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 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 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 to examine the marine life-history phase of Ungava Arctic charr introduced into a previously unoccupied river system. Previously 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. Obtained field results are compared to data gathered in Labrador through collaborations with Fisheries and Oceans Canada. Results and comparisons are critical for assessing the possible impacts of climate change 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 affects 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. The project also identifies key environmental indicators of changes in Arctic Char (*Salvelinus alpinus*) growth using both quantitative (ecological) and qualitative (Indigenous Knowledge) data by linking community-based monitoring, local expert Indigenous and ecological knowledge. Arctic Char is 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 and report these changes and variability in local climate and the effects they have 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 projected climate variability and change. Using a mixed-methods research approach 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 comparative analysis of spatial differences in lacustrine and anadromous Arctic charr (*Salvelinus alpinus*) along a latitudinal gradient in the eastern Canadian Arctic, assessment of differences in basal mercury concentrations and biomagnification rates in freshwater and marine food webs and their consequent effects on Arctic charr, an analysis of historical differences in mercury concentrations in Labrador Arctic charr and western Canadian Dolly Varden charr.
- When spatial patterns of total mercury concentration (THg) were measured in Arctic charr from 9 spatially paired anadromous and non-anadromous populations along a latitudinal gradient in eastern Canadian Arctic charr were assessed mean THg in non-anadromous populations were found to exceed mean THgin co-located anadromous populations. The lower THg concentrations in anadromous fish were not explained by differences between anadromous and non-anadromous fish in age, fork-length, trophic level, or growth rate. Among-individual variation in THg within a population, however, was best explained by fish age. Finally, anadromous and non-anadromous Arctic charr THg concentrations were independent of latitude (49 – 81° N) along the gradient studied in eastern Canada.
- 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 δ^{15}N-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.
- Historical comparisons of total mercury concentrations (THg) in Arctic charr from Labrador captured between 1977-78 and 2007-09 showed no wide-scale changes in age- and length-adjusted THg concentrations between the two periods, although mean age and fork-length of captured fish declined between the two time periods. Patterns were similar in anadromous and non-anadromous Arctic charr. The constancy of THg patters occurred even though significant warming trends were observed at Labrador weather stations between 1977-78 and 2007-09, suggesting that climate change related impacts on THg levels may be minimal.
- Total mercury concentrations were measured in Dolly Varden (Salvelinus malma) populations located in the Yukon and Northwest Territories similarly showed THg concentrations were not related to latitude or longitude. The assessment was the first comprehensive assessment of THg concentrations in Dolly Varden charr that has ever been undertaken. In Dolly Varden charr among-population variation in THg was best explained by fork-length, not age as with Arctic charr. THg concentrations were also found to be related to age, δ^{15}N, and δ^{13}C., suggesting a significant role for habitat and prey use in the ultimate determination of measured THg concentrations. In all instances, mean THg concentrations were below the guidelines for subsistence consumption.
- Follow on studies of thermal habitat use by Arctic charr were completed using data collected in the Nepihjee River collaborative (U of

Waterloo/Nunavik research) project. Individual measurements of annual, or within-season growth were determined from tag-recaptured Arctic charr and examined in relation to summer sea surface temperatures and within-season capture timing in the Ungava (Nephijee River) and Labrador regions of eastern Canada. Differences between two years of growth (2010-2012) were significant for Ungava Bay Arctic charr, with growth being higher in the warmer year. Growth of Labrador Arctic charr did not vary significantly among years (1982-1985). Regional comparisons demonstrated that Ungava Arctic charr had significantly higher annual growth rates, and experienced warmer temperatures than Labrador Arctic charr. The higher annual growth of Ungava Bay Arctic charr was attributed to the high sea surface temperatures experienced in 2010-12 and the localized differences in nearshore productivity as compared to Labrador. A complete analysis of the data will be completed in 2014 for publication.

- Temperature use studies with larger anadromous fish were supplemented by detailed comparison of the effects of juvenile habitat use on growth. Despite differences in predicted hydroecological responses to climate change in fluvial and lacustrine environments, little is known of whether fluvial and lacustrine Arctic charr populations may respond differentially to increasing temperatures. To compare growth and thermal habitat use between habitat types, otolith-inferred average water temperatures estimated from whole otoliths and fork lengths at capture were measured for young-of-the-year (YOY) Arctic charr obtained from two proximal fluvial and lacustrine sites in Labrador, Canada. Otolith-inferred average experienced water temperatures were not significantly correlated with air temperatures at both sites, suggestive of behavioural thermoregulation by YOY. The majority of Kogluktokoluk Brook (fluvial) YOY were found using water temperatures consistent with laboratory determined preferred temperatures for juvenile Arctic charr, whereas most Tom's Pond (lacustrine) YOY were found using temperatures ranging between preferred temperatures and optimal temperatures for growth. There was no consistent difference between mean temperatures used between YOY from the two sites. Otolith-inferred average experienced water temperatures were only correlated to fork lengths in Tom's Pond YOY. The lack of correlation in Kogluktokoluk Brook YOY is argued to reflect resource partitioning occurring as a result of territoriality known to occur among stream salmonids. The limited range of temperatures used by fluvial YOY in this study, particularly the lack of cooler temperatures, also suggests that fluvial YOY may face barriers to thermal refugia, and as a result may be particularly vulnerable to climate change.
- Finally, as part of continuing tool development to better understand the responses of Arctic charr to the varying environments in which they live, a proof-of-concept genetics study was completed in 2013. Among Arctic charr divergent populations have adapted to thrive in the prevailing oligotrophic environments, developing morphotypes with different ecological behaviours. The morphotypes usually differ in size, morphology, coloration, feeding ecology and/or habitat occupancy. Although morphotypes that have very divergent spawning seasons should become genetically segregated, most attempts to distinguish them genetically have failed. Thus results to date have suggested that Arctic charr morphotype separation has been driven largely by the environmentally mediated phenotypic plasticity of the species, with differentiation between morphotypes having commenced too recently to generate measurable genetic drift. Here we used the Major Histocompatibility (MH) Class II genes in an attempt to isolate sympatric Arctic charr morphotypes known to be ecologically differentiated. These morphotypes are from postglacial lakes in both Siberia and Eastern Canada, and differ in either diet, habitat

occupancy or both. The MH Class II allelic polymorphism was significantly different between morphotypes. This suggested differential heritable adaptation to the natural selection exerted by pathogens unique to each ecologic niche within each lake. The technique, therefore, should allow differentiation of morphs that were not previously genetically distinguishable, which will facilitate understanding the importance of genotype in differentiation of sympatric morphotypes.

Objectives

2012-14 – Overall Project 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 in relation to other competing anadromous species and the foodwebs within which they feed. A third key objective was to improve understanding of the structure and function of Beaufort Sea foodwebs. And a fourth 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. (Completed)
- Measured differences in THg levels among individuals will be correlated with trophic level and feeding, with THg increasing as δ15N increases and δ^{13}C decreases. (Completed)
- Measured THg levels will be positively correlated with the size and age of tested fish. (Completed)
- 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. (On-going)

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. (Completed)
- 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. (Completed)
- To compare and contrasted with IPY-related studies of anadronmous Arctuic 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. (Completed)

Specific objectives for the improved understanding of Beaufort Sea foodwebs:

- Characterize niche overlap amongst offshore (deeper than 200 m) marine fish, and trophic linkages between fish and invertebrates. (Completed)
- Investigate the effect of depth on food web structure. Paired comparisons between shelf (shallower than 200 m) and offshore (deeper than 200 m) food webs. (On-going, further work planned for 2104-15)

- Investigate how offshore food web structure varies with water mass influence (does water column complexity relate to food web complexity?), with emphasis on areas of potential upwelling along the shelf. (On-going)
- Provide a good characterization of pelagic and benthic food webs from 1000 m to 1500 m (deepest sampling conducted in the Canadian Beaufort). (On-going, further work panned for 2014-15)

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. (Completed)
- The introduction of Arctic charr will increase omnivory in lake trout diets as a result of Arctic charr becoming a prey resource. (Completed)
- 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. (Completed)

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 was not a limiting factor. (Completed)

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

- There will be no significant differences among individuals in terms of mean over-winter thermal habitat use. (On-going, data to be analyzed)
- Smaller Arctic charr will remain longer in the marine environment and, as a consequence, experiencing higher average marine temperatures and greater proportional seasonal growth in comparison to conspecifics remaining shorter periods of time in the Marine environment. (On-going, nearing publication)

Finally the objectives related the study of 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 were as follows:

- 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 Char 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 Char identified through IK interviews with local experts
- Examine meteorological and hydrological data for the areas surrounding the study sites to determine effects on Arctic Char growth
- Characterize lake habitat conditions and compare between study lakes to determine effects on Arctic Char 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 expertise to implement effective CMBPs for char in ISR 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 successful collaborations with Nunavik Research, component 1 of the project will focus on 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. To better understand climate change implications, sites at differing latitudes will be selected for study, including but not limited to the Ungava Bay area and the Labrador coast. 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 also 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 the nearshore portions of the foodweb. Coupled, these changes recommend a detailed assessment of anthropogenic impacts on Beaufort nearshore foodwebs and the anadromous fish species that rely on them. Finaly, component 4 focuses on the effects of climate change on Arctic Char subsistence resource in the Inuvialuit Settlement Region and community-based monitoring of the resource. 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., 2006). 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., 2006), 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 Char growth using both scientific and local expert Indigenous Knowledge in a mixed methods approach. The current importance of Arctic char 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 2013 Research Activities:

[1]

- What: Finalization and proofs correction of the following papers for final release in 2013 and finalization of joint collaborative reports and papers summarizing Arctic wide trends in THg. Work here relates to objectives related to components 1 and 2 of the project.

    1. van der Velden, S., Dempson, J. B., Evans, M. S., Muir, D. C. G. and Power, M. 2013. 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. 444:531-542.
    2. van der Velden, S., Evans, M. S., Dempson, J. B., Muir, D. C. G. and Power, M. 2013. Comparative analysis of total mercury concentrations in anadromous and non-anadromous Arctic charr (*Salvelinus alpinus*) from eastern Canada. Science of the Total Environment. 447:438-449.
    3. Murdoch, A., Power, M., Klein, G. and Doidge, D. W. 2013. Assessing the food web impacts of an anadromous Arctic charr introduction to a sub-Arctic watershed using stable isotopes. Fisheries Management and Ecology. 20:302-314.
    4. Chételat, J. Amyot, M., Arp, P., Blais, J., Depew, D., van der Velden, S., Emmerton, C., Evans, M., Gamberg, M., Gantner, N., Girard, C., Graydon, J., Kirk, J., Lean, D., Lehnherr, I., Muir, D., Nasr, M., Poulain, A., Power, M., Rencz, A., Roach, P., Stern, G. and Swanson, H. Mercury in freshwater ecosystems of the Canadian Arctic: Recent advances on its cycling and fate. Submitted to Science of the Total Environment.
    5. Chételat, J. Amyot, M., Arp, P., Blais, J., Depew, D., Dorn, S., Emmerton, C., Evans, M., Gamberg, M., Gantner, N., Girard, C., Graydon, J., Kirk, J., Lean, D., Lehnherr, I., Muir, D., Nasr, M., Poulain, A., Power, M., Rencz, A., Roach, P., Stern, G. and Swanson, H. 2013. Freshwater Environment. Pages 101-157 (Chapter 5) in Canadian Arctic Contaminants Assessment Report III 2012. Chetelat, J. and Braune, B. (eds). Public Works and Government Services Canada, Ottawa, ON. 276 p.

- Where: All work completed in laboratory settings at the University of Waterloo (manuscript writing, revision and proofing) or in Environment Canada and other University laboratories (collaborative writing of the Chételat et al. report and submitted manuscript),
- When: van der Velden and Murdoch et al manuscripts: analysis completed January 2012 through November 2012, final proofing completed January - April 2013. Chételat et al. report and manuscripts: writing and proffing completed January through November 2013.
- Who: MSc students S. Dorn (now van der Velden) and A. Murdoch, Dr. M. Power and co-authors M Evans, J. B. Dempson, D. C. G.

Muir, D. Doidge and G. Klein. For the Chételat et al. report and papers, who inckudes the listed co-authors.

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

[2]

- What: Finalization and publication of: "Murdoch, A. and Power, M. 2013. The effect of lake morphometry on thermal habitat use and growth in Arctic charr populations: implications for understanding climate-change impacts. Ecology of Freshwater Fish. 22:453-466." A study linking differences in available lake habitat types to differences in climate-warming impacts on Arctic charr populations. Work here relates to objectives related to component 1 of the project.
- Where: All work completed in 2013, completed in laboratory settings at the University of Waterloo (manuscript writing, revision, proofing).
- When: Analysis completed January 2013 through June 2013.
- Who: MSc student A. Murdoch and Dr. M. Power.
- How: Face-to-face collaboration and discussion of written material.

[3]

- What: Finalization and publication of: "Sinnatamby, R. N., Shears, M., Dempson, J. B. and Power, M. 2013. Thermal habitat use and growth in young-of-the-year Arctic charr from proximal fluvial and lacustrine populations in Labrador, Canada. Journal of Thermal Biology. 38:493-501." A second study linking differences in available habitat types to differences in climate-warming impacts on Arctic charr populations, this time looking at differences between rivers and lakes. Work here relates to objectives related to component 1 of the project.
- Where: All work completed in 2013, completed in laboratory settings at the University of Waterloo (manuscript writing, revision, proofing).
- When: Analysis completed January 2013 through August 2013.
- Who: PhD student N. Sinnatamby, J. B. Dempson and Dr. M. Power.
- How: Face-to-face collaboration and discussion of written material.

[4]

- What: Finalization and publication of: "Sinnatamby, R. N., Reist, J. D. and Power, M. 2013. Identification of the maternal source of young-of-the-year Arctic charr in Lake Hazen, Canada. Freshwater Biology. 58:1425-1435." A study providing the first estimates of the reproductive importance of differing morphotypes in Lake Hazen for overall population abundance. Work here relates to objectives related to component 1 of the project.
- Where: All work completed in 2013, completed in laboratory settings at the University of Waterloo (manuscript writing, revision, proofing).
- When: Analysis completed January 2013 through June 2013.
- Who: PhD student N. Sinnatamby, J. D. Reist and Dr. M. Power.
- How: Face-to-face collaboration and discussion of written material.

[5]

- What: Finalization and publication of several collaborative studies on Arctic charr in the Arctic:

    1. Reist, J. D., Power, M. and Demspon, J. B. 2013. Arctic charr (*Salvelinus alpinus*): a case study of the importance of understanding biodiversity and taxonomic issues in northern fishes. Biodiversity. 14:45-56.

2. Eloranta, A., Mariash, H., Rautio, M. and Power, M. 2013. Lipid-rich zooplankton subsidize the winter diet of benthivorous Arctic charr (*Salvelinus alpinus*) in a subaractic lake. Freshwater Biology. 58:2541-2554.

- Studies were designed to advance understanding of biodiversity within Arctic charr both in terms of their form (Reist et al., 2013) or their function (Eloranta et al., 2013) by examining variation in the morphology across Canada in the one instance and the variation among individuals min terms of feeding tactics during the winter in the second instance. The Eloranta et al. (2013) study is among the first to have looked in detail at winter feeding in Arctic charr and in conditions that Arctic charr spend more than half their lives (i.e. under ice). Work here relates to objectives related to component 1 of the project.
- Where: All work (manuscript writing, revision, proofing) completed in 2013, completed in laboratory settings at the University of Waterloo, Fisheries and Oceans Canada, the University of Jyväskylä, or Université du Québec à Chicoutimi.
- When: Analysis completed January 2013 through May 2013.
- Who: A. Eloranta, H. Mariash, M. Rautio , J. D. Reist and Dr. M. Power.
- How: Face-to-face collaboration and discussion of written material.

[6]

- What: Finalization and publication of several methods studies pertaining to Arctic charr and the development of methods for improved study and understanding of Arctic charr:

1. Michaud, W. K., Dempson, J. B., Reist, J. D. and Power, M. 2013. Ecological influences on the difference in $\delta^{15}N$ and $\delta^{13}C$ values between fish tissues: implications for studies of temporal diet variation. Ecology of Freshwater Fish. 22:520-529
2. Conejeros, P., Power, M., Alekseyev, S. and Dixon B. 2012. Global major histocompatibility Class II β (mh-II β)-polymorphism in Arctic charr Salvelinus alpinus. Journal of Fish Biology. 81: 1158-1174

- The first study was designed to advance understanding of the use of stable isotopes to improve our understanding of the feeding ecology of Arctic charr, with results demonstrating that ecological factors other than a change in diet can influence the differences in stable isotope signatures and need to be properly accounted for in future studies.The second study was designed as a proof of concept study to validate the use of the Major Histocompatibility (MH) Class II genes as a means of genetically isolating sympatric Arctic charr morphotypes known to be ecologically differentiated. Isolation was achieved and the technique should allow better differentiation of morphs that were not previously genetically distinguishable, which will facilitate understanding of Arctic charr diversity and the importance of genotype in differentiation of sympatric morphotypes. Work here relates to objective related to component 1 of the project.
- Where: All work (manuscript writing, revision, proofing) completed in 2013, completed in laboratory settings at the University of Waterloo,
- When: Analysis completed January 2013 through November 2013.
- Who: P. Conejeros, B. Dixon and Dr. M. Power.
- How: Face-to-face collaboration and discussion of written material.

[7]

- What: continued monitoring of Nepihjee River Arctic charr population and re-capture of previously PIT-tagged fish. Work here relates to objectives related to component 1 of the project.
- Where: field site on the Nepihjee River.

- When: August to September 2013.
- Who: Nunavik Research fisheries technicians.
- How: via live capture of Arctic char in a special purpose live trap inserted into a fishway and use of standard PIT-tagging equipment.

[8]

- What: Continued monitoring of acoustic tagged Arctic charr (n = 50) in the marine environment for purposes of monitoring marine thermal habitat use, and monitoring of fish in over-wintering lakes. Data from the over-winter period was download in June, with second summer marine use data downloaded in August. The over-winter monitoring data is the first of its kind. Work here relates to objectives related to component 1 of the project.
- Where: field site at Gilbert Bay, Labrador.
- When: January to August 2013.
- Who: Corey Morris and Curtis Pennell, DFO, Dr M. Power, University of Waterloo.
- How: Recording of fish movement and temperature use in Arctic char with Vemco V13 (n = 40) and V9 (n = 10) acoustic tags. Monitoring and recording of fish location and temperature using a special purpose array of receivers in both marine and freshwater environments.

[9]

- 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 to consider differences among life-history forms: anadromous, freshwater resident and freshwater isolates. Work here relates to objectives related to component 2 of the project.
- 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. Additional archival samples for the life-history analysis were acquired directly via collaborative contacts with DFO to improve the statistical robustness of the analysis. For the temporal analysis, additional samples were acquired for several sites directly via field work completed in 2012 (Shingle Point, Firth River and Thetis Bay) where sample numbers were low and via collaborative contacts with DFO for 2013 with the aim being to improve the statistical power of the on-going temporal analyses that have shown no temporal effect to date.
- When January to December 2013.
- Who: MSc student L. Tran, S. van der Velden, J. D. Reist and M. Power.
- 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 DDO 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). Data for the life-history analysis has been analysed and written up for presentation at the upcoming 67th Canadian Conference for Fisheries Research in Yellowknife, N.W.T. (Tran, L., vand der Velden, S. Reist, J. D. and Power, M. Life-history differences in Dolly Varden (*Salevlinus malma*) mercury concentrations). Analysis of the temporal changes in THg concentrations is ongoing.

[10]

- What: Completion of stable isotope sample analysis from the first (2012) field season and completion of the second field season for 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. Work here relates to objectives related to component 3 of the project.
- Where: Beaufort Sea in conjunction with the Beaufort Sea Environmental Assessment initiative.
- When: Completion of first field season samples by December 2013. Collection second filed season samples, August-September of 2013 by PhD student Ashley Stasko during F/V Frosti summer sampling program. The analysis of samples second field season samples commenced in November 2013 and is on-going.
- Who: M. Power, J. Reist, K. Mitchell (BSc laboratory technician), A Stasko (PhD student).
- How: Samples obtained via various trawl methods directly from a ship (M/V Frosti). All stable isotope analysis 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). Results disseminated at the ArcticNet 9th Annual Scientific Meeting, Dec 9-13, 2013, Halifax, NS, Canada, via a poster (Stasko, A. D., Reist, J. D., Swanson, H. K. and Power, M. Pelagic food web structure of the Canadian Beaufort Sea: a sneak-peak at complexity from shelf-break out).

[11]

- What: continued characterization of the variation in immunological responsiveness of Lake Hazen Arctic charr using previously obtained field and archival samples. The purpose of this study was to apply techniques developed by Conejeros et al. (See Point 6 above) to evaluate genotypic differences in the described morphotypes of Lake Hazen. The analysis is part of a larger effort to characterize Major Histocompatibility (MH) differences along a latitudinal gradient in order to better understand the relationship between pathogen load, the local environment and the function of the immune system both within and between individuals of a northern cold water fish species. For morphtypes found in Lake Hazen the work to date has indicated that in spite of measurable morphological and meristic differences, MH tools only substantiate the presence of two distinct forms with the proposed third form likely representing a life-history transition of the small form. The results increase our understanding of evolutionary processes, functional differences between Arctic charr groups and the processes through which adaptive potential is maintained within and between populations of this adaptable fish species. Work here relates to objectives related to component 1 of the project.
- Where: University of Waterloo laboratories.
- When: January to December 2013 and on-going.
- Who: PhD student T. Robinson, B. Dixon, R. and M. Power.
- How: using state-of-the-art genotyping methods (MH) as described in the methods of DNA extraction and genotyping described by Conjeros et al. (2008, 2013). Results disseminated at the ArcticNet 9th Annual Scientific Meeting, Dec 9-13, 2013, Halifax, NS, Canada, via a poster (Robinson, T. N., Reist, J. D., Bajno, R., Power, M. and Dixon, B. Genetic assessment of possible ecological forms of Arctic charr (*Salvelinus alpinus*) in Lake Hazen, Ellesmere Island, Nunavut, Canada).

[12]

- What: presentation of interim results to appropriate national and international conferences. Work here relates to objectives related all components of the project.
- Where: International Conference on Mercury as a Global Pollutant, Edinburg, Scotland; Canadian Conference for Fisheries Research, Windsor; and the 9th ArcticNet Annual Scientific Meetings, Halifax.
- When: January 2013, June-August 2013, October 2013 and December 2013:
- Who: M. Power, J.D. Reist, S. van der Velden, T. Robinson, A Stasko and S. Swanson.
- How: platform and poster presentations as follows:

1. Swanson, H. K., Tonn, W.M., Power, M., Johnston, T.A. and Reist, J.D. Life and times of anadromous lake trout (*Salvelinus namaycush*) in the Canadian Arctic. 66th Canadian Conference for Fisheries Research. January 4-6, 2013, Windsor, Ontario, Canada.
2. Burgess, N. M, Depew, D. C., Gamberg, M., Chételat, J., Campbell, L. M., Clayden, M., Evans, M. S., LeBeuf, M., Letcher, R. J., Loseto, L .L. Muir, D. C. G., Power, M., Stern, G. A. and van der Velden, S. National Assessment of Geographical Variation of Mercury in Biota across Canada. 11th International Conference on Mercury as a Global Pollutant, July 28-August 2, Edinburgh, Scotland.
3. Robinson, T. N., Bajno, R., Dempson, J.B., Jones, S., McLaughlin, J.D., 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. Aquaculture Association of Canada Conference, Guelph, ON, June 2-5, 2013.
4. van der Velden, S., Dempson, J. B., Evans, M. S., Muir, D. C. G. and Power , M. Basal mercury concentrations and biomagnification rates in freshwater and marine food webs: effects on Arctic charr (*Salvelinus alpinus*) from eastern Canada. 11th International Conference on Mercury as a Global Pollutant, July 28-August 2, Edinburgh, Scotland.
5. van der Veldon, S., Dempson, J. B. And Power, M. Comparing mercury concentrations across a thirty year time span in anadromous and non-anadromous Arctic charr from Labrador, Canada. 11th International Conference on Mercury as a Global Pollutant, July 28-August 2, Edinburgh, Scotland.
6. Robinson, T. N., Bajno, R., Dempson, J.B., Jones, S., McLaughlin, J.D., 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. Atlantic Canada Association of Parasitologists (ACAP)/ Pictou, NS, October 18-20, 2013
7. Dixon, H. J., Dempson, J. B., Sheehan, T. F., Renkawitz, M. D. and Power, M. Assessing trophic ecology of migrating Atlantic salmon (*Salmo salar l.*) caught off the West Greenland coast. ArcticNet 9th Annual Scientific Meeting, Dec 9-13, 2013, Halifax, NS, Canada.
8. Robinson, T. N., Reist, J. D., Banjo, R., Power, M. and Dixon, B. Genetic assessment of possible ecological forms of Arctic charr (*Salvelinus alpinus*) in Lake Hazen, Ellesmere Island, Nunavut, Canada. ArcticNet 9th Annual Scientific Meeting, Dec 9-13, 2013, Halifax, NS, Canada.
9. Stasko, A. D., Reist, J. D., Swanson, H. K. and Power, M. Pelagic food web structure of the Canadian Beaufort Sea: a sneak-peak at complexity from shelf-break out. ArcticNet 9th Annual Scientific Meeting, Dec 9-13, 2013, Halifax, NS, Canada.

[13]

- What: worked with the funding partner Ouranos to produce an information sheet on climate change impacts on Arctic charr "Measuring the effects of temperature variation on arctic charr growth: implications for the management of the species in northern Québec" that summarizes the climate change impact implications of research work conducted on the Nepihjee River.
- Where: University of Waterloo, Montreal
- When: June to December 2013:
- Who: A. Debrabandere (Ouranos) and M. Power
- How: Collaborative writing and refining of a 2 page fact sheet for distribution.

[14]

- What: Completion of Arctic Char otolith analyses to determine fish age and annual growth.
- Where: Trent University, Peterborough ON; Fleming College, Lindsay ON; Fisheries and Oceans Canada Freshwater Institute, Winnipeg MB
- When: April 2013 – February 2014
- Who: PhD Candidate J.Knopp, research assistants/lab technicians Mike Harte and Marie Gautreau, Fisheries and Oceans Canada ageing technician Rick Wastle
- How: Remaining otoliths to be analyzed were embedded, sectioned, polished, photographed, aged and their annual growth rings are measured and analyzed for comparisons among lakes.

[15]

- What: Local expert knowledge (IK) additional analyses.
- Where: Trent University, Peterborough ON and Inuvik NT
- When: April 2013 – January 2014
- Who: PhD Candidate J.Knopp, research assistant Vinay Rajdev
- How: Qualitative analyses methods using thematic coding and NVivo software.

[16]

- What: Char tissue analysis for total mercury levels.
- Where: Trent University, Peterborough ON
- When: April 2013 – Mar. 2013 (work on-going)
- Who: Hogler Hintelmann lab, Trent University
- How: Requests from the community for the char 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. Total mercury content was analysed in ppm from Arctic Char and Lake Trout tissue samples from five study lakes on Banks Island.

[17]

- What: Total mercury analyses report.
- Where: Trent University, Peterborough ON
- When: April 2013 – March 2014 (work on-going)
- Who: PhD Candidate J.Knopp, Research Associate Lisa Kraemer
- How: Report of results of total mercury analyses of from Arctic Char and Lake Trout tissue samples from five study lakes on Banks Island

[18]

- What: Invertebrate expert identification of Arctic Char stomach contents.
- Where: York University, Toronto ON
- When: September 2013 – February 2014

- Who: PhD candidates Ryan Scott and Chris Luszczek
- How: Invertebrates from Arctic Char stomach contents sample preparations, expert identification to lowest taxononmic level possible and total counts for each taxon.

[19]

- What: Presentations
- Where: ArcticNet Annual Scientific Meetings in Halifax NS
- When: December 2013
- Who: PhD Candidate J.Knopp
- How: Poster presentation (see publications section).

[20]

- What: PhD Thesis Writing
- Where: Trent University, Peterborough ON and Inuvik NT
- When: April 2013 – March 2014 (work on-going)
- Who: PhD Candidate J.Knopp
- How: Data analyses and thesis writing.

[21]

- What: Consultations and work with northern partners for the implementation of the proposed Arctic Char Community-Based Monitoring Program in Sachs Harbour.
- Where: Sachs Harbour and Inuvik NT
- When: April 2013 – March 2014 (work on-going)
- Who: PhD Candidate J.Knopp, Sachs Harbour Hunters and Trappers Committee, Inuvialuit-Canada Fisheries Joint Management Committee, Inuvialuit Game Council, Joint Secretariat, ISR Community-Based Monitoring Program
- How: Meetings, teleconferences and consultations with northern organizations listed above to determine most effective way to implement the community-based monitoring program designed through the research project and facilitate community capacity building and execution of the Arctic Char community-based monitoring program.

[22]

- What: Community meetings for review of final results and analyses.
- Where: Sachs Harbour and Ulukhaktok NT
- When: January – February 2014 (upcoming)
- Who: PhD Candidate J.Knopp, Sachs Harbour and Olokhaktomuit Hunters and Trappers Committees, community harvesters
- How: Meetings with Hunters and Trappers Committees and community meetings for review of final data and analyses, local expert input on interpretation of results.

[23]

- What: Water quality sampling.
- Where: Sachs Harbour NT
- When: January – February 2014 (upcoming)
- Who: PhD Candidate J.Knopp, Sachs Harbour Hunters and Trappers Committees, community harvesters
- How: Travel to field sites to collect additional water samples and submit to lab for analyses.

Results

Work on thermal habitat use completed in 2013 demonstrated the importance of habitat use for understanding the consequences of climate change on the growth of Arctic charr. Using otolith-inferred average water temperatures estimated from whole otoliths and fork lengths at capture were measured for young-of-the-year (YOY) Arctic charr obtained from two proximal fluvial and lacustrine sites in Labrador, Canada, Sinntamaby et al. (2013) demonstrated that average experienced water temperatures were not significantly correlated with air temperatures. The result is suggestive of behavioural thermoregulation by YOY. The majority of Kogluktokoluk Brook (fluvial) YOY were found using water temperatures consistent with laboratory determined preferred temperatures for juvenile Arctic charr, whereas most Tom's Pond (lacustrine) YOY were found using temperatures ranging between preferred temperatures and optimal temperatures for growth. There was no consistent difference between mean temperatures used between YOY from the two sites. Otolith-inferred average experienced water temperatures were only correlated to fork lengths in Tom's Pond YOY. The lack of correlation in Kogluktokoluk Brook YOY is argued to reflect resource partitioning occurring as a result of territoriality known to occur among stream salmonids. The limited range of temperatures used by fluvial YOY in this study, particularly the lack of cooler temperatures, also suggests that fluvial YOY may face barriers to thermal refugia, and as a result may be particularly vulnerable to climate change. Similarly, Murdoch and Power (2013) noted the importance of habitat for conclusions about the impacts of changing climates on Arctic charr. They used oxygen stable isotope temperature reconstruction methods to estimate mean experienced summer temperatures from growth zones within individual Arctic charr otoliths sampled from lakes with contrasting morphologies but proximate locations from the Ungava region of northern Quebec (see figure 1).

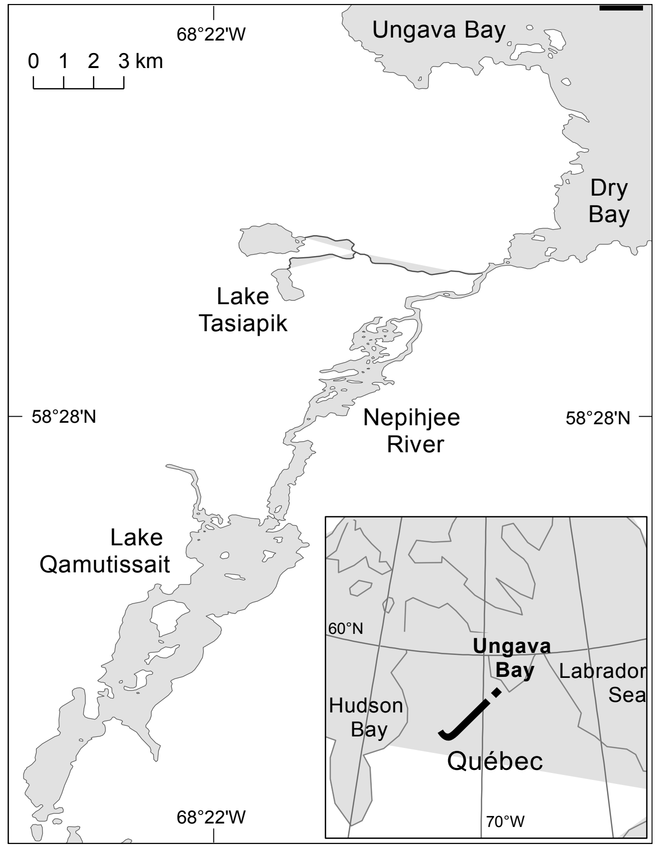

Figure 1. Map of the downstream portion of the Nepihjee watershed, including Lake Qamutissait, Nepihjee River and adjacent Lake Tasiapik sites used in the Murdoch and Power (2013) study. All lakes drain into Dry Bay, Ungava Bay (DMTI Spatial Inc. 2010).

For either lake, otolith-estimated temperatures were not significantly related to back-calculated growth. 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, possibly because of better behavioural thermoregulation opportunities in the cooler, deeper lake. Results provide evidence for differing climate-influenced growth outcomes among proximately located populations, with outcomes likely to depend on the differences among habitats, including lake size and morphometry which may act to influence fish densities in available preferred thermal habitats.

The monitoring of the Nepihjee River (Dry Bay, Ungava) returning Arctic charr run was continued but encountered significant problems. Extreme low flows made the use of the fish trap hazardous to the fish entering and retained in the trap because low water flows risked exposing the fish to air for unsafe periods of time. Accordingly, the fishway was visually monitored several times to ensure fish passage was occurring and a community outreach and advertising program was completed to ensure any previous tagged fish captured in the recreational fishery were identified and key biological data obtained. Obtained observational data continue to show persistent used of the fishway by returning Arctic charr, with anecdotal observation still indicating a similar size range of returning fish. Existing data for the fishway were used in a comparative analysis of annualized growth rates recorded among Arctic charr on the Labrador coast. The comparison suggests that Ungava Arctic charr have significantly higher annual growth rates, and tend to experience warmer temperatures than Labrador Arctic charr but also occupy higher productivity waters (see figure 2).

To better understand the implications of differences in marine water temperatures and/or productivity, a detailed comparative analysis of growth during the marine phase of the life-cycle has been undertaken with a view to formal publication of results by the end of 2014. Finally, 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 finalized and reported on in Murdoch et al. (2013). Findings were summarized in the 2012 report and suggest anadromous Arctic charr may be introduced at moderate densities to other sub-Arctic watersheds without major negative foodweb consequences for other resident fish species.

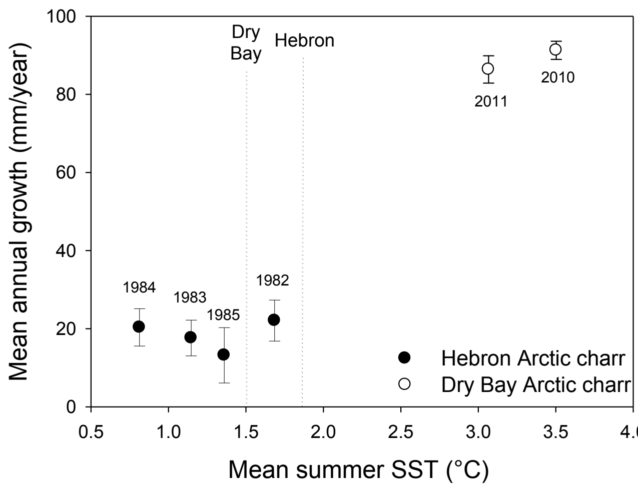

Figure 2. Mean summer sea surface temperatures (SST) and length-adjusted mean annual growth ±95% confidence intervals of Arctic charr in Hebron Fjord, Labrador and Dry Bay (Nepihjee River), Ungava Bay. Mean growth is adjusted to site-specific mean lengths of 418 mm for Hebron Arctic charr and 376 mm for Dry Bay Arctic charr. Years for which the growth rates are relevant are given above or below each point. Long-term summer means (1971-2000) for each region are plotted with dotted lines.

Finalized mercury studies of Arctic charr in eastern Canada reported on in 2012 (van der Velden et al., 2013a) showed consistent differences in total mercury concentrations THg in co-located anadromous and non-anadromous Arctic charr populations, with Mean THg in non-anadromous populations exceeding mean THg in spatially paired anadromous populations. Among-individual variation in THg was best explained by fish age and the lower THg in anadromous fish was not explainable by differences in age, fork-length, trophic level, or growth rate.To better understand the pattern of differences, including the fact that variations in Arctic charr THg were independent of latitude (49–81° N) in eastern Canada, a study of foodweb THg concentrations was completed (van der Velden et al., 2013b). Results showed that biomagnification rates (slopes of THg or [MeHg] versus δ^{15}N-inferred trophic level) were similar in the two habitat types and mrcury concentrations at the base of the food web were higher in lacustrine than in marine food webs. The percentage of methylated mercury was found to increase with trophic level similarly in the two habitat types and the biomagnification rate of MeHg exceeded that of THg in both habitats. To better answer questions about whether contemporary patterns of THg varied significantly from those observed in the past, the study work was extended to include a comparative analysis of the data gathered in the studies above to data available from the historical archive (Bruce et al., 1979). Anadromous and non-anadromous Arctic charr from multiple sample sites in Labrador, Canada were used to investigate possible differences in total mercury concentration (THg) between 1977-78 and 2007-09 (see figure 3).

The mean THg of anadromous Arctic charr was 0.03 µg/g wet weight (ww) in 1977-78 and 0.04 µg/g ww in 2007-09, while mean concentrations in nonanadromous conspecifics were 0.18 µg/g ww in 1977-78 and 0.14 µg/g ww in 2007-09. After correcting for the effects of fish age and fork-length, there was no widespread difference in the mean THg of anadromous or non-anadromous fish between the two time periods. However, at individual sites sampled during both time periods, THg increased, decreased, or did not change. The mean age of sampled fish declined from 9.0 years in 1977-78 to 8.2

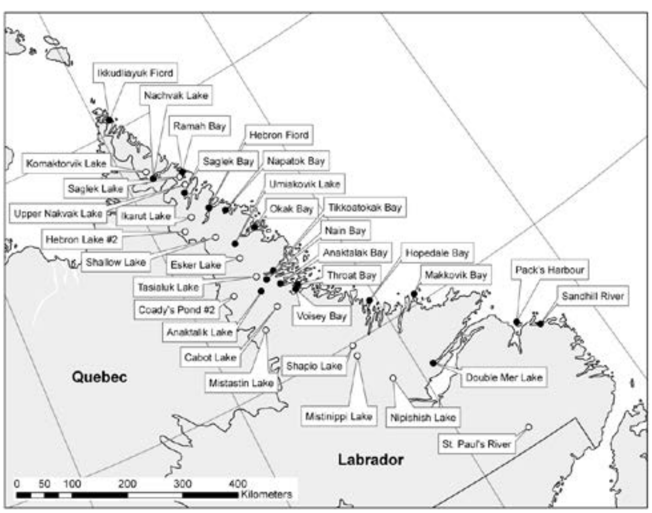

Figure 3. Map of Labrador, Canada indicating the sampling locations of anadromous (black circles) and non-anadromous (white circles) Arctic charr used for the temporal comparison of totalmercury values in Arctic charr (van der Velden et al. accepted).

years in 2007-09 for anadromous fish, and from 11.7 years to 10.5 years in non-anadromous Arctic charr. Similarly, mean fork-lengths decreased from 450 mm to 417 mm in anadromous and from 402 mm to 335 mm in non-anadromous fish between 1977-78 and 2007-09. he lack of an overall trend in anadromous or non-anadromous Arctic charr THg despite warming temperatures that favour increased mercury methylation suggests that regional changes in climate-driven factors have had limited impacts on mercury exposure in Labrador freshwater or marine fish.

The work completed in the eastern Arctic served as a useful comparative template for work completed in the western Arctic on Dollay Varden charr (*Salvelinus malma*), for which there has historically been little THg work completed. In view of the importance of Dolly Varden charr (DVCH) 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, archived DVCH tissue samples were obtained from DFO (1986 on) to construct spatial and temporal profiles of total mercury (THg) in DVCH for relevant populations of concern in the Yukon and Northwest Territories. Supplementary FJMC and DFO funding was latterly obtained with the specific aims of extending and updating both the spatial and temporal limits of the archival samples to include the 2012-13 period.

Spatial Study: In this study (Tran et al., submitted) historical baseline total mercury (THg) concentrations were determined for anadromous Dolly Varden from 10 populations in the Yukon and Northwest Territories (see figure 4).

Spatial variation across a range of latitudes (67-69° N) and longitudes (136-141° W) were analysed as well as possible factors influencing the observed differences. Mean THg concentrations were below the guidelines for subsistence consumption at all sites. Unadjusted mean THg concentrations ranged from 15 to 254 ng/g

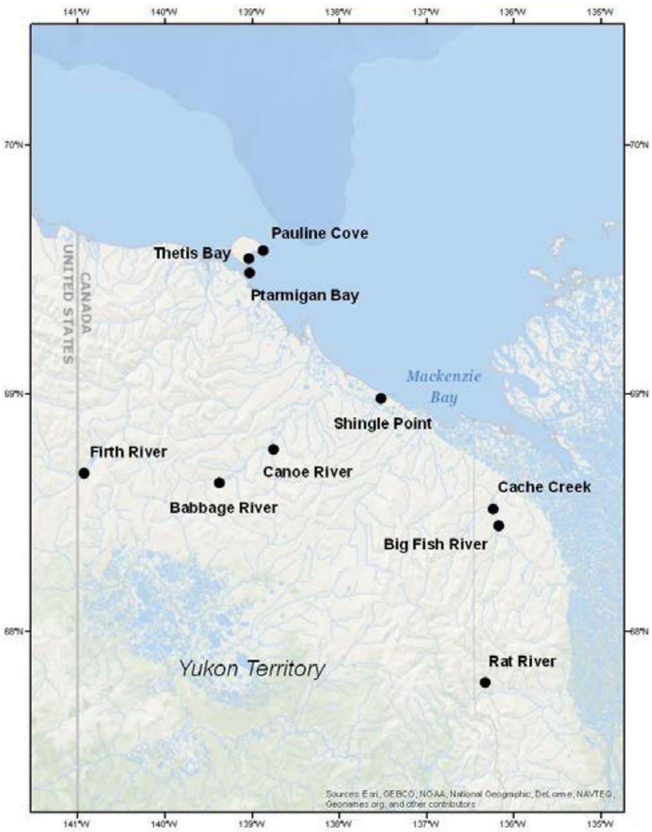

Figure 4. Location of sampling sites for populations of Dolly Varden used in the Tran et al. (submitted) mercury study.

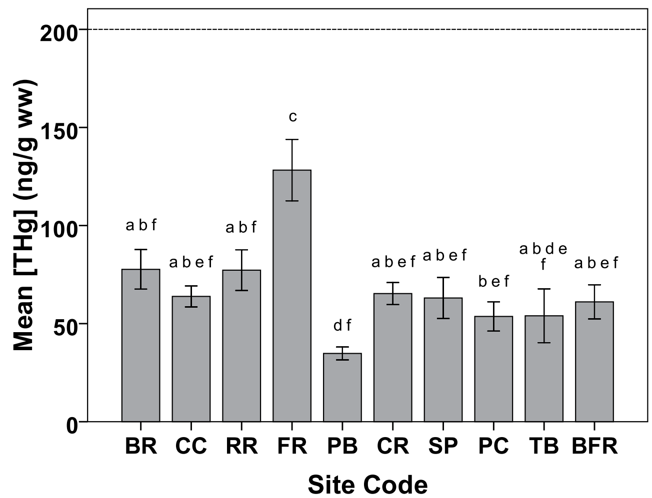

Figure 5. Mean length-adjusted THg (ng/g ww) for Dolly Varden charr sample sites. Error bars represent 95% confidence intervals. Sites with the same letter were not significantly different from one another (Tukey's HSD p > 0.05). The dotted line at 200 ng/g represents the maximum recommended THg limit for subsistence fisheries (Health and Welfare Canada 1984). Site codes and (sample sizes) are as follows: BR=Babbage River (30), CC= Cache Creek (30), RR= Rat River (30), FR = Firth River (14), PB = Ptarmigan Bay (28), CR = Canoe River (30), SP = Shingle Point (16), PC = Pauline Cove (30), TB = Thetis Bay (8) and BFR = Big Fish River (30).

wet weight. Length-adjusted THg concentrations were significantly different among sites , but were not related to latitude or longitude. Within- and among-populations, THg was significantly related to fork-length, age, $\delta^{15}N$, and $\delta^{13}C$. Results show that the variation in THg found among populations was best explained by size (see figure 5).

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 to 94.86 ng/g ww in 1988 to 129.12 ng/g ww n 1995 for the Firth River. For the Rat River length adjusted means showed a significant difference between 1986 and 1988 ($p < 0.05$) and 1986 and 1995 ($p < 0.05$), but no significant trend was observed over time from 1986 to 2011. To improve the robustness of the existing study results, samples were acquired in the summer of 2012 and 2013 to expand the temporal data set. Acquired samples are currently being analyzed and will be included in the statistical analysis of the data for publication.

Life-History Study: Compares the THg concentrations in Dolly Varden charr from the Babbage River watershed where DVCH are found to occur in three life-history variants: anadromous, resident and isolate. Anadromous DVCH migrate to the Beaufort Sea each summer to feed, whereas resident DVCH spend their entire lives in their natal stream and isolate DVH complet their life-cycle in the upper reaches of the Babbage River system as a result of separation from downstream resident populations by either a physical barrier or distance. Freshwater forms (resident and isolate) are smaller and mature at an earlier age than the anadromous form and, therefore, have the potential to display differentiated mercury accumulation dynamics. Data on teh three life-history forms were used to test the hypotheses that: [1] life-history forms exhibit different feeding habits (as measured by $\delta^{13}C$) and occupy different trophic levels (as measured by $\delta^{15}N$), [2] anadromous DVCH had lower THg levels than non-anadromous Dolly Varden, as noted for Arctic charr; and, [3] THg differences among forms would be explained by differences in their isotope values, particularly $\delta^{15}N$. With respect to hypothesis [1] significant differences between marine and freshwater caught DVCH were found for both $\delta^{13}C$ (t-test, $p = 0.00$) and $\delta^{15}N$ (t-test, $p = 0.00$), with differences also found among the freshwater forms for both $\delta^{13}C$ (t-test, $p = 0.013$) and $\delta^{15}N$ (t-test, $p = 0.00$). With respect to hypothesis [2] anadromous THg was found to be 3.8 times higher than isolate THg and 1.3 times higher than resident THg, with resident THg 3 times higher than isolate THg. Interestingly, among life-history form differences contrast with those reported for Arctic charr where the freshwater lacustrine forms have higher mercury concentrations than the anadromous Arctic charr (e.g., van der Velden et al., 2013 a,b). With respect to hypothesis [3], both $\delta^{13}C$ and $\delta^{15}C$ explained a high proportion of the observed variation in among form differences in THg (64% and 75%, respectively). Nevertheless, other factors (e.g. size and age) are responsible for explaining some of the THg differences between the Dolly Varden life history forms. Differences in the among-form results observed for Arctic and Dolly Varden charr are believed to relate to physical differences in the occupied environments (lakes vs rivers) and the implicatiosn of each habitat type for Hg methylation rates. Freshwater DVCH occupy riverine habitats dominated by waters originating in mountainous watersheds where MeHg production is low due to turbulent, oxygenated waters (Emmerton et al., 2013). In contrast, lakes occupied by freshwater Arctic charr are typically small and have higher water temperatures, with higher water temperatures leading to higher methylation rates (Bodaly et al., 1993).

At Gilbert Bay n = 50 Arctic charr were captured, tagged in 2012 and monitored in the marine using an existing array of Vemco receivers deployed by DFO in the summer of both 2012 and 2013. Using the DFO maintained network of 37 receivers covering an area of some 330km2.Of the initial number of fish tagged, n = 5 were captured by local fisherman in 2012 and the tags and associated data (including otoliths) were recovered. By the end of July 2012 the majority of tagged fish had returned from the marine to the freshwater (N = 31) 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 for the period Sept 2012 to April 2013. The attempted over-winter monitoring of Arctic charr obtained the first ever recorded data on the over-winter portion of the life-history. Data downloads were completed in August 2012 (documenting the 1st summer marine period), June 2013 (documenting the 1st over-wintering period) and August 2013 (documenting the 2nd summer marine period). In all, a total of 2.25 million detections were made over the 18 month period for which tags were active, 0.05 million detections made from the n = 10 smaller (<40 cm) VR-9 tags used to tag smaller fish and 2.2 million detections made from the n = 40 smaller VR-13 tags used to tag larger fish (>40 cm) in the summer of 2012, the winter of 2012-13 and the summer of 2013. Over the duration of the tagging fishing and natural related mortality was estimated to be in the 25-30% range. Of the 40 fish tagged with VR-13 tags with extended battery life, 15 fish over-wintered in the first lake of the Shinney's River system that was monitored during the over-winter period. Fishing mortality (n = 13), natural mortality (n = 6) and other loses, including emigration from the monitored area, accounted for the remainder of the tagged fish. No mortality was observed during the over-wintering period and only a single fish did not return to the marine environment. Preliminary analysis of the over-wintering data indicates fish preferred deep-water locations (<20 m) for the majority of winter period. Use of the DFO receiver system, set up for on-going long-term monitoring of Marine Protected Area, facilitated collation of valuable environmental correlate data being gathered as part of DFO study, including: ice conditions, temperature-depth profiles, river flow conditions and discharge, and commercial fishing information in collaboration with the local aboriginal fisheries for Arctic charr. To ensure all tagged fish captured by the local subsistence fishery were accounted for in the study a community information program was under-taken to encourage locals to return any tags obtained in the summer fishery. Returned tags were re-implanted to increase the number of monitored over-wintering fish. Some evidence of tag expulsion was obtained during the re-implant phase and it is expected that some of the tags were naturally expulsed during the rapid summer growth period.

Work continued with the development of tools for using Major Histocompatibility (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, exploratory studies published in 2012 (Conejeros et al., 2012) were advanced to include consideration of detection of differences among morphotypes. The Major Histocompatibility (MH) Class II genes were used to isolate sympatric Arctic charr morphotypes known to be ecologically differentiated from sites in Siberia and Eastern Canada where Arctic charr morphotypes differed in either diet, habitat occupancy or both. The MH Class II allelic polymorphism was shown to be significantly different between morphotypes. The result suggested differential heritable adaptation to the natural selection exerted by pathogens unique to each ecologic niche within each lake. The MH technique, therefore, should allow differentiation of morphs that were not previously genetically distinguishable, which will facilitate understanding the importance of genotype in differentiation of sympatric morphotypes. Results of the study were written up for publication in Conejeros et al. (Accepted) and further developed in Robinson et al. for presentation at the 9th Annual Scientific Meeting of ArcticNet (Halifax 2013 as noted above). In this study differences between samples of ecologically distinctive forms of Arctic charr located in Lake Hazen, Ellesmere Island, Nunavut, were examined using MH methods. Two forms, a larger piscivore that feeds pelagically and a smaller one that tends to feed on benthic invertebrates, are reasonably well differentiated (e.g. Guiguer et al., 2002). Genotyping at the MH Class IIB locus, which is under selection by pathogens in the environment, was completed to evaluate selection for immune function and local adaptation of each possible form. Results support the presence of two distinct forms. The results increase our understanding of evolutionary processes, functional differences between groups and the processes through which adaptive potential is maintained within and between populations by highlighting the importance of the pathogen environment for maintaining differences among groups of related fishes. The promising results of this work will be extended to specifically include consideration of a latitudinal gradient effect as a proxy for climate-driven differences in work planned for 2014.

As part of a multi-agency initiative to better understand the ecosystem dynamics of the Beaufort Sea, significant progress has been made on 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, in association with a number of other government departments undertook the Beaufort Regional Environmental Assessment (BREA) as a means of identifying significant gaps in the scientific and local stakeholder understanding of the Beaufort Sea ecosystem, one of which was that associated with the structure and function of off shore foodwebs. In collaboration with DFO, we have now obtained some 4858 samples of offshore biota from sea depths ranging from 35 to 1500 m for both benthic and pelagic zones respectively. Tissue samples from sampled biota are linked to complementary occurrence, relative abundance and diversity data and habitat descriptors (e.g., depth, substrate, temperature) available through the collection of standard oceanographic variables obtained coincident with biota sampling. Samples were obtained in both 2012 and 2103 at varying depth ranges for sampling transects in the southern Beaufort Sea ranging from the Alaskan border to Amundsen Gulf. Biota were collected from July to September 2012 and again in July to September 2013 using zooplankton hauls, mid-water fishing trawls, and benthic trawls deployed from the F/V Frosti along transects that spanned depths from 20 to 1500 m. All samples obtained in 2012 were catalogued and a sub-sample (n = 1967) were shipped to Waterloo (June 2013) for processing and processed over the period July to November 2013. Samples consisted of n = 56 sediment samples, n = 656 invertebrates, n = 144 zooplankton and n = 1111 fish. Processed samples are currently being analysed for stable isotopes and a preliminary data set (n = 400) was used to complete and analysis of contrasting habitat types to characterize how community structure of marine fishes, benthic invertebrates, and epifauna change with depth and water mass properties. All samples obtained in 2013 have been catalogued and some (n = 500) have been shipped to Waterloo for processing. A total of n = 3135 samples will be processed for the 2013 season, most by the end of March 2103. Samples include: n = 2027 fish, n = 1000 invertebrates, n = 100 zooplankton and n = 108 sediments, with the larger number of 2013 samples resulting from the larger number of habitat types sampled in the 2013 field season (see table 1).

Transects selected for analysis included the GRY transect located at the mouth of the MacKenzie River in an area that receives high freshwater and sediment input and the KUG transect in an area that spans the submarine Kugmallit Canyon to the east of the MacKenzie River estuary that is a site of potential turbulent upwelling. Trophic position and dietary carbon source were inferred from stable isotope analysis of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$), respectively, in muscle (fish, large decapods) or whole viscera without shell (all other animals). Fish $\delta^{15}N$ and $\delta^{13}C$ were adjusted to a standard body size where significant relationships existed with weight. Results to date suggest that fish from deeper habitats may occupy higher trophic positions and exhibit less

Table 1. Beaufort Sea fish families and epibenthos orders sampled and analyzed from contrasting transects in 2012. Yellow highlighting in the grid indicates the sites at which taxa were collected. The GRY transect is located at the mouth of the MacKenzie River and receives high freshwater and sediment input. The KUG transect spans the submarine Kugmallit Canyon to the east of The MacKenzie River estuary and is a site of potential turbulent upwelling.

Taxa	# of Species	Common Name	GRY Transect			KUG Transect		
			40 m	200 m	1000 m	40 m	200 m	1000 m
Fish (Family)								
Cottidae	5	Sculpins	■	■		■	■	
Gadidae	1	Arctic cod	■	■		■	■	
Liparidae	3	Snailfishes	■		■	■	■	■
Pleuronectidae	1	Greenland halibut	■		■			
Stichaeidae	1	Stout eelblenny	■	■		■		
Zoarcidae	3	Eelpouts		■	■	■	■	■
Epibenthos (Order)								
Amphipoda	1	Amphipod	■					
Decapoda	4	Decapods	■	■	■	■	■	
Holothuroidea	1	Sea cucumber	■					
Isopoda	2	Isopods				■		
Mysida	1	Mysis	■					
Nemertea (Phylum)	1	Ribbon worm	■					
Ophiurida	2	Brittle stars	■	■				
Pectinoida	1	Fingernail clam	■					

intra-community variation in diet. Sinking organic matter (i.e., marine snow) which becomes enriched in ^{15}N with depth may also result in higher $\delta^{15}N$ in macrofauna. Available data have not allowed us to determine whether lower intra-community variation in stable isotope signatures is a result of feeding habits, lower variation in available food, or due to smaller sample sizes at deep sites (less species represented). Although the results are preliminary, they provide a fi rst preview of the Beaufort pelagic food web in greater detail than has previously been available. Ultimately, this study will aim to understand how food web structure varies with habitat complexity and depth within the Beaufort Sea. An increase in the size of the available data from the available sample pool for 2012 and 2013 (n >5000) should permit us to distinguish between the possibilities. The final data set will include stable isotope data for sediment and particulate organic matter (POM) in water to help characterize changes in resource availability at the base of the food web and will include more than 40 species of fish, 20 species of zooplankton (including crustaceans, jellies, and krill), and 30 species of epibenthos.

Continued work with local experts in Sachs Harbour reported extensive knowledge and understanding about fish condition, size, numbers, feeding, and migra¬tion. Local experts also provided a detailed understanding of changes in local climate and environmental conditions and how these changes affected both arctic char and char habitat. An example of an emergent theme of an environmental condition that has the potential to affect lake resident Arctic Char 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 that 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 Char community-based monitoring programs.

The results of the quantitative analyses of scientific data showed differences in water chemistry, lake volume and depth among the study lakes near Sachs Harbour. Arctic Char diet and parasite load also varied among the study lakes, despite their close proximity to one another. The von Bertalanffy growth curves (Isely and Grabowski 2007) (Figures 6 and 7) estimated from otoliths collected from Kuptan, Middle, and Capron lakes near Sachs Harbour 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 char and the age at which the maximum size was reached. Von Bertalanffy growth curves were statistically different from each

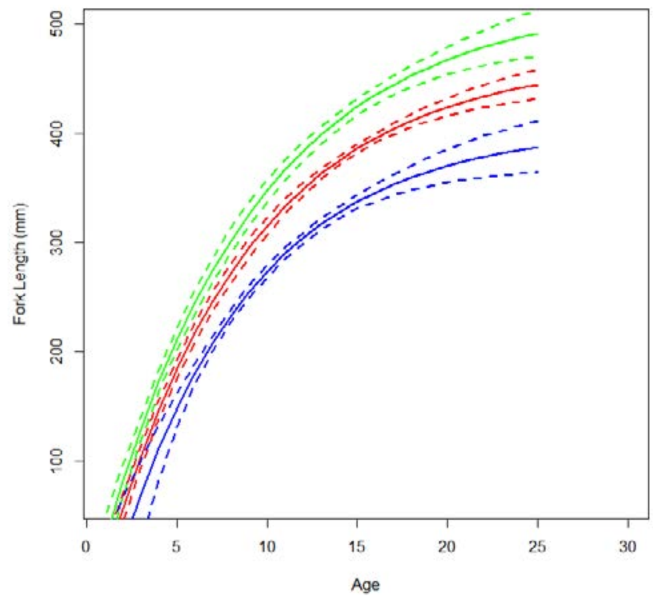

Figure 6. Von Bertalanffy growth curves for Arctic Char collected in 1993-1994 from three landlocked lakes near Sachs Harbour (green = Middle Lake, red = Kuptan Lake, blue = Capron Lake).

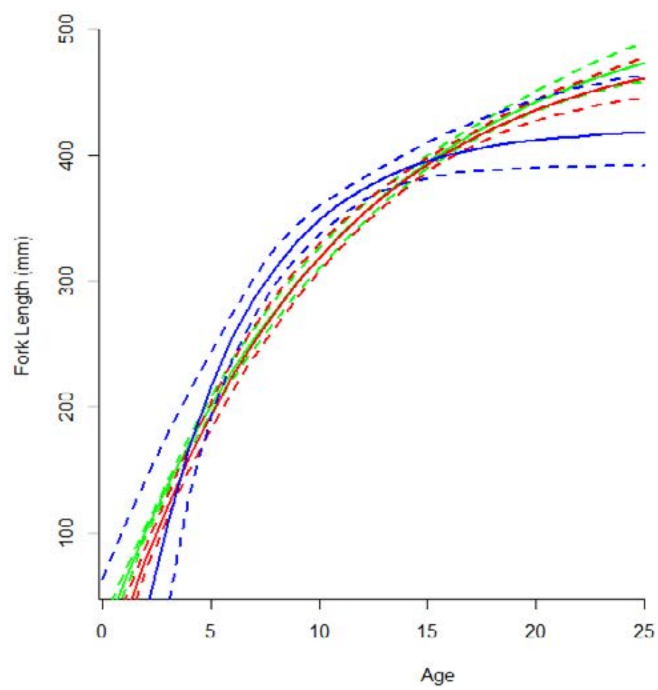

Figure 7. Von Bertalanffy growth curves for Arctic Char collected in 2008-2012 from three landlocked lakes near Sachs Harbour (green = Middle Lake, red = Kuptan Lake, blue = Capron Lake).

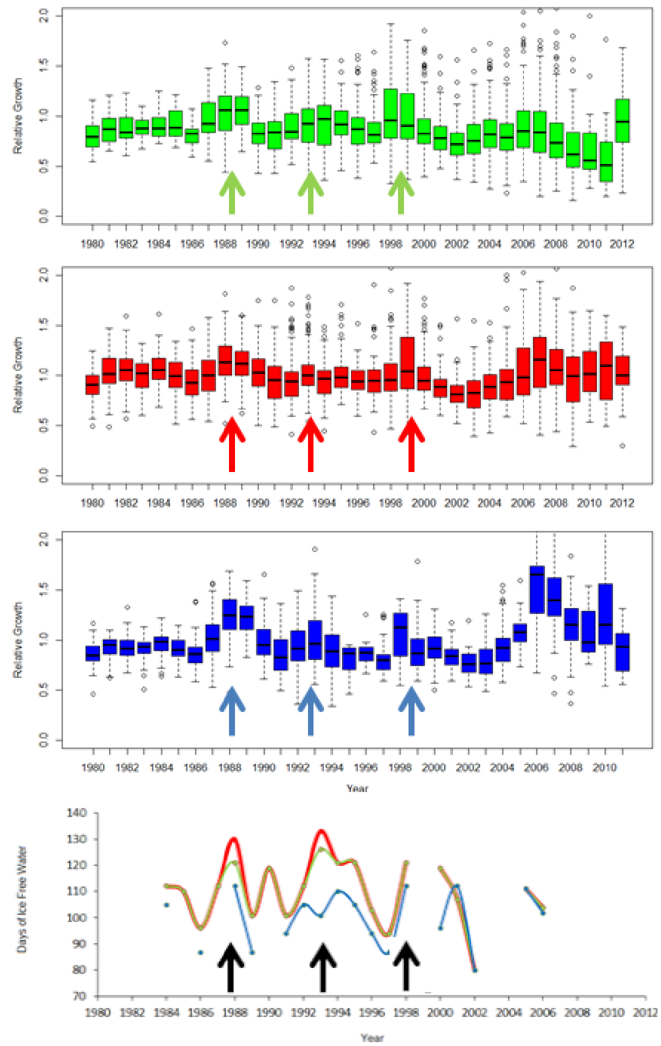

Figure 8. (Top three graphs) The relative growth of Arctic Char in Middle (green, n=376), Kuptan (red, n=161) and Capron (blue, n=134) lakes over the last three decades. The arrows represent years of high growth. (Bottom graph) Number of ice-free days on each lake (Middle Lake = green, Kuptan Lake = red, Capron Lake = blue). The arrows represent years with long ice-free seasons in all three lakes. These three years correspond to the same years of increased growth in Arctic Char.

other in the 1990s with the largest growth rates and body sizes being found in Middle Lake, followed by Kuptan Lake, and last by Capron Lake. In the 2000s, none of the curves were different from each other, yet were still relatively high indicating that the Capron Lake had grown faster and larger, while Middle and Kuptan Lakes populations had each shifted their individuals growth rates slightly towards each other. The influence of the age of the fish and the year of growth on individual growth rates was highly significant within each lake, however, the variation in growth rates was lowest in Middle Lake, followed by Kuptan Lake, and highest in Capron Lake. The knowledge shared in the IK interviews complements the scientific findings of the effect of local lake environment on arctic char growth; interview analyses show that local experts have observed char 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 char growth.

Preliminary results of the otolith back-calculation for char captured in the landlocked study lakes show a large increase in growth in single calendar years across a range of age classes in Middle, Kuptan and Capron lakes (Figure 8, top three graphs). The knowledge shared in the IK interviews complements the scientific findings of changes in Arctic Char growth with interview analyses showing that changes to landlocked char sizes occurred approximately a decade before the start of this research. The IK interview analyses as well as previous IK documented in research proj-ects (Riedlinger and Berkes, 2001, Nichols et al., 2004) showed that major climate and environmental changes occurred around 1998 with late sea ice formation, warmer air temperatures, and major shifts in storm and precipitation events. As noted above, reduced sea ice and warmer ocean waters can lead to warmer ambient air temperatures (open ocean water absorbs more heat from the sun), which in turn could result in warmer conditions in the local landlocked lake environments resulting in more ice-free days on the lakes, resulting in longer growing season. The relationship between ice-free days and percent relative growth ratios (Figure 8) were highly significant in Capron and Kuptan Lakes ($p < 0.00001$), but not in Middle Lake, however due to the high variation among individuals, correlation coefficients were very low. A similar regression approach using only the mean relative growth values demonstrated a stronger correlation that was found across all lakes.

Discussion

Studies of the relationship between water and air temperatures have suggested strong correlations between the two, with the result often being used to drive climate-change related predictions for aquatic biota on the basis of available air temperature predictions. As Sinnatamby et al. (2013) have noted the consequences of habitat choice need to be considered when making such predictions. Contrary to the stated hypotheses, average experienced water temperatures inferred from young-of-the-year (YOY) Arctic charr otoliths obtained from two sites in Labrador (Tom's Pond and Kogluktokoluk Brook) did not correlate with mean air temperatures assumed to characterize the estimated period of growth. That average experienced water temperatures did not correlate with environmental air temperatures suggests that YOY Arctic charr from both sites were not exclusively using shallower bankside or nearshore habitats. The lack of correlation may also indicate behavioural thermoregulation in which fish select habitat with more favourable temperatures (e.g. Murdoch and Power, 2013). Otolith-inferred average experienced water temperatures from Tom's Pond YOY reflect the use of a wider range of thermal habitats than Kogluktokoluk Brook YOY. The use of cooler water temperatures by some Tom's Pond YOY likely reflects the ability of Tom's Pond YOY to access deeper areas of the lake. Godiksen et al. (2011, 2012b) found similar evidence of use of cooler temperatures, and suggested profundal habitat use by YOY. Since average water temperatures experienced by YOY Arctic charr from both populations were largely near or below the optimal temperatures for growth for Arctic charr recorded in the laboratory (e.g. Larsson and Berglund, 1998), it was also expected that temperatures would be positively related to fork length. While a positive correlation was observed in the study for Tom's Pond YOY, it was not observed for Kogluktokoluk Brook YOY. Even among Tom's Pond YOY, otolith-inferred water temperatures accounted for only 9.5% of the observed variation in fork length. Murdoch and Power (2013) similarly observed a distinctive lack of correlation between apparent habitat temperatures and growth ($r2 \leq 0.19$ for all tested relationships) for two Quebec populations, as did Godiksen et al. (2011) for YOY from Dieset Lake, Svalbard ($r2 = 0.13$), with the latter study suggesting that the unexplained variation in size may be related to individual differences in length at hatch (Baroudy and Elliott, 1994) or ration (Elliott, 1994).

Understanding of contemporary relationships between experienced water temperatures and achieved fork lengths may provide insight into possible population-specific responses to climate change. As long as summer temperatures remain within or near the optimal temperatures for growth, and ration levels meet metabolic demands (Elliott, 1994), high temperatures will likely result in increased growth in YOY Arctic charr, as demonstrated by the Sinnatamby et al. (2013) Labrador study. The observed differences in behavioural thermoregulation between fluvial and lacustrine YOY, demonstrated here, also highlight the increased risk posed to fluvial YOY Arctic charr by climate change. As noted, results of Sinnatamby et al. (2013) parallel findings reported in Murdoch and Power (2013) that noted how two proximately located Arctic charr populations with differing life-history strategies and preferred thermal habitat availability can display strikingly different growth patterns. Similarities in lake productivities and key inter-specific competitive pressures suggest experienced temperature differences associated with varying lake morphometry drove the observed growth differences. In the smaller, shallow lake fish used warmer temperatures at a given age than fish in the larger, deeper lake, although the reverse was true for growth, with growth at common age being higher in the larger, deeper lake. Thus in the larger lake, fish may have been better able to select optimal thermal growth habitat. In contrast, in the smaller lake fish were confined to the warmer littoral areas, possibly to reduce predation risks, and were less able to select optimal thermal growth habitats. However, in the small lake fish experienced increased growth at older ages once they were able to move to cooler profundal habitats. Results provide evidence for differing climate-influenced growth outcomes among proximately located populations, with outcomes likely to depend on the differences among habitats, including lake size and morphometry which may act to influence fish densities in available preferred thermal habitats.

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., 2012a), but were hypothesized to be related to differences in THg at the base of the foodchain. Work published in 2013 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 of 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., 2010a,b; 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.

Subsequent work on patterns of historical change (1977-78 compared to 2007-09) in THg concentrations in Arctic charr provided insufficient evidence to suggest there has been a widespread change in THg of anadromous or non-anadromous Arctic charr over the past thirty years, although the mean annual temperature increased by 1.6°C to 2.9°C between the two sampling periods (van der Velden et al., In Press). The lack of a widespread change in Arctic charr THg between 1977-78 and 2007-09 supports the general lack of consistent mercury temporal trends observed in studied Arctic biota over the past thirty years (Riget et al., 2011). Results imply that mercury concentrations in Labrador lacustrine and marine fish habitats and prey resources have remained constant over the past three decades (Braune et al., 2011). Evidence from elsewhere suggests that the global atmospheric mercury pool, and therefore the rate of mercury deposition, has been relatively stable or declining in recent decades. Global anthropogenic mercury emissions to the atmosphere were in the range of 3500 ton/year during the late 1970s and early 1980s, but decreased during the 1980s to reach relatively stable levels of approximately 1900 to 2200 ton/year from 1990 to 2005 (Pacyna et al., 2006, 2010). Consequently, direct measurements of atmospheric mercury have indicated steady or declining concentrations since the 1970s at Canadian temperate and Arctic sites (Li et al., 2009; Steffen et al., 2005; Temme et al., 2007) and globally (Lindberg et al., 2007).

Fish mercury concentrations are typically positively related to atmospheric mercury deposition (Hammerschmidt and Fitzgerald, 2006). However, the response of fish THg to changing mercury inputs is site-specific, depending on a variety of physical, chemical, and biological factors (Munthe et al., 2007). Consequently, Arctic charr THg increased at Hebron Fiord and Tasialuk Lake, and age-specific THg increased at Okak Bay, despite the lack of a widespread change in fish THg throughout Labrador. At the same time, age-specific THg decreased at Esker Lake, but there was no corresponding reduction in length-specific mercury concentration. Our results support previous conclusions that regional characteristics (e.g., mean annual temperature, atmospheric mercury deposition) are less important than site-specific factors (e.g., population age and size distribution, food web structure, fish diet composition) in determining fish THg (e.g., Rose et al., 1999; van der Velden et al., 2013a,b).

Operation of the Nepihjee fishway in 2013 continued to yield quality data useful for studying the marine portion of the life-history in Arctic charr. Sampled biological data collected from the returns was employed in on-going otoliths microchemistry analysis aimed at determining the effect of temperature on growth. Initial regional comparisons have indicated that Ungava Arctic charr had significantly higher annual growth rates than Arctic charr captured on the Labrador coast. While the influence of temperature on Arctic charr growth has been well documented by laboratory research (Jobling, 1983; Larsson and Berglund, 1998; Larsson et al., 2005) and is well understood in the context of aquaculture settings where ration and photoperiod covariates can be experimentally controlled (e.g., Johnston, 2002), the influence of temperature is less well understood when food supply is variable and the capacity for growth at a given temperature may be limited by ration (Elliott 1994; Elliott and Hurley 2000a, 2000b). Thus in contrast to laboratory-based findings, field-based studies have suggested lower optimal temperatures for Arctic charr growth. For example, Berg and Berg (1989) and Rikardsen et al. (2000) observed high early-season growth while temperatures were still low, suggesting compensatory growth following restricted winter feeding and an apparent adaptation to low temperature growth, even under conditions of ration constancy, as possible causal mechanisms. Other studies have shown Arctic charr prefer water temperatures of around 11°C, notably lower than laboratory reported optima (Larsson, 2005; Rikardsen et al., 2007). Results have led to the suggestion that wild Arctic charr select temperatures closer to their optimal growth efficiency point (9°C) as an adaptation to living in food variable environments where individuals risk achieving a reduced scope for growth if they remain at more metabolically expensive temperatures during periods of food shortages (Elliott, 994; Larsson and Berglund 1998; Larsson et al., 2005).

Limited North American studies that have examined consequences of local temperature variation on growth (Power et al., 2000; Chavarie et al., 2010; Michaud et al., 2010) were completed using population-level data that inferred somatic growth rates from size-at-age averages. Such data disregarded intra-population growth variability, and do not use individual fish-specific temperature data (Power et al., 2000; Kristensen et al., 2006; Michaud et al., 2010). To overcome these limitations, individual measurements of annual or within-season growth were determined from tag-recaptured Arctic charr from Ungava and Labrador and examined in relation to summer sea surface temperature and within-season capture timing. Based on laboratory and existing field-based studies (e.g., (Jobling, 1983; Berg and Berg, 1989; Larsson and Berglund, 1998; Rikardsen et al., 2000; Larsson et al., 2005) to test the hypotheses that: [1] annual averages for individual fish growth would correlate positively with water temperature while (annual temperature-growth hypothesis) [2] within-season growth would not positively correlate with average water temperature (within season growth hypothesis). Preliminary analysis indicates that the effects of sea surface temperature and days at sea variably influenced the in-situ marine growth of anadromous Arctic charr in the two regions. Growth-temperature comparisons between Hebron Fjord, Labrador, and Dry Bay, Ungava, has yielded evidence of conditional temperature effects, with individual annual incremental growth increasing as a function of temperature when comparing between sites and among years at Dry Bay, but not among years at Hebron. At Nain, increases in mean SST did not demonstrate a significant positive relationship with growth. Instead, increases in SST associated with longer seasonal marine residency were correlated with lower mean growth as a result of the observed inverse relationship between growth rate and the length of marine residency. Data, therefore, provided partial support for the annual growth-temperature hypothesis and substantiated the within season growth hypothesis. The study of specific mechanisms driving growth differences in natural environments is required and critical for the development of management strategies for sustaining Arctic charr population levels as climate varies and further investigation into possible causal mechanisms that can explain the results is currently being completed.

Statistical analysis for the Dolly Varden charr THg analysis has indicated that length-adjusted THg differed spatially among populations, but that there were no significant large-scale spatial patterns related to latitude or longitude. Measured THg levels within and among populations were positively correlated with the size and age of tested fish in some of the studied populations, with length generally being a better correlate with THg than age. There was also evidence to suggest that differences in THg levels within and among populations were influenced by differences in the trophic ecology of the studied populations. When grouped in multivariate analyses, differences among individuals (length, age, and $\delta^{15}N$) were the most important factors for explaining spatial differences in the Dolly Varden THg concentrations.

The historical THg concentrations (means 35-128 ng/g ww) in anadromous Dolly Varden described here were similar to the levels found in anadromous broad whitefish, lake whitefish, and landlocked Arctic charr from the Yukon Territory (YT) and Northwest Territories (NWT) measured for the same time period. A fact that would suggest health risks associated with Dolly Varden fish consumption were on par with other consumed fish species. For example, anadromous broad whitefish from Campbell Lake, Kugaluk River, Lake 100, and Travaillant Lake, NWT (1988-1992), recorded mean THg levels ranging from 20 – 70 ng/g ww (Lockhart et al., 2005). THg levels in lake whitefish from the Mackenzie Delta and Mayo Lake, YT and Burnt Lake, Colville Lake, Manuel Lake, and Lac Ste. Therese, NWT (1989-1993), ranged from 20 – 295 ng/g ww, whereas landlocked Arctic charr captured at Paulatuk, NWT, in 1984 registered mean THg concentrations of 40 ng/g ww (Lockhart et al., 2005).

The present study is the first, to our knowledge, to comprehensively report on the spatial variability in THg tissue concentrations in Dolly Varden. In the time period for which samples were tested (1988-1991), observed mean THg levels in Dolly Varden from all sites were well below the human consumption guidelines, with no readily apparent patterns evident in the among population differences that were found. Variation among individuals within a population and between populations was significantly influenced by size, with larger fish tending to have higher concentrations of THg. The effect of size, however, did not dominate the effect of age. Although the index of trophic level ($\delta^{15}N$) included in this study suggests a role for trophic status in determining THg, variations among individuals in terms of their use of different foraging habitats or tactics appears less important for determining THg concentration levels than for other studied charr species (e.g., Arctic charr). While not complete in the sense that it provides only limited spatial coverage, the data reported here does provide a useful historical baseline against which future changes in THg levels in Dolly Varden may be statistically compared to determine where significant changes or increases have occurred. In an era and for an area being marked by significant ecological change (e.g., climate change) and the increased pressure of industrial development (e.g., mining), the utility of historical baseline information cannot be understated.

Analyses completed to date on temporal trends have provided only marginal evidence of temporal trends. 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 to 94.86 ng/g ww in 1988 to 129.12 ng/g ww n 1995 for the Firth River. Data showed that the Rat River had a significant overall increasing trend from 1986 to 1995 ($r2 = 0.322$, $p <.05$) in age 7 adjusted logTHg values, with a significant difference between 1986 – 1988 ($p <.05$) and 1986 – 1995 ($p <.05$). However, the Firth River showed no significant overall trend from 1986 to 1995 ($r2 = 0.037$, $p >.05$). The lack of significant age-related trends precluded between river testing for differences in slope and intercept. The number and range of years of data available for the temporal study are limited and the data set is being expanded to include 2013 samples obtained for through collaborative interactions with DFO. The 2013 samples have yet to be analysed and will be used to re-estimate relationships reported above.

To date only preliminary observations on the tagging work at Gilbert Bay can be named owing to the fact that the last data download occurred in August of 2013. Data have been archived are currently being vetted to remove multiple identifications (identifications of a single tagged fish at more than one receiver simultaneously). All Arctic charr tracked during this component of work were caught and tagged in the marine environment near the mouth of Gilbert Bay, as tagging coincident with ice-out marine migrations is not possible owing to ice-related issues. Tracking indicates fish tend to utilize marine areas proximate to the over-wintering system and generally forage <20 km from the mouth of the Shinneys River to which they return in the late summer. Data gathered to date on the marine summer feeding phase suggest fish spend 6–8 weeks in the marine environment near coastal areas, returned from marine feeding to the over-wintering system in the Shinneys River over a relatively short period of time (approximately a week), congregating in the River until suitably high water allowed passage to suitable inland lake approximately 1 km upstream from the marine environment where over-wintering occurred. Marine movement data suggest fish tend to utilise habitat at the mouths of coastal bays. Dempson et al. (2002, 2008) suggested that capelin (Mallotus villouss) and other fish are important components of the Arctic charr diet and will be found in greater abundances near bay mouths. Based on data reported in Morris and Green (2010) the prey community available to char will also consist of Atlantic cod (*Gadus morhua*) and sand lance (*Ammodytes americanus*). The length of time spent in the marine environment by Arctic charr tagged in Gilbert Bay is similar to that noted for Nain area Arctic charr (Dempson, 1995). Arctic charr typically leave over-wintering waters with ice-out in spring and return in late July and early August (Dempson and Green, 1985; Dempson, 1995; Power et al., 2000). Work continues on collating the large amounts of data gathered to determine the following: mean water temperatures used summer and winter, mean home-range size during the summer foraging period in the marine environment and the over-wintering period, identification of the out-migration and in-migration period (i.e. run timing), variation in thermal habitat use and home range size by fish size. To appropriately analyse the data, an MSc student will be sought to complete and augment the data set pending availability of further funding.

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 the marine movements of Arctic charr and, in particular, poor understanding of patterns of movement between freshwater and marine habitats and how these relate to environmental cues. Given predicted and observed climatic changes and existing hypotheses about its likely consequences on northern fishes (Reist et al., 2006), such information is of increasing importance to the management of this vital Arctic species and its associated fisheries. Further analysis of 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. In addition, the study data will shed critical light on movement and use of over-wintering habitat. From very preliminary analysis of the data, we do know that Arctic charr within the over-wintering lake are active, exhibit movement among available habitats and display a diverse range of movement strategies which may be correlated with winter feeding. The tracking data corroborates detailed winter feeding studies conducted by Eloranta et al. (2013) that demonstrated active feeding by Arctic charrr in shallow Finnish sub-Arctic lakes.

Work with the application of Major Histocompatibility (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 that permit within and among population differentiation of Arctic charr populations. To that end a demonstration of the utility of the method was completed for publication (Conejeros et al., In Press) that examined the ability to detect differences among morphotypes within populations originating from a common environment. Stable isotope analyses were used to confirm the separation of tested Arctic charr morphotypes in terms of primarily habitat for Gander Lake (Power et al., 2005; Power et al., 2012) and primarily trophic ecology for the Kiryalta lake sites used in the study. Concurrent with the isotope results, differences in the allele composition of sampled morphotypes also varied, with MH-based separation being stronger in Gander Lake where morphotypes occupied different habitats than in the Kiryalta lakes where ecological separation between the morphs was based mostly on feeding ecology. The high divergence of MH Class II α and MH Class II β genes in Gander Lake and the Kiryalta lakes Arctic charr was mostly caused by intra-population variation, which indicated that only a small percentage of the observed variation has occurred separately within each morphotype stock, consistent with our previous observations (Conejeros et al., 2008).

To date, Arctic charr morphotypes living in sympatry have only been differentiated using genetic markers in cases where the reproductive isolation given by differential spawning times has been evident (Gomez Uchida et al., 2008, Westgaard et al., 2004) or suspected (Power et al., 2009). In most studies the separation has been obscure (Danzmann et al., 1991, Hindar, 1986, Magnusson and Ferguson,1987, Volpe and Ferguson, 1996) which obstructs the understanding of the biological significance of the morphotype segregation. Although some reports have shown the heritability of the characters specific to the small or large morphotypes (Svedang, 1990), the genetic results to date have reinforced the argument that the segregation has its origin in phenotypic plasticity acted on by varying environments (Jonsson and Jonsson, 2001, Skulason et al., 1996). These lakes have only formed since the last glaciation and thus the morphotypes have separated too recently to see effective separation of morphotypes through genetic drift. Thus, the resulting drift is too small to be detected by most neutral molecular markers. In contrast, the nature of the MH molecules as a population marker is that they are influenced by both drift and natural selection, which facilitates differentiation of morphotypes in lakes such as Gander Lake and Kiryalta where separation among the morphotypes has been too recent to allow genetic drift to detect meaningful differences. The presence of differentiation in both study lakes with disparate in location and environmental conditions suggests that rapid MH allele differentiation is common and will be seen for most other lakes where sympatric morphotypes occur.

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 resulted in a basic understanding of inshore fishes, and their habitats, 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 3745 samples from the 2012 samplings season for the purposes of characterizing foodweb structure and function and inshore-offshore linkages. Sample types consist of: 144 zooplankton, 26 sediment, 575 epifauna and 3000 fish. A similar set of samples from the 2013 field sampling is expected, although to date only 400 have been sent to Waterloo for analysis.

From the available samples a preliminary analytical plan to address key hypotheses has been developed and we see the following as likely products of the statistical analysis of the eventual data set, with each being the focal point of a primary publication:

1. An analysis of the offshore food web structure of the Beaufort Sea. This will consist of a general overview of the food web structure of offshore communities as inferred from stable isotopes and will update similar analysis available for the Bering sea (e.g., McCooaughey and Roy, 1979). The analysis will catalogue the trophic positions of numerically abundant species and feeding linkages between species, with an emphasis on marine fishes. Data will also be used to assess whether size-structuring of food webs related to 15N holds true in the Beaufort (e.g., Jennings et al., 2001).
2. Niche overlap and trophic linkages between offshore fishes of the Beaufort Sea will provide a more in-depth analysis of feeding niche overlap among marine fishes and potential prey items. The analysis will use stable isotope plots and ellipse analyses that directly allow for the uncertainty associated with sampling and which generate robust measures of isotopic niche width of both community members and entire communities (Jackson et al., 2011). The analysis will aim to tease apart how marine fishes partition resources in the offshore Beaufort environment.
3. The influence of depth on food web and community structure in the Beaufort Sea from shelf-break out will provide the first detailed comparison of how food web and community structure changes with depth, moving out from the shelf towards the deepest sampling points. Data will be pooled across sampling transects into depth bins (shelf, slope, and deep offshore) and the analysis focus changes in basic food web structure, feeding niche overlap among species and changes in species packing as a function of depth. The analysis, therefore, will be the first to consider the implications of changes in physical habitat for food-web structure and function and provide a parallel to analyses which have been completed longitudinally within the Arctic ocean (e.g. France et al., 1998).
4. A comparative analysis of foodweb differences between the northern and southern Beaufort Sea. The comparison of food web structure between the northern and southern Beaufort will address the question of whether the simpler water column structure in the northern Beaufort is linked to a simpler food web, and if the complexity of the water column in the southern Beaufort from upwelling is associated with greater trophic complexity or more diverse communities.

Finally, observational work completed in conjunction with local communities has suggested that the timing of the ocean ice-free season coupled with the length of lake ice-free season appear to be important drivers of char growth for smaller lakes, yet a general pattern influence of increased growth from lake ice-free days was observed across all three lakes. The change in char growth in different study lakes around the same year observed in both knowledge bases indicates that regional climate-driven changes in Arctic Char growth may be occurring (Chavarie, 2008). Regional sea ice coverage is a potential indicator relevant for consideration in Arctic Char community-based monitoring program along with ambient air temperatures, number of lake ice-free days.

Community members from Sachs Harbour and Ulukhaktok 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 tempera¬tures, 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 Char resource take place because of its importance to the Inuvialuit people and the increasingly dynamic nature of the environment in which they live (Knopp et al., 2012). Ultimately, this information is needed for the management of arctic char stocks harvested by Inuvialuit communities. The results of the research and creation of the Sachs Harbour community-based Arctic Char monitoring plan will provide data for management decisions to be made by local hunters and trappers committees and co-management boards. The approach developed here, and lessons learned, may be used as a model in other arctic communities in the future.

Conclusion

Work at examining THg concentrations in northern populations of Arctic and Dolly Varden charr has contributed significant to improved understanding of the biological and ecological characteristics associated with high contaminant loadings in both the eastern and western Arctic. In most instances age, rather than length, is more critical for determining THg levels in charr species. Comparative study of marine and freshwater foodwebs supporting charr species has further indicated no difference in freshwater or marine habitat-related biomagnification rates, with differences in the concentrations found in fish being related to differences in THg values at the base of each habitat the foodweb. While anadromous charr in the eastern Arctic have lower loadings than non-anadrmous charr, the reverse is true in the western Arctic because of the implications of the occupied lake versus river habitats for the THg loadings of freshwater residents. Analyses of historical baselines for charr in both the west and east have shown them to be low (i.e., generally below health consumption guidelines) and that in Labrador there has been no significant change in measured THg concentrations in Arctic charr. Preliminary analysis of data in the west for Dolly Varden charr indicates a similar pattern of no significant change. 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 gap about the relative safety of both Arctic and Dolly Varden charr. Assessment of the influence of habitat type on conclusions concerning the risks of climate change have shown that that habitat type can hold significant consequences for growth, with occupants of shallow lakes and rivers likely to be among the first affected by climate change and to show reduced growth. 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. The mixed methods component of the project identified key environmental indicators of changes in growth of Arctic Char using both quantitative and qualitative data. It is crucial that CBM of the Arctic Char resource take place because of its importance to the Inuvialuit people and the increasingly dynamic nature of the environment in which they live. Incorporating the parameters identified through this research as influential on Arctic Char growth into the CBMP will provide further understanding of a complex and changing ecosystem. The results of the research and the implementation of the Sachs Harbour Arctic Char Community-Based Monitoring Program next fiscal year will provide critical data for management decisions to be made by local Hunters and Trappers Committees and co-management boards.

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