Effects of Climate Change on the Canadian Arctic Wildlife

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Abstract

Many northern ecosystems are undergoing major shifts related to climate change. This adds to increasing pressures due to resource development. An understanding of these transformations and of the significance of their consequences is critical to anticipating ways in which potential negative and positive effects to wildlife populations (and ultimately humans) may be mitigated or used through sound management. Our overall goal is to provide the wildlife-related knowledge necessary to conduct the integrated regional impact studies of the 'Eastern Arctic' and 'Hudson Bay', two of the four regions identified by ArcticNet to conduct regional impact studies. In addition, we contribute to all international efforts synthesizing knowledge on biodiversity for the benefit of northern populations and policy makers. We work through 5 specific objectives. First, we identify the main vulnerabilities of Arctic wildlife with regards to climate change and resource development. Second, we monitor more than 30 wildlife populations (mostly tundra wildlife and marine birds) at study sites located in the Eastern Canadian Arctic (e.g., Belcher Islands, Rankin Inlet, Coats Island, East Bay-Southampton Island, Digges Island, Deception Bay, Bylot Island, St.Helena Island). Third, we develop models to better understand the key interactions between species that drive the tundra food web. Fourth, we use data from our field work and from the literature to analyze past and present responses of wildlife to climatic variability in order to develop Impact Models. Finally, we project some wildlife patterns into the future by forcing these Impact Models with regional climate change scenarios. This project is a collaboration between ArcticNet researchers and a number of partners including the Canadian Wildlife Service (Environment Canada), Parks Canada Agency, Wildlife Conservation Society Canada, Nunavut Tunngavik Inc., Nunavut Wildlife Management Board, Baffinland Iron Mine Corporation, Department of Environment of Government of Nunavut, Nunavut General Monitoring Program, and many Northern communities, especially members of their Hunting and Trapping Organizations.

Key Messages

- Monitoring a set of key wildlife species is extremely important to assess ecosystem changes taking place in the Arctic, whether or not they are caused by climatic variation of natural resources development.
- This project monitors more than 30 wildlife populations from the arctic tundra and marine ecosystems. This provides Canada with an important warning system regarding ecosystem changes in the Arctic. It also feeds important Arctic Council initiatives such as the Arctic Biodiversity Assessment.
- In addition, this project tests important ecological hypotheses through long-term field observations and detailed field experiments, some of them unique at the scale of the circumpolar Arctic. In particular, we generate lots of new knowledge about the importance of the role of sea ice in wildlife ecology.
- Consequences of climate warming on wildlife can sometimes be negative and sometimes be positive, depending on the species that is considered. Those species most specialized for Arctic environments (e.g. Peary caribou, polar bear, arctic fox, snowy owl) should be the most negatively affected.
- In the short term, increases in weather variability (rain in winter, heavy wet snowfalls in early spring) might have more negative influences than changes in average temperature or precipitation, although this may change quickly.
- As the abundance of some species will increase while others will decrease, we expect important shifts in wildlife species assemblages and that this will vary longitudinally.
- A general northward movement of wildlife species is ongoing and should amplify in the next few decades. This is mostly detected at the southern margin of the Arctic.

- Species that play a key role in the organization of ecosystems, and thus influence ecosystem services such as provision of food to human communities, will likely change in many parts of the Arctic.
- Wildlife exploitation and food diversity of arctic human communities depend on the composition and health of ecosystems. Therefore, assessing the vulnerabilities of ecosystems and wildlife is important to assessing the vulnerability of human communities.

Objectives

We continue to pursue the objectives identified at the start of the project:

1. to identify the main vulnerabilities of Arctic wildlife with respect to climate change;
2. to pursue and enhance the wildlife monitoring program forming the core of this project;
3. to develop trophic interaction models to better understand key interactions driving the tundra food web;
4. to develop some Impact Models describing selected responses of Arctic wildlife to climate change;
5. to force these Impact Models with regional climate change scenarios.

Introduction

The increase in Arctic surface temperatures over the last few decades and the increased development of natural resources in northern regions have generated major concerns about the future of Arctic wildlife, traditional hunting activities, and the integrity of arctic ecosystems. Effects of climate change on the timing of biological events (phenology of species), the distribution of species, and the food webs (trophic dynamics) of wildlife communities are now apparent. Effects of mining sites and mineral shipping routes on wildlife are anticipated. Yet, as Arctic climate continues to warm and the pace of development increases, our capacity to measure and predict the responses of biological systems and their cascading effects through food webs, and ultimately their effects on humans, remains limited. We need baseline data of natural systems. We are also faced with complex interactions between wildlife species and between ecosystems and humans. The mandate of this project is to better understand the current and anticipated effects of climate change and natural resource development on Arctic wildlife.

Wildlife species are sentinels of environmental change and the first effects of climate change on species can be detected in the timing of biological events (their phenology; Berteaux et al. 2004). We monitor the phenology of many populations, such as eider ducks and greater snow geese, which are significant to the Inuit and for which extensive data sets already exist. We also monitor the phenology of long distance migrants like shorebirds and raptors, as they form an important component of the arctic biodiversity. The movement of wildlife over the land, sea and sea ice is another important component of wildlife ecology that responds quickly to changing environmental conditions (CAFF 2013).

The northward progression of isotherms in the Arctic will have wide-ranging impacts on the distribution of wildlife, with cascading effects on the functioning of ecosystems. Many arctic species may undergo population declines in response to warming not because they cannot tolerate more benign environmental conditions, but because they will be out-competed in these new environments by southern invaders with less tolerance for harsh conditions but better growth potential under more benign conditions. Invading species come from the southern boundary of the Arctic and can sometimes move fast to more northerly locations. For example red foxes have invaded Baffin Island and are now found in southern Ellesmere Island.

Climate imposes a rough structure to wildlife communities through its effects on plant growth (primary productivity). However, the interactions between plants, herbivores, and predators (the food web dynamics) shape the fine-scale structure of communities (Legagneux et al. 2013). We need to know how the relative influences of climate and biotic factors vary geographically, to better anticipate where the effects of climate change on the functioning of the tundra will be greatest. We study the interactions between plants, herbivores, and predators at several sites, such as Bylot Island, Rankin Inlet, and Southampton Island to better understand climatic impacts on the food web dynamic. We also investigate how seabirds and several other species are influenced by sea ice and potential mineral shipping routes, as this is a poorly understood aspect of their ecology.

Activities

Time frame and study area: Field work was carried out by our team from May-August 2013 at East Bay (Southampton Island), Rankin Inlet, Igloolik, Steensby Inlet, Digges Island, Coats Island, Deception Bay and Bylot Island. Boat-based bird research was carried out in July 2013 along the south coast of Baffin Island and in Frobisher Bay, in partnership with the communities of Kimmirut and Iqaluit. Electronic equipment allowed us to collect climatic and biological data throughout the year. Carcasses of carnivores were collected in winter from hunters in Kivalliq and Kitikmeot.

Research: Intensive field work was done and detailed analyses of collected data (capture and marking of wildlife, nest abundance, nest survival, digital pictures, locations of animals and movement behaviour, avian distance sampling, avian disease sampling) and samples (tissues from wolf and wolverine carcasses, lemming winter nests, bird of prey food pellets, plant above-ground biomass, insects and spiders, wildlife blood, and hairs/feathers) were performed. In addition, a particular effort was made to synthesise existing data and integrate them into circumpolar research efforts. This resulted in the following investigations:

Climate

- Retrieval of climatic data from four automated weather stations on Bylot Island and one on north Baffin Island.

Plants

- Monitoring of plant primary production and goose grazing impacts in wetland habitats at Bylot Island (24 exclosures).

Insects and spiders

- Monitoring of insect and spider emergence and diversity using pitfall traps (1000 samples collected over the summer).

Birds

- Monitoring of ca. 450 Peregrine Falcon, Gyr Falcon and Rough legged Hawk nest sites at Rankin Inlet, Igloolik and Steensby Inlet.
- Monitoring of peregrine falcon yearly movements using 70 Lotek geolocators.
- Monitoring of ca. 100 shorebird nests and ca. 119 passerine nests at Bylot Island.
- Monitoring of chick growth rate from ca. 40 passerine nests (ca. 100 chicks) at Bylot Island.
- Monitoring of chick growth rate from 70 raptor nests.
- Monitoring of reproductive activity of 451 nests of snow geese at Bylot Island.
- Marking of ca. 50 shorebirds and ca. 150 passerines at Bylot Island.
- Monitoring of the habitat use of eider duck flocks by conducting snowmobile surveys, and comparison of their distribution with previous years (Inuit field workers were trained to continue this work without our direct participation).
- Detailed observation of peregrine falcon behaviour using infrared-triggered cameras and direct observation.

- Monitoring of the reproductive activity of seven species of predatory birds (Parasitic Jaeger, Long-tailed Jaeger, Snowy Owl, Rough-legged hawk, Peregrine Falcon, Gyrfalcon, Glaucous Gull; 10-130 nests per species per site, depending on species and site) and long-term marking of jaegers (47 individuals), peregrine falcons (122 individuals) and Rough-legged hawks (26 individuals).
- Capture and marking of 10 adult female Snowy Owls with satellite transmitters at Deception Bay.
- Collection of prey samples and blood plasma for analysis of peregrine falcon diet using isotopes.
- Banding and re-sighting of 200 adult eider ducks on Southampton Island to estimate annual survival of birds in relation to disease, harvest, and weather conditions.
- Collection of blood samples from 200 eider ducks on Southampton Island to assess links between hormones, body condition, and vulnerability to avian cholera.
- Banding and attachment of geolocators to seven Black-bellied Plovers, five Ruddy Turnstones, and 11 Sabine's Gulls at East Bay, Southampton Island, and recovery of previously deployed geolocators from one Black-bellied Plover and six Sabine's gulls.
- Deployment of 35 geolocators on Semipalmated Sandpipers at Coats Island to establish migratory routes and wintering locations of this declining species.
- Implanted 21 Common Eider and 10 King Eider ducks with satellite transmitters (with Danish collaborators) to track their migratory movements and marine habitat use in the Canadian Arctic and west Greenland.
- Deployment of seven satellite tags on Herring Gulls at East Bay Island to monitor their migratory movements in relation to diet composition and contaminant levels.
- Monitoring of 72 nests of six species of shorebirds, and 13 nests of Sabine's Gull on Southampton Island to better understand potential mechanisms of population decline.
- Monitoring of predation rates of shorebird nests using time-lapse photography at Southampton Island (five cameras) and Coats Island (five cameras).
- Banding of 204 adult passerines on Southampton Island and near Iqaluit. Instrumentation of 25 of these with geolocators to monitor their migration, and recovery of eight geolators from recaptured individuals.
- Monitoring of the growth rate of 45 known-aged passerine chicks from 16 nests on Southampton Island.
- Surveying of 72 Common Eider breeding colonies in Hudson Strait and Frobisher Bay, Nunavut to evaluate the severity and geographic scope of avian cholera and polar bear nest predation on eider reproduction.
- GPS tracking of 38 Thick-billed Murres from Digges Island to establish key marine habitat areas during the breeding season.
- Retrieval of 12 geolocators from peregrine falcons at Rankin Inlet (5), Peru (2), Greenland (2), Igloolik (2) and Baffin Island (1).
- Deployment of geolocators on 19 peregrine falcons.
- Collection of 49 three-minute post-capture and 49 thirty-minute post-capture peregrine blood samples for analysis of corticosterone, triglycerides, total solids and B-hydroxybuterate.
- Monitoring of 10 supplemented and 10 control falcon nest sites for effect of food supplementation.
- Request, filtering and analysis of all banding data for peregrine falcons from 1970 – 2010 for estimation of population size and trend.
- Detailed observation of nest predator (e.g. Polar bear, fox) behaviour using infrared-triggered cameras and direct observation.

Mammals

- Monitoring of ca. 100 fox dens on Bylot Island.
- Monitoring of 30 arctic fox yearly movements in the eastern High Arctic using Argos satellite transmitters.
- Observation of long-range movements (up to 2000 km) of arctic foxes across Nunavut.
- Monitoring of lemming abundance and demography (19 winter nests, 1 lemming trapped during ca. 3500 trapping-days) at Bylot Island. Monitoring of lemming abundance at Rankin Inlet, Igloolik, and north Baffin Island.
- Monitoring of 17 ermine dens at Bylot Island.
- Detailed observation of fox behaviour on Bylot Island using 70 infrared-triggered cameras and direct observation.
- Collection of carcasses of 80 arctic wolf and 50 wolverines from Inuit hunters in Qikiktaaluk (Hall Beach, Igloolik), Kitikmeot (Kugaaruk, Taloyoak, Gjoa Haven, Cambridge Bay, Kugluktuk) and Kivalliq (Arviat, Whale Cove, Rankin Inlet, Chesterfield Inlet, Baker Lake, Repulse Bay).
- Determination of diet of wolverines and wolves by analysing stomach contents of animals harvested in Nunavut during the hunting season of 2012.
- Participated in the annual meeting of the Arctic Borderland Knowledge Coop (Yukon) to analyse the benefits of wildlife community monitoring, particularly caribou.

Syntheses

- Synthesis of climatic and ecological changes during the last two decades at one of our tundra study sites (Bylot).
- Modelling of ecosystem trophic structure at one of our tundra study sites (Bylot).
- Synthesis across several circumpolar study sites of climatic and ecological factors structuring tundra ecosystems.
- Participation in a major circumpolar synthesis of arctic biodiversity: the Arctic Biodiversity Assessment (2013).

Results

We focus here on some particularly interesting results obtained in 2013-2014 with regards to the effects of climate variability and resource development on arctic wildlife. Specifically, we summarize five new scientific findings that represent well our activities. All are in direct line with our proposed objectives and milestones.

Diminshing sea ice season length increases presence of polar bears at seabird colonies

Data collected from East Bay Island and Coats Island suggest that the occurence of polar bears at each of these seabird breeding colonies has increased > 7-fold in the past decade, and that bear presence was more important when ice season length was shorter (Iverson et al. 2014). Our survey of more than 200 Eider breeding colonies in 2010-2013, done in Hudson Strait in collaboration with seven communities, allowed us to evaluate the extent and severity of nest depredation by polar bears. We encountered polar bears or sign of polar bear on 34% of the colonies that we surveyed (Table 1) and Eider nesting success was three times lower on islands with bears than without bears (Iverson et al. 2014).

Table 1. Proportion of common Eider nests remaining active (hen, eggs, or chick present) in the eastern Canadian Arctic, according to the type of predator sign found on the colonies.

Type of sign	Number of islands	Total nests	Active nests (± SE)
None	15	183	0.72 (± 0.03)
Gull only	114	14,416	0.66 (± 0.01)
Fox and gull	22	3,041	0.39 (± 0.02)
Bear and gull	75	14,441	0.22 (± 0.01)
Bear, fox and gull	4	511	0.06 (± 0.01)
Total	230	32,592	0.44 (± 0.01)

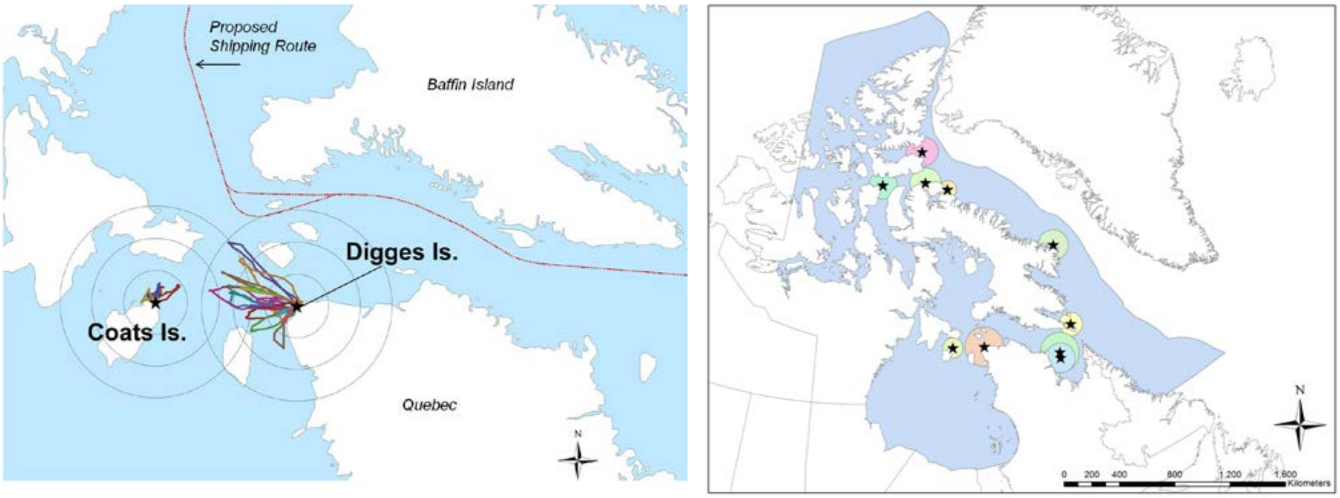

Figure 1. Summer foraging tracks of Thick billed Murres at Digges Island and Coats Island (left) and model projections for the foraging areas of all Thick Billed Murre colonies in the Eastern Canadian Arctic, based on the most recent estimates of population size (right; Gaston et al., 2013).

Increased development activities will overlap with important seabird feeding areas

In collaboration with Environment Canada and Baffinlands Iron Mines, we have undertaken an expansive seabird tracking initiative to assess the potential impacts of increasing resource development activities in the eastern Arctic, particularly year-round shipping. We have used GPS and satellite tracking to follow Thick-Billed Murres, Herring Gulls, Common Eiders and King Eiders at sea. For Thick-billed Murres, we have then applied a time-budget analysis combined with Central Place Foraging Theory (Hamilton and Watt 1970, Charnov et al. 1976), to model the relations between foraging range and colony size. We then calibrated these predictions against real foraging trips recorded by GPS loggers attached to incubating birds at Coats Island and Digges Island (Gaston et al. 2013). This allowed us to identify key marine habitat areas throughout their annual cycle (Figure 1).

To build on tracking data collected in 2012, we continued our tracking efforts with Common Eiders and also initiated tracking programs with Herring Gulls and King Eiders at East Bay Island in an effort to identify important marine habitat areas for these species in the eastern Canadian Arctic. This revealed the extensive movements of birds (Figure 2).

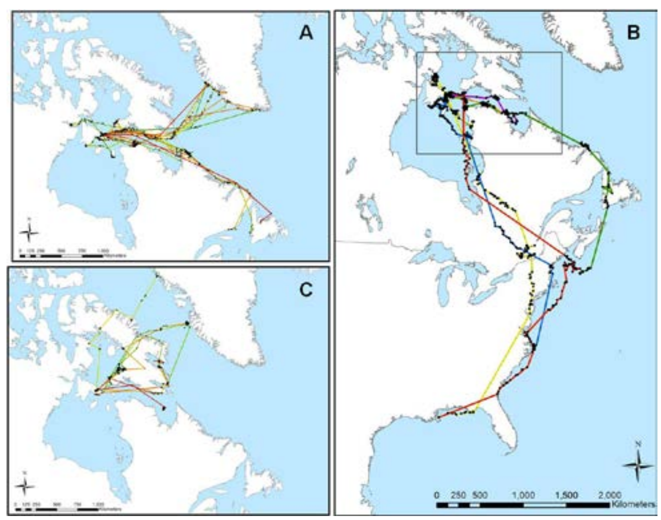

Figure 2. Satellite telemetry data for Common Eiders (A), Herring Gulls (B), and King Eiders (C) from July-November 2013.

Climate variability and interactions between species have cascading effects on wetland plants

Based on our current understanding of the mechanisms linking climate, plants, herbivores and predators

(Gauthier et al. 2004, 2011), we investigated climate-induced and predator-mediated indirect effects on grazing intensity in the tundra food web of Bylot Island. This site experienced a clear warming trend over the last two decades. Using a 22-year time series, we evaluated the relative effects of environmental parameters on the proportion of plant biomass grazed by geese in wetlands, and examined the temporal changes in the strength of these cascading effects. Migrating geese can consume up to 60% of the annual production of wetland graminoids. Spring North Atlantic Oscillation, mid-summer temperatures and summer abundance of lemmings (prey sharing predators with geese) best explained annual variation in grazing intensity (Figure 3). Goose grazing impact increased in years with high temperatures and high lemming abundance. However, the strength of these indirect effects on plants changed over time (Figure 3). Grazing intensity was weakly explained by environmental factors in recent years, which were marked by a sharp increase in plant primary production and a steady decrease in grazing pressure.

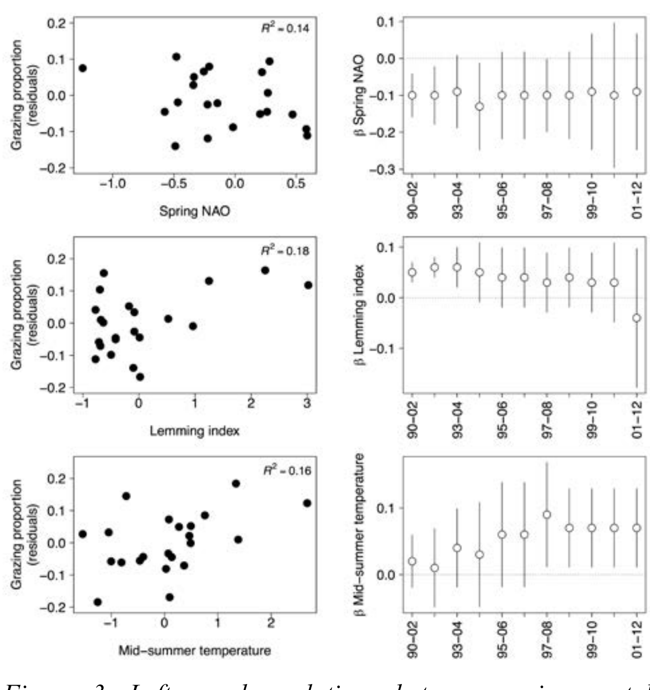

Figure 3. Left panels: relations between environmental parameters (spring North Atlantic Oscillation index, summer lemming abundance and mid-summer temperature on Bylot island) and the proportion of plant biomass grazed by geese on Bylot Island (shown: residuals of the relation between proportion of biomass grazed and time). Right panels: change in the relation between grazing proportion and the covariates over the eleven successive 12-year sliding windows (period 1990-2012). Values of the slopes of the relations for each sliding window are shown on the X-axis (bars indicate ± 0.95 confidence intervals). All covariates are standardized.

Primary tundra production increases with climate warming

We synthesed the long-term (up to 24 years) monitoring records available on Bylot island, to examine temporal trends in several terrestrial vertebrates and in primary production (Gauthier et al. 2013). Despite a clear warming trend (snow-melt advanced by 4 to 7 days and cumulative annual thawing degree-days increased by 37% over 23 years; Figure 4), the phenology, abundance or productivity of snow geese, foxes, lemmings and avian predators did not change significantly. Only primary production

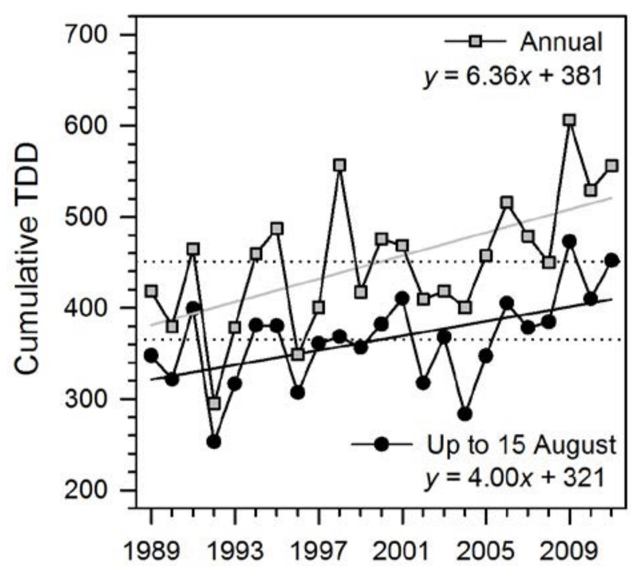

Figure 4. Cumulative thawing degree-days (TDD = degree-days > 0°C) in the Qarlikturvik Valley of Bylot Island from 1989 to 2011. The dotted lines show the mean for the whole period. The regression lines show the temporal trends (1989 = year 0 in the regression equations). From Gauthier et al. (2013).

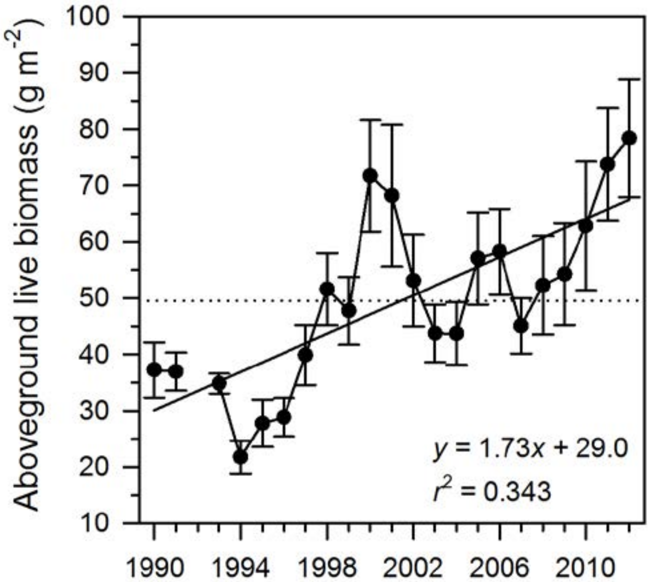

Figure 5. Annual aboveground production of wetland graminoid plants (mean ± SE) in the Qarlikturvik Valley of Bylot Island from 1990 to 2012. The dotted line shows the mean for the whole period. The regression line shows the temporal trend (1989 = year 0 in the regression equation). From Gauthier et al. (2013).

showed a clear response to warming, as annual aboveground biomass of wetland graminoids increased by 123%; Figure 5). We nonetheless found evidence for potential mismatches between herbivores and their food plants in response to warming, as snow geese adjusted their laying date by only 3.8 days on average for a change in snow-melt of 10 days, half of the corresponding 7.1 day-adjustment shown by the timing of plant growth.

Using an 18-year time series of brown lemming abundance on Bylot Island, we found support for the hypothesis that snow cover can affect the amplitude and possibly the periodicity of lemming population cycles in the High Arctic (Bilodeau et al. 2013). Summer abundance of brown lemmings was higher following winters with a deep snow cover and a low density snow pack near the ground, but was unaffected by the date of establishment of melting and duration of the snow cover. Moreover, two snow variables showed a temporal trend; mean winter snow depth increased and date of establishment of the hiemal threshold occurred earlier over time. These temporal trends, which should be favourable to lemmings, may explain why healthy population cycles have been maintained at our study site, contrary to other Arctic sites (Hörnfeldt et al. 2005, Ims et al. 2008, Kausrud et al. 2008, Gilg et al. 2009).

Heavy rainfall affects nestling survival of Peregerine falcons

Peregrine Falcons breeding near Rankin Inlet show an on-going decline in productivity, despite decreased organochlorine contamination below levels causing reproductive failure (Franke et al. 2010). Using a nest

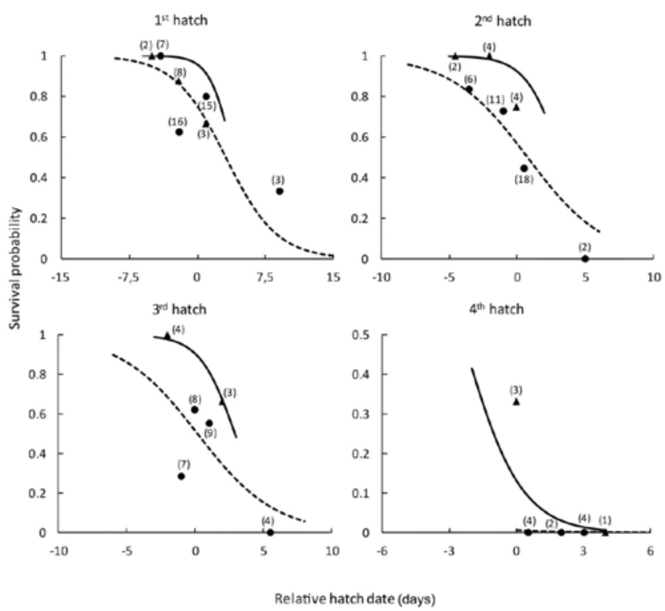

Figure 6. Survival probability of Arctic-nesting peregrine falcon nestlings, in relation to their relative hatch date (values are standardized relative to the yearly median) and within brood hatch sequence (from top left to bottom right). Lines represent values of the fitted logistic regression model [nestlings sheltered in a nest box (solid line), unsheltered nestlings (dashed line)]. Values were obtained using the average random effect calculated for each hatching position, with or without shelter, separately. Each point represents the proportion of surviving nestlings grouped by similar hatch date. Sample size is shown near each point. Sheltered nestlings (triangles), unsheltered nestlings (circles). From Anctil et al.(2014).

box experiment, we demonstrated that the nestlings raised in nest boxes survived the negative effects of exposure to rainfall better than those raised on natural ledges (Figure 6). More importantly, we found that the increase in the frequency of heavy rain over the last three decades is likely an important factor explaining the recent decline in falcon nestling survival rates, and hence the decrease in annual breeding productivity of the population. Our study is among the first experimental demonstrations of the direct link between rainfall and survival in wild birds, and clearly indicates that top arctic predators can be significantly impacted by changes in precipitation regime.

Using motion sensitive cameras, we observed infanticide and cannibalism in Peregrine Falcons. A marked adult female and unmarked adult male produced and hatched two eggs at a known and regularly monitored nest site. Motion sensitive camera images indicated that two nestlings were attended to by the adults and were fed in a manner that resulted in growth and development typical for the nestlings produced in the study population. During a period of intense rainfall, both nestlings were left unattended for several hours; they were clearly distressed and one was close to death. When the visibly wet marked adult female returned to the nest ledge, she killed and partially consumed the smaller and weaker of the two nestlings. The female flew from the nest ledge without feeding the remaining nestling and returned shortly afterward to kill and partially consume the second nestling (Figure 7).

Figure 7. A motion sensitive camera image shows a resident adult female Peregrine Falcon killing her nestling. The nestling was alive as the female tore a wound into the back of its neck (this is also how falcons kill their prey).

Discussion

Diminshing sea ice season length increases presence of polar bears at seabird colonies

We have demonstrated how the direct effects of sea ice loss on polar bears are having unanticipated indirect effects on breeding birds. Hudson Strait has undergone a near two-month reduction in annual ice cover over the past three decades (Sahanatien and Derocher 2012). This has resulted in Polar bears coming ashore sooner (Cherry et al. 2013) and in poorer condition (Rode et al. 2010), apparently as a consequence of lost seal hunting opportunities. There is now considerable evidence that bears visit more often bird colonies during the nesting season (e.g., Stempniewicz 2006, Smith et al. 2010). Our work suggests that depredation of Eider nests by polar bears is widespread among Eider colonies in Hudson Strait and severe enough to have significant demographic impacts at a regional scale for breeding Common Eiders and result in population declines (Iverson et al. 2014).

Increased development activities will overlap with important seabird feeding areas

Current plans for shipping in Hudson Strait include year-round ice-breaking that will see ships passing through the Strait every 48 h (Fisheries and Oceans Canada 2012). The consequences for marine ecosystems of this ice-breaking, on top of the rapid ongoing changes in ice conditions, are unknown. By tracking marine birds through Hudson Strait, we can identify important marine habitat areas as part of marine spatial planning (e.g., Douvere and Ehler 2011, Camphuysen et al. 2012). Our preliminary results strongly suggest that increased development activities in Canada's Arctic will overlap with important feeding areas for murres and other seabirds (e.g., Gaston et al. 2013). In response, we are continuing to study how shipping and other human activities influence seabird distribution and foraging at sea.

Climate variability and interactions between species have cascading effects on wetland plants

The nature and strength of the emergent effects of global change on ecological food webs remain poorly understood because they are the net result of multiple species responding to various changes in their environment (Suttle et al. 2007, Post 2013). Identifying the key direct and indirect environmental effects is fundamental to begin understanding potential ecological consequences (Le Roux et al. 2005). Indirect interactions in food webs can strongly influence the net effect of global change on ecological communities, yet they are rarely quantified and hence remain poorly understood. As predicted, we found that climatic factors and predator-mediated interactions between herbivores can have significant cascading effects on wetland plants in the Bylot Island terrestrial ecosystem (Bêty et al. 2014). However, the strength of these indirect effects changed over the last two decades. Cascading effects weakly explained grazing intensity in recent years, which are marked by a sharp increase in plant primary production and steady decrease in grazing intensity (Bêty et al. 2014, Gauthier et al. 2013).

On Bylot Island, indirect effects do not seem to be reversing the direct positive effect of warming on wetland plants (Bêty et al. 2014). While species interactions can offset short-term responses of plants to changes in environmental conditions in invertebrate-dominated systems (Suttle et al. 2007, Barton et al. 2009), indirect effects of climate on plants may lag considerably behind the direct effects in vertebrate-dominated communities (Bêty et al. 2014). Such time lags should be especially amplified in arctic ecosystems where key herbivores are long distance migrants strongly affected by environmental factors encountered away from the Arctic.

Primary tundra production increases with climate warming

A surprising outcome of our recent data synthesis has been the lack of changes in the phenology, abundance or productivity of several species of vertebrates on Bylot Island, despite the warming trend that has affected this area over the past three decades. Several reasons could explain the lack of response by herbivores and predators to climate warming at our study site. This includes the duration of our time series, the large annual variability in environmental conditions, the amplitude of observed climate change, the non-linear dynamic of the system (i.e. threshold not yet reached), or the constraints imposed to migrants by various rates of warming across latitudes (Gauthier et al. 2013). Because of their simplicity, arctic food webs may be especially prone to exhibit nonlinear dynamics in response to climate warming, and to show abrupt changes owing to threshold effects and feedback processes. Therefore, great care is needed when trying to extrapolate future ecological responses (or lack of them) observed at the early stage of warming, especially considering that upcoming warming should greatly exceed what has been observed so far.

Heavy rainfall affects nestling survival of Peregerine falcons

Our results strongly suggest that the frequency of heavy rain has a much greater impact on nestling survival than the total amount of precipitation recorded during the rearing period. The latter parameter is, however, typically used in most ecological studies (Bradley et al. 1997, Lehikoinen et al. 2009). In our study system, direct observations showed that fatalities can occur in less than 2 h of heavy rain. The long-term precipitation data for our study site are consistent with the increase in extreme precipitation events noted in climate studies (Stone et al. 2000, Groisman et al. 2005), and it is predicted that the frequency of rainstorm events will increase at a rapid pace in the Arctic (Min et al. 2011). The negative effect of rainstorms on annual breeding productivity of Arctic-nesting falcons is therefore predicted to increase. Furthermore, although the direct effects of heavy rain explained an important proportion of the annual variation in nestling survival at our study site, other environmental factors, such as food availability (Potapov 1997, González et al. 2006), could strongly affect breeding success.

The influence of weather on trophic interactions clearly contributes to spatial and temporal variations in organisms. Although our study did not focus on trophic levels below Arctic-breeding birds, the presence or absence of a correlation between weather and the distribution and abundance of each avian guild allows us to prioritize which trophic interactions should be the focus of future investigations. Generalist species, such as gulls and songbirds, were less influenced by weather than specialists such as insectivorous shorebirds. Generalists with more trophic interactions may be more resilient to environmental perturbations than specialists, because generalists can switch to alternative prey (Clavel et al. 2010). The fossil record confirms that past communities have homogenized toward fewer trophic interactions and become dominated by ecological generalists in the face of climate warming (Blois et al. 2013), a trend that has also been observed over the last 20 years (Davey et al. 2012).

Conclusion

The Inuit population, the international scientific community, and the public in general are concerned about the future of Arctic wildlife. One of these sources of concern is the effects of climate change, as was highlighted in the recent Arctic Biodiversity Assessment (CAFF 2013), a major report endorsed by the Arctic Council to provide policy makers and conservation managers with a synthesis of the best available scientific and Traditional Ecological Knowledge information. Through our data collection, our data syntheses, and our direct implication in the writing phase (several of our PIs were lead or contributing authors), our project has greatly contributed to the Arctic Biodiversity Assessment. A Report for Policy Makers now provides decision-

Figure 8. The Report for Policy Makers of the Arctic Biodiversity Assessment, to which this project strongly contributed, highlights many measured or potential effects of climate change and resource development on arctic wildlife. The report is freely available at http://www.arcticbiodiversity.is/index.php/the-report.

makers with key findings and policy recommendations (Figure 8).

It is crucial to continue supplying monitoring information on wildlife populations of the Arctic, and on the functioning of arctic ecosystems. It is also important to research the mechanisms that link ecosystems to climate and other drivers of change (such as resource exploitation), and to attempt to predict the future trajectories of arctic biodiversity. Moreover, research is critical to identify the best ways to manage wildlife populations and protected areas, at a time of changing environmental conditions.

In this project, we generate some of the needed baseline information on more than 30 wildlife populations spread over a gradient ranging from the Low to the High Eastern Canadian Arctic. We also produce critical information on the functioning of ecosystems and its links with climatic variation. Our results are obtained through efficient collaborations and are transmitted to most governmental and non-governmental organizations active in the field of wildlife and ecosystem research and management in the Canadian Arctic.

As in previous years, numerous northerners took part in our research activities and, in some cases, were trained to take the lead in future wildlife monitoring. Conversely, some northerners visited our universities to exchange knowledge in a way that was beneficial to university researchers. To finish, we highlight that our students take a remarkable lead to further bridge northern communities and scientific research. For example, some of them developed ARCTIConnexion (http://www.arcticonnexion.ca/en), a very successful initiative that was, for example, instrumental in organizing the project “IKAARVIK: from barriers to bridges”. IKAARVIK was awarded the Arctic Inspiration Prize during the 2013 ArcticNet Scientific Meeting.

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