Understanding and Responding to the Effects of Climate Change and Modernization in Nunatsiavut

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Abstract

Nunatsiavut Nuluak is addressing Inuit concerns about the impacts of climate change and modernization on the health of coastal ecosystems and communities of northern Labrador. The overarching goal is to provide meaningful and timely research on regionally identified priorities while involving Inuit and Inuit Knowledge in all aspects of the project. The first cycle of research activity focused on data collection throughout northern Labrador, with an emphasis on fjord ecology and marine systems along the north coast. In ArcticNet's second cycle the project is concentrated on coastal regions that are, or in the future may be, subject to the dual stressors of climate change and industrial activities. Specifically, Phase III field activities focus on Lake Melville, an estuary downstream from a sanctioned hydroelectric development. The research program, officially called 'Lake Melville: Avativut, Kanuittailinnivut' (Our Environment, Our Health), is establishing baseline conditions for Inuit health, community wellbeing and ecosystem integrity prior to industrial hydroelectric development upstream of Inuit territory. It is also developing the science for monitoring the effects of industrial activity on subarctic estuaries and coastal Inuit communities in the context of ongoing climate change impacts.

Key Messages

ArcticNet's Nunatsiavut Nuluak research program studies the impacts of climate change, modernization and contaminants on the health of ecosystems and communities in and adjacent to Nunatsiavut, the Labrador Inuit Land Claims region.

- The mixing and exchange dynamics of Lake Melville are tidally forced and strongly influenced by fresh water river discharge at the west end of Lake Melville. The oceanographic dynamics of Lake Melville are strongly controlled by the long and very active sill near Rigolet which (1) restricts the exchange between the lake and open sea, and (2) permits part of the tidal energy to enter the lake.
- Extensive surface mixing and/or high sedimentation rates are found at shallow depths near the mouths of the Goose and Churchill Rivers, while steady-state sedimentation and minimal surface mixing are found at greater depths within the Grand Trough of Lake Melville.
- Levels of inorganic mercury in Lake Melville are poorly related to methylmercury in sediments, suggesting environmental and physical factors exert a strong influence on methylmercury dynamics. Levels of total and inorganic mercury are relatively low compared to other estuaries, although mass budgets for Lake Melville show rivers are the main source of total and methylmercury. The influence of major rivers can be detected in Lake Melville 150 km downstream. This suggests that any change in mercury inputs from the freshwater tributaries will therefore have a relatively larger impact on methylmercury availability to biota in the ecosystem.
- Analysis of observational atmospheric data reveals warming trends over the last two decades but no significant change in precipitation.
- The Labrador climate record demonstrates pronounced variability, particularly in winter. In addition to notable extreme events, the region experiences slow-activating decadal-scale oscillation, with extended cold/warm periods persisting for several decades. Both decadal and interannual variability are strongly connected to atmospheric circulation.
- Analysis of circulation anomalies suggests warming is associated with fewer systems entering Labrador from cold source regions (e.g. Arctic and Hudson Bay), rather than an increase in systems entering from warmer source regions (e.g. open Atlantic waters).
- A multibeam mapping program was undertaken in Lake Melville. The detailed bathymetric and backscatter maps and sub-bottom acoustic

profiles were used to identify locations of net deposition and erosion and to support seabed sampling, oceanographic monitoring and biological observations for habitat mapping.

Objectives

The primary goals of Lake Melville: Avativut, Kanuittailinnivut are to establish baseline lake conditions and develop the science for monitoring the downstream effects of hydroelectric development prior to any Lower Churchill development in the context of Inuit health, community wellbeing and ecosystem function/integrity and against a background of ongoing climate change impacts. Specifically, our objectives are:

- To conduct high resolution marine geophysical surveys in Lake Melville in support of seabed mapping and sampling, substrate characterization and sampling, benthic habitat classification and sampling, and oceanographic monitoring and modeling;
- To determine the factors that regulate the physical oceanography of Lake Melville, with special emphasis on the sill, which plays a primary role in determining the mixing that influences the water properties of the Lake and the transport of freshwater and contaminants to coastal Labrador;
- To understand how changes in freshwater runoff have influenced the oceanography of Lake Melville; in particular, how the changes in freshwater runoff, both in degree and timing, have influenced the exchange characteristics and heavy metal retention in the lake;
- To understand how climate change has influenced the oceanography of Lake Melville and the exchange dynamics, with a particular focus on the changes in coastal oceanographic conditions and atmospheric forcing;
- To quantify the relative contributions of anthropogenic activity and natural climate drivers on central Labrador climate and to investigate the physical processes underlying Labrador climate variability;
- To establish a sea ice climatology and history for Lake Melville, and identify trends/variability in timing of freeze-up and thaw;
- To understand how sea-ice dynamics in Lake Melville are tied to the freshwater cycle and the mixing dynamics at the sill and how the formation and breakup of sea-ice is related to freshwater runoff and exchange control at the sill;
- To develop sediment and organic carbon budgets of Lake Melville to identify the major processes responsible for the overall functioning of the system and to characterize the components within the system that may be sensitive to hydrological or climatic changes;
- To determine current and recent (100 years) rates of sedimentation and organic carbon and nitrogen burial within Lake Melville to assess any past or future changes to the estuary as a result of climate change and/or industrial activity upstream;
- To quantify the major sources of methylmercury to biota in Lake Melville, characterize the influence of climate-driven physical and chemical variability in the ecosystem on methylmercury dynamics, and quantify the potential impacts of hydroelectric development on the lower Churchill river on fish and seal methylmercury levels;
- To identify and understand baseline environmental health status in Lake Melville communities;
- To identify / generate key indicators of community and environmental health to monitor over time before, during and after hydroelectric development;
- To document in video format Inuit Knowledge of the observed impacts of the Upper Churchill hydroelectric development in the Lake Melville basin and current research activities by the Nunatsiavut Government and partners to understand baseline biophysical and human health conditions prior to any proposed Lower Churchill development.

Introduction

ArcticNet's Nunatsiavut Nuluak is a research program that studies the impacts of climate change and modernization on the health of ecosystems and communities in and adjacent to Nunatsiavut, the Inuit Land Claims region of northern Labrador. The current project emphasis is concerned with coastal regions that are, or in the future may be, subject to the dual stressors of climate change and industry-related activities. Lake Melville, the current focus of research activities, is an estuary downstream from established and proposed hydroelectric development (Figure 1).

Since 1970, the Churchill River in central Labrador has been diverted from its natural channel through a hydroelectric power generating station at Churchill Falls and the headwaters have been controlled through the creation of the Smallwood Reservoir. The downstream effects of this Upper Churchill project on Lake Melville, the large saltwater estuary that drains the Churchill River into the Labrador Sea, are largely unknown, although recent fish studies have documented elevated mercury levels and local residents have observed changes in wildlife, sea ice, water quality, and climate, among others, since the 1970s. A second hydroelectric scheme, the Lower Churchill project, is now proposed for the Churchill River at Muskrat Falls, about 25 km upstream of Lake Melville. Flooding of its associated 59-km-long reservoir is scheduled to begin in 2015.

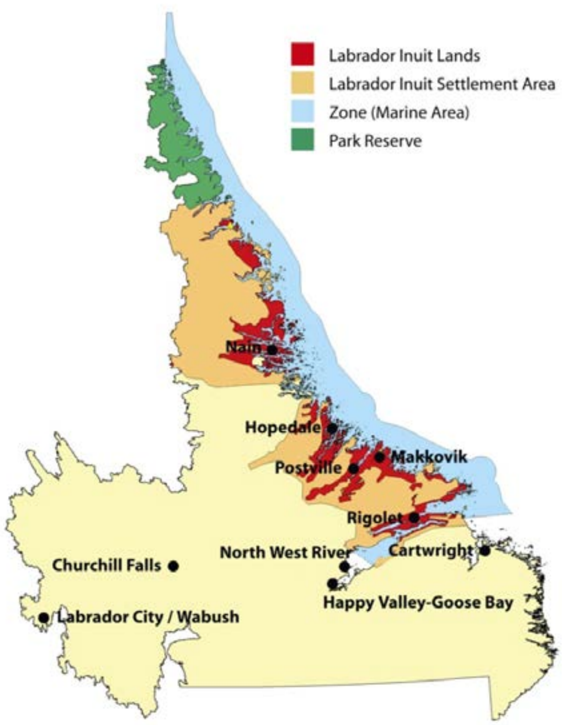

Figure 1. Map of lake Melville showing locations of Labrador Inuit lands (darker yellow) and Labrador Inuit Settlement Area (lighter yellow). Note locations of Happy Valley-Goose Bay, North West River and Rigolet.

Lake Melville: Avativut, Kanuittailinnivut is a Nunatsiavut Government-led research and monitoring program to study the downstream effects of the proposed Lower Churchill project on Inuit community health and well-being in the Lake Melville region. The Labrador Inuit Settlement Area includes the eastern two-thirds of Lake Melville. Rigolet, the southernmost Nunatsiavut community, is located at the Narrows, where Lake Melville is connected to the Labrador Sea. Significant numbers of Labrador Inuit and land claim beneficiaries live in the two main communities of Upper Lake Melville (ULM); Happy Valley-Goose Bay and North West River. Harvesting of country foods is a central component of traditional Inuit lifestyles in the region and an important cultural activity in the mixed economy of ULM. Winter sea ice travel connects communities at either end of Lake Melville and provides access to country foods.

Two main goals of Lake Melville: Avativut, Kanuittailinnivut are: 1) to establish baseline conditions for Inuit health, community wellbeing and ecosystem function/integrity in Lake Melville prior to any Lower Churchill development, and 2) to develop the science for monitoring the downstream effects of hydroelectric development on a subarctic estuary and coastal Inuit communities in the context of ongoing climate change impacts. Specifically, the project focuses on three interconnected components that directly impact Inuit health: Methylmercury; Ecosystem Intergrity, and Community Wellbeing. Our reserach activities and results are prioritized and structured around four key actions in each component: Measuring; Modelling; Monitoring; and Messaging.

Activities

Measuring

- Two current meter moorings, previously deployed in the fall of 2012 on either side of The Narrows near Rigolet, were recovered (Figure 2). The moorings took water current measurements over the full water column depth at each location, providing a complete year-long dataset from both sides of the sill. Both moorings had thermistors to provide temperature over the full water column. The deeper mooring was equipped with two acoustic Doppler current profilers (ADCP); the shallower mooring had only one.
- A high-resolution marine geophysical survey was conducted in Lake Melville aboard the Nunavut Government-owned research vessel MV

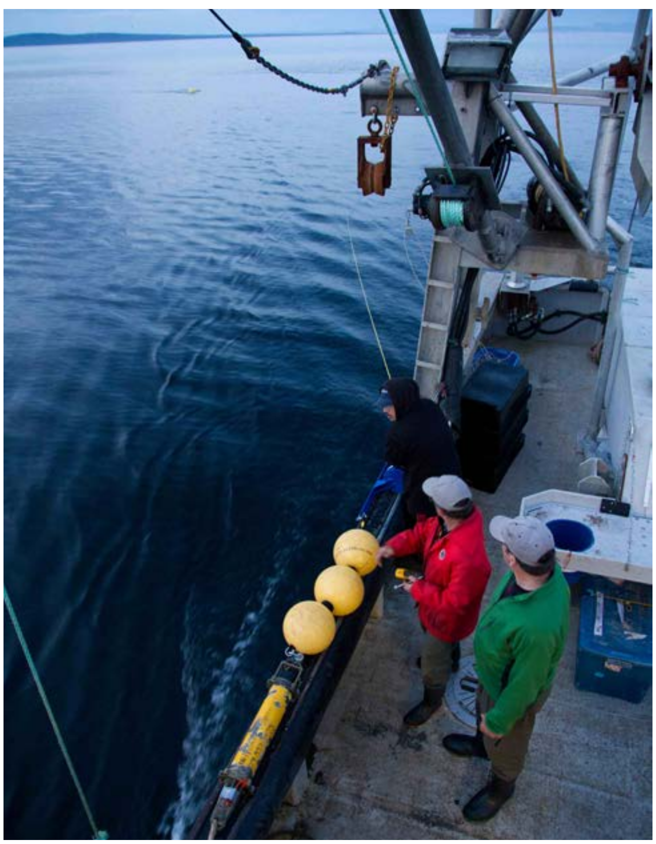

Figure 2. Mooring retrieval taking place onboard the MV What's Happening.

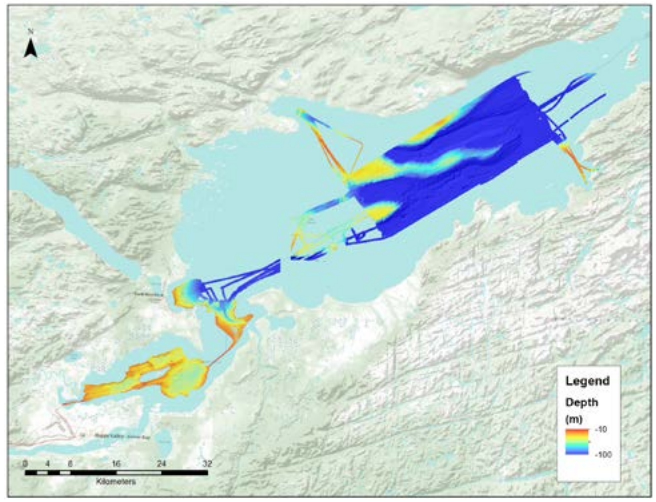

Figure 3. Multibeam sonar-derived bathymetry from Lake Melville collected in 2013

  Nuliajuk, which is equipped with a Kongsberg EM3002 multibeam echosounder. Over a 17-day period, a total area of 485 km^2 was surveyed, providing detailed bathymetric, backscatter and sub-bottom data of the seafloor (Figure 3).
- Seabed sediment cores (n=14) were also collected from onboard the MV Nuliajuk to determine the sediment and organic carbon budget for Lake Melville. Following the field sampling, sediment core sections were analyzed for radioisotopes (210Pb, 137Cs, and 226Ra) and together with appropriate models sedimentation rates determined.
- Related field data collection included CTD profiles and surface and near-bottom water samples. Samples were also collected from tributary rivers (Churchill, Goose, and North West rivers) as part of this sampling program.
- Sediment, seawater and plankton data for mercury studies were collected onboard the MV Nuliajuk in June 2013. A minimum of eight sediment cores were collected at six intensive sampling stations for bulk THg, MeHg and organic matter (Figure 4).
- During the June 2013 science cruise, the water column was sampled at 1-4 depths (surface,

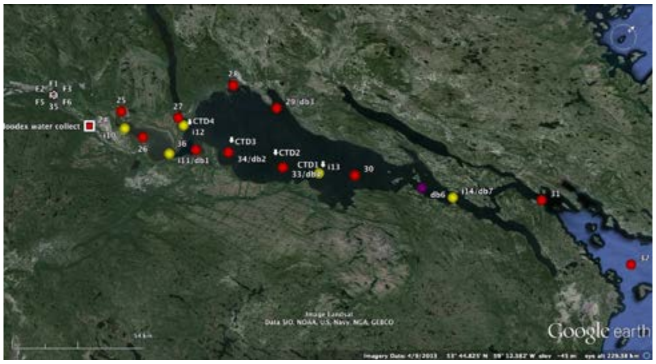

Figure 4. Map of June 2013 sampling sites onboard the MV Nuliajuk

mid-water column and bottom) for unfiltered and filtered Hg and MeHg samples, dissolved gaseous mercury, total suspended solid and Chlorophyll a. Once in the laboratory, water was processed for THg and MeHg analyses, and subsamples prepared for total organic carbon, total nitrogen and nutrient analyses.

- The first systematic food-frequency questionnaire of Labrador Inuit to identify magnitudes and frequencies of country food consumed from Lake Melville and to corroborate these dietary survey results using hair Hg biomarkers began in winter 2014. This involves three individual three-month recall surveys combined with 24 hour recall surveys over a year long period.

Modelling

- Historical atmospheric and river discharge data for Lake Melville and the Labrador Sea were assessed for quality assurance, analysed and archived. Biogeochemical data for Lake Melville and the western coastal region of the Labrador Sea were collected and archived. A comparison of atmospheric observations with high-resolution atmospheric model simulations was completed.
- A Finite Volume Coastal Ocean Model (FVCOM) for Lake Melville was developed and compared with current meter observations. The FVCOM is being coupled with Lake Melville sediment and mercury models under development.
- High resolution atmospheric forcing data for Lake Melville from the past 30 years was analyzed and a comparison of atmospheric model reanalysis with observations was undertaken. Preliminary work on coupling the PISCES model (an ecosystem and carbon-cycle model) to the NEMO physical model (a state-of-the-art European modeling framework for oceanographic research and climate studies) was completed.
- In order to better understand the relationship between storms and regional temperatures, the storm track activity in eastern Canada and the western North Atlantic ocean was analyzed. The application of a semi-objective storm identification and tracking algorithm was employed to identify storms affecting Labrador, and also supply information on their source region, characteristics (strength, pressure tendency, etc), trajectory, and travel speed. Also being explored are the links between jet characteristics and atmospheric blocking event (Scherrer et al. 2006) frequency west of Greenland, which may be responsible for diverting storms towards or away from Labrador, depending on their approach trajectory.
- Data analyses have begun related to the production of a budget of the sources and sinks of sediment and organic carbon within Lake Melville with an emphasis on freshwater and nutrient contributions from the Churchill River.
- We have used field data to develop a preliminary mercury mass budget for the Lake Melville system and used this information to parameterize a dynamic mercury cycling model (Sunderland et al. 2010). We are currently evaluating model simulations and will be using the model to investigate the impacts of ecosystem changes.
- We are also developing a mechanistic model for mercury cycling in Lake Melville that relates changes in inputs from atmospheric deposition and riverine inflows to concentrations in fish and seal.

- The project team is developing a probabilistic human exposure model based on dietary survey data and anticipated changes in MeHg levels of country foods to estimate future changes in MeHg exposures and health risks for Inuit corresponding to climate variability and flooding of the Lower Churchill River.

Monitoring

- A sampling survey was conducted on board the Inuit-owned MV What's Happening in Lake Melville to establish a benthic faunal and substrate monitoring program that is capable of detecting changes in faunal assemblages and substrate characteristics and distinguishing between climate and industrial disturbance of the system. In total, 63 box cores were collected from 8 sentinel monitoring sites to sample faunal assemblages and sediment properties (Figure 5). Our faunal analysis will be conducted in partnership with McGregor GeoScience Limited, the only laboratory in North America that complies with the standards and best practices outlined by the National Marine Biological Analytical Quality Control (NMBAQC) scheme for marine benthic faunal analysis and identification. These international standards and best practices are key to developing our "Science for Monitoring" program for faunal assemblages in Lake Melville.
- The project has established a community-based monitoring program to assess seasonal and interannual variability in Hg and MeHg concentrations in freshwater tributaries flowing into Lake Melville as well as mercury concentrations in marine subsistence foods. Community Research Advisory Committees are supervising all community-based monitoring tasks, and have received the necessary orientation and training for this purpose. They have initiated the facilitation of freshwater sampling of rivers flowing into Lake Melville at monthly intervals, as well as the sampling of numerous seal and fish species coinciding with traditional harvesting times and locations.

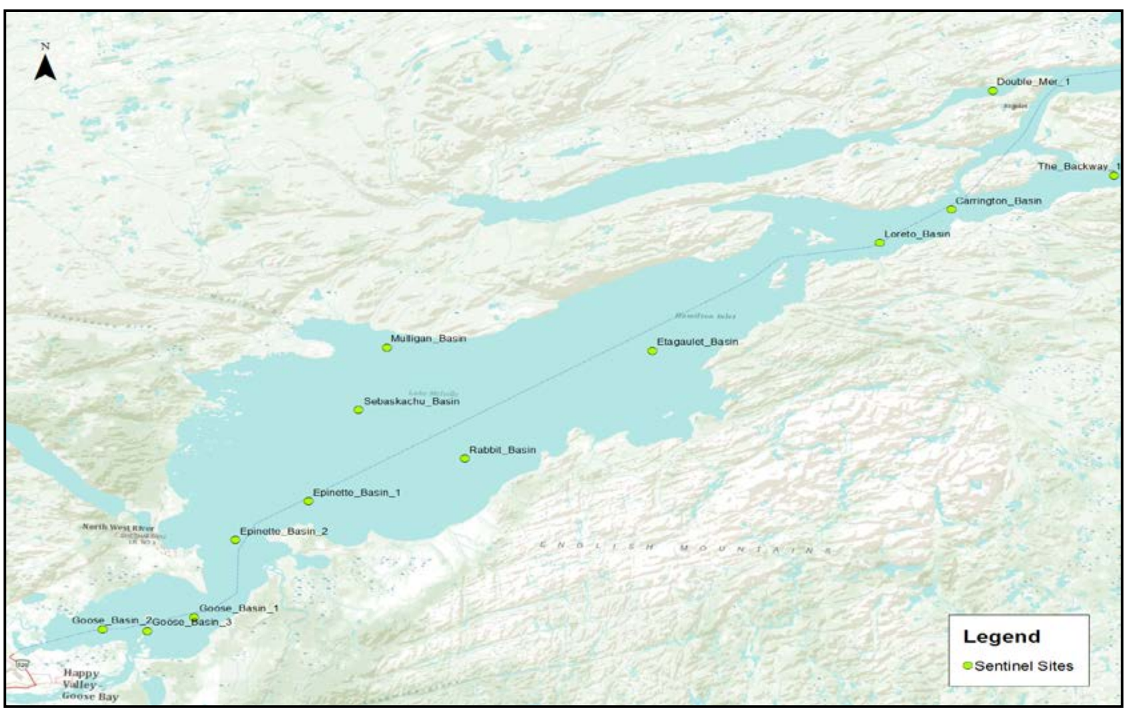

Figure 5. Map of sentinel sampling sites for benthic faunal and substrate monitoring program

- Preliminary discussions are underway with Oceans Network Canada (Kim Juniper, PI) to design and deploy a small, cabled observatory in Lake Melville, similar to what is in place at Cambridge Bay. This nearshore mini-observatory studies the interaction of local sea-ice, water, weather and biology. This opportunity would also permit field-testing a new mercury sensor that is being developed by a European group headed by Milena Horvat, one of the principal scientists in the Global Mercury Observation System. This sensor would be paired with a pH sensor to detect total dissolved mercury.

Messaging

- The project established a Research Advisory Committee in each of the three communities in the Lake Melville region and presented terms of reference for their activities. The project leaders met with the committees in their communities in May 2013 to listen to community perspectives and to receive advice on research plans and activities.
- Research Advisory Committee members and the local media were invited to observe sampling operations onboard the MV What's Happening during the science cruise in November 2013 (Figure 6; http://www.cbc.ca/player/News/Canada/NL/ID/2419843580/, http://www.cbc.ca/news/canada/newfoundland-labrador/inuit-scientists-monitor-water-quality-near-muskrat-falls-1.2435710)
- The project leaders hosted public meetings in each of the project communities in May 2013 to provide an update on research activities and plans and to receive input on program direction.
- A community newsletter was developed and distributed to every home in Rigolet and North West River and to Nunatsiavut Government mailing lists for Happy Valley-Goose Bay/Mud Lake. The newsletter will be a semi-annual information tool of the project.

Figure 6. Dr. Trevor Bell discussing the Lake Melville benthic sampling with Patricia Kemuksigak, Minister of Health and Social Development for the Nunatsiavut Government and Ed Tuttauk, Chairperson of the Sivunivut Community Corporation

- A web page was developed for the project on the Nain Research Centre website (nainresearchcentre.com).
- In partnership with Dr. Ian Mauro (University of Winnipeg) and the Rigolet Digital Storytelling Lab and Media Centre, the project has initiated a documentary video program to record Elder observations of impacts of the Upper Churchill hydroelectric development on Lake Melville in the 1970s and to document the current research and monitoring activities. Members of the documentary project interviewed and videotaped research advisory committee members and scientists during the Fall science cruise on Lake Melville.

Results

Modelling

- Preliminary analyses identified five distinct clusters of cyclones influencing Labrador, classified on the basis of (a) a period of time spent near Labrador, and (b) their history prior to their Labrador approach. Named on the basis of their source region, these are referred to as:

i. Arctic cyclones (approach from the west & northwest at high latitudes); ii. Hudson Bay cyclones (approaching following passage over Hudson Bay); iii. ON/QC systems (from the southwest); iv. Coastal cyclones (tracking along the east coast of US/Canada before entering from the south); and v. Atlantic systems (approaching from the west and southwest, having passed over regions of the open Atlantic). The systems in clusters i) and ii) are associated with cooling in Labrador, generally acting to bring cold arctic air into the region. Similarly, clusters iv) and v) are associated with warmer conditions, through the advection of air warmed over warmer Atlantic waters.

- All the meteorological stations around Lake Melville show a warming trend in the past two decades (Figure 7). The precipitation (snow and rain) shows strong variations on timescales of two to three years, while no significant long-term trend is identified. Atmospheric high-resolution models show significant improvements in representing atmospheric characteristics in terms of their seasonal cycle and interannual trends with respect to the NCEP reanalysis. The offshore sea-ice and water mass variability in the Labrador Sea was analyzed and the links between sea-ice, seawater temperature, salinity and atmospheric forcing were studied (Figure 8).

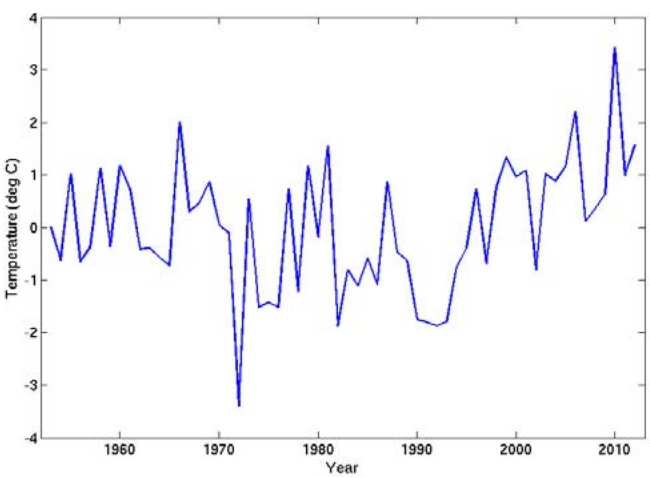

Figure 7. Annual mean temperature anomaly observed in Goose Bay

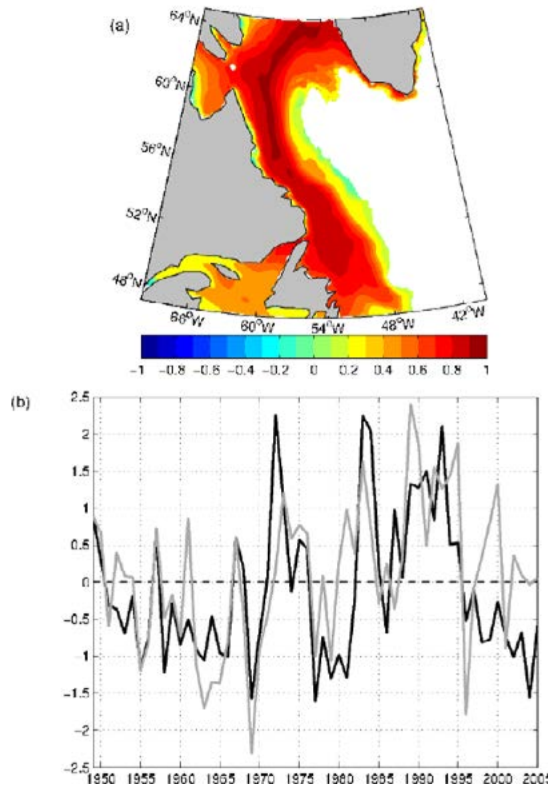

Figure 8. (a) The leading Empirical Orthogonal Function of winter sea ice concentration and the winter; (b) the leading PC time series of winter SIC (black) and the winter NAO index (gray).

Measuring

- In August/September 2012 Lake Melville was stratified with 15°C water at the surface and water temperatures below 2.5°C under a depth of 25 m. Warmer (4°C) and higher salinity (35 psu) bottom waters were entering Lake Melville from Groswater Bay. Waters with salinity below 5 psu were entering Lake Melville from Churchill and Northwest River. Salinities below 10 psu were measured at the surface 100 km from Churchill River, and salinities below 20 psu were measured at the surface in the Narrows (approximately 160 km from Churchill River). All waters below 50 m had a salinity of 25 psu and higher.
- We have direct observations of water properties and currents in Lake Melville from both the

summer and winter period. The surface outflow is very intense (greater than 40 cm/s inside the sill; 50 cm/s outside the sill) and clearly demonstrates the estuarine nature of the circulation. The return flow at depth is quite strong and it may be that we have observed deepwater exchange. Lake Melville's tidal dynamics are not surprisingly quite complex with strong tidal currents outside that are blocked at the sill with the K1 tide more strongly influenced than the M2 tide. The M2 tide shows a reduced amplitude at 20 m depth, a result of tidal dissipation over the sill, and a constituent amplitude of 15-20 cm/s from 20 m depth down to the bottom. Such strong tidal currents play a significant role in the mixing of the water through Lake Melville.

- To date, four sediment cores have been analyzed for radioisotopes ^{210}Pb, ^{137}Cs, and ^{226}Ra (Figure 9). Cores 26 (10 cm) and I10 (15 cm) were obtained from Goose Bay, near the mouths of the Churchill and Goose Rivers, at water depths of 49 and 25 m, respectively. Core 33 (20 cm) was obtained from Grand Trough in Lake Melville from a water depth of 175 m while core DB6 (15.5 cm) was collected from a depth of 196 m from the east end of Lake Melville.
- A preliminary sedimentation rate and sediment velocity of 0.13 g cm^2 a^{-1} and 0.21 cm^2 a^{-1} for core 33 was estimated from the 210Pb profile using a steady state two-layer advection-diffusion model (Lavelle 1985) and checked against 137Cs. The surface mixed layer (SML) was visually determined as the top 6 cm. 137Cs was high in the top 11 cm of core 33 but was not detected below 15 cm (Figure 10). The increase in 137Cs at 11 cm reflects the onset of nuclear weapons testing in the early 1960s. Smoothly decreasing porosity profiles for cores 26, 33, and DB6 suggest consistency in sediment texture while variations in texture were observed below 6 cm in core I10 (Figure 11).
- Soils collected at the future site of the Muskrat Falls reservoir were incubated in water collected

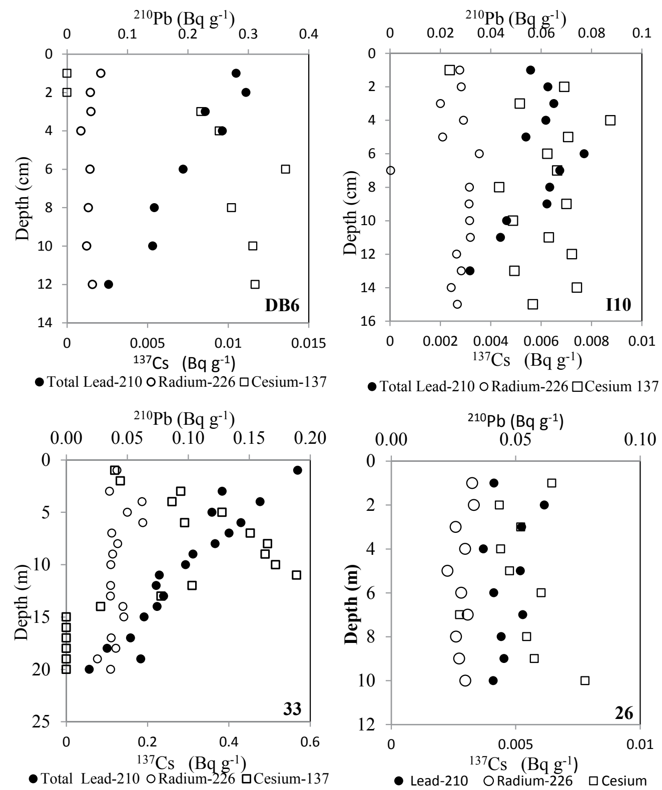

Figure 9. Downcore profiles of total 210Pb, 226Ra , and 137Cs activity in cores 26, I10, 33, and DB6. Points, open circles, and squares represent total 210Pb, 226Ra, and 137Cs, respectively.

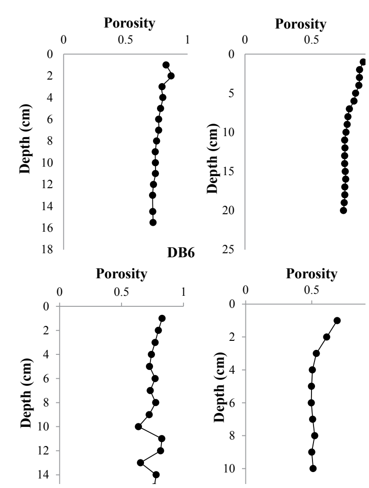

Figure 10. Profile of natural log 210Pb (black circles) and 137Cs (squares) for core 33 represent measured values while the black line represents the modelled 210Pbex using the two-layer advection-diffusion model.

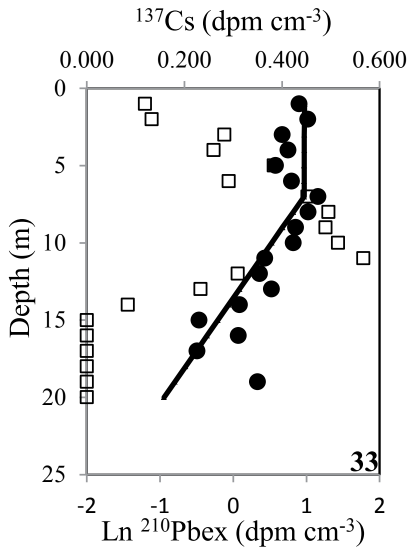

Figure 11. Porosity profiles for cores 26, 33 and DB6 from Lake Melville.

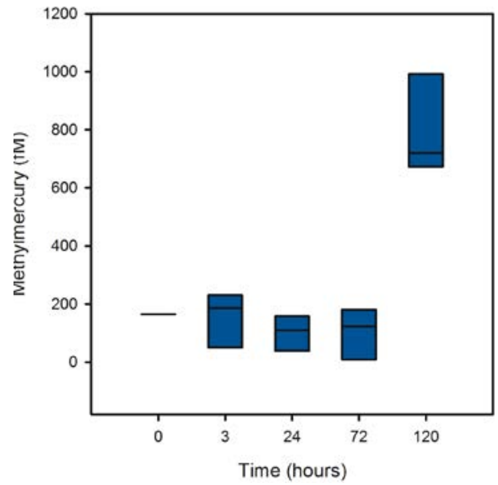

Figure 12. Change in concentrations of methylmercury in water (over time) that is overlying soils from the future site of the Muskrat Falls impoundment area.

from Churchill River for 5 days as part of a controlled flooding experiment (floodex). Overlying water was replaced every 24 hours to maintain adequate levels of nutrients and oxygen to sustain the biological and chemical oxygen demand and mimic in situ conditions. Overlying water at t= 3, 24, 72 and 120 hours was filtered and collected for MeHg, THg, nutrients and DOC analyses. The results show that methylmercury concentrations in the water above the soil increases sharply by a factor of 4-5, after five days of incubation (Figure 12).

- Sediment THg concentrations and organic matter (OM) content are in the same range as that of many estuaries with low anthropogenic impact (Sunderland 2006, Schartup 2013). Both OM and THg are highest in the deepest part of Lake Melville, where finer grained sediment accumulates (observational), and lowest near river mouths where larger grain sized particules settle (sandy sediments).
- The mercury budget in 2012 findings showed that the lifetime of mercury in the water column is <1 year and therefore inputs balance losses. The largest net input of MeHg and THg is from rivers. Sedimentary production of MeHg appears to be very low relative to other systems and the net accumulaion is derived from water column MeHg.
- The preliminary findings from June 2013 measured a higher total suspending solids in the water column of Lake Melville than in September. This is most likely due to a higher riverine solids load (Table 1). The distribution of dissolved gaseous mercury in the surface water of Lake Melville was quantified in June 2013. The June concentrations of dissolved gaseous mercury in Lake Melville are similar to those measured in September, suggesting that the air-sea exchange is comparable in both months (Figure 13).
- The average MeHg is 0.414 +/- 0.400 (n=113) pmol/g; this corresponds to an average % MeHg of 0.81 +/- 1.40 % (=113) which is consistent with other systems (Hammerschmidt 2006). Interestingly, unlike in most other estuarine systems (Hollweg 2010, Hammerschmidt 2006, Benoit 2003), THg and MeHg do not correlate, suggesting that environmental and physical

Table 1. Total suspended solids (TSS) in the water column from Lake Melville.

Station	**Depth [m]**	**TSS [mg/L]**
24	1	_
25	1	7.64
26	1	11.12
27	1	2.5
27	1	9.06
28	_	_
28b	_	_
29	_	_
30	1	16.82
30	221	22.75
31	1	42
31	110	30.07
32	1	32.37
32	75	28.28
33	1	15.55
33	174	27.43
34	1	10.89
34	160	7.67
35	1	16.62
36	1	9.78
i10	1	8.2
i10	24	9.16
i11	1	4.94
i11	10	6.18
i11	40	3.73
i12	1	8.29
i12	6	6.54
i12	47	40.03
i13	1	13.94
i13	10	6.95
i13	75	26.8
i13	174	19.03
i14	1	30.91
i14	6	14.34
i14	75	23.72
i14	196	25.05

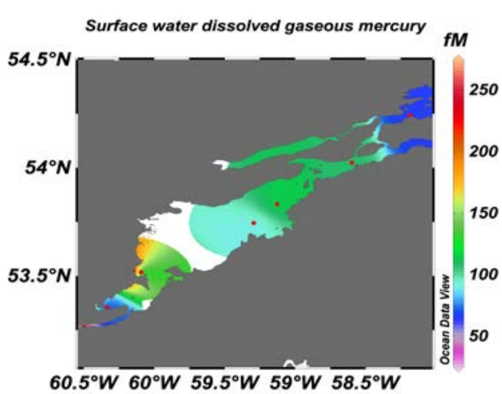

Figure 13. Distribution of dissolved gaseous mercury in the surface water of Lake Melville in June 2013.

factors exert a strong influence on methylmercury dynamics.

- Preliminary particulate MeHg was measured from the mouth of the Churchill River throughout Lake Melville (Figure 14). Particulate MeHg concentrations are highest at the surface while concentrations below 50 m deep are <1 fM. The highest concentration was found in Groswater Bay were where sediment appeared more biologically active.
- In the water column, average concentrations are 2.30 pM in the dissolved fraction and 2.48 pM in the unfiltered fraction for the whole system. Unfiltered, dissolved and particulate THg concentrations were highest at the surface. This is due to a riverine input rather than atmospheric depostion as high surficial THg concentrations end where most of the riverine influence ends.

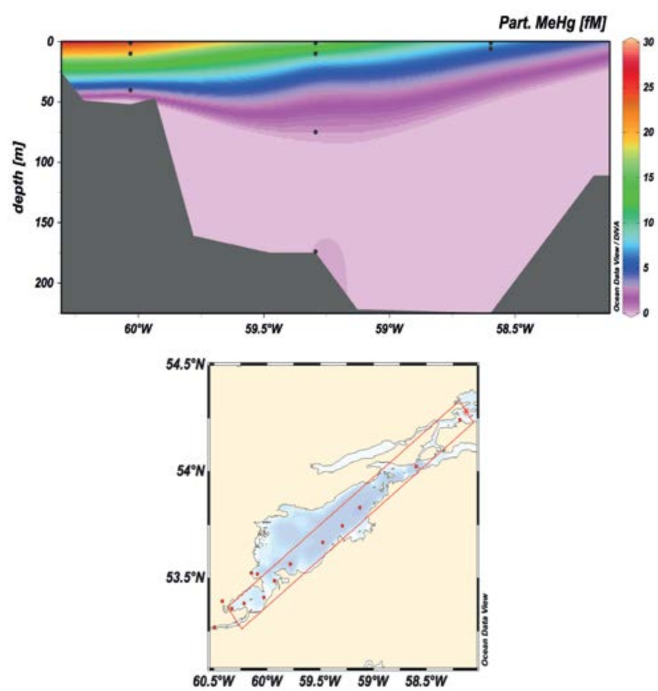

Figure 14. The distribution of particulate methylmercury in Lake Melville.

Discussion

In the past year we assessed the characteristics of the warming atmospheric trend in Goose Bay and the western Labrador Sea. We found the surface ocean temperature and Labrador Sea sea-ice responded to this trend, which caused changes in the ocean characteristics in the area adjacent to Lake Melville.

Current work provides the necessary context for broader efforts to identify and compare health impacts related to climate change and industrial development. The pronounced climate variability of the Labrador region, strongly related to atmospheric circulation, complicates efforts to quantify regional climate and industry impacts. The timing of low-frequency variability presents a particular challenge, with shifts in multi-decadal climate regimes coinciding with key industrial and climate signals. For example, the onset of the cold regime that extended through the 1980s and 1990s (Banfield & Jacobs 1998, Finnis & Bell 2014) followed shortly after the opening of the Churchill Falls hydroelectric plant. This is likely to have produced hydrologic changes (e.g. in timing of peak flows, and/or total streamflow) that would be masked by the larger signal from hydroelectric operations. This cold regime also largely masked the regional impact of climate change over this time period. Similarly, the end of the cold regime in the late 1990s coincided with a period of accelerating Arctic-wide climate change, amplifying the apparent impact of climate change over the past 10-15 years. Improved understanding of atmospheric contributions to Labrador's climate is necessary if we are to adjust for these factors in our environmental and health analyses.

Related atmospheric drivers are responsible for recent winter warm anomalies that have had significant social, economic, and health impacts for Labrador residents. Assessing the risk of similar events recurring requires improved understanding of the events themselves. At present, it is unclear whether climate change will act to increase or decrease the probability of these extreme warmings, although research suggests the jet stream mean position and variability will shift in response to a warming climate (Francis & Vavrus 2012, Woollings & Blackburn 2012). The current work will provide context for interpreting such changes and their potential impact on climate-related health concerns, informing long-term health, infrastructure, and hazard-related planning.

Our observations confirm the complex role that the strong freshwater runoff and tidal mixing plays in Lake Melville. Further observations made over the winter of 2012/13 confirm the role played by tidal exchange and mixing, and freshwater runoff in mixing and the transport of freshwater and tracers through the lake. The models that we have developed will be needed to explore the sensitivity of the lake to freshwater and tidal forcing. With an understanding of the key oceanographic forcing we will be able to address questions of contaminant movement through this system and the senstivity of production to changes in forcing and to climate change.

Modern sediment accumulation rates, and hence the potential sedimentary sink for mercury, vary widely within the Lake Melville system. We expect proximity to river mouths to explain much of the variation in accumulation rates, while water depth likely plays a secondary role, especially in terms of accumulation rates of organic matter. When the analyses of the sediment cores collected in 2013 (and any collected in 2014) are completed, we will be able to use these data together with published literature to construct a contemporary sediment and organic carbon budget for the Lake Melville system, which will provide a basis for evaluating future change and identifying sensitivities to change. We will also use the dated sediment cores to evaluate the evidence for past change in the inputs of terrestrial organic matter to the system.

To date our mercury field program has obtained the first measurements of inorganic Hg and MeHg in Lake Melville seawater, suspended sediments and bottom sediments. It has also collected baseline concentrations of MeHg and total Hg in the Churchill River; previous sampling in 1999 produced samples below the analytical detection limits of the procedure used for MeHg analysis (Nalcor 2009). In June 2013, follow-up sampling took place to assess seasonal variability in concentration distributions and measure net MeHg production using stable isotope incubation experiments in a variety of environments. Plankton tows were also conducted during both sampling periods. In both sampling seasons sediment cores were collected for bulk and porewater THg and MeHg and organic matter.

Preliminary results from 2012 showed elevated Hg and MeHg inputs from freshwater discharges, with highest concentrations observed in low salinity waters. Baseline levels of total Hg are slightly higher than oceanic concentrations (generally ~1-2 pM) and MeHg levels in seawater are very low with concentrations in the North Pacific ocean for example up to ten times higher (Sunderland et al. 2009). Benthic sediments contained similarly low levels of total Hg (range 10-50 ng/g dry weight) and MeHg levels were highest near the mouth of the Churchill River. These preliminary data suggest in situ production of MeHg in Lake Melville is low and that any change in inputs from the freshwater tributaries will therefore have a relatively larger impact on MeHg availability to biota in the ecosystem.

Our proposed mechanistic model for mercury cycling in Lake Melville will relate changes in inputs from atmospheric deposition and riverine inflows to concentrations in fish and seal. This model is being developed in an iterative manner as field data on mercury concentrations and physical oceanography become available as part of the overall project. To date we have developed a simple mass balance for mercury inputs, losses and internal cycling/speciation in Lake Melville. Inputs from freshwater for the preliminary phase were estimated at the annual resolution based on Hg and MeHg concentrations measured in the summer of 2012. Since there is considerable variability in seasonal discharges of mercury from Arctic rivers (e.g., Leitch et al. 2007, Schuster et al. 2011), this estimate will greatly benefit from additional refinement with more intensive measurements from the community-based river sampling in progress.

Atmospheric inputs are estimated from the GEOS-Chem global Hg model v9-01-02 (http://geoschem.org). This model has been extensively evaluated against observations, as described in other studies (Soerensen et al. 2010, Amos et al. 2012). Internal reservoirs and mass flows for elemental mercury (Hg0), divalent mercury (HgII) and MeHg are estimated following Sunderland et al. (2010) and using measured concentrations to parameterize flux estimates.

Ongoing Hg model development is occurring in parallel with the development of a physical oceanographic model for Lake Melville. We are using degraded resolution hydrodynamic data from the oceanographic simulations to parameterize a multi-compartment model box model for Hg dynamics in Lake Melville (Figure 15). Presently, this simulation includes five surface and subsurface seawater compartments and five sediment compartments.

The final phase of model development will implement Hg species and chemistry (Hg0, HgII, MeHg) as tracers in the oceanographic simulation. Each phase of model development will be evaluated with all available field observations. Output from the physical model (seawater and sediment MeHg concentrations) will be used to drive a food-web bioaccumulation model for MeHg. The model will be parameterized to the specific

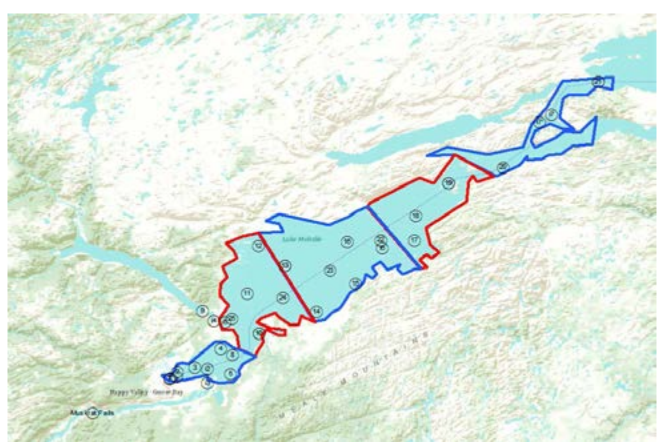

Figure 15. Framework of a multi-compartment box model for mercury dynamics in Lake Melville

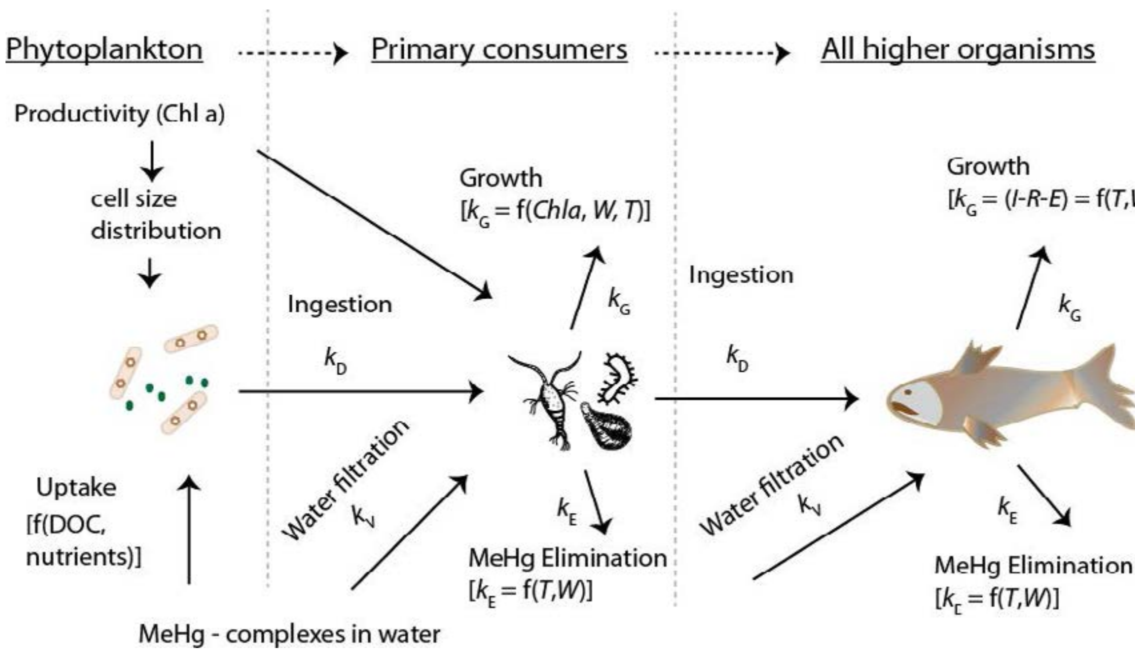

Figure 16. Schematic of food-web bioaccumulation model to be parameterized for Lake Melville. The model describes MeHg uptake by phytoplankton as a function of volumetric partitioning, nutrients, and dissolved organic carbon (DOC). For higher trophic level species, including predatory zooplankton, uptake and elimination are modeled using rate coefficients for uptake from water (kV) and diet (kG) and effective losses in tissue concentrations through growth dilution (kG) and elimination (kE). Standard species bioenergetics is used to describe dietary intakes needed to meet energy requirements and growth

food webs of Lake Melville fish and seal species commonly consumed by Inuit (Figure 16). Information on the diet composition and foraging habitats of these species will be obtained from the scientific literature and traditional knowledge of Inuit, where applicable. Mercury concentrations measured in fish, seal and lower trophic levels as part of our field-based work will be used to evaluate food-web simulations and constrain model results.

Conclusion

The two main goals of Lake Melville: Avativut, Kanuittailinnivut are: 1) to establish baseline conditions for Inuit health, community wellbeing and ecosystem function/integrity in Lake Melville prior to any Lower Churchill hydroelectric development, and 2) to develop the science for monitoring the downstream effects of hydroelectric development on a subarctic estuary and coastal Inuit communities in the context of ongoing climate change impacts. Research thus far demonstrates that mixing and exchange dynamics are tidally forced and strongly influenced by the freshwater river discharge, especially from the Churchill River, at the west end of Lake Melville. Levels of inorganic mercury in Lake Melville are poorly related to methylmercury in sediments, suggesting environmental and physical factors exert a strong influence on methylmercury dynamics.

Mass budgets for Lake Melville show that rivers are the main source of total and methyl mercury and the influence of major rivers can be detected in Lake Melville 150 km from river mouths. In situ production of methylmercury in Lake Melville is low and any change in inputs from the freshwater tributaries will therefore have a relatively larger impact on MeHg availability to biota in the ecosystem. At a climatic level, analysis of observational atmospheric data reveals warming trends over the last two decades but no significant change in precipitation while analysis of circulation anomalies suggests warming is associated with fewer systems entering Labrador from cold source regions (e.g. Arctic & Hudson Bay).

Future work will focus on integration and coupling of biophysical and human health systems. All field and community work related to Lake Melville will be complete in 2014-15. A final major report involving baseline establishment, modeling and state of the art monitoring with associated communication materials (eg. video documentary) will be published in 2015. This will allow ArcticNet Nunatsiavut Nuluak to take on new challenges in priority areas related to resource development, climate change and healthy communities beginning in 2015.

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