Environmental Monitoring and Assessment (2006) **113:** 31–48
DOI: 10.1007/s10661-005-9095-3 © Springer 2006

MARINE BIRDS AS INDICATORS OF ARCTIC MARINE ECOSYSTEM HEALTH: LINKING THE NORTHERN ECOSYSTEM INITIATIVE TO LONG-TERM STUDIES

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Abstract. Marine birds are sensitive indicators of the condition of marine ecosystems in the Arctic, partly because they feed at the top of the arctic food chain. The Northern Ecosystem Initiative (NEI) recently supported four separate studies that investigated aspects of Arctic marine bird science which simultaneously addressed goals of the NEI to better understand northern ecosystems and their response to environmental stressors. The projects used both scientific and traditional knowledge to examine the relationship between sea-ice, contaminants, and the ecology of marine birds, and to transfer environmental knowledge to students. Results from these investigations confirm that changes are occurring in Arctic environments, and that these are captured through marine bird research. Collectively these studies provided new data that supported NEI objectives of monitoring the health of the Arctic ecosystem, and contributed to Canada's international obligations for Arctic science.

Keywords: Arctic, marine birds, contaminants, sea-ice, climate change, inuit, polynya, nunavut

1. Introduction

Canada has an international responsibility to manage a large Arctic marine bird resource. In excess of 10 million seabirds inhabit the Canadian Arctic archipelago and surrounding marine zone (Mallory and Fontaine, 2004), representing nationally and globally significant populations. Marine birds are a ubiquitous feature of polar environments, typically feeding at the upper trophic levels, and thus are sensitive indicators of the condition of marine ecosystems because they are affected by changes in many levels of the marine food web (Nettleship and Duffy, 1993). In particular, most polar marine birds forage over considerable geographic areas, integrating the distribution, abundance and contaminant burdens of zooplankton and fish over these regions. Many also rely on features of sea-ice for feeding (edges, polynyas, underside of ice; Stirling, 1997). In years when marine food resources are reduced, aspects of marine bird reproduction are concordantly reduced (e.g., Barbraud and Weimerskirch, 2001).

Marine birds also form part of the traditional diet for Inuit communities (the indigenous residents of the Canadian Arctic), and thus the long-term sustainability and health of marine bird populations is important to the people of the North (Kinloch *et al.*, 1992; Robertson and Gilchrist, 1998; Furgal *et al.*, 2003). It is not surprising, therefore, that scientists and Arctic communities both harbour concern for the resources of this region, because of documented patterns of contaminant accumulation (Muir *et al.*, 1999), and because the Arctic is predicted to be among the ecozones most affected by climate change (Roots, 1989; Vinnikov *et al.*, 1999). In fact, environmental conditions in the Arctic (and specifically sea-ice) are already changing (Krupnik and Jolly, 2002; Laxon *et al.*, 2003), so studying marine bird ecology should serve as a proxy and harbinger of changes in marine ecosystems.

In the Canadian Arctic, marine birds have been the focus of research and monitoring for several decades (e.g., Gaston and Nettleship, 1981; Hobson, 1993; Braune *et al.*, 2001, 2002).The amount of research and the integration of studies has increased since the early 1990s, as the effects of climate change and other environmental stressors are being observed (e.g., Vinnikov *et al.*, 1999), and potential linkages to concurrent changes in some marine bird populations are being suggested (e.g., Robertson and Gilchrist, 1998; Gilchrist and Mallory, 2005).

In this paper, we review the findings from four recent studies of marine birds in Arctic Canada that have been supported by the Northern Ecosystem Initiative (NEI). The projects fit into the NEI mandate to improve our understanding of northern ecosystem responses to climate change and contaminants, to monitor ecosystem change, and to build capacity in northern communities (Mallory *et al.*, 2005 – this issue). At the same time, these projects have all been designed to gather data required to meet Canada's national and international obligations to monitor and manage marine bird populations (Government of Canada, 1997, 2001, 2002; CAFF, 2001; NAWCP, 2002) and to monitor contaminants in the Arctic (Furgal *et al.*, 2003). Our objective in each investigation was to gather data on the health, reproductive success, population size or distribution of marine birds. This contributed to an integrated, long-term monitoring program, designed to elucidate why variation exists in these parameters, and how they might be related to environmental threats currently facing Arctic Canada.

2. Methods

These studies looked at different parameters at different times and, in some cases, were conducted in different regions of the Arctic, so the methodology employed in each case varied. Here we provide a brief overview of the methods, and cite relevant papers where more details can be obtained.

2.1. Sea-ice and marine birds at Prince Leopold Island

Prince Leopold Island (74°N, 90°W) is an oval island (11 × 8 km) surrounded by 350 m cliffs, located in Lancaster Sound (Figure 1; see Gaston and Nettleship 1981). It is one of the largest seabird colonies in the Canadian Arctic, supporting

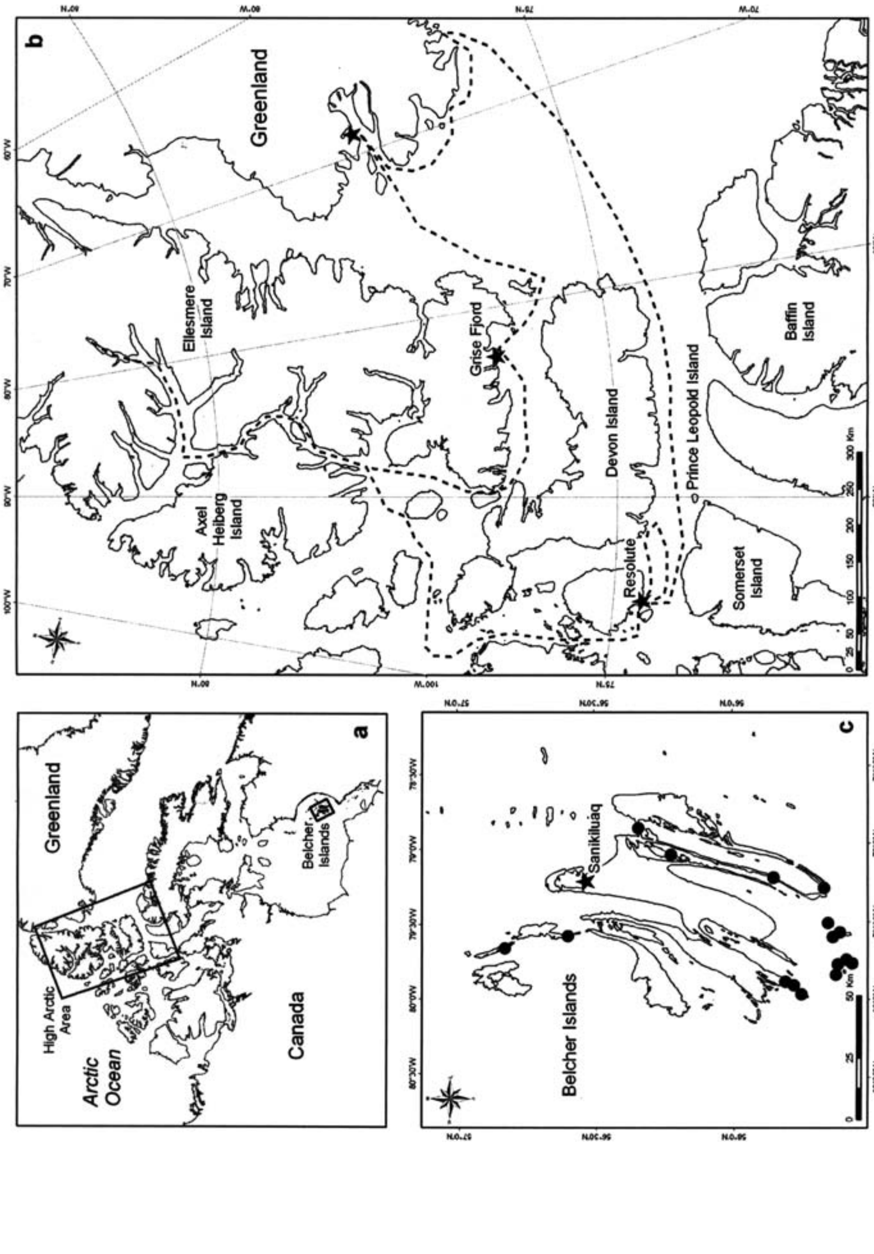

Figure 1. Map of study locations in Arctic Canada, showing: (a) two main areas of study, bounded by boxes; (b) Prince Leopold Island in Lancaster Sound and the route of the 2002 icebreaker cruise; and (c) the polynyas around the Belcher Islands.

approximately 62,000 breeding pairs of northern fulmars (*Fulmarus glacialis*), 100 pairs of glaucous gulls (*Larus hyperboreus*), 30,000 pairs of black-legged kittiwakes (*Rissa tridactyld*) and 100,000 pairs of thick-billed murres (*Uria lomvia*) (Mallory and Fontaine, 2004;, Gaston, unpubl. data). All of these birds breed on the cliffs, or on rock stacks around the periphery of the island.

Seabirds have been monitored at Prince Leopold Island since the mid-1970s. Techniques were developed at that time in which portions of the cliffs were delineated as long-term monitoring ‘plots’. At these locations, protocols were established for assessing numbers of birds attending the colony, timing of nest initiation, egg size, adult mass, nestling growth rates, incubation shift length, and other parameters required to assess reproductive success of the birds (Birkhead and Nettleship, 1980; Gaston and Nettleship, 1981). These protocols have been followed at this and other Arctic colonies between the 1970s and 2003. Field parties were typically present at the study site between June and August during monitoring years (2000–2003 with NEI support).

There are usually 4–5 months of open water near the island, but the pattern of ice break up and movement through Lancaster Sound varies annually. A recurrent ice-edge between consolidated pack ice and open water forms at or near the island in June and early July each year (Smith and Rigby, 1981), but the position of the ice edge can vary at this season by >300 km. We compared reproductive parameters of birds at the colony in years when the ice-edge was close to (=relatively “early ice years”) or distant from (=relatively “late ice years”) the colony.

2.2. Polynyas and wintering eiders in Hudson Bay

The Belcher Islands are located in southeastern Hudson Bay, Nunavut (Figure 1). Small, recurring polynyas (areas of permanent open water, surrounded by sea-ice) form among the islands due to strong currents that prevent the formation of ice, while current-driven, shifting pack ice provides temporary areas of open water habitat (leads and floe edges) around the Belcher Islands for marine birds and mammals.

These habitats are the only areas of open water in south eastern Hudson Bay during winter (Smith and Rigby, 1981), meaning that marine mammals and birds that winter in the region are restricted to those areas and are vulnerable to mass die-offs because they cannot escape to alternative habitats if polynyas freeze. Thus, the polynyas and floe edges in the Belcher Islands are among the most important marine habitats in Hudson Bay.

The Hudson Bay common eider (*Somateria mollissima sedentaria*) is a large sea duck that resides year-round in Hudson and James bays, and is harvested by the Community of Sanikiluaq (McDonald *et al.*, 1997; Robertson and Gilchrist, 1998). Die-offs of eiders had been reported (Robertson and Gilchrist, 1998), and were thought to be linked to more severe winter ice conditions (Gilchrist and Robertson, 2000). In 1998, the community invited the Canadian Wildlife Service to collaborate on research to investigate eider population declines in Belcher Islands. This work included: gathering traditional ecological knowledge on eiders from Inuit elders and hunters, conducting aerial surveys to examine winter habitat use by eiders, and conducting research on the diet and foraging ecology of eiders throughout the winter.

Traditional knowledge (TEK) was gathered both through informal discussions with hunters during work near the polynyas between 1996–2003, and also as part of a structured, individual interview process in 2003, following earlier TEK work in this community (Nakashima and Murray, 1988; McDonald *et al.*, 1997). Data from the 2003 interviews were transferred to 1:250,000 topographic maps of the Belcher and Sleeper Islands, and then inputted to a GIS. One aerial survey was flown each year in February 2002 and 2003 using a DeHavilland Twin Otter flying over polynyas, along floe edges, and in transects across the sea-ice at 400–500 feet and at 200 km/h groundspeed, with four observers. At the polynyas, eiders were observed to measure daily activity budgets under differing environmental conditions. The latter observations were obtained by camping on the sea-ice, at wind chill temperatures often down to $-70\,^{\circ}$C, and recording eider activities through the day in relation to temperature, tidal current velocity, and predator activity.

2.3. Contaminants in high arctic marine birds

Contamination of Arctic marine environments by organic pollutants and trace elements is well-documented (Muir *et al.*, 1999; AMAP, 1998, 2004). Pollutants arrive via long-range transport from regions far to the south, become assimilated in lower levels of food chains, and typically bioaccumulate and biomagnify to varying degrees in higher trophic levels (e.g. Muir *et al.*, 1999; Braune *et al.*, 2002). Levels of contaminants in wildlife inhabiting the Canadian Arctic are of particular concern for two key reasons:

1) the Arctic supports large, often internationally important breeding populations of certain species; and
2) Inuit communities continue to harvest wild game to fulfil cultural and dietary needs (Van Oostdam *et al.*, 2003).

Thus, consumption of contaminated wildlife could pose a health risk (e.g. Kinloch *et al.*, 1992).

Concentrations of organochlorines, PCBs and trace elements have been evaluated in marine birds from locations across Arctic Canada since the 1970s (Braune *et al.*, 2001, 2002; Wayland *et al.*, 2001), using standardized and internationally recognized methodologies carried out at accredited laboratories in Canada (described in Braune *et al.*, 2002; Mallory *et al.*, 2004). Support from the Northern Contaminants Program (NCP), administered by Indian and Northern Affairs Canada, has helped sustain long-term monitoring of contaminants (Braune *et al.*, 2001) and has also allowed: (a) an examination of contaminant levels in regions or colonies not previously tested (Mallory *et al.*, 2004); (b) an evaluation of new contaminant threats (Braune and Simon, 2003, 2004); and (c) use of new approaches such as biochemical markers (e.g., Wayland *et al.*, 2002), which can be used to screen for potential biological effects to help assess wildlife health. In recent years, the NCP and NEI have refined their program objectives to be complementary.

One of the goals of NEI-funded research is to increase our understanding of the adverse biological effects of contaminants on the health of ecosystems in the Canadian North. In 2003, NEI supported an international collaborative study examining potential biochemical effects of organochlorines in circumpolar fulmar populations. Samples of adult liver and blood plasma tissue were collected from northern fulmars at Prince Leopold Island (Figure 1) and Cape Vera (76°15′ N, 89°15′ W) in the Canadian Arctic, as well as from colonies in Norway and the Faeroe Islands. Samples were stored in liquid nitrogen and shipped to laboratories in Ottawa, Canada, for analyses of biochemical markers. Specifically, samples were examined for metabolic capacity as indicated by induction of cytochrome P450 enzymes and hepatic EROD [7-ethoxyresorufin O-deethylase] activity, which is catalyzed by isoenzymes from the cytochrome P4501A [CYP1A] subfamily. Some persistent organic pollutants (POPs) have been shown to induce CYP1A enzymes in liver which can be used as an index of contaminant exposure whereas others can interfere with vitamin A homeostasis. The thyroid hormones generally affect basal metabolic rate and can either increase or decrease the activities of EROD and decrease P450 content. This is the first time this approach has been used on fulmars in Arctic Canada. Concomitantly, as part of the ongoing contaminants monitoring program supported by the NCP, eggs of several species of marine birds were collected at Prince Leopold Island and at Cape Vera, and analysed for various contaminants of concern, (e.g. mercury [Hg]; ΣPCB – Sum of 67 PCB congeners; ΣCHL – Σchlordanes [oxychlordane, *cis*- and *transnonachior*, *cis*- and *trans*-chlordane, heptachlor epoxide]; ΣMirex – Sum photo-mirex and Mirex; ΣCBz–Sum Chlorobenzenes [tetra-, penta- and hexachlorobenzene]; ΣHCH – Sum hexachlorocyclohexanes [α-, β- and γ-HCH]; dieldrin).

2.4. Marine bird surveys on a student ice-breaker cruise

Pursuant to the Nunavut Land Claim Agreement (INAC, 1993), aboriginal communities in the Arctic have a strong voice in scientific activities permitted to be undertaken annually. One of the key elements of successful scientific investigation in Arctic Canada is the close partnership and collaboration between scientists and communities, particularly where scientists make efforts to help build capacity among young people. In August 2002, the NEI supported a project where a marine bird biologist taught classes and trained Inuit and non-Inuit students on how to monitor marine birds from sea vessels during an educational cruise offered by Students On Ice (SOI), using the PIROP (Programme Intégré des Recherches sur les Oiseaux Pélagiques) seabird monitoring protocol established by the Canadian Wildlife Service. These techniques are Canadian at-sea standards for recording seabird occurrence for fixed time periods within fixed fields-of-view from a forward-moving ocean vessel (Brown *et al.*, 1975), as described by Tasker *et al.* (1984). These data can be used to map marine habitat use by various species as described in detail by Brown *et al.* (1975). There are relatively few data for the High Arctic (e.g., Jones Sound), so the SOI cruise provided an opportunity to train students and gather useful data to fill in a knowledge gap.

3. Results

3.1. Sea-ice and marine birds at Prince Leopold Island

The edge of the sea-ice was approximately 200 km east of the Prince Leopold Island seabird colony in late June 2001 and 2002 (=late ice years), but was within 20 km of the colony during the same period in 2000, and was 150 km W of Prince Leopold Island in late June 2003 (=early ice years; Figure 1). These contrasting ice conditions corresponded to marked differences in reproductive parameters for breeding marine birds (Gaston *et al.*, in press). In late ice years, egg-laying by thick-billed murres, black-legged kittiwakes and glaucous gulls was delayed. Similarly, murre eggs were up to 5% smaller, chicks grew slower and weighed 42% less at 10 d old, and chick feedings were 1.6–3.3 times less frequent per day in late ice years compared to early ice years. Kittiwake reproductive effort was reduced; significantly fewer 2-egg clutches were laid in late ice years (Figure 2), resulting in fewer chicks produced. In late ice years, foraging trips by adult northern fulmars were 29% longer than in early ice years, and significantly fewer fulmar chicks that hatched survived to fledging (Figure 2), suggesting lingering effects into the chick-rearing period after the ice had broken up. Collectively, many reproductive parameters for marine birds were reduced in years when ice cover was more extensive in Lancaster Sound, and these directly or indirectly translated into reduced reproductive success (Hipfner and Gaston 1999, Gaston *et al.*, 2005).

3.2. Polynyas and wintering eiders in Hudson Bay

Traditional ecological knowledge (TEK) interviews yielded important information of differing ice conditions, and the consequent effect on eiders near Sanikiluaq. For example, Inuit stated that extensive sea-ice during the winter of 1991–1992 had limited the locations where eiders could feed in open water, and that this had resulted in their mass starvation. Subsequent surveys confirmed a 75% decline in eider populations (Robertson and Gilchrist, 1998) following the severe winter of 1991 (which was linked to the Mount Pinatubo volcanic eruption that lowered circumpolar temperatures; Ganter and Boyd, 2000). Without their TEK, this dramatic population

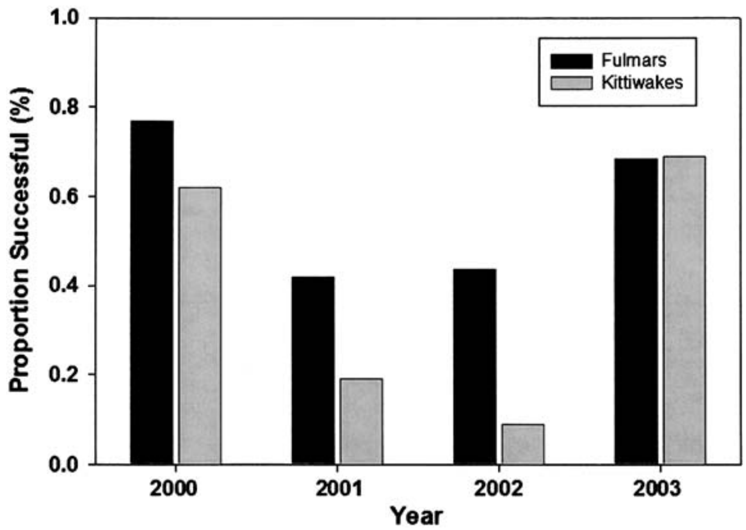

Figure 2. Measures of reproductive success of northern fulmars and black-legged kittiwakes, showing the proportion of fulmar nests that hatched a chick which was still alive in late August (black bars), and the proportion of kittiwake nests that had 2 rather than 1 egg (gray bars).

decline would have gone undetected by western science. Other TEK provided by Inuit hunters of Sanikiluaq indicated that: a) the eider population had increased since the mortality event in 1992 (Gilchrist and Robertson, 2000); b) harvest of eiders by Inuit is greatest in the fall; c) there is age-specific habitat use (i.e. juvenile eiders are more likely to overwinter in polynyas without ever travelling to leads or floe edges in the pack ice to feed); and d) eider ducks residing in polynyas cannot feed for several hours each day because of strong tidal currents which prevent them from reaching the sea floor. Subsequent scientific investigation has confirmed all of these observations (e.g., Figure 3; H.G. Gilchrist, unpublished data).

Aerial surveys in the area also confirmed that polynyas were critical habitats for wintering eiders, but that many birds congregated at the floe edge between the Belcher and Sleeper Islands. This latter information was unknown to the community because hunters could not travel safely to these locations due to shifting ice. TEK interviews in 2003 confirmed this (Figure 4), as data we gathered on wildlife distributions around the Sleeper Islands dealt with spring through fall patterns, but winter information was generally absent (Figure 4). Although breeding population counts suggested about 50,000 birds, the winter surveys documented over 100,000 eiders in this population in 2002 and 2003.

3.3. Contaminants in high arctic marine birds

Samples of liver tissue were collected from adult fulmars breeding at Cape Vera, Prince Leopold Island, Bear Island (Norway) and Nólsoy/Nósoyarfjord (Faeroe

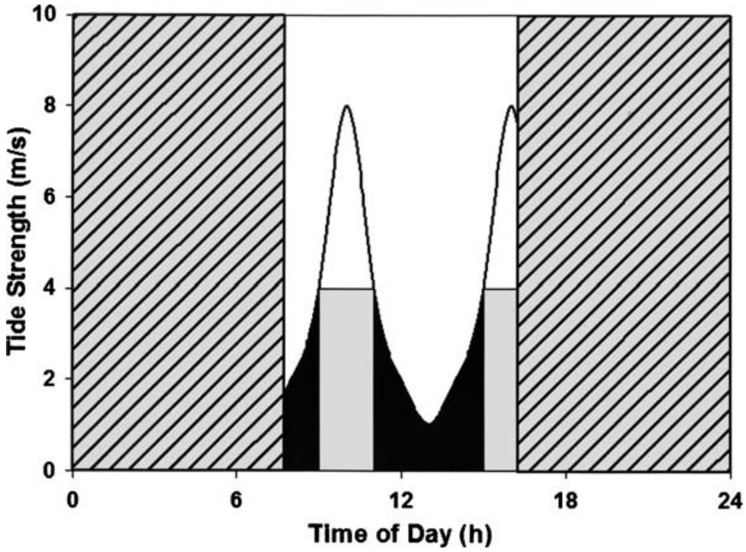

Figure 3. Theoretical graph of amount of time available for eiders to forage in a day, in relation to light and tide. Shaded and hatched areas are times where there is insufficient light during winter conditions for eiders to forage, whereas times with lightly shaded boxes are periods when tidal currents are strong and above a threshold value (T) and preclude eiders from effectively foraging in polynyas. Eiders can only forage during the periods indicated in black.

Islands) to examine bird health using biomarker indicators. Biomarker analyses of both liver and plasma samples from a total of 64 birds from the four colonies have been completed. These include Vitamin A in liver (as retinol and retinol palmitate) and in plasma (as retinol), EROD in liver, and thyroid hormones (T3, T4) in plasma. Preliminary results indicate that variation exists within and among fulmar colonies in biochemical markers (e.g., liver retinol 20–275 μg/g; liver retinol palmitate 280–5135 μg/g), with concentrations higher in Faeroe Island fulmars. Statistical analyses will be initiated once associated contaminant analyses on these birds are completed.

Samples of eggs collected in 2003 from thick-billed murres, black-legged kittiwakes, northern fulmars and glaucous gulls at Prince Leopold Island confirmed the patterns of species differences in contaminant concentrations due to trophic levels. Glaucous gull eggs had approximately 10 times the concentrations of ΣPCB and DDT than eggs of murres, kittiwakes and fulmars, consistent with earlier data (Braune *et al.*, 2002). The data for 2003 also showed that certain contaminant trends described by Braune *et al.* (2001) are continuing. For example, concentrations of ΣPCB in fulmars remain lower than in the 1970s (Spearman rank correlation; $r_{s6} = -0.9$, $P < 0.05$) while total Hg continues to increase ($r_{s6} = 0.8$, $p < 0.05$); Figure 5). Analyses of eggs from fulmars collected at Cape Vera for the first time suggested that contaminant burdens were very similar to those of fulmar eggs from

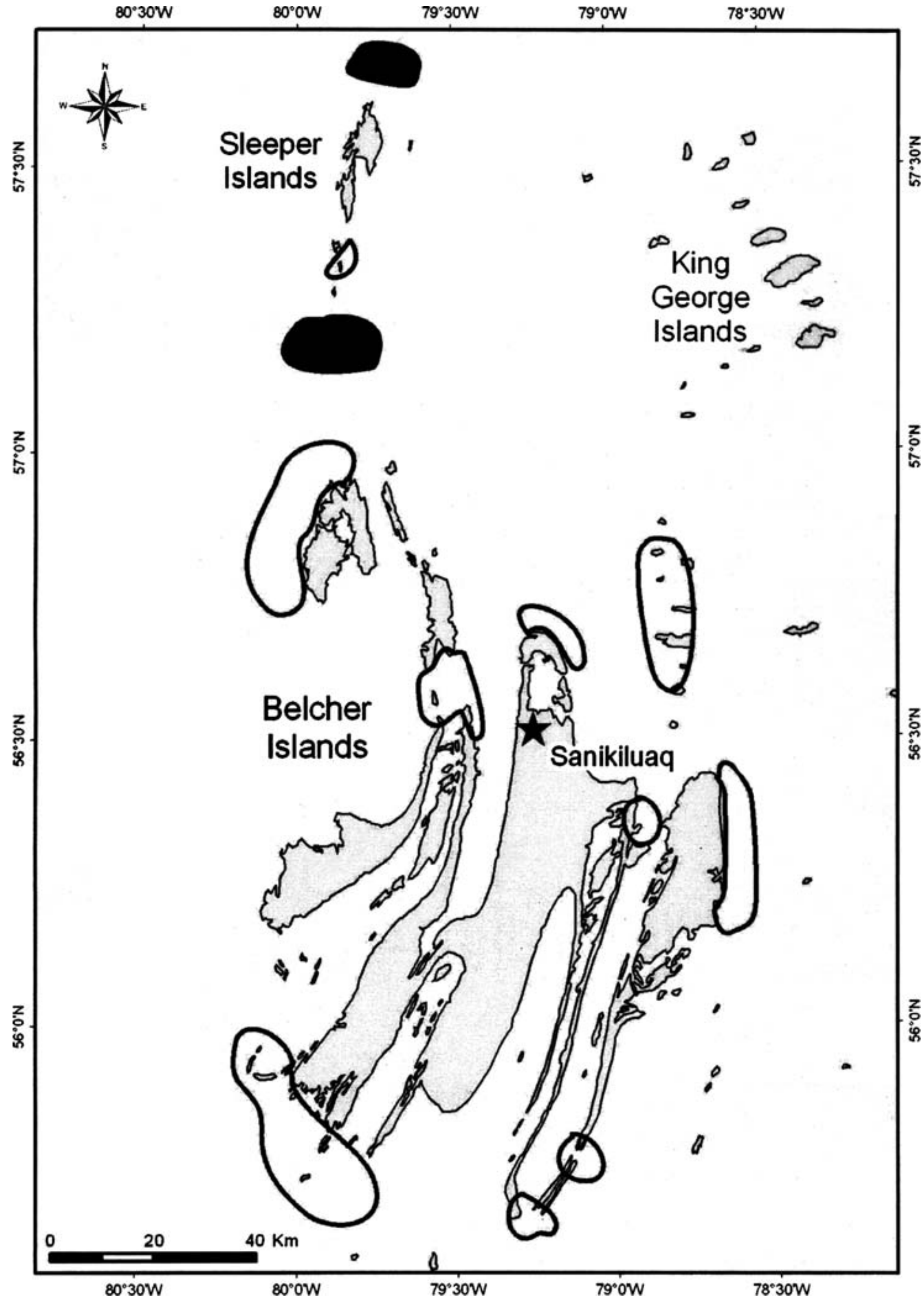

Figure 4. TEK information from the community of Sanikiluaq on important locations where eiders overwinter near the Sleeper Islands. The filled polygons represent the main overwintering areas discovered during aerial surveys. These were unknown to local Inuit because hunters cannot safely access the ice edge in this region.

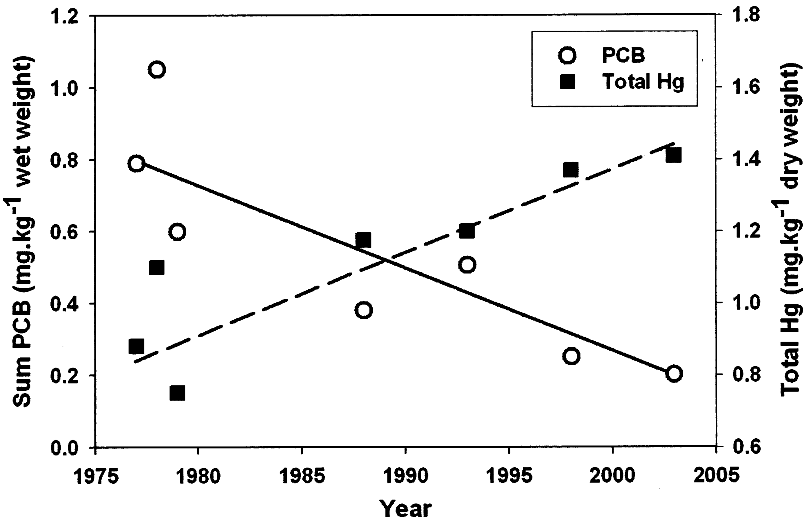

Figure 5. Temporal trends of PCBs and total Hg in northern fulmar eggs collected from Prince Leopold Island (Spearman rank correlations; both $P < 0.05$). Open circles represent ΣPCB, while filled squares represent Total Hg.

Prince Leopold Island, 200 km due south (*t*-tests, all $P > 0.05$ except ΣHCH where $P = 0.03$; (Figure 6)

3.4. Marine bird surveys on a student ice-breaker cruise

During the expedition through Lancaster and Jones Sounds, as well as Baffin and Norwegian Bays, from 16–29 August 2002, students were instructed on at-sea survey protocols, but also listened to lectures on marine birds in the Arctic, and the location and function of Migratory Bird Sanctuaries and National Wildlife Areas in Nunavut. Seabird surveys were conducted in 11 survey segments over the course of the expedition (Figure 1). Over 1500 individual seabirds were observed during the surveys, 93% of them from three species: thick-billed murre (700), northern fulmar (604), and black-legged kittiwake (176). Students gained confidence and interest in conducting at-sea bird surveys as the project progressed, and collecting these data reinforced the educational information acquired during the lectures or discussions with instructional staff. While survey data were used to fill in gaps in our knowledge of at-sea distributions in these regions, of particular scientific importance was the lack of observations of ivory gulls (*Pagophila eburnea*), a Species of Concern in Canada. In particular, a comparison of at-sea survey information from 1993 and 2002 showed that markedly fewer gulls were observed anywhere along the route, but especially in Jones Sound where it was formerly common (Chardine *et al.*, 2004).

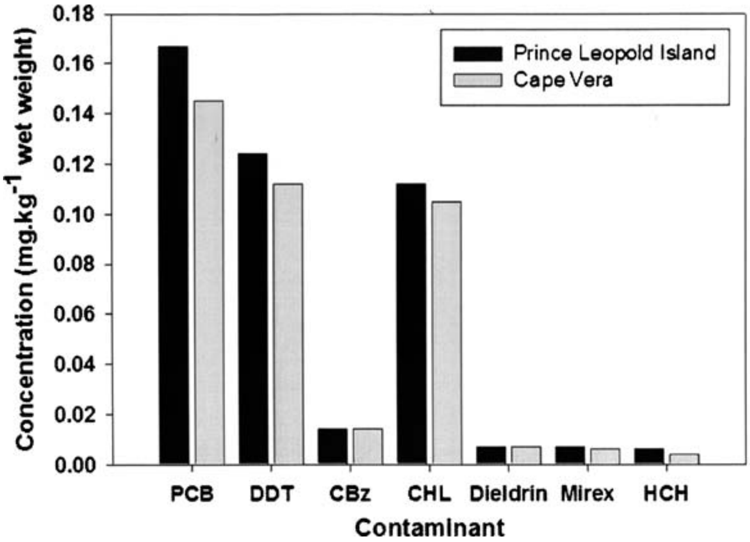

Figure 6. Comparison of mean concentrations of contaminant groups in northern fulmar eggs collected in 2003 at Prince Leopold Island (black bars) and Cape Vera (gray bars) (no significant differences except for ΣHCH; t-test, $P = 0.03$). All contaminants are sum (Σ) except for dieldrin.

4. Discussion

The Arctic research supported by the NEI has helped advance our knowledge of marine birds in the Arctic environment. We note that our focus in this review was to describe investigations in Nunavut, but marine bird studies have also received NEI support in northern Quebec and Labrador, regions where bird harvest is of high importance to local residents (Robertson *et al.*, 2002; Falardeau *et al.*, 2003). The studies described in this paper have revealed effects or associations of marine environmental conditions on reproductive success, survival, key habitat sites and health of marine birds, and has also demonstrated the utility of collaboration and capacity-building with Arctic communities and the indigenous residents of the region. This has set the stage for more detailed work to assess current threats of new contaminants as well as climate change on Arctic wildlife.

4.1. Sea-ice and marine birds

In Arctic regions, considerable data now suggest that sea surface temperatures, sea-ice thickness, and sea-ice distribution are changing (e.g., Parkinson *et al.*, 1999; Grumet *et al.*, 2001). The distribution of sea-ice and the duration of the open water season are of critical importance to the annual cycle of Arctic marine wildlife (Stirling, 1997), and thus changing sea-ice conditions are expected to have a variety of effects on marine birds and other biota (Brown, 1991). Indeed, some studies have found that reproduction in polar marine birds varies in response to annual ice conditions (e.g., Gaston and Hipfner, 1998; Barbraud and Weimerskirch 2001; Jenouvrier *et al.*, 2003). Marine birds should incur higher energetic costs in years with more extensive sea-ice due to higher commuting costs to and from the colony to feeding areas, and perhaps increased costs of finding food during less productive seasons (i.e., increased ice cover and reduced light penetration resulting in lower productivity in the marine zone; Welch *et al.*, 1992). Consistent with this prediction, we found that reproductive success of four different species of marine birds was markedly poorer in years with more extensive ice cover, even during chick-rearing after open water was available near the colony, suggesting that the effects of heavy ice lingered until late in the breeding season. What does this mean for marine birds breeding at Prince Leopold Island? In the short term, this research suggests that current trends towards earlier ice break-up in the Arctic may be beneficial for local marine birds, because commuting times should be relatively short and food more predictably available. However, the longer term consequences, such as changes in the location and timing of local food production, increased storm frequency, altered contaminant deposition or release into food webs, and invasion of new, more southern species into Arctic marine ecosystems remain to be determined.

To follow up on some of this initial work, the NEI provided support in 2004 to examine where fulmars were feeding and wintering using satellite telemetry. This study addresses foraging distances and activity patterns of birds in relation to ice, similar to the work conducted with some Antarctic marine birds (Jenouvrier *et al.*, 2003). Moreover, the role that sea-ice plays in the annual cycle of Arctic wildlife has been identified as a key program priority for the NEI Climate Change Table.

4.2. Polynyas and wintering eiders in Hudson Bay

The TEK and survey work conducted near the Belcher Islands has already had two major implications for marine bird management in Hudson Bay. First, the TEK information from the Community of Sanikiluaq was detailed and accurate; indicating that local Inuit have extensive knowledge of this eider population, and it provided clear companion support for our scientific studies (Nakashima and Murray, 1988; Gilchrist and Robertson, 2000). This level of detail is greater than we have encountered elsewhere in Nunavut regarding TEK and migratory birds (e.g., Mallory *et al.*, 2003), perhaps reflecting the fact that these eiders are non-migratory, they are harvested throughout the year, and that local hunters frequently travel to areas that support eider ducks even in winter. In any case, TEK is now being incorporated in management plans for this population, and this project is being used internationally as an example of how to work with local communities to achieve wildlife management objectives. Also, Sanikiluaq applies annual TEK assessments of the eider population to self-impose eiderdown harvest restrictions following years of heavy ice and related eider die-offs. Second, the confirmation of key polynyas for eiders, and the discovery of important wintering areas during surveys have revised the identification of key marine areas in this region (Mallory and Fontaine, 2004). This information will contribute to regional land use planning, environmental assessment, and consideration for future protected areas.

4.3. Contaminants in high arctic marine birds

The long-term monitoring of contaminants in Arctic seabirds, particularly from Prince Leopold Island, is one of the best datasets available tracking these chemicals in the Arctic marine environment (Braune *et al.*, 2001). Consistent with earlier work, the contaminant patterns vary among marine bird species at Prince Leopold Island, with those feeding highest in the food web (glaucous gulls) generally having the highest contaminant concentrations. Concentrations of some contaminants, notably PCBs and DDT, have declined in marine bird eggs since the 1970s, but other pollutants are increasing, including total Hg (Figure 5) and certain organochlorines (Braune *et al.*, 2001; Braune and Simon, 2003, 2004). These trends are worrisome.

To date, Arctic marine birds have been very useful monitors of various contaminants, but concentrations have generally been considered lower than levels expected to affect the health or reproductive potential of the birds (Fisk *et al.*, 2003). However, there is some evidence (Braune and Simon, 2003, 2004; Fisk *et al.*, 2003) that certain chemical compounds are being found at concentrations which may be affecting the health of individual birds, a possibility that initiated the fulmar biomarker project described above. Although northern fulmars feed at the same level in the food chain as other seabird species throughout the Canadian Arctic, organochlorine levels in fulmars are higher than expected (Braune and Simon, 2003). The ongoing investigation into whether biomarkers in blood and liver of free-ranging northern fulmars are related to contaminant burden will provide insight on the possibility that the health of Arctic wildlife is now being affected by pollutants released in the south.

4.4. Marine bird surveys on a student ice-breaker cruise

With its vast marine bird and mammal resources, the eastern Canadian Arctic is a region of increasing interest for ecotourism (Hall and Johnston, 1995). Such activity provides a benefit to outdoor enthusiasts, but seabird colonies may also be sensitive to disturbance (Gaston and Hipfner, 2000), so appropriate protocols must be taken when nearby. The opportunity to provide instruction on marine birds and wildlife habitats to young Inuit and non-Inuit students allowed us to directly transfer environmental information in a meaningful and memorable way to the people who will be making environmental decisions in the future. The data gathered from this region were also added to the PIROP database, which is used for broad, regional analyses on seabird distributions (e.g., Huettmann and Diamond, 2000). Future collaboration with Arctic ecotourism companies would be an appropriate approach in developing scientific capacity among Northern residents, while simultaneously gathering important data on marine bird distributions in a time of ecosystem change (Krupnik and Jolly, 2002).

As an example of the type of information that can be gained through this type of co-operation, the 2002 survey data have been compared to data from a similar ecotour in 1993. They indicate a decline in the number of ivory gulls observed at-sea, notably near an area known to support many gulls in eastern Jones Sound (Chardine *et al.*, 2004). These findings lend further support to suggestions of population declines in this species based on TEK (Mallory *et al.*, 2003) and colony surveys (Gilchrist and Mallory, 2005), and collectively argue for an urgent reassessment of the status of this species. In the interim, to examine the possible role of contaminants in ivory gull declines, the NEI has already provided some funding review all contaminants data for circumpolar ivory gulls currently available, and to examine temporal trends in contaminants of ivory gull eggs from the Canadian high Arctic.

5. Conclusions

Because of its remote and inhospitable nature, the Arctic is often thought of as a pristine region of Canada. However, the integrity of ecosystems in the Canadian Arctic is threatened by anthropogenically-induced changes from developed regions to the south, including long-range transport of pollutants, climate change, increasing ecotourism, and resource development. The NEI aims to monitor and understand how these changes are affecting the Arctic. NEI concurrently supports national and international Arctic agreements on ecosystem health, and it encourages northern residents to get involved in this work. Many of these ecosystem changes, and the approaches to studying and addressing them, are captured in the scientific and TEK work on Arctic marine birds described in this paper. Because marine birds integrate and reflect the conditions of Arctic marine ecosystems (e.g., productivity, ice conditions, contaminant levels, community harvest), continued research and monitoring of this group will contribute to effective tracking of environmental changes occurring in Canada's northernmost regions.

Acknowledgements

We extend our sincere gratitude to the agencies that supported the studies described in this paper: the Northern Ecosystem Initiative (Environment Canada), the Canadian Wildlife Service (Environment Canada), the Polar Continental Shelf Project (Natural Resources Canada), the Nunavut Wildlife Research Trust (Nunavut Wildlife Management Board), the Northern Contaminants Program (Indian and Northern Affairs Canada), and the Environmental Capacity Development Initiative (Indian and Northern Affairs Canada). Thanks as well to our collaborators in these projects: the Sanikiluaq Hunters' and Trappers' Association and Students

On Ice; the numerous students and contractors who braved challenging field conditions to help gather these data; J. Akearok, C. Eberl, A. Fontaine, B. Fournier, and M. Robertson who provided expert field and logistic assistance in various aspects of these studies; and finally Myra Robertson who prepared the maps for this paper.

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