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: •How will marine mammals adapt to global warming – and what are the possibilities for future survival? •What is the relationship between warming temperatures and the habitats of seals, whales, and polar bears? •What are the potential effects of global warming on reproduction and survival? •What will be the effects of changes on northern communities and Inuit lifestyle? •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 will be 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, Inuvialuit, Nunavut, Manitoba, Ontario, Québec, 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

Diet and Food Web Structure

- 120 ringed seal muscle samples were analysed for nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) stable isotopes. These samples complement the nearly 450 muscle samples and 250 hair samples previously prepared and analysed for δ15N and δ13C in a long-term diet study.

- Blubber samples were collected from 53 beluga whales from across the Inuvialuit Settlement Region for fatty acid analysis and will be compared with the fatty acid signatures of potential prey species collected from the Beaufort Regional Environmental Assessment trawling program to determine dietary linkages.
- Spleen mass, blood and muscle samples were taken from 14 beluga whales for hemoglobin, hematocrit, and myoglobin analysis as indicators of beluga health and energetics. Blubber thickness and girth were also measured as indicators of body condition.
- Narwhal skin and muscle samples collected from communities across the eastern Canadian Arctic (Pond Inlet, Repulse Bay, Arctic Bay, Grise Fiord, Pangnirtung, and Resolute) and western Greenland (Ittoqqortormiut, Scorebysund, Savissivik, Uummannaq, and Qaresut) have been analyzed for stable nitrogen and carbon isotopes. Blubber samples from narwhal hunted in Pond Inlet and Repulse Bay have also been profiled for fatty acids.
- Stable nitrogen and carbon isotope ratios were measured within annual growth layer groups of beluga teeth (n=30) from three eastern Canadian Arctic populations to reconstruct ontogenetic diet trends in individuals, and explore differences between males and females.
- Stable isotopes in the teeth of 170 beluga whales have been measured to determine diet trends over the past four decades, and relate any trends to environmental variation.
- Profiles of 15 trace elements (e.g. magnesium and strontium) were measured in teeth of beluga whales (n=200) to learn more about seasonal diet variation and habitat use.
- Fieldwork to collect photographs of bowhead whale flukes was carried out near Igloolik, NU, and added to photographs collected from Igloolik and other locations from 2007-2011. Analysis of photographs for evidence of killer whale attacks (teeth rake marks) was completed.

Habitat Use and Movement Patterns/Distribution

- Satellite transmitters were deployed on 15 ringed seals at Sanikiluaq/Belcher Islands, NU. Seal tagging was also attempted at Churchill, MB.
- Five narwhals from the Baffin Bay population were tagged with satellite transmitters in in Tremblay Sound, near Pond Inlet, NU. This research added to data from ongoing narwhal tagging studies during previous years in Tremblay Sound (2010 and 2011), Admiralty Inlet (2009), and Repulse Bay (2006 and 2007), NU, and east Greenland (1994 and 1995).
- Boat-based surveys along transects in five fiords off northern Cumberland Sound to count marine mammals and seabirds were conducted for a fourth year.
- Ten GPS satellite collars were deployed on adult female polar bears near Ulukhaktok, NWT, which are currently being monitored. An additional 10 collars were deployed on bears from the Western Hudson Bay population. Individuals collared from the same population in 2010 continue to be monitored.

Population Structure and Demographics

- Over 150 bowhead whales were biopsied in Cumberland Sound and Foxe Basin to collect skin for use in a genetic capture-mark-recapture study.
- Bowhead samples from all years up to 2012 were genetically sexed and profiled at 24 microsatellite loci. Samples from 2012 are currently being processed. As a test case for estimating a local population size the samples collected from Foxe Basin in 2009 were analysed.

Emergent Ecological Response

- Stress hormone (cortisol) concentrations were measured in ringed seal blubber collected by Inuit hunters during subsistence hunts in Arviat and Pangnirtung, NU, and Ulukhaktok, NT between 2004-2011. Cortisol levels and body condition (blubber thickness) were assessed along with covariates year, sex and age class (<1, 1-5 and >5 years old) to determine how segments within the population may be impacted differently by chronic stress.
- A procedure for extracting low concentrations of cortisol from beluga whale blubber was developed, and archived beluga whale skin and blubber were sampled for cortisol (stress) and stable isotopes (diet) analysis. A sub-set of these samples have been analysed to examine temporal trends in cortisol and stable isotope values to make preliminary assessment of trends in beluga whale stress and diet over the past several decades throughout the Canadian Arctic.
- The width of annual growth layers in ringed seal teeth (n=60 individuals) were measured as a proxy for annual growth rates over several decades. Future analyses include determining whether individual growth trends are synchronous at the population level, and if such patterns can be linked with environmental variation (such as patterns in sea ice or prey abundance).

Results

Diet and Food Web Structure

A primary goal of our ringed seal research is to investigate seasonal, inter-annual, and spatial variability in feeding ecology in Hudson Bay using stable isotope and fatty acid analysis. Variability in feeding ecology was interpreted in the context of current environmental and ecological changes occurring in Hudson Bay. Fatty acid composition and stable isotope ratios in ringed seal tissues from eastern Hudson Bay varied by season. Peak δ13C and δ15N values occurred in samples collected in July following fasting, and lowest values occurred in the open water season. Fatty acid composition of blubber was most unique for samples collected in June and July, following the fasting period. Stable isotope ratios also varied spatially and inter-annually. Seals from western Hudson Bay (Arviat) had higher δ15N and lower δ13C than seals from eastern Hudson Bay (Sanikiluaq), and there was a strong relationship between spring air temperature and δ15N for both communities. Peak δ15N occurred within a range in spring air temperatures between approximately -5 °C and -2 °C (Figure 1).

We are also employing stable isotopes and fatty acids to investigate intra- and inter-annual diet trends in narwhal, including assessment of diet differences between sexes and among populations in Canada and Greenland. To date, statistical comparisons of isotope values have been conducted on narwhals from the Baffin Bay, east Greenland, and northern Hudson Bay populations. Narwhals from the three populations had significantly different stable isotope values in skin, suggesting they may differ in their preferred

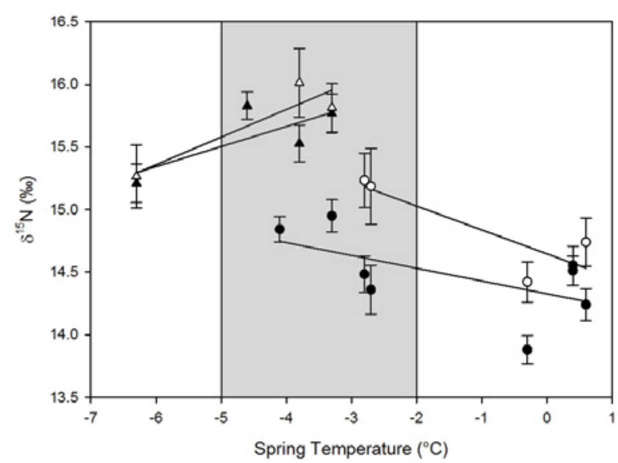

Figure 1. δ15N stable isotope ratios (mean ± SE) of ringed seal muscle (closed symbols) and hair (open symbols) from western Hudson Bay (triangles) and eastern Hudson Bay (circles) in relation to spring air temperature. The shaded area represents the proposed temperature range for increased capelin in ringed seal diet.

prey. In addition, males and females in Baffin Bay had significantly different stable isotope values, while males and females in east Greenland, and northern Hudson Bay could not be distinguished based on their isotope values. Fatty acid analysis has also been conducted on narwhal blubber from the Baffin Bay and northern Hudson Bay populations and results supported conclusions from the isotope analyses: narwhals from these two populations have different preferred prey and males and females in Baffin Bay have significantly different chemical signatures in their tissues.

In addition to studies of diet differences among different populations and between sexes in Arctic whale species, our research on stable isotopes and trace element profiles over periods up to 25 years in beluga teeth is allowing us to assess individual diet variation over time. Preliminary analyses of both stable isotope ratios and trace element concentrations suggests considerable seasonal and inter-annual variation in diet, and apparent cycling in stable isotope ratios over the past several decades may be related to environmental factors such as sea ice or climate oscillations. Patterns of stable isotope (SI) ratios in annual growth layer groups (GLGs) of teeth were used to infer weaning ages in 31 belugas from the Western Hudson Bay (n=8), Cumberland Sound (n=12), and Eastern High Arctic (n=11) populations in the eastern Canadian Arctic to provide weaning age estimates. Most (n=28) individuals showed a gradual decrease in δ15N of ~1 ‰ over the first 2-4 GLGs, which was interpreted as evidence of a gradual decrease in reliance on milk (which has relatively higher δ15N) (Figure 2). δ15N trends suggested 38 % of these individuals were weaned by their second summer (i.e., ~12-15 months old), 31 % by their third summer (~24-27 months old), and 19 % by their fourth summer (~36-39 months old). Despite the considerable variation in individual weaning age, there were no clear differences in δ15N patterns among population, sex, or decade of birth (1970, 1980, 1990). After the initial decrease in δ15N associated with weaning, δ15N trends were unrelated to population or decade of birth, but did show differences related to sex. Values in females remained relatively stable post-weaning, while males showed a gradual increase in δ15N that was ~0.5 ‰ higher than females from GLG8 onward. This is suggestive of a gradual ontogenetic diet change, with males feeding at a higher trophic level than females.

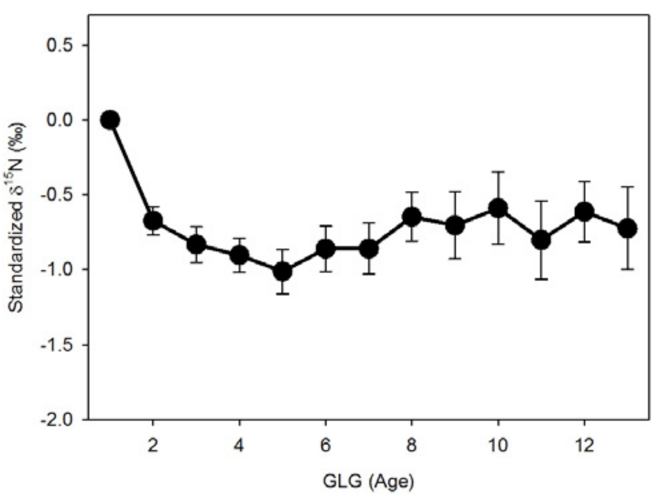

Figure 2: Mean δ15N over the first 13 growth layer groups of 32 beluga whales decline over the first three years, consistent with gradual weaning.

Our work on killer whale diet/predation in the eastern Canadian Arctic has continued with the quantification of rake mark occurrence (Figure 3), scars caused by killer whale (Orcinus orca) dentition, in the Eastern Canada-West Greenland (EC-WG) bowhead whale (Balaena mysticetus) population. We wanted to know in particular whether rake mark occurrence varied temporally or spatially, or among bowhead age classes

Figure 3: Killer whale rake marks, defined as three or more parallel lines occurring in close proximity, present on a bowhead whale fluke (photo D Yurkowski).

and sexes. An additional objective is to determine whether rake mark occurrence differs between the EC-WG and Bering-Chukchi-Beaufort (BCB) Sea bowhead populations. Rake marks were present on 10.2 percent of identified whales from the EC-WG population. Bowhead whales in Repulse Bay, NU and Disko Bay, West Greenland had significantly higher killer whale scarring rates than the northern Foxe Basin nursing group. Cumberland Sound and Isabella Bay had low rates of rake mark occurrence. Rake mark occurrence was lower in younger bowhead whales (calves and juveniles) compared with sub-adults and adults. Additionally, rake mark abundance appeared to increase over time, although this trend was not significant. No male bowhead whales were identified from the photographs, but of the females identified from the presence of a calf, >30 % were scarred with rake marks.

Habitat Use and Movement Patterns/Distribution

Research on whale distribution focuses on fine and coarse-scale differences in habitat use, as well as understanding links with environment. Narwhal diving behavior in the Baffin Bay, East Greenland, and northern Hudson Bay populations is being studied to better understand dietary differences inferred from stable isotopes and fatty acids. Analysis of dive behaviour for males and females from Baffin Bay and northern Hudson Bay showed that males and females in northern Hudson Bay have similar dive behaviour where both males and females spend a large amount of time at shallow (0-6 m) and deep depths (>200 m), whereas in Baffin Bay, females spend more time at depths >800 m than males. Overall, narwhals from Baffin Bay dive longer and deeper than those in northern Hudson Bay. Analysis of dive behaviour of narwhals from the east Greenland population is currently underway.

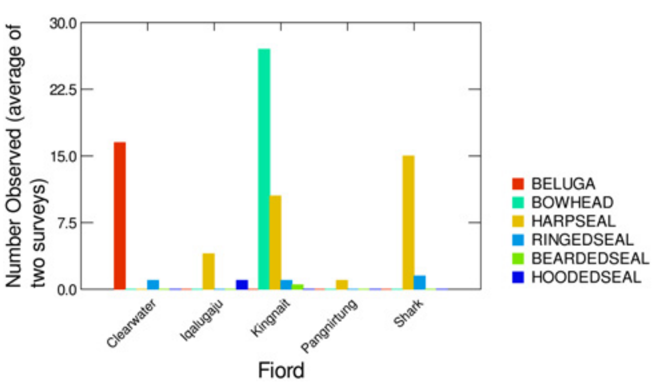

Figure 4: Numbers of marine mammals observed during surveys of Cumberland Sound fiords. Belugas (red) were seen only in Clearwater Fiord, while bowheads (green) were observed only in Kingnait Fiord. Harp seals (yellow) were observed in all fiords except Clearwater.

Over the past several years, we have also been conducting boat-based surveys of fiords in Cumberland Sound to learn more about marine mammal habitat use in the region. Marine mammals observed in 2012 were similar to those seen in other years, including belugas, bowhead whales, and harp, ringed, bearded, and hooded seals. As in previous years, belugas were observed only in Clearwater Fiord, while bowheads were observed only in Kingnait Fiord (Figure 4). Harp seals were observed in all fiords except Clearwater Fiord. Harp and ringed seals were also observed in Cumberland Sound while traveling to and from surveyed fiords, and bowhead whales were observed off-transect in Cumberland Sound between the mouths of Kingnait and Pangnirtung Fiords. No killer whales or polar bears were observed at any time. 2012 is the fourth year of data collection, and we are compiling an observation-based dataset that will be suitable for tracking future changes in marine mammal distribution and abundance in the area, and to help with identifying critical habitat. For example, a high proportion of bowhead whales observed in Kingnait Fiord are calves, suggesting this may be an important nursing area.

Overall objectives of our polar bear research program include investigation of the relationships between sea ice dynamics and polar bear population delineation and habitat use. As the sea ice in the Arctic responds to climate change, the overarching goal is to understand how polar bears are responding to changing sea ice conditions. Within this context, we use a variety of remote sensing techniques to describe polar bear habitat use. We employ resources selection functions, utilization distributions, individual based movement models, and habitat fragmentation methods to assess polar bear habitat. Developing new means of monitoring polar bear populations and the ecology of polar bears is a key objective. Research into predator-prey relationships is yielding new insights into polar bear population dynamics. 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, and sea ice models for Hudson Bay indicate population extirpation is highly likely by mid-century because critical thresholds for fasting endurance will be exceeded. In the western Canadian Arctic, new movement models for polar bears have been developed which will form the basis of oil spill impact models for the Beaufort Sea.

Population Structure and Demographics

Cost effective and efficient methods to census marine mammals are needed to monitor and manage populations. For bowhead whales, aerial surveys are commonly used but can be cost prohibitive and may not be capable of tracking individual animals. Genetic capture-mark-recapture (CMR) techniques are being used more often and may be able to both estimate local population size and to track animals as they move throughout the Arctic. This research uses genetic CMR to estimate a local population size for bowhead whales which were sampled at the floe edge near the community of Igloolik, NU. Samples were collected in June and July 2009 over a period of 11 days using 40- and 60mm biopsy darts. DNA was extracted and used to determine sex and to generate a 24 microsatellite loci profile for 89 samples. These data were then used to determine if animals captured on a particular day were recaptured on subsequent days. Using between-day captures and recaptures we aim to estimate the local population size and infer whether animals are staying within the study area for the sampling period or just passing through. Three individuals were found to be recaptured over the course of sampling. These include both two within-day and one between-day recaptures. These results suggest that most animals are not staying in the immediate area but a small proportion may be using the floe edge for longer periods at this time of year.

Emergent Ecological Response

Exposure to an increasing number of stressors across the Canadian Arctic may negatively impact marine mammal health, with eventual consequences at the population level. Typically, animals exposed to environmental stressors initiate a stress response resulting in physiological, behavioural and hormonal changes (Burek et al. 2008). The extent or magnitude of chronic stress exposure is associated strongly with the overall health of an animal, and this component of our project aims to assess whether marine mammals that have been chronically exposed to stress will demonstrate higher levels of stored chronic stress associated hormone (cortisol) levels within their blubber. Research in 2012 focused on assessing chronic stress in ringed seals and beluga whales, two ideal indicator species given their widespread distribution and subsistence hunting

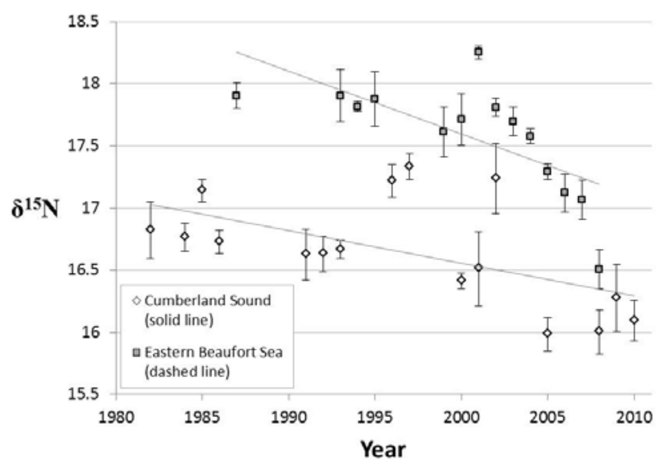

Figure 5. δ15N of skin has shifted over time (mean ± SE; ANCOVA: F1,281=39.947, p<0.0001). No relationship was found between individual cortisol concentrations and stable isotope ratios (ANCOVA: F3,125=0.602, p=0.615).

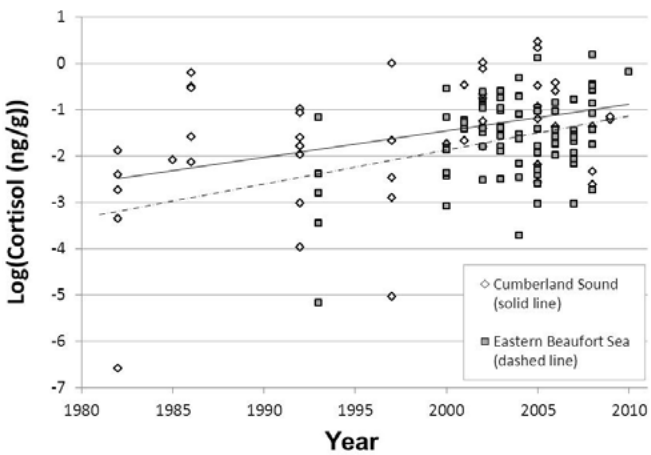

Figure 6. Increase in Beluga whale blubber cortisol concentrations over time from Cumberland Sound and Eastern Beaufort Sea (ANCOVA: F1,133=170.425, p<0.0001). Cortisol concentrations are significantly higher in Cumberland Sound (mean ± SE; ANCOVA: F1,133=4.079, p=0.0454).

across the Canadian Arctic.

Preliminary results have shown an increase in the stored cortisol levels found in the blubber of female ringed seals from Arviat over the past five years (2007-2011). Body condition in these same seals has decreased over the same time period. There is no apparent change in the condition of ringed seal pups, although there has been an increase in stored cortisol levels similar to that seen in females. Research on beluga response to environmental changed included assessment of links between long-term diet trends and stress hormone (cortisol) levels and potential changes in diet and predation pressure over time. Preliminary analysis of stable isotope ratios in skin of belugas harvested over the past several decades show a downward shift in nitrogen isotope ratios for the Cumberland Sound and Eastern Beaufort Sea beluga whale populations (Fig. 5). Preliminary results show the decline in δ15N was concomitant with an increase in blubber cortisol levels (Fig. 6), which suggests a dietary change accompanied by increasing stress. Our results also show that predator abundance may be related to increased cortisol in beluga whales.

Discussion

Diet and Food Web Structure

The Arctic is expected to change significantly with climate warming (Gagnon and Gough 2005; Stirling 2005). These changes may include shifts in species composition in response to variations in environmental conditions (Bluhm and Gradinger 2008; Wassmann et al. 2011). As a result, marine mammals will be indirectly affected through changes to food web structure, and a better understanding of their diet, including how diet differs among population segments (e.g. juvenile vs. adult) and varies across seasons, will help to assess future impacts. Seasonal variation in fatty acid composition and stable isotope ratios in ringed seals suggest seasonal changes in foraging habitat and diet. Patterns of δ13C indicate pelagic feeding during the open water season (Aug - Dec) when fat and energy stores are replenished, increased benthic foraging during the period of ice cover (Jan - May), followed by a period of fasting during the spring molt (June - July). Fatty acid composition suggested seasonal changes in diet which could include increased importance of pelagic fish in the fall during the period of positive energy balance. For both eastern and western Hudson Bay, the patterns of variability in ringed seal δ15N suggest inter-annual dietary shifts. However, eastern and western Hudson Bay showed opposing patterns of inter-annual variation in δ15N in relation to ice breakup date and spring air temperature. Peak δ15N occurred within a range in spring air temperatures, between approximately -5 °C and -2 °C. This temperature range was characteristic of warm years in western Hudson Bay and cool years in eastern Hudson Bay. We propose that the high δ15N observed in ringed seals are indicative of relatively greater importance of capelin (Mallotus villosus) in the ringed seal diet.

Observed seasonal variation in stable isotope ratios and fatty acid composition have important implications for studies of marine mammal feeding ecology. As warming continues, it is possible that the abundance of sub-Arctic species, including capelin and sandlance

(Ammodytes sp.), will continue to increase in Hudson Bay and shifts to temperate species may occur (Wassmann et al. 2011). Continued change to Hudson Bay forage fish populations may eventually lead to an energetic mismatch in which ringed seals are not able to meet seasonal energy requirements. Ringed seals will not only be affected by changes to prey populations, but also by changes to their ice habitat, and levels of competition and predation. Continued monitoring is required to ensure we have the knowledge necessary for effective conservation of ringed seals in the future. The success of ringed seals is especially important for polar bear (Ursus maritimus) populations that rely on ringed seals as the dominant food source (Thiemann et al. 2008), and Inuit communities for whom ringed seals provide subsistence food and are culturally significant.

Similarly, understanding cetacean diet is important for understanding narwhal ecology and predicting impacts of future climate change. No study has investigated isotope and fatty acid values in narwhals and their preferred prey, and none has compared diet and foraging behaviour among the three narwhal populations. Current analyses suggest the three narwhal populations may specialize on different prey, which may enhance their adaptability to changing climate. Differences among males and females in the Baffin Bay population is likely related to their different dive behaviour and suggests the sexes may use different foraging strategies when habitat segregation is possible. Stable nitrogen isotope ratios in beluga teeth also suggest foraging differs between males and female belugas, which may be due to habitat segregation during summer, when females are known to frequent estuaries. Future work on narwhals will focus on comparing dive behaviour of narwhals from the Baffin Bay and northern Hudson Bay populations with behaviour of narwhals from east Greenland. This, in conjunction with comparisons of prey signatures, will give us better insight into what prey constitute narwhal diet in each of the three populations. This is the first study to investigate narwhal dietary trends among the world's three narwhal populations using both stable isotopes and fatty acids. By coupling the results of the chemical analyses with investigations of dive behaviour we get a better understanding of narwhal dietary requirements and what habitats are critical to their survival.

Changing ice conditions in the Arctic are also expected to impact killer whales, which are anticipated to increase the spatial extent of their range, as well as the duration of time they spend in Arctic waters, as reduced sea ice opens up previously inaccessible areas. If this occurs, killer whale prey populations will likely be subjected to greater predation. Rake mark incidence suggests killer whales may be targeting younger bowhead whales in the northern Foxe Basin during summer. Due to the immense size difference between these two species, killer whales likely have greater success in killing bowhead calves and juveniles (Higdon et al. 2012 Reeves et al. 2006). If calves and juveniles are indeed targets of killer whale predation events, females may have greater exposure to killer whales during calf protection; greater exposure likely results in females exhibiting higher rake mark scarring compared to their male counterparts. The 10.2 percent rake mark occurrence estimate for the EC-WG population differed from the published estimate of approximately 7.1 percent for harvested BCB bowheads. The larger estimate for eastern bowhead whales is consistent with greater abundances of killer whales in the eastern versus western North American Arctic (Higdon et al. 2012). However, whether killer whale predation threatens the recovery of EC-WG bowhead whales from previous commercial whaling remains an important question for recovery planning. The findings may also provide insight into the feeding specializations and strategies of Arctic killer whales, namely the targeting of calf and juvenile bowhead whales.

Habitat Use and Movement Patterns/Distribution

Our polar bear data sets have developed significantly over time to allow novel insights into temporal dynamics of movement, distribution, 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. Understanding the effects of climate change and projecting the effects into the future have provided new insights into the ecology of polar bears. The research is important in designing new management and conservation strategies but is also of great interest to the public and northern communities.

Population Structure and Demographics

The very low number of bowhead recaptures (R = 1) may suggest that most bowhead whales occupying the area near the floe edge in northern Foxe Basin at this time of year are not staying in the immediate area. This is concordant with local Traditional Ecological Knowledge (Hay et al. 2000) and satellite telemetry data (LeBlanc unpublished data). Bowhead in this area move through Fury and Hecla Strait and into Prince Regent Inlet as soon as the ice starts to break up. The single between-day recapture may suggest that some animals remain slightly longer but more research is needed to better understand this dynamic. Although biopsy sampling is not likely to cause whales to avoid boats, and observations of the reactions to darting seem minimal, there may be a bias due to whales avoiding the sampling teams after the first encounter. Biopsy sampling has continued in the years subsequent to 2009 and future research will incorporate these data into population estimates and biological inferences that can be used in the sustainable co-management of this Arctic species.

Emergent Ecological Response

Ongoing climactic changes in the Arctic could strongly influence the organisms that inhabit this region over shorter (e.g., seasonally) and longer periods of time. Two major stressors in the Arctic that could affect marine mammal populations are: (1) an increase in the ice-free period (National Snow and Ice Data Centre 2012) allowing greater killer whale predation and (2) warmer ocean temperatures (Morison et al. 2000) resulting in a shift in prey composition (Jefferson et al. 2008), abundance and availability, along with a potential for an increase in disease incidence. Because chronic stress can reduce survival and reproductive success, a change in predation risk not only has immediate direct demographic effects, but also chronic indirect effects that may contribute to prey population declines in the future (Romero 2004). Increased cortisol concentrations over time suggest both ringed seals and beluga whales are responding physiologically to changing conditions in the Arctic. Higher mean cortisol concentrations in Cumberland Sound beluga whales, where killer whales are more common, suggests predation risk may be a major stressor. The shift in diet over time does not appear directly related to increased cortisol levels.

Conclusion

Along with findings over previous years, results from research in 2012 on diet and food webs, habitat use and distribution, population structure, and emergent ecological responses continue to indicate coupling between all aspects of marine mammal ecology and physical environment across the Canadian Arctic. Strong seasonal and inter-annual variation in measures of diet and distribution have 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-, reproductive- and population-specific foraging and movement behaviours indicate climate change impacts could vary within and across populations. Preliminary results from chemical diet and stress analyses of beluga and ringed seal tissues indicating unidirectional, long-term shifts in diet as well as chronic stress exposure suggests 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 currently 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 inputting this information into population and ecosystem models to understand and predict impacts of Arctic climate change on marine mammal populations.

Acknowledgements

Many thanks are due to the individuals and organizations for their help in the field, in the lab, and funding. We would like to thank the hunters and northern communities that participated in sample collection over the years, including the Hunters and Trappers Associations of Arviat and Sanikiluaq, NU for providing samples from seals harvested during their subsistence hunt, and Inuit hunters in various communities throughout Canada and Greenland for collection of narwhal tissue samples. We thank all of those who provided bowhead whale fieldwork support: Duncan Stewart, Brad Parker, Tam Akittirq, Nathan Parker, David Akkittirq, Daniel Akkitirq, Laimikee Iqqasaq, Manasi Angutigjuaq, Steve Ambruzs, Lily Peacock, Pituillie Qulitalik, Levi Qaunaq, Natalino Piugattak, Joachim Alarak, Dave Yurkowski, and the Igloolik Hunters and Trappers Organization (Igloolik); Laurent Kringayark, Luky Putulik, Paul Tegumiar, Elly Chmelnitsky, Jessica Haines, Joel Heath, Harry Milortok, Frank Siutinuar, Philip Kringayark, Laimikee Malliki, Brent Young, and the Aivik Hunters and Trappers Organization (Repulse Bay); Cory Matthews, Ricky Kilabuk and Mark Kilabuk (Cumberland Sound); Mads Fage Christoffersen, Camilla Ilmoni, Amingaaq Dahl and Louise Norman Jensen (Disko Bay), and Rolph Davis, Apak Quqqasiq, Peter McLaren, and Kerry Finley (Isabella Bay). We thank Jack Orr for leading narwhal tagging expeditions, as well as James Simonee and many others for assisting with the tagging. We thank Tara Bortoluzzi and Peter Beaudoin at the Department of Fisheries and Oceans Canada (DFO) for logistical support during all fieldwork operations.

Numerous samples were also collected and processed in various ways by Fisheries and Oceans Canada research staff in the field and at the Freshwater Institute, Winnipeg. We would like to acknowledge Margaret Treble and Kevin Hedges for providing prey samples, Bruno Rosenberg for assisting with fatty acid analyses. Thank you to Aaron Fisk and Anna Hussey for conducting the stable isotope analysis on all narwhal and prey tissues, and to Paul Middlestead, Wendy Abdi, and Patricia Wickham at the University of Ottawa for conducting stable isotopes analyses on all beluga teeth samples. Thank you to Panseok Yang and Norm Halden (University of Manitoba) for their expertise and support during measurement of trace element concentrations in beluga teeth, and to Misuk Yun for logistical support during various lab procedures. Gretchen Freund has generously provided her time and photographs of bowhead and killer whales during various field endeavours over the past five years. We thank Ruby Chang from the RVC is acknowledged for her help during statistical analysis. For use of a transcript from their Oral History Database, the Igloolik Inullariit Elders Society and the Igloolik Research Center are recognized.

We are grateful to the following organizations for funding our research:

- Canadian Association of Zoos and Aquariums
- Canadian Wildlife Federation
- Canadian Circumpolar Institute’s Boreal Alberta Research

- Environment Canada
- E. Scherer Memorial Scholarship
- Federal Program Office of International Polar Year
- Fisheries & Oceans Canada (Nunavut Implementation Fund and the Species at Risk Fund)
- Fisheries Joint Management Committee
- Garfield Weston Foundation
- Hauser Bears
- Inuvialuit Game Council
- Kenneth M. Molson Foundation
- L'Oreal UNESCO Women in Science Fellowship
- Manitoba Conservation
- Natural Sciences and Engineering Research Council (NSERC)
- Northern Contaminants Program
- Northern Scientific Training Program
- Northwest Territories Department of Renewable Resources
- Northwest Territories Department of Environment and Natural Resources
- Nunavut Wildlife Management Board (NWMB)
- PetroCanada Explorations
- Polar Continental Shelf Project
- Polar Bears International
- Quark Expeditions
- Royal Veterinary College (RVC), University of London
- United States Geological Survey
- United States Department of the Interior
- University of Manitoba
- World Wildlife Fund (Canada & International)
- Zoological Society of London

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