is of particular importance in fish aquaculture. The research was supported by budget (VI.50.1.4.) and grants (15-04-06847, 14-04-01242).
Common Garden Experiments for Coregonidae: Study of Reticulate Evolution, Biodiversity Conservation, Aquaculture

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Until recently, hybridization was not thought to play a very constructive role in animal evolution. Now, new genetic evidence suggests that hybrid speciation, even without polyploidy, is more common in animals than we have believed. Today, biologists armed with new and abundant molecular marker data increasingly find new examples where hybridization seems to facilitate speciation and adaptive radiation in animals. Coregonidae is a vivid example among them. The major pattern of reticulate evolution in Coregonus is clearly traced in joint ITS1rDNA/ mtDNA analysis and suggests that hybridization accompanies the group throughout the evolution. Further evidence is needed to study a direct role of hybridization in creating reproductive isolation or in accelerating diversification. Great potential for such studies lies in the creation of artificial hybrids in the laboratory and analysis of the structure of genomes and transcriptomes. To carry out such work, it is necessary to adapt and/or improve existing technologies for coregonids and to develop new reproductive techniques, such as rearing in aquaculture, cryopreservation, hormonal stimulation, interspecies pregnancy, etc. This will allow us to get hybrids between populations or species isolated in space and time, including those with a long reproductive cycle. This is a possibility not only to study reticulate evolution and adaptive radiation in coregonids, but also to preserve biodiversity and develop aquaculture. This work is carried out at the Experimental Freshwater Aquarium Complex for Baikal Hydrobionts with the support of the State Project VI.50.1.4 (N 0345-2016-0002).
Incorporation of Otolith Morphometry and Environmental Determinants into Stock Discrimination of Phenotypically Subarctic Lake Whitefish Stocks

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Lake Whitefish is typical representative of the coregonid fishes in oligotrophic Great Slave Lake (GSL), and has sustained the largest commercial fishery in the Northwest Territories, Canada. The knowledge of fish stock structure is essential to effectively assess the stock dynamics and manage fisheries, yet in GSL it remains poorly understood. Otolith morphometrics have been shown to provide a practical basis for stock discrimination and subsequent stock-specific fisheries assessment. In this context, shape descriptors of a total of 394 sagittal otolith images were retrieved to investigate to what extent possible differences in otolith morphometrics of fish exist, and how physical environments act on the differentiation of the otolith morphology. The study encompassed three separate components, asymmetric test, canonical discriminant analysis (CDA) and Canonical Correspondence Analysis (CCA). Pair-wised statistical test indicated no significant difference between the left and right sides in a pair of otoliths. Otolith morphometric variables (length, width, perimeter, area and weight) and otolith shape indices (form factor, circularity, aspect ratio, and rectangularity) were included within a traditional CDA to differentiate phenotypes of fish. Incorporated with on-site limnological observations, CCA was explored to discriminate otolith-based ecotypes of fish, suggesting that the fish may be comprised of a meta-population structure along southwest-northeast axis of the lake.
Cisco Body Morphology, Relative Weight Redundancy, and Oxythermal Habitat Relationships in Wisconsin Inland Lakes, U.S.A.

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Cisco (Coregonus artedi) exhibit substantial variation in body morphology across populations in North America. Understanding cisco body morphology is important, since their form can be a symptom of environmental conditions and possibly used as an indicator of habitat suitability. We used standard geometric morphometric techniques to assess cisco body shape variation of 17 lake populations in Wisconsin during 2013. We then evaluated body form associations with environmental factors and cisco relative weight. Principle components analysis showed lake-specific forms varying from deep- to narrow-bodied cisco morphotypes. Cisco morphotypes strongly corresponded to water temperature at which dissolved oxygen reached 6 mg/L in a vertical profile (TDO6). TDO6 was positively associated with the deeper-bodied morphs, indicating that the deeper-bodied morphs were associated with poorer quality oxythermal habitat. Furthermore, cisco relative weight was highly redundant with body form variation. Our results provide insight about the use of cisco morphotypes as indicators of coldwater habitat quality and the alternative use of relative weight to characterize cisco morphotypes.
Parallel Expression of Trophic-mediated Morphologies: A Key to Evolution?

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An important goal of evolutionary biology is to identify the causes of diversification and to determine why some evolutionary lineages are especially diverse. Resource polymorphism, viewed as an early stage in the speciation process, is defined as the occurrence of discrete intraspecific morphs showing differential niche use, usually through differences in feeding ecology and habitat use. Many populations within a species can differ in the expression of resource polymorphism, including ecological and genetic differences, and some even show partial reproductive isolation. To better understand how resources may be partitioned in large lakes that support intraspecific diversity of ciscoes (Salmoniformes: Coregonidae), trophic niches were compared among morphotypes from Great Slave Lake (61.45° N, 115.09° W; 27 200 km2) and Lake Superior (47.72° N, 86.94° W; 82 103 km2). Diversity of cisco among these two systems included lacustrine C. artedi, C. zenithicus, C. hoyi and C. kiyi and adfluvial C. artedi. MixSiar analyses of carbon and nitrogen isotopes were conducted on adult individuals ≥ 150mm and covariances with phenotype was tested against δ13C and δ15N values. The objectives of this study were to determine if: 1) parallel patterns of phenotypic diversity occur among lakes, within deep versus shallow regions; 2) a repeatable from-function relationships (e.g., morphology predicts carbon resource use) among shallow- versus deep-water morphs; and 3) trophic niche overlap among morphs is consistent with divergent natural selection.
Genetic Stock Structure of Lake Herring and Bloaters Across the Upper Great Lakes

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The structure of Great Lakes fish communities has and will continue to change appreciably over time in response to exploitation, species introductions, and to environmentally-mediated changes in species composition and relative abundance. Greater awareness of inter- and intra-species relationships, commonalities and differences in ecological requirements, and degree of spatial population structure is critical to a comprehensive understanding of ecosystem structure, function, and responses to management efforts. Such knowledge enables managers to better predict and evaluate trophic change as well as community response to environmental perturbations. Our study quantifies the degree of spatial genetic structuring for lake herring (*Coregonus artedi*, N=565) and bloater (*C. hoyi*, N=789) across 27 locations in the upper Great Lakes based on mitochondrial DNA sequence and multi-locus microsatellite data. Hierarchical analyses of molecular variance that partitions variance in mitochondrial DNA haplotype and microsatellite allele frequency revealed significant variation among lake basins and sampling locations within basins for both species. The greatest level of genetic discordance was between samples from Lake Superior and Lakes Huron and Michigan for both species. Results are discussed in the context of abiotic lakescape features and ongoing discussions concerning proposed management actions.
The Story of the Whitefish (*Coregonus lavaretus*) Inhabiting the Bay of Puck, the Southern Baltic

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Whitefish is a socio-economically important species found in the coastal zone of the Baltic Sea. The species is listed among endangered species on the HELCOM red list of Baltic Sea. Taking into account protection of the resources, the hatchery produced fingerlings of whitefish originated from the Pomeranian Bay in the Southern Baltic, were stocked along the Polish coast. Stocking programs carried out in the Polish Exclusive Economic Zone (EEZ) of the Baltic Sea during last two decades, have resulted in a partial recovery of the resources. However, according to our research, the genetic resources have been negatively affected. We analyze the genetic variation at ten microsatellite loci for five whitefish samples from the Polish coast (Stettin Lagoon and Puck Bay) and the Curonian Lagoon, Lithuania. DNA of archive samples for 142 fish, collected from Polish coast between 1958 and 1984, and contemporary samples for 148 fish, of pointed three sites, were amplified and genotyped. FST pairwise estimates showed that archive and contemporary sample from the Stettin Lagoon were genetically homogenous (genetically stable over time). In turn contemporary sample from Puck Bay was significantly different from all other samples (pairwise FST from 0.017 to 0.159) in particular from archive one collected in the bay.
Cisco, *Coregonus artedi*, was once found in all five Laurentian Great Lakes, but is now widespread in only Lake Superior with reduced populations in lakes Michigan, Huron, and Ontario and is considered extirpated from Lake Erie. However, fish identified as cisco are sometimes discovered in the bycatch of commercial gillnet and trawl fisheries targeting lake whitefish, yellow perch, white bass, rainbow smelt and walleye in Lake Erie. The appearance of these individuals raises questions as to their origin. We used molecular techniques to confirm the identity of these coregonids and compare their genetic profiles to those of contemporary cisco from Lake Huron and historical samples from Lake Erie. While many individuals were verified as cisco, some were determined to be lake whitefish based on cytochrome oxidase I sequences. Significant differences were found among contemporary and historical samples from Lake Erie and Lake Huron allowing the contemporary Lake Erie cisco to be assigned to a specific lake of origin.
Population Genetics Analyses of Inconnu (Stenodus leucichthys) Populations: Implications for Fisheries Management in Great Slave Lake, Northwest Territories

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Inconnu (Stenodus leucichthys) from the Great Slave Lake (GSL), NWT, are highly valued in commercial and subsistence fisheries. Exploitation from intense fishing pressure has caused declines in many Inconnu populations. Although some populations are declining, others are thought to be healthy and productive. Areas with higher observed catches could be the result of expansion by healthy populations effectively masking a decline in other populations. It is important to determine the number of genetically discrete populations so fisheries management can monitor the declining populations. Microsatellite markers and population genetic analyses were used to determine the number of genetic populations that reside in GSL and surrounding tributaries. Our hypothesis is that each river supporting a population of Inconnu migrating into GSL represents a genetic population because of Inconnu’s natal philopatry. From 1992 to 2016, tissue samples were collected from fish in GSL and eight lakes and surrounding river systems. Data analyses using 17 microsatellite markers suggest the presence of distinct and mixed stocks. Additional analyses are presented to determine which populations contribute to the mixed stocks. Further, the effective population size of each genetic stock was estimated. This research will assist in future management decisions for important Canadian fisheries.
Transcriptomics Identifies Genes Associated with Phenotypic Differences among Great Lakes Ciscoes (*Coregonus* spp.)

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We sequenced expressed genes ("transcriptome") from the heads of eight individuals from each of the four species of ciscoes found in Lake Superior (*Coregonus artedi, C. hoyi, C. kiyi*, and *C. zenithicus*). This approach identified sequence polymorphisms (SNPs) within many expressed genes. A number of these SNPs were taxonomically informative (e.g., FST > 0.20) and comparison annotated fish genomes indicated that many of these genes are associated with lipid metabolism (associated with buoyancy and depth preferences) and head shape development (associated with trophic morphology). Patterns of variation in the transcriptome were largely concordant with morphological differences among samples. High-FST SNPs in genes associated with functional phenotypic variation provide candidates for local adaptation in the cisco species flock. Future studies will be aimed at validating these results with larger sample sizes and more detailed functional genetic analyses.
Developing a Rapture Panel to Investigate Genetic Diversity in Cisco Across the Great Lakes Region

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Cisco are native to the Great Lakes region and represent an important component of the food web as well as a valuable resource for commercial fishers. Abundance of cisco has declined significantly over the last century, prompting significant efforts to restore and conserve these species. The long term goal of our research is to inform conservation of cisco by improving our understanding of neutral and adaptive genetic variation. In this talk, we will focus on recent efforts to develop a panel of genetic markers for cisco using RAD capture (Rapture). Rapture combines two well established protocols, RAD and sequence capture, and facilitates efficient genotyping of 1000s of SNPs in hundreds to thousands of individuals. To construct the panel, we RAD sequenced 2-5 individuals from 20 inland populations throughout the Midwest and combined these data with data from Great Lakes cisco. Capture baits were then designed for SNP sequences identified from these data. We show results from phylogenetic analyses incorporating ascertainment individuals, discuss the panel development process, and outline how the Rapture panel will be used to address future research goals for cisco in the Great Lakes region.
Algonquin Park is a Landscape of Coregonine Diversity

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In Algonquin Park, Ontario, Canada, reside many lake populations of coregonines including Lake Whitefish, Cisco, Round Whitefish, and apparently Blackfin Cisco. Lake surveys over the past eight years have revealed extraordinary examples of diversity in this group of fishes – including evolved species assemblages for Lake Whitefish and Cisco, and occurrence of Blackfin Cisco. This has occurred for two important reasons. First, the northern region of the park was the glacial outflow for Lake Algonquin for over a millennia resulting in essentially Laurentian Great Lake food webs among many lakes. Second, the park sits on a dome and as such is a headwater region for many river systems in southcentral Ontario. This has served as a barrier to species invasion, and limited access to the park interior has prevented unintended introductions of fish from occurring. In this presentation, we outline this diversity including clear evidence of different timing of post-glacial recolonization for Cisco and Lake Whitefish of Algonquin Park - and by extension the Laurentian Great Lakes. Cisco arrived a millennia after Lake Whitefish. There is reason to believe Cisco diversity once observed in the Great Lakes may reside in landscapes west of Algonquin Park.
Morphological Assessment of Contemporary Cisco Populations in Lake Michigan and their Relationship to Historic Forms

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Interest in restoration of Cisco Coregonus artedi populations has been increasing, particularly in northern Lake Michigan where evidence exists of rapidly expanding populations. Populations in Lake Michigan are presently assumed to be a single form referred to as an albus-like C. artedi ecotype. Contemporary assessments of Lake Michigan Cisco have been focused on collections from Grand Traverse Bay where early evidence of the expansion was most prevalent. However, designation of the form(s) of Cisco which remain in Lake Michigan and the lake wide representativeness of the Grand Traverse Bay stock remains unclear. In the present study, Cisco were collected from six Lake Michigan sites and four connected inland waterways to assess the degree of morphological variation within the basin. To determine how current Cisco relate to historic forms, we imaged Lake Michigan C. artedi artedi (n = 144) and Lake Erie C. artedi albus (n = 58) from the Koelz 1929 collections. Body and head shape were assessed using geometric morphometric methods on digitized images, phenotypic characteristics were measured with eight linear anatomical measures and gillraker counts of individual fish. This study represents a practical first step in assessing the current morphological diversity of Cisco within the Lake Michigan basin.
Development of Culture Practices and Captive Broodstocks for *Coregonus hoyi* to Support Bi-national Efforts to Restore the Species to Lake Ontario

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Bloater is one of four species of deepwater cisco that was extirpated from Lake Ontario in the 1980s. In winter 2011, OMNRF and USGS initiated efforts to develop culture practices for the species using fertilized eggs collected from Lake Michigan to support restoration into Lake Ontario. This presentation describes OMNRF’s progress since that time. Survival during early rearing (1-12 weeks) and mid-rearing (13-20 weeks) improved from 11% and 80%, respectively, in 2011, to 50-60% and 90%, respectively, in recent years. Survival during advanced rearing (21-82 weeks) remained steady at 90% across all years. Improved feed delivery was the primary factor for increased rearing survival. We also evaluated the effect of diet and temperature on growth and survival. The diet studies identified several readily accessible commercial micro-diets from among five tested that produced good results during early and mid-rearing. Temperature trials conducted during early and mid-rearing found increased growth rates but reduced survival rates as temperatures were increased from 10 oC to 14 oC. In 2011, OMNRF also began developing captive broodstocks. Three of seven year classes have now matured and produced some viable gametes; however, the degree of maturation and synchronization between males and females has been variable.
Collecting Viable Deep-water Cisco Gametes from Lake Michigan for Propagation - Lessons Learned

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We collected gametes from the Bloater form of deepwater cisco in Lake Michigan to support deepwater cisco reintroduction in Lake Ontario where they have been extirpated since early 1980s. Our objective was to develop protocols for the collection of viable Bloater gametes to support rearing and reintroduction in Lake Ontario. Bloaters spawn over a protracted winter spawning season in offshore waters at depths that can exceed 80m. We evaluated capture gear, fertilization techniques, and transportation methods to optimize survival to eye-up. Gill nets collected fewer, but larger and more fecund adults that were in poorer condition, and survival to eye-up was 1.5 – 43.6%. Bottom trawls caught greater numbers of smaller adults in better condition, resulting in a greater number of viable eggs, and survival to eye-up improved to 50.5 -80.0%. Pressure effects during net retrieval from 80m expelled many ripe eggs and sperm, consequently hand stripping of gametes was ineffective. Body cavity incision was necessary to maximize gamete collection. Male testes were pressed through screening to maximize available sperm and improve fertilization. Overnight shipping most efficiently transported fertilized eggs to hatcheries in New York and Ontario. Up to two million fertilized eggs were collected in single spawning season.
An Overview of Lake Herring (*Coregonus artedi*) Culture and Rearing at the University of Wisconsin Stevens Point Northern Aquaculture Demonstration Facility

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Building upon previous successful culture experience with Lake Herring (*Coregonus artedi*) at UWSP-NADF, recent advances in aquaculture technology will be applied at a commercial scale level to develop a propagation and culture manual that will apply new technologies to rear Coregonine species to augment natural resources agency conservation activities in the Great Lakes. Included in this evaluation and summary are:

Various egg collection methods and the effectiveness of iodophor treatments and post treatment survival of eggs/larval lake herring. Evaluation of egg incubation water temperatures. Evaluate the hatchery production attributes (i.e., feed acceptance, survival, and growth) of immediate post-hatch larval lake herring fed selected commercially available diets. Evaluation of hatchery production attributes (i.e., feed acceptance, survival, tank density and growth) of fingerling lake herring fed selected commercially available diets.
Feasibility of Using Native Lake Michigan Cisco as Parental Stock for Hatchery-based Restoration

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In 2013, Little Traverse Bay Bands of Odawa Indians (LTBB) began a pilot study to evaluate the feasibility of using Lake Michigan stocks to assist Cisco (Coregonus artedi) stock recovery in Lake Michigan. Here we review lessons learned from four years of successful Cisco egg collection, rearing, tagging, and release. We obtained Adult Cisco using short term, monofilament gillnets from a known spawning reef in Grand Traverse Bay. We maintained gravid adults in large holding pens to guarantee peak ripeness and availability. We successfully spawned these ripe individuals using the dry pan method. Fecundity rates were high, relative to literature-derived values for Cisco. Total egg survival varied widely across parings but appears to be principally driven by female ripeness. Fry readily accepted commercial feed and performed well in round-tank culture. We found the maximum rearing density to be low relative to other salmonids however, increased light intensity appears to allow for a higher maximum density, increased growth rates, and reduced daily mortality. Additionally, we evaluated the effectiveness of fin clipping and coded wire-tagging Cisco in several locations. The results of our Cisco culture investigation demonstrate that using extant Lake Michigan Cisco stocks for hatchery-based recovery efforts is highly feasible.
Post-stocking Behaviour, Habitat use, and Survival of Hatchery-reared Bloater (*Coregonus hoyi*) in Lake Ontario Using Acoustic Telemetry

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Until the mid-1950s, a diverse group of deepwater ciscoes including bloater (*Coregonus hoyi*) were part of Lake Ontario’s native fish community, now reduced to a single shallow-water species (*C. artedi*). Plans to re-establish a self-sustaining population of deepwater ciscoes in Lake Ontario include stocking hatchery-reared juvenile bloater each year. To determine the post-stocking behaviour, habitat use, and survival of these hatchery-reared bloater, we implanted 122 yearling bloater with acoustic transmitters between 2015-2017 and released these fish intermixed with the restoration stocking individuals in eastern Lake Ontario. First year results showed high detection (68 of 70 tagged bloater) and high dispersal although 8 fish continued to be tracked within the array 7 months later. This presentation will include updates following the second year download of the array, and preliminary survival estimates using Bayesian mark recapture analyses. Establishing a self-sustaining population of deepwater ciscoes will help restore fish native to Lake Ontario, thus increasing biodiversity, improving food web stability, and serving as a basis for improving reintroduction and management of other species.
Historical Habitat Uses by Ciscoes (*Coregonus artedi*) in Lake Michigan

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In Lake Michigan, ciscoes were among the most important fisheries in early 20th century but were extirpated in the 1970s, likely due to overfishing and habitat degradation. Ciscoes are increasing their distribution and abundance in Lake Michigan in the 2000s, but their highest density areas are in and around Grand Traverse Bay. Managers are supportive of continued restoration of this native species as it will not only enhance the biological diversity and integrity of the planktivore community but also supplement the shrinking salmonine prey base. Knowledge of their historical distribution and abundance could inform ongoing restoration efforts, as most of the knowledge is derived from fishery-dependent data that suggest their highest density areas were in Green Bay. We investigated historical spatiotemporal distribution of ciscoes in Lake Michigan by analyzing fishery-independent gillnet survey data collected by the R/V Fulmar in 1930–1932 with a regression model. Datasets include catch-per-unit-effort at 21 ports from April to November in 1930–1932, individual length and weight measurements, and water temperature by depth at each sampling station. Our results can support future restoration efforts by informing the locations of areas where fishing could be minimized or fish could be stocked.
Characterizing Spawning and Nursery Habitat of Great Lakes Cisco (*Coregonus artedi*) and Applications to Areas Targeted for Restoration

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Cisco (*Coregonus artedi*) are shallow-water coregonines that were historically abundant in the Great Lakes, serving as an important prey for piscivores and supporting large commercial fisheries. In response to threats including fishing pressure and interactions with nonnative species, populations declined precipitously through the early 1900s, leading to local extirpations and low abundances still observed today. Recent efforts to improve system resiliency in Lake Ontario through native fish restoration have included remnant Cisco populations. To support these efforts, information on spawning ecology is needed to assess available spawning and nursery habitat to facilitate the prioritization of target areas for restoration actions. We are studying documented spawning sites, a high-energy reef complex in Lake Michigan and a relatively low energy area in Lake Superior, to identify habitat variables associated with egg presence and viability. We utilize a diaphragm pump to collect eggs from the lake bottom and assess the association between spawning evidence and habitat variables using an occupancy modeling framework. This is coupled with large-scale sonar maps to estimate the distribution of quality spawning habitat in Lake Ontario. In this talk, we present preliminary results from study sites and a controlled experiment testing the efficiency of benthic pump egg sampling.
Dispersion of Larval Vendace Around Potential Nursery Areas

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Depending on their reproductive strategy, different fish species aim to aggregate or disperse the eggs and larvae in their reproductive habitat. Especially many pelagic species disperse both eggs and larvae widely around the potential nursery areas. Here we aim to quantify the dispersion of larval vendace (*Coregonus albula* (L.)) in the different types of lakes and examine the density-dependent and environmental-induced effects on the inter-annual variation in the dispersion by analyzing spatial larval abundance data from Finnish lakes from 1990 to 2017. Vendace larvae dispersed lake-wide to both littoral and pelagic zones. For example, in Lake Konnevesi from 1990 to 2016, only in 9% of total 1278 random sampling plots no vendace larvae were observed. Similarly, the density of vendace eggs in the spawning ground is generally low with no particular tendency for aggregations. The spawning behavior of vendace with several small egg batches and spawning rises in the dark seem to have the potential to promote the lake-wide dispersal of early stages.
From Side Scan Sonar to Egg Pumping – Quantifying Spawning Habitat of Anadromous Whitefish in a Constructed River

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Current information on spawning habitat requirements of anadromous whitefish is scarce. Earlier the spawning sites and egg densities have been studied with egg pumping, but most often with transect based sampling, to e.g. identify the depth zone for eggs and spawning. Without prior knowledge of bottom type these studies have often covered relatively small areas. New side scan sonar technology has made possible to map bottom structure in large areas with good accuracy and reasonable costs, thus making possible the identification and quantification of suitable whitefish spawning areas. Our objective was to map the whitefish spawning habitats in a certain part of heavily constructed river Kokemäenjoki. Side scan sonar was used to survey the study area and the sonar transects were classified and mosaicked to high resolution bottom structure map with depth information. Whitefish eggs were sampled after spawning period and before hatching with an egg pump. The data was used to analyze the effect of bottom structure, river flow, water depth and detritus to egg densities. The results indicate that side scan sonar maps can be used to estimate the potential spawning habitats and further, to design artificial spawning reefs on constructed rivers to enhance natural reproduction.
Vertical Habitat Use of Lake Whitefish in a Small Canadian Shield lake: Insights from Acoustic Telemetry

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Lake whitefish (Coregonus clupeaformis) is an important commercial and subsistence species found in lakes with sufficient oxythermal habitat over a broad geographic range. Environmental impacts of climate change are expected to vary regionally, with increases in precipitation and temperature predicted around the Laurentian Great Lakes and in northwestern Ontario. For small lakes, these changes may yield warmer surface water temperatures and decreased clarity due to increasing allochthonous DOC concentrations. We examined the vertical habitat use of five lake whitefish in a small, shallow (maximum depth 13 m), thermally-stratifying lake in northwestern Ontario using acoustic telemetry. Water temperature and light levels were recorded at 1 m depth intervals every 60 minutes, and oxygen concentrations were measured biweekly using a handheld probe. Preliminary results indicated that during summer when lake surface temperatures were warm (>20 °C), lake whitefish occupied a narrow depth range (2-3 m) below the thermocline.
Restoration of Whitefish Population in Lake Bourget: An Historical Analysis

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Lake Bourget whitefish (*Coregonus lavaretus*), an indigenous fish that is at the southern limit of its range, has been dramatically impacted by eutrophication. In the 1950s catches were close to 90 tons and decreased to less than 1 ton by the 1970s. Important remediation work has been carried out to reduce phosphorus inputs to the lake and a major supportive breeding program was undertaken. Today, Lake Bourget is returning to oligotrophic conditions and whitefish catches are equivalent to the pre-eutrophication period. However, in recent decades, annual mean air temperatures significantly increased possibly impacting the fish population. The objective of this study is to analyse the long-term whitefish population dynamics and to identify the main environmental factors involved in their evolution. Paleolimnology data combined with recent observations, have been correlated to the whitefish catches over a 70-year time series. Contribution of the main forcing factors (climate change, reoligotrophication and stocking) was explored using a Generalized Additive Model. According to our results, phosphorus has been the main parameter influencing whitefish dynamics, with the stocking effort also contributing to the restoration of the population. However, recently, rising temperatures have likely impacted whitefish dynamics, raising concern for the future of the population.
Lake Whitefish Re-colonization in Wisconsin’s Green Bay Tributaries

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Large numbers of lake whitefish (*Coregonus clupeaformis*) historically spawned in the Menominee River, a tributary to Green Bay in Lake Michigan. However, by the late 1800s they were extirpated largely due to saw mills and overfishing. During the early to mid-1990s, incidental catches of lake whitefish were increasingly recorded in the Menominee during the November spawning period. Returns have continued to increase and the population has become self-sustaining. Genetic analyses indicate this population is likely an admixture of fish from multiple Lake Michigan stocks. Spawning runs have since been documented in several other Wisconsin tributaries to Green Bay with the largest apparently in the Menominee and Fox Rivers. Age structure in these tributary fish differs considerably from adjacent stocks supporting the premise this is a recently re-established population. Tag recovery data suggest, unlike a nearby bay-spawning stock, fish from the tributary populations generally do not move out of Green Bay into Lake Michigan. It is likely these populations support the growing southern Green Bay commercial fishery and the large sport fishery that emerged there in 2007. Multiple research projects have recently begun that will provide important information used to manage these newly established populations.
Cisco Restoration in Lake Ontario

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Cisco *Coregonus artedi* are native shallow water coregonines that were formerly very abundant in Lake Ontario and provided important commercial fisheries and healthy prey to native piscivores. Cisco abundance is greatly reduced and mainly restricted to the eastern region of Lake Ontario. Re-establishing self-sustaining populations of native cisco in Lake Ontario is the focus of cooperative efforts between the Department, the U.S. Geological Survey (USGS), the Ontario Ministry of Natural Resources (OMNR), and the U.S. Fish and Wildlife Service (USFWS), and the Great Lakes Fishery Commission, with supporting research conducted by The Nature Conservancy, Queens and Cornell Universities. This paper reviews ongoing Lake Ontario cisco restoration efforts and recommends future areas for research and rehabilitation of cisco. Restoration efforts currently focus on rehabilitation of spawning populations in historical embayments; culture of cisco and evaluation of stocking stage and locations; assessing the suitability, distribution of existing cisco spawning habitat; conducting acoustic tagging to evaluate movement and spawning site fidelity, and evaluating genetic heterozygosity and the potential for hybridization with lake whitefish *Coregonus clupeaformis*. 
We sought to determine if this gradient still exists and to evaluate the distribution patterns of bloater in the three lakes using hydroacoustic survey data collected from the three upper Great Lakes in 2016. We used classification trees to identify areas in the lakes where catches in midwater trawls were dominated by bloaters. We used generalized additive models to evaluate potential drivers of the distribution of bloater-like fishes. We hypothesized that in lakes Michigan and Superior, but not Lake Huron, bloater are aggregated in areas with bottom depth where they maximize vertical overlap with *Mysis diluviana*. Shallow areas with few mysids have few if any bloater and few if any mysids. Areas of intermediate depth have highest bloater density. In deeper areas bloater density is also low, because the upper depth bloater can occupy is restricted by buoyancy limitations and as a result overlap potential between bloater and mysids is reduced to the point where occupation of these depths is not energetically feasible. We argue that the distribution pattern in Lake Huron is different because of low density of mysids.
Total Mercury Concentrations in Liver, Muscle and Scales of European Whitefish (*Coregonus Lavaretus* (L.)) in a Subarctic Lake – Assessing the Factors Driving Year-Round Variation

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Subarctic lakes are subject to extreme seasonal climatic variation, but we know little the effects on total mercury concentration (THg) of European whitefish (*Coregonus lavaretus*). We conducted a year-round study of THg and ecological metrics of whitefish. We measured the accumulation of THg in tissues with fast (liver), moderate (muscle) and slow (scale) turnover rates. In liver and muscle, THg were highest in winter and the lowest in summer. THg increased in winter following the summer dietary shift to pelagic zooplankton and starvation after spawning in mid-winter. Whitefish THg decreased towards summer, and were associated with consumption of benthic macroinvertebrates and subsequent growth dilution. THg of scales were low and displayed high variance, showing lowest value in May and highest in July. THg in liver and muscle were correlated throughout year, whereas scale and other tissues showed relations only during summer. Multiple regression models revealed that sexual maturity, δ13C values and condition factor explained most of variation in liver (50%) and muscle (55%). A model examining scale THg explained 6% of variation. The higher level of seasonal variation (21-33%) in whitefish THg in muscle and scale, than their inter-annual accumulation (8-7%), suggests to include seasonal factors in future THg studies.
Short-term Survival of Lake Whitefish Following Surgical Implantation of Acoustic Transmitters Using Two Forms of Anesthesia

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We evaluated 48-h survival of lake whitefish *Coregonus clupeaformis* following surgical implantation of acoustic transmitters using chemical anesthesia (i.e., AQUI-S 20E®) and electroanesthesia by conducting a series of surgery trials during November 2016. Adult lake whitefish were randomly assigned to one of five treatments: 1) a loop tag; 2) a loop tag and dummy acoustic transmitter with no anesthesia; 3) a loop tag and dummy transmitter using AQUI-S; 4) a loop tag and dummy transmitter using electroanesthesia; or 5) reference fish. In treatments involving anesthesia, fish were monitored for induction and recovery times, and all fish were monitored for post-trial mortality. After 48-h, all fish undergoing anesthesia of both types were alive and 4 of 25 fish implanted with a transmitter without anesthesia were dead. Induction and recovery times were substantially lower for fish anesthetized using electroanesthesia than for those anesthetized using AQUI-S. Results indicate that survival of lake whitefish following implantation of acoustic transmitters was high when surgeries were conducted under anesthesia. While mortality rates did not differ between anesthesia methods, our results suggest that electroanesthesia may offer a better option than AQUI-S for tagging lake whitefish in a field setting due to substantially lower induction and recovery times.
Movement Patterns of Lake Whitefish in Lake Erie

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Lake Whitefish (Coregonus clupeaformis), an ecologically important species to the Lake Erie ecosystem, support a commercial fishery spanning more than a century. Aside from harvest monitoring and ancillary catches observed during assessment surveys, little information exists concerning the movement patterns of Lake Whitefish. Aggregations of spawning condition fish are annually harvested in the western basin at the mouth of the Maumee River and near the Ontario open-water reef complex; however, it is unclear if these are spawning nearby or transient. To address this research question, we implanted acoustic transmitters into gravid Lake Whitefish (n=10) in Maumee Bay during fall 2015 and monitored movement patterns throughout the lake. Additional fish (n=37) were tagged near the Ontario reef complex during the fall of 2016. Preliminary results suggest that Maumee River Lake Whitefish reside in the central and eastern basins of Lake Erie during summer (i.e., during thermal stratification) and return to the western basin in fall. Eight percent of the fish released in 2016 were harvested by the commercial fishery within 2 weeks, whereas none of 2015 fish were harvested. Results of this study will increase our knowledge of Lake Whitefish ecology, can inform population assessment models and guide future management decisions.
A Comparison of Size and Age Structured Assessment Models Applied to a Cisco Stock in Thunder Bay, Ontario

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Stock assessment is a critical component of the fisheries management process, involving the calculation of key quantities such as how much harvest a stock can sustain. However, there is still considerable uncertainty in assessment science as to which class of models is appropriate to use under which circumstance. A common class of models used when age data are available are catch-at-age models (CAA), which track cohorts through time. When age data are unavailable, as is often the case in invertebrate fisheries where the lack of a bony structure such as otoliths makes aging difficult, catch-at-size (CAS) models can be employed, tracking fish or invertebrates through time by size classes rather than ages. Do CAA models actually perform better than CAS models when age data are available, or is this just an assumption we make in fisheries research and management? We examined this question as it relates to a specific case study by evaluating the effectiveness of both CAA and CAS models in characterizing Cisco population dynamics in Thunder Bay, Ontario. Both models were fit using an integrated framework utilizing multiple sources of data including hydroacoustic estimates of spawning stock, commercial and fishery independent age/length compositions, and harvest data.
Can Recruitment Rates of Contemporary Cisco Stocks Support Historical Levels of Yield in Lake Superior?

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Historically, the cisco (Coregonus artedi) was the predominant prey of most fish predators and target of commercial fisheries in Lake Superior. Annual yield averaged 5.4-million kg/year during 1912–1962, but declined steadily thereafter as spawning stocks were overfished. Stock size remained low until age-1 recruitment and resulting stock density increased during the early 1980s. For the last 25 years, sporadic recruitment, along with great longevity (25+ years), has been interpreted as similar to historical conditions. We developed stochastic, age-structured simulation models based on the Ricker stock-recruit function to address the following questions: (1) can cisco stocks that exhibit sporadic recruitment and 25-year longevity support historical levels of yield in Lake Superior, or (2) was historical yield sustained by higher adult density and more frequent recruitment than is observed today? In all four geographic modeling units, calibrated stock-recruit functions produced substantially larger estimates of peak recruitment (Rmax) and spawning stock sizes required to produce peak recruitment (Smax) for historical stocks. Calibrated process error terms (Ɛ) were substantially larger for contemporary stocks. Our results suggest that: (1) cisco stocks that exhibit sporadic recruitment and 25-year longevity cannot support historical levels of yield in Lake Superior, and (2) historical yield was sustained by higher adult density and more frequent recruitment than is observed today.
A Permafrost Thaw Slump’s Effect on Selawik River Inconnu Recruitment

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In summer of 2004, a retrogressive permafrost thaw slump (slump) began dumping sediment into the Selawik River in northwest Alaska. Its location above the spawning area of one of two Inconnu populations (*Stenodus leucichthys*) that share rearing and overwintering habitat in Selawik Lake, Hotham Inlet and Kotzebue Sound which was cause for concern for local subsistence users and fisheries managers. The subsequent erosion and redeposition of material from the slump has deposited more than 365,000 m$^3$ of sediment into the river, and the silt plume could be seen over 145 km downstream. The spawning area only 40 km downstream was threatened by heavy sedimentation. An age structure study to explore the effects of the slump using otolith aging began in 2011. The first recruits from the 2004 spawning event wouldn’t return until the age-9. Age structure data has revealed an interesting population dynamic not only in the Selawik River population, but also in its sister population of Inconnu in the Kobuk River that is being used as an experimental control.
Development of a Collaborative Beach-seine Based Recruitment Index for Lake Whitefish *Coregonus clupeaformis* in Shoreline Nursery Habitats of the Great Lakes

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Lake Whitefish *Coregonus clupeaformis* stocks in the upper Great Lakes are intensively managed for commercial harvest and have declined in Lakes Huron and Michigan over the last decade largely in the response to poor recruitment. Annual recruitment for a given stock is highly variable and may be influenced by physical and biological processes of shoreline nursery environments. In 2013, several agencies collaboratively initiated a relatively inexpensive, low effort, standardized beach seining survey with the goals of 1) indexing the abundance juvenile (25-55mm) whitefish in shoreline areas and 2) documenting physical characteristics that may explain recruitment trends. As of 2017, the survey is standardized, coordinated, and conducted at over 51 sites across Lakes Michigan, Huron, and Superior by Tribal, state, provincial, and federal agencies and a university. Through this growing collaborative effort, we have observed substantial interannual variability in juvenile whitefish abundance, growth, and timing however, sites in close geographic proximity appear to exhibit similar interannual trends. Preliminary analyses reveal broad regional trends that may be associated with general climatic patterns. This survey produced one of the most comprehensive datasets of shoreline fish community structure in the Great Lakes basin and may provide a valuable predictive tool for whitefish stock assessment.
Stock Monitoring Tools for Commercial Vendace (*Coregonus albula* (L.)) Fisheries Management Decision Makers

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The vendace stock of Lake Konnevesi, Finland, has been monitored since 1970s with CPUE, catch age distribution and fish growth. More recently, density of newly hatched larvae and echo sounding estimate of pelagic fish density have been recorded. The time series were assessed for their ability to bear information useful for management decision makers regarding stock status, short term predictions and harvest control rules. The between-time-series correlation and method-specific precision and accuracy were assessed. The problem of temporal representativeness of the series due to methodological changes and persistently developing fishing methods were tackled. The decision makers tested the information sources in a simulation exercise. Annual data on CPUE of seining and trawling, of catch age distribution and fish growth were considered minimum requirements for understanding stock fluctuation and for forecasting. These data are heuristically simple and low cost. The density of newly hatched larvae bears valuable stakeholder-independent information about the potential for future recruitment and previous autumn spawning biomass but its interpretation is less univocal and the data are costly. The echo sounding estimate of pelagic fish density as a proxy for vendace density suffers from low and variable precision due to overlapping size distribution of the fluctuating smelt population.
Long Term and Targeted Surveys Inform Lake Ontario Cisco Dynamics

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Cisco *Coregonus artedi* were likely the dominant native pelagic prey fish in Lake Ontario however their current abundance has been greatly reduced. We use long-term observations from bottom trawl and gill net surveys to describe Lake Ontario Cisco population and spatial dynamics from 1970s to the present and a recent targeted survey to estimate density and year class variability. Despite sampling different lake areas bottom trawl and gill net surveys were generally concordant and suggested Cisco abundance has been low since the beginning of the time series in the 1970s. Both time series illustrated an increase in the late 1980’s - early 1990’s and a similar increase more recently (since 2015). A targeted acoustic and midwater trawl survey in 2016 estimated Lake Ontario Cisco density ranged from 25-51 fish/ha in eastern Lake Ontario. Age interpretations from sectioned Cisco otoliths suggests the current population is comprised of relatively few year classes. Long term and targeted surveys illustrated the eastern portion of Lake Ontario to be critical habitat for the remaining Cisco population. Density estimates provide context for how current densities relate to other systems and set baselines for ongoing rehabilitation efforts.
Cisco Population Characteristics in Wisconsin Lakes

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Because of their dual roles as planktivores and as prey, cisco *Coregonus artedi* represent an important coolwater fish species in many northern Wisconsin lakes. Cisco are sensitive to changes in oxy-thermal habitat and projected changes in climate and continued landscape-level perturbations will likely affect the demographics and dynamics of cisco population in the future. However, little is known about the population characteristics of cisco because standard annual fishery surveys are not designed to sample these fish. Our objectives were to determine if growth and population demographics of cisco varied among Wisconsin lakes in relation to a suite of abiotic and biotic variables. Our analyses relied on cisco information (including otolith-based age estimates) obtained during vertical gill-net surveys conducted by WDNR personnel across the state of Wisconsin during the summers of 2013 and 2014. Our initial analyses incorporating data from 23 lakes indicates growth rates and average maximum total length (TL) are inversely related to relative abundance of cisco and that relative abundance and mean TL may be related to variables such as latitude and longitude. Additional lakes will be added to our assessment and we will present a more comprehensive analysis of these relationships.
A Summary of Mobile, Vertical Hydroacoustic Assessment of the Bonneville Cisco Prosopium gemmifer Population in Bear Lake, Utah/Idaho, USA 1989-2016

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The first population estimates of Bonneville Cisco (Prosopium gemmifer) in Bear Lake were made using dual-beam hydroacoustic equipment beginning in 1989. These assessments continued annually through 1995. From 1996-2016, annual surveys continued, but split beam hydroacoustic equipment was used. The annual population estimates have been compiled into a long-term data set, which allows the Utah Division of Wildlife Resources to monitor population changes. These data also allows for comparison of the population to be made to lake water levels, predator stocking, and/or other management changes. The data also show some promise in being able to track stronger year classes of Bonneville Cisco in some of the years. Bonneville Cisco numbers were relatively stable from 1989-1999 and averaged approximately 3-4 million fish. In 2000, their numbers increased, and although more variable, they stabilized at approximately 7-8 million fish from 2000-2016. During this same time the stocking of yearling Cutthroat Trout (Oncorhynchus clarki) was reduced almost 50 percent. It appears the Bonneville Cisco population fluctuations may be correlated with the number of stocked of juvenile Bonneville Cutthroat Trout. The Bonneville Cisco population does not appear to be correlated with water levels.
Can Lake Whitefish Abundance be Estimated with a Hydroacoustic Survey?

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Great Lakes Lake Whitefish (*Coregonus clupeaformis*) support commercial fisheries valued at $17 million. Statistical-catch-at-age models are used to estimate abundance and set harvest, but managers have recommended that a fishery-independent survey approach be developed to ground truth fishery-based estimates. During the summer of 2015, we conducted a depth-stratified (<40 m, 40-80 m, >80 m), randomized nighttime survey at 25 sites in the Apostle Islands region of Lake Superior with effort optimally allocated for Lake Whitefish. Fish densities were estimated with hydroacoustic methods, while midwater trawls, bottom trawls, suspended and bottom set gill nets were used to assign the acoustic targets. Fish catches across capture gears were pooled by stratum and used to develop classification and regression tree (CART) models which we used to apportion acoustic targets to species based on predicted length, latitude/longitude, distance off bottom and depth of capture. Lake Whitefish were the dominant large-bodied fish species residing within 10 m of the lakebed at 20-40 m depths at night. We estimated lake whitefish abundance at 2.8 million fish equivalent to 21/ha in the < 40 m stratum. The hydroacoustic survey provided reasonable estimates of abundance in an area containing a mixed species assemblage and shows promise for other Lake Whitefish populations in the Great Lakes.
Commercial Fishing of Coregonids in the Russian Part of the Gulf of Finland, Baltic Sea

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Coregonids in the eastern Gulf of Finland of the Baltic Sea are represented by two species: common whitefish Coregonus lavaretus (L.) and vendace Coregonus albula (L.). Their total commercial catch in alongshore catch is small making up 1.6% of total catch. Over a 85-year period of fishing statistics the greatest whitefish catches were reported in 1937-1939 (max. 76 t), 1950-1956 (max. 97 t.), 1972 (32 t.) and 1983 (27 t). In the past 6 years whitefish catches were about 10 t. Variations in vendace catches were higher than those in whitefish catches: from 2006 onwards catches stabilized at a low level of about 11 t, while maximum catches were reported in the 1950s (max. 1017 t) and in the early 1970s (max. 125 t). In 2016, the largest quantities of whitefish (51%) were caught along the north coast of the Gulf of Finland (including Vyborg Bay) and in the easternmost portion of the bay adjoining to St.Petersburg (45%). Less than 4% of total whitefish catch were caught along the south shore of the gulf, including Narva Bay, Luga Bay and Koporskaya Bay. Vendace fishing areas are restricted to the easternmost parts of the Gulf of Finland, while in other parts of the gulf this species is not practically mentioned in commercial fishing statistics. The greatest whitefish catches are in the pre-spawning concentration period (September-October), when almost 60% of annual whitefish and over 80% of vendace catches are reported. On the average, about 70% of the whitefish in the gulf were caught by a gill net (nets with a mesh size of 45 to 60 mm) and 30% were caught by trap nets of varied design (weirs, fyke nets and fixed nets). Trap nets play the leading role in vendace fishing. Over 90% of vendace are caught using trap nets and 10% are caught with small-mesh nets.
Mass Chemical Marking of Cisco (Coregonus artedii) using Calein

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Efforts are underway to restore Cisco (Coregonus artedii) to Lake Ontario. Currently the Northeast Fishery Center (USFWS) and Tunison Laboratory of Aquatic Science (USGS) are rearing Cisco that will subsequently be stocked in Lake Ontario for this purpose. An essential component for evaluating the success of this stocking effort is ability to differentiate wild stocks from hatchery fish. Chemical mass marking of hatchery fish with calcein is one tool that is both effective and minimally invasive. Calcein is a fluorochrome dye that chemically binds with calcium phosphate found in bony fish tissue resulting in non-lethally detectable fluorescent marks when viewed at proper light wavelengths. We immersed Cisco fry (mean 0.3g) in a 1.5% NaCl solution for 4 minutes and then immediately into a bath of 0.5% calcein solution for 4 minutes as a method of chemical mass marking. The 1.5% NaCl immersion aided calcein uptake by establishing osmotic pressure differential. To determine marking success a small subset of fish were examined for calcein uptake. We experienced only a slight short term increase in mortality post marking, and fish assessed displayed calcein chemical marks upon evaluation. This suggests that this technique is both an effective and minimally lethal method for differentiating wild and stocked fish. Fish will also periodically be examined until stocking for mark retention as a continuation of assessing the effectiveness of this method.
Forty Years of Changes in Wisconsin’s Bloater Chub (*Coregonus hoyi*) Fishery in Lake Michigan

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Bloater chubs (*Coregonus hoyi*) are an important commercial fish species in Lake Michigan that has exhibited large fluctuations over the last 50 years. Recently, the commercial harvest of chubs has dramatically declined to an all-time low of 54,514 pounds in 2015, down from a peak of 2,094,397 pounds in 1997. Here, we use Wisconsin Department of Natural Resources (WDNR) bloater chub assessments to assess spatial and temporal dynamics of bloater chub catch-per-unit-effort, age and growth, and other population demographics from 1975 until present. Bloater chub assessments are conducted in the fall using graded mesh gill nets, which consist of 1,300 ft. net per box with 100’ panels of 1.5, 1.75, and 2 inch mesh, 200’ panel of 2.25 inch, 300’ of 2.5 inch, 200’ of 2.75 inch and 300’ of 3 inch net, fished in a commercial set. We discuss these results in the context of recent ecosystem changes in Lake Michigan and efforts by the WDNR to institute a rule change to make harvest limits responsive to increases or decreases in bloater chub abundance determined through fishery-independent surveys.
Assessment of Whitefish Reproduction Success by an in Situ Fish Egg Incubation Method in Catchments Receiving Multi-metal Mining Effluents

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Fertilized eggs of whitefish (Coregonus lavaretus) were incubated from November to April in a boreal lake and six streams having received effluents from an open-pit multi-metal mine. The mine uses a bioheapleaching technology of low-grade ore in which metals are extracted by bacterial activity. The mining effluents have caused salting and metal contamination in the downstream waterways. In the lake, salt-stratified by the mining effluents, whitefish eggs were incubated in floating containers in 1 m depth above the lake salting halocline, and 1 meter above the lake bottom. In the streams, eggs were incubated in cylinders on the bottom. Egg survival related to water quality on the sites was investigated. The purpose was to evaluate the in situ method usability for assessment of fish reproduction success in stressed lake and riverine environments. The salting anomaly causing high specific conductivity, and enhanced concentrations of sulfate and a mixture of metals, clearly decreased the whitefish egg survival in the lake epilimnion and especially in the hypolimnion. In the streams, no similar connections were observed although conductivity peaked above 1 300 µS/cm. Both the lake and the stream incubation methods proved technically applicable for water quality assessment.
Preference and Diversity of Stomach Contents and Growth Rate of Vendace (Coregonus Albula) in the North District Lakes of Poland

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Vendace (Coregonus albula L., 1758) belongs to family Salmonidae. This fish prefers cold and oxygenated waters. Thus it occurs only in deep lakes with oxygenated hypolimnion which are called vendace lakes. Siecino and Miedwie belongs to those lakes and in the period of time 2009 and 2015 vendace was taken from those spots for research. It was determined that the analyzed fish were aged 3+, 4+ and 5+ years on the basis of otoliths and up to 3+ using scales. The underestimation of vendace age on the basis of scales may be the cause for erroneous decisions taken in determining the age and the seasons for protecting spawning fish. The analysis of stomach contents was conducted by two methods: the frequency of distribution method and the percentage by weight method. Our indicated that research bigger biodiversity in stomachs of vendace from Siecino Lake was observed. In this group of stomachs taxons were observed e.g. Colonaidae and Cyclopoidae. However, vendace stomachs from Miedwie Lake contained only 17 taxons e.g Cyclopoidae. The above research contribute to the recognition of trophic levels and to the estimation of vendace pressure on zooplankton.
The Effect of Static and Diminishing Diet Regimes on Growth and Survival of Cisco (Coregonus artedi) Fry in a Culture Setting

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The Cisco (Coregonus artedi) is a native species that holds a paramount importance both ecologically and economically in the Great Lakes Region. After the collapse of Alewives (Alosa psuedoharengus) in Lake Huron, there is now an opportunity to rehabilitate Cisco populations that were depleted via overharvest, habitat destruction, and aquatic invasions. However, little is known about raising the species in a hatchery environment. The purpose of this study was to determine which of the two diet regimes, static or diminishing, would result in a better growth rate, condition, feeding efficiency, and survival of Cisco during the fry stage. Five replicates of each diet regime were maintained for three weeks post-yolk absorption. T-tests were used to determine if each performance variable differed between diet regimes. There were no significant differences between growth, condition or feeding efficiency. However, survival was higher for Cisco fed the diminishing diet, likely due to decreasing water quality of the static feeding group over time. Longer term feeding trials are recommended to help further understand which feeding regime would be best for rearing Cisco.
Seasonality in Macroparasite infection in two Coregonid species

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Seasonal variation in prevalence and intensity of infection by the ectoparasite crustacean Salmincola sp. and the cestodes Diphyllobothrium spp. and Trienophorus crassus were recorded in vendace (Coregonus albula) and whitefish (C. lavaretus) in Lake Mjøsa. Maximum prevalence and intensity of Salmincola was in late summer and autumn. The parasitic copepods were attached to fin bases as well as gills. In whitefish, 48% were attached to gills, 36% to the pectoral fins, 29% to the pelvic fin. In vendace, 6% were attached to the gills, while 56% were attached to the pectoral, and 38% to the pelvic fins. Salmincola prevalence increased with age in both fish species, up to the oldest age group, 7 yrs in vendace, and in the long-lived whitefish to a maximum at 8 yrs. In both vendace and whitefish, the prevalence of Diphyllobothrium spp. varied without any seasonal pattern, while intensity was fairly equal and stable. Prevalence of T. crassus was very high in whitefish, between 81 and 100%, with no seasonal pattern in the variation. T. crassus was not recorded in vendace by our simplified index method. The infection patterns are discussed in light of host as well as parasite ecology.
Historical Habitat Use and Assessment of Spawning Locations of Coregonines in the Great Lakes and Connecting Channels

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Identifying historical and contemporary spawning locations is a key priority for developing Great Lake’s coregonine restoration goals and objectives. Habitats occupied by 11 species of coregonines (e.g., seven deepwater cisco forms, cisco, lake whitefish, round whitefish, pygmy whitefish) were identified from agency reports, historical publications, online resources, and interviews from commercial fishermen. Using this information, we constructed an updated spatial distribution map of known and potential coregonine spawning locations using a geographic information system. Verification of spawning activity at many of these sites was made by sampling for adults, eggs, and larvae in 2017. By reviewing and analyzing historical distributions of coregonines and overlaying the data with contemporary distributions, we developed a temporal comparison of spawning locations that can be used as a tool for conservation in the Great Lakes region.
Identifying Overwintering Habitat for Whitefishes in Arctic lagoons using Remote Sensing

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The Arctic coast provides critical overwintering habitat for whitefish populations, which in turn sustain vital subsistence fisheries for many northern communities. Over one-third of Alaska’s Arctic coastline is comprised of lagoons and barrier island ecosystems; nevertheless, very little is known about the overwintering habitat of whitefishes in these habitats. To better understand this critical habitat, we are using Synthetic Aperture Radar (SAR) remote sensing techniques to understand availability and persistence of overwintering lagoon habitat by examining a time series of historical and current data, locating areas that consistently have liquid water. To groundtruth the remote sensing techniques, field studies are assessing the accuracy of SAR imagery for identifying liquid water in brackish lagoon habitats. This information will further our understanding of the winter distribution of overwintering habitat for whitefishes across the Arctic coast and the potential impacts of climate change on overwintering habitat. This may enhance management of whitefish habitat that support subsistence fisheries and the food security of Alaska Native communities.
Morphological and Enzymatic Changes in the Digestive Tract of Whitefish (*Coregonus lavaretus*) Related to an Experimental Nutritional Program

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An experimental feeding was carried out for 5 weeks on whitefish larvae in the Naterki (Poland) fish farm, during which a commercial feed (Otohime) was introduced at different times after hatching. There were four experimental groups: with commercial feed started in the second week of life (group C), with commercial feed started in the third week (group B), and group A and D that were fed only with *Artemia* or commercial feed respectively during the whole the experiment. After 5 weeks, fish were sacrificed and preserved for histological and enzymatic analysis. On the last day of the experiment, fish from the B group had the highest body mass and length. Histological analysis of the digestive tract revealed that the hepatocyte nuclear volumes were significantly different among the feeding groups. Fish from the group C had the highest hepatocytes nuclear volumes ($p<0.05$). The highest hepatocyte proliferation index was observed in groups A and B, but enzymatic analysis of digestive enzymes proved that group C had the best activity. The results of histological and enzymatic analyses indicated that the time of introduction of commercial feed to larvae rearing is a significant factor for the proper morphology and functioning of the digestive tract of whitefish.
Evidence for Alteration of Spawning Location in Inconnu (*Stenodus leucichthys*) in Response to Siltation Caused by Thawing Permafrost

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In the spring of 2004 a retrogressive permafrost thaw slump began depositing large quantities of sediment into the Selawik River in northwest Alaska, about 40 km above the Inconnu (*Stenodus leucichthys*) spawning area. High silt concentrations gave the normally tannic stained water the appearance of a turbid glacial river. In 2006, anecdotal reports by sport hunters on the Tagagawik River, a tributary of the Selawik River, questioned the perception that the Kobuk and Selawik river Inconnu spawning populations were the only two in the Kotzebue Sound region. Local elders, who lived a nomadic life in their youth, did not know of Inconnu spawning in the Tagagawik River. In response to this information the U.S. Fish and Wildlife Service launched a radio telemetry study in 2007 implanting 30 radio transmitters with a 5 year lifespan to record movement and spawning frequency. Later in the fall of 2007 concentrations of the tagged fish were found in the Tagagawik near the southern border of the Selawik NWR, and in subsequent years some returned to spawn in the Selawik River, but not the Tagagawik River.
Geographical and Temporal Variation in the Diet of European whitefish (*Coregonus lavaretus L. sensu lato*) in the Gulf of Bothnia and Gulf of Finland.

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The aim of the study is to describe the differences in the diet composition of the European whitefish populations of the Baltic Sea. We investigated whether there are detectable regional and temporal differences between the structure of diet composition of whitefish from Bothnia bay and Gulf of Finland. The food composition of all together 1100 whitefish from the Bothnian Bay (Hailuoto and Bergö in Vasa), and from the Archipelago Sea (Jurmo in Åland) has been investigated seasonally during the year 1974-1975. Additionally whitefish from the Archipelago region were studied. 63 fish came from Boxö (Åland) in 1964, 69 fish came from Kustavi (Uusikaupunki) 1980 and 400 fish were collected from Åland region 2013-2014. 170 whitefish from Hogland area (Gulf of Finland) and 200 whitefish from Estonian coast were also sampled during 2000-s. The stomach content was examined by frequency of occurrence, the numerical method and the degree of fullness.
Spatio-temporal Pelagic Distribution and Mortality of Maraena Whitefish \((Coregonus maraena)\) Early Juveniles in a Newly Created Oligotrophic Lake

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Diel vertical distribution of strictly pelagic juvenile (23-47 mm total length) maraena whitefish \(Coregonus maraena\) (Bloch, 1779) was repeatedly investigated in spring primarily using hydroacoustics in the artificial post-mining Most Lake in the Czech Republic. At the same time, an ichthyoplankton trawl was used to identify acoustical targets. During the day, fish performed extensive shoaling behaviour in depths between 2 and approximately 40 meters and were not accessible for trawling. By evening, with decreasing light intensity, shoals started to disintegrate and at night fish were relatively homogeneously distributed in the water column from the surface down to a depth of 40 m. Juvenile maraena whitefish could be caught by trawl as the only fish species at night. Shoaling behaviour started again approximately 1.5 hour before sunrise. The data showed steep decreases in fish density between the two surveys in spring which indicates significant mortality of early juvenile coregonids as a result of poor availability of zooplankton in a highly oligotrophic post-mining lake.
Parallel Ecomorphological Divergence Drives Differential Mercury Bioaccumulation in Polymorphic Whitefish (*Coregonus Lavaretus*) Populations of Subarctic Lakes

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Resource polymorphism is common in coregonids, but the effects of specialization to total mercury concentrations (THg) remains unexplored. We compared of whitefish (*Coregonus lavaretus*) THg and their invertebrate prey in relation to ecological metrics across six subarctic lakes inhabited by polymorphic and monomorphic populations. Amongst invertebrate prey, highest THg were observed in profundal macroinvertebrates, followed by pelagic zooplankton, with concentrations lowest in littoral macroinvertebrates. Parallel patterns were apparent in polymorphic systems, where average THg and bioaccumulation rates were highest in pelagic, intermediate in profundal and lowest in littoral morph. In monomorphic systems, THg were generally lower, and showed pronounced lake-specific variation. In the polymorphic systems, we found significant relationships between whitefish muscle THg and gill raker count, resource use, lipid content, growth and maximum length, whilst no such relationships were apparent in the monomorphic systems. Across all polymorphic lakes, the major variables explaining THg in whitefish were gill raker count and age, whereas in monomorphic systems, the factors were more lake-specific. In compound analyses of polymorphic and monomorphic lakes, a total of 71% and 39% of the observed variance was explained by the examined variables. Results highlight the importance of recognizing intraspecific diversity in future studies and mercury monitoring.
Age and Growth of Blackfin Cisco in Relict Populations: From Data Deficient to Data Rich

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Blackfin Cisco (Coregonus nigripinnis), a species endemic to the Laurentian Great Lakes region, was driven to extinction by introduced species and overfishing in the early twentieth century. They are currently ranked extinct on the IUCN Red List. Blackfin Cisco were discovered in four lakes during fish community surveys conducted in Algonquin Park, Ontario, Canada. The lakes are situated in a historic drainage outflow of glacial Lake Algonquin. Life history including age, growth and survival will be examined from sectioned sagittal otoliths and used in a biphasic Von Bertalanffy growth model. Preliminary analysis indicates that Blackfin Cisco reach maximum ages of 18-28 years – an age much older than the congener C. artedi. Findings from this research are important since very little is known about Blackfin Cisco life history.
Changes in Lake Whitefish (*Coregonus clupeaformis*) Maturity Schedules from 1976-2013 in the Upper Great Lakes

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Maturation schedules often vary within a given fish species, between individuals, and among different stocks within a population. These variations in maturation schedules can usually be linked to plastic or adaptive responses as a result of changes within the environment or population size. We evaluated, using fishery independent and fishery dependent biological data, the changes in Lake Whitefish maturity schedules in the U.S. waters of lakes Huron, Michigan, and Superior from 1976 to 2013 to better understand how maturity schedules have changed over time and inform the future management of the Lake Whitefish fishery. Lake Whitefish population maturation schedules varied between sexes, temporally and spatially among populations in all three lakes. Females generally matured at older ages and longer lengths (5.0 years-old and 439 mm) than males (4.6 years-old and 419 mm). Additionally, the L50 for both sexes declined significantly in lakes Huron and Michigan after 1990, and both sexes in Lake Superior matured at larger lengths (F= 458 mm, M= 447 mm) for given ages. These findings reflect the plasticity of maturation schedules that lake whitefish possess, which are influenced by ecological changes in the food web and the magnitude of Lake Whitefish abundance.
Analyses of Growth Layers of Otoliths in the Experimental Groups of Young Coregonid Fishes from Lake Baikal and Use of Their Characteristics for the Estimation of Ontogenetic Effects

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We studied the microstructure of the otoliths in coregonid fishes from Lake Baikal that formed at the embryonic, larval, fry, and juveniles stages. Two types of omul and lacustrine whitefish hybrids, female omul + male whitefish and male omul + female whitefish, were reared under the experimental conditions of the freshwater aquarium complex. At the initial stage, the hybrids were kept in stationary conditions, in aquaria inside cold chambers, and at a water temperature of 2-5°C (embryonic stage) and 8°C (larval stage) and were fed with dry food. At the fry stage, the hybrids were divided into three subgroups. One subgroup remained in the freshwater aquarium complex. The other two subgroups were transferred to the open private pool and the fish hatchery with the conditions close to natural. The study was aimed at the analysis of otolith growth relative to the habitat conditions, and a possible identification of the most viable hybrid type by tracing the quality of otolith growth and linear growth. In parallel, the data on the hatching and death of specimen were tracked. At the larval stage, all three subgroups had almost the same otolith growth alternating with the same frequency. The main differences in growth were detected at the fry and juveniles stages. At these stages, the subgroups reared in the open pool showed the growth intensification. The otoliths of the hybrids reared in these conditions were twice larger than those reared at the same time in the conditions of the freshwater aquarium complex. In all subgroups during summer, opaque growth dominated despite the growth intensification. Probably, the deep mechanisms associated with the metabolism in a certain season are invariable. Therefore, the description of the growth periods in coregonid fishes attributed to the certain time intervals should not be based on the sizes, but should be determined by a pattern, i.e. a specific bar code. This tentative conclusion considerably complicates the final result of the evaluation of age patterns formed by the growths and requires further comparisons with those formed in the native coregonid fishes.
Specific Characteristics of the Oxygen Transport System in Native and Reared Baikal Whitefish

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Habitat conditions of whitefish reared and kept under artificial conditions affected physiological needs and the structures participating in oxygen transfer. Cytometric erythrocyte parameters in omul, whitefish, pidschian, peled, and hybrids (omul × pidschian, omul × lacustrine whitefish, pidschian × lacustrine whitefish, and omul × peled) of different crosses reared under artificial condition, on the one hand, and in native forms on the other hand were statistically lower. Intra-specific variability of cytometric parameters were determined genetically and associated with environmental conditions. Electrophoresis and isoelectric focusing performed under special conditions did not reveal differences in a number of protein components of hemoglobin in the fish under study. Their composition, however, differed. All forms possessed anode fractions, whereas native forms had anode and cathode fractions. This attested to a different level of oxygen affinity. The results obtained showed that the mechanism of oxygen transfer in the fish inhabiting the natural environment was characterized by higher values of metabolism than in fish reared artificially. This work was performed at the Baikal Joint Instrumentation Centre and in the Unique Scientific Installation “Experimental freshwater complex of Baikal aquatic organisms” with the support of the State Project VI.50.1.4 (№0345-2016-0002).
Coregonus lavaretus Pidschian (Coregonidae) from the Anabar River: Morphology, Biology, and Genetic

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Data on morphology, biology and genetic of two ecological forms/species of the pidschian-like whitefishes, C. lavaretus pidschian natio brachymystax and C. lavaretus pidschian natio glacialis, from the Anabar River (the Laptev Sea basin) are presented. Differences on the main meristic traits between these ecological forms were not found, but they are clear distinguished on body traits, growth rate and ecology. Both whitefish forms are benthoeuryphagous. They consumed Mollusca (Bivalvia and Gastropoda), Isopoda, Gammarus. Additionally, C. lavaretus pidschian natio brachymystax feed on juvenile of fishes. Some differences between these ecological forms has revealed based on the genetic analysis at the level of mtDNA and allozymes. Probably, C. lavaretus pidschian natio brachymystax has common origin with the whitefishes from the downstream of the Ob River and Lake Teletskoye and are characterized by same structure of the gene of ND1 of the mitochondrial DNA. We believe there were some refugia for whitefishes in the upstream of the Ob River during last glaciation. It was shown that the whitefishes from the Anabar River exhibit the similarity with the whitefish populations from water bodies situated the Taimyr Peninsula.
Great Bear Lake (NT, Canada) and its Unique Opportunities for Intraspecific Diversification: Multiple Morphs of Lake Whitefish

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Great Bear Lake is the most northerly lake of its size and provides unique opportunities for intraspecific diversification, as it supports unusually high degrees of diversity within several species. Four shallow-water morphotypes of Lake Trout and up to four shallow- and deep-water morphs of Ciscoes have been described in Great Bear Lake in the past ten years. More recently, a similar level of intraspecific diversity has been observed in Lake Whitefish. Here, we document and quantify the extensive Lake Whitefish diversity in Great Bear Lake and compare and contrast the patterns of divergence among morphs. We combine analyses of classical morphometric and traditional linear measures with shape analysis (geometric morphometrics) to quantify differences in body and head shape, and fin and body lengths among four Lake Whitefish morphs. Polymorphism contributes significantly to biodiversity in northern freshwater fish, however, the extent and mechanism(s) of intra-specific diversification in large northern lakes remain largely unknown.
Genetic Limitations to Cisco Recovery in Lake Ontario

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Cisco *Coregonus artedi* are an important prey fish for many Great Lakes predators, including lake trout *Salvelinus namaycush*. Their numbers have declined in the last century due to overfishing, habitat degradation, and invasive species. Chaumont Bay, New York and the Bay of Quinte, Ontario contain the last two known spawning stocks of cisco in Lake Ontario. Our current project aims to assess the genetic diversity of the remnant spawning population in order to test for genetic bottleneck effects following historical population size reductions, determine the wild effective population size, compare the genetic status of the Chaumont and Quinte stocks, and identify potential cases of hybridization with lake whitefish *Coregonus clupeaformis*. Results from this project will give managers a better understanding of the population structure of the Lake Ontario stock, assist with future management decisions, and provide guidance for hatchery-based population supplementation efforts.
Differentiation in Translocated Populations of Lake Superior Cisco *Coregonus artedi* Introduced into Small, Inland Lakes

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Historical introductions of *Coregonus artedi* from Lake Superior into several inland lakes in Minnesota constitute a natural experiment to investigate how phenotypic plasticity and genetic adaptation can shape cisco diversity. The lakes were stocked with fry, hatched from cisco eggs captured in Lake Superior commercial nets during fall spawning periods in the 1920s and 1930s. Cisco were considered absent from the lakes at the time of introduction. Morphological traits and genetic structure of the introduced populations were compared to contemporary Lake Superior cisco to provide insight into the relative roles of phenotypic plasticity and genetic adaptation for shaping this inherently plastic taxon. The information should prove useful for fisheries managers considering re-establishment of depleted or lost cisco forms in the Laurentian Great Lakes. Morphological and genetic changes since introduction into the new environment should provide insight into the capacity of cisco to adapt to rapidly changing environments (the concept of “evolutionary rescue”) driven by climate change and eutrophication.
Gene Expression Analysis of Cisco (*Coregonus artedi*) Eggs and Larvae Reared in Varying Light Treatments

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Climate change is expected to increase winter temperatures and reduce ice and snow cover on lakes. Such changes could impact the development and hatch time for fish species that incubate over winter, such as cisco (*Coregonus artedi*). Warmer winter temperatures are expected to result in earlier hatch dates, but impacts of an increased light environment through reduced ice/snow cover remain unclear. To test if changes in the light environment could influence cisco egg and larval development, we are currently conducting a pilot experiment started in December 2016. Fertilized eggs were exposed to three light treatments: continuous light, regular photoperiod, continuous dark. To understand how these conditions may impact cisco development we plan to sequence the transcriptomes of individuals from each treatment group during pre-hatch, hatch, and post-hatch periods. Various programs will aid in sequence data analysis, including Trinity for de novo transcriptome assembly. We will compare the cisco assembly to the zebrafish (Danio rerio) and Atlantic salmon (Salmo salar) reference genomes. Differential gene expression (DE) between the treatments will be estimated using DESeq2 and gene ontology (GO) will help to identify the function of the DE genes to yield insights to the physiological and developmental impacts of changing ice coverage.
Diversity and Evolution of Blackfin Cisco (*Coregonus nigripinnis*) in a Postglacial Outlet of Lake Algonquin

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The Great Lakes ciscoes diversity arose via repeated local adaptive divergence following postglacial colonization. Much of this diversity has vanished or is threatened. The Blackfin Cisco (*Coregonus nigripinnis*) is extirpated from the Great Lakes and supposedly found only in Lake Nipigon. In 2010, new populations corresponding to Blackfin Cisco were discovered east of Lake Huron in an area invaded by the former proglacial Lake Algonquin. Given this postglacial context, Blackfin Cisco may have colonized this area as a distinct lineage. This scenario challenges current knowledge about their divergence pattern throughout their North American range. In 2016, we sampled over 850 fish from 14 lakes to uncover the evolutionary origin of Blackfin Cisco. We use linear and geometric-morphometric analyses to test for morphological differences between Blackfin Cisco and sympatric or allopatric Cisco (*C. artemi*). We used genetic markers (SNP) to determine patterns of genetic similarity among samples. A distinct genetic cluster comprising Blackfin Cisco from five lakes would support colonization by a pre-existing lineage, whereas local genetic similarity between pairs of Blackfin Cisco and sympatric Cisco would support repeated local origin. A better understanding of Blackfin Cisco origin could inform managers on potential sources for reintroduction in the Great Lakes ecosystem.
Morphometric Comparison of Cisco Ecomorphs from Three Large Lakes

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Cisco communities in north-temperate lakes have evolved to fill a number of trophic niches. Similar cisco species or ecomorphs are found in lakes across a wide geographic range, and there remains considerable debate about the mechanism for observed diversity in most north-temperate fishes. We examined whether the morphologies of putative cisco species (Cisco, Shortjaw Cisco, Kiyi/Big-Eye Cisco, Bloater) were more similar within lakes than they are between lakes by comparing fish from three large, North American lakes; Lake Superior, Lake Nipigon and Great Slave Lake. Ciscos from the three lakes each had distinct morphological signatures. Our results strongly support the hypothesis that the observed patterns of diversity in North American ciscos is caused by parallel sympatric radiation within each lake after initial colonization, as opposed to the diversity within each lake arising solely from founding events by the same genetic sources of allopatrically derived ecomorphs. The observed diversity in cisco ecomorphs in large, post-glacial lakes appear unique, and as such require special conservation consideration.
Late Quaternary Freshwater Refugia in European Russia, as Shown by the Genetic Study of the Fish of the Families Coregonidae, Salmonidae, Thymallidae and Osmeridae

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The history of colonizing water bodies in European Russia and adjacent territories by northern fish species is inseparably connected with Late Pleistocene glaciation events. During this period of time some species were first isolated in periglacial refugia, where some of them display intense form forming processes and after glacial retreat spread east-west and north-south along newly-formed hydrological connections. The goal of the present study is to analyze scientific publications on the genetic differentiation of the fish of the families Coregonidae, Salmonidae, Thymallidae, Osmeridae in European Russia water bodies. The fish species studied were as follows: Coregonus albula, C. autumnalis, C. lavaretus complex, C. nasus, C. peled, C. sardinella, Stenodus leucichthys, Huho taimen, Salmo salar, S. trutta, Thymallus arcticus, Th. thymallus, Salvelinus alpinus, Osmerus eperlanus and O. mordax. These species collectively make up about 1/2 of fish fauna in the water bodies of North European Russia. They differ substantially in modern areas and display a variety of life strategies. The idea of the study conducted is to reveal a general intraspecific genetic differentiation pattern associated with Late Pleistocene-Holocene events. The genetic heterogeneity of the widely scattered fish species analyzed is shown to be due to the existence of 2-5 large freshwater refugia in and outside European Russia. An attempt to locate major periglacial refugia by integrated analysis of biogeographic, genetic and paleolimnological data was made, the composition of their fish population was assessed and the ways and time of recolonizing water bodies in European Russia by individual species or their philogenetic lineages were reconstructed.
Genetic Diversity Among Great Lakes Cisco Species: Exploring Taxonomic and Population Boundaries

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Ciscoes (*Coregonus artedi, hoyi, kiyi*, and *zenithicus*) once formed a diverse species flock that was an important part of the Great Lakes food web. Now the deepwater forms of cisco are most abundant in Lake Superior, bloater and cisco are observed in lakes Huron and Michigan, and only cisco are observed in Lake Ontario. Prior to their collapse, there were questions about the taxonomic status and population structure of the species flock that were never completely resolved. Recent changes to the community structure of lakes Michigan and Huron has generated interest in restoring a native fish community to promote healthy ecological function of the food web. Understanding the population structure of current populations is necessary to inform management actions that involved establishment and use of stocking of hatchery fish. To this end, mitochondrial and nuclear DNA diversity was assessed in a collection of contemporary ciscoes from the Great Lakes to determine levels of diversity and population structure of the remaining populations. Microsatellite DNA variation indicated that there were differences among species. There were also differences in levels of observed population structure between bloater and cisco.
Michigan Commercial Fisheries Marketing and Product Development

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The Great Lakes commercial fishery is undergoing a fundamental change that threatens the long term viability of the industry. Loss of traditional markets, foreign competition, changes in regulatory requirements, ecological change, and fishery population dynamics have impacted the marketability and competitiveness of Great Lakes whitefish. In partnership with fishery stakeholders and with fisheries extension enhancement funding from the National Sea Grant Office, Michigan Sea Grant conducted a five year project to assess the Michigan whitefish market, identify and cultivate new markets, enhance consumer awareness and create a "brand identity" for whitefish products.
A Comparison of Adikameg Population Indices Between Two Areas Along the Western Side of the Keweenaw Peninsula, Lake Superior

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Adikameg (*Coregonus clupeaformis*) supports important state and tribal fisheries within the Michigan 1842 Ceded Territory waters of Lake Superior. Fisheries managers have questioned whether the Adikameg population on the western side of the Keweenaw Peninsula (MI-2 and MI-3) is comprised of two spatially discrete stocks or if it is supported by only one stock. The distinction between one or two stocks in MI-2 and MI-3 may have implications regarding modeling efforts and results that could alter adult population size estimates. Preliminary data suggest that Adikameg along the western side of the Keweenaw Peninsula may be part of a single stock in that area. In order to confirm this, population indices including age, length, diet, and movement were compared between MI-2 and MI-3 waters along the western Keweenaw shoreline.
An Approach to Sampling Larval Coregonines in Large Embayments of Lake Huron

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Great Lakes large embayments provide important nursery habitat for numerous ecologically significant species. Sampling larval fish in these embayments can be a challenge due to their large size and uncertainty associated with the timing of peak larval emergence. We employed an approach that explored the feasibility of sampling such embayments in their entirety during periods of presumed peak larval emergence. Study sites were Saginaw Bay (2900sq. km) and Thunder Bay (212sq. km), the two largest embayments in U.S. waters of Lake Huron. Larval coregonines were collected with 2 x 1-m nueston net towed at the surface in waters depths greater than 2m during a two-week period corresponding with presumed peak larval emergence. Random sampling locations were distributed across a broad spatial scale to optimize coverage. Sampling occurred in Thunder Bay (n=20) in 2015 and 2016 (n=35) then expanded to Saginaw Bay (n=79) in 2016. Mean larval density was significantly higher during 2015 in Thunder Bay. No consistent pattern emerged when analyzing the effects of water depth or distance from shore on larval density. Employing a sampling design that encompasses broad spatial and temporal coverage may offer an opportunity to provide meaningful estimates of annual larval production for an embayment.
Vendace Populations’ Genetic Structure in Latvian Lakes: As a Result of Introduction

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The European vendace (*Coregonus albula* (L.)) is a widespread species in the waters of the Holarctic, however in Latvian lakes its share in the fishery is not big, and the catch is insignificant and unstable. At the beginning of the last century, the vendace (*Coregonus albula* (L.)) was introduced from lakes Ladoga (Russia) and Peipus (Estonia) to more than 30 Latvian lakes. Later these species was registered in about ten Latvian lakes in the 60s of the last century. Presently vendace (*Coregonus albula* (L.)) is found in several Latvian lakes and is included in a list of specially protected species with restricted use in Latvia. Intraspecific genetic polymorphism among the nine *Coregonus albula* populations in Latvia was evaluated based on microsatellite analysis. The genetic diversity and divergence patterns among nine vendace populations were analysed in order to reveal: the dispersal pattern and genetic structure in these populations; how the introduction influence allele diversity in studied vendace populations. The genetic differentiation of the studied vendace populations was analysed by combining several approaches. There was revealed that the vendace individuals of the studied populations could be divided into several genetic groups (Bayesian grouping). The indices of genetic distance reflect similar result. We revealed that level of genetic diversity differs among the studied populations. The cause of the differences among the various populations may be the consequences of the introduction and genetic drift, which influence the allele frequencies in different ways. The genetic differentiation of the studied populations can indicate the result of the acclimatization of the imported genotype, i.e. the founder effect; the interaction of the introduced genotypes with the indigenous genotypes etc.
Rebuilding Cisco Stocks in Northern Lake Michigan

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Recent decreases in Alewife *Alosa pseudoharengus* and Rainbow smelt *Osmerus mordax* abundance, along with improving Lake Michigan water quality have allowed Cisco *Coregonus artedi* populations to rebuild. Anecdotal evidence, including increased recreational, Tribal and assessment catch, suggest that Lake Michigan Cisco stocks are expanding both in terms of abundance and range from their current, near historic low, levels. Similarly, the decreasing abundance of pelagic invasive forage species in Lake Michigan has led to increased interest in and opportunities for restoration of native planktivore communities. Adequate assessment of the Lake Michigan Cisco population is needed both to understand the status of the Lake Michigan population as well as to evaluate the efficacy of current and future management efforts. Beginning in 2015, LTBB partnered with the Michigan DNR in a northern Lake Michigan investigation focused on three areas: (1) understanding the life history of Lake Michigan Cisco, (2) quantifying population demographics, and (3) comparing current demographics and life history traits to those of fish collected by Koelz in the 1920s. Increased knowledge of life history, including the connection between morphologic form and ecological function is critical to achieve the goals and objectives set out by the Lake Michigan Native Planktivore Task Group.
Variation in Vital Rates in Coregonidae and the Likelihood of “Black Swan” Events

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Fecundity and age-at-maturity determine the intrinsic rate of increase in animal populations. To persist the intrinsic rate of increase must balance with mortality. We review the intra-specific and inter-specific variation in fecundity, age-at-maturity, age information across the Coregonid family from 88 species. Using life history invariant models we calculate and compare the expected instantaneous natural mortality rate and intrinsic rate of increase among members of the family. Coregonid species and populations vary greatly in the life history traits that contribute to population resilience. We consider the likelihood of improbable events or “black swan” events within the Coregonid family. Black-swan events are important to consider in fisheries assessment as they manifest primarily as population die-offs and crashes rather than unexpected increases.
Mark-recapture Study to Estimate Anadromous Whitefish Larval Production in the River Tornionjoki

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The river Tornionjoki, descending to the Baltic Sea, is the only large river in the Finnish coastal area without dams or any other obstacles for fish migration. It has a viable anadromous whitefish stock, thus being a suitable reference river when the level of natural reproduction of whitefish is studied. In an initial study in May 2016, 250 000 newly hatched whitefish larvae were marked with alizarin red and released into the river. During a period of two weeks larvae were captured with dip net from release site down to river mouth. The origin of larvae was identified with fluorescence microscope. The results indicate that mark-recapture study with alizarin red can be used to estimate the level of natural larvae production which is not well known in the Finnish rivers. The study will be extend in spring 2017 and 2018 when one million newly hatched marked larvae are released in both years to estimate the annual reproduction in the river Tornionjoki. The results can be compared with the concurrent mark-recapture studies conducted in large dammed rivers nearby and used to evaluate the adverse effects of river construction to larval production of whitefish.
Larval Year Class Strength and Spatiotemporal Distribution Patterns of European Whitefish (*Coregonus Lavaretus* L.) in Pre-alpine Austrian Lakes

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Year class strength of newly hatched whitefish larvae were surveyed for seven years at Hallstättersee, and sporadic years in other nearby lakes, all of them pre-alpine lakes with whitefish dominating the fish community. A push-net system was used in combination with high resolution of sampling both in time and space. Alternating years of strong and weak year classes were observed apparently related to winter conditions. During hatching periods of several weeks a peak of densities could be determined for most years and those peaks shifted in time between years by approximately one month reflecting variations in winter temperatures rather than variations in spawning times. Spatial distribution patterns across the lake surface were strongly influenced by preferred spawning areas in the tributary rivers, however, there was considerable variation between years indicating variable usage of spawning areas within the lake. The high annual variability in newly hatched, prae-feeding whitefish larvae point to the egg stage as being crucial in forming a year class rather than food conditions for first feeding larvae.
Many statistical models have been used for allometric growth of fishes. Among these, a power-function model \((W = aL^b)\) has become conventional to describe the weight \((W)\) - length \((L)\) relationship, indicating both individual and cohort fitness. Condition factor is also determined through this power-function, assuming regression coefficient \(b\) is constant \((a = WL^{-b})\). The primary objective of this study, using a total of 4924 Lake Whitefish from a fishery-independent survey in the main basin of Great Slave Lake (GSL), June–August, 2011–2016, is to develop a multimodel inference (MMI) framework to address the appropriateness of log-transformed length and weight model selections. Four candidate models, linear, quadratic, cubic and piecewise are included. Information-based MMI indicated that allometric growth patterns may be biased when arbitrarily selecting a linear model. Although measurements of the morphometric variables and parameter estimates are sensitive or related to fitness of individuals, substantial spatiotemporal variation may influence our ability to interpret the changes in allometric growth of subarctic populations of Lake Whitefish in the oligotrophic GSL. The potential application and associated uncertainties of MMI statistical models for the evaluation of cumulative changes in fish population abundance, hydroclimate environment and exploitation are discussed.
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