Impacts of Global Warming on Arctic Marine Mammals

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Abstract

This project examines various aspects of Arctic marine mammal (seals, whales, and polar bears) ecology to try to determine the impacts of global warming on their abundance and distribution. Research will answer: 1) How will marine mammals adapt to global warming and what are the possibilities for future survival? 2) What is the relationship between warming temperatures and the habitats of seals, whales, and polar bears? 3) What are the potential effects of global warming on reproduction and survival? 4) What will be the effects of changes on northern communities and Inuit lifestyle? 5) How can we reduce the impacts of these changes on Arctic peoples and marine mammals? Satellite tracking, analysis of tissue samples collected by local hunters, and genetics and population modeling are methods that will be used to understand how these animal populations may respond to environmental change. Several areas of Arctic marine mammal health are also being studied, including diet, diseases, contaminants, and stress. Knowing how polar ecosystems may change with global warming will help to develop strategies for conservation and species management. Northerners depend on these species as a food source and as an integral part of their unique culture, and results will help Inuit communities adapt to changes in marine mammal distribution and abundance.

Key Messages

- Average global temperatures are predicted to increase over the next century. Temperature increases are expected to be most intense in polar regions, and recent evidence shows the Arctic climate is already warming.

- Sea ice reductions resulting from climate warming will considerably alter Arctic marine ecosystem structure and function.

- Arctic marine mammals (seals, whales, and polar bears) are vulnerable to changes in their environment through direct impacts such as habitat loss (for example, sea ice as a platform for hunting or giving birth) and indirect impacts, such as changes in prey abundance.

- We are using an integrated ecosystem-based approach to study the effects of climate warming on Arctic marine mammals. This involves research on marine mammal diet and food web structure, seasonal movement patterns and migration, reproduction and population structure, and ecosystem modelling.

- Arctic marine mammals are culturally and economically important for Northerners, and understanding links between their ecology and physical environment will help to develop adaptive conservation and management programs as their abundance and distribution change in a warming Arctic.

Objectives

- Study coupling between physical environment (e.g. sea ice dynamics) and marine mammal abundance, distribution, and population structure.

- Use chemical signals (stable isotopes, fatty acids, and contaminants) to study Arctic marine food web structure and marine mammal diet responses to environmental changes.

- Conduct satellite telemetry, chemical analysis of tissues, and modelling studies to understand marine mammal movements and migration in response to seasonal changes in their environment.

- Study emergent ecological responses such as disease and invasion by competitors or predators.

- Conduct species-level extinction risk analysis.

- Build community-based monitoring programs that provide marine mammal and food web tissues for lab-based analyses.

- Build ecosystem models encompassing biological and environmental variables to predict whole-

ecosystem responses under future climate scenarios; model effects of non-linear changes such as predation and regime shifts.

- Develop adaptation strategies to mitigate effects on Northerners who are dependent on Arctic marine mammals as a cultural and economic resource.

Introduction

Our research investigates impacts of global warming on Arctic marine mammals and development of adaptation strategies to mitigate these effects on Northerners. In the Arctic, where climate warming is already occurring, changes in sea ice cover will considerably alter Arctic marine ecosystem structure and function. Arctic marine mammals (seals, whales, and polar bears) are vulnerable to these changes in their environment through direct impacts such as habitat loss (for example, sea ice as a platform for hunting or giving birth) and indirect impacts, such as changes in prey abundance. We predict shifts in climate and oceanographic processes affecting sea ice will impact food webs, diseases, contaminants, competition, and predation, ultimately resulting in changes in Arctic marine mammal distribution and abundance.

The central emphasis of this project is to study the coupling between physical environments, particularly sea ice dynamics, and marine mammal population demography to better understand how Arctic marine systems will respond to global warming. We are collecting detailed empirical information throughout Canadian Arctic marine ecosystems using both scientific and traditional ecological knowledge to quantify changes in Arctic marine mammal reproductive success, condition, and survival. Research will incorporate community-based monitoring to collect samples and engage Northerners in developing their science, and focuses on all Arctic marine mammals (ringed and bearded seals, walrus, beluga, narwhal, bowhead, killer whales, and polar bears).

Links between key ecological components of the study will be integrated using chemical analytical methods (e.g., stable isotope and fatty acid profiles to infer food web structure, contaminants analysis to track pollution), satellite telemetry to study fine-scale habitat use and broad movement patterns/distribution, and genetics profiling to determine group and population structure. Emergent ecological responses such as disease and invasion by competitors and predators will also be studied. Ultimately, statistical and mathematical models will be used to integrate data on focal species with climate, oceanography, and sea-ice data to identify sensitivities of species to particular habitat variables. These relationships will then be used to quantify the direction and species-specific consequences of regime shifts and other ecosystem changes.

Our results will help to develop adaptive conservation and management programs for marine mammals as their distributions and abundances change, which will also benefit Northerners who are culturally and economically reliant on these species. Success will require community support and participation throughout Alaska, the Inuvialuit Settlement Region, Nunavut, Manitoba, Ontario, Quebec, Nunavik, Nunatsiavut, and Greenland. Project activities include training and engaging northern communities as an extended network of on-site collaborators through incorporation of northern students and hunters into our programs in the field and in the laboratory. These collaborations will facilitate knowledge transfer and contribute to building science capacity in the North. Our project provides a unique opportunity to link rigorous scientific methodologies with traditional ecological knowledge to advance an integrated view of climate change and its impacts on Arctic marine ecosystems.

Activities

Seals

- Community-based monitoring of ringed seals continued in 2013 with tissue samples collected

from subsistence-harvested seals in Sanikiluaq, Resolute Bay, and Kugaaruk, NU. The sampling program was also expanded to include the collection of hair and skin samples taken from pelts of seals harvested in approximately 20 Nunavut communities.

- An aerial survey of western Hudson Bay ringed seals was conducted in late May and early June 2013. As in previous years, survey lines were flown between Churchill, MB and Arviat, NU in order to estimate ringed seal density and abundance and, through comparisons with past surveys, to identify any trends in western Hudson Bay ringed seal population abundance.

- Analysis of ringed seal muscle and hair nitrogen and carbon stable isotope data was conducted to identify spatial and inter-annual variation in isotopic niche widths and feeding ecology in Hudson Bay as related to recent changes in environmental and ecological conditions.

- Analysis of ringed seal reproductive tracts from various eastern Canadian Arctic communities was conducted in order to identify potential spatial differences in growth and reproductive parameters.

Beluga, Narwhal, Bowhead, and Killer Whales

- Radioimmunoassay was performed on beluga whale blubber samples to obtain cortisol concentrations to identify degradation of cortisol in archived samples, to assess variation of cortisol concentration with blubber depth, and to assess sex, age, spatial, and temporal variation. Stable isotope analysis of beluga skin samples was also completed.

- In mid to late June 2013 beluga whale aerial surveys were conducted in the Beaufort Sea just north of Inuvik, ranging from Herschel Island (western edge) to Baillie Island (eastern edge). 2013 was the third field season of aerial surveys in the Beaufort Sea corresponding with the breakup of sea ice and migration of beluga whales into the Mackenzie Estuary.

- Beluga whale tissue samples and morphometric measurements were taken from whales harvested at Kendall Island, Northwest Territories in the Inuvialuit Settlement Region from June 28 to July 27, 2013. Spleen mass, blood and muscle samples were taken from 30 beluga whales for hemoglobin, hematocrit, and myoglobin analysis as indicators of beluga health and energetics. Blubber thickness and girth measurements were taken from 30 whales as indicators of body condition. Blubber samples were collected from 60 beluga whales across the Inuvialuit Settlement Region for fatty acid analysis and will be compared with the fatty acid signatures of potential prey species to determine dietary linkages.

- A narwhal tagging expedition to Grise Fiord, Nunavut was undertaken in August 2013. Unfortunately no narwhals were tagged this year; however, narwhals from the Baffin Bay population were tagged in August 2010, 2011 and 2012. Narwhals from the northern Hudson Bay population were tagged in August 2006 and 2007 and those from the east Greenland population were tagged by Danish colleagues in 2010.

- Stable isotope and fatty acid analyses have been completed for narwhals and their potential prey from the Baffin Bay and Northern Hudson Bay narwhal populations over the last 30 years. Spatial and temporal trends have been investigated.

- In September 2013, we retrieved acoustic recorders in Scott Inlet, NU near the community of Clyde River. The recorders were left underwater for an entire year to record whale calls. After uploading the data, the recorders were redeployed for another entire year.

- Stomach contents and tissue samples were collected from a bowhead whale harvested near Pangnirtung, NU in August 2013. Samples will be used to assess bowhead diet, to estimate foraging efficiency, and to predict mean daily bowhead whale energy needs. Zooplankton sampling

was conducted in August 2013 in Cumberland Sound in order to assess quality and quantity of prey available to bowheads for use in energetic modelling and foraging studies.

- In addition to the harvested bowhead tissue samples (above), 51 tissue biopsies and numerous photographs were collected from bowhead whales in Cumberland Sound, near Pangnirgung, NU in August of 2013. Photographs will be utilized in a photo-identification database of Eastern Canada-West Greenland bowhead whales, and biopsied tissue will be used to assess foraging and genetics.

- Compound-specific stable isotope analysis of killer whale dentinal collagen was conducted as a follow-up to bulk tissue analysis completed over 2010-2012. Bulk and amino acid (AA) specific isotopic composition of dentinal collagen in teeth of 13 Eastern Canadian Arctic (ECA) and North-West Atlantic (NWA) killer whales were analysed to assess the degree, if any, of dietary specialization of killer whales across the region.

- Dentine was sampled from within annual growth layer groups (GLGs) of killer whale teeth to construct chronological profiles of stable nitrogen (δ^{15}N) and carbon (δ^{13}C) isotopic compositions for individual whales spanning three to 25 years.

- In August 2013, killer whales were encountered near Pond Inlet, NU and five satellite transmitters were deployed and seven tissue biopsies were collected. In addition, hundreds of photographs were collected to be utilized in the photo-identification database of eastern Canadian Arctic killer whales.

- No killer whales were encountered during fieldwork in Cumberland Sound in August 2013; however, after researchers departed, a field team comprised of Inuit successfully biopsied a killer whale. An initiative of the Orcas of the Canadian Arctic project is to train and equip Inuit field teams to collect data independent of sourtherner support. The collection of this biopsy is the first under this initiative, and provides a promising approach to studying killer whales in the eastern Canadian Arctic.

Polar Bears

Tissue samples were collected, and GPS collars were deployed on Viscount Melville Sound polar bears in spring 2013 and on Western Hudson Bay polar bears in autumn 2013, as part of ongoing population monitoring studies.

Approximately 500 polar bear hair samples were analyzed for cortisol levels, mercury, and stable isotopes as part of our monitoring and assessment analyses.

Results

Seals

The 2013 aerial survey of ringed seals in western Hudson Bay was completed successfully, marking the 10th seal survey of the area since 1995. The density of ringed seals observed over the entire study area was 0.20 seals/km$_2$ (calculated as a strip transect using a strip width of 800 m) (Figure 1).

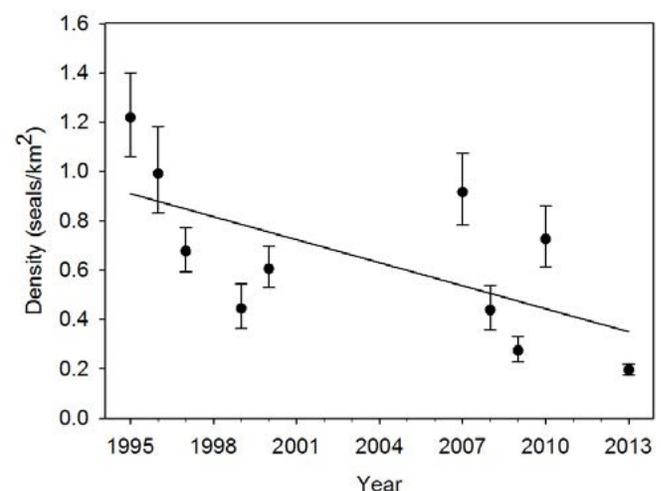*Figure 1. Estimated densities of ringed seals (± standard error) in western Hudson Bay from strip transect analysis of observation data collected during aerial surveys flown between 1995 and 2013.*

The analysis of ringed seal muscle and hair nitrogen and carbon stable isotope data indicated spatial and inter-annual variation in isotopic niche widths and feeding ecology. Ringed seals from western Hudson Bay had higher $\delta^{15}N$ and lower $\delta^{13}C$ than seals from eastern Hudson Bay, and stable isotope ratios varied inter-annually within each region. Peak $\delta^{15}N$ occurred in years with spring air temperatures between approximately -5°C and -2°C. We hypothesize that the high $\delta^{15}N$ observed in ringed seals is indicative of greater importance of capelin in ringed seal diet. A comparison of ringed seal isotopic niche widths indicated greater dietary differences between western and eastern Hudson Bay with warming, suggesting
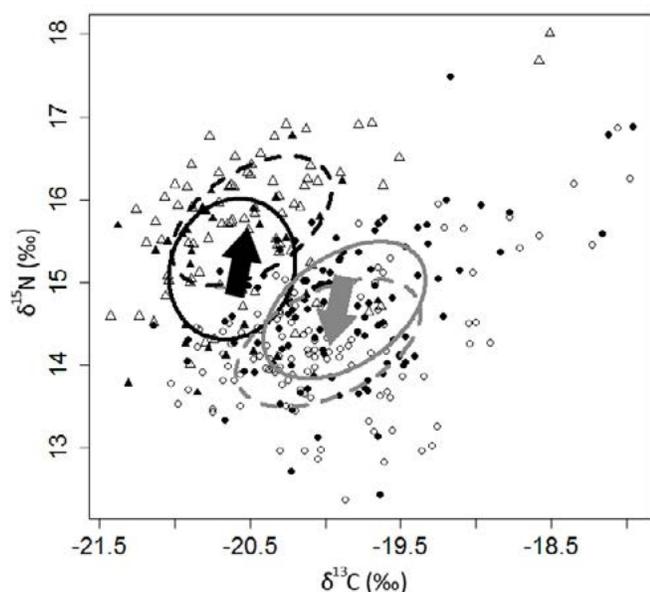
Figure 2. Stable isotope bi-plot of western (WHB; triangles) and eastern (EHB; circles) Hudson Bay ringed seal muscle samples. Samples collected in years with cold spring air temperatures are represented by closed symbols (WHB 2009; EHB 2003, 2004, 2007, 2009), and samples collected in years with warm spring air temperatures are represented by open symbols (WHB 2007, 2008, 2010; EHB 2005, 2006, 2008, 2010). Standard ellipse areas (SEA) represent the core isotopic niche for ringed seals in the different regions under different environmental conditions (WHB cold = solid black line, WHB warm = dashed black line, EHB cold = solid gray line, EHB warm = dashed gray line). Arrows indicate the direction of divergence between WHB (black) and EHB (gray) with warming temperatures.

a possible ecological divergence related to climate change (Figure 2).

Analyses of ringed seal growth and reproductive data are ongoing, though preliminary results indicate significant variation in both growth and reproductive parameters. Spatial differences in asymptotic standard length, age of sexual maturity, and ovulation rate have been observed in the eastern Canadian Arctic. Further analyses are required to better understand the patterns of spatial variation in growth and reproduction.

Beluga, Narwhal, Bowhead, and Killer Whales

Analysis of cortisol in beluga whale blubber indicated that sample quality decreased with increased time in storage and had an effect on cortisol concentrations. Samples identified as highest quality had higher cortisol concentrations than lower quality samples. Cortisol concentration differed among blubber depths with mean cortisol concentration being higher in the inner depth (closest to the muscle). Cortisol concentrations obtained from whales during entrapment events were higher than from whales harvested during seasonal subsistence hunts. Cortisol varied among populations with cortisol concentrations being highest in Cumberland Sound: the population listed with highest conservation concern.

Beluga whale aerial surveys in the Beaufort Sea were completed on June 18th, 22nd, and 23rd with a total of approximately 2120 km of transects flown over all three days. There were 54 beluga sightings on June 18th, 305 sightings on June 22nd (Figure 3), and 54 sightings on June 23rd. Although belugas were sighted all three days, observations were generally lower than 2012, with over 300 sighted on June 22nd. In 2011-2013, ice break up appeared to occur a few days earlier than the date observed from 1979-1984, which averaged June 24-25 (Norton and Harwood 1986). A full assessment of the historical surveys is required for an adequate comparison.

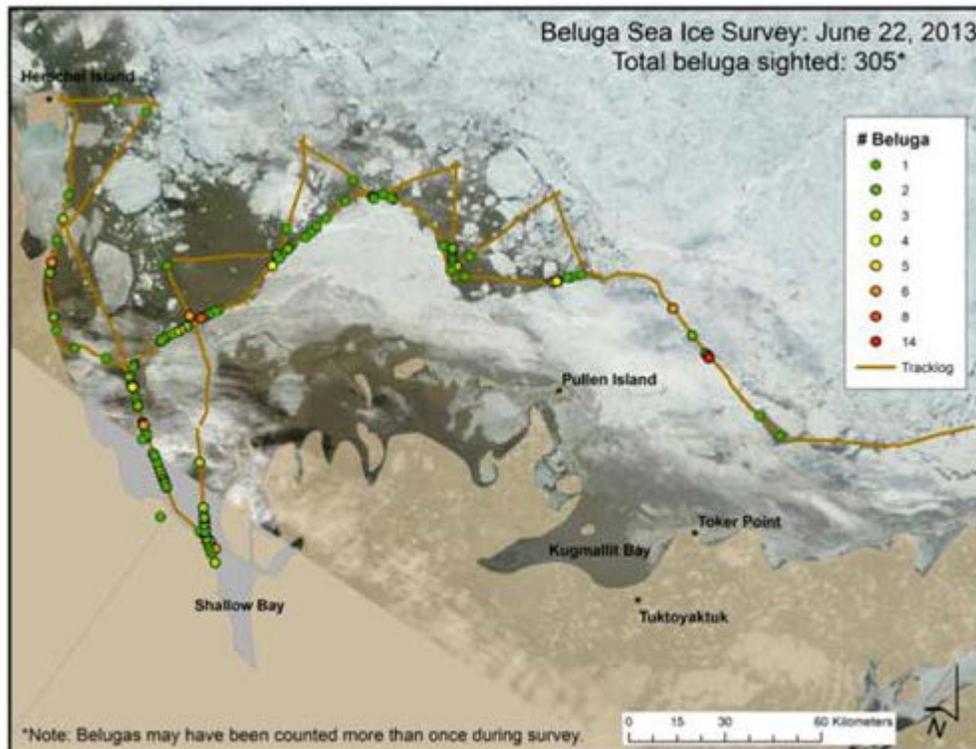Statistical comparisons of isotope values conducted on narwhals from the Baffin Bay, east Greenland, and

Figure 3. Transects from June 22nd with preliminary data indicating location and number of beluga whales.

northern Hudson Bay populations have shown that the three populations have significantly different stable isotope values in their skin tissues, suggesting they may differ in their preferred prey. In addition, males and females differ significantly in their $\delta^{13}C$ values. Long term analysis, dating back to the 1980's, of stable isotopes (SIs) and fatty acids (FAs) in narwhal skin and muscle (SIs), and blubber (FAs) has also been conducted on narwhals from the Baffin Bay and northern Hudson Bay populations. Long term data indicates there has been a shift in narwhal diet, which is more evident in the northern Hudson Bay population.

Although analyses of year-round acoustic recordings from Scott Inlet, NU have not yet been performed, preliminary analyses indicate that narwhals were present at the end of October and at the beginning of November, bowhead whales were present in November, and bearded seals were heard under the ice

in the spring. Analysis and comparison of telemetry data and dive behaviour for narwhals from the Baffin Bay, east Greenland, and northern Hudson Bay populations is also currently underway.

Zooplankton sampling, for use in the study of bowhead whale foraging and energetics, was conducted in Cumberland Sound in August 2013. In total, 19 zooplankton samples were collected in Cumberland Sound, 12 of which were collected near bowhead whales in Kingnait Fiord (Figure 4). Zooplankton samples collected in the upper 15 m of the water column contained few organisms and appeared to be dominated by pteropods. Behavioral observations of whales conducting long (>10 minutes) high-fluking dives suggests that individuals were likely going on deep dives. The lack of zooplankton found in the upper 15 meters of the water column and probable deep diving of individual whales suggests that the whales were unlikely to be feeding near the surface.
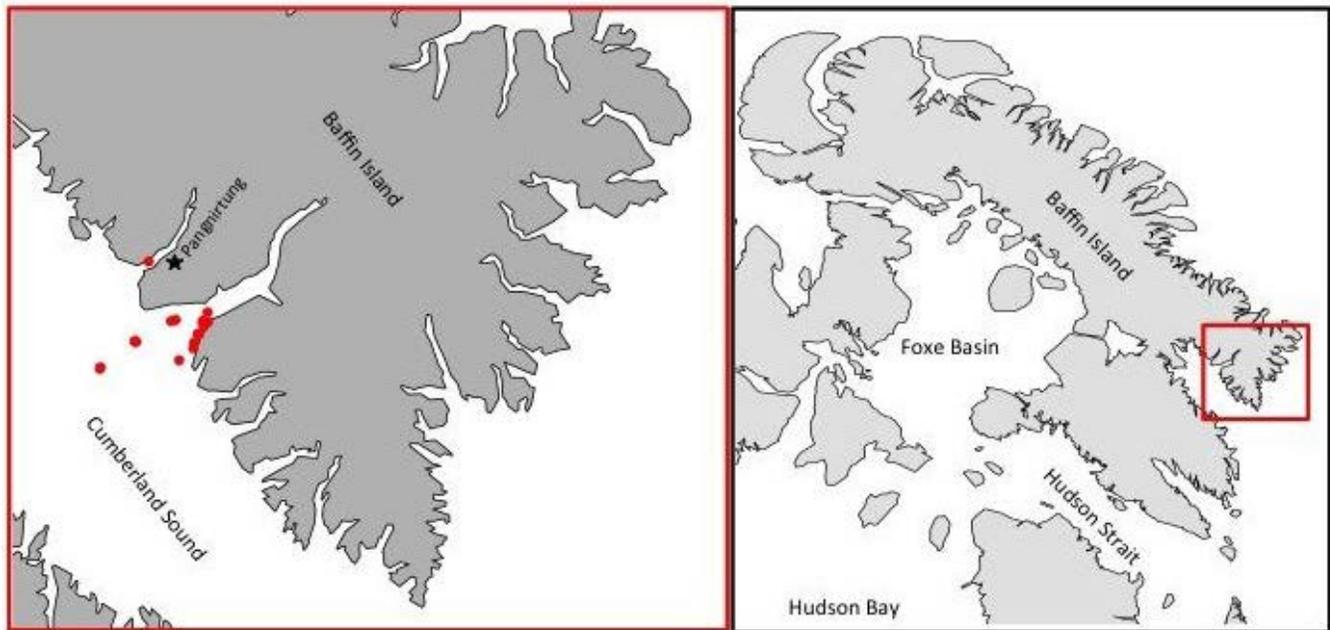
Figure 4. Map of study area showing zooplankton sampling locations (red dots) on the left and map of general area highlighting sampling region on the right.

Comparatively high concentrations of zooplankton (likely dominated by calanoid copepods) were found in eight vertical tows taken near bowheads. Six vertical samples were collected in the absence of bowheads near the mouth of Kingnait Fiord. These samples also contained calanoid copepods, but appeared to be in lower concentration than those sampled near whales. Depth-stratified sampling yielded higher zooplankton concentrations at depth whereby bins 0-200 m and 0-120 m appeared to contain the most organisms (based on visual observation only). However, zooplankton enumeration and identification is required before any conclusions can be made regarding the density, composition and vertical distribution of sampled organisms.

Stable isotope analysis in killer whale teeth indicates significant correlation between bulk $\delta^{15}N$ values and baseline (source AA) $\delta^{15}N$ values (Figure 5). Much of the observed isotopic variation among individuals reflected foraging within isotopically distinct food webs, rather than diet differences. This interpretation is supported by consistent differences in bulk $\delta^{13}C$ values between the two individuals with lowest source

AA $\delta^{15}N$ values and the remaining whales. After accounting for baseline isotopic variation, comparable $\delta^{15}N$ values among individuals indicates similar trophic-level diet, although uncertainties in relative trophic ^{15}N enrichment of individual AAs currently limits trophic position estimates for top consumers such as killer whales.

Of the five killer whales equiped with satellite transmitters near Pond Inlet, NU, two tags transmitted locations for ~10 days, one tag for ~20 days, one tag for ~1 month, and the final tag provided locations for approximately 2 months. Identification of individual killer whales from collected photographs is ongoing. Newly identified individuals will be added to the exisiting photo-identification database, while re-sightings of previously identified individuals will provide important information on social structure, movements and site fidelity, and will be important in eventually obtaining abundance estimates. Further analyses will be conducted throughout 2014 for telemetry and photography data, as well as biopsied tissue.
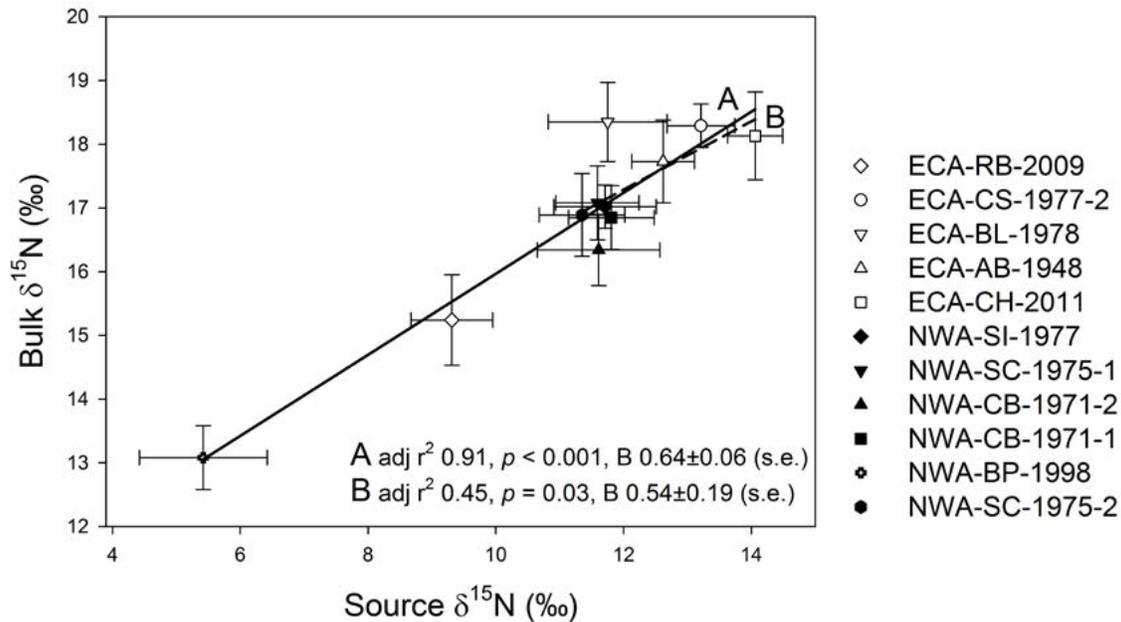
Figure 5. Simple linear regression of mean bulk GLG vs. mean source AA δ¹⁵N values shows up to 91% of variation in bulk δ¹⁵N is explained by isotopic variation in source AA among individuals (A, solid line). The relationship holds when whales ECA-RB-2009 and NWA-BP-1998 are not included in the regression (B, dashed line). Regression coefficients (slopes) are similar for both.

Polar Bears

In 2013, 10 GPS collars were deployed in Western Hudson Bay and three were deployed in Viscount Melville Sound. The total dataset of polar bear GPS satellite data now comprises well over 190 bear-years and over 300,000 locations in all seasons from the three core study populations. A new study in collaboration with the governments of Nunavut and NWT is underway in cooperation with WWF Canada to assess polar bear habitat dynamics in the High Arctic. The focus is sea ice dynamics and trends.

Analyses show the importance of specific habitats for polar bears and the role that sea ice plays in determining predation success. New understanding of the diet of polar bears from the Beaufort Sea allows modelling of possible impacts of climate change. Sea ice models for Hudson Bay indicate population extirpation is highly likely by mid-century because critical thresholds for fasting endurance will be exceeded.

Discussion

Seals

The completion of the 2013 ringed seal aerial survey of western Hudson Bay allows us to compare with density estimates from past surveys and identify possible trends in population abundance. The estimated ringed seal density of 0.20 seals/km² was considerably lower than the density estimate of 0.73 seals/km² obtained from the previous survey of this area which was flown in 2010. The ice conditions during the 2013 survey were very difficult (including numerous melt ponds and bare patches of dark ice) for spotting seals and may have contributed to the relatively low density estimate. It appears that western Hudson Bay ringed seal populations are cyclical with an overall trend of decreasing abundance.

Our findings on ringed seal foraging ecology suggests the diet of Hudson Bay ringed seals varies in concordance with prey responses to environmental

changes, such as temperature and the interannual timing of sea ice breakup. A comparison of ringed seal isotopic niche widths between western and eastern Hudson Bay indicated greater differences between the two regions with warming, suggesting a possible ecological divergence over time related to climate change. With continued warming, we are likely to see further ecosystem changes and shifts from Arctic to subarctic or even temperate species and ecosystems (Bluhm and Gradinger 2008, Wassmann et al. 2011). Continued change may eventually create phonological mismatches in energetic requirements to specific life stages (e.g., food requirements to weaned pups in July) and will possibly contribute to direct competition with more temperate species, such as harbor seals, that may be better adapted to take advantage of recent shifts in the availability and accessibility of estuarine fish.

In addition to population abundance estimates, information on growth and reproduction is essential in being able to assess population viability. Given the range of ecological features represented latitudinally in the Canadian range of ringed seals, one might expect variation in these life history features (Harwood et al. 2012, Krafft et al. 2006, McLaren 1993). As environmental and ecological conditions change in the Arctic, it is likely that ringed seals will be exposed to various stressors which could have an impact on growth and reproduction. Preliminary analyses have revealed spatial differences in growth and reproduction; however, further analyses are required in order to better understand the patterns of variation, and the mechanisms driving them. This information can then be used to assess the current state of ringed seal populations, and can be compared with future studies to monitor change in growth and reproduction.

Beluga, Narwhal, Bowhead, and Killer Whales

Results of beluga whale blubber cortisol analysis provide support for using blubber cortisol as a measure indicating population health status. We suggest that measures of cortisol be used when assessing population health, specifically when blubber biopsy collection is part of monitoring protocols. Similarly,

the elevated blubber cortisol concentrations from whales that had been entrapped in the ice for over two months support the use of blubber cortisol as an indicator of long-term stress. However, we suggest that samples archived over years prior to extraction should be assessed for sample degradation prior to testing for ecological patterns. To avoid depth effects, samples should be taken through the entire blubber column uniformly or consistently from the same depth.

Although statistical analyses are yet to be completed, the Beaufort Sea beluga aerial survey data will be compared with historical survey data (1977-1985, 1992) to address questions related to changes in beluga arrival dates and habitat use over the past 30 years and factors contributing to these changes. The purpose of this analysis is to identify how the abundance and timing of belugas has changed due to changes in sea ice and other variables. In addition future analysis of the aerial survey data will focus on examining beluga habitat preference using a resource selection function (RSF). This type of model-based approach to analyzing visual surveys will map distribution within the Mackenzie Estuary using species-environment patterns and help to identify areas of high use for belugas.

Through a combination of stable isotope, fatty acid, and satellite telemetry, we achieve a greater understanding of narwhal habitat and dietary requirements. This information, in the wake of increasing ship traffic, mineral exploration, and commercial fishing activity in the Arctic, may be vital to conserving narwhals, which are socially and culturally important for Inuit communities. Understanding narwhal foraging behaviour is important for understanding narwhal ecology and predicting impacts of future climate change. This is the first study to investigate isotope and fatty acid values in narwhals and their preferred prey, to investigate long term dietary trends, and to compare diet and dive behaviour among the world's three narwhal populations.

Narwhal feeding ecology and movements are also being studied using passive acoustic monitoring

(PAM). PAM is an effective and low cost monitoring technique for whales, with the capacity to sample 24 hours per day, in poor weather conditions and over long periods. This year was the second year of the monitoring project. Multi-year data will allow us to investigate trends in the occurrence of marine mammals in Scott Inlet as well as the effect of environmental factors on the timing of their movement. Future work also includes an analysis of the echolocation clicks and buzzes of narwhals to infer feeding events. Previous studies using stomach content analyses showed that narwhals feed on Greenland halibut. However, it is not clear if Scott Inlet is an important feeding ground for narwhals. In collaboration with members of the Ocean Tracking Network, the presence of Greenland halibut will also be detected using acoustic telemetry. Then, we will investigate the co-occurrence of narwhals and halibuts.

The foraging ecology of bowhead whales is also being investigated. The collection of zooplankton samples provides some preliminary insights into the foraging behaviour of bowhead whales in Cumberland Sound. Few organisms were found in surface and oblique sample collections near bowheads on 22 August. Combining behavioural (e.g., high-fluking dives, no open mouths observed) and environmental information (e.g., temperature profile, negative zooplankton data) suggested it was unlikely that the whales were feeding in the upper 15 m of the water column and that prey sampling was required at depth. Fortunately, we were able to adapt our sampling methodology and collect samples at depth near high-fluking bowheads using additional line and an automatic-hauler. Based on our observations of high fluking whales and lack of zooplankton in the surface waters, it appeared as though the bowhead whales were feeding deep in the water column in Kingnait Fiord. Furthermore, it is likely that bowhead whales were foraging on calanoid copepods as several species of *Calanus* were found in vertical zooplankton samples collected near diving animals. The exact depth of foraging and the abundances of prey consumed, however, remain unknown.

For killer whales, evidence of significant baseline isotopic variation among ECA and NWA killer whales suggests consistent, long-term isotopic variation recorded in dentine GLGs reflected spatial segregation, rather than individual diet specialisation. Consistent isotope profiles across GLGs spanning periods up to 25 years suggest both distribution and diet of sampled individuals were fairly stable over the long-term. Future research efforts on ECA and NWA killer whales should focus on microspatial chemical analysis of teeth or tissues with fast turnover rates (e.g. metabolically active blubber) that can allow diet and habitat reconstructions over narrow periods of time, given GLGs sampled with annual resolution limit the scope for investigating seasonal distribution and diet patterns. This would provide a clearer idea of seasonal variation in killer whale diet in these regions, and could help determine, for example, whether killer whales show diet plasticity over the short-term. Diet variation could be especially pronounced in the ECA, where seasonal aggregations of marine mammals offer a predictable food resource, and recent studies (e.g. Higdon et al., 2012; Reinhart et al., 2013) have identified possible spatial and temporal patterns in predation too fine to be detected using diet indices integrated over the entire year. Our results add to a growing literature on global killer whale predation patterns, and provide critical trophic information necessary for ecosystem management and conservation at broad spatial scales.

The use of telemetry to remotely track wildlife is particularly useful for studying highly mobile killer whales in the remote Arctic. Upon preliminary inspection of killer whale telemetry data from 2013, the tagged whales' movements appear similar to the killer whale tagged in 2009 (Matthews et al. 2011). Planned analysis for 2014 includes determining predator-prey movements in relation to each others presence in Prince Regent Inlet and the Gulf of Boothia using 2013 and 2009 telemetry data from narwhal, bowhead and killer whales. While the effect of killer whale consumption on prey populations is important to consider in order to determine their predatory impact, intimidation effects may also have important implications for prey population dynamics.

An ongoing photo-identification catalogue is maintained for killer whales in the eastern Canadian Arctic. After the success of the 2013 field season, a large quanitiy of good quality photos greatly inflated the size of the current catalogue. While analysis of photographs for individual identification of killer whales is currently taking place, it appears that at least some individuals identified from 2013 field work are re-sightings from previously encounters. In 2014, the photo-identification database for eastern Canadian Arctic killer whales will be used to compare to other catalogues from killer whale groups in the North Atlantic to elucidate spatiotemporal separation.

Polar Bears

Our research is focussed on understanding the effects of climate change and other human activities on polar bears. The various polar bear data sets have developed significantly over time to allow novel insights into temporal dynamics of movement, distribution, stress indicators, and habitat use. Coupling of sea ice images with polar bear location data allow new insights into the effects of climate change and likely future changes. Our insights suggest that polar bears are being affected by climate change yet the magnitude of such effects remain unclear. The research is important in designing new management and conservation strategies but is also of great interest to the public and northern communities.

Conclusion

Along with findings over previous years, results from research in 2013 on foraging ecology and food webs, habitat use, distribution, reproduction, and population structure continue to indicate coupling between all aspects of marine mammal ecology and the physical environment across the Canadian Arctic. Strong seasonal and inter-annual variation in measures of diet and distribution has been related to parameters such as sea ice condition and air temperature. Although we are currently in the process of determining these relationships across several spatial and temporal

scales, sex-, age-, and population-specific foraging and movement behaviours indicate climate change impacts could vary within and across populations. Results from studies of foraging ecology and stress in ringed seals and beluga whales indicate shifts in diet, niche width, and chronic stress exposure suggesting ecosystem changes are already occurring. In the context of unidirectional climate change, environmental conditions could reach or exceed species' tolerances, having negative impacts on Arctic marine mammal abundance, distribution, and population structure. For all species, the fast rate of environmental change occurring in Arctic ecosystems challenges populations to adapt quickly to shifts in habitat and food web structure.

We are collecting important information on Arctic marine mammals relevant to determining how environmental variation impacts various aspects of their ecology. This information is allowing us to determine how Arctic climate warming may impact marine mammal populations, and to provide an assessment of how to mitigate these impacts. Such measures could include protection of seasonally critical areas, identification of most vulnerable populations, and direct management efforts. Study findings can be used by Northerners who will also need to adapt to preserve cultural and economic relevance of Arctic marine mammals in their communities. Future research will focus on acquiring more data in partnership with Northern collaborators, and incorporating this information into population and ecosystem models to understand and predict impacts of Arctic climate change on marine mammal populations.

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