Growth variability and mercury tissue concentration in anadromous Arctic charr

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Abstract

The project was designed to build on prior work that examined probable climate change related growth and contaminant impacts on land-locked populations of Arctic Charr by extending the analysis to include important migratory and land-locked populations of Dolly Varden charr in the Yukon Territory. There is a notable lack of data for Dolly Varden charr, despite the importance of the species as a country food resource. Here we plan to use existing archival tissue samples to construct an historical spatial baseline for total mercury (THg) levels in Dolly Varden charr against which contemporary data can be compared to examine the impacts of climate change and development activities on current THg levels. Work will also be extended to include comparative examination of Dolly Varden charr in the Beaufort Sea and a determination of where and how they function in Beaufort Sea foodwebs likely to be affected by oil and gas exploration activities. The project will also continue important partnering work begun with Nunavik Research Centre to examine the marine life-history phase of Ungava Arctic Charr introduced into a previously unoccupied river system. Previously passive integrated transponder (PIT)-tagged fish have begun to return in numbers and we are now able to estimate annualized marine growth and compare that growth to monitored water temperatures as a means of estimating site-specific growth temperature relationships using oxygen stable isotope methods. Results are critical data for assessing the possible impacts of climate change on Nunavik Arctic Charr and understanding how overall availability of Arctic charr will respond to predicted climate changes. To further improve conceptual understanding of temperature-growth effects location-temperature tags will be inserted into Arctic charr and monitored via acoustic receivers to track temperature use in both the marine and freshwater environments. In concert with growth studies, the project has been monitoring the ecological impacts of Arctic charr introductions and found them to be negligible. This effort represents the first attempt to scientifically evaluate the consequences of northern ecosystem manipulation and has provided important data and insights for management purposes by showing it is possible to proactively manage Arctic charr stocks with minimal ecological consequences. Finally work continues on genetic typing of Arctic charr populations to improve our understanding of how climate change may impact the immunological capabilities of Arctic charr and their abilities to deal with new diseases and pathogens likely to be introduced into northern environments as a result of changing environmental conditions. All study-generated information will contribute to the improvement of management abilities to make informed decisions about the risks associated with continued country food consumption in the face of changing conditions in the Arctic.

This project also identifies key environmental indicators of changes in Arctic Charr (*Salvelinus alpinus*) growth using both quantitative (ecological) and qualitative (Indigenous Knowledge) data by linking community-based monitoring, local expert Indigenous and ecological knowledge. Arctic Charris a staple subsistence resource for Inuvialuit on Banks and Victoria Islands in the Northwest Territories, Canada. In recent years, significant climate variability and change has been observed in the area, raising local concerns about how this variability will affect subsistence resources. Residents in local communities are the first to directly observe these changes and variability in local the climate and the effects on their land, water and animals. Centuries of knowledge and observations about the environment and natural resources exist among Inuvialuit hunters and fishers. Local expert Indigenous Knowledge (IK) can complement our scientific understanding of environmental variability and change and its effects on Arctic species. Community-based monitoring (CBM) provides an opportunity to better understand the current status of Arctic species and can form the basis for understanding and preparing for future changes in Arctic species in light of climate variability and change effects. Using a mixed-methods approach to

research is one way in which ecological scientific and Traditional Knowledge can be brought together to complement one another and provide a more thorough understanding of northern fish species in a changing environment.

Key Messages

- Results of studies of mercury contamination in eastern Canadian populations of Arctic charr were completed and published. Studies focused on a case-study of a single high Arctic lake (Heintzelman) and differences in basal mercury concentrations and biomagnification rates in freshwater and marine food webs and their consequent effects on Arctic charr (*Salvelinus alpinus*) mercury levels.
    - » In Heintzelman Lake it was noted that migratory history was significant in determining muscle total mercury (THg) concentration levels, with anadromous fish having a lower mean THg concentration (64 µg/kg wet weight (ww)) than non-anadromous Arctic charr (117 µg/kg ww). The increase in individual THg concentration with age was found to be independent of length-at-age (i.e., average somatic growth rate) when large and small individuals within the same age groups were compared. The diets of individual Arctic charr were comparable regardless of size and could not explain differences in length-at-age or THg concentration among fast- and slow-growing groups of fish. The differences in THg concentration among individual Arctic charr were best explained by fish age. Thus it was concluded that while the increase in mercury concentration with age could be altered by a shift in diet (e.g., to piscivory) or habitat (e.g., anadromy), THg concentrations were otherwise unaffected by changes in size or somatic growth rate.
    - » When patterns of total Hg (THg) and methyl Hg (MeHg) biomagnification were compared in six pairs of co-located lacustrine and marine food webs supporting Arctic charr, it was found that mercury biomagnification rates (the slope of log Hg concentration versus δ15N-inferred trophic level) did not differ significantly between feeding habitats for either THg or MeHg. However, THg and MeHg concentrations at the base of the food web were higher in the lacustrine environment than in the marine environment. The proportion of THg as MeHg was related to trophic level, and the relationship was statistically similar in the lacustrine and marine habitats. The biomagnification rate of MeHg also exceeded that of THg in both habitats. Thus the known differences in Hg concentration between anadromous and non-anadromous Arctic charr are driven by differential Hg concentrations at of the base of the lacustrine and marine foodwebs, and not by differential biomagnification rates.
- Studies of THg concentration levels in baseline samples of Dolly Varden charr found they were generally low, i.e. within consumption guidelines, but differences exist among populations by location and life-history type. Spatial and temporal patterns in the data were examined with the following results.
    - » THg concentrations from the spatial study ranged from 9.13 – 254.0 ng/g ww (nanograms per gram wet weight). The highest and lowest contamination levels were found in the Firth River samples and it was concluded that local spatial (geographic) differences in muscle tissue THg concentrations exist among populations of Dolly Varden charr. There was, however, no consistent latitudinal (south-north) or longitudinal (east-east) pattern in the spatial differences, with correlation by longitude being $r^2 = 0.002$ ($p > 0.05$) and by latitude $r^2 = 0.068$ ($p < 0.05$).
    - » Differences in THg levels among individuals were partially explained by trophic level

and feeding differences among individuals with THg increasing as trophic level (δ15N) increased at all study sites. Thus, in general, Dolly Varden charr exhibit increasing THg concentrations as they become more piscivorous (i.e., have higher δ15N), but there is no general pattern with respect to the habitat types in which they feed (i.e., there was no relationship between THg and measured δ13C values). Variation in THg levels was also examined in relation to the size and age of tested fish. THg concentrations were all positively correlated with fork-length and age, except for a single site at Canoe Creek, where older fish had lower THg levels.

 » Limited archival sample availability restricted the number of sites at which temporal trends in THg concentrations could be examined. Changes in THg concentrations over the temporal period 1986 to 1995 for which samples were available ranged from 74.11 ng/g ww in 1986 to 83.41 ng/g ww in 1988 for the Rat River, and from 94.86 ng/g ww in 1988 to 129.12 ng/g ww in 1995 for the Firth River. Data showed that the Rat River had a significant overall increasing trend from 1986 to 1995 ($r^2 = 0.322$, $p < 0.05$) in age 7 adjusted logTHg values, with a significant difference between 1986 – 1988 ($p < 0.05$) and 1986 – 1995 ($p < 0.05$) . However, the Firth River showed no significant overall trend from 1986 to 1995 ($r^2 = 0.037$, $p > 0.05$). The lack of significant age-related trends precluded testing among rivers for differences in slopes and intercepts of these relationships.

- Studies of thermal habitat use were completed using oxygen stable isotope temperature reconstruction methods that were able to estimate the mean experienced summer temperatures from summer growth zones within individual Arctic charr otoliths sampled from lakes with contrasting morphologies but proximate locations. For either lake, otolith-estimated temperatures were not significantly related to growth rate, contrary to expectations. Fish in the smaller lake evidenced an increase in growth with age related to increasing use of cooler thermal habitats, with the use of thermal habitat possibly governed by predation risks. No relationships between age, growth or temperature were observed in the larger lake. Significant negative effects on back-calculated growth were observed due to increasing air temperatures in the smaller and shallower lake, possibly owing to warmer surface and littoral waters and a limited amount of preferred cool-water habitat. A similar relationship was not observed in the larger and deeper lake and indicated that resident Arctic charr were not as vulnerable to the impacts of temperature warming because of better behavioural thermoregulation opportunities in the cooler, deeper lake. Results provide evidence for differing climate-influenced growth outcomes depending on lake size and morphometry, with both factors acting to influence fish densities in available preferred thermal habitats.
- Studies of introduction impacts indicate that when anadromous Arctic charr were introduced to a sub-Arctic river-lake system there were minimal foodweb-related impacts on other resident fish species. The minor ecological impact was interpreted in relation to the availability of open niches exploitable by ecological generalists such as Arctic charr, the known habitat and feeding flexibility of Arctic charr and the ecological immaturity of sub-Arctic lakes known to have driven adaptive variation among Arctic charr. Findings suggest that anadromous Arctic charr may be introduced at moderate densities to other sub-Arctic watersheds without major negative foodweb consequences for other resident fish species.
- Results of the interdisciplinary studies examining the impacts of environmental and climatic change on Arctic Charrin the Inuvialuit Settlement Region demonstrated that lake

habitat, local climate and regional climate may all be affecting Arctic Charr growth.

» The importance of Charras a subsistence food to Inuvialuit Settlement Region communities requires on-going and effective community-based monitoring plans (CBMPs) that ensure continual local observation and monitoring to contribute towards effective proactive management of this valuable resource in light of the effects of climate variability and change.

» Studies using both local expert knowledge and study locations of locally fished lakes within close proximity to one another (max. 30 km apart) demonstrated different habitat characteristics. Lake habitat features including zooplankton abundance, ice on/off dates and fish parasite loads will be important indicators to include Arctic CharrCBMs.

» Studies of Arctic Charr growth among lakes with varying lake habitat characteristics demonstrated differences in fish size, condition factor and age at which maximum size is reached. Arctic Charr growth varies among proximal lakes indicating that lakes should be monitored independently when there are changes to lake habitat characteristics.

» A large increase in Arctic Charr growth across lakes and different aged Charr in a single calendar year indicates that the regional environment also has an effect on Charr growth and indicators such as local sea ice coverage should be included in Arctic Charr community-based monitoring programs.

» Studying Arctic Charr, Arctic freshwater ecosystems and the local environment using both scientific and local expert Indigenous Knowledge has produced a more robust suite of monitoring indicators that incorporate local expertise and understanding of the resource and provides a more in-depth understanding of the ecosystem and the variables that affect Arctic Charr growth and health.

Objectives

A key objective is to address critical knowledge deficiencies concerning THg levels in populations of Dolly Varden charr and to relate differences among populations to variations in population-specific biological characteristics. A second key objective is to improve associated knowledge of the marine life-history phase of Dolly Varden charr in the Beaufort Sea in relation to other competing anadromous species and the foodwebs within which they feed. A third key objective was continuation of the long-term study of the effects of Arctic charr introductions in the Ungava region and of marine habitat use and growth in relation to temperature for Arctic charr in the same region as a means of capacity building (i.e. training of Inuit technicians) and improving scientific-based abilities to predict the consequences of climate warming.

Specific hypotheses tested in the Dolly Varden charr THg component:

- Spatial differences in THg concentrations exist among populations of Dolly Varden charr in the Yukon, but as noted for other fish species, there will be no significant trend in differences either by latitude or longitude.
- Measured differences in THg levels among individuals will be correlated with trophic level and feeding, with THg increasing as δ15N increases and δ13C decreases.
- Measured THg levels will be positively correlated with the size and age of tested fish.
- No significant temporal trend in THg concentration levels measured in Dolly Varden charr will be observed, as has been noted for other studied fish species in the Arctic. If trends are observed, the sub-hypothesis that the direction and magnitude of any observed trends will be the same at all sites will be tested.

Specific objectives for the Dolly Varden charr (DVC) Beaufort marine foodweb component:

- To determine the position and role of DVC in Beaufort Sea nearshore foodwebs.
- To compare and contrast the position and role of DVC to other key anadromous fish species (e.g., cisco) as a means of assessing baseline conditions for key fisheries resources.
- To compare and contrast with IPY-related studies of anadronmous Arctic charr in the eastern Arctic as a means of enhancing overall understanding of the trophic position and role of charrs in the Arctic marine environment.

Specific hypotheses tested in the Arctic charr introduction impacts component:

- The introduction of Arctic charr will shift the isotopic ratios of resident fish species with pelagic and littoral dietary preferences
- The introduction of Arctic charr will increase omnivory in lake trout diets as a result of Arctic charr becoming a prey resource
- The introduction of Arctic charr will alter food web metrics by increasing the overall vertical food web length and forage fish redundancy within the fish community, while having no effect on niche diversification at the base of the food web or other qualitative characteristics of the resident fish community trophic structure

The specific hypothesis to be tested in the Arctic charr marine thermal habitat use component:

- Arctic charr experiencing warmer marine habitats will evidence increased individual growth rates in comparison to conspecifics using cooler marine habitats under the assumption that food is not a limiting factor

Additional study hypotheses added this year related to the Arctic charr marine thermal habitat use component and the deployment of acoustic tags:

- Smaller Arctic charr will remain longer in the marine environment and, as a consequence, experience higher average marine temperatures and greater proportional seasonal growth in comparison to the conspecifics of remaining in shorter periods of time in the marine environment
- There will be no significant differences among individuals in terms of mean over-winter thermal habitat use

The overall goal of Component 3 of this study was to examine new ways of monitoring local Arctic charr populations using the resources and knowledge of scientists and local residents to create effective, long-term, community-based monitoring programs. Specific Research Objectives of Component 3 are to examine the effects of environmental parameters on Arctic Charr growth in the ISR and to:

- Use a collaborative and interdisciplinary approach to determine effective environmental and biological indicators which can be used by Inuvialuit Settlement Region (ISR) communities to monitor Arctic Charr in a changing environment
- Conduct new and innovative research which includes IK and social research methods linked to scientific studies on important Arctic resources
- Examine IK-derived environmental indicators of change in growth for Arctic Charr identified through IK interviews with local experts
- Examine meteorological and hydrological data for the areas surrounding the study sites to determine effects on Arctic Charr growth
- Characterize lake habitat conditions and compare between study lakes to determine effects on Arctic Charr growth
- Examine potential relationships between annual environmental conditions (using IK indicators) and annual growth rates of Arctic Char
- Identify effective indicators for community monitoring and fisheries management purposes with community input

- Use IK and local input and expertise to contribute towards creating effective long-term CMBPs for Charr in the ISR and all northern communities

Introduction

The Charr Project as currently configured has several key research aims each of which form the focus of a project component. Building on the successes of successful collaborations with Nunavik Research Centre, component 1 of the project will focus continued monitoring and tagging of Arctic charr using the Nepihjee fishway to build a data time-series on marine thermal habitat use and the effects of environmental variability on Arctic charr marine survival and growth using PIT-tagging and oxygen isotope methodologies. The work will be expanded to include a site on Fraser River (Nunatsiavut) where baseline tagging data from the 1980s exist and will eventually involve the deployment of acoustic or data storage tags (DSTs) to gain a detailed picture of the marine habitat use by individual fish. Such tagging will permit the collection of high frequency observations on the temperatures and depths used by fish, will allow the behaviour of Arctic charr to be connected directly to changes in the marine environment, and will provide important biotic response observations to complement detailed oceanographic research on marine environmental change being conducted in other ArcticNet projects.

Component 2 of the project seeks to addrsss known data deficiencies concerning mercury contamination levels in Dolly Varden charr (DVC). Dolly Varden charr are of significant cultural and dietary importance for the Inuvialuit and Gwich'in, but only limited attempts have been made to study to total mercury (THg) levels and trends in DVC. For example searches of the ISI Web of Science yielded only a single primary scientific literature reference to THg levels in DVC and routine assessment of THg levels in DVC has not been included in NCP or AMAP related programs or reports. To construct a baseline for the species, research will use archived tissue samples available through DFO (1986 on) to construct spatial and temporal profiles of THg in DVC for relevant populations of concern. THg data will also be combined with age, length, life-history type and trophic position information obtained from parallel stable isotope analyses to determine the importance of these factors for determining overall THg levels in DVC, thereby creating a data set to complement the extensive data sets that already exist for Arctic charr. Component 3 of the project will use available archival sample data to address critical questions with respect to the function and structure of Beaufort Sea foodwebs, particularly as they pertain to anadromous fish species. There is currently a notable lack of understanding about Beaufort Sea food webs in general and of the integrative role of DVC within Beaufort foodwebs. For example searches of the ISI Web of Science and Cambridge Scientific Abstracts yielded only 24 primary scientific literature references to Beaufort foodwebs. Most reference the roles of microbial and geophysical processes or marine mammals. None referenced the position or role of key fish species harvested by local communities. With global warming, sea ice losses will result in substantial changes to Beaufort foodweb production, with the consequences for benthic and pelagic foodwebs being unknown. Oil and gas exploration will further impact important nearshore portions of the foodweb. Coupled, these changes call for a detailed assessment of anthropogenic impacts on Beaufort nearshore foodwebs and the anadromous fish species that rely on them.

Component 3 focuses on the effects of climate change on Arctic Charr subsistence resource in the Inuvialuit Settlement Region. Climate changes have already been observed in many parts of the Canadian North including higher than average annual temperatures, changes in lake ice thickness, melting permafrost, and the shortening of ice cover periods on lakes (Wrona et al., 2006). It is hypothesized that these climate changes will lead to indirect secondary effects on Arctic freshwater and anadromous fishes, resulting in changes to body condition and growth, changes in anadromous behaviours, and losses of local biodiversity due to alterations to habitat (Reist et al., 2006a). The people in the local communities will have to adapt to the potential outcomes of these secondary effects. However, there is a general lack of long-term environmental and faunal data for many of the northern regions of Canada, including the Inuvialuit Settlement Region (ISR) (Reist et al., 2006a), and therefore, a lack of understanding of how the changing climate will ultimately affect northern species. This component of the research focuses on studying the effects of the local environment on Arctic Charr growth using both scientific and Traditional Knowledge in a mixed methods approach. The current importance of Arctic Charr to Inuvialuit communities (Usher, 2002) and the impending effects of a changing environment necessitate effective long-term community-based monitoring (CBM) plans. CBM supports opportunities for both local study and the collection of scientific data to inform the ongoing inquiry into how environmental stressors affect northern fish species.

Activities

Completed 2012 Research Activities:

[1]

- What: Finalization and publication of THg data for Heintzleman Lake (van der Velden, S., Reist, J. D., Babaluk, J. A. and Power M. 2012. Biological and life-history factors affecting total mercury concentrations in Arctic charr from Heintzelman Lake, Ellesmere Island, Nunavut. Science of the Total Environment. 433: 309-317).
- Where: All work completed in 2012, completed in laboratory settings at the University of Waterloo (manuscript writing and revision).
- When: Analysis completed January 2012 through May 2012.
- Who: MSc student S. Dorn (now van der Velden), Dr. M. Power and co-authors J. D. Reist and J. Babaluk.
- How: Face-to-face collaboration and discussion of written material.

[2]

- What: Finalization and publication of THg data on paired marine and lacustrine foodwebs used by Arctic charr (van der Velden, S., Dempson, J. B., Evans, M. S., Muir, D. C. G. and Power, M. In Press. Basal mercury concentrations and biomagnification rates in freshwater and marine food webs: Effects on Arctic charr (*Salvelinus alpinus*) from eastern Canada. Science of the Total Environment. Accepted November 28, 2012).
- Where: All work completed in 2012, completed in laboratory settings at the University of Waterloo (manuscript writing and revision).
- When: Analysis completed January 2012 through November 2012.
- Who: MSc student S. Dorn (now van der Velden), Dr. M. Power and co-authors M Evans, J. B. Dempson, and D. Muir.
- How: Face-to-face collaboration and discussion of written material.

[3]

- What: Finalization and publication on the ecological effects of Arctic charr introductions into previously unoccupied watersheds (Murdoch, A., Power, M., Klein, G. and Doidge, D. W. In Press. Assessing the food web impacts of an anadromous Arctic charr introduction to a sub-Arctic watershed using stable isotopes. Fisheries Management and Ecology. Accepted September 30, 2012).
- Where: All work completed in 2012, completed in laboratory settings at the University of Waterloo (manuscript writing and revision).
- When: Analysis completed January 2012 through September 2012.
- Who: MSc student A. Murdoch, Dr. M. Power and Nunavik Research co-authors D. W. Doidge and G. Klein.

- How: Face-to-face collaboration and discussion of written material.

[4]

- What: continued monitoring and PIT-tagging of Nepihjee River Arctic charr population and re-capture of previously tagged fish and expansion of the project to include use of acoustic tags for monitoring the marine phase of the life-history.
- Where: field site on the Nepihjee River.
- When: August to September 2012.
- Who: Nunavik Research Centre fisheries biologist D. Campbell and K. Mitchell, University of Waterloo.
- How: via live capture of Arctic Charr in a special purpose live trap inserted into a fishway and use of standard PIT-tagging equipment. Data on fish ID and size recorded to update existing database. Sub-sample of fish obtained for complete biological analysis.

[5]

- What: capture and acoustic tagging of n=50 Arctic charr in the marine environment for purposes of monitoring marine thermal habitat use, monitoring of fish in the marine environment and deployment of a receiver array in over-wintering lakes.
- Where: field site at Gilbert Bay, Labrador.
- When: August to October 2012.
- Who: Corey Morris and Curtis Pennell, DFO, Dr. M. Power, University of Waterloo.
- How: Live capture of Arctic Charr in large mesh, short duration set gill nets and surgical implantation of Vemco V13 (n=40) and V9 (n=10) acoustic tags. Subsequent monitoring and recording of fish location and temperature using a special purpose array of receivers in both marine and freshwater environments.

[6]

- What: Use of archival tissue samples of Dolly Varden charr to expand existing spatial and temporal baseline datasets on THg contamination in Dolly Varden charr for the Yukon Territory.
- Where: Dolly Varden charr samples obtained from archival storage at DFO Winnipeg. Stable isotope and THg analyses completed on available in-house facilities at the University of Waterloo.
- When January to December 2012.
- Who: MSc student L. Tran.
- How: Sample analysis for THg completed via thermal decomposition and atomic absorption spectroscopy following U.S. EPA method 7473 (U.S. Environmental Protection Agency 2007) using a Milestone Direct Mercury Analyzer (DMA-80) at Environment Canada Laboratories in Burlington, Ontario. Sample analysis for stable isotopes completed via tissue excising of archive fillets in DFO facilities in Winnipeg and mass spectrometry analysis at the Environmental Isotope Laboratory at the University of Waterloo using a A Delta Plus Continuous Flow Stable Isotope Ratio Mass Spectrometer (Thermo Finnigan, Bremen, Germany) coupled to a Carlo Erba elemental analyzer (Carbo-Erba, Milan, Italy).

[7]

- What: Supplementary collection tissue samples of Dolly Varden charr to expand existing spatial and temporal baseline datasets on THg contamination in Dolly Varden charr.
- Where: Samples obtained in collaboration with DFO monitoring of aboriginal fishery at Shingle Point, NWT.
- When: July to August 2012.
- Who: MSc student L. Tran.
- How: Sub-sampling of aboriginal fish samples.

[8]

- What: continued characterization of the variation in immunological responsiveness of Arctic charr using previously obtained field and archival samples. The purpose of this study is therefore, to evaluate differences in major histocompatibility (MH) constitution along a latitudinal gradient in order to better understand the relationship between pathogen load, the local environment and the function of the immue system both within and between individuals of a northern cold water fish species.
- Where: University of Waterloo laboratories.
- When: all of 2012 and on-going.
- Who: PhD student T. Robinson.
- How: using state-of-the-art genotyping methods (MH) as described in the methods of DNA extraction and genotyping described by Conejeros et al. (2008).

[9]

- What: Commencement of stable isotope sampling to determine the foodweb structure of the slope and shelf areas of the Beaufort Sea, with emphasis on the fish component of the foodweb.
- Where: Beaufort Sea.
- When: Collection summer of 2012. The analysis of samples commenced in November 2012 and is on-going.
- Who: M. Power, J. Reist, K. Mitchell (BSc laboratory technician) in conjunction with the Beaufort Sea Environmental Assessment initiative.
- How: Samples were obtained via various trawl methods directly from a ship (F/V Frosti). All stable isotope analyses completed at the University of Waterloo using a A Delta Plus Continuous Flow Stable Isotope Ratio Mass Spectrometer (Thermo Finnigan, Bremen, Germany) coupled to a Carlo Erba elemental analyzer (Carbo-Erba, Milan, Italy).

[10]

- What: presentation of interim results to appropriate national and international conferences.
- Where: International Polar Year 2102 Conference, Montreal, Ecological and Evolutionary Ethology of Fishes Conference, Windsor, ASLO Aquatic Sciences Meetings, Lake Biwa, Japan, 8th International Conference on Applications of Stable Isotope Techniques to Ecological Studies, Brest, France and the 8th ArcticNet Annual Scientific Meetings, Vancouver.
- When: April 2012, June 2012, July 2012 , August 2012,and December 2012.
- Who: M. Power, J.D. Reist, S. Dorn, A. Murdoch, N. Sinnatamby, W. Michaud and T. Robinson.
- How: platform and poster presentations as follows:

1. Murdoch, A., Power, M., Klien, G., and Doidge, D. W. Short-term Individual Temperature-Growth Patterns of Anadromous Arctic Charr in Ungava and Labrador, Canada. International Polar Year 2012 Conference, April 22-27, 2012, Montreal, Québec, Canada.
2. Murdoch, A., Power, M., Dempson, J. B. and Martin, F. Short-term Individual Temperature-Growth Patterns of Anadromous Arctic Charr in Ungava and Labrador, Canada. International Polar Year 2012 Conference, April 22-27, 2012, Montreal, Québec, Canada.
3. van der Velden, S., Reist, J., Babaluk, J., Wastle, R. and Power, M. Biological and Life-History Factors Affecting Total Mercury Concentrations in Arctic Charr from Heintzelman Lake, Ellesmere Island, Nunavut. International Polar Year 2012 Conference, April 22-27, 2012, Montreal, Québec, Canada.

4. van der Velden, S., Muir, D., Evans, M., Dempson, B, Reist, J. and Power, M. Comparing Total Mercury Concentrations in Anadromous and Non-Anadromous Arctic Charr (*Salvelinus alpinus*) from Eastern Canada. International Polar Year 2012 Conference, April 22-27, 2012, Montreal, Québec, Canada.
5. Reist, J. D., Power, M., Dempson, J. B., Furgal, C., Wrona, F., Muir, D., Kidd, K. and Halden, N. Climate Variability and Change Effects on Chars in the Arctic: An Overview. International Polar Year 2012 Conference, April 22-27, 2012, Montreal, Québec, Canada.
6. Robinson, T. N., Bajno, R., Dempson, J. B., Jones, S., Power, M., Reist, J. D. and Dixon, B. Local Adaptation to Pathogens and Variation in the Major Histocompatibility Genes of Arctic charr (*Salvelinus alpinus*) across a Latitudinal Gradient. International Polar Year 2012 Conference, April 22-27, 2012, Montreal, Québec, Canada.
7. Tran, L., Reist, J. D., Power, M. and Johnson, J. Spatial and Temporal Trends of THg in Dolly Varden from the Yukon Territories, Canada. International Polar Year 2012 Conference, April 22-27, 2012, Montreal, Québec, Canada.
8. Robinson, T. N., Bajno, R., Dempson, J. B., Jones, S., Power, M., Reist, J. D. and Dixon, B. Local Adaptation to Pathogens and Variation in the Major Histocompatibility Genes of Arctic charr (*Salvelinus alpinus*) across a Latitudinal Gradient. Ecological and Evolutionary Ethology of Fishes, June 10-14, 2012, Windsor, Ontario, Canada.
9. Gantner N.; Veillette, J., Michaud, W. K., Bajno, R.; Muir, D.; Vincent, W. F., Power, M. Dixon, B., Reist, J. D., Hausmann, S. Factors affecting mercury and perfluorinated contaminants in Arctic Charr of Pingualuit Crater Lake (Nunavik, Canada). 2012 ASLO Aquatic Sciences Meetings, July 8-13, Lake Biwa, Otsu, Shiga, Japan.
10. Murdoch, A., Dempson, J. B., Martin, F. and Power, M. Temperature-growth patterns of individually tagged anadromous Arctic charr *Salvelinus alpinus* in northeastern Canada. ArcticNet 8th Annual Scientific Meeting, December 12-14, 2012, Vancouve, BC, Canada.
11. Murdoch, A., Dempson, J. B. and Power, M. The effect of lake morphometry on thermal habitat use and growth in Arctic charr populations: implications for understanding climate-change impacts. ArcticNet 8th Annual Scientific Meeting, December 12-14, 2012, Vancouver, BC, Canada.
12. Sinnatamby, R. N., Storm-Suke, A., Shears, M. Dempson, J. B. and Power, M. Thermal habitat use and growth in young-of-the-year Arctic charr: a comparison of riverine and lacustrine populations in Labrador. ArcticNet 8th Annual Scientific Meeting, December 12-14, 2012, Vancouver, BC, Canada.
13. Sinnatamby, R. N., Dempson, J. B., Reist, J. D. and Power, M. Latitudinal compensation in growth and metabolic rate of Canadian young-of-the-year Arctic charr. ArcticNet 8th Annual Scientific Meeting, December 12-14, 2012, Vancouver, BC, Canada.
14. Tran, L., Reist, J. and Power, M. Recent spatial and temporal trends of mercury (Hg) concentrations in Dolly Varden charr from the western Canadian Arctic. ArcticNet 8th Annual Scientific Meeting, December 12-14, 2012, Vancouver, BC, Canada.

[11]

- What: Field sampling for lake habitat characteristics including zooplankton, bathymetry, water quality and shoreline integrity.
- Where: Ikahavik Lake, Victoria Island, NT. Field sampling at Ikahavik Lake could not be completed this year due to poor weather logistic issues. One attempt was made by J.Knopp with a local assistant in March 2012

and a second attempt was made by locally-hired field workers in November 2012.

- When: March 2012, November 2012.
- Who: PhD candidate J.Knopp, local field assistant and Olokhaktomiut Hunters and Trappers Committee (OHTC) hired local field workers.
- How: Accessed lake by snowmachine and ice auger from the community of Ulukhaktok.

[12]

- What: Training of local residents in Arctic Charr scientific sampling methods.
- Where: Sachs Harbour, Banks Island, NT study sites included Middle and Kuptan Lakes and Aulavik National Park building, Sachs Harbour, NT.
- When: May 2012 (two weeks).
- Who: PhD candidate J.Knopp, field assistant and local expert fishers with cabins on the lakes, Sachs Harbour youth.
- How: J. Knopp and local fishers stayed out at the lake to train on how to scientifically sample the fish captured in the local catch. J. Knopp held a youth evening at the local Parks Canada office to teach youth how to scientifically sample fish.

[13]

- What: Ulukhaktok Traditional Knowledge interview analyses community verification meetings.
- Where: Ulukhaktok, NT.
- When: March 2012.
- Who: PhD candidate J.Knopp, local expert interviewees.
- How: Thematic coding and NVivo analysis of IK interviews. Verification completed with the community of Ulukhaktok.

[14]

- What: Arctic Charr tissue analysis for mercury levels.
- Where: Trent University, Peterborough, ON.
- When: Jan. 2012 – Mar. 2013 (work on-going).
- Who: Hogler Hintelmann lab, Trent University.
- How: Requests from the community for the Charr monitoring plan included the monitoring of contaminants in char, specifically mercury levels in lake fish to provide current baseline information on the status of mercury levels in these fish.

[15]

- What: Data analyses of collected and archival quanitative field data.
- Where: C. Furgal lab, Trent University, Peterborough, ON and R. Wastle ageing lab, DFO Freshwater Institute Winnipeg, MB and other associated labs (University of Calgary, Aquatic Bio-Services).
- When: 2011-2013, finalizing in early 2013-14 fiscal year.
- Who: J. Knopp, two research assistants, lab technicians in associated labs.
- How: Charr ageing from otoliths, age-specific otolith back-calculation for growth determination, ArcGIS bathymetry analyses, lake ice on/off dates analyses from satellite imagery, local sea ice annual condition analyzed from satellite imagery and online databases, annual climate conditions analyzed from online databases, stomach contents sorting and preliminary identification of prey items, lake zooplankton sample identification and biomass measurements, Arctic Charr parasite identification and load analyses, and small Charr stomach content analyses.

[16]

- What: Presentations and publications
- Where: International Polar Year Conference in Montreal and ArcticNet Annual Scientific Meeting in Vancouver, BC.
- When: April 2012 and December 2012.
- Who: J. Knopp and other team members.
- How: 2012 Papers and Presentations (see below for complete list).

1. Knopp, J.A., C. Furgal, J.D. Reist, Sachs Harbour Hunters and Trappers Committee andthe Olokhaktomiut Hunters and Trappers Committee. 2012. Indigenous and Ecological Knowledge for Understanding Arctic Charr Growth. Eds. Carothers, C., K.R. Criddle, C.P. Chambers, P.J. Cullenberg, J.A. Fall, A.H. Himes-Cornell, J.P. Johnsen, N.S. Kimball, C.R. Menzies, and E.S. Springer. Fishing People of the North: Cultures, Economies, and Management Responding to Change. Alaska Sea Grant, University of Alaska Fairbanks. pp. 177-192. http://seagrant.uaf.edu/bookstore/pubs/AK-SG-12-03.html.
2. Knopp, J.A., C. Furgal, J.D. Reist and the Sachs Harbour Hunters and Trappers Committee. 2012. Inuvialuit and Ecological Knowledge to Examine Effects of Lake Environment on Arctic Charr Growth and Health. ArcticNet Annual Science Meeting, Vancouver BC. (Oral presentation).
3. Knopp, J.A., The Communities of Sachs Harbour and Ulukhaktok, C. Furgal, and J. D. Reist. 2012. "Reciprocal Learning: Two Inuvialuit Communities and a Student Researcher Sharing Different Ways of Knowing and New Ways of Understanding". International Polar Year – From Knowledge to Action International Conference. Montreal QC. (Poster) ***INTERNATIONAL POLAR YEAR KNOWLEDGE TO ACTION AWARD***.
4. Knopp, J.A., C. Furgal, J.D. Reist, and the Sachs Harbour and Olokhaktomuit Hunters and Trappers Committees. 2012. "Inuvialuit Knowledge and Science to Understand a Changing Country Food Resource". International Polar Year – From Knowledge to Action International Conference. Montreal QC. (Oral presentation) ***Featured on CBC Regional News and News North ***.
5. Knopp, J.A. 2012. "Arctic Climate Change Sciences – Studying Environmental Effects on Arctic Charr using Science and Traditional Knowledge". Destiny Quebec, School's on Board and Montreal's Lower Canada Youth College – Arctic Climate Change Youth Forum, Montreal QC. (Invited speaker).
6. Knopp, J.A., C. Furgal, and J.D. Reist. 2012. "Scientific and Traditional Knowledge of Arctic Charr and Community-based Monitoring". Inuvialuit Fisheries Joint Management Committee Annual Meetings. Winnipeg, MB (Oral presentation).

Results

A sample of Arctic charr from Heintzelman Lake (81°42'N, 66°56'W), Ellesmere Island, was used to elucidate the biological and life-history factors potentially influencing individual total mercury (THg) concentrations. Results from the study (van der Velden et al. 2012a) indicated that anadromous Arctic charr had a significantly lower mean [THg] (64 µg/kg ww) than non-anadromous fish (117 µg/kg ww) (Figure 1) but that length-at-age (i.e., average somatic growth rate) was not related to mean [THg] when the same-age groups were compared. Within the non-anadromous grouping, differences in growth rate did not influence [THg] and prey resource use, as determined by δ13C and δ15N isotopes and gut contents, was similar among fast- and slow-growing fish. Maturity state was neither related to [THg], although the slow-growing group had a greater

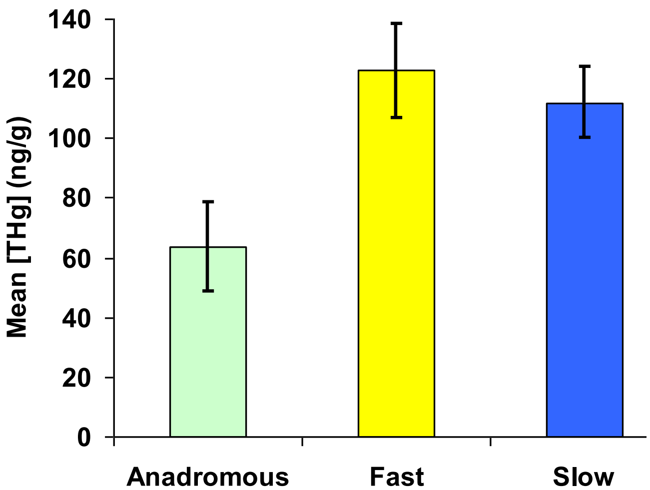

Figure 1. Mean THg concentration in anadromous and non-anadromous (as seperated into fast and slow-growing groups) Arctic charr from Heintzelman Lake, Ellesmere Island, NU.

proportion of current year spawners.

Patterns of total Hg (THg) and methyl Hg (MeHg) biomagnification were investigated in six pairs of co-located lacustrine and marine food webs supporting Arctic charr along a latitudinal gradient from Ellesmere Island to southern Quebec. Results indicated

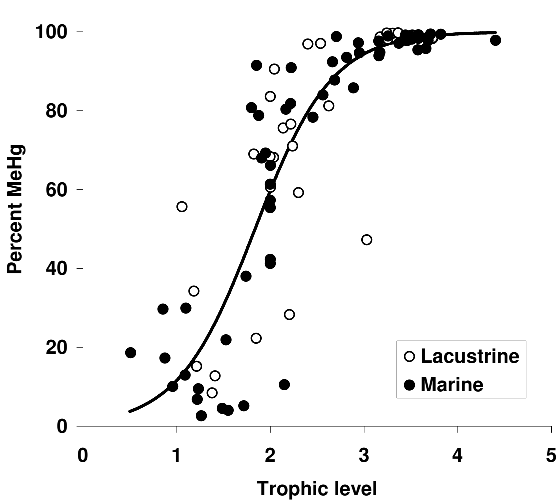

Figure 2. Percent MeHg versus trophic level for taxa from marine (solid circles) and lacustrine (open circles) food webs. The non-linear logistic model was estimated using data from both habitats.

mercury biomagnification rates (the slope of log Hg concentration versus δ15N-inferred trophic level) did not differ significantly between feeding habitats (freshwater, marine) for either THg or MeHg, but that THg and MeHg concentrations at the base of the food web were higher in the lacustrine environment than in the marine environment (van der Velden et al. 2012b). The proportion of THg as MeHg was related to trophic level, and the relationship was statistically similar in both feeding habitats (Figure 2). The biomagnification rate of MeHg, however, exceeded that of THg in both habitats. Based on the available data the study concluded that the differences in Hg concentrations between anadromous and non-anadromous Arctic charr are driven by differential Hg concentrations at the base of the lacustrine and marine foodwebs, and not by differential biomagnification rates.

Between August 9 and September 13, 2012 we monitored Arctic charr returning to the Nepihjee River, counting 566 in total. Of these 16 had been previously tagged. The average annual increment equalled 96 mm. The increment compares with average annual increments of 90.1mm and 88.6 mm observed in 2010 and 2011, respectively, with differences among years likely being influenced by differences in the mix of ages included in the sample. Observed annual increments continue to remain substantially above those observed at similar latitudes on the Labrador coast. For example mean annual Arctic charr increments in length varied between a low of 13.2mm ±3.55(SE) in 1985 to a high of 22.1 mm ±2.62(SE) in 1982 at Hebron Fjord (J.B. Dempson, University of Waterloo, personnel communication). The migration run consisted of two peaks. The first peak occurred between August 13-18 and the second peak occurred between September 1-8 (Figure 3). There was a general tendency for larger fish to return earlier and smaller fish to return later as a consistent decline in sizes was observed throughout the run. Other species observed migrating from the estuarine environment included: Atlantic salmon (1), brook charr (15), lake charr (2), longnose sucker (1) and round whitefish (92).

In concert with the operation of the fishway, an analysis of the ecological impacts of the introduction of Arctic charr into the Nepihjee River was completed by assessing shifts in the fish community

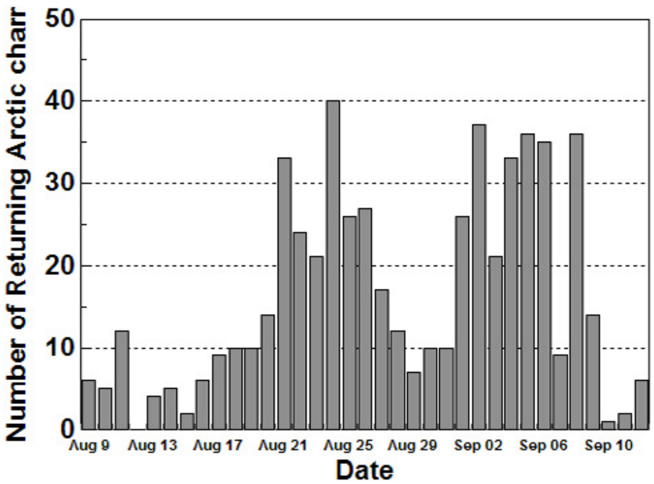

Figure 3. Counts of Arctic charr monitored returning to the Nepihjee River near Kuujjuak, Quebec, 2012.

foodweb structure of the largest upstream lake (Lake Qamutissait 58°24'N 68°23'W) used for over-wintering purposes. Assessment of changes in feeding patterns completed using stable isotopes (Murdoch et al., in press) showed most species did not differ significantly between the pre- and post-introduction periods, with observed shifts being within the bounds of expected natural variation. Lake chub were the only species to show a difference between study periods, with a small but significant increase in δ15N. No significant post-introduction changes were seen in lake trout omnivory or in any of the assessed quantitative food web metrics. Supplementary gut contents of major fish species similarly showed significant temporal overlap between the pre- and post-introduction periods (Figure 4) and there was no significant change in species' weight-length relationships. The minor ecological impact was

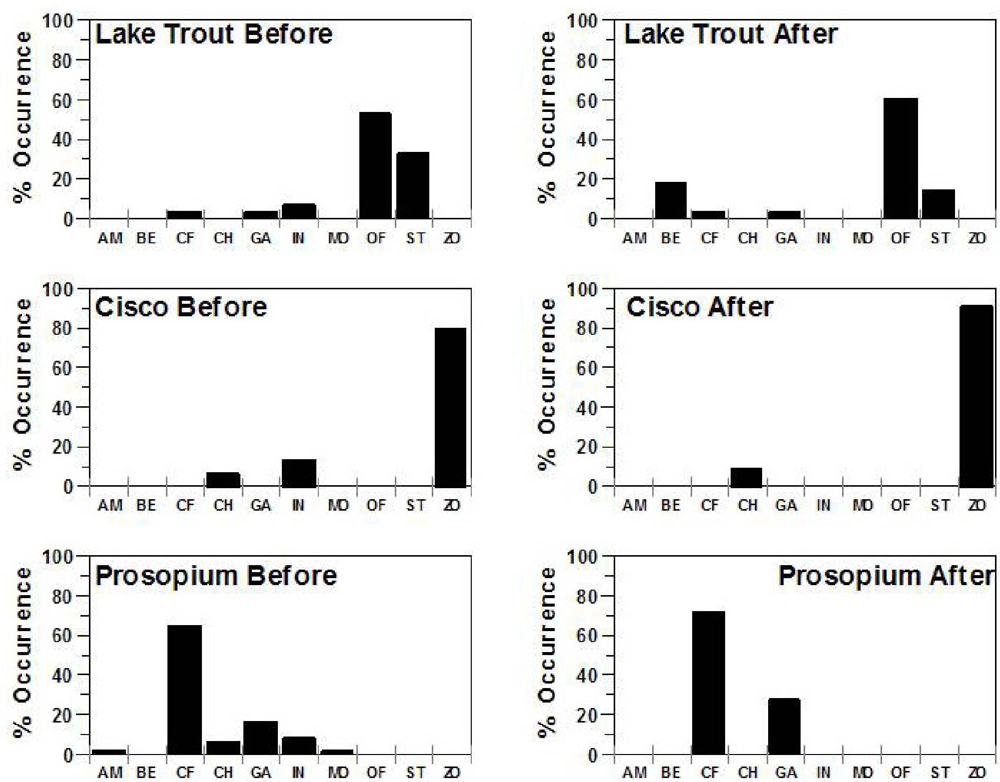

Figure 4. Percent occurrence of dietary items found in fish stomachs pre-and post-introduction of Arctic charr. Am, amphipods; BE, beetles; CF, caddis fly; CH, chironomids; GA, gastropods; IN, insect remains; MO, molluscs; OF, other fish (largely Catostomus catostomus, C. artedii, Couesius plumbeus and Lota lota); ST, sticklebacks (Gasterosteus aculeatus and Pungitius pungitius), and ZO, zooplankton.

interpreted in relation to the availability of open niches exploitable by ecological generalists such as Arctic charr. The explanation accords with the known habitat and feeding flexibility of Arctic charr and the ecological immaturity of sub-Arctic lakes known to have driven adaptive variation among Arctic charr. Findings suggest that anadromous Arctic charr may be introduced at moderate densities to other sub-Arctic watersheds without major negative foodweb consequences for other resident fish species.

In view of the importance of Dolly Varden charr as a source of dietary protein (Daviglus et al., 2002), the increasing concerns for changes in mercury accumulation rates as a result of predicted climate change (Macdonald et al., 2005) and the fact that so little information exists on mercury in Dolly Varden, Reist and Power obtained archived DVC tissue samples through DFO (1986 on) to construct spatial and temporal profiles of total mercury (THg) in DVC for relevant populations of concern in the Yukon. Supplementary Fisheries Joint Management Committee (FJMC) funding was obtained with the specific aims of extending and updating both the spatial and temporal limits of the archival samples. Progress to data with both studies is described below.

Spatial Study: The THg concentrations from the spatial study ranged from 9.13 – 254.0 ng/g. The highest and lowest contamination levels were found in the Firth River samples. The first hypothesis (1) tested that spatial differences in muscle tissue THg concentrations would exist among Dolly Varden charr populations from the Yukon and Northwest Territories, but there would be no significant trend by latitude or longitude; this was supported. Results determined that significant differences in logTHg concentrations existed between the nine sites sampled in the Northwest and Yukon Territories, but that there was no correlation by longitude ($r^2 = 0.002$, $p > .05$), or high explanatory power by latitude ($r^2 = 0.068$, $p < .05$). The second hypothesis (2) was partially supported in that measured differences in THg levels among individuals were correlated with trophic level and feeding, with THg increasing as δ15N increased or δ13C decrease. The data indicated that the THg levels were all positively correlated to trophic level (δ15N), but that only Cache Creek and Rat River DVC exhibited a decrease in δ13C with increasing THg concentrations. Thus, in general, Dolly Varden charr exhibit increasing THg as they become more piscivorous (i.e., have higher δ15N), but there that is no general pattern with respect to the habitat types in which they feed. Variation in THg levels was also examined in relation to the size and age of tested fish. THg concentrations were all positively correlated with fork-length and age, except for Canoe Creek, where older fish had lower THg levels. No age data were available for Babbage River and Ptarmigan Bay, which precluded age-related testing for those populations.

Temporal Study: The THg concentrations over the temporal period (1986-95) of study ranged from 74.11 ng/g ww in 1986 and 83.41 ng/g ww in 1988 for the Rat River (a tributary to the Mackenzie River in the Northwest Territories) to 94.86 ng/g ww in 1988 to 129.12 ng/g ww n 1995 for the Firth River in the Yukon territory. For the Rat River length-adjusted means showed a significant difference between 1986 and 1988 ($p < .05$) and 1986 and 1995 ($p < .05$), but no significant trend was observed over time (Figure 5) from 1986 to 2011 ($r^2 = 0.019$, $p >.05$). In the Firth River length-adjusted THg concentrations showed no significant trend over time ($r^2 = 0.794$, $p > .05$), although mercury concentrations in 1986 and 1995 were significantly lower than those witnessed in 2011 (Figure 5).

At Gilbert Bay, Labrador, n=50 Arctic charr were captured, tagged and monitored in the marine habitat using an existing array of Vemco receivers deployed by DFO. Detections were obtained on all fish. By the end of July the majority of tagged fish had returned from the marine to the freshwater and four receivers were moved from the marine environment to the presumed over-wintering lake for purposes of monitoring over-winter movement and thermal habitat use. This will be the first ever recorded data on the over-winter portion of the life-history. Of the

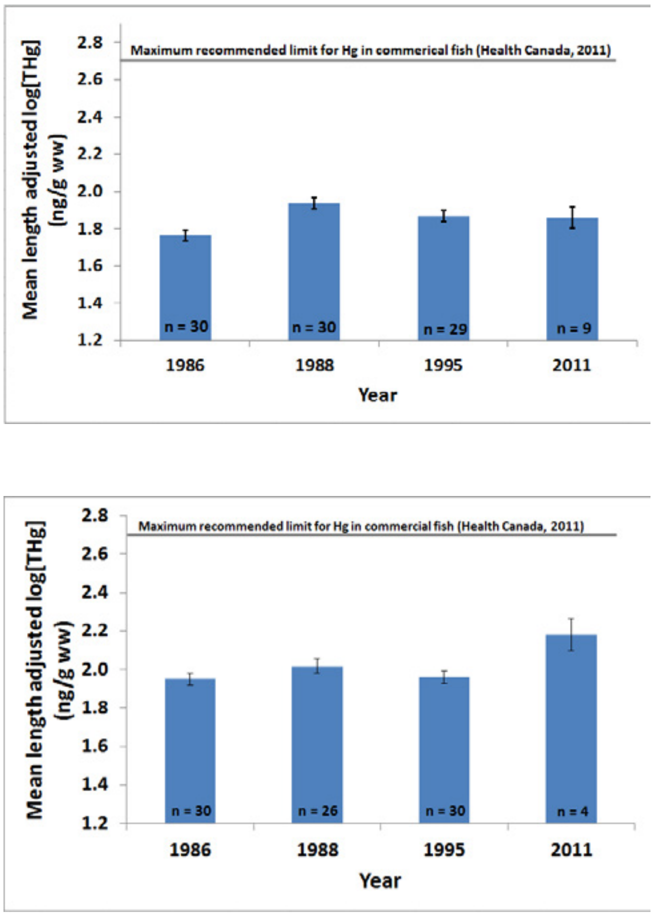

Figure 5. Length-adjusted THg means of Dolly Varden charr by year in the Rat River (top panel) and Firth River (bottom panel).

tags returned through the summer fishery n=7 were suitable for re-implanting and were placed in new fish at this time. By July a total of n=31 fish could still be accounted for. To account for others a community information program was under-taken to encourage locals to return any tags obtained in the summer fishery. Some evidence of tag explusion was obtained during the re-implant phase and it is expected that some of the tags will have been naturally expulsed during the rapid summer growth period.

Work continued with the development of tools for using MH gene molecular techniques to better understand the evolutionary history of Arctic charr and its likely susceptibility to climate warming as a result of lack of immunological competency (i.e. increased susceptibility to disease). To that end, the final exploratory study using the gene encoding of the β subunit of the major histocompatibility (MH) receptor as a population marker in Arctic charr was published (Conejeros et al. 2012). Use of the marker allowed good differentiation of Arctic charr lineages previously defined using mitochondrial DNA (mtDNA) and further allowed differentiation between the populations studied within those lineages. The methods thus promised to provide both macro- and micro-scale differentiation abilities and will help us to better describe differences in immunological susceptibilities among populations. As a result of these encouraging results, the method will be expanded across the full latitudinal range for which we have sample data (Ellesmere Island to Nain, Labrador) as part of on-going studies.

To date no results are available for the Beaufort Sea baseline foodweb studies as catalogued field samples have only begun to arrive in the lab for processing. A total of 1600 samples will be processed from multiple trophic levels and from multiple sites, both along the slope and in the main basin. A PhD student (A. Stasko) has been selected to lead the project analyses and will commence in May of 2013. In the meantime, samples are being processed as they are made available.

The results of the quantitative analyses of scientific data studied in Component 3 showed differences in water chemistry, lake volume and depth and zooplankton biomass among the study lakes near Sachs Harbour. Arctic Charr diet and parasite load also varied among the study lakes, despite their close proximity to one another (max. 30km apart). The von Bertalanffy growth curves estimated from otoliths collected from Kuptan, Middle, and Capron Lakes showed the populations in each lake fit expected growth patterns, but there are differences among the three populations in the maximum size attained by the Charr and the age at which the maximum size was reached. The knowledge shared in the IK interviews complements the scientific findings of the effect of local lake environment on Arctic Charr growth; interview analyses show that local experts have observed Charr from each of the study lakes to have different maximum sizes. The two knowledge bases complement one another, indicating that local lake environment does have an effect on Arctic Charr growth.

Preliminary results of the otolith back-calculation for annual Arctic Charr growth show a large increase in growth in a single calendar year, across a range of age classes in both Middle and Capron Lakes. The knowledge shared in the IK interviews complements the scientific findings of changes in Arctic Charr growth with interview analyses showing that changes to landlocked Charr sizes occurred at approximately the same time. These changes in Arctic Charr sizes prompted the community to request the implementation of an Arctic Charr community-based monitoring plan. The IK interview analyses as well as previous IK documented in research projects (Riedlinger and Berkes 2001, Nichols et al. 2004) showed that major climate and environmental changes occurred around the same time, including late sea ice formation, warmer air temperatures, and major shifts in storm and precipitation events. The change in Charr growth in different study lakes around the same year observed in both knowledge bases indicates that regional climate-driven changes in arctic Charr growth may be occurring. Lake habitat and environmental parameters determined through ecological and Indigenous knowledge are currently being analyzed in association with that year of observed increased growth in order to test links between Charr growth and climate.

Discussion

Observed non-anadromous Arctic charr THg levels (mean = 0.117 mg/kg) in Heintzelman Lake Arctic charr generally fell within the ranges of THg concentrations reported for landlocked Arctic charr from other areas of the Arctic lakes (e.g. Gantner et al. 2010a,b; Evans et al. 2005a,b). The examination of mercury accumulation dynamics in a population of Arctic charr from the Canadian high Arctic provided an ideal opportunity to examine Arctic charr with a minimum of confounding factors, as all fish were captured from the same lake in the same year, and there are no other fish species present in the lake. A key contribution of the study was the demonstration that in populations of fish that display only subtle variations in feeding strategy (i.e., where consumption opportunities are restricted), it is age and not size that determines fish mercury concentration. Arctic charr display large variations in growth rate and size at maturity (Johnson, 1980; Klemetsen et al., 2003; Parker and Johnson, 1991), and often display bimodal size distributions or “standing waves” in length-frequency distributions (Power et al., 2008). Thus, Arctic charr of the same size can be of very different ages. As predicted by fish ages, fast-growing individuals had lower THg concentrations than slow-growers at a given size, and the disparity increased with increasing fork-length. Accordingly, monitoring of non-anadromous Arctic charr for purposes of human health risk assessment should take into account the age distribution of consumed fish, particularly as climate change may significantly alter existing length-at-age relationships for many populations of Arctic charr. Furthermore, in order to elucidate the mechanisms of mercury accumulation with respect to physiological factors such as growth rate, future studies should aim to obtain a reasonably large sample size including representatives from all size and age classes, morphotypes, and life-history variants (e.g., anadromous and non-anadromous) present in the population (van der Velden et al. 2012a).

Previous research has documented that total mercury concentrations ([THg]) are lower in anadromous Arctic charr than in non-anadromous conspecifics (e.g. Riget et al., 2000; Evans et al., 2005; Swanson et al., 2011). Differences in [THg] are not related to differences in length-at-age (i.e., average somatic growth rate) among populations of either life-history type (van der Velden et al., 2012b), but were hypothesized to be related to differences in THg at the base of the foodchain. Work completed in 2012 was the first wide-scale spatial investigation of THg and MeHg biomagnification in co-located pairs of lacustrine and marine food webs supporting Arctic charr. Differences in [THg] between anadromous and non-anadromous Arctic charr were found to be driven by differential Hg concentrations at the base of the lacustrine and marine food webs, as hypothesized, and not by differential biomagnification rates. The conclusion was corroborated by other evidence in the literature that differences in fish Hg concentrations among lakes may not be related to within-lake biomagnification rates (Gantner et al. 2010b; Wyn et al. 2009). The difference in prey Hg concentration is important for understanding the difference in [THg] between anadromous and non-anadromous in Arctic charr and has important implications for understanding the trophic transfer of THg and MeHg, as well as other biomagnifying contaminants, in diverse aquatic food webs. Results of the Arctic charr study suggest that [THg] and [MeHg] in biota are influenced more by individual site characteristics than wide-scale regional differences, and highlight the importance of contaminant uptake processes at the base of the food web.

Operation of the Nepihjee fishway in 2012 continued to yield quality data useful for studying the marine portion of the life-history in Arctic charr. Some 566 returns were counted and measured during the monitoring period, down from 826 recorded in 2010, but well above the 429 long-term (1999-2010) average return. Returns peaked in mid-August and again in early September, with larger fish retuning earlier and smaller fish retuning later, as has been noted during the monitoring of Labrador returns to the Fraser River (Dempson and Green, 1985). Sampled biological data collected from the returns will be used in on-going otoliths microchemistry analysis aimed at determining the effect of temperature on growth. Among the returning fish were n=16 previously measured that continued to display high annual growth as a result of the use of Ungava Bay. Analysis to date and comparison with tagging data obtained from the Labrador coast (J.B. Dempson, University of Waterloo, personnel communication) indicate differences in among-year growth were significant for Ungava Bay *S. alpinus*, with growth being positively correlated with temperature. The Ungava *S. alpinus* also had significantly higher annual growth rates, which were attributed to the high sea surface temperatures experienced in 2010-12 and the localized differences in nearshore productivity as compared to Labrador. Results thus suggest that increases in water temperature may have profound consequences for *S. alpinus* growth in the Canadian sub-Arctic, depending on the responses of local marine productivity to those same temperature increases.

The analysis of the ecological impacts of the introduction of Arctic charr into the Nepihjee River represents the first and only such study available for the North. Impacts were assessed by examining pre- and post-introduction dietary patterns of the key resident fish species (Murdoch et al. in Press). The introduction of Arctic charr had only a minimal effect on the measured isotopic values of resident fish species, with results for most species showing no significant changes relative to the introduction. Dietary overlap of the numerically abundant species pre- and post-introduction was high and no significant changes were observed in species' associated weight-length relationships. Northern lake chub evidenced a consistent but small (<1‰) post-introduction effect. Other significant changes observed were typically characterized by an inconsistent pattern with respect to the baseline introduction year, as was observed for cisco and round whitefish. Lake trout mean $\delta15N$ decreased in 2009 when compared to pre-introduction values, however, there was no support for the hypothesis that lake trout omnivory increased as a result of incorporating Arctic charr as an additional prey source. Furthermore, changes in standard quantitative food web metrics were not statistically significant among years. Study findings suggest that anadromous Arctic charr may be introduced at moderate densities to other sub-Arctic watersheds without major negative foodweb consequences for other resident fish species or on resident fish community structure. Notably, even in the study lake where the fish community was relatively developed for subarctic conditions, the impacts appeared minimal.

This suggests that findings may be easily extendable to other subarctic and Arctic lakes in equivalent or higher latitudes where fish communities are even simpler. However, effects on watersheds that are less productive or containing more complex species assemblages may be harder to predict, and must still be evaluated case by case. Other factors such as watershed size and proximity to source populations may also alter results. For example, in areas that are close to large established anadromous Arctic charr populations, newly opened lakes may receive high influxes of charr, potentially negatively affecting resident fish species. In this regard, the proximity of the Nepihjee watershed to nearby overwintering sites (>50km, Barton et al., 1984) allows it to be a more conservative case, and may explain why fairly low sustainable numbers of migrating Arctic charr have been reported to-date. Finally, fisheries management should prioritize Arctic charr habitat remediation for established populations before undergoing major projects such as facilitating introductions, as exemplified by the Arctic Charr Stream Enhancement Project (ACSEP) which has been ongoing in Nunavik since the late 1980`s (Mesher, 1999; Mesher, 2001; Mesher, 2003; Chum, 2005; Chum, 2006). Arctic charr have reportedly had difficulty ascending 40% of rivers that were traditionally fished in the Ungava Bay basin (Power and Barton, 1987), and the implementation of ACSEP has facilitated many small-scale remedial works with the goal of mitigating these stream obstructions. Only in exceptional cases, the Nepihjee being a primary example where the payoff for removing a single barrier was quite high, will an introduction be a viable undertaking for a community

Statistical analysis for the Dolly Varden charr THg analysis has indicated no specific geographic patterns and only marginal evidence of temporal trends. To date both spatial and temporal data sets are limited and efforts are continuing to add data to extend both data sets as it is important to accurately characterize patterns of THg accumulation in this important food resource. Consumption of fish is one of the main pathways of mercury exposure for humans (Health Canada, 2007). Once in the body, mercury can cause neurological impairment and have harmful effects on the nervous system, the kidneys and the cardiovascular system (Health Canada, 2007). As a result, the maximum recommended limit for total mercury (THg) allowed in commercially sold fish by the Canadian Food Inspection Agency is 0.5 ppm (parts per million) (Health Canada, 2007). The provisional tolerable daily intake for an adult is 0.4 µg (micrograms) MeHg per kg body weight for the protection against neurotoxicity effects (WHO, 2007), with lower levels recommended for pregnant women and children.

Local native communities have fished Dolly Varden charr (DVC) for subsistence purposes for generations, yet until now little has been known about total mercury (THg) loadings in Dolly Varden or how THg concentrations in the fish may vary spatially, temporally or by life-history form (Sandstrom et al., 2009). Thus localized THg risks from the consumption of DVC remained largely unknown, although detailed studies have looked at THg contamination levels in all other key food consumption fish species in terms of spatial and temporal variability and the factors (physical and environmental) that influence THg concentrations in fish (Ford et al., 2005). Species that have been studied include: Arctic charr (*Salvelinus alpinus*), northern pike (*Esox lucius*), broad whitefish (*Coregonus nasus*), walleye (*Stizostedion vitreum*), inconnu (*Stenodus leucichthys*) and lake trout (*Salvelinus namaycush*) (Stewart et al., 2003; Evans et al., 2005a,b; Lockhart et al., 2005; Muir et al., 2005). Based on data made available by this study, Dolly Varden charr sampled to date do not pose a significant consumption threat.

Work with the application of MH genetic methods to the study of Arctic charr has progressed well. We have noted that variations within the β subunit gene of the Class II MH molecule permitted both within and among population differentiation of Arctic charr populations obtained from across the distributional range of the species. Differences among populations were broadly similar to those hypothesized by previous mtDNA-based studies (Brunner et al., 2001) but indicated commonalities not suggested by previous analyses. In addition, use of the β subunit of the Class II MH molecule permitted distinguishing between populations from the same apparent lineal grouping (Brunner et al., 2001). A discrete molecular marker that informs about the relatedness among individuals and adaptation to a specific niche is desirable when evaluating populations from a broader ecological perspective because it allows comment on both relatedness and differences in life-history tactics that may eventually favour selective breeding within a population. As demonstrated by the present study, the MH-II β gene appears to be an excellent candidate marker (Conejeros et al. 2012).

To date the significance of work at Gilbert Bay cannot be commented on as data collection is on-going but is expected to generate critical information on important subsistence, recreational and commercial species. Although significant research has been carried out on population genetics, contaminants and life history characteristics of the Arctic charr, there is still a lack of basic information on their marine movement and, in particular, poor understanding of patterns of movement between freshwater and marine habitats and how these relate to environmental cues and how this varies across the Arctic. Given predicted and observed climatic changes and existing hypotheses about its likely consequences on northern fishes (Reist et al., 2006b), such information is of increasing importance to the management of this vital Arctic species and its associated fisheries. The data collected at Gilbert Bay will permit quantification of the timing, and relationship to environmental variables (temperature, ice cover, etc.) of Arctic charr movement at the Labrador study site and allow us to perfect field methods for transfer to study sites in Ungava Bay. In addition to environmental use data, the study will generate data on the prevalence of straying between Arctic charr stocks, which is important for understanding colonization dynamics and the adaptive of abilities of Arctic charr in the face of changing climates. An important by-product of the research will be the provision of immediate data and information to fisheries managers (DFO and Nunavik Research Centre) and local stakeholders (Inuit fishermen and community members) on the marine ecology of Arctic charr needed for the sustainable management of the species.

Finally, as part of a multi-agency initiative to better understand the ecosystem dynamics of the Beaufort Sea we have initiated the collection and analysis of foodweb samples to better characterise the structure and function of Beaufort Sea food webs. The Canadian Beaufort Sea currently hosts 95 oil and gas leases, with recent exploration licenses issued for deep off-shelf waters. Fisheries and Oceans Canada is tasked with the regulation of oil and gas activities with the aim of minimizing the impacts to fishes and their habitats. To regulate effectively, regional baseline information on fish species composition, distribution, abundance, life history and critical habitats is required. In addition, an understanding of trophic structure and energy pathways within the ecosystem is required to discriminate between impacts from industry versus those from other stressors (e.g. climate change). While work was conducted in the 1970’s and 1980’s to understand the ecology of fish communities found nearshore along the shelf and in coastal/estuarine habitats, which resulted in a basic understanding of inshore fishes and their habiats, no comprehensive study of deeper offshore marine habitats and their associated fish communities has been completed. Furthermore, linkages between nearshore communities/habitats and those found in offshore marine waters which may be critical for overall ecosystem function are poorly understood. To that end we have acquired some 2000+ samples for the purposes of characterizing foodweb structure and function and inshore-offshore linkages. Samples are currently being processed and it is of yet, too early to provide commentary on results. Nevertheless, the data will eventually represent a significant step forward in our understanding of important marine foodwebs and habitats that support and/or subsidize the key fisheries on which northerners depend.

The purpose of Component 3 of this project is to demonstrate the secondary effects of climate variability on Arctic Charr resources and to provide an understanding of these effects to the local resource users, allowing them to make informed choices about adapting to upcoming changes through community-based monitoring efforts. This component of the research has provided the opportunity to exchange information and concepts of western science and Inuit traditional knowledge and to assist directly with the monitoring and management of local fish resources (Berkes et al., 2007). Local experts shared a detailed understanding of changes in local climate and environmental conditions and how these changes affected both Arctic Charr and Charr habitat. Emergent theme analyses of the qualitative data demonstrated the wide breadth and depth of local expert knowledge on the topics of fish, fishing, and environmental variability and change in the region of Sachs Harbour. An example of an emergent theme of an environmental condition that has the potential to affect lake resident Arctic Charr growth is sea ice. Local experts observed noticeable changes in sea-ice conditions around the same time other changes to the lakes and fish were occurring. Low sea-ice coverage in nearby ocean environments can lead to more open water. Open water in the sea environment has a lower albedo than sea ice, resulting in the absorption of more solar radiation which has the potential to lead to warmer water (Barber et al. 2008). Reduced sea ice and warmer ocean waters could lead to warmer ambient air temperatures and perhaps increased precipitation, which in turn could result in warmer conditions in the local landlocked lake environments. Therefore regional sea-ice coverage is a parameter relevant for consideration in Arctic Charr community-based monitoring programs. The equal inclusion of IK in the study design, knowledge input and results analyses has been critical in achieving a thorough understanding the lake habitat and environmental conditions that have the potential to affect Arctic Charr growth and health.

Conclusion

Work at examining THg concentrations in northern populations of Arctic charr has contributed significant to improved understanding of the biological and ecological characteristics associated with high contaminant loadings. It is clear from the work to date that age, rather than length, is more critical for determining THg levels in Arctic charr. Comparative studies of marine and freshwater foodwebs supporting Arctic charr further showed that there was no difference in habitat-related biomagnification rates but that differences at the base of the foodweb drove the significant differences in THg levels found in freshwater resident and anadromous Arctic charr. Pioneering work with the study of THg in Dolly Varden charr has provided an important baseline against which future changes may be compared to determine significance. The work has not shown particular geographic or temporal patterns but generally found levels of THg in Dolly Varden charr to be well below the safe consumption limits set by Health Canada. In completing the work we have thus, provided important information to locals about the safety of the food supply and filled in a much needed knowledge hap about the relative safety of Dolly Varden charr. Assessment of the foodweb impacts of an anadromous Arctic charr indicated significant ecological impacts. The explanation for the lack of ecological impact due to the introduction was related to the availability of open ecological niches in the evolutionary young aquatic systems found in the North that allow Arctic charr to use resources which were previously unused by resident fish species. Findings from this study indicate that anadromous Arctic charr may be introduced to similar watersheds in the North without negative consequences for resident fish community structure, a fact that will facilitate the judicious management of the resource to meet the increasing demands for Arctic charr that will result from increased human populations. Finally, work on the Beaufort Sea food webs, the utility of MH genetic analytical methods and marine tagging of Arctic charr are all making important contributions to improved understanding of critical Arctic ecosystems or species, with the Beaufort Sea work representing the first comprehensive attempt to describe the structure and function of the foodwebs that support critical northern fisheries and the marine tagging work being the first to study both marine and freshwater over-wintering thermal habitat use and growth.

Residents of the ISR have observed local environmental and unprecedented climate conditions and variability including unpredictable and rapidly changing weather patterns, large increases in summer and winter ambient air temperatures, significant permafrost degradation and erosion, major changes to the local sea-ice and water conditions including thinner sea ice in winter and a lack of ice floes in summer, changes to freshwater flow regimes, new species occurrences, and species not normally seen in this area showing up in higher numbers including beluga whales and Pacific salmon. It is crucial that monitoring of the Arctic Charr resource take place because of its importance to the Inuvialuit people and the increasingly dynamic nature of the environment in which they live. Ultimately, the information and knowledge collected through Component 3 of this project is needed for the management of Arctic Charr stocks harvested by Inuvialuit communities. The results of the research and creation of the Sachs Harbour community-based Arctic Charr monitoring plan will provide data for management decisions to be made by local hunters and trappers committees and co-management boards. Using the mixed methods research approach has expanded our understanding of local and regional environmental indicators of change that are effective and feasible for use in Arctic Charr community-based monitoring plans in these communities. The approach developed here, and lessons learned, may be used as a model in other Arctic communities in the future.

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