MONITORING THE ENVIRONMENTAL AND ECOLOGICAL IMPACTS OF CLIMATE CHANGE ON BYLOT ISLAND, SIRMILIK NATIONAL PARK

2004-2008 FINAL REPORT

by

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ABSTRACT

Our ecological and environmental program has been monitoring the climate, the reproduction and the abundance of several key species of birds, mammals and plants on Bylot Island, Sirmilik National Park, Nunavut for the past 19 years. The main goal of our project is to measure changes occurring in the Arctic ecosystems, analyse temporal trends, and evaluate to what extent these changes may be driven by climate change. Our results showed that the region surrounding Bylot Island has been experiencing a strong warming trend over the past three decades. These trends were mostly detectable during the spring, summer and fall (from 2.1 to 4.5^{o}C for that period), which is contradictory to GCM models that forecast changes to be more intense during the winter months. Nonetheless, our long-term dataset on ecological monitoring of several birds, mammals and plants already show some signs of change on Bylot Island, which could be due in part to climate change. Plant production in wetlands has increased by 84% over the last 18 years, most likely a consequence of climate warming. Climatic variations also appear to be the most important driver of the annual production of several migratory birds such as Greater Snow Geese, as warm spring temperature increases their breeding effort and advances their breeding phenology. The two lemming species found on Bylot Island play a key role in the food web as they are the primary prey of most tundra predators. Their large cyclical fluctuations in annual abundance not only affect their main predators (Snowy Owls and foxes) but also indirectly affect other species like geese through shared-predator interactions. Other bird species such as shorebirds, longspurs, gulls and jaegers are likely to be influenced by fluctuating abundance of lemmings but further studies are needed to investigate this relationship. We found evidence that lemming cycles have dampened in recent years and that their abundance during peak years of the cycle is much lower than in the past. Although this could be linked to the strong warming trend observed in the fall, which could lead to poor snow conditions and low overwinter lemming survival, more data are needed to test this hypothesis. The proportion of fox dens with reproductive activity has decreased over the years, possibly a consequence of the low abundance of lemmings recorded recently during peak years of abundance. Our Traditional Ecological Knowledge study pertaining to snow geese and foxes has shown that Elders knowledge can provide complementary information to our monitoring program. Indeed, we found that traditional knowledge on foxes expanded the spatial and temporal scales of our current scientific knowledge. Our community workshops and public presentations proved to be valuable tools to foster communications and exchanges with the community of Pond Inlet on ecological studies carried out on Bylot Island. Finally, we contributed to increase the capacity building of the community through the hiring of several northerners during our field activities.

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1 INTRODUCTION

Global climatic change caused in part by the greenhouse gases released due to human activities is a major challenge faced by the earth ecosystems in this century. However, nowhere else on earth are these effects more threatening than in the Arctic. Indeed, all models predict that warming trends will be strongest in the Polar regions as annual temperatures in Arctic should increase by as much as 3° to 5°C over the course of the XXIst century (ACIA 2004). Precipitation is also expected to increase from 10 to 20%, as well as daily and seasonal variability in both temperature and precipitation, leading to more frequent climatic extremes. Recent analyses indicate that temperatures in the Arctic have been increasing steadily for the last three decades, and the extent and thickness of sea ice has been reduced considerably (Moritz et al. 2002, ACIA 2004, IPCC 2007).

Several long-term studies in different parts of the globe have detected ecological changes due to climate warming, such as alterations in geographical and breeding ranges, flowering dates, breeding dates, and migration schedules (reviewed by McCarty 2001, ACIA 2004, Berteaux et al. 2004, Møller et al. 2004). Impacts of climatic changes on arctic ecosystems are expected to be particularly strong because community structure is increasingly dominated by abiotic factors as we move closer to the poles and the climate becomes harsher (Hansell et al. 1998). Disruption of close ecological linkages, such as trophic interactions among plants-herbivores and herbivores-predators, will affect a significant proportion of the species assemblages in these depauperate communities (Gauthier et al. 2004). Thus, the simple ecological communities of the arctic may be at great risk.

Yet, evidences of these changes and of their impacts on biological communities are still scarce in the Arctic, mainly because few sites have adequate long-term data sets to address these questions. Our ongoing, long-term ecological research program on Bylot Island, Sirmilik National Park, Nunavut has been running for 19 years and has become one of the longest, most comprehensive, and rigorous long-term biological monitoring program in Nunavut. We have been monitoring the abundance and reproduction of several key species of birds, mammals, and plants. In addition, we have been continuously recording the most significant climatic variables through a network of automated weather stations. Hence, this program offers an exceptional opportunity to fill important knowledge gaps on climate/ecosystem status and may help to improve future ecological monitoring programs at other sites in the Arctic.

1.1 OBJECTIVES

The overall aim of our project is to measure changes occurring in the Arctic ecosystems, analyse temporal trends, and evaluate to what extent these changes may be driven by climate change. This is achieved by continuing and expanding for the period 2004-2008 the climatic and ecological monitoring already in place on Bylot Island, and involving local communities into our research activities. Our specific objectives during that period were as follows:

1) Continue the climate monitoring of Bylot Island and examine temporal trends.
2) Continue the monitoring of breeding activities of bird species such as Snow Geese and Lapland Longspurs and expand it to shorebirds and avian predators.
3) Continue the monitoring of lemming populations.
4) Continue the monitoring of breeding activities of Arctic and Red Foxes.
5) Continue the monitoring of plant production in wetland communities and expand it to plant phenology and goose grazing impact.
6) Expand the monitoring of goose grazing impact to mesic communities.
7) Develop an Inuit Knowledge Component to our monitoring program in order to get a more complete understanding of the ecosystem and of the ecological impacts of climate change.
8) Hold an annual community workshop in Pond Inlet to discuss the project findings and future work.
9) Present study results to high school students in Pond Inlet.
10) Maintain the project English-French-Inuktitut web site.
11) Hire and train individuals from local communities.

2 METHODS

2.1 STUDY AREA

All field work is conducted on the south plain of Bylot Island at the northern tip of Baffin Island (Fig. 1). The island is a Migratory Bird Sanctuary and is included in the Sirmilik National Park. The island is recognised for its rich and diversified bird life (Lepage et al. 1998b), and is the site of the largest known nesting colony of Greater Snow Geese (*Chen caerulescens atlantica*), which is estimated at about 20,000 nesting pairs (Reed et al. 2002). Therefore, geese are considered the most important herbivores on the island since large mammals (i.e. caribous or muskoxen) are absent (Gauthier et al. 1996). Our activities are conducted primarily at two sites on the island, the Qarlikturvik Valley (73° 08' N; 80° 00' W), which is a prime brood-rearing area for geese, and the main goose nesting colony (72° 53' N, 79° 55' W; Fig. 1). At both sites, lowlands are covered by a mixture of wetlands and mesic tundra, and uplands are largely dominated by mesic tundra (Gagnon et al. 2004).

2.2 CLIMATIC DATA

We have seven automated environmental monitoring stations at our study site. Our network includes three full climatic stations that record data on an hourly basis, year-round (see Appendix A for a full description of climatic data recorded at each station). One is in operation since 1994 (elevation: 20 m ASL), another one since 2001 (340m ASL) and the most recent one since 2004 (21 m ASL). The two oldest stations are 3-m high towers that record air temperature and humidity (at 2 m), soil temperature (at depths of 2, 5 and 10 cm), wind speed and direction (at 3 m), and snow depth. The newest one is a 10-m meteorological tower that hosts more recording instruments and over a greater height range above the ground. In compliance with recognized standards, we record air temperature (at 5 m), wind speed and direction (at 10 m), full solar radiation (i.e. far infrared, photosynthetic active radiation, albedo, net solar radiation, and UV-B radiation), barometric pressure, soil temperature (at depths of 5 and 10 cm; two sites each), snow depth and air humidity. A fourth station monitors ground surface temperature (at a depth of 2 cm) at five paired sites (each pair has a site protected from goose grazing by an exclosure and a nearby site exposed to grazing). Finally, three additional stations record permafrost temperature at various depths down to 3 m (two sites) or 11 m (one site). All automated stations were visited annually during the summer to download data, including in 2007, and were found to be operating normally. A few damaged sensors (mostly those recording ground temperatures) were replaced in most summers.

Daily precipitation is recorded manually during the summer (1 June to 17 August) using a pluviometer. Snowmelt is monitored from 1 June until snow disappearance using two methods: 1) by measuring snow depth at 50 stations along two 250-m transects at 2-day intervals and 2) by visually estimating the proportion of snow cover on the study area every 2-3 days.

2.3 BIOLOGICAL DATA

The monitoring of all biological components on Bylot Island follows very precise, standardized field protocols. This is essential to ensure consistency in data that are collected by many people over a large number of years. In the following section, we just provide a brief overview of the methods used for each component monitored. However, the full set of field protocols that we used can be found at the following web site: www.cen.ulaval.ca/arcticwolves/. All data gathered during this project are hosted at the Centre d'études nordiques (Université Laval, Université du Québec à Rimouski and Université du Québec à Trois-Rivières). Over the coming months, all the data will be consolidated into a common, unique database.

2.3.1 Birds

Greater Snow Geese

We are monitoring the reproduction of Greater Snow Geese annually on Bylot Island since 1989. Goose nests are searched extensively in the Qarlikturvik Valley and especially at the main goose nesting colony (Fig. 1) where several thousand geese nest every year. In the goose colony, nest searches are conducted in two ways: 1) over an intensively-studied core area (ca 50 ha) located in the centre of the colony every year, and 2) within a variable number of 2.25-ha plots randomly located throughout the colony. Nest density was calculated over a fixed 30-ha area within the intensively-studied core area. All nests found are positioned with a GPS receiver and their fate is monitored by revisiting them several times during the nesting period. On each visit we determine the number of eggs and/or goslings (dead or alive) and from these data we are able to determine the following parameters: total clutch laid (total number of egg laid by the female during nesting), clutch size at hatch, number of goslings leaving nest, laying and hatching dates, and nesting success.

Avian predators

We are monitoring the reproduction of Snowy Owls (*Nyctea scandiaca*) since 1993 and of Long-tailed Jaegers (*Stercorarius longicaudus*), Parasitic Jaegers (*Stercorarius parasiticus*) and Glaucous Gulls (*Larus hyperboreus*) since 2004. Every year, we search systematically for nests of these species in our two study areas (Qarlikturvik Valley and the main goose nesting colony). In 2007, the survey area for owl nests was extended and covered most of the coastal areas between our two study areas (ca 200 km^2). The position of all nests found is recorded with a GPS receiver and nests are revisited periodically to determine laying and hatching dates, total clutch laid, and nesting success. Before 2004, nests of gulls and jaegers were found and monitored opportunistically.

Shorebirds

We are monitoring the reproductive activity of all shorebird species since 2005. Systematic searches of shorebird nests are conducted annually in several areas of the Qarlikturvik Valley and the nesting goose colony. Species include White-rumped Sandpiper (*Calidris fuscicollis*), Baird's Sandpiper (*Calidris bairdii*), American Golden Plover (*Pluvialis dominica*), Black-bellied Plover (*Pluvialis squatarola*), Common Ringed Plover (*Charadrius hiaticula*), Red Phalarope (*Phalaropus fulicarius*), Purple Sandpiper (*Caladris maritime*), Pectoral Sandpiper (*Calidris melanotos*), Buff-breasted Sandpiper (*Tryngites subruficollis*) and Ruddy Turnstone (*Arenaria interpres*). The position of all nests found is recorded with a GPS receiver and nests are revisited periodically to determine laying and hatching dates, total clutch laid, and nesting success.

Other bird species

We are monitoring the reproductive activity of Lapland Longspurs (*Calcarius lapponicus*) since 1995. Longspur nests are found in a portion of the Qarlikturvik Valley only (but also at the nesting goose colony since 2007) while walking throughout the study area for other activities, often when females are flushed from their nest. The position of all nests found is recorded with a

GPS receiver and nests are revisited periodically to determine laying and hatching dates, total clutch laid, and nesting success. Since 1996, similar information on the reproductive activity of other bird species is also collected opportunistically, mostly for Sandhill Cranes (*Grus canadensis*), King Eiders (*Somateria spectabilis*) and Long-tailed Ducks (*Clangula hyemalis*).

2.3.2 Mammals

Lemmings

We are monitoring the populations of Collared (*Dicrostonyx groenlandicus*) and Brown Lemmings (*Lemmus sibiricus*) using two techniques: snap-trapping, which has been conducted at two sites since 1994, and live trapping, a new sampling program that we developed in 2004. The monitoring using snap-traps takes place in July and is carried out in two study plots of the Qarlikturvik Valley (one in wetlands, one in mesic tundra) since 1994, and at a third study plot in mixed wetland/mesic tundra at the main goose nesting colony since 1997. We use Museum Special® traps baited with peanut butter and rolled oats. Until 2006, we followed the protocol of the small mammal survey developed by the Northwest Territories Renewable Resources office in Yellowknife (Shank 1993). In 2007, we modified slightly our protocol to follow the one developed by the International Polar Year project ArcticWOLVES (*Arctic Wildlife Observatories Linking Vulnerable EcoSystems*). At each site, we use 204 traps (50 before 2007) set at 15-m intervals (10-m before) along two parallel transect lines 100 m apart. We set three traps (compared to one before) within a 2-m radius of each station and traps are left open for a period of four days (ten days before). Traps are checked daily and all lemmings caught are identified at the species and sprung traps are reset. The most significant difference between the two protocols is the length of trapping (four vs. ten days before). However, comparison of the abundance index obtained after the first four days of trapping vs. the full ten days during the period 1994-2006 revealed that both were highly correlated ($R^2 = 0.92$, $P < 0.001$). Thus, data collected in 2007 is directly comparable to that obtained in previous years.

Our sampling program based on live-trapping of lemmings uses two permanent grids laid out in the Qarlikturvik Valley (one in wetlands and one in mesic tundra). In 2006, we increased the size of the grids to 360 × 360 m (compared to 300 × 300 m in 2004 and 2005) and the number of traps per grid to 144 (compared to 100 traps in 2004 and 2005) to increase the trapping effort. We use Longworth® traps baited with apples and set at each grid intersection every 30-m. We trap during periods ranging from three to five consecutive days four times on each grid (approximately every 15 days) from mid-June to mid-August. All trapped animals are identified, sexed, weighed and marked with electronic PIT tags (or checked for the presence of such tags). The reproductive condition of females is also assessed.

Arctic and Red Foxes

We are monitoring the breeding activity of Arctic (*Vulpes lagopus*) and Red Foxes (*Vulpes vulpes*) at dens annually since 1993. Until 2002, den monitoring only occurred in the Qarlikturvik Valley and the vicinity of the main goose nesting colony (about 100 km^2). Dens were found opportunistically and their position recorded with a GPS receiver. We have considerably expanded the monitoring area since 2003 and it now covers about 475 km^2 (see Szor et al. 2008 for more details). A systematic survey of fox dens in this area has been conducted, which considerably increased the number of known dens. All dens are visited at least once (but mostly twice) in June or early July and any signs of fox activity is noted (e.g. fresh digging, new hairs, fresh prey). Dens showing signs of activity are re-visited later in the summer to determine the presence of a litter and the number of pups in each litter. Litter size data are the minimum number of pups observed at dens, which may sometimes be lower than the true number of pups present. All observations of adults near dens are also noted, and the species of fox identified.

2.3.3 Plant monitoring

Plant production and goose grazing impact in wetland communities

We are monitoring the annual plant production in wetlands and the impact of goose grazing at three sites on Bylot Island (see Fig. 1): the Qarlikturvik Valley (monitored since 1990), the main goose nesting colony (monitored since 1998), and north of Pointe Dufour (monitored since 1998). At each site, 12 exclosures (1 × 1 m fenced areas built with chicken wire to keep geese off the plots) are installed in late June. At the end of the plant-growing season (i.e. mid-August), we sample the vegetation inside and outside the exclosures (i.e. ungrazed and grazed areas, respectively). All live above-ground plant biomass is cut, sorted out into sedges (*Eriophorum scheuchzeri* or *Carex aquatilis*), grasses (mostly *Dupontia fisheri*) and forbs, dried, and weighed. Above-ground biomass of vascular plants includes all green material and white basal stems buried in mosses. Live above-ground biomass in mid-August is a good measure of annual graminoid production (Gauthier et al. 1995). We also monitor use of the area by geese by counting feces on 1 × 10 m transects located near each exclosure at the end of the season, and also at 2-week intervals for transects located in the Qarlikturvik Valley.

Plant phenology in wetland communities

In 2005, we expanded our monitoring to the plant phenology of *C. aquatilis, E. scheuchzeri* and *D. fisheri* in the Qarlikturvik Valley. Inside each exclosure, two permanent quadrats of 25 × 25 cm (except in early July 2005 when a 20 × 20 cm quadrat was used and for the rest of 2005 and in 2006 when only one 25 × 25 cm quadrat was used) were delimited and every two weeks the number of shoots of each species was determined as well as their phenological stages, i.e. green leaves only, bud emergence, stigmas visible (*C. aquatilis* only), anthers visible, yellowing leaves (*C. aquatilis* only), fruit formed (*E. scheuchzeri* and *D. Fisheri* only), seed dispersal.

Grazing impact in mesic communities

In 2002, we established an experimental set-up of long-term exclosures in two dominant mesic habitats used by geese (mesic meadows on the hills and mesic polygons in the lowlands; see Fig. 1). This experiment includes, in each community, three treatments: goose exclosure (3 × 2 m surrounded by chicken wire 0.45 m high, 2.5-cm mesh), goose+lemming exclosure (3 × 2 m surrounded by welded wire 0.45 m high inserted 0.15 m into the ground, 1.25-cm mesh) and control (unfenced plots receiving normal grazing pressure) in four replicated blocks (each with three groups of exclosures and a control) for a total of 24 groups of exclosures.

In 2003, 2004 and 2005, we monitored the grazing impact in mesic habitat using this experimental set up. To quantify the plants grazed by geese and lemmings, each treatment (see above) was sampled with two marked contiguous 70 × 70 cm quadrats early (prior to massive goose arrival in the valley) and late in season (mid-August). All inflorescences, along with their phenological stage and marks of grazing and/or grubbing (mostly on leaves and shoots) were counted. It was possible to distinguish and exclude grazing by invertebrates (mostly insects). After three years of sampling grazing marks, the long term exclosure experiment in the mesic habitats was not sampled in 2006 and 2007 to minimize disturbance. The exclosures were simply visited and repaired where necessary. We plan to sample vegetation changes in 2008. In 2002, we also marked a permanent 1 × 20 m feces transect near each exclosure and the number of feces was counted at each visit, i.e. early and late in the summer to assess use by geese during the fall and the summer seasons, respectively.

Plant phenology in mesic communities

The monitoring of flowering parameters of four vascular species was initiated at Bylot Island in 1998. This environmental monitoring is part of the International Tundra Experiment (ITEX, www.itex-science.net) network that evaluates the impact of environmental change on tundra communities around the world. In 1998, a site was selected on top of a low hill in the Qarlikturvik Valley. The site was chosen because it had four of the ITEX species in sufficient abundance. The four plant species are: the evergreen shrub Mountain Avens (*Dryas integrifolia*), the cushion plant Purple Saxifrage (*Saxifraga oppositifolia*), the deciduous shrub Arctic Willow (*Salix arctica*; males and females) and the graminoid Arctic Woodrush (*Luzula nivalis*). To facilitate monitoring, reduce trampling and allow adding treatments in future years if desired, 30 quadrats (70 × 70 cm) were established throughout the site. One individual of each of the four selected plant species were marked within or in close proximity of each quadrat, following standard ITEX protocols (Molau and Mølgaard 1996). Each year from 1999 to 2005, the number of flowers and phenological phases of the marked individuals were monitored in order to elucidate relationships between plant phenology and climate variables. To minimize disturbance the site was not visited in 2006 and 2007. The monitoring of this site will occur again in 2008.

2.4 RELATIONSHIPS BETWEEN THE CLIMATE AND BIOLOGICAL DATA

Recently, two MSc students have completed their thesis where they each analysed the impact of climate on one of our two longest and most detailed data sets from our ecological monitoring program: goose nesting activities and plant production in wetlands. Both studies examined the impact of local and regional climate parameters. Local climate was based on our longest running weather station (20 m ASL) on Bylot Island while large-scaled indices such as North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO) were used as regional climate parameters. These two indices were obtained from the Climate Prediction Center of the National Weather Service (www.cpc.ncep.noaa.gov). The NAO represents fluctuations in atmospheric pressure between Iceland and the Azores (Hurrell 2000), while the AO represents fluctuations in atmospheric pressure between polar and middle latitudes (Thompson and Wallace 1998). These large-scale phenomena can have a strong effect on the local climate regime (Stenseth et al. 2002). When these indices are negative, it brings relatively warm temperatures and high precipitations in north-eastern North America, including the North Baffin area, whereas positive indices are associated with reduced temperatures and precipitations (Hurrell 1995). In this report, we present a few key results from these studies but more details can be found in Dickey (2006), Dickey et al. (2008) and Graham-Sauvé (2008). Additionally, we also present results of the impact of local climatic parameters on plant phenology in mesic habitats.

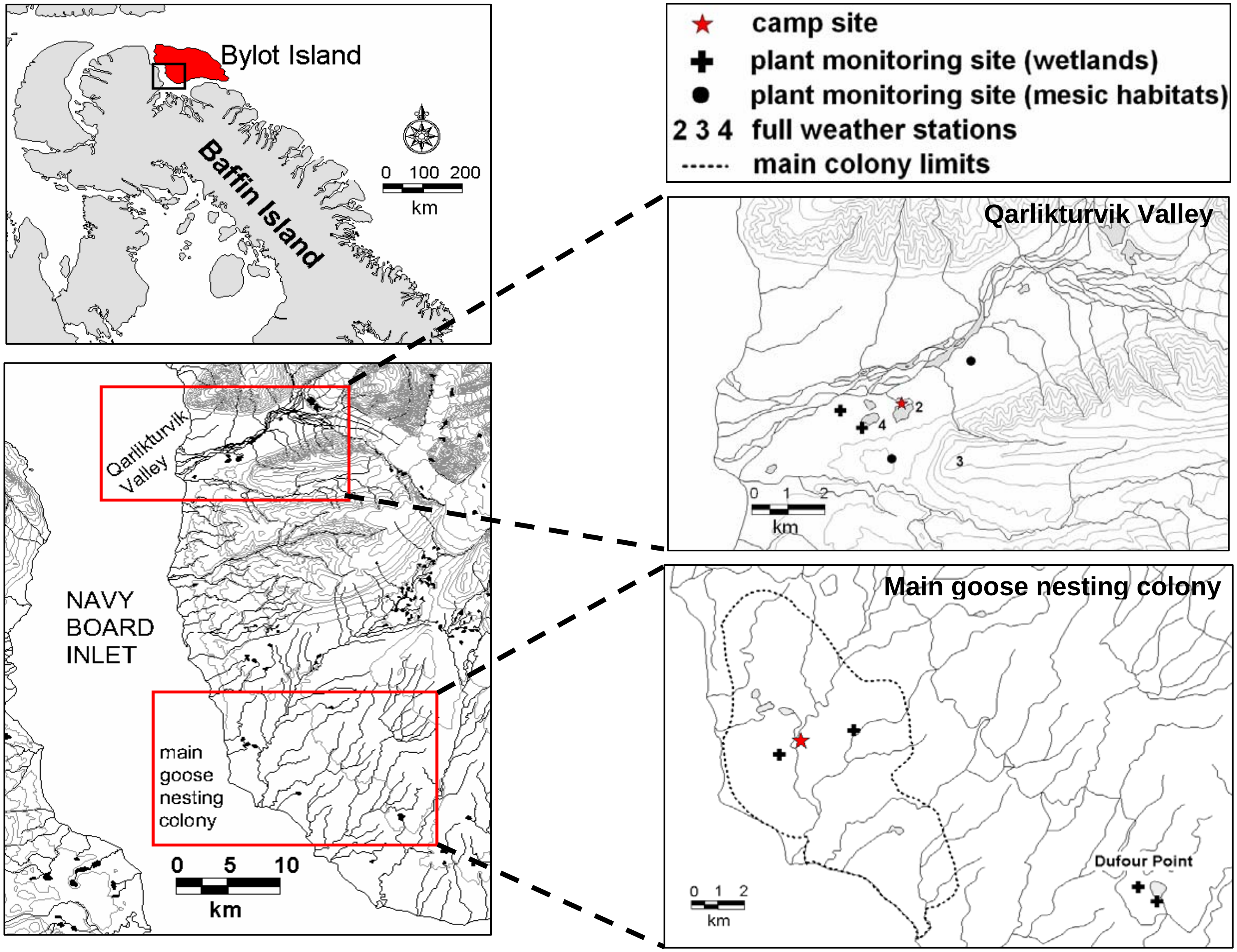


Figure 1. General location of the study area, Bylot Island, Nunavut, and of the two main study sites (Qarlikturvik Valley and the main goose nesting colony) on the south plain of the island. Enlarged maps on the right present these study sites in more details, including camp locations, sampling sites and our three full weather stations.

3 RESULTS

3.1 CLIMATIC DATA

The data retrieved from our automated environmental stations spanned the period from March 1994 to August 2007. All data were compiled, validated (e.g. missing or erroneous values were excluded), and archived. We present here an overview of the most important climatic variables and an update of long-term trends detected at our study site.

3.1.1 Air temperature

Over the past 14 years, the annual average air temperature on Bylot Island was -14.5°C. Three of the past four years have been among the warmest ever recorded since 1995 with an average annual air temperature above -14.0°C. However, we found no detectable trend yet in annual air temperature (Fig. 2). Seasonal temperatures vary greatly from year to year and only fall temperatures showed a weak increasing trend with an increase of 2.2°C over the past decade (Fig. 3). Overall, average air temperature was -19.3°C in the spring, 4.5°C in the summer, -10.8°C in the fall and -32.8°C in the winter.

In 2007, the temperature during the period that most migratory birds arrive on Bylot Island and initiate egg-laying (i.e. 1-15 June) was relatively cold with an average temperature of 1.04°C (1.51°C below the long-term average for the month of June; Fig. 4) while the second part of June (16-30 June) when most plants initiate their growth was much warmer with an average temperature of 4.07°C (1.52°C above the long-term average for June). During the period of peak plant growth and hatching for most bird species (1-15 July), air temperature was near normal with an average of 6.25°C (0.14°C above the long-term average in July; Fig. 4). Similarly, temperature during the period of chick growth of most bird species, temperature was near normal, averaging 6.00°C (0.11°C below the month's overall average).

The annual number of thawing degree-days (TDD) at Bylot Island averaged 438 over the past 14 years (Fig. 5). Most of these degree-days were cumulated over the summer months (95% of the annual total). A weak negative temporal trend was detected in the spring TDD (Fig. 5) but this trend should be viewed with caution because it is entirely due to the exceptionally high value recorded in 1994, a year with virtually no snow cover during the winter.

3.1.2 Snow cover and precipitations

The average snow depth on 1 June in the lowlands of the Qarlikturvik Valley was 30.5 cm over the past 13 years. Snow depth varied greatly among years, but no trends were detected (Fig. 6). The average percentage of snow cover recorded in the Qarlikturvik Valley on 5 June was 67%. Snow cover varied similarly to snow depth, with no evidence of a temporal trend (Fig. 7). On average, snow melted at a speed of 2.1 cm per day in the first half of June. However, despite large inter-annual differences, the speed of snowmelt showed a weak decline over time with a decrease of 1 cm of snow per day per decade (Fig. 8A) which was reflected in the date where >95% of the Qarlikturvik Valley was snow-free (Fig. 8B). On average, snowmelt was delayed by almost seven days over the past decade.

Rainfall received during the summer on Bylot Island averaged 91.4 ± 8.6 mm. Most of these precipitations were generally received during the month of July (42.9 ± 5.9 mm) and August (33.4 mm when extrapolated to the whole month) while June appeared to be drier (21.2 ± 3.5 mm, Fig. 9). Data showed no trend in precipitation either on an annual or seasonal basis.

3.1.3 Wind speed

In the Qarlikturvik Valley, wind speed is highest during the summer and fall (long-term averages: 2.9 and 2.1 m s^{-1}, respectively) and the lowest during winter and spring months (long-term averages: 1.2 and 1.5 m s^{-1}, respectively; Fig. 10). No temporal trend was detected in the seasonal wind speed on Bylot Island.

3.2 Biological data

3.2.1 Birds

Greater Snow Geese

Over the past 14 years, the average goose nest density was 3.41 nest/ha. Nest density varied greatly from year to year but no trend was detected. The lowest density was found in 1996 (0.91 nest/ha) while the highest density was in 2003 (8.87 nests/ha; Fig. 11).

Overall, the median date that the first egg was laid in goose nests (i.e. egg-laying date) over the last 19 years was 12 June (n = 5831). In 2007, egg-laying date was 16 June, which is relatively late. Median egg-laying date showed relatively large inter-annual variations (from 6 to

20 June) but analyses revealed no temporal trend in egg-laying dates (Fig. 12A). Because incubation has a set time length in birds (23-24 days in snow geese), egg hatching dates followed annual trends similar to laying dates. The median hatching date was 9 July (n = 4379). There was no detectable long-term trend in hatching date (Fig. 12B).

The long-term average of eggs per nest (i.e. total clutch laid) was 3.71 ± 0.08 eggs (n = 5480; Fig. 13). The lowest average clutch size was found in 1999 following the instauration of a spring conservation harvest for geese on the Quebec staging grounds while the highest clutch size was in 1993, a year with a very warm spring. In 2007, mean clutch size was 3.91, slightly higher than the long-term average. We did not find any temporal trends in clutch size but there is a strong inverse relationship between the average annual clutch size of geese and the average annual laying date. Geese usually lay smaller clutches when they initiated their nest late in the reproductive season ($R^2 = 0.465$; df = 18; $P = 0.001$).

On average, 64% of goose nest initiated since 1989 hatched at least one egg (nesting success, n = 5729). The best nesting success was found in 1993 (89%) while the worst year for geese was 1999 (14%; Fig. 14). In 2007, nesting success was 82%, a fairly high value. As for the other components of reproductive success, we did not find any temporal trends in nesting success.

Avian predators

Snowy Owls only nest on Bylot Island in peak lemming years, which occur every 3-4 years on Bylot Island (see below). Owl nests were thus found in 1993, 1996, 2000, 2004 and 2007, but never in the years in between (Table 1). Egg-laying usually starts around 22 May (n = 45) and hatching date of the first egg was 23 June (n = 45). Clutch sizes and nesting success showed moderate annual variations and, overall, averaged 7.1 ± 0.3 eggs laid per nest (n = 60) and 80% (n = 49), respectively. Even though the number of owl nests found in 2007 appear comparable to previous years of owl nesting activity, their distribution differed markedly. Contrary to previous years, only one owl nested in the Qarlikturvik Valley and most owls nested between our 2 camps, toward the goose colony. Their density was also relatively low because we searched an area at least twice as large as in previous years to find the nests in 2007. Laying date tended to be late in 2007, and the clutch size and nesting success were low compared to previous years (Table 1).

As with owls, Long-tailed Jaeger nests appear to be most numerous in lemming peak years (i.e. 2004 and 2007) although, contrary to owls, jaegers also nest in between those years Table 1). However, nesting success has been generally low with only one good reproductive year in the past four years (2004) when 86% of nests found hatched at least one egg (overall average: 26%; n = 35). Laying and hatching dates remained relatively constant with nests being initiated on average on 16 June (n = 17) and eggs hatching on 10 July (n = 9).

Nests of Glaucous Gulls were mostly found in the Qarlikturvik Valley (Table 1). If we exclude years prior to 2006 because the coverage of the study area for gull nests was not as exhaustive, the number of nests found at this site was less variable than for the other avian predators. Over the past three years, female initiated their nest around 16 June (n = 16) and young hatched in mid-July (average: 13 July; n = 16). Similar to jaegers, gull clutch sizes was fairly constant with an average of 2.4 ± 0.2 eggs per nest (n = 37). The overall nesting success of gulls was relatively good (53%; n = 32) but lower during the past two breeding seasons.

Shorebirds

Among the ten species of shorebirds seen regularly on Bylot Island, seven of them were found nesting, mostly in the Qarlikturvik Valley (Table 2). The most abundant shorebirds were the White-rumped Sandpipers and the Baird's Sandpipers (67 and 63 nests found over the past three years, respectively). American Golden Plovers (17 nests), Red Phalaropes (5 nests), Pectoral Sandpipers (3 nests), Common Ringed Plovers (1 nest), Black-bellied Plovers (1 nest), Purple Sandpipers, Buff-breasted Sandpiper and Ruddy Turnstone were also observed on the island since 2005. Clutch size of all shorebird nests monitored was 4.0 eggs. Mean laying and hatching dates were between 10 and 21 June, and 4 and 20 July, respectively (Table 2). In 2007, the nesting activity of the two most abundant species (White-rumped and Baird's Sandpipers) was considerably lower than in the previous two years and their nest initiation date was relatively late (Table 2). However, their nesting success was much higher in 2007 compared to the previous two years.

Other bird species

The large annual variation in numbers of Lapland Longspur nests found since 1995 partly reflects variations in sampling effort, which increased markedly in the past three years (Table 3). Average egg-laying and hatching dates of longspurs were 18 June (n = 183) and 4 July (n = 130), respectively. No temporal trends were detected for both laying and hatching dates. The clutch size was 5.3 ± 0.1 eggs (n = 326; Table 3) and no temporal trend was detected. Nesting success varied from year to year and averaged 49% (n = 310). Nesting activity in the Qarlikturvik Valley appears lower in 2007 compared to the previous two years, but the nesting phenology was similar (Table 3). Clutch size and especially nesting success was higher in 2007 than the long-term average.

Every year, we also found a few nests of Sandhill Cranes, King Eiders and Long-tailed Ducks, but the numbers are too low to look for temporal trends. Over the past three years, the average clutch size of these species was 2.0, 3.9 and 4.8 eggs per nest, respectively (Table 3).

3.2.2 Mammals

Lemmings

As commonly observed in the Arctic, lemming populations have been going through marked fluctuations of abundance on Bylot Island. Our longest record based on snap-trapping in the Qarlikturvik Valley indicated peak abundance in 1993, 1996, 2000, 2004 and again in 2007 (Fig. 15). Our longest temporal series of index of abundance was analysed in detail by Gruyer (2007) over the period 1993 to 2005. His analysis strongly suggest that both species, but especially Brown Lemmings, undergo cyclic fluctuations and the intervals between the peaks were estimated at 3.69 ± 0.04 years for Brown Lemmings and 3.92 ± 0.24 years for Collared Lemmings (Gruyer 2007). Brown Lemming showed typical cyclic population fluctuations of large amplitude (>40 fold), whereas Collared Lemming fluctuations were weak and of much smaller amplitude (4 fold). Fluctuations in abundance at the same site were relatively well synchronized between species (r_s = 0.67, df = 11, P = 0.02; Gruyer 2007). Trapping conducted at the main goose colony suggested that the two sites generally fluctuated either in synchrony or possibly with a 1-year time lag at the main goose colony for the year of peak lemming abundance. The large annual fluctuations in lemming abundance makes the examination of long-term trend in abundance exceedingly difficult but it is noteworthy that the abundance index during the two most recent peak years (2004 and 2007) was fairly low compared to the previous three peaks (Fig. 15). Overall, there was some evidence for a decreasing trend in our annual index of lemming abundance in the Qarlikturvik Valley ($R^2 = 0.160$, $P = 0.139$; Fig. 15).

The relative abundance of the two lemming species generally differed between the two sites (Fig. 16). In the Qarlikturvik Valley, the site with the highest density of wetlands, Brown Lemmings were typically more abundant than Collared, whereas at the main goose colony, where mesic tundra is most abundant, the reverse was true, except during the 2001 lemming peak.

The number of lemmings captured during our live-trapping sessions corrected for the trapping effort provides another index of lemming abundance. For the period 2004 to 2006, the two indices changed in parallel, with a large number of lemmings captured in 2004, a much lower number in 2005 and an even lower numbering 2006 (Table 4). However, the two indices diverged in 2007 as the snap-traps indicated an increase in lemming abundance (Fig. 15) whereas the live-trapping indicated persistent low numbers. We have no explanation for this discrepancy in 2007 but the presence of nesting owls clearly suggest that lemming abundance increased that year. Gruyer (2007) detailed analyses of the 2004-2005 live-trapping data showed that the proportion of juvenile Brown Lemmings in the population was lower during the decline phase of the lemming cycle (i.e. 2005) than in the peak phase of 2004 ($\chi^2 = 24.0$, df = 1, $P < 0.001$), but did not differ between years in the Collared Lemmings ($\chi^2 = 0.64$, df = 1, $P < 0.420$; Fig. 17). The proportion of juveniles in the population increased seasonally in both years for both species (brown: $\chi^2 = 31.6$, df = 3, $P < 0.001$; collared: $\chi 2 = 20.5$, df = 3, $P < 0.001$). Furthermore, based on the weight and age of Brown Lemmings captured during the summers of 2004 and 2005, Gruyer (2007) was able to infer the distribution of their birth seasons. Results showed that during the 2004 peak most births occurred during the summer while in 2005 (decline phase) most of the lemmings captured over the summer were born during the previous winter and spring (interaction year × time period: $\chi^2 = 8.68$, df = 3, $P = 0.030$; Fig. 18).

Arctic and Red Foxes

The number of fox dens monitored on Bylot Island has increased over time (from 3 in 1993 to 99 in 2007), especially since 2003, the year of the extensive den survey. This allowed us to obtain an accurate map of the location of fox dens over a large part of Bylot Island (Fig. 19). Over the last 15 years, we detected signs of activity (fresh digging and/or footprints) at dens every year but the breeding activity of foxes differed markedly from year to year (Fig. 20). The proportion of dens with pups varied annually from 0 to 28% since 1996 (we excluded the previous three years because sample size was too small). Although we observed both Arctic and Red Fox litters, overall Arctic Foxes accounted for 92% of all litters found and they produced litters in most years, contrary to Red Foxes who were recorded breeding only once in the past six years (Fig. 20). The annual proportion of dens used by Arctic Foxes for reproduction showed a weak positive relationship with lemming abundance since 1996 ($R^2 = 0.266$, df = 11, $P = 0.104$) as they seem to reproduce in higher numbers when lemming abundance was greater. However, the proportion of dens used by both species of foxes showed a decline since 1996 ($R^2 = 0.307$, $P = 0.060$; Fig. 20). In 2007, the proportion of dens used by foxes was the lowest ever recorded (11%) for a year of peak lemming abundance.

The long-term average minimum litter size was 4.2 ± 0.5 pups for Arctic Foxes (minimum: 2.0, maximum: 6.9; Fig. 21A) and 4.7 ± 0.6 pups for Red Foxes (minimum: 2.0, maximum: 6.0; Fig. 21B). We did not examine for trends in litter size because this metric is quite sensitive to the effort spent in determining its value in the field. Since 2003, this effort increased markedly and thus the most recent estimates may not be directly comparable to previous ones.

3.2.3 Plant monitoring

Plant production in wetlands

Wetland communities on Bylot Island are largely dominated by graminoid plants (i.e. >90% by sedges and grasses), and thus only these plants are considered here. Among the three sites where wetland plants are monitored on Bylot Island, the longest time series comes from the Qarlikturvik Valley, a major brood-rearing site for geese (Fig. 1). Above-ground biomass of graminoid plants in the valley averaged 45.2 ± 3.4 g m^{-2} in ungrazed areas in mid-August since 1990 (Fig. 22). In 2007, plant production was very close to this long-term average. Overall, *Dupontia fisheri* accounted for 63 % of the graminoid biomass, i.e. 28.5 ± 1.6 g m^{-2} in ungrazed areas while *Eriophorum scheuchzeri* represented 31% with an average production of 14.1 ± 2.0 g m^{-2} in ungrazed plots. Since 1990, the biomasses of all graminoids, and *Dupontia* have showed significant increasing trends in the Qarlikturvik Valley. Average production of all graminoid plants has increased by 1.5 g m^{-2} yr^{-1} since 1990 (Fig. 23). At the species level, *Dupontia* production increased by 0.8 g m^{-2} yr^{-1} (R^2 = 0.363, df = 16, P = 0.011) and *Eriophorum* showed the same trend with a non-significant increase of 0.6 g m^{-2} yr^{-1} (R^2 = 0.138, df = 16, P = 0.143).

Wetland plant monitoring at the two other sites (main goose nesting colony and Pointe Dufour) has been conducted since 1998 only. The long-term average of above-ground biomass of graminoids at the end of the summer was 31.7 ± 2.6 g m^{-2} in ungrazed areas of the main goose nesting colony (Fig. 24). Graminoid biomass was also dominated by *Dupontia fisheri*, with an average annual production of 18.2 ± 1.6 g m^{-2} (i.e. 58% of the total biomass) followed by *Eriophorum scheuchzeri* with 11.9 ± 1.3 g m^{-2} (i.e. 38% of the total biomass). Since 1998, average production of graminoids plants showed no significant temporal trend at the main goose colony (P > 0.211). Graminoid plants production at Pointe Dufour averaged 50.3 ± 3.4 g m^{-2} at the end of summer (Fig. 25). *Dupontia* represented 46% of the graminoid biomass, i.e. 22.9 ± 3.4 g m^{-2} while *Eriophorum* accounted for 26%, i.e. 13.1 ± 2.0 g m^{-2}. We found a significant temporal trend in *Dupontia*'s annual production at Pointe Dufour with an increase of 2.4 g m^{-2} yr^{-1} (R^2 = 0.655, df = 6, P = 0.027) but no temporal trends were detected in the total annual plant production (i.e. all graminoids, P = 0.654) or in *Eriophorum*'s annual production (P = 0.582). Over the period 1998-2006 when sampling was carried out at the three sites, we noted that plant production was comparable in the Qarlikturvik Valley (55.0 g m^{-2}) and Pointe Dufour (50.3 g m^{-2}) but lower at the main goose colony (30.6 g m^{-2}).

Goose grazing impact and use of wetlands

In wetlands, we define the goose grazing impact as the proportion of above-ground plant biomass removed by geese calculated as the difference in biomass inside vs. outside exclosures. In the wet meadows of the Qarlikturvik Valley, a main brood-rearing area, geese removed an average of 35% of the above-ground biomass by mid-August during the period 1990-2007, but with large annual variations (range: 0 to 60%; Fig. 22). On a specific basis, they removed 40% of the total annual production of *Eriophorum* (annual range: 2 to 75%) and 31% of *Dupontia* (annual range: 0 to 52%). We found some evidence for temporal trends in goose grazing impact in the Qarlikturvik Valley. Since 1990, grazing impact on total graminoid plants and *Dupontia* tended to decrease by 1.0% yr^{-1} (all graminoids: R^2 = 0.185, df = 16, P = 0.085; Dupontia: R^2 = 0.187, df = 16, P = 0.083). No detectable trend was observed for *Eriophorum* (P = 0.266).

At the main colony, geese removed 29% of the graminoid biomass (38% of *Eriophorum* and 22% of *Dupontia*; Fig. 24). This value was similar to the one observed at the Qarlikturvik Valley for the same period (29% from 1998 to 2007). No temporal trend of goose impact was detected at the goose colony ($P > 0.241$). Similarly, at Pointe Dufour geese removed on average 25% of the total biomass (31% of *Eriophorum* and 24% of *Dupontia*; Fig. 25). No temporal trend was detected in the long-term proportion of total biomass removed by geese at Pointe Dufour.

Based on feces densities measured at the end of the summer at each site, we are able to obtain an index of use by geese over the summer. Wetland use by geese varied greatly among years but no temporal trend was detected at either site ($P > 0.104$; Fig. 26). Overall, geese used both brood-rearing areas (Qarlikturvik Valley and Pointe Dufour) similarly over the years (long-term average 1998-2007: 6.3 ± 0.8 and 6.3 ± 1.4 feces m^{-2}, respectively; Fig. 26) while the nesting area was less intensively used (3.6 ± 0.3 feces m^{-2}). Goose feces densities recorded at the Qarlikturvik Valley were positively correlated with goose grazing impact on graminoid plants from 1990 to 2007 ($R^2 = 0.305$, df = 16, $P = 0.022$) but not at the two other sites (for the period of 1998-2007: $P > 0.294$).

Plant phenology in wetlands

After only three years of monitoring the phenology of graminoid plants in wetlands, a few noticeable differences were observed. Among the three species monitored, *C. aquatilis* had very low shoot density (3-year average: 114 ± 22 shoot m^{-2}) and showed low reproductive activity (Fig. 27). It did not seem to have produced any buds in 2006 but its reproductive phenology was generally similar in 2005 and 2007 although buds and anthers were produced over a shorter period of time in the latter year. Over the years, *E. scheuchzeri* had the earliest start in its reproductive cycle (i.e. bud emergence) and in 2007 it occurred two weeks earlier than in 2006 (around 24 June in 2007 vs. 6 July in 2006; Fig. 28). Similarly, anthers production, fruits and seed emergence as well as senescence of plants occurred earlier in 2007 than in the two previous years. Shoot density also varied over the three years with less than half the density observed in 2007 compared to 2005 (618 ± 125 and 1327 ± 287 shoots m^{-2}, respectively; Fig. 28). Finally, *D. fisheri* also had an earlier reproduction in 2007 with buds emerging two weeks sooner than in 2005 and 2006 (around 6 July in 2007 compared to 19 July in 2005-2006; Fig. 29). A higher density of shoots produced anthers in 2007 (51 ± 21 shoots m^{-2} compared to ≤ 31 ± 10 in previous years) and most of them appeared in mid-July. Since 2005 all fruits of *D. fisheri* were formed in August but the density was higher in 2007 (140 ± 41 shoots m^{-2} compared to ≤ 61 ± 17 in previous years; Fig. 29). Seed dispersal of *D. fisheri* occurred in August in the last two years which was sooner than in 2005 when seed had not yet occurred when we last visited the site.

Goose use of mesic communities

The summer use of mesic habitats of the Qarlikturvik Valley by geese was much less intense than the use of wetlands (mesic: < 0.4 feces m^{-2}, wetlands: > 3.0 feces m^{-2}, for the period 2003-2007; Fig. 26 and 30). On average, goose feces density during the summer was almost identical in mesic meadows and in mesic polygons (0.18 ± 0.08 vs. 0.19 ± 0.08 feces m^{-2}, respectively). Except for 2003, geese used more intensely mesic meadows than mesic polygons during the fall (0.19 ± 0.04 vs. 0.15 ± 0.10 feces m^{-2}, respectively; $t = 2.109$, df = 94, $P = 0.038$; Fig. 30).

Plant phenology in mesic communities

From 1999 to 2005, the average date of first flowering for the species monitored in mesic communities was 29 June for *S. oppositifolia*, 2 July for *S. arctica* female, 3 July for *S. arctica* male, 4 July for *L. nivalis* and 11 July for *D. integrifolia* (Fig. 31). For all these species, except for male *S. arctica*, the date of first flowering has been advancing since 1999. Over a 7-year period, the first flowering date has been sooner by 4 days for *D. integrifolia*, 6 days for *S. oppositifolia*, 12 days for *S. arctica* female and 14 days for *L. nivalis*.

The number of flowers produced per plant varied between years. Average number of flowers produced by individual plants was 8.9 ± 0.8 for *D. integrifolia*, 2.3 ± 0.3 for *S. oppositifolia*, 1.0 ± 0.1 for *L. nivalis*, 0.5 ± 0.1 for *S. arctica* male and 0.2 ± 0.1 for *S. arctica* female (Fig. 32). Analysis also showed that since 2000-2001, the annual average number of flowers produced per plant of *D. integrifolia*, *S. oppositifolia* and *L. nivalis* has been declining (*D. integrifolia*: $R^2 = 0.723$, $P < 0.001$, *S. oppositifolia*: $R^2 = 0.505$, $P < 0.05$ and *L. nivalis*: $R^2 = 0.901$, $P < 0.05$; Fig. 32). No trend was observed for either male or female ramets of *S. arctica*.

3.3 RELATIONSHIPS BETWEEN THE CLIMATE AND BIOLOGICAL DATA

3.3.1 Climatic effect on goose breeding phenology and reproduction success

Dickey et al. (2008) have analysed in details the links between goose reproductive parameters and climatic variables for the period of 1989 to 2004. Because the goal of this study was to examine the relative importance of climatic parameters on geese at various stages of their breeding cycle, the summer season was divided into three periods. These periods were *spring*, when geese arrive at the breeding site and begin egg-laying (20 May to 20 June), *early summer*, which corresponded to the incubation and hatching period (21 June to 15 July), and *late summer*, which corresponded to the brood-rearing period (16 July to 15 August). Among the local climatic parameters recorded on Bylot Island, air temperature, precipitation and snow cover in spring were thought to be most influential on goose reproduction and were entered in the different models analysed.

The most important climatic variable affecting egg-laying date was mean temperature in spring as laying was delayed in cold springs (Fig. 33A). However, a model where mean temperature was replaced by snow cover in spring provided an equal fit to the data (identical AIC value, R^2 of the model = 0.421) as laying data was delayed in spring with high snow cover. Because of the close link between laying and hatching date, a large proportion of variation in hatching date was also explained by air temperature from the previous period (i.e. spring). Hatching was delayed when the minimum temperature of the coldest day in spring was very low (Fig. 33B). The density of goose nests in the colony was also positively related to mean temperature in spring (Fig. 34). This effect was very strong because the average density of goose nests could show more than a 6-fold variation between a cold and a warm spring.

Climatic effects were also detected on gosling growth, which is an important fitness component because it affects subsequent survival of young (Menu et al. 2005). The most important climatic variable affecting gosling mass and size near fledging was mean temperature in spring (mass: $F_{2,19231} = 16.2$, $P < 0.001$; size: $F_{6,19324} = 20.8$, $P < 0.001$; Fig. 35). Goslings were smaller and lighter with increasing spring temperature but only above a threshold, i.e. when temperature was above average. This effect was thus contrary to the one reported for nest density and nesting phenology, i.e. warm spring had a negative effect on goslings growth.

3.3.2 Climatic effect on plant production and goose grazing impact in wetlands

Graham-Sauvé (2008) looked at the combined effects of climate and indirect trophic interactions on plant production and goose grazing impact in the wetlands of Bylot Island for the period of 1990 to 2006.

The best model explaining annual variation in above-ground production of graminoid in wetlands of the Qarlikturvik Valley included summer thawing degree-days and the total amount of summer precipitation (Fig. 36). Collectively, these two variables explained as much as 70% of the annual variation in annual plant production. Overall, plant production was lower in cold and wet summers (Fig. 36).

The impact of goose grazing on graminoid plants in wetlands of the Qarlikturvik Valley was best explained by four variables: the spring North Atlantic Oscillation (NAO) index, the index of lemming abundance, early summer mean temperature and the presence of a spring goose harvest on the Quebec staging grounds (Fig. 37). Collectively, these four variables explained as much as 63% of the annual variation in the proportion of plant biomass grazed by geese, of which 35% was accounted for by climatic variables alone. Warm spring temperatures (i.e. negative spring NAO) combined with warm early summer temperatures and a high lemming density lead to a high proportion of plant biomass grazed by geese. Moreover, the implementation of a spring harvest in southern Quebec apparently reduced by about 10% the average proportion of plant biomass grazed on Bylot Island.

Table 1. Data on the reproduction of Snowy Owls, Long-tailed Jaegers and Glaucous Gulls on Bylot Island, from 1993 to 2007. Mean values are provided for each parameter except for number of nests (total).

Species		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Snowy Owl	N of nests [a]	12 / -	0 / 0	0 / 0	7 / 3	0 / 0	0 / 0	0 / 0	12 / 1	0 / 0	0 / 0	0 / 0	13 / 9	0 / 0	0 / 0	1 / 16
	Laying date	21 May	- [b]	-	16 May	-	-	-	29 May	-	-	-	18 May	-	-	25 May
	Hatching date	22 June	-	-	17 June	-	-	-	30 June	-	-	-	19 June	-	-	26 June
	Clutch size	7.6	-	-	7.9	-	-	-	6.4	-	-	-	7.1	-	-	6.4
	Nesting success	-	-	-	-	-	-	-	85%	-	-	-	95%	-	-	60%
Long-tailed Jaeger	N of nests	-	-	-	-	6	3	0	9	9	0	0	17 / 6	9 / 9	3 / 4[c]	16[c] / 14
	Laying date	-	-	-	-	-	-	-	-	-	-	-	15 June	16 June	-	16 June
	Hatching date	-	-	-	-	-	-	-	-	-	-	-	10 July	11 July	-	9 July
	Clutch size	-	-	-	-	-	-	-	-	-	-	-	1.8	1.8	-	1.9
	Nesting success	-	-	-	-	-	-	-	-	-	-	-	86%	8%	0%	9%
Glaucous Gull	N of nests	-	-	-	-	3	5	7	5	4	1	-	5 / 5	11 / 1	12 / 4	16 / 6
	Laying date	-	-	-	-	-	-	-	-	-	-	-	-	13 June	18 June	16 June
	Hatching date	-	-	-	-	-	-	-	-	-	-	-	-	10 July	17 July	12 July
	Clutch size	-	-	-	-	-	-	-	-	-	-	-	2.3	2.9	2.1	2.3
	Nesting success	-	-	-	-	-	-	-	-	-	-	-	-	80%	38%	40%

[a] Qarlikturvik Valley / main goose nesting colony; otherwise, number of nests combines both sites.
[b] No data available.
[c] Includes 1 nest of Parasitic Jaeger.

Table 2. Data on the reproduction of shorebird species on Bylot Island, from 2004 to 2007. Mean values are provided for each parameter except for number of nests (total).

Species		2004	2005	2006	2007
White-rumped Sandpiper	N of nests [a]	- [b]	36 / 3	17 / 3	7 / 1
	Laying date	-	13 June	15 June	17 June
	Hatching date	-	8 July	10 July	12 July
	Clutch size	-	4.0	4.0	4.0
	Nesting success	-	11%	1%	73%
Baird's Sandpiper	N of nests	5 / 0	20 / 0	32 / 1	10 / 0
	Laying date	-	10 June	11 June	18 June
	Hatching date	-	4 July	4 July	11 July
	Clutch size	4.0	4.0	4.0	4.0
	Nesting success	-	25%	2%	78%
American Golden Plover	N of nests	-	6 / 0	5 / 1	4 / 1
	Laying date	-	17 June	15 June	21 June
	Hatching date	-	13 July	13 July	20 July
	Clutch size	-	4.0	4.0	4.0
	Nesting success	-	19%	20%	4%
Black-bellied Plover	N of nests	-	1 / 0	0 / 0	0 / 0
	Laying date	-	18 June	-	-
	Hatching date	-	18 July	-	-
	Clutch size	-	4.0	-	-
	Nesting success	-	-	-	-
Red Phalarope	N of nests	-	1 / 0	0 / 1	1 / 2
	Laying date	-	-	-	19 June
	Hatching date	-	-	-	14 July
	Clutch size	-	4.0	-	4.0
	Nesting success	-	-	-	-
Common Ringed Plover	N of nests	-	-	0 / 1	0 / 0
	Laying date	-	-	-	-
	Hatching date	-	-	-	-
	Clutch size	-	-	-	-
	Nesting success	-	-	-	-
Pectoral Sandpiper	N of nests	-	-	2 / 0	0 / 1
	Laying date	-	-	-	13 June
	Hatching date	-	-	-	18 July
	Clutch size	-	-	-	4.0
	Nesting success	-	-	-	-

[a] Qarlikturvik Valley / main goose nesting colony.
[b] No data available.

Table 3. Data on the reproduction of Lapland Longspurs, Sandhill Cranes, King Eiders and Long-tailed Ducks on Bylot Island, from 1995 to 2007. Mean values are provided for each parameter except for number of nests (total).

Species		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Lapland Longspur	N of nests [a]	23	5	13	18	7	22	18	13	18	27	68	89	56 / 22
	Laying date	16 June	13 June	23 June	13 June	22 June	19 June	16 June	16 June	7 June	24 June	21 June	18 June	21 June
	Hatching date	1 July	29 June	9 July	30 June	8 July	4 July	2 July	1 July	23 June	9 July	3 July	6 July	7 July
	Clutch size	5.7	5.2	4.7	5.6	5.3	5.6	5.1	5.8	5.5	5.2	5.1	5.1	5.7
	Nesting success	75%	40%	40%	38%	50%	82%	- [b]	50%	-	75%	19%	9%	62%
Sandhill Crane	N of nests	-	2	1	1	2	3	1	0	1	2 / 0	1 / 0	3 / 0	4 / 0
	Clutch size	-	-	-	-	-	-	-	-	-	2.0	2.0	2.0	2.0
King Eider	N of nests	-	-	-	2	2	7	3	1	2	2 / 2	5 / 0	3 / 0	3 / 0
	Clutch size	-	-	-	-	-	-	-	-	-	-	5.0	3.7	3.0
Long-tailed Duck	N of nests	-	-	-	1	-	5	1	-	-	1 / 1	4 / 0	4 / 0	3 / 0
	Clutch size	-	-	-	-	-	-	-	-	-	-	4.8	3.8	5.7

[a] Qarlikturvik Valley / main goose nesting colony; otherwise, number of nests is for Qarlikturvik Valley only (Lapland Longspurs) or combines both sites (other species).
[b] No data available.

Table 4. Number of Brown and Collared Lemmings captured and recaptured during the live-trapping program on Bylot Island, along with the trapping effort from 2004 to 2007.

Year		Wetland trapping grid			Mesic tundra trapping grid			Total	
		Brown Lemming	Collared Lemming	Trapping effort[1]	Brown Lemming	Collared Lemming	Trapping effort	Lemmings	Trapping effort
2004	Number captured	84	1	1500	58	26	1600	169	3100
	Number recaptured[2]	55	0		33	9		97	
2005	Number captured	12	13	2000	16	14	2000	55	4000
	Number recaptured	7	5		10	6		28	
2006	Number captured	14	10	2880	12	11	2880	47	5760
	Number recaptured	6	8		6	5		25	
2007	Number captured	8	8	2304	9	4	2304	29	4608
	Number recaptured	2	4		4	0		10	

[1] Cumulative number of trap-days over the summer.
[2] Number of individual recaptured more than once.

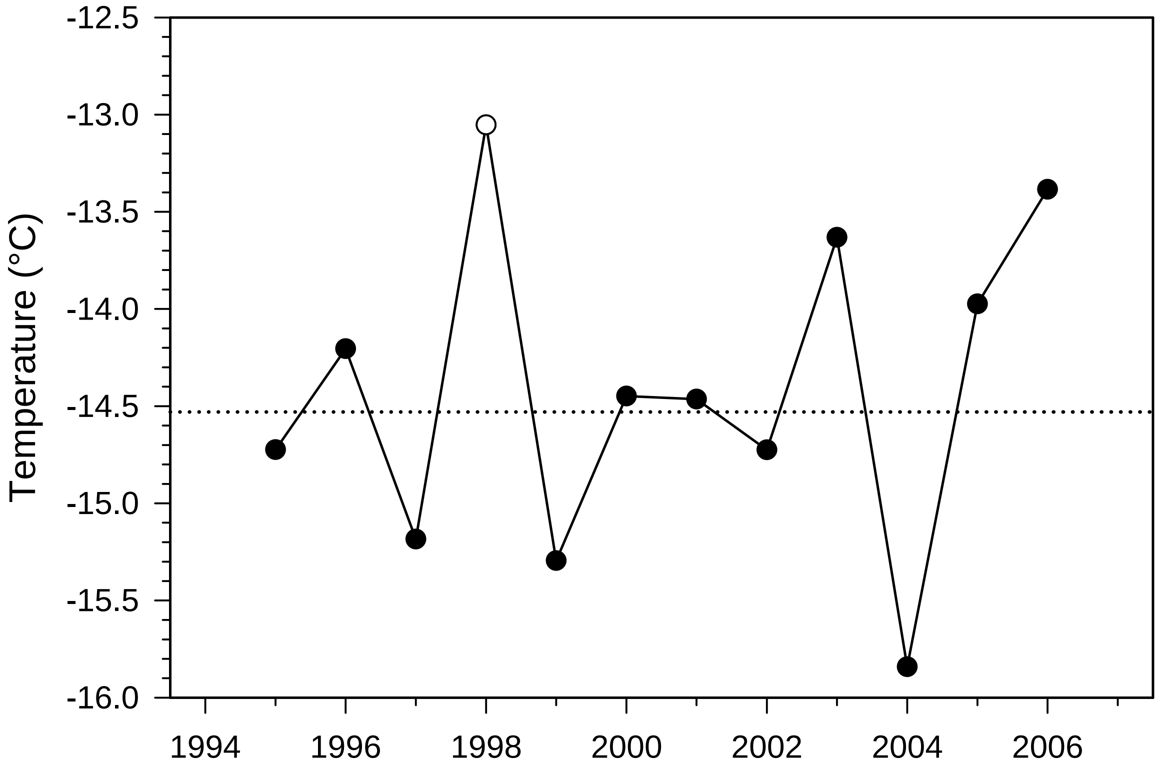


Figure 2. Average annual air temperature in the Qarlikturvik Valley lowlands of Bylot Island from 1995 to 2006. The dotted line shows the mean for the whole period. Air temperature for 1998 is represented by a white circle as it was extrapolated for part of the year from the relation between the air temperatures at Bylot Island and Pond Inlet due to missing values.

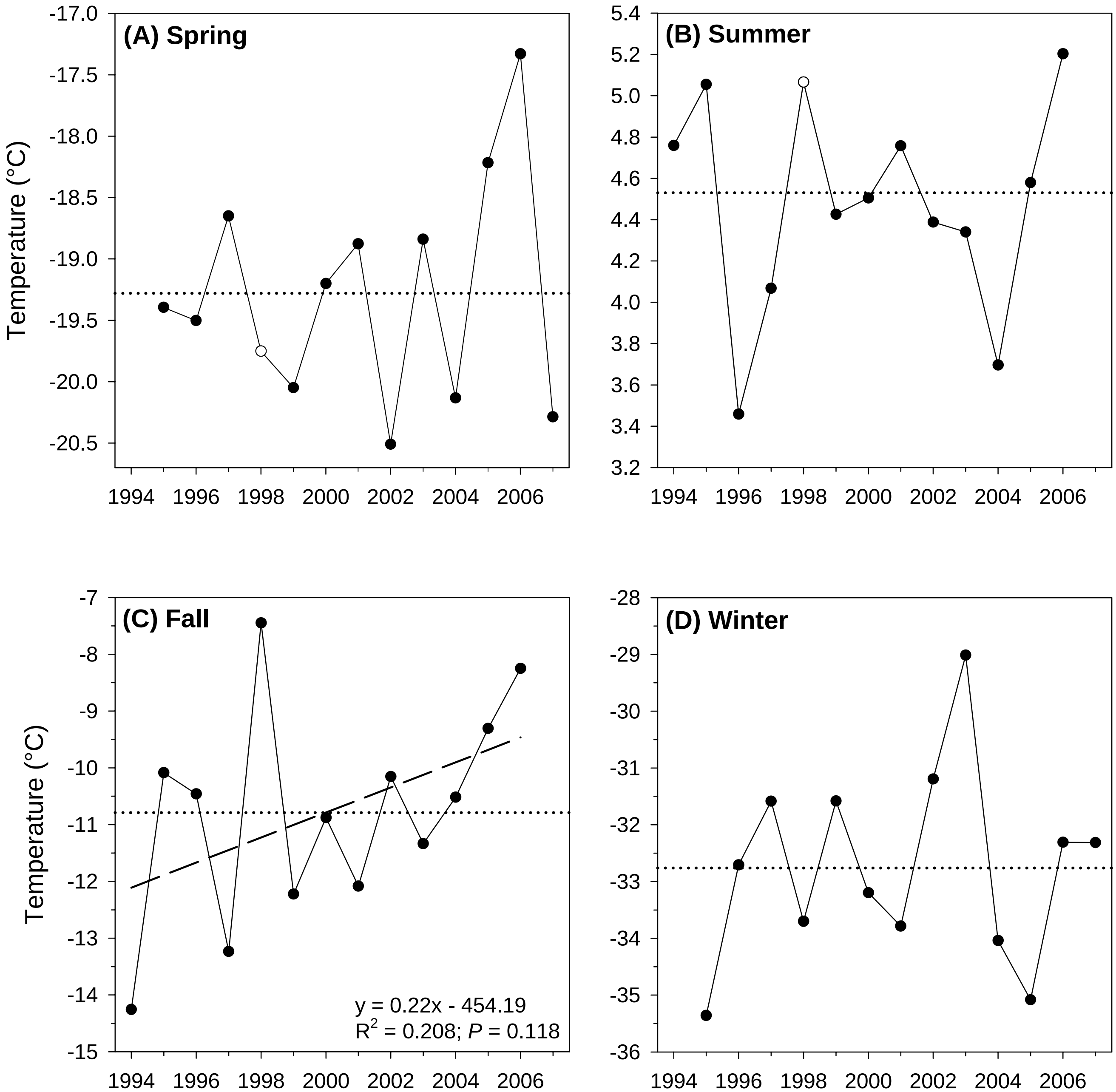


Figure 3. Average air temperature in the Qarlikturvik Valley lowlands of Bylot Island from 1994 to 2007 for (A) spring (March to May), (B) summer (June to August), (C) fall (September to November) and (D) winter (December to February). The dotted line shows the mean for the whole period. Air temperature for the spring and summer 1998 is represented by a white circle as it was extrapolated from the relation between the air temperatures at Bylot Island and Pond Inlet. Temporal trends are represented by a dashed line when approaching significance ($0.05 < P < 0.15$).

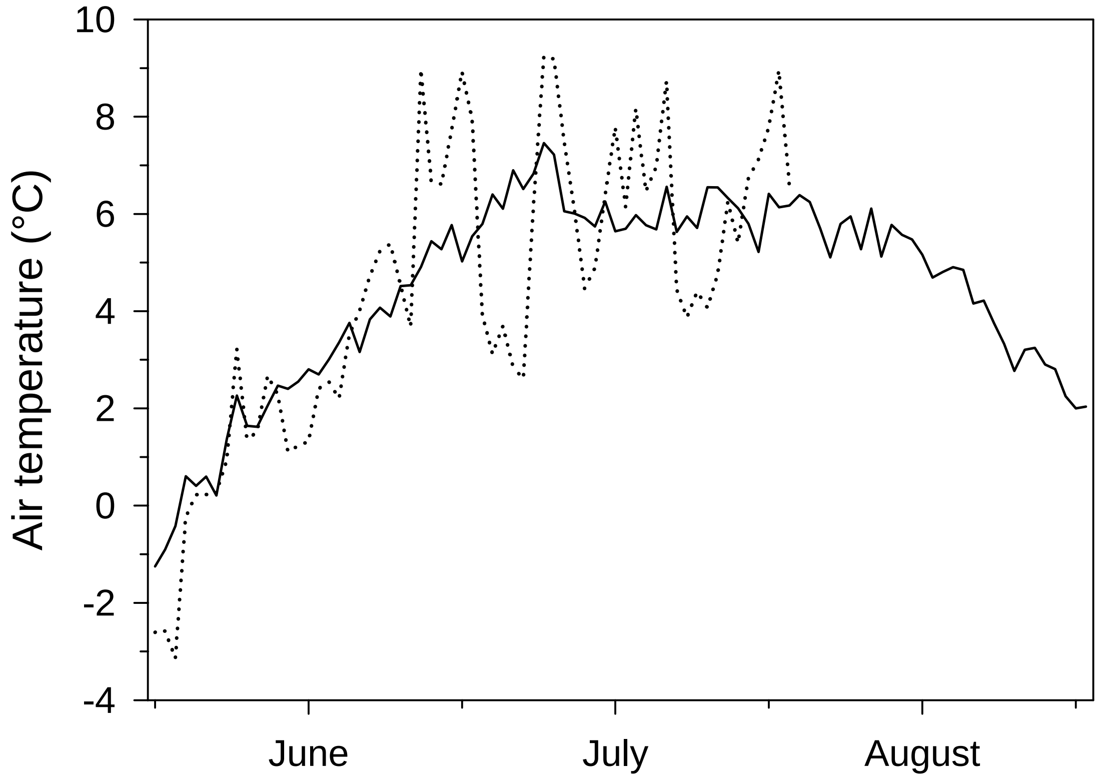


Figure 4. Average air temperature in the Qarlikturvik Valley lowlands of Bylot Island. The solid line shows the long-term average from 1 June to 31 August from 1994 to 2007 while the dotted line shows the average air temperature from 1 June to 2 August 2007.

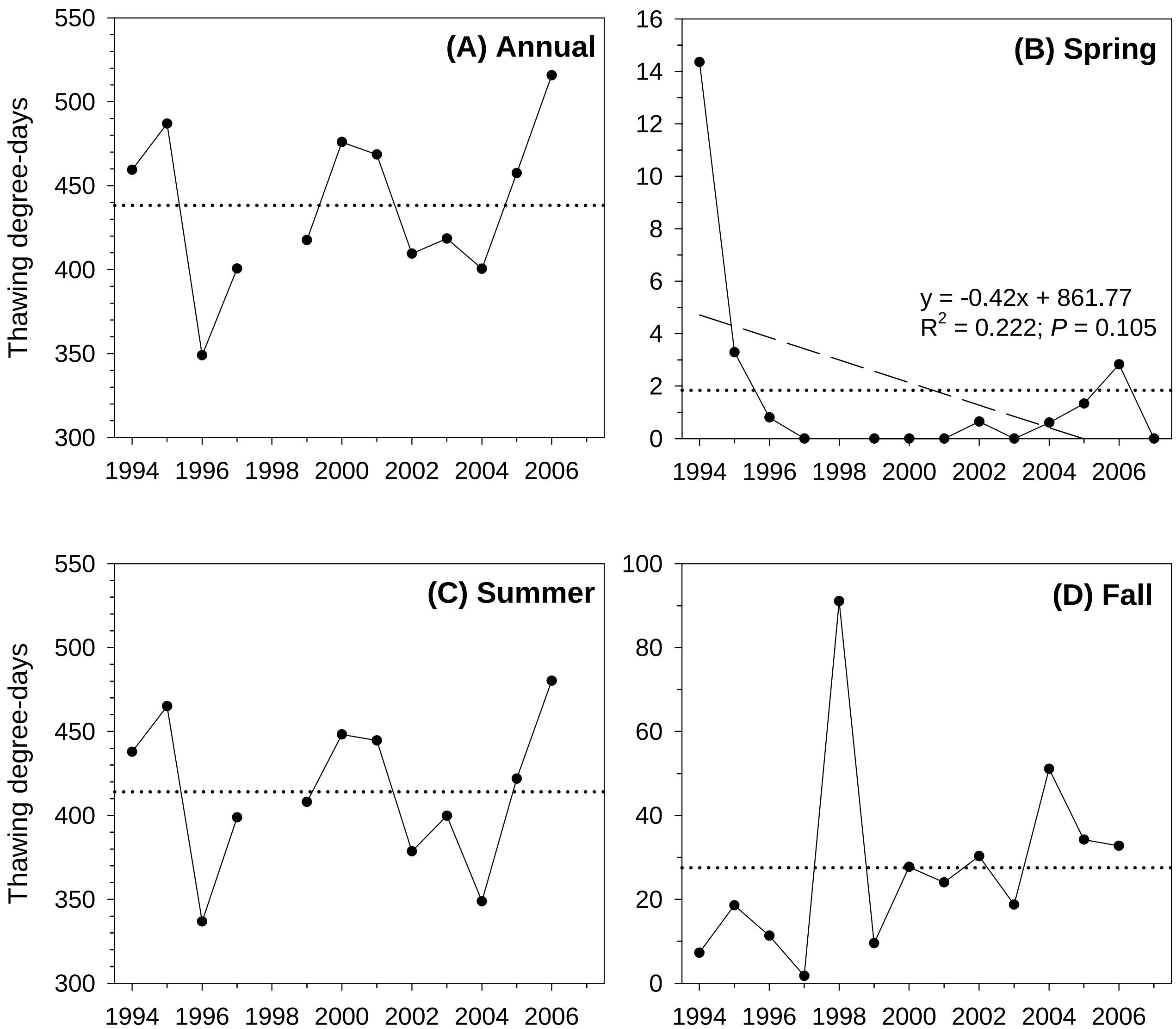


Figure 5. Number of thawing degree-days in the Qarlikturvik Valley lowlands of Bylot Island from 1994 to 2007 for (A) entire year, (B) spring (March to May), (C), summer (June to August) and (D) fall (September to November). Temporal trends are represented by a dashed line when approaching significance ($0.05 < P < 0.15$). The dotted line shows the mean for the whole period.

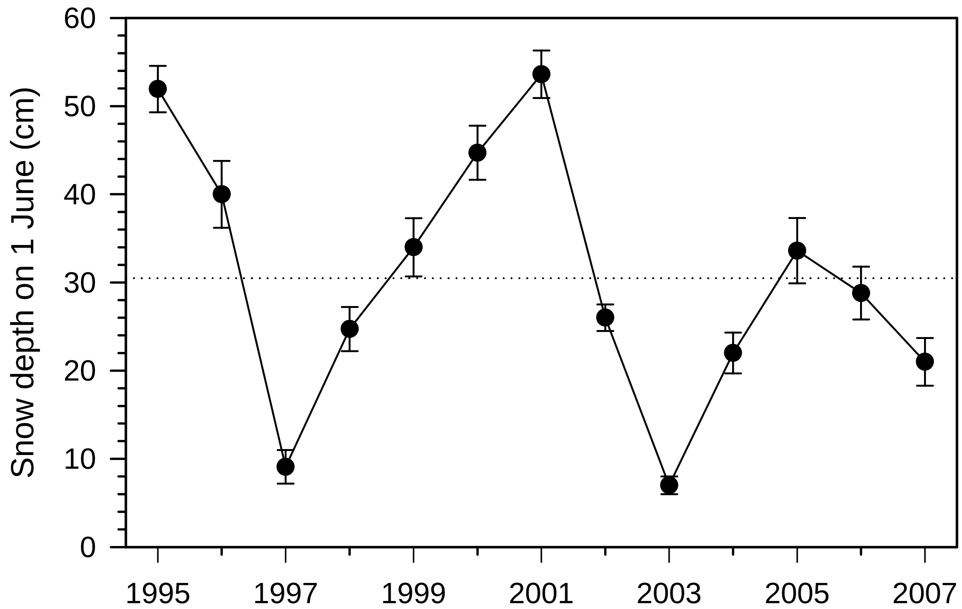


Figure 6. Average snow depth (mean ± SE) on the ground on 1 June in the Qarlikturvik Valley lowlands of Bylot Island from 1995 to 2007. The dotted line shows the mean for the whole period.

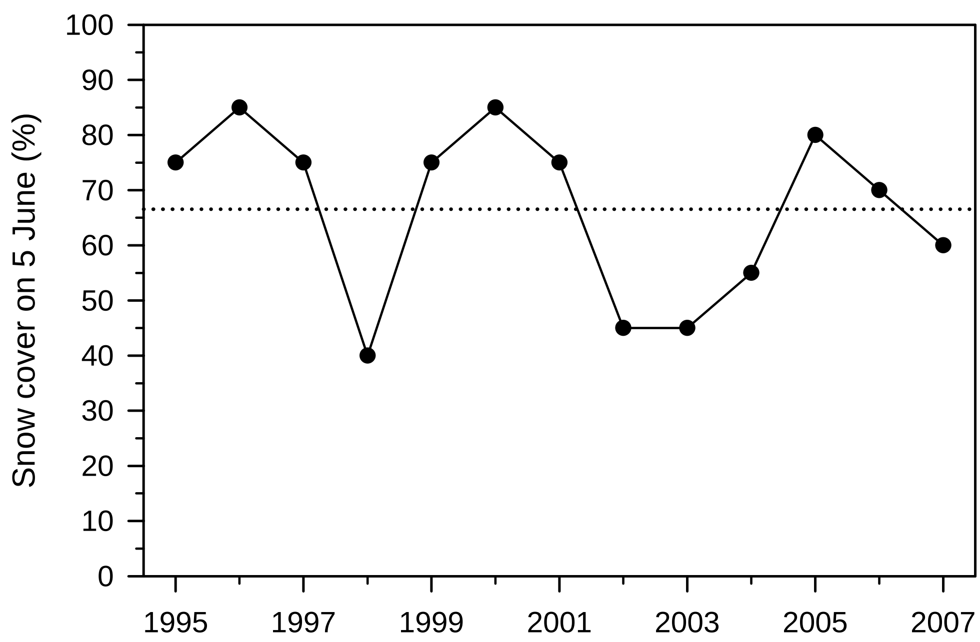


Figure 7. Average percentage of snow cover on the ground on 5 June in the Qarlikturvik Valley lowlands of Bylot Island from 1995 to 2007. The dotted line shows the mean for the whole period.

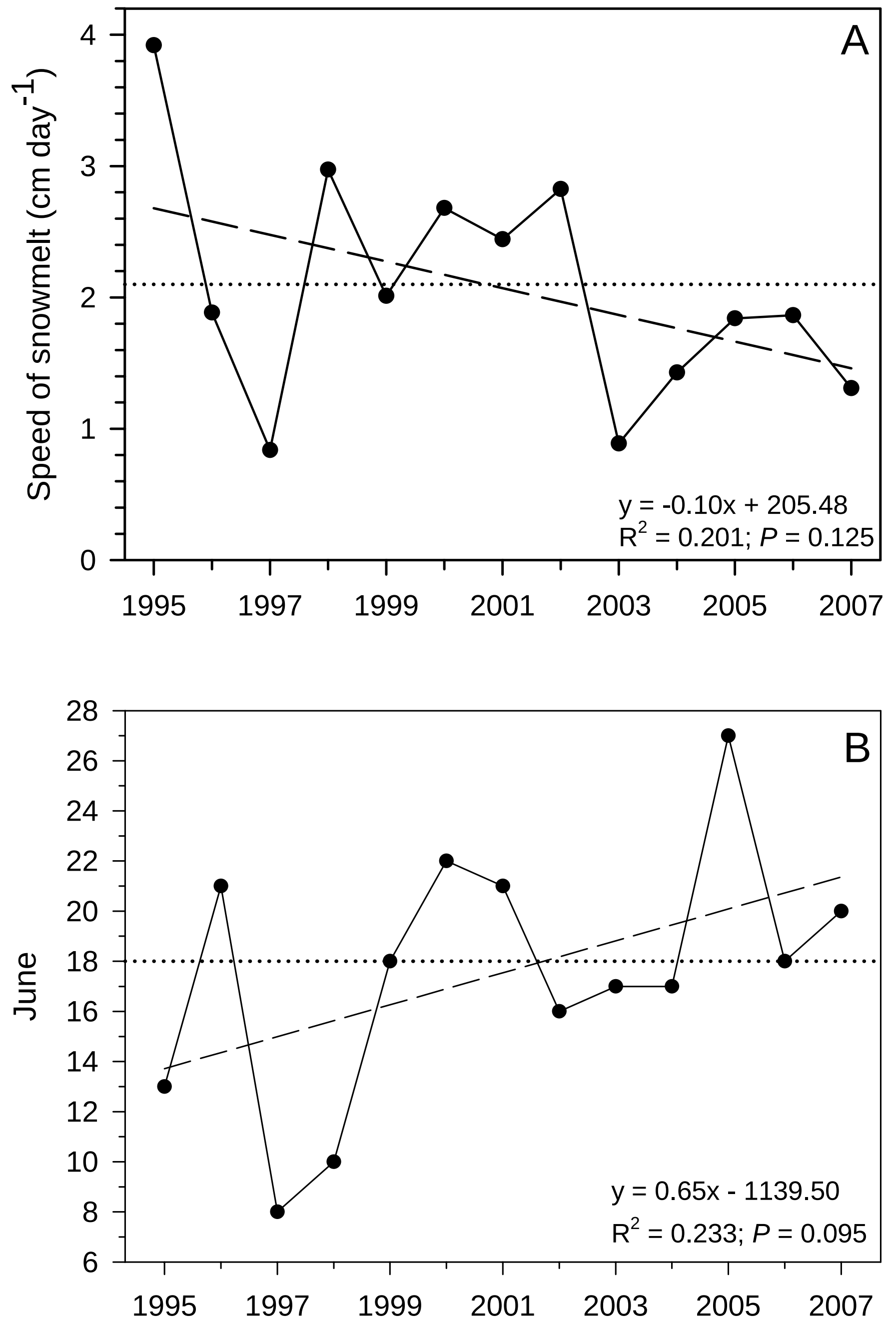


Figure 8. (A) Average speed of snowmelt in early June and (B) date of the end of snowmelt (>95% of the area snow-free) in the Qarlikturvik Valley of Bylot Island from 1995 to 2007. The temporal trend is represented by a dashed line when approaching significance ($0.05 < P < 0.15$). The dotted line shows the mean for the whole period.

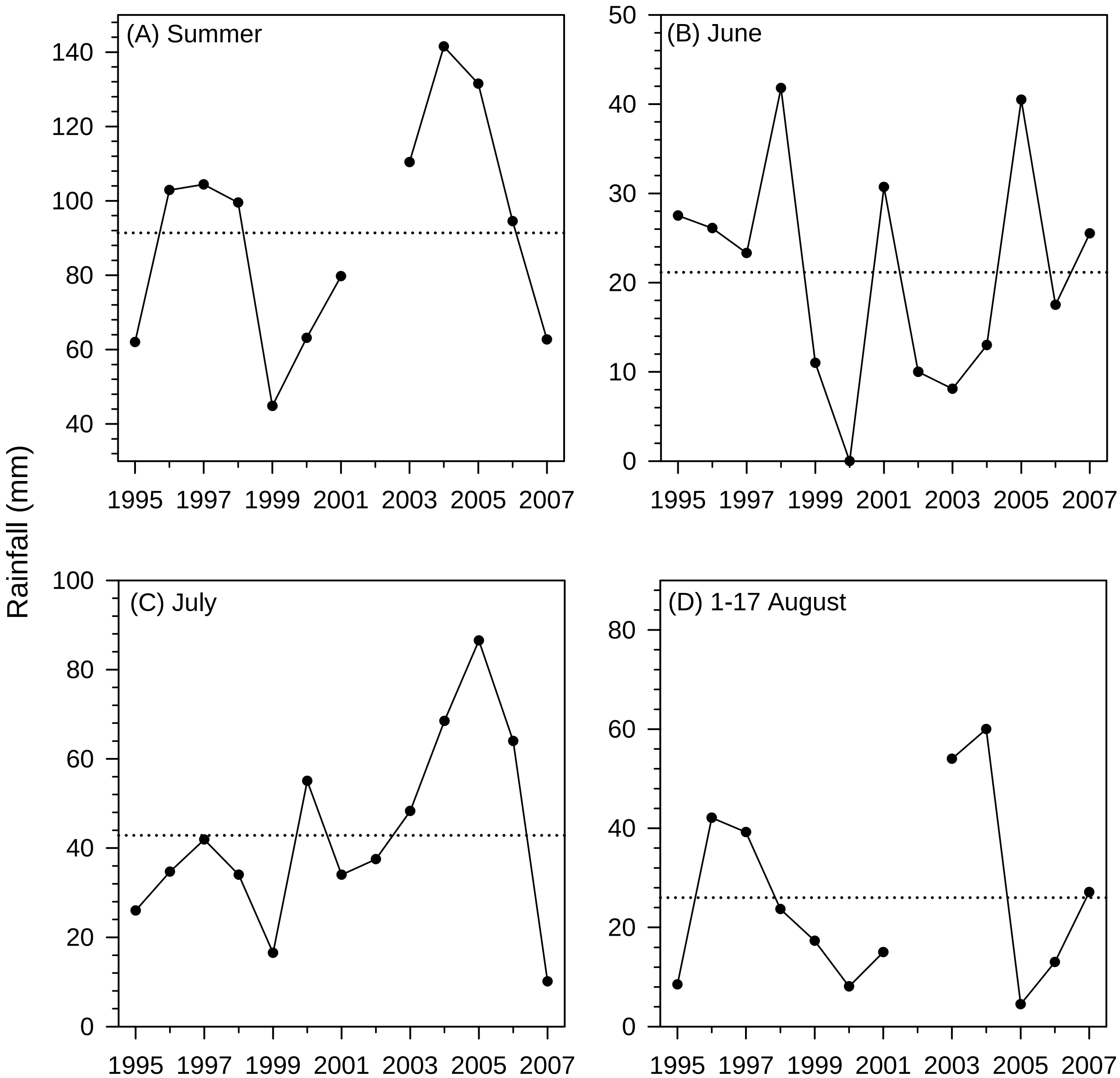


Figure 9. Average summer and monthly rainfall in the Qarlikturvik Valley lowlands of Bylot Island from 1995 to 2007 for (A) summer (1 June to 17 August), (B) June, (C) July and (D) August (1-17). The dotted line shows the mean for the whole period.

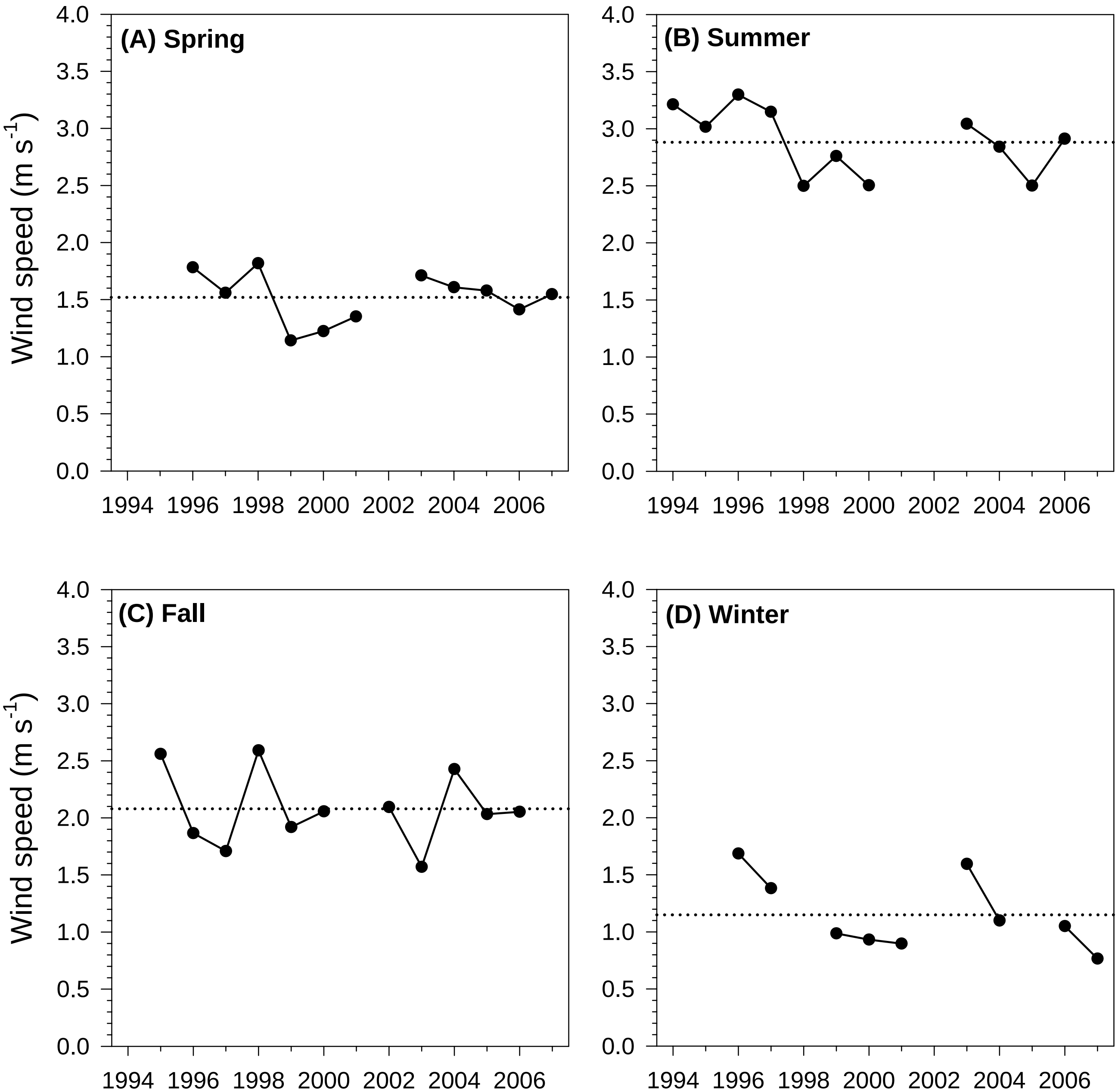


Figure 10. Average wind speed in the Qarlikturvik Valley lowlands of Bylot Island, from 1994 to 2007 for (A) spring (March to May), (B) summer (June to August), (C) fall (September to November) and (D) winter (December to February). The dotted line shows the mean for the whole period.

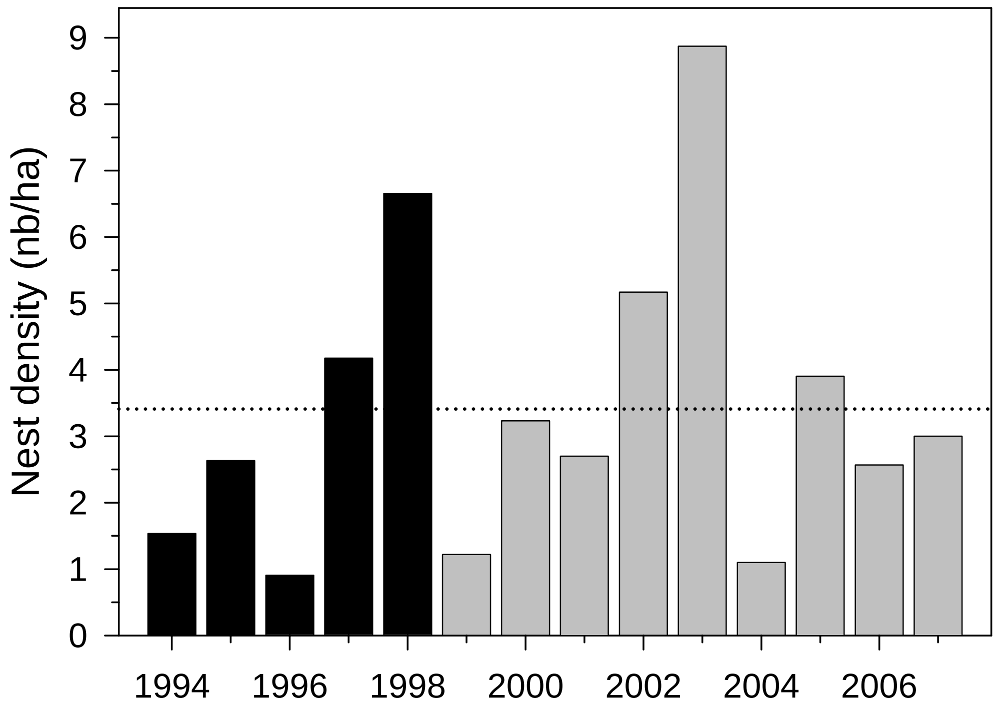


Figure 11. Nest density of Greater Snow Geese at the nesting goose colony on Bylot Island from 1994 to 2007. Grey columns represents years during which a spring conservation harvest occurred in Quebec. The dotted line shows the mean for the whole period.

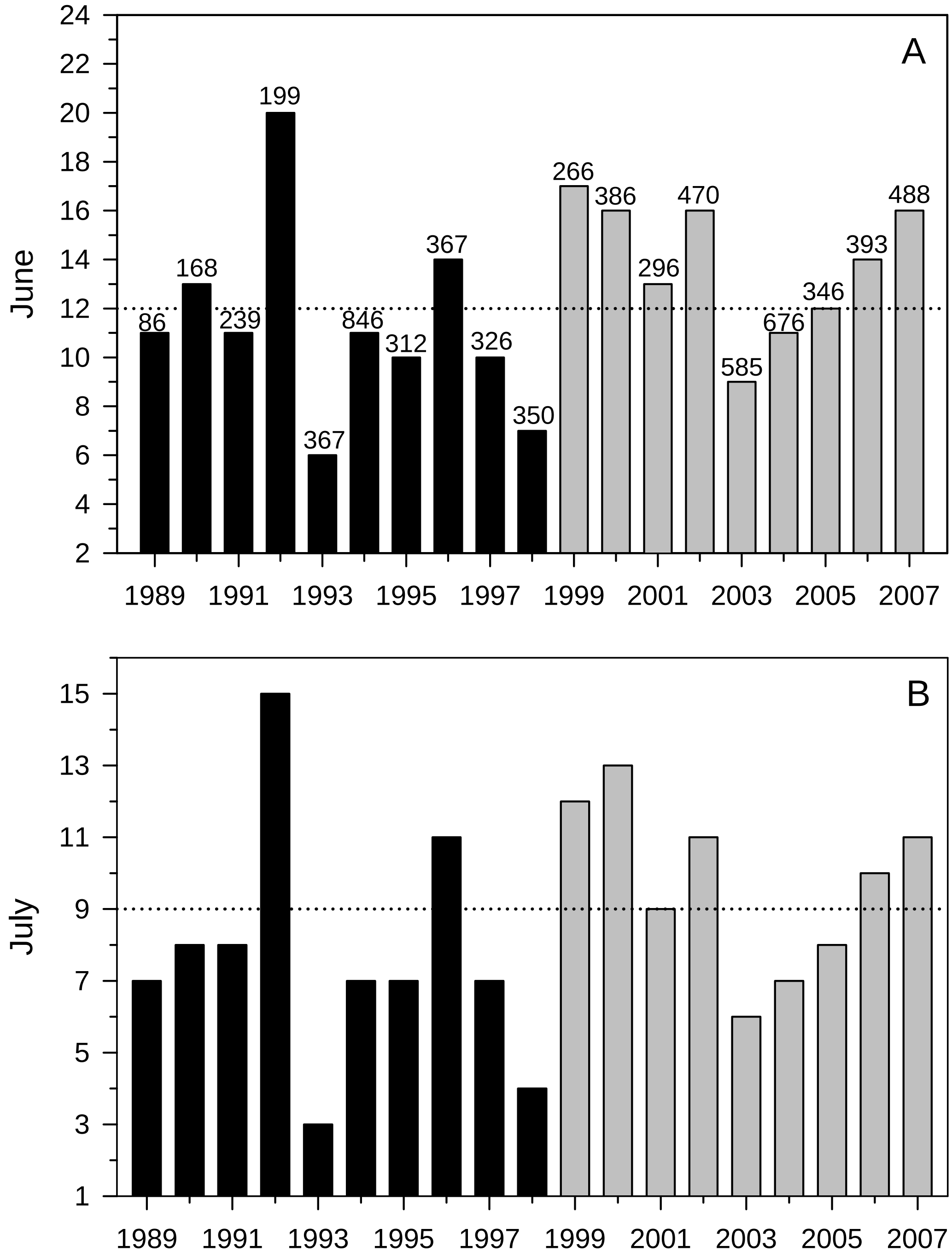


Figure 12. Median annual (A) egg-laying dates and (B) egg-hatching dates of Greater Snow Geese on Bylot Island from 1989 to 2007. Grey columns represents years during which a spring conservation harvest occurred in Quebec. The dotted line shows the mean for the whole period. Numbers on top of bars in panel A indicate the number of nests monitored each year.

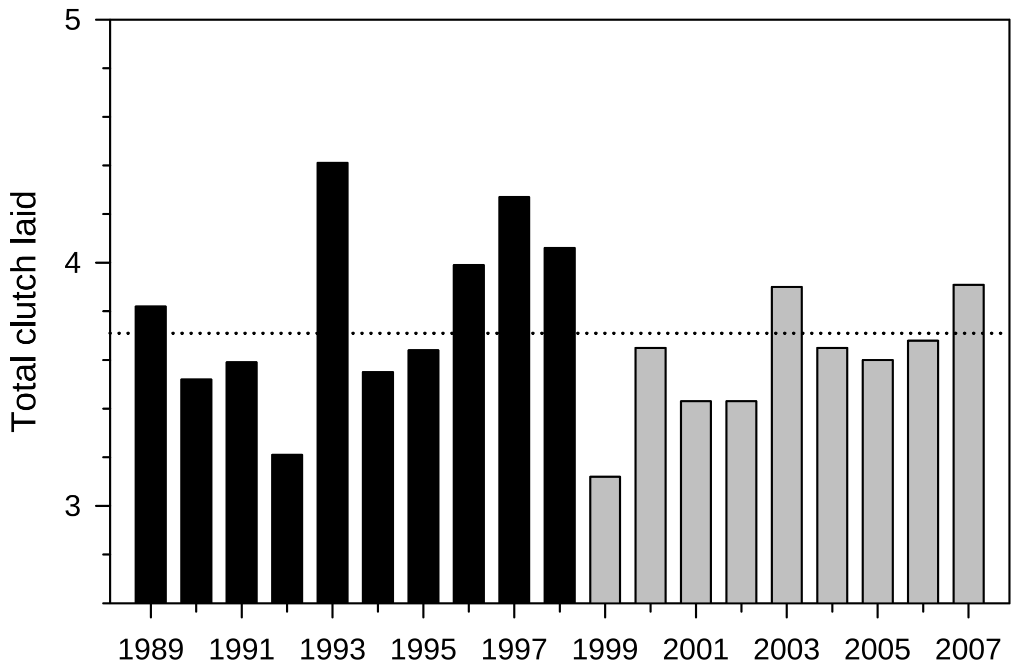


Figure 13. Annual total clutch laid of Greater Snow Geese on Bylot Island from 1989 to 2007. Grey columns represents years during which a spring conservation harvest occurred in Quebec. The dotted line shows the mean for the whole period.

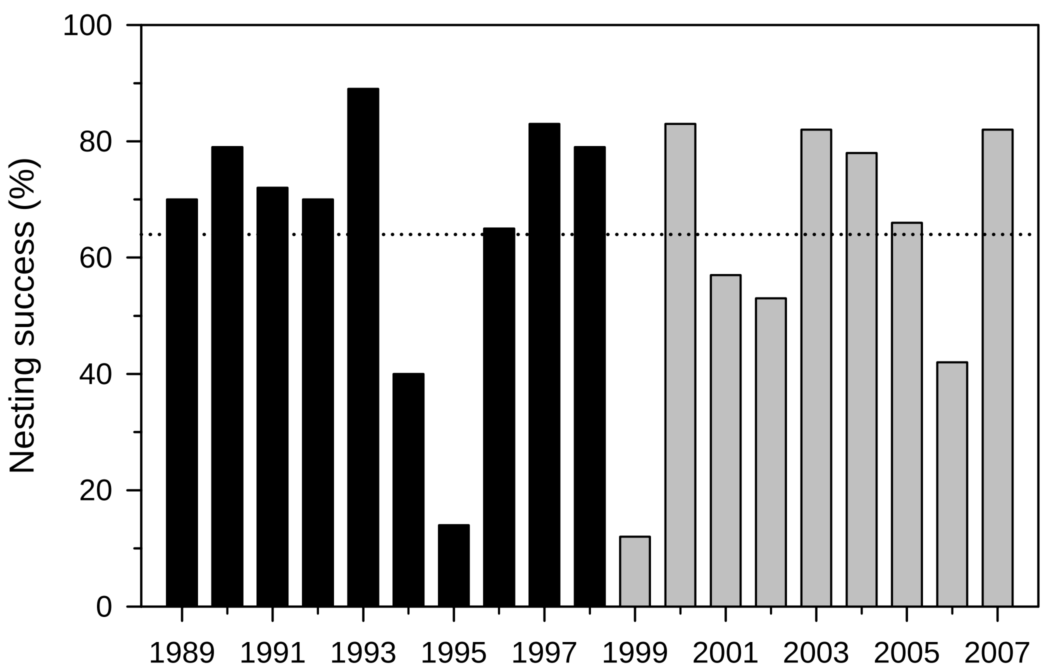


Figure 14. Annual nesting success (percentage of nests where at least one egg hatched) of Greater Snow Geese on Bylot Island from 1989 to 2007. Grey columns represents years during which a spring conservation harvest occurred in Quebec. The dotted line shows the mean for the whole period.

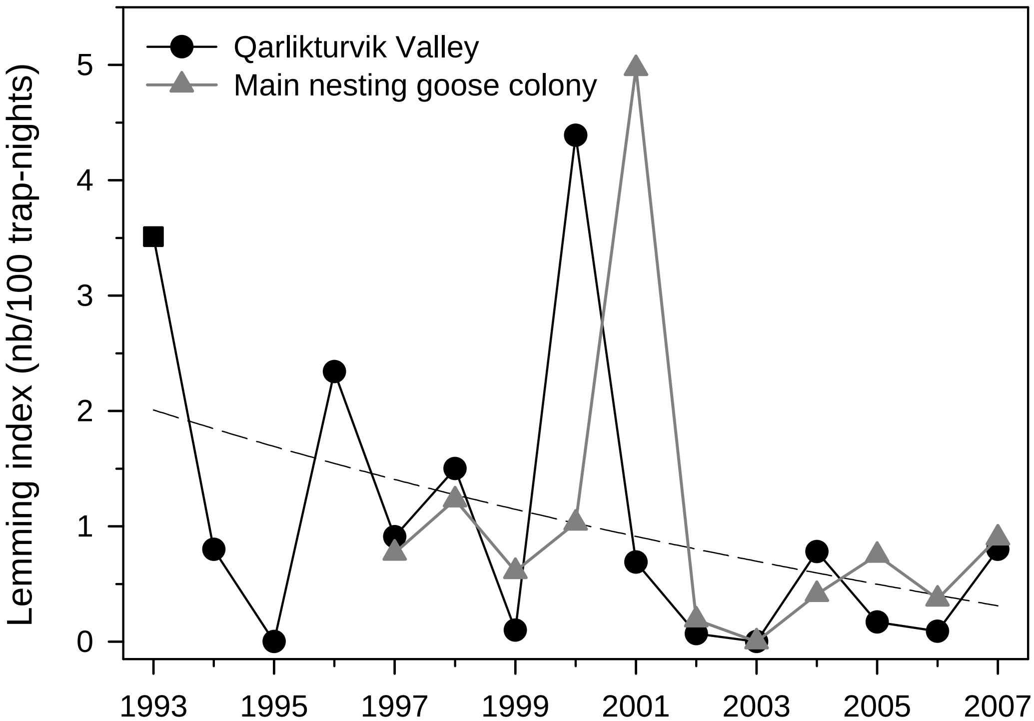
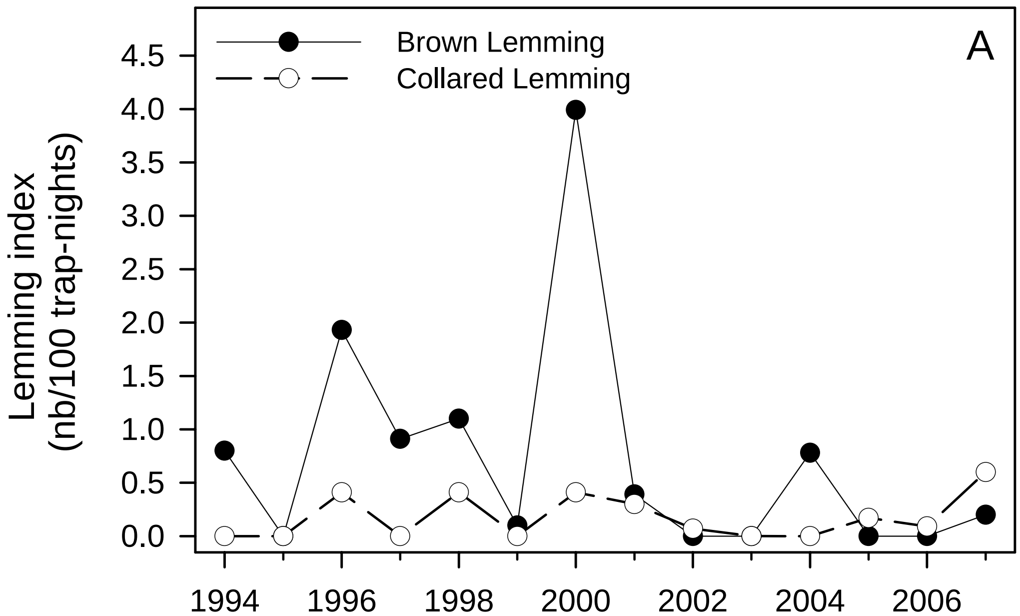


Figure 15. Index of total lemming abundance (number caught per 100 trap-nights) in the Qarlikturvik Valley and the main goose nesting colony of Bylot Island from 1993 to 2007. Although no lemmings were trapped in 1993, an estimate was derived based on a winter nest survey (see Gruyer 2007). The temporal trend is represented by a dashed line when approaching significance ($0.05 < P < 0.15$).



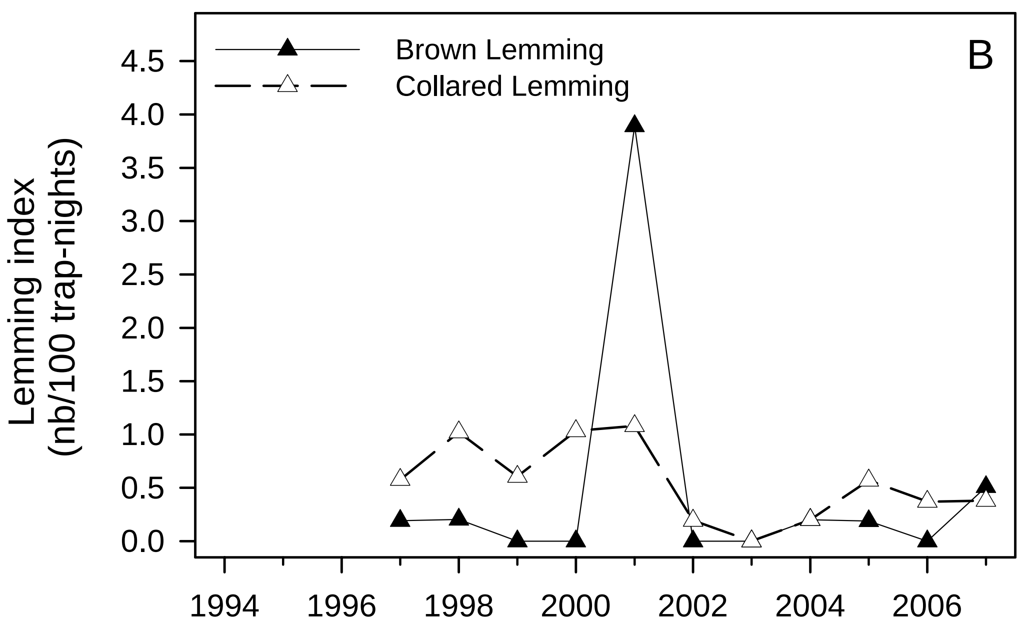


Figure 16. Index of Brown and Collared Lemmings abundance (number caught per 100 trap-nights) in (A) the Qarlikturvik Valley and (B) the main goose nesting colony of Bylot Island from 1994 to 2007.

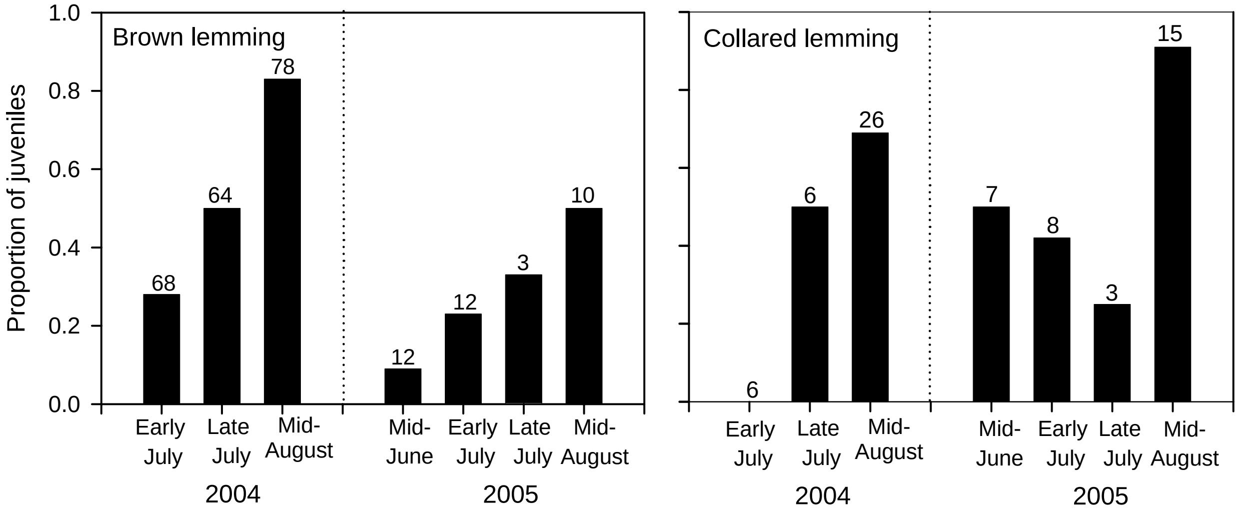


Figure 17. Proportion of juveniles among all individual Brown and Collared Lemmings trapped at different periods of the summer on Bylot Island in 2004 and 2005. Numbers above bars indicate sample size. The dotted vertical line separates years. From Gruyer (2007).

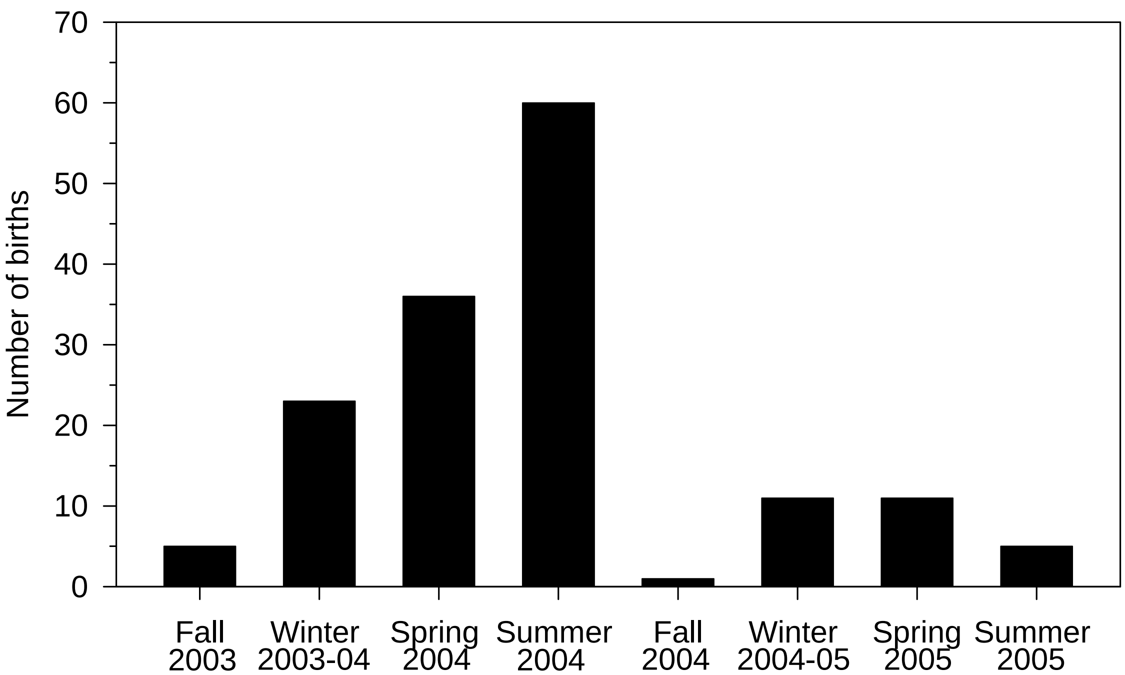


Figure 18. Distribution of inferred birth season of Brown Lemmings captured during the summers 2004 and 2005 on Bylot Island based on a relationship between body mass at capture and age determined with eye lens on a sample of dead individuals. Adapted from Gruyer (2007).

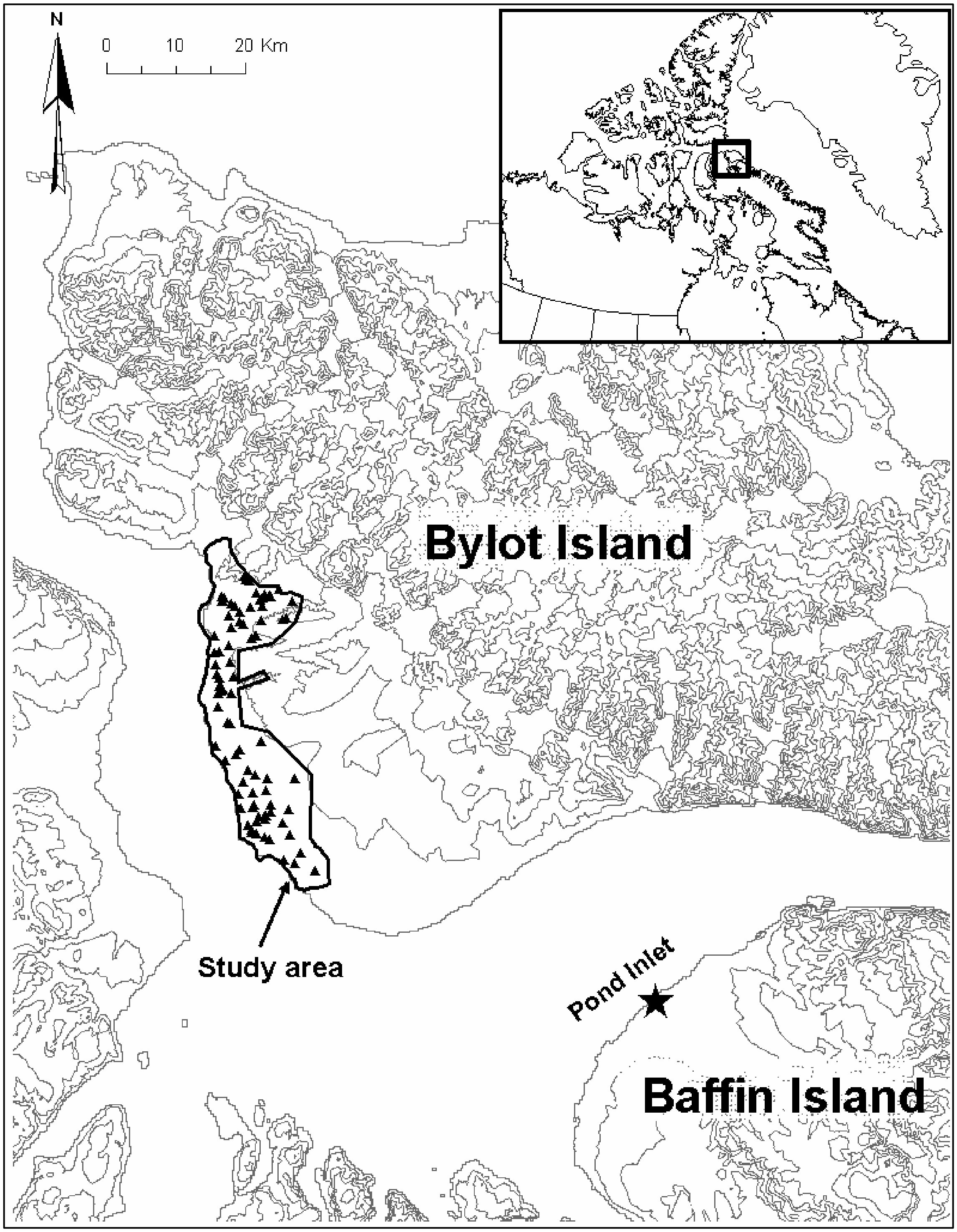


Figure 19. Area monitored for fox dens on Bylot Island (thick line) and location of dens (triangles). From Szor et al. (2008).

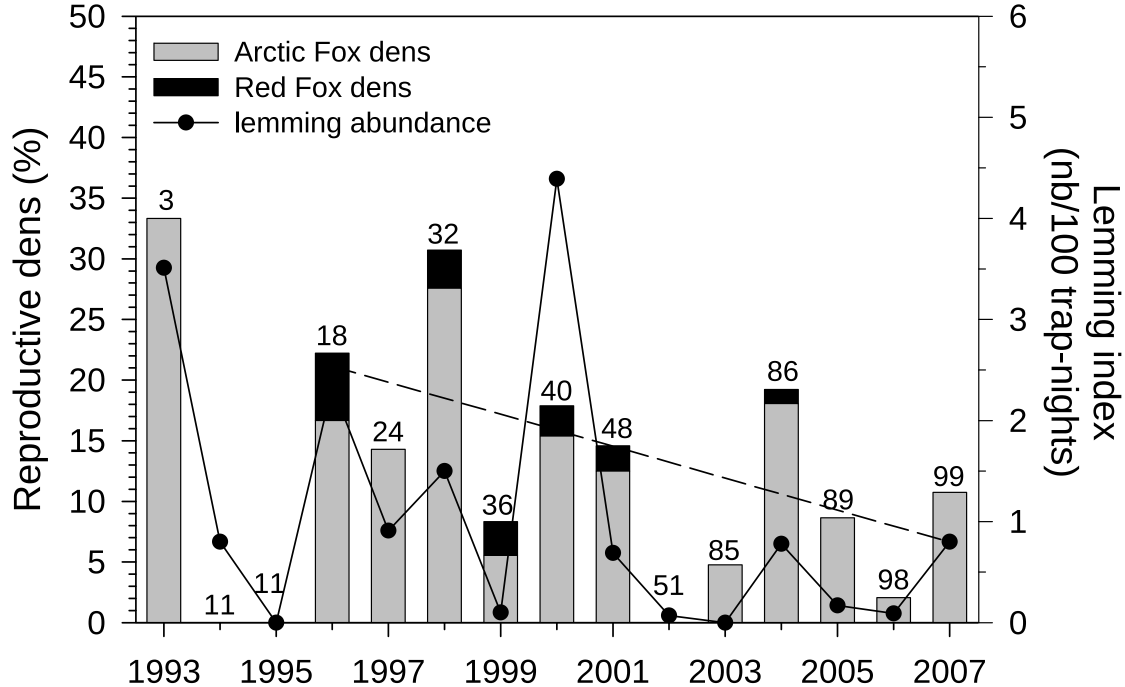


Figure 20. Annual percentage of Arctic and Red Fox dens with presence of pups (i.e. reproductive dens) on Bylot Island and index of total lemming abundance in the Qarlikturvik Valley from 1993 to 2007. Numbers on top of bars indicate the number of dens monitored each year. The temporal trend is represented by a dashed line when approaching significance ($0.05 < P < 0.15$).

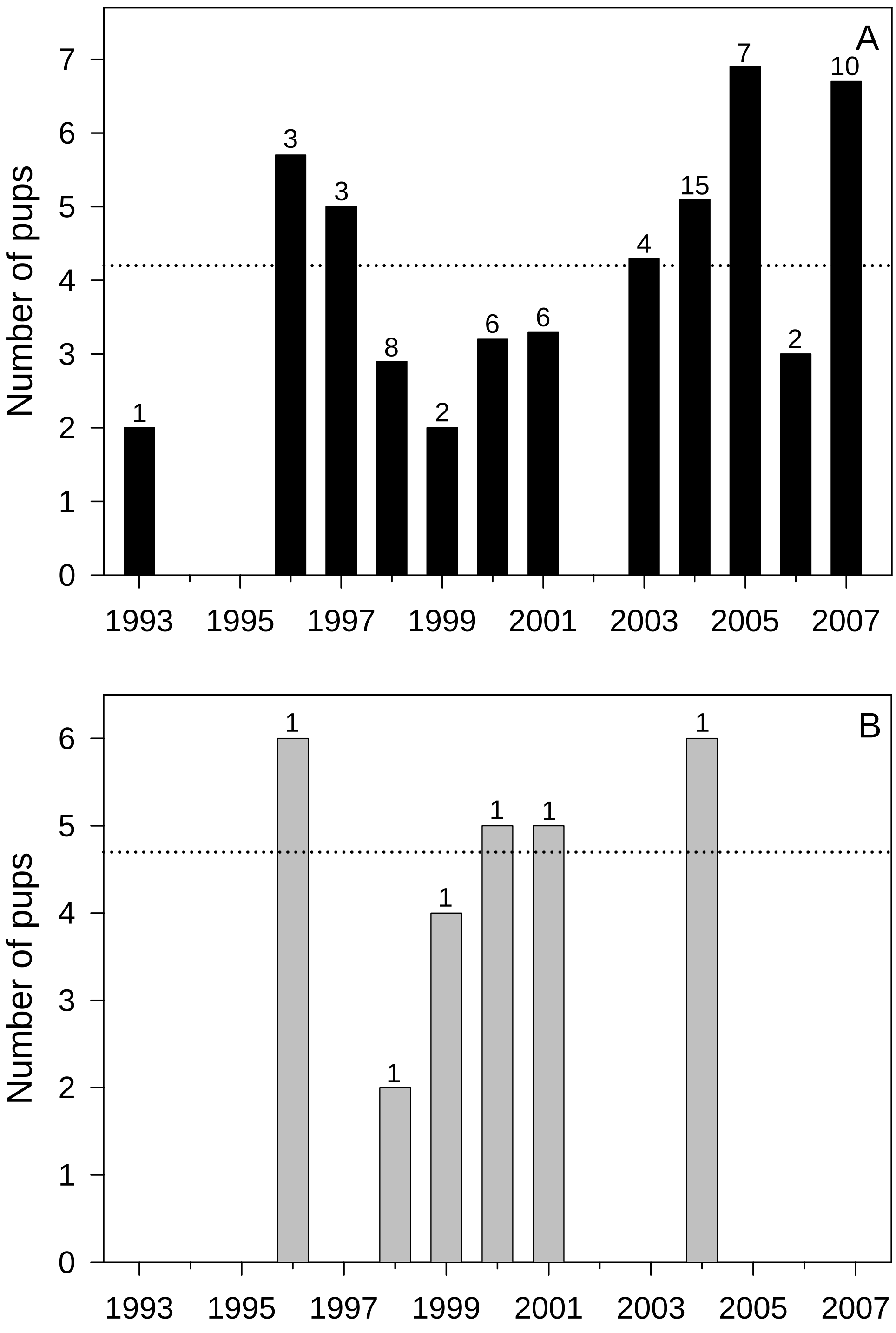


Figure 21. Average minimum litter size of (A) Arctic and (B) Red Foxes on Bylot Island from 1993 to 2007. The dotted line shows the mean for the whole period. Numbers on top of bars indicate the number of litters monitored each year.

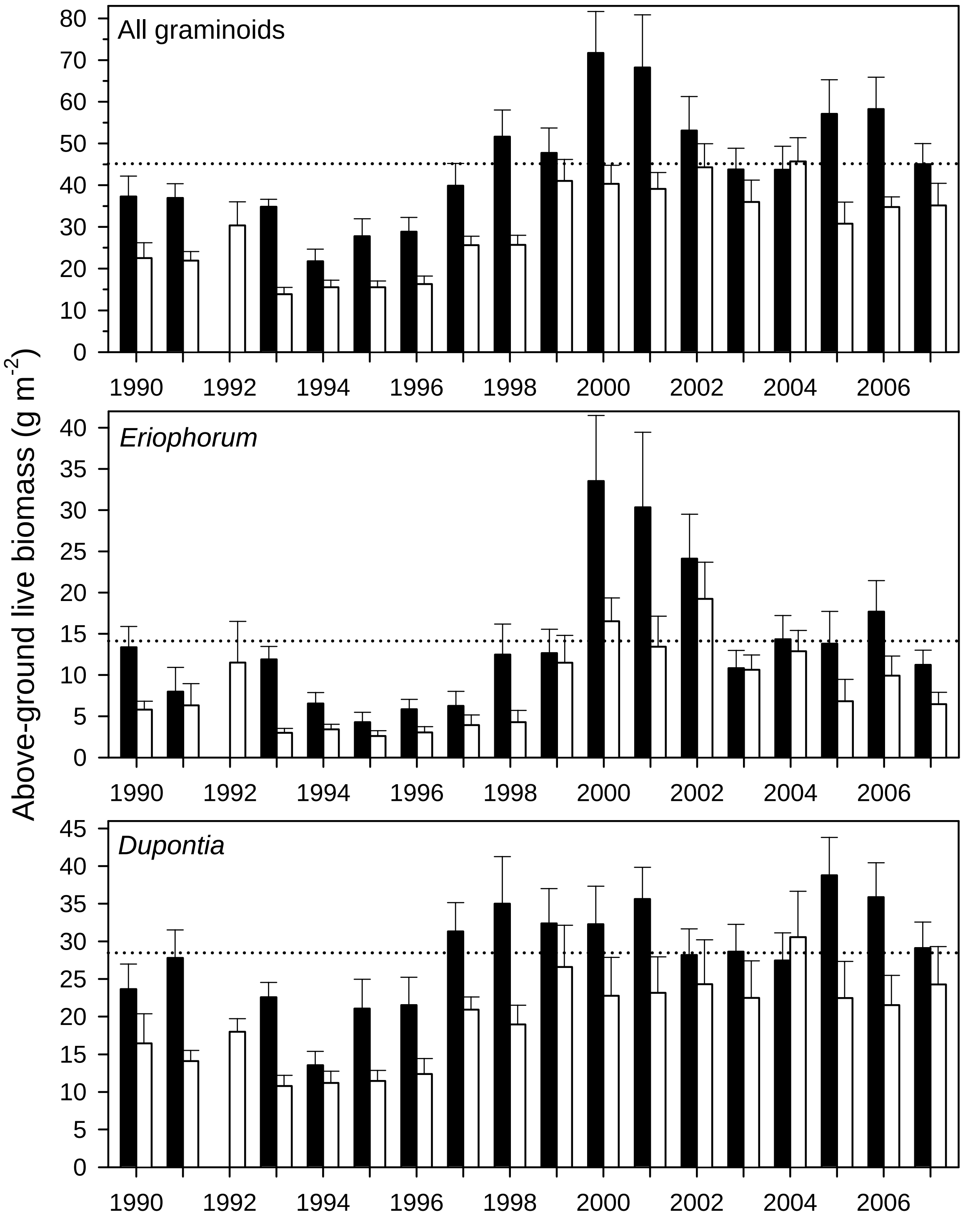


Figure 22. Live above-ground biomass (mean ± SE, dry mass) of (A) all graminoids, (B) *Eriophorum scheuchzeri* and (C) *Dupontia fisheri* in mid-August in grazed and ungrazed wet meadows of the Qarlikturvik Valley, Bylot Island, from 1990 to 2007 (n = 12 each year). There is no data from ungrazed area in 1992. The dotted line shows the mean plant production for the whole period.

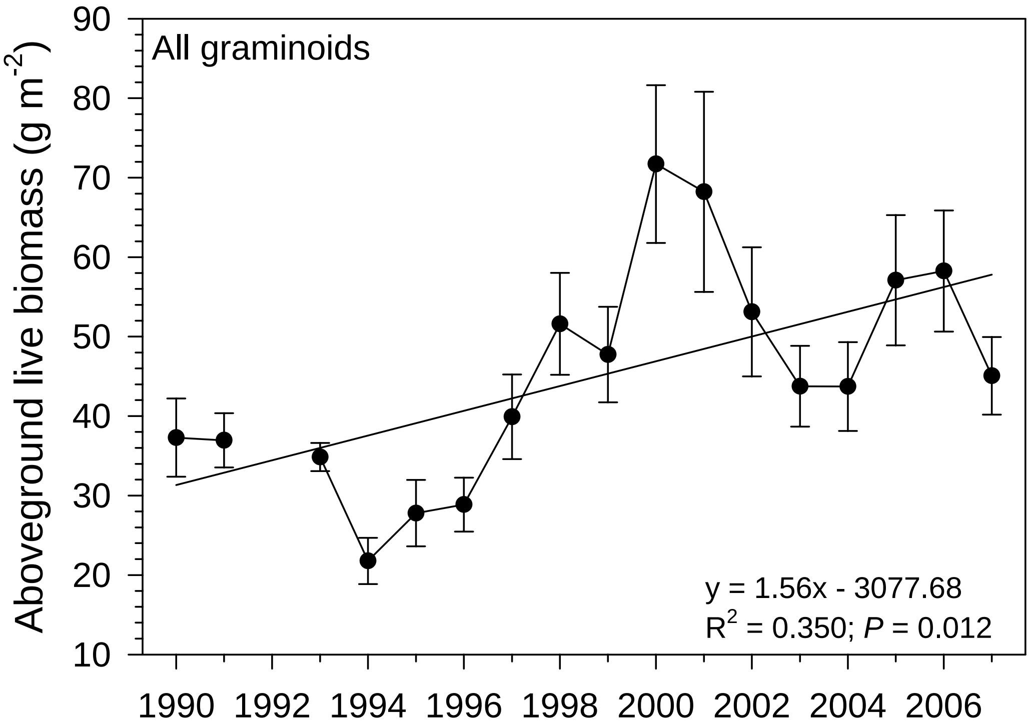


Figure 23. Trend in live above-ground biomass (mean ± SE, dry mass) of all graminoids in mid-August in ungrazed wet meadows of the Qarlikturvik Valley, Bylot Island, from 1990 to 2007 (n = 12 each year).

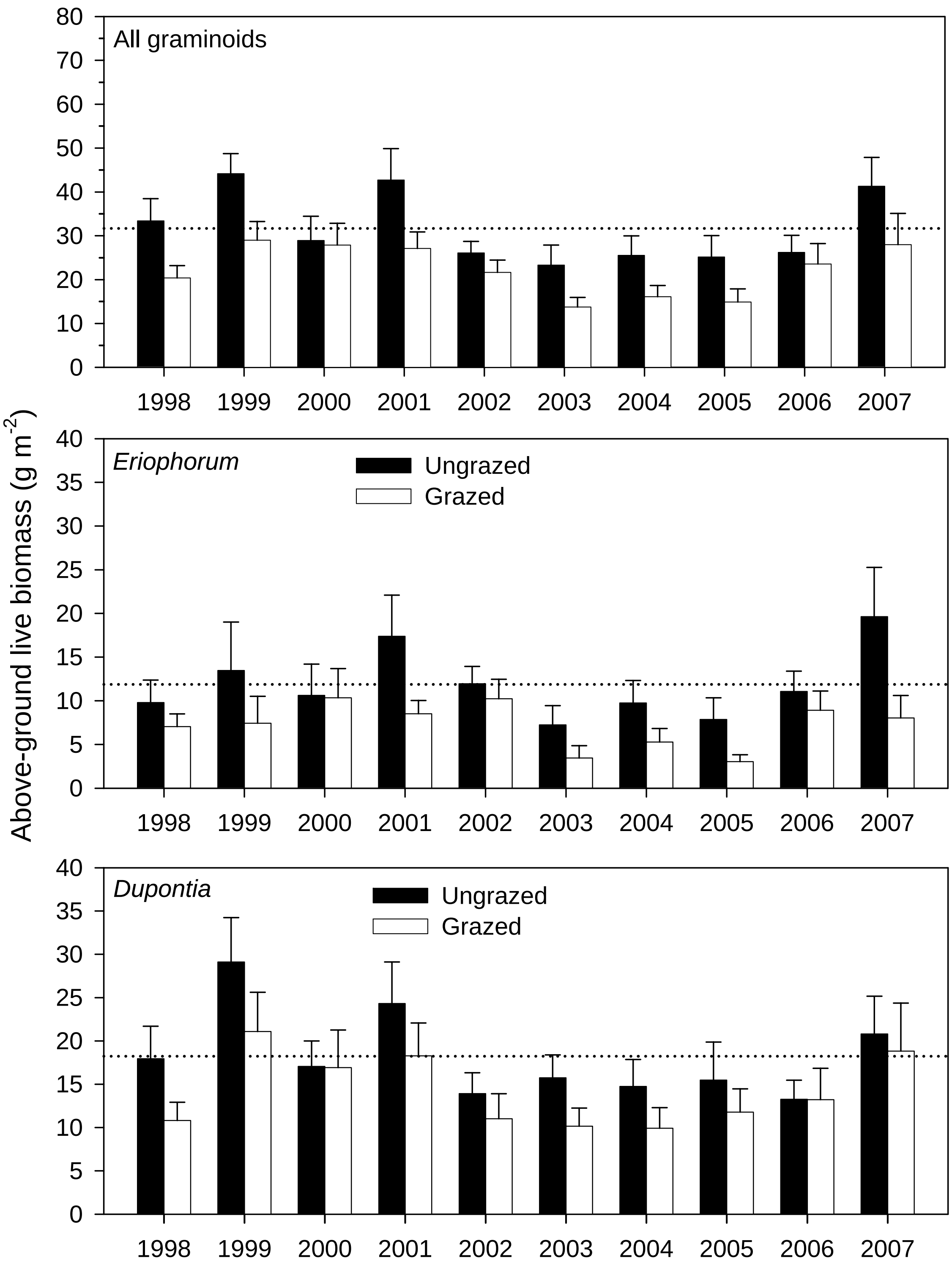


Figure 24. Live above-ground biomass (mean ± SE, dry mass) of (A) all graminoids (B) *Eriophorum scheuchzeri* and (C) *Dupontia fisheri* in mid-August in grazed and ungrazed wet meadows of the main nesting goose colony, Bylot Island, from 1998 to 2007 (n = 12 each year). The dotted line shows the mean plant production for the whole period.

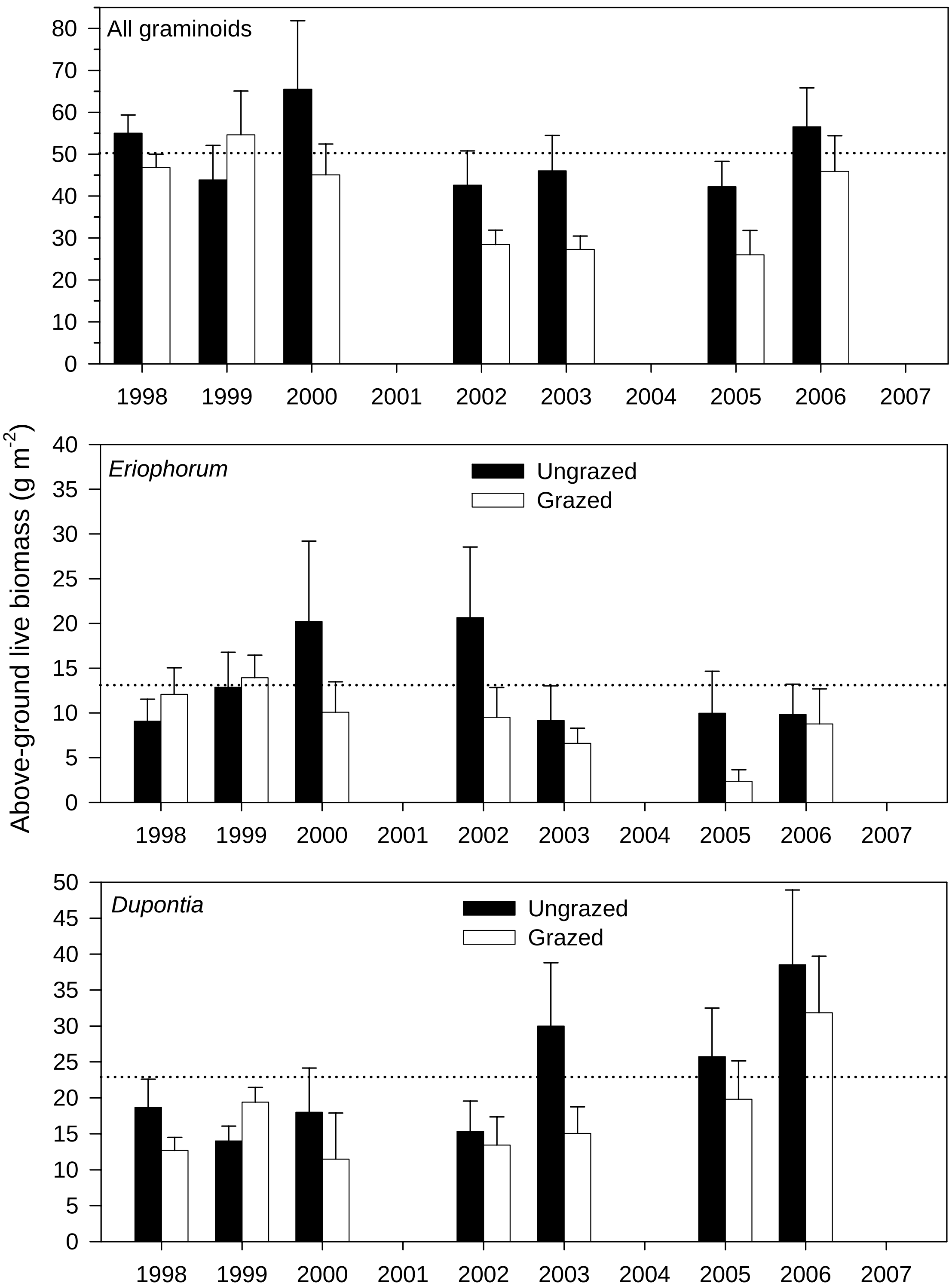


Figure 25. Live above-ground biomass (mean ± SE, dry mass) of (A) all graminoids (B) *Eriophorum scheuchzeri* and (C) *Dupontia fisheri* in mid-August in grazed and ungrazed wet meadows of Pointe Dufour, Bylot Island, from 1998 to 2007 (n = 12 each year). No sampling took place in 2001, 2004 and 2007. The dotted line shows the mean plant production for the whole period.

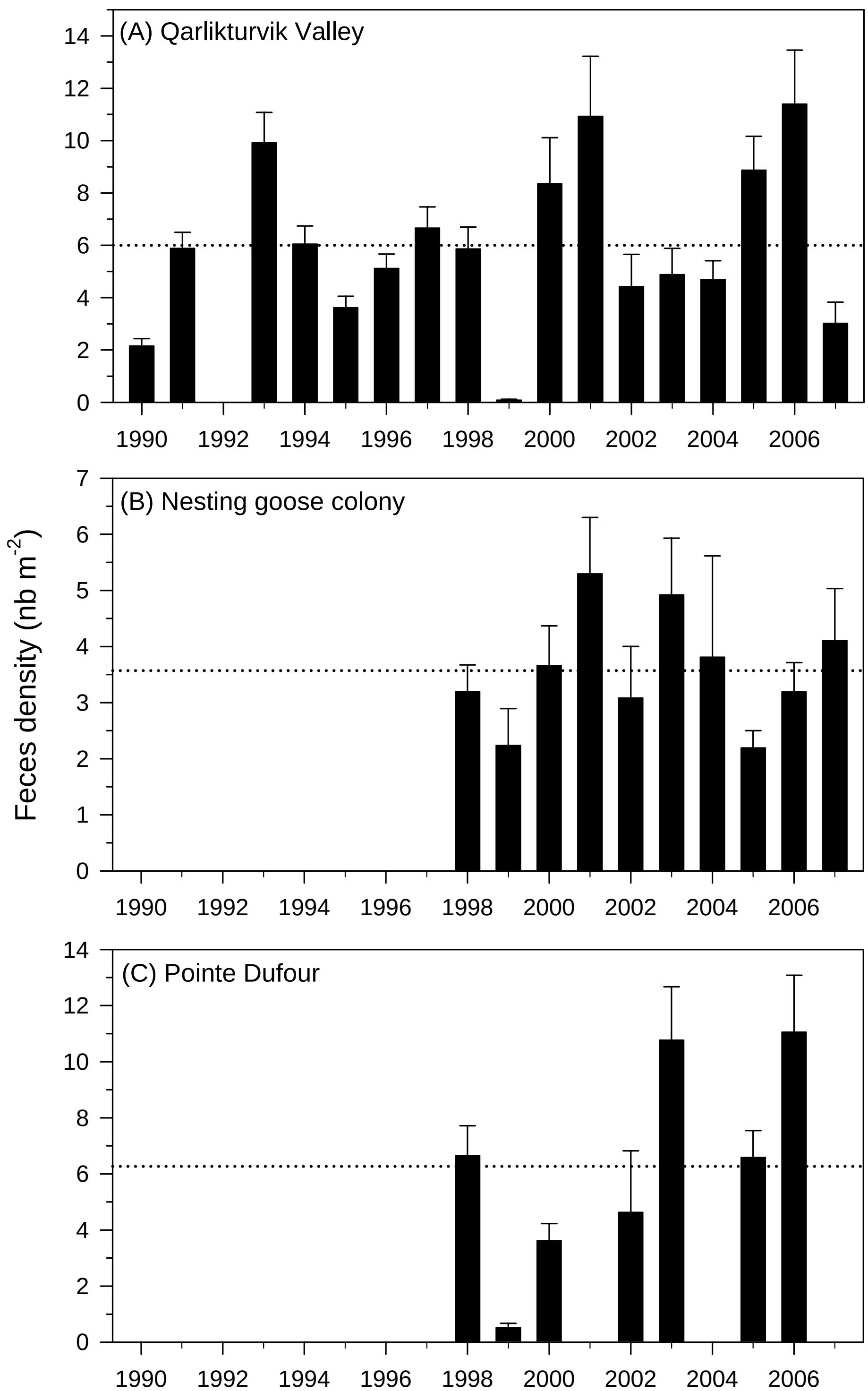


Figure 26. Annual cumulative feces density (mean ± SE) showing the use of wetlands by Greater Snow Geese in (A) the Qarlikturvik Valley, (B) the nesting goose colony and (C) at Pointe Dufour during the summer on Bylot Island, from 1990 to 2007 (n = 12 transects of 1 × 10 m each year). No sampling took place in 1992 in the Qarlikturvik Valley and before 1998 at the nesting goose colony and Pointe Dufour as well as in 2001, 2004 and 2007 at Pointe Dufour. The dotted line shows the average feces density for the whole period.

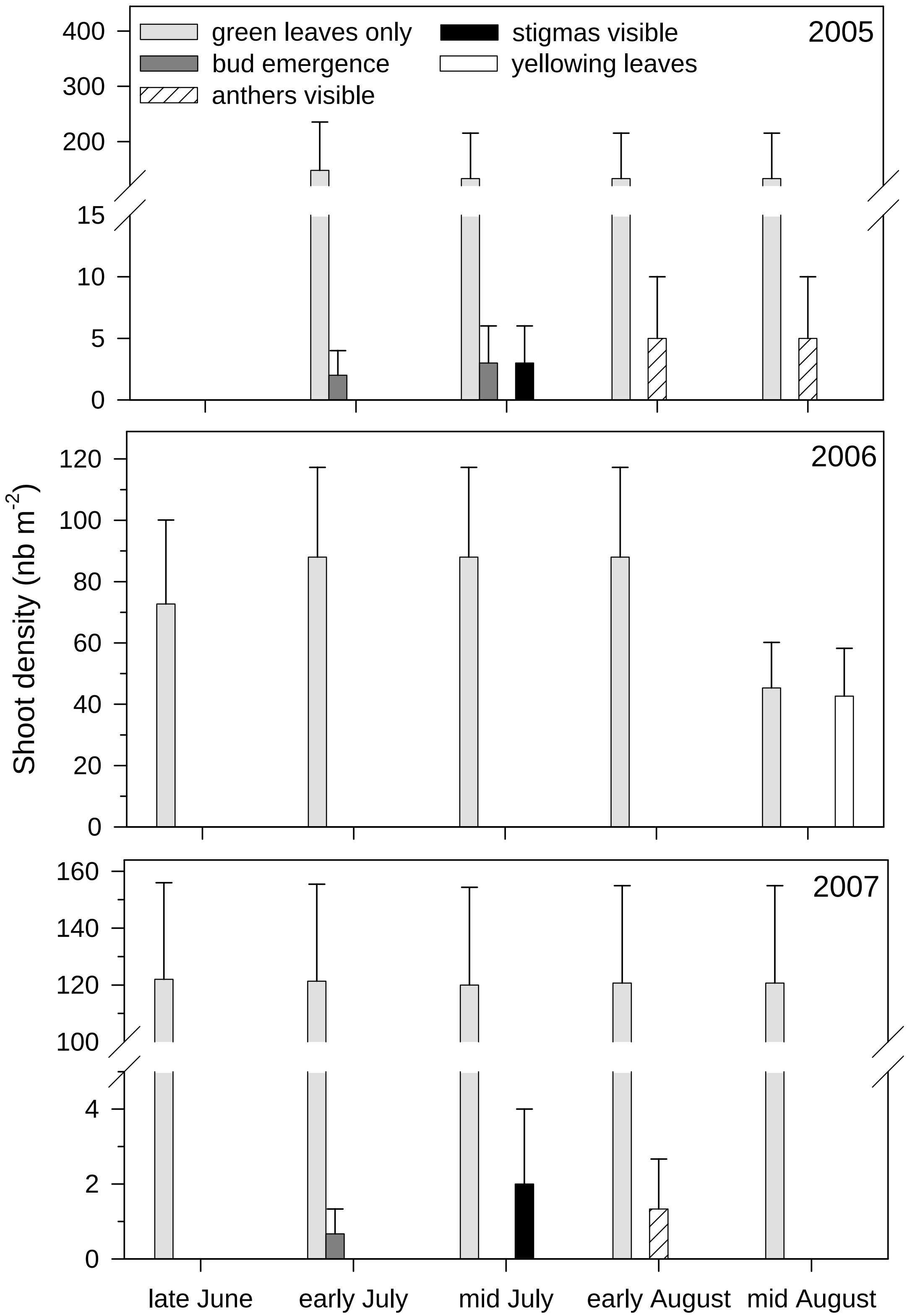


Figure 27. Plant phenology of *Carex aquatilis* (mean ± SE) in ungrazed wet meadows of the Qarlikturvik Valley, Bylot Island, from 2005 to 2007 (n = 12 for each sampling date). No sampling occurred in late June 2005.

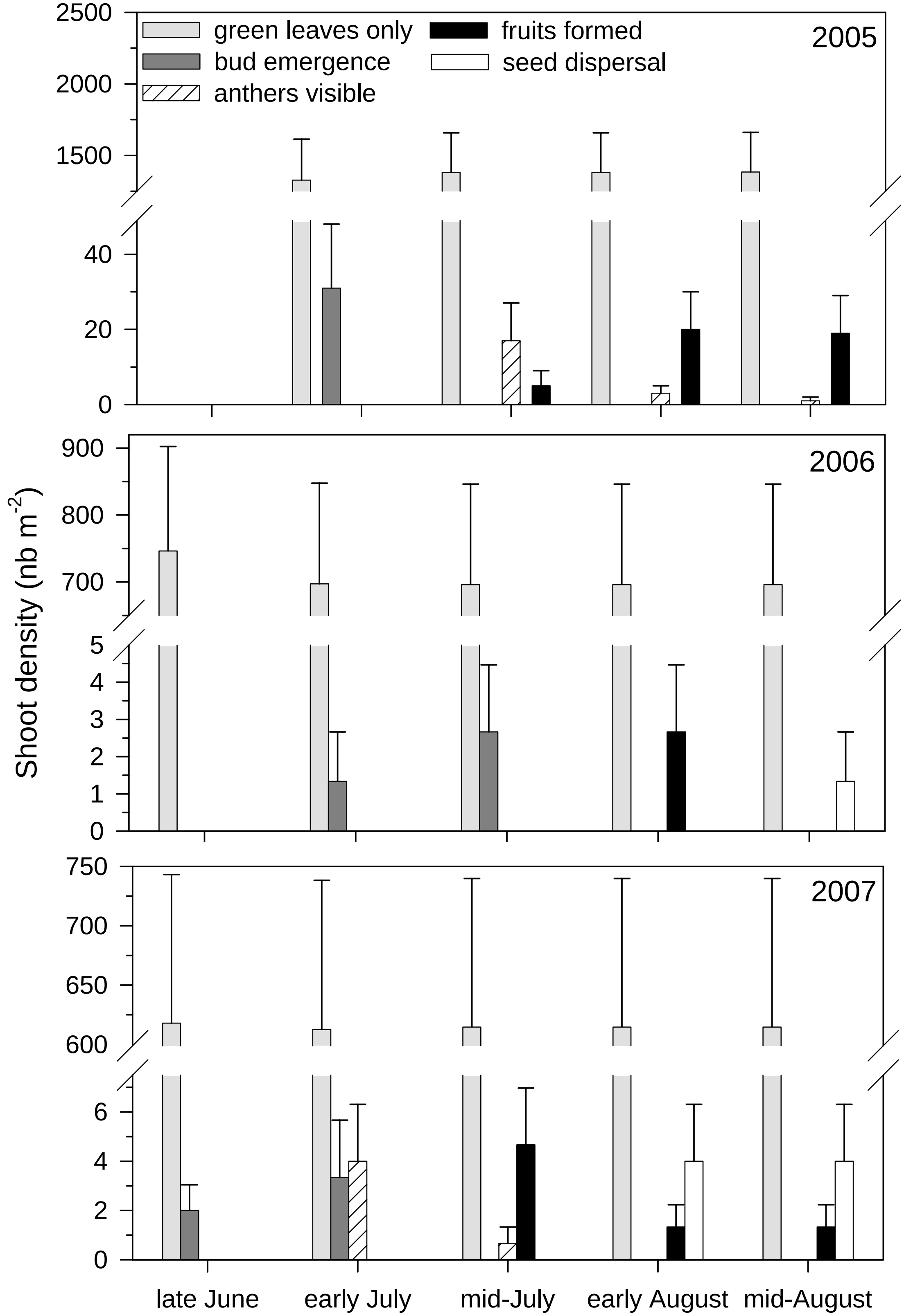


Figure 28. Plant phenology of *Eriophorum scheuchzeri* (mean ± SE) in ungrazed wet meadows of the Qarlikturvik Valley, Bylot Island, from 2005 to 2007 (*n* = 12 for each sampling date). No sampling occurred in late June 2005.

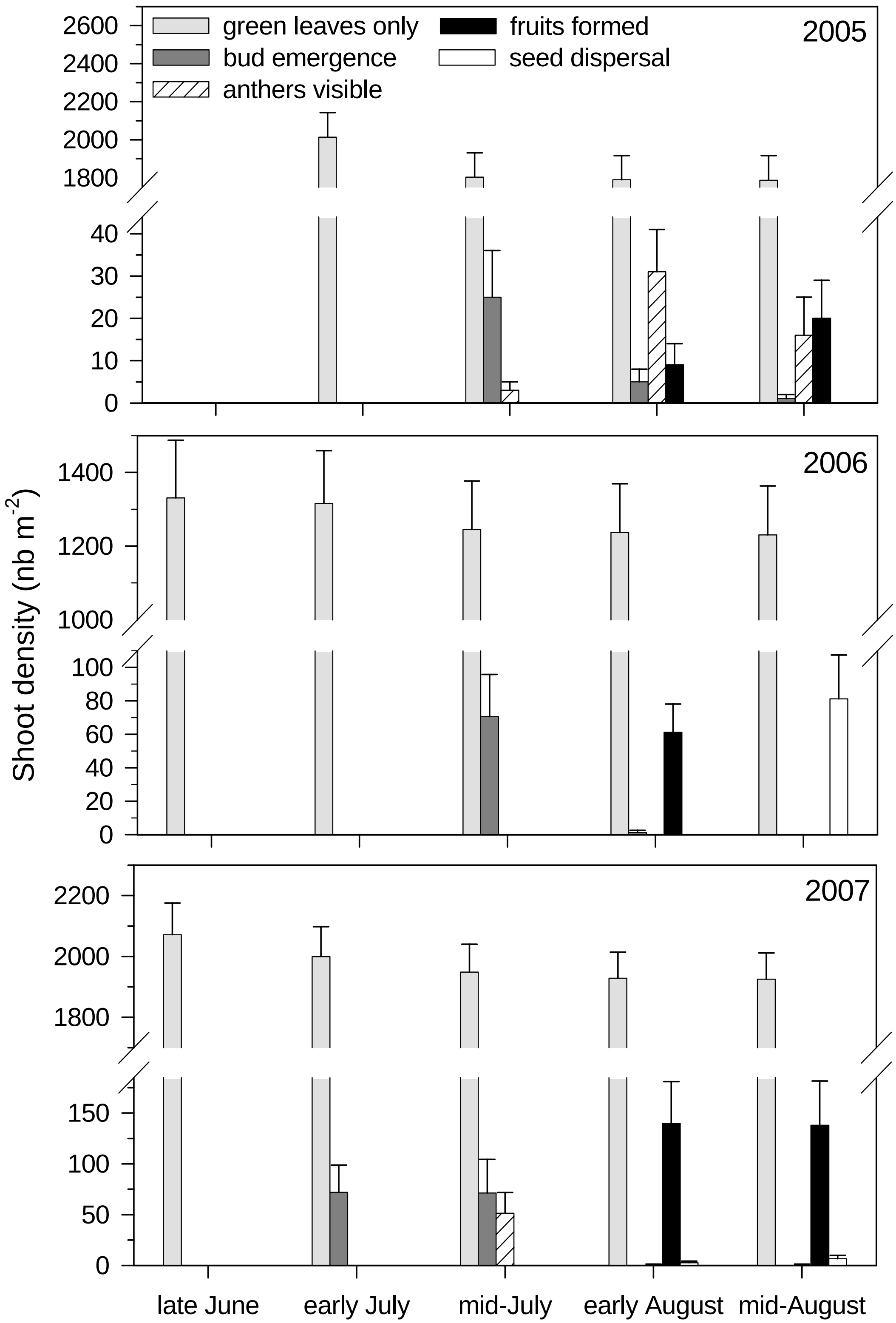


Figure 29. Plant phenology of *Dupontia fisheri* (mean ± SE) in ungrazed wet meadows of the Qarlikturvik Valley, Bylot Island, from 2005 to 2007 (*n* = 12 for each sampling date). No sampling occurred in late June 2005.

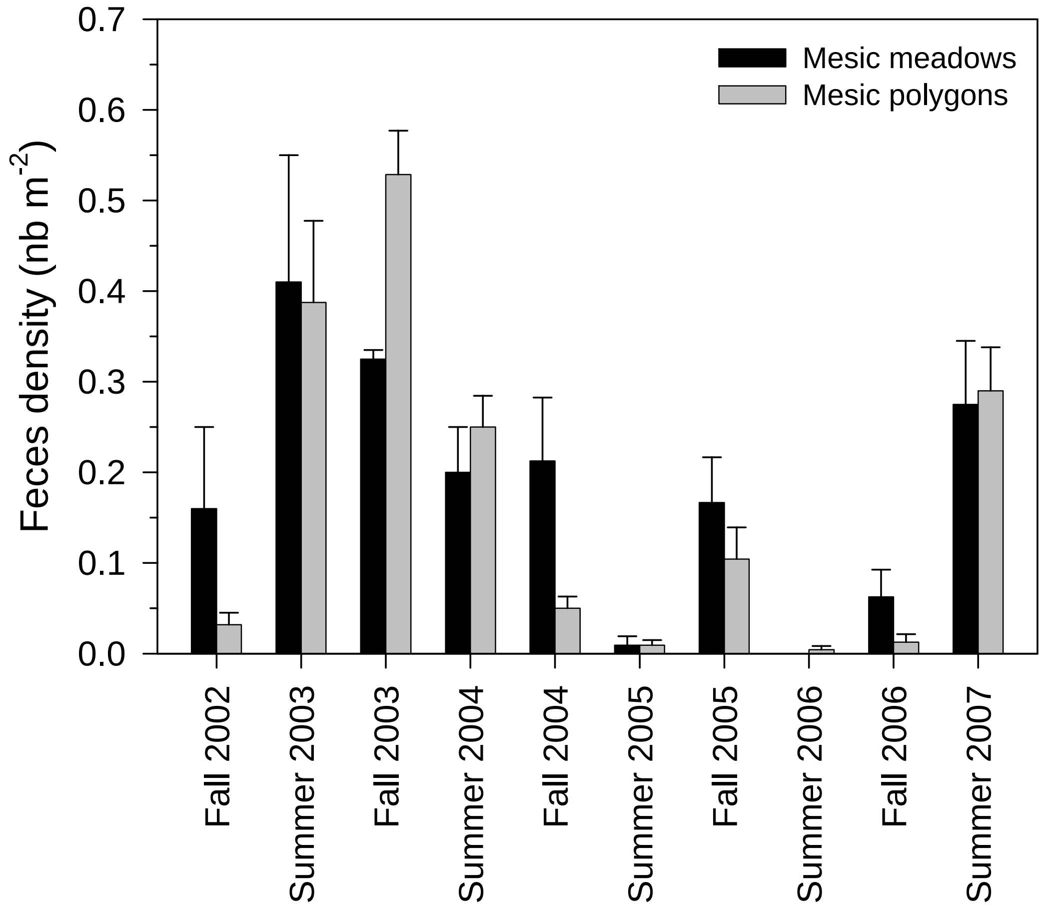


Figure 30. Feces density (mean ± SE) showing the use of mesic meadows and mesic polygons of the Qarlikturvik Valley, Bylot Island, by Greater Snow Geese (n = 12 transects of 1 × 20 m) during the fall and summer seasons from 2002 to 2007.

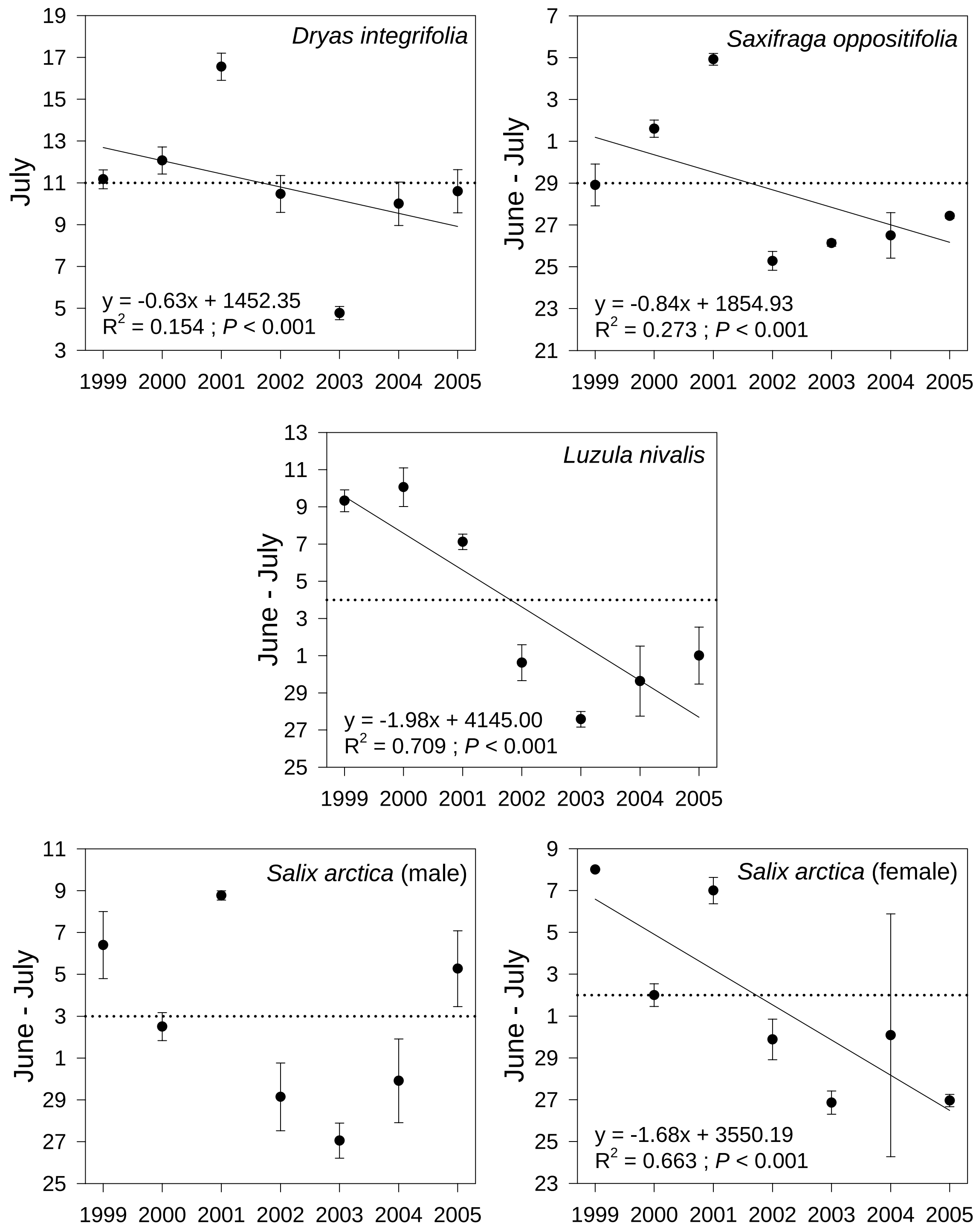


Figure 31. Annual first flowering date (mean ± SE, n ≤ 30 plants per species per year) of *Dryas integrifolia*, *Saxifraga oppositifolia*, *Luzula nivalis*, *Salix arctica* male, and *Salix arctica* female in mesic communities of of the Qarlikturvik Valley, Bylot Island, from 1999 to 2005. Temporal trends are represented by a solid line when significant ($P < 0.05$). The dotted line shows the mean for the whole period.

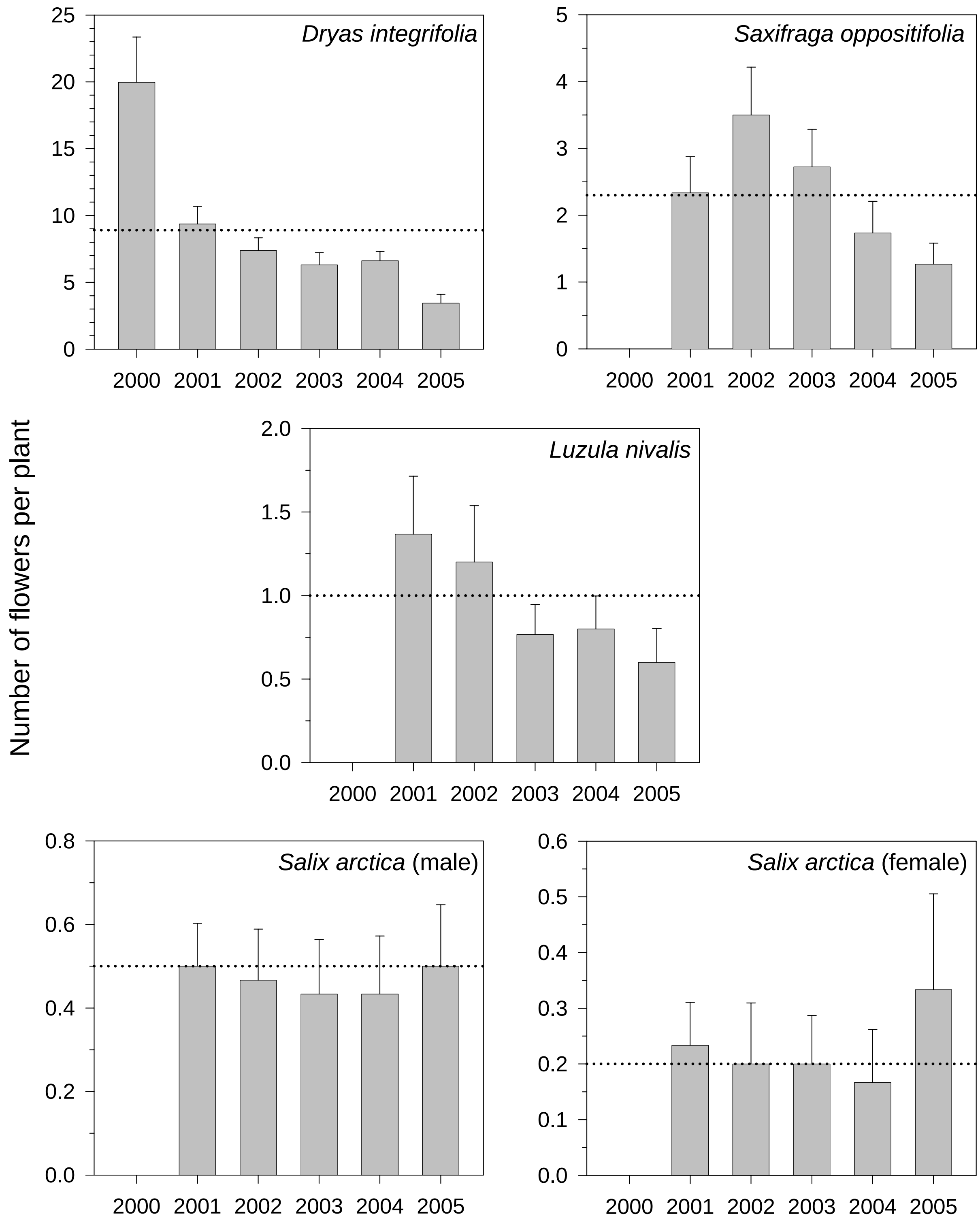


Figure 32. Number of flowers (mean ± SE, n = 30 plants per species per year) produced annually by *Dryas integrifolia*, *Saxifraga oppositifolia*, *Luzula nivalis*, *Salix arctica* male, and *Salix arctica* female in mesic communities of the Qarlikturvik Valley, Bylot Island, from 2000 to 2005. No data available in 2000 except for *D. integrifolia*. The dotted line shows the mean for the whole period.

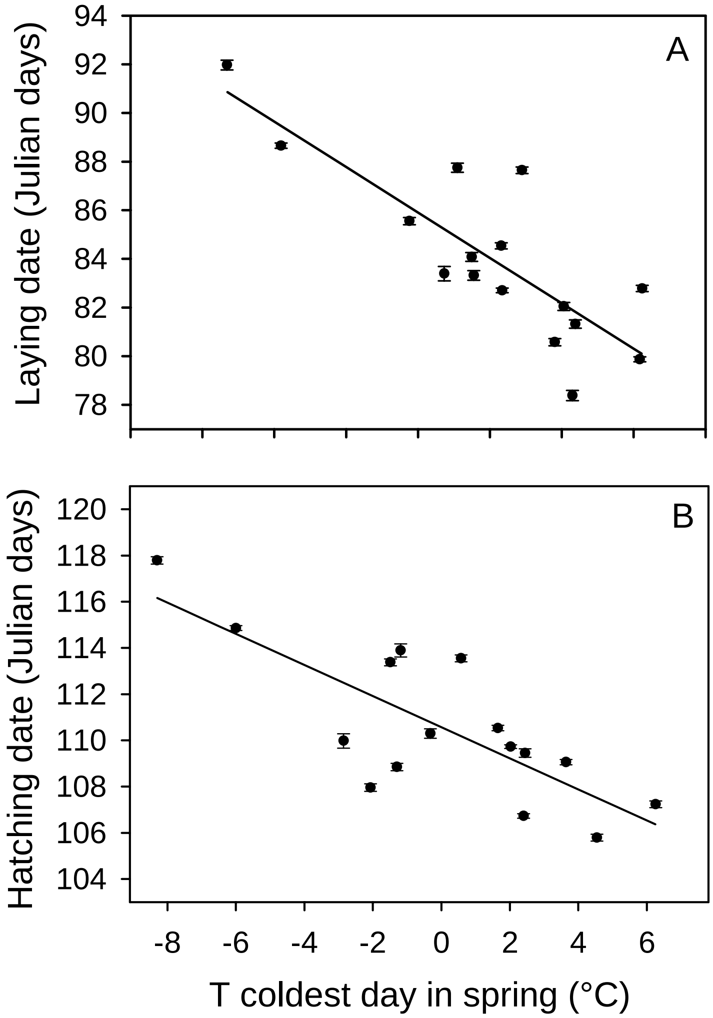


Figure 33. Relationships between (A) egg-laying date of geese (Julian days relative to vernal equinox) and mean temperature in spring (partial R^2 = 0.339, β_x =-1.224±0.303), and (B) hatching date of goose nests (Julian days relative to vernal equinox) and minimum temperature of the coldest day in spring (partial R^2 = 0.404, β_x = -0.354±0.089). Mean annual values with SE are shown to illustrate the fit of the model (temperatures are expressed as deviations from the 16-year mean). Adapted from Dickey et al. (2008).

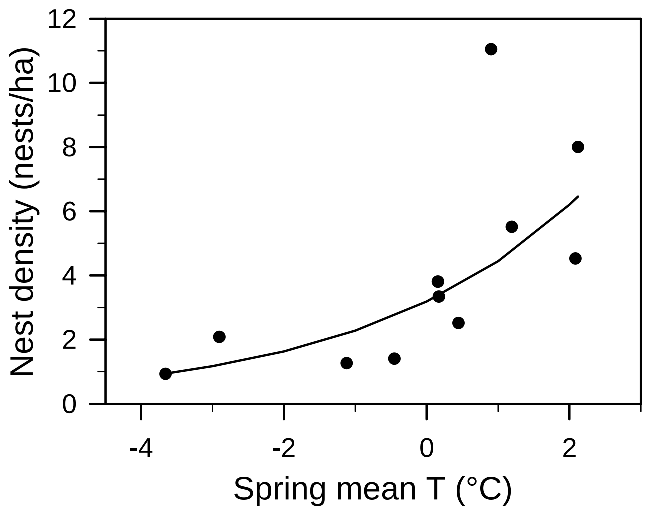
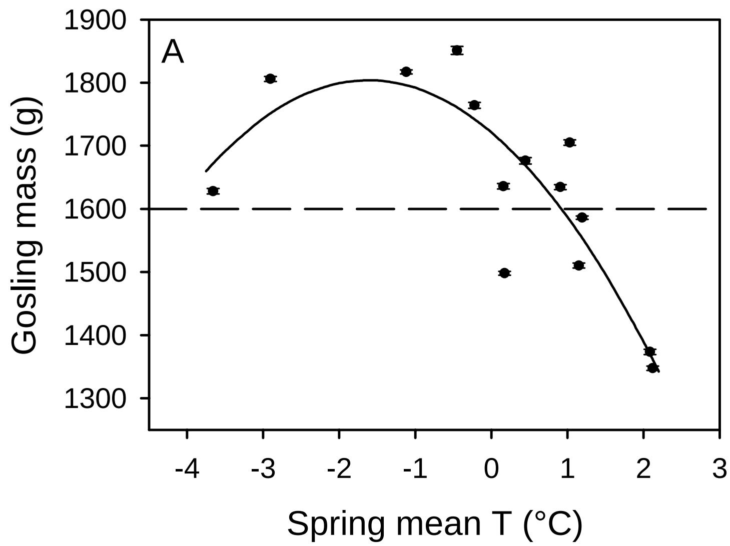


Figure 34. Relationship between goose nest density and mean temperature in spring (R^2 = 0.585, β_x = 0.145±0.037, n = 11). Nest density was log-transformed to respect normality. From Dickey et al. (2008).



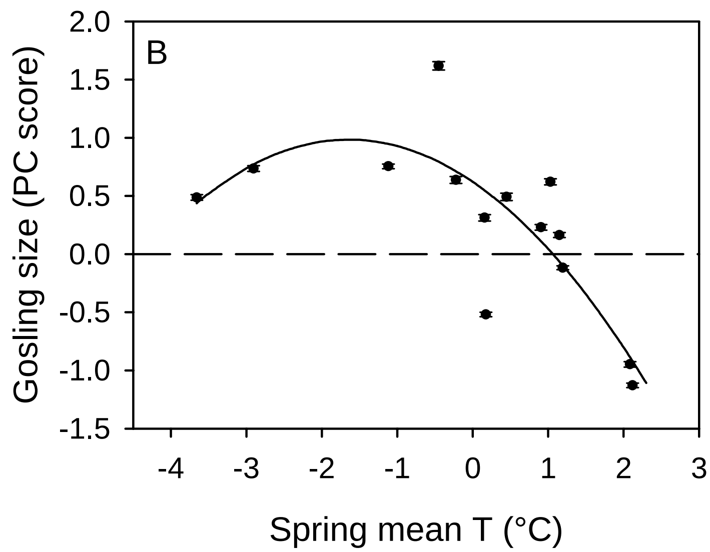


Figure 35. Relationships between (A) gosling mass and mean temperature in spring (partial R^2 = 0.373, β_x = -102.5 ± 18.1, β_{x^2} = -31.7 ± 7.8; annual minimum-maximum n = 605-2258), and (B) goslings size (PC score) and mean temperature in spring (partial R^2 = 0.228, β_x = -0.647 ± 0.110, β_{x^2} = -0.204 ± 0.036; annual minimum-maximum n = 609-2290). Mean annual values with SE are shown to illustrate the fit of the model. The dashed line indicates mean goslings size (temperatures are expressed as deviations from the 16-year mean). Adapted from Dickey et al. (2008).

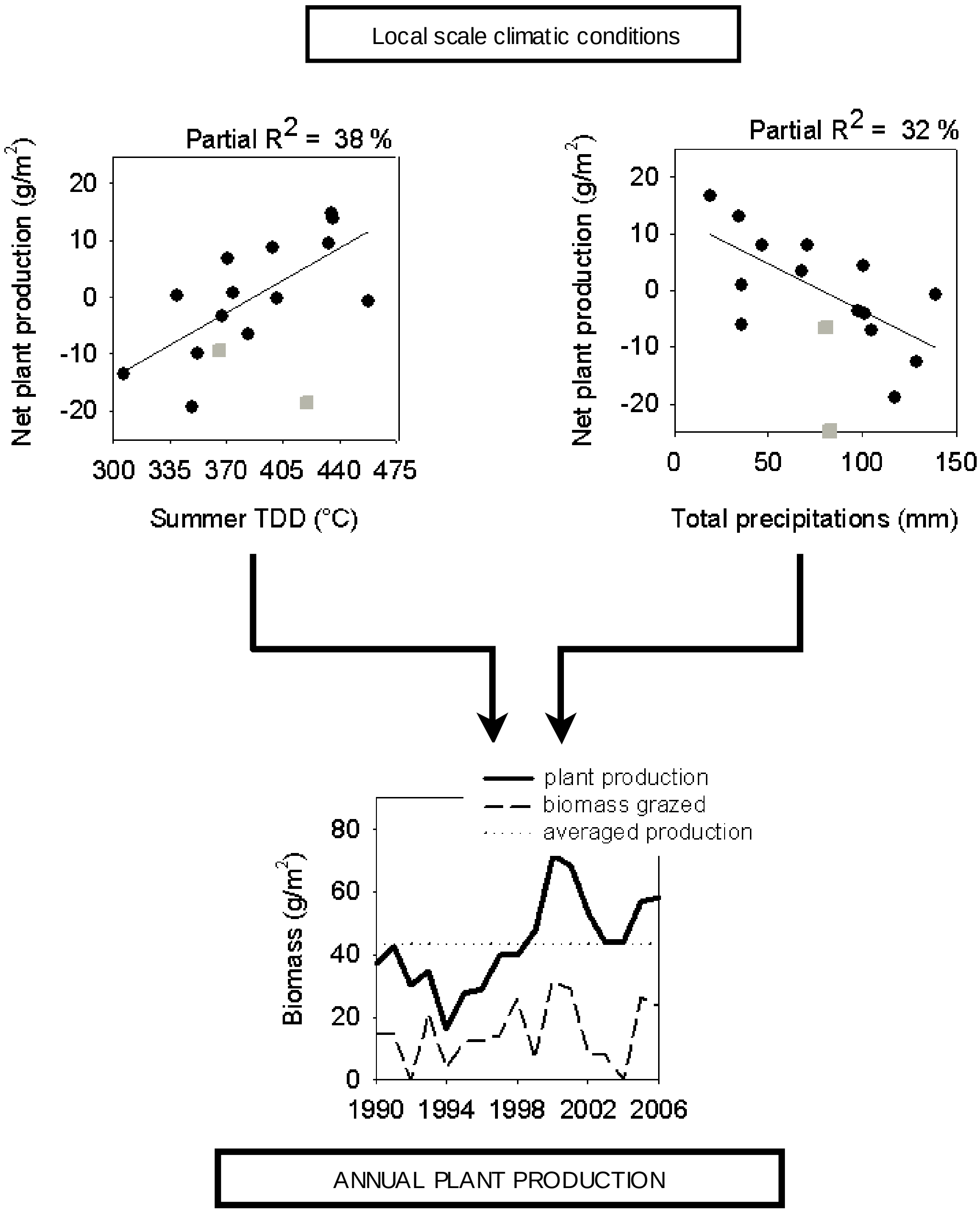


Figure 36. Relationship between residual annual plant production on Bylot Island with summer thawing degree-days (TDDsummer) and total summer precipitations (TOTprec). Circles represent data used to build the regression model and squares are data points excluded because of missing values for some covariates. Predictive equation including parameter estimates ± SE: plant production = −2.7±21.8 + 0.16±0.05 (TDDsummer) − 0.17±0.05 (TOTprec). From Graham-Sauvé (2008).

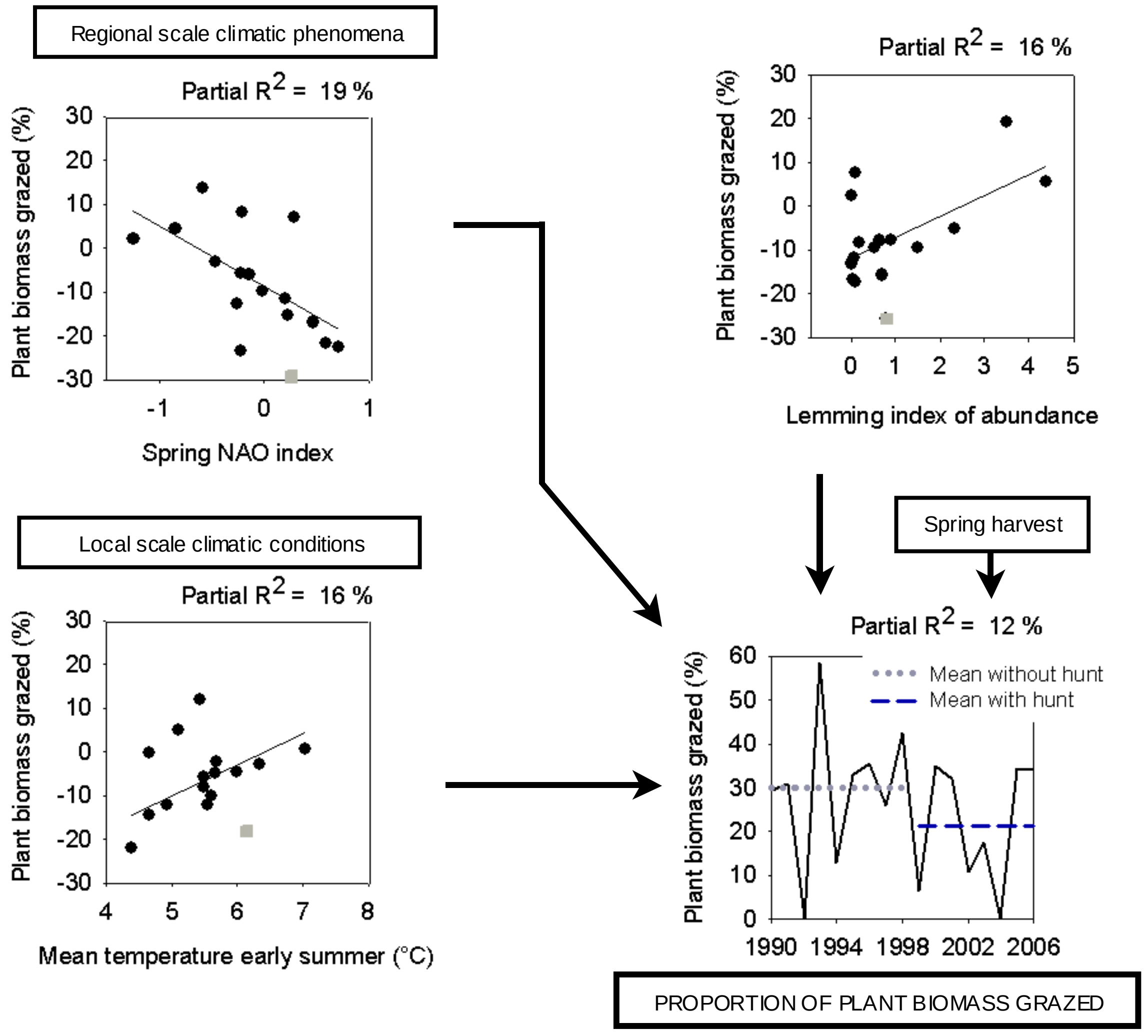


Figure 37. Relationship between the proportion of plant biomass grazed by geese (residual values) with the North Atlantic Oscillation (spring NAO), lemming abundance (Lem), early summer temperatures (Tmean_e_sum) and spring harvest (Hunt). Circles represent data used to build the regression model and the square is one data point excluded because of missing values for some covariates. Predictive equation including parameter estimates ± SE: proportion of plant biomass grazed = -24.6±26.1− 12.2±6.3 (NAOspring) + 4.5±2.5 (Lem) + 9.2±5.1 (Tmean_e_sum) + 10.3±6.8 (if Hunt=0). From Graham-Sauvé (2008).

4 DISCUSSION

4.1 CLIMATIC TRENDS ON BYLOT ISLAND

So far, few temporal trends were observed in the climatic data collected on Bylot Island over the last 14 years. Annual air temperature has varied greatly from year to year and no trend was detected. On a seasonal basis, we detected an increasing trend in fall temperatures but not during the other seasons. The absence of temporal trends in air temperatures on Bylot Island is likely related to our relatively short time series (i.e. 14 years) and the large inter-annual variability. In order to increase the temporal coverage, we used the 32-year record (1976-2007) from the Environment Canada weather station located at the Pond Inlet's airport (ca. 80 km south of the Qarlikturvik Valley; 72°41'N, 77°59'W; www.climate.weatheroffice.ec.gc.ca/climateData/canada_e.html) to update the analysis of Gagnon et al. (2004). The climatic regime of these two sites is very similar (see Appendix B, Fig. B1). Even though slight differences in air temperature were detected for some months between the two sites, it never exceeded 1.9°C and were greatest in winter. It is therefore safe to say that trends observed at Pond Inlet should accurately reflect those occurring on Bylot Island during the same period. Since 1976, the annual air temperature of Pond Inlet has increased by 2.1°C (see Appendix B, Fig. B2). The year 2006 was the warmest of the last three decades and six of the last seven years showed temperatures above the long-term average. This warming trend was most impressive during the fall (4.5°C or 1.5°C per decade), which confirms the warming trend observed on Bylot Island (2.1°C per decade). Pond Inlet also showed a strong warming trend during the summer (2.1°C) and the spring (2.1 °C) but no apparent trend occurred over the winter (see Appendix B, Fig. B3).

The trends observed in the Pond Inlet area are somewhat contradictory to regional variations observed elsewhere in the Canadian Arctic where winter temperatures in western Canada have shown a more rapid increase than summer temperatures over the past 50 years (ACIA 2004). Projected models also predict a rise of 3 to 5°C in annual average temperatures across the Arctic before the end of the 21st century, with the strongest increase predicted to occur during the winter (ACIA 2004). Thus, it remains to be seen if this discrepancy is due to a local anomaly or some deficiencies in the theoretical models. Nonetheless, the warming observed so far in the Pond Inlet area is enormous considering the average predictions of these models for the next 80 years, and apparently follow the most pessimistic scenario. The observed trends also have important implications for the terrestrial arctic ecosystem because most of the biological activity occurs during the summer. We may expect impacts of these changes on several components of the ecosystem in the near future (Gagnon et al. 2004).

4.2 Temporal trends in the ecosystem and their relationships with climatic factors

Even though the ecosystem of Bylot Island is fairly simple in terms of the number of species present, it is nonetheless difficult to explain changes in individual components alone without examining the links among species, i.e. the trophic interactions. The most important ones at our study site are between plants, herbivores (geese and lemmings) and predators (foxes and avian predators) (Gauthier et al. 2004) and we have to consider the impact of the weather in these processes.

4.2.1 Greater Snow Geese

Although our analysis of the reproductive parameters of Greater Snow Geese yielded no significant temporal trends, Dickey et al. (2008) and Morrissette (2008) showed the importance of the local climate in annual variations in breeding phenology and reproductive success. Indeed, goose laying and hatching dates are mostly affected by spring temperatures and snow cover on Bylot Island (Dickey et al. 2008). Previous studies have shown that the breeding probability of Greater Snow Geese was negatively affected by the amount of snow at our study site (Bêty et al. 2003, Reed et al. 2004), a result further confirmed by Dickey et al. (2008). This relationship is not surprising in ground nesting species that must wait for the availability of nesting sites before initiating their breeding season (Clarke and Johnson 1992, Hendricks 2003). Another important aspect of goose breeding effort is their clutch sizes. This reproductive parameter is little influenced by the local weather (Dickey et al. 2008) but the timing of reproduction has a strong influence as we found that clutches are larger when nests are initiated earlier. Clutch size in Greater Snow Geese results from a complex interaction between the body condition of female upon arrival in the Arctic, the timing of arrival and the female ability to acquire additional reserved after arrival on the breeding grounds (Bêty et al. 2003, 2004; Gauthier al. 2003).

Because the summer is very short compared to lower latitudes, goslings of Arctic-nesting geese have less than two months to grow and reach a body size and mass similar to their parents before the fall migration (Aubin et al. 1986, Sedinger 1986, Lesage and Gauthier 1997). This requires large amount of high quality plants during their growing season (Aubin et al. 1993, Lindholm et al. 1994, Lepage et al. 1998a, Leafloor et al. 1998, Sedinger et al. 2001). Dickey et al. (2008) showed that climatic factors can affect gosling growth by influencing food availability during this critical period. Their analysis revealed that gosling mass and size were primarily influenced by climatic conditions prevailing in spring through a carry-over effect rather than by climatic conditions during the growing period itself. As high spring temperatures and low snow cover are associated with a high breeding effort (Reed et al. 2004, Dickey et al. 2008), such conditions should lead to high brood density during the summer. This should in turn increase the grazing pressure (Gauthier et al. 1995, 2004), leading to a reduced food availability for goslings due to density-dependent effects, hence a reduced growth. In addition, a mismatch between goose and plant phenology may also explain why favourable spring conditions decrease gosling growth. Because plant phenology responds more quickly than goose phenology to high spring temperature, hatching of goslings tends to occur later than the peak of high quality food in years with early, warm springs (Dickey 2006), leading to a mistiming between hatching date and peak in food quality (Visser and Both 2005). An experimental study examining in details the mismatch hypothesis between geese and their food as a result of climate warming is currently underway by a PhD student (M. Doiron) with our research team.

4.2.2 Lemmings and their predators

As is commonly observed in high latitudes, lemming populations on Bylot Island show large cyclic fluctuations (Turchin 1993, Krebs et al. 1995, Stenseth 1999) which have a strong influence on the terrestrial ecosystem of the island. Indeed, our results showed that lemming abundance primarily affects their main predators (Snowy Owls and foxes) but also indirectly affects snow geese through shared-predator interactions (Bêty et al. 2002, Gauthier et al. 2004). Snowy Owls, who are nomadic specialist predators of small mammals (Parmelee 1992, Hakala et al. 2006, Gilg et al 2006), only nest on Bylot Island in years of high lemming abundance. Arctic Foxes, on the other hand, are opportunistic specialist predators that mainly feed on lemmings but also on alternative prey and show higher reproductive activities during peak years of lemming abundance (Angerbjörn et al. 1999, Elmhagen et al 2000). Greater Snow Geese and possibly also other species (e.g. shorebirds) benefit from lemming peak years as their nesting success is very high in those years (Bêty et al. 2001, Gauthier et al. 2004). This occurs because Arctic Foxes rely heavily on goose eggs as an alternative food source in years when lemmings are scare but very little in peak lemming years (Bêty et al. 2002, Gauthier et al. 2004).

Other avian predators of Bylot Island, such as gulls and jaegers, also prey upon lemmings during the summer. However, since these birds are generalist predators, lemmings are less important in their diet and their reproduction does not heavily depend on them because they can rely on a much larger array of prey (Wiley and Lee 1998, Gilchrist 2001). This seems particularly true for Glaucous Gulls as their nesting success does not vary as much as that of jaegers. A graduate student (M.-A. Valiquette) is currently investigating the diet of gulls on Bylot Island in relation to the lemming cycle.

In recent years, with the expansion of our monitoring program towards others bird species, we have discovered that Arctic Foxes are important predators of shorebird eggs (unpublished data, L. McKinnon). It is therefore possible that foxes also switch to shorebirds when small mammal abundance is low, which could explain the annual variations observed in nesting success of White-rumped Sandpipers and Baird's Sandpipers since 2005. The same explanation could also apply to Lapland Longspurs and explain some of the large annual variations in nesting success but further work is needed in order to establish the role of foxes as a predator for this species.

Gruyer (2007) showed annual and seasonal differences in demographic parameters of lemming populations on Bylot Island, which could explain in part the cyclic pattern in their annual abundance. As shown by our long-term snap-trap survey, differences were more pronounced in Brown Lemmings, which were more abundant in peak years and experienced larger annual fluctuations than Collared Lemmings. This was confirmed by our live trapping program, which showed that Brown Lemming densities differ between a peak and a decline year (density in the peak of 2004 was 6.2 times higher than in 2005), compared to the densities of Collared Lemmings, which was lower and more similar between the two years (1.1 times higher in 2004 than in 2005; Gruyer 2007). The decline phase in Brown Lemmings following a peak in abundance is likely due to a decrease in adult survival and juvenile recruitment (i.e. proportion in the population) (Korpimäki et al. 2004, Gruyer 2007). In contrast, reproductive parameters of Collared Lemmings did not change between the two years. Their apparent constant reproductive activity fits with the low variation in abundance observed between 2004 and 2005.

One of the most intriguing result of our long-term monitoring of lemming abundance is the relatively low abundance of lemmings recorded in the two most recent peak years of the cycle (2004 and 2007) compared to the previous three peaks (1993, 1996 and 2000). Despite the huge inter-annual variation in lemming abundance due to their multi-annual cycles, we found evidence for a decreasing trend in their abundance. In some areas of northern Scandinavia, disruption or even disappearance of lemming cycles have been reported in recent decades, possibly as a consequence of climate warming (Angerbjörn et al. 2001, Ims and Fuglei 2005). The winter period is believed to be one of the most critical periods for lemmings. A thick and dry snow cover provides them with a good insulation from the winter cold (Chappell 1980) but thawing periods or freezing rains could have devastating effects on lemmings. Surface thaw refreezes into ice layers with a low thermal index, thereby reducing the subnivean temperatures and the insulative capacity of the snowpack (Courtin et al. 1991), and even reducing food availability by icing the ground vegetation. In Norway, Aars and Ims (2002) found that lemming survival decreased with an increase in number of days above freezing in winter. Winter reproduction of lemmings under the snow is believed to be an important pre-requisite for the occurrence of a year of peak lemming abundance (Krebs et al. 1995, Millard 2001, Gruyer 2007). MacLean et al. (1974) found that the reproduction of both Collared and Brown Lemmings was impaired in winters with thin snow cover and cold subnivean conditions.

In the High Arctic, the transition period from fall to winter may be the most critical for lemmings because this is when alternating periods of freeze-thaw and freezing rain are most likely to occur. Favourable climatic conditions at that period (i.e. early, thick and dry snow cover) may be determinant for the occurrence of lemming population increase in the following year (Scott 1993, Reid and Krebs 1996). It is noteworthy that in the Pond Inlet area, it is at this period that climate warming has been most pronounced in recent years. Although it is premature to attribute the low abundance of lemmings observed on Bylot Island during recent peak years to climate warming, a link between the two phenomena is certainly possible. Further work is needed to confirm this relationship on Bylot Island and we have started investigating the link between subnivean temperatures experienced by lemmings and temperature, snow depth, and snow density. This is currently the subject of a graduate student thesis (D. Duchesne).

If a link between climate warming and decreasing lemming populations is confirmed, this could have far-reaching effects on the whole food chain of the tundra considering the key role played by lemmings (Krebs et al. 2003). Predators could potentially be the first species affected, as shown by our monitoring. Indeed, we have found evidence that, over the past 12 years, the reproductive activity of foxes has declined on Bylot Island. Although other factors could affect the reproduction of foxes, the relatively low abundance of lemmings in recent years may certainly be a key factor involved considering the importance of this prey in the fox diet.

Szor et al. (2008) have studied the process of den site selection by Arctic Foxes on Bylot Island and found that climate may also directly influence this species through the availability of adequate denning sites. An analysis of the effect of snow cover on the selection of den sites by Arctic Foxes has shown the importance of early snow free areas for denning. According to their results, sites selected by foxes have on average less than half the snow cover of other surrounding potential denning sites. This suggests that early snowmelt may be essential to allow sufficient warming of the ground and enable foxes to dig their dens. It is thus becoming obvious that climate may have both direct and indirect (e.g. via the food supply) effects on predators, making predictions of the overall effects of climate change on these species exceedingly difficult.

4.2.3 Plant-herbivore interactions

On Bylot Island, wetlands represent only 11% of the south plain (1600 km^2) and geese show a strong selection towards this habitat, especially during the brood-rearing season (Hughes et al. 1994, Massé et al. 2001, Mainguy et al. 2006). This is because wetlands provide the highest amount of their preferred food (*Eriophorum* and *Dupontia*; Manseau et al. 1993, Massé et al. 2001) as well as refuges (lakes and ponds) against predators (Giroux et al. 1984, Hughes et al 1994, Duclos 2002). The remaining area is covered by upland or mesic habitats, which are considered as lower quality for geese (Massé et al. 2001). These drier habitats are mainly use by geese upon their arrival in the spring, before lowlands become free of snow, and to a lesser extent during the summer and the fall, possibly due to a decreased availability of food in wetlands (Hughes et al. 1994, Duclos 2002, Mainguy et al. 2006). Our results of feces counts clearly shows this difference of habitat use by geese during the summer as the wetlands of the Qarlikturvik Valley were used from 12 to 300 times more intensely than its surrounding mesic habitats during the period of 2003 to 2007.

The annual plant production of wetlands is generally low due to the short growing season of plants in arctic tundra regions (see review in Gauthier et al. 1996). The analysis of our long-term record of annual plant production in wetlands by Graham-Sauvé (2008) clearly showed the strong effect of climatic factors, especially local summer temperature and precipitation, in affecting the annual plant production on Bylot Island. The accumulation of thawing-degree-days over the summer was the most important variable probably because it integrates both the length of the growing season and the intensity of heat experienced by the plants. Hence, for plants such as *Eriophorum*, which initiate their growing activity late in spring (Gebauer et al. 1995, Wahren et al. 2005), warmer summer can be beneficial if conditions remain favourable for growth until August. However, Arctic plant responses to variations in summer temperature regime and growing season length are not well documented, may be species-specific, and are complicated by species interactions (e.g., response to increased shading due to a positive response of another plant; Chapin et al. 1995, Chapin and Shaver 1996).

Snow depth in the lowlands of the Qarlikturvik Valley on 1 June is normally around 30 cm (see results). This typically leads to high water runoff in wetlands during spring snowmelt. High rainfall in July and August can also lead to flooding of wetlands for several days. Hence, large amount of precipitation combined with the relatively poor drainage of this habitat, can cause delays in the onset of plant growth and affect nitrogen availability (Aerts et al. 2006). On Bylot Island, nitrogen is the most limiting nutrient for the growth of graminoid plants and mosses in wetlands and may also interfere with the absorption of nutrients by vascular plants (Pouliot 2006). High summer precipitations is also associated with high cloudiness reduced solar radiation, another factor that could also reduce plant production in the Arctic (Chapin and Shaver 1996).

Over an 18-year period, we found that plant production in the wetlands of the Qarlikturvik Valley of Bylot Island almost doubled. In light of the previous evidence, it seems most likely that this increase is due to the summer climate warming observed in the area. This may only be beginning, as long-term warming experiment of the tundra have shown that increase in productivity is followed by major change in species composition and plant community structure (Chapin et al. 1995, Chapin and Shaver 1996). Although increased primary production may be seen as beneficial for herbivores, it is likely to be associated with a decrease in plant quality (i.e. increased plant fiber, reduced protein), which may have a negative impact on the goose feeding (Manseau and Gauthier 1993, van der Graaf et al. 2006). Furthermore, we showed before that it could lead to a mismatch between plant and goose breeding phenology and negatively affect gosling growth (Dickey 2006; see above). Therefore, these results further exemplify the complexity of predicting the outcome of climate warming on Arctic wildlife.

In addition to the climate, geese can also directly affect the annual plant production through their grazing pressure (Cargill and Jefferies 1984, Kerbes et al. 1990, Gauthier et al. 1995), which has sometimes proven to be devastating and almost irreversible for plant communities (Gadallah and Jefferies 1995, Jefferies et al. 2006). As mentioned above, spring climatic conditions on the breeding grounds are dominant factors affecting the reproductive phenology of Greater Snow Geese on Bylot Island (Bêty et al. 2003, Reed et al. 2004, Dickey et al. 2008). Graham-Sauvé (2008) further showed that this could in turn affect the goose grazing pressure on graminoid plants through the size of the summer local population. Indeed, goose family densities during the summer are primarily mediated by the annual goose reproductive effort and the proportion of eggs and goslings that survive, which is primarily influenced by the indirect trophic interaction between lemmings and geese through shared predators (see above). Even though geese have been shown to remove up to 60% of the total plant biomass of wetlands, their grazing pressure apparently does not seem to have a long-term effect on plant production on Bylot Island, as evidenced by the long-term increase in plant production detected in wetlands. Even though the population size has increased drastically during the 1980s and 1990s (Calvert et al. 2007), the carrying capacity of wetland habitats on the island has apparently not yet been reached (Massé et al. 2001). Furthermore, the spring conservation harvest occurring in southern Quebec has apparently been successful in stopping the increase of the goose population during the last decade (Calvert et al. 2007).

5 INUIT TRADITIONAL ECOLOGICAL KNOWLEDGE

Through millennia of interactions and use of arctic ecosystems, Inuit have developed an extensive ecological knowledge about northern environments. In recent years, there has been an increased interest in finding innovative ways to enhance the incorporation of this Traditional Ecological Knowledge (TEK) within ecological investigations and environmental management.

Through legislative agreements and recommendations made by co-management bodies, Parks Canada is required to include Inuit TEK in the management of its national parks in Nunavut (Gagnon and Berteaux 2006). To satisfy this requirement, the Nunavut Field Unit of Parks Canada launched a first Inuit Knowledge Project (www.lecol-ck.ca/index.php) in 2004 to increase the involvement of Inuit TEK into the understanding and management of its parks (Parks Canada 2005). The TEK component of our study initiated in 2004 has been conducted in collaboration with this larger project (Gagnon and Berteaux 2006).

To avoid redundancy in collecting TEK, the first part of the project consisted in preparing an inventory of TEK that had been documented on topics related to the environment in the area of the Sirmilik National Park. This review involved a visit to several agencies in Iqaluit and Igloolik (17 to 23 October 2004).

Following the TEK review (winter 2004-2005), consultation meetings were held in Pond Inlet on 26 and 28 February and on 1 March 2005 in collaboration with Parks Canada. The goals of the consultations were to present the project and invite the community to express ideas, concerns and advice on how to proceed. Elders, hunters, representatives of the Joint Park Management Committee and the community attended the meetings and approved the project.

5.1 COLLECTION OF KNOWLEDGE

From May to September 2005, we launched the first phase of TEK collection. We created a list of informants to be interviewed based on recommendations by Elders, members of the Mittimatalik Hunters and Trappers Organization, and community members working for Parks Canada, the Hamlet Office, and the Nunavut Wildlife Management Board. The informants whose names were mentioned most often were selected first. We believe that using multiple sources of recommendations diminished biases in the selection of informants. Using semi-directive interviews (Grenier 1998, Huntington 1998), a methodology that allows unanticipated information to emerge (Ferguson and Messier 1997; Huntington 1998), we interviewed 21 local experts on geese, foxes, and the land. We conducted interviews in places where local experts felt comfortable (Ferguson and Messier 1997). These included the local Parks Canada office (n = 6) and visitor centre (where Elders have weekly gatherings; n = 10), houses of informants (n = 3) as well as traditional campsites (n = 2).

A total of 38 hours of interviews were recorded, each individual interviews lasting between 1.5 to 4 hours. At the beginning of interviews, we asked questions regarding the informants' birth location and hunting and travelling areas (according to seasons) that they knew best. This later provided us with a biographical context for the information collected. Interviews then covered topics regarding the ecology of foxes and geese as well as their importance to the community. These species were selected because they are two important components of the local terrestrial ecosystem. They are also being extensively studied by scientists in the area, and Inuit representatives expressed the desire to contribute their knowledge about them. In addition, we collected Inuit TEK on environmental changes observed in the area, as well as on the location of ecologically sensitive areas (see Appendix C for the questionnaire used during interviews).

Every interview was conducted in both English and Inuktitut, thanks to the assistance from a professional interpreter who was born in Pond Inlet. His knowledge of the land surrounding the community helped stimulate conversations, along with the use of 1:250,000 topographic maps that served as recording aid. A second assistant from Pond Inlet also audio and video recorded every interview. It was decided from the beginning of the project that all material (audio, video, photo, text) collected and produced during the project would remain the property of the community and this material was later archived and made accessible by Parks Canada.

5.2 Analysis and verification of TEK collected

In fall and winter 2005-2006, we transcribed and imported the English portions of all audio recordings into the NVIVO software version 2.0 (QSR International Pty. Ltd. 2002). The transcripts of all interviews and focus groups were compiled into one NVIVO project. For every single interview, every quotation was analysed and codified pertaining to the subject it covered (e.g. arctic fox denning areas, goose nesting areas, etc.; a single quotation could be assign more than one code). Codifying the transcripts allowed extracting all quotations pertaining to particular topics in order to proceed to further analysis. Using the ArcView software versions 9.1 (ESRI 2005), we also digitalized and geo-referenced all spatial information in order to produce comprehensive maps.

In February 2006, the main investigators (D. Berteaux and C.-A. Gagnon) held a workshop in Pond Inlet during which they reported the preliminary results of the project. Results were presented to community representatives, as well as to members of the Joint Park Management Committee of Sirmilik National Park. From May to July 2006, we entered the validation phase of the project (Creswell 1998, p. 210-211). Working with a research assistant from Pond Inlet, we reviewed every confusing segment of interviews and discussed our interpretations. In some instances, we conducted more interviews to clarify some points. From 20 to 22 June 2006, we also organised four verification workshops. Each workshop gathered four local experts and pertained to one of the following topic: goose ecology, fox ecology, ecological integrity, and ecological changes. From 11 to 17 June 2006, C.-A. Gagnon and D. Berteaux also participated to an Elder-youth camp they had planned over the previous winter. The goal of the camp was to ensure that the knowledge discussed with Elders and hunters while performing the Inuit Knowledge Project on geese and foxes was shared with the younger generation. The camp also provided us with the opportunity to observe the knowledge of local experts being put into practice and to have numerous informal discussions. Both the focus groups and informal discussions allowed us to verify that the information collected through varying approaches was consistent (Creswell 1998, p. 210-211). A short film entitled *Ikpiugalik* (i.e. the name of the location of the camp, which means ‘the one with small hills’ in Inuktitut) was also produced following the Elder-youth camp. It presents life at the camp and the various traditional activities in which campers engaged. Copies of the DVD were distributed widely to the camp participants, Parks Canada Offices in Nunavut, schools of Pond Inlet, the Pond Inlet library, the Nunavut Research Institute, and the Department of Culture, Language, Elders and Youth (Government of Nunavut).

The results presented here in this report are based on firsthand observations by the informants. Because semi-directive interviews are a flexible process, local experts did not always provide comments on every topic. Results are therefore presented as number of informants who made a particular observation/number of informants who did discuss the topic pertaining to the observation. We excluded from the analysis all quotations made by informants who had mentioned their lack of knowledge regarding that specific topic.

5.3 INUIT TEK FROM POND INLET

Throughout three years of working with the community of Pond Inlet, a multitude of information (both cultural and ecological) was collected regarding foxes, geese and the environment nearby Pond Inlet. Due to the extent of the information collected, only certain topics discussed in the interviews have been analysed in details. Three major results will be presented here: the invasion of the area by Red Foxes, the winter ecology of Arctic Foxes, and observations by local experts of changes in the environment and activities that have affected the land. Further results from our TEK project can be found in Gagnon (2007).

5.3.1 Arrival of the Red Fox in the area

Red Foxes have only recently expanded their range to the Baffin Island area. This recent colonisation has only been sparsely documented and the impact it may have on Arctic Fox populations raises some concerns. In order to complement the information available on the arrival of the Red Fox in the area of Pond Inlet, based on pelt records from the Hudson Bay Company trading post, interviewees were asked if they remembered having seen a Red Fox for the first time in their hunting area.

> "It was probably in the … early 50s, when we had a camp at Nunatsiaq. Somebody caught a red fox and it was very unusual to see a fox like that. We were quite amazed to see the red fox. It was something different and it was a big thing for us. We had a camp at Nunatsiaq and the hunters in Nadluat used to set their traps along this shore here (pointing on the map). It was one of the hunters who lived in Nadluat that caught a red fox and on his way back he stopped at our camp" (Sangoya 2005).

Of the 21 informants, 17 provided comments. The majority of those 17 informants (13/17) remembered the first time they had seen a Red Fox in their hunting areas: 1/17 stated having seen one for the first time in 1943 when he was living in Igloolik, 2/17 stated having seen one in 1947-1948 in the Pond Inlet area, 8/17 stated that first sightings occurred in the 1950s, and 2/17 stated having seen a Red Fox for the first time in the 1960s. Of the remaining 4/17 informants, three mentioned having always seen an occasional Red Fox in the area and one informant believed, based on information from his parents, that Red Foxes had always been around. Nine out of 17 informants also commented that since the Red Fox has colonized the Pond Inlet area, its abundance increased. This observation was also mentioned during the verification workshop on foxes.

According to local experts, the silver and cross colour morphs of the Red Fox have also been sighted in the area, after the arrival of the Red Fox. Locations where Red Foxes and its two morphs have been sighted have been recorded on maps (Fig. 38). Two informants commented that Red Foxes can be seen more often on the mainland but that they are rarely observed at the floe edge (east of Bylot Island).

5.3.2 Winter ecology of the Arctic Fox

When asked to comment on the winter distribution and habitat use of Arctic Foxes, the answers provided by the 18 informants who commented varied. Eight out of 18 mentioned seeing Arctic Foxes mostly on the land in winter, 3/18 mentioned seeing them on the shorelines for the most part, 3/18 either on the land or the ice, 2/18 on the sea ice, 1/18 at the floe edge, and 1/18 at the floe edge and on the mainland. In addition, 4/8 informants stating that foxes were seen mostly on the land added that they also saw fox on the sea ice, but to a lesser extent. Similarly, 2/18 informants mentioned seeing Arctic Foxes mostly on the sea ice and one of them also commented seeing them on the land, but less often.

When discussing the winter diet of Arctic Foxes informants stated that Arctic Foxes are scavengers (3/16) and eat anything they can find (1/16). More specifically, knowledge holders stated that items consumed by Arctic Foxes in winter consist mainly of carcasses of sea mammals (12/16) and lemmings (11/16). Informants specified the origin of the sea mammal carcasses, mentioning that they came from beached animals (7/12), were left on the ice by polar bears (5/12), or were leftovers from hunters (3/12). Caribou meat (2/16), arctic hares (1/16), birds (most likely ptarmigans; 1/16), and food caches prepared by hunters (1/16), were also mentioned as winter feeding items for Arctic Foxes.

One subject that was not included in the questionnaire but that was brought up spontaneously by 11 informants is the use of two different over wintering strategies by Arctic Foxes from the Pond Inlet area. Indeed, according to 11 informants, some foxes mostly remain on the land and others mostly remain on the sea ice. These are commonly called the 'land' and the 'sea' foxes. Informants also reported on the physical characteristics differentiating those two types of foxes, the 'land fox' being recognized as having a thicker fur (8/11), a whiter fur (4/11), a larger size (2/11), a harder and less oily fat (1/11), longer fur (1/11), thinner skin (1/11), are better to eat (1/11), and turn white earlier in the winter (1/11; the inner fur of the 'sea' fox turning completely white only in spring).

> "There's also a difference between foxes who live on the mainland and foxes who live on the sea ice… they're all white but the difference is the…foxes that live mainly on the sea ice, their fur is thinner and the foxes that live on the mainland, their fur is thicker" (Peterloosie 2005).

> "And there's a difference too in foxes. Foxes that usually remain on the mainland have thicker fur, and the ones that are on the sea ice tend to have thinner fur" (Nutarariaq 2005).

Seven informants provided reasons to explain those differences in physical characteristics. Six out of seven stated that food sources are the principal reason. One out of seven knowledge holders also mentioned that due to the fact that the floe edge is close to open water, the temperature is warmer at the floe edge than on the mainland. Thus, 'sea foxes' that live close to the floe edge do not develop a fur as thick as the 'land foxes'. The general distribution of 'land' and 'sea' foxes has been noted on a map during a workshop (Fig. 38). However, one local expert attending the workshop considered that it was worth mentioning that foxes roam in various places and that the distributions noted on the map should not be considered fixed.

Another fact that emerged spontaneously during the interviews are observations of a massive migration of Arctic Foxes from the land to the sea ice during spring (March-April), where they move to hunt the newborn ringed seal pups. Seventeen (out of 21) informants brought up this comment.

> "And also in spring…like at the last week of March, you find them (arctic foxes) on the sea ice, hunting for seal pups" (Mucktar 2005).

> "From the middle of April, when seals start having their pups… you see a lot of tracks from the land going down to the ice … starting in April. … We use to see, when we'd go out seal pup hunting, we would see fox holes diggings into seal dens. … And one time, while I was seal pups hunting, I opened a seal den and inside was a fox" (Kilukishak 2005).

5.3.3 Changes observed in the local environment

Each local expert interviewed provided her/his own personal comments on changes he/she perceived in the local environment, with a special focus on unexpected changes. Because interview sections related to changes observed in the environment were purposely not oriented towards any specific topic (e.g. climate), answers covered a broad spectrum of subjects, ranging from climate related changes, to beach erosion (Table 5), animal health and distribution (Table 6), and changes observed within the community (Table 7). Although changes related to climate have been mentioned, no clear trend could be discerned amongst all informants. On the other hand, many informants recognized that changes in weather, ice conditions, and precipitations are part of natural cycles, and thus are expected to vary from year to year. More consistent statements about receding glaciers and eroding beaches have been noted.

> "There's also some areas too where the land has gone down further, like where the shore has gone down further, just all because of the water, the sea and the weather. There's many changes like that in a lot of different ways. (…) that's to be expected and there's always gonna be changes, whether it's now or later. But there'll be changes in a lot of ways. But, I just understand, because that is to be expected" (Nutarak 2005).

Declines in animal abundance over certain areas have also been noted (e.g. seals, geese and caribou). Changes in animal abundances have lead to a discussion, during a focus group, about Inuit perspectives on overall variations in animal numbers. In accordance with statements made during individual interviews, the local experts who attended the focus group reiterated on the Inuit belief that changes in animals abundance are due to animal moving away and not necessarily to a decline in overall abundance. Based on their experience, local experts stated that animal abundances have always shown cyclical variations. Hence according to knowledge holders, cyclical reductions in animal numbers are normal and not worrisome.

> "It's normal for the Inuit (that animal numbers vary) and they don't worry about them that they're gonna disappear. We don't worry about them. Even when the biologists think there's no more. We don't worry about them as long as the hunters just don't leave the meat wherever they killed it, or don't destroy the meat (without using it)" (Koonoo 2006).

5.4 TRADITIONAL ECOLOGICAL KNOWLEDGE AND WESTERN SCIENCES

5.4.1 Arrival of the Red Fox in the area of Pond Inlet

An aspect of fox ecology of that raises concerns in the Arctic is the northern expansion of Red Foxes, a phenomenon that has been observed in North America, Europe and Eurasia (Chirkova 1968, MacPherson 1964), and the impact it may have on Arctic Fox populations (Tannerfeldt et Angerbjorn, 1998). Indeed, following expansion of Red Foxes, a decline in Arctic Fox abundances has been observed throughout its arctic range (Angerbjorn et al. 1994, Chirkova 1968). Several studies on the impacts of Red Foxes on Arctic Foxes have been performed in Europe, but nothing has been done in North America so far (Szor 2006).

For the Baffin Island area, the only published information regarding the colonisation of the island by the Red Fox is based on pelt records from Hudson's Bay Company trading posts located on the island (MacPherson 1964). According to these records, the arrival of the Red Fox is estimated to have occurred around 1947, and the first scientific report of a Red Fox being observed on Bylot Island dates from 1977 (Kempf et al. 1978).

TEK on the arrival of the Red Fox around Pond Inlet partially confirmed and complemented the information published so far. Interestingly, 1947 was the earliest data mentioned by local experts who remembered seeing a Red Fox for the first time, a date that coincided exactly with the first pelt records. However, there was also variability in the answers of informants, which seems mostly associated with the geographical context of informants (rather than to their credibility) and the nature of the question addressed. Indeed, in the 1940s, '50s and '60s, most Inuit families (at least the trappers) lived in camps spread over large territories. Therefore, it is most plausible that while one Red Fox was sighted and caught in 1947, it took several years (up to the 60s) for the area to be colonised by the species and for people living in some remote camps to observe the species. As for the informants who claimed always seeing a Red Fox or believing they have always been around, two were born in the 1940s. It is therefore plausible that by the time they started to trap, Red Foxes were already present over their hunting territory. The third informant, who was originally from Clyde River, was born in 1924 and thought that Red Foxes were always around because of his father speaking about the species. Because Clyde River is located hundreds of kilometres south of Pond Inlet and because his father worked for whaling crews and trading posts, it is possible that he had heard of the species a long time before. The fourth informant's statement is harder to explain.

Finally, TEK on the increase in abundance of Red Foxes since its arrival in the area provided a historical perspective on changes in its abundance over several decades. TEK on the locations where various color phases of Red Foxes have been sighted also expanded the scale of scientific observations on this species by providing observations that fall outside Bylot Island.

5.4.2 Winter ecology of the Arctic Fox

TEK concerning the winter ecology provided valuable information on the distribution and diet of the Arctic Fox during this season. In fact, scientific information is currently lacking about the winter diet and distribution of foxes in the Pond Inlet area. Moreover, because Arctic Foxes are opportunistic omnivores, it is hard to generalize the few existing winter dietary data across populations (Angerbjorn et al. 1994, Eide et al. 2005, Fay and Stephenson 1989).

TEK holders provided evidence that Arctic Foxes from around Pond Inlet are not confined to one habitat, but rather use a variety of habitats during winter (from land to sea ice). They also informed us that both lemmings and sea mammal carcasses are important food items during that season, and pointed to the potential importance of seal pup consumption by Arctic Foxes in early spring.

Inuit TEK on the existence of two distinct strategies of resource use, one based on marine and one based on terrestrial resources, among the Arctic Fox population of the Pond Inlet area provided information unknown to scientists working in the area. The existence of two fox 'ecotypes' has been documented by scientists outside of the study region but only for the summer diet, in areas where foxes have access to large bird colonies (Eide et al. 2005, Fay and Stephenson 1989) or at a pan-arctic scale across fox populations evolving in very different habitats (Angerbjorn et al. 1994). TEK on the differences in fur characteristics between the two 'ecotypes' is also an aspect of the Arctic Fox natural history apparently never documented in the scientific literature. This information could have implication for future research or population management.

The importance of sea ice for wintering Arctic Foxes, as reported by local experts, pinpoints to the potential risk that declining ice cover may harm Arctic Foxes in the future. This could be especially significant if a large portion of the Arctic Fox population, as was commented by local experts, move to the sea ice to feed on seal pups in early spring, at a time when their body condition has probably declined due to the harsh winter conditions.

5.4.3 Changes observed in the local environment

Interestingly, when asked if they had observed changes in their environment since they were young, the Elders and hunters interviewed provided a variety of answers on a variety of topics. Comments on changes in the weather and ice conditions have been brought up by some informants, but not all. Indeed, it was not unanimous among informants that changes related to climate had been observed, at least by the summer of 2005. Changes in animal species (behaviour and numbers), and in their condition within and around the community are two topics that were brought up often when talking about changes, probably reflecting (at least in part) the fact that these topics are of direct interest and concern for members of the community.

According to Elders, changes observed are not necessarily considered a trend, or permanent but they are to be expected. This concept may further explain why many informants did not seem concerned about the physical changes they had observed in the environment.

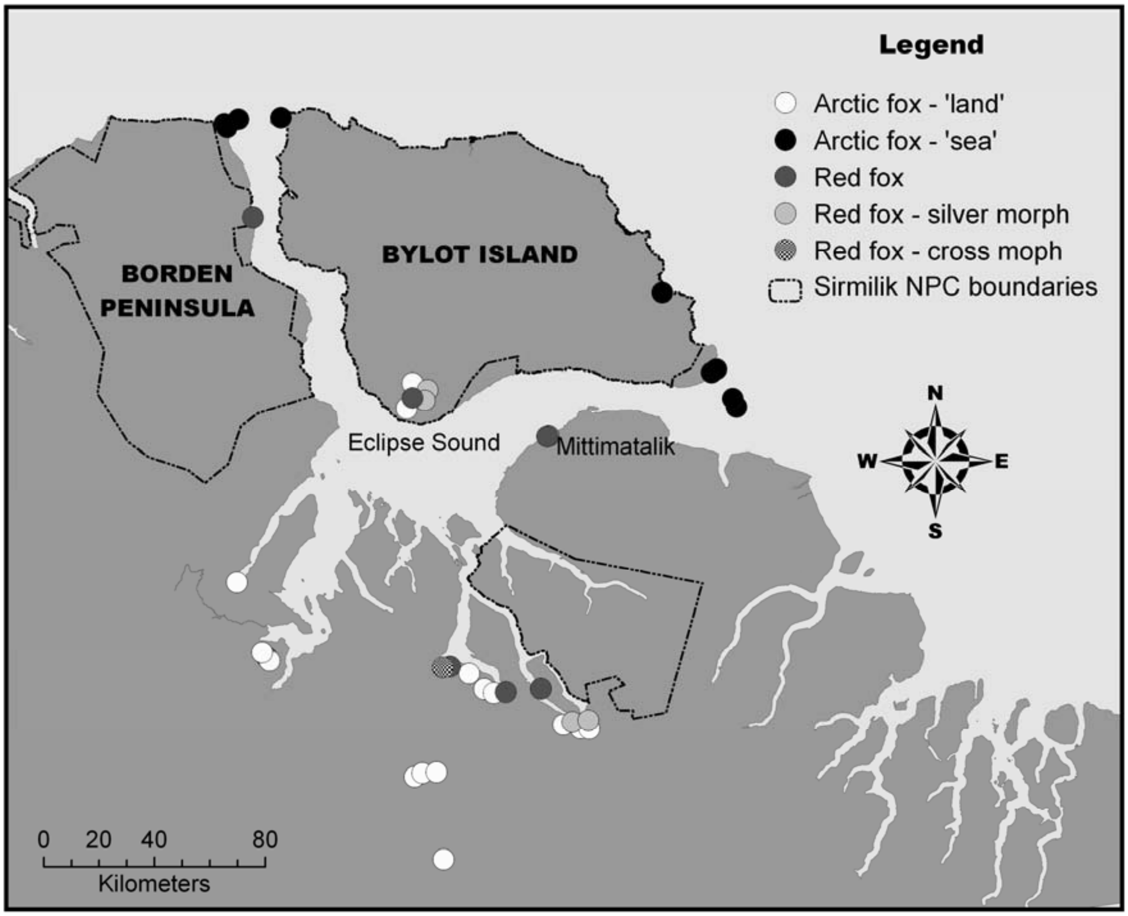


Figure 38. Distribution of 'land' and 'sea' Arctic Foxes and of the color morphs of Red Foxes, as reported by local experts from Pond Inlet, Nunavut.

Table 5. Examples of changes in physical characteristics of the environment, as observed by local experts from Pond Inlet, Nunavut. In some instances, changes have been classified as usual (part of a normal cycle) and are identified as such. When not mentioned, time span corresponds to a comparison of conditions between now and when the informant was young (30 to 40 years ago).

Topic	Observed changes	Evidence, Impacts and Reasons	Time span (if mentioned)
Seasonal temperature	More extreme temperatures	Sometimes it gets colder than before in winter and summers are very hot	
	Winters used to be colder		
	Winters are more humid	Before you could hear your breath, like the noise you can hear when you are blowing a fire. The noise used to be like that.	1990s
	Summers and sun are hotter		
	Warmth seems to stay in fall	In October, when it is suppose to be snowing, rain comes.	Recent years
	Warmth comes earlier in spring, but then it turns cold again.	When it's March it feels like May. The warmth used to come more gradually as the sun is getting higher in spring.	Last few years
	It gets cooler more quickly		Last few years
	Temperatures have shifted	When it is supposed to be warm in spring, it stays cold, and when it is supposed to get cold in fall, it stays warm.	
Precipitations	Varies from year to year (usual)		
	More snow		
	Snow comes later in fall		
	More rain		Last few year
Weather	Weather is harder to predict	Wind and storms come all of a sudden and stay longer. Clouds are different from predictions we used to have. People are more indoors than in the past so they do not see the weather changing and thus have more difficulty to predict it. Elders today cannot predict because the way weather comes is very much different.	

Table 5 (continues)

Topic	Observed changes	Evidence, Impacts and Reasons	Time span (if mentioned)
Wind	Windy more often	Impedes on capacity to go hunting The seeds of dead plants are blown a lot into the ocean	Recent years
	No changes in wind direction in winter	If the weather is mild you can still predict that the wind will be coming from the south or east and if it is extremely cold, you can still predict that the wind will be coming from the west.	
Currents	Currents are slower on Eclipse Sound	Ice moves more slowly during summer break up	Since 1975
Beaches	Beaches have eroded	Archaeological sites have been eroded and this presents a concern. Old tent rings and meat caches have disappeared	
Glaciers	Some glaciers have been receding	Some glaciers used to go down to the water and were thicker. Not anymore Other glaciers, higher in the mountains, have not changed	
Ice	Conditions vary from year to year (usual)		
	Melt is faster	Now that currents are slower, there is more fresh water on top of the ice, so it melts faster Seal holes melt much more quickly now	
	Freeze up is later	Before, in December, used to be able to go to Button Point on the ice, not anymore	Last 3 to 4 years
	Fewer cracks on sea ice		
	Cracks are in different locations	They are different from year to year, but used to be in more or less the same place	

Table 5 (continues)

Topic	Observed changes	Evidence, Impacts and Reasons	Time span (if mentioned)
Ice (continues)	Floe edge is very close	The ice stops before Button Point, a traditional hunting site	Last 3 to 4 years
	Ice is softer	Looks more like compact snow now	
	Ice is thinner	From drilling and looking at seal holes, hunters noticed it is thinner	
		The water puddles that form on the ice when it melts used to be deeper.	

Table 6. Examples of changes in animal condition and abundance, as observed by local experts from Pond Inlet, Nunavut. In some instances, changes have been classified as usual (part of a normal cycle) and are identified as such. When not mentioned, time span corresponds to a comparison of conditions between now and when the informant was young (30 to 40 years ago).

Topic	Observed changes	Evidence, Impacts and Reasons	Time span (if mentioned)
Caribous	Caribous have changed their distribution (usual)	There are less caribous around Mittimatalik now and this always happened like that, because caribou have always moved around looking for food	
	Caribous are less scared of humans	Caribous used to be more scared with dog team	
Insects	New species	There are different species of mosquitoes now in the inlets south of Eclipse Sound	
Sea mammals	Skinny seals	Sometimes you sea seals that are very skinny	
	Poor health	Some seals now have livers that are not as healthy, they have white spots – thus are less edible	
	Decline in seals in some areas	Areas near Mittimatalik have less seals; there is hardly any young seals in Milne Inlet anymore	
		Since arrival of snowmobiles, less seals are basking in front of Mittimtatlik	
	Narwhals have relocated	Where there uses to be no narwhals, there are some now	
		In the earlier days you would always see narwhals passing by Mittimatalik, now you hardly see them.	
		There is less narwhals passing in Nunatsiaq	Compared to 50s
	Narwhals migrate later	Narwhals no longer migrate through the seal holes and cracks in July, they migrate later	
		Since snowmobiles go to the floe edge, narwhals don't migrate early anymore. They used to migrate through cracks in the ice, before the ice breaks up	

Table 7. Examples of changes that happened within the community, as they were observed by local experts from Pond Inlet, Nunavut. In some instances, changes have been classified as usual (part of a normal cycle) and are identified as such. When not mentioned, time span corresponds to a comparison of conditions between now and when the informant was young (30 to 40 years ago).

Topic	Observed changes	Evidence, Impacts and Reasons	Time span (if mentioned)
Community	Younger generation is less aware of the tradition	They go out at any time, without taking into account advice on weather predictions	
		Youth are ignorant of traditional rules on how to keep the environment healthy	
		Youth do not know how to survive as well on the land	
		Youth eat more food bought in stores , they are more dependent on money	
	New technologies	With snowmobiles and outboard motors, people go to different hunting places	
		People use more machinery	
		Because hunters have rifles, people do not go as hungry as before and there seems to be more animals because they are more accessible	
	People are more numerous	People used to live in small settlements – people were then not as sick and there was less garbage than nowadays	
	Garbage	There are more garbage lying around	
		Animals eat garbage and get sick	

6 COMMUNITY WORKSHOPS

Since 2005, we have organized annual community workshops with representatives from the community of Pond Inlet. Every year, at least one researcher from our team, accompanied by students or research associates, travelled to the community to present the most recent findings of our monitoring program. Here we present in details the activities organized in 2008. The details of our past workshops can be found in our previous reports (see Cadieux et al. 2005, 2006, 2007).

In 2008, we organized a full day workshop on ecological monitoring on Bylot Island with representatives from the community of Pond Inlet on 5 March. Invited representatives were from the Joint Park Management Committee (JPMC Pond Inlet members), the Hamlet of Pond Inlet, the Mittimatalik Hunters and Trappers Organization (HTO), the Government of Nunavut, the Elders of Pond Inlet, the Inuit Knowledge Working Group of Pond Inlet, the Parks Canada Office (Pond Inlet an Iqaluit). The workshop was organized by Esther Lévesque, with support from the local Parks Canada Office, and was held in the conference room of the Nattinak Visitor Centre, Pond Inlet. One principal investigator (Esther Lévesque, Université du Québec à Trois-Rivières [UQRT]), two students (Jean-François Therrien, Université Laval and Catherine Gagnon, Université du Québec à Rimouski [UQAR]) and one research associate (José Gérin-Lajoie, UQTR) from southern universities also participated to the meeting. The workshop was followed the same evening by a public presentation at the Nattinak Center, Pond Inlet. Everybody from the community was invited to attend the public meeting through announcements made on the local radio and with posters. Simultaneous Inuktitut/English translation was available during the workshop and public meeting. On the morning of 6 March, the four researchers gave talks to the students of the Pond Inlet Nassivik High School. The school principal organized the schedule of these talks.

Despite the flight cancellation by First Air on 4 March which prevented people from Iqaluit and Arctic Bay to attend, the workshop on 5 March was very successful, with 17 participants (all from Pond Inlet; the list of participants and their affiliation are given in Appendix D). We decided not to change the day of our meeting since some people who had confirmed their presence could not have been able to attend on another day. Four presentations were planned (two by Esther Lévesque with the participation of José Gérin-Lajoie from UQTR and two by Jean-François Therrien from U. Laval; see schedule in Appendix E). All presentations were supported by visual material (Power Point presentations are available upon request). Whenever a question arose and at the end of every presentation, considerable time was devoted to questions and discussions with participants. The purpose of the workshop was to 1) inform the community about the ecological monitoring activities performed on Bylot Island, with a special focus this year on studies related to the vegetation and to predatory birds, 2) present the proposed monitoring activities in the coming years, seeking suggestion and advices, especially new projects associated with the impact of permafrost degradation on goose habitat, berry ecology and predatory birds monitoring. Maps of Bylot Island, Snowy Owl transmitters and regurgitation pellets were presented to the attendees. The four maps derived from aerial photos and satellite imagery were donated to Parks Canada at the end of the meeting. During the workshop, a pamphlet that summarizes the Snowy Owl studies performed on Bylot Island was distributed. The pamphlet was bilingual (Inuktitut-English) and copies were distributed to all participants (see Appendix F). A leaflet introducing the berry project initiated in Nunavik in 2007 (which will be the basis of our new project on berry ecology) was also available in English only (see Appendix G).

The evening consultation with the general public was also very successful with 13 participants including three from Iqaluit, one from Arctic Bay and seven from Pond Inlet. The activity had been publicised in the community (on the community radio). Talks were given by Esther Lévesque, Jean-François Therrien and José Gérin-Lajoie and generated lots of discussion. Snowy Owl pamphlets and berry leaflets were also distributed during the consultation. It was followed by snacks and coffee, which allowed people to discuss in a more informal way.

The morning of 6 March was dedicated to talks given at the high school. Esther Lévesque and Jean-François Therrien presented their research, with a special focus on predatory birds and vegetation monitoring in one classroom while Catherine Gagnon and José Gérin-Lajoie presented research results and proposed projects with a special focus on local ecological knowledge in another room. After 30 minutes the students changed class. The 15 to 20 minutes presentation supported by visual material (Power Point) was repeated for each group. Photographs, maps and other material including Snowy Owl pellets, was also presented. During the presentations, the possibility for students to get summer jobs with the researchers was advertised. Students and teachers enjoyed the talks and our presentation generated several questions from the students. Overall, the interactions between researchers and students were very positive and very stimulating for everybody.

7 HIRING AND TRAINING OF INDIVIDUALS FROM POND INLET

Over the last four years, we hired a total of 14 different persons from the Pond Inlet community to work with us in the field for various lengths of time during the summer. All these people received valuable training in environmental studies while working with us. We also hired 10 additional people for the TEK component to assist Catherine A. Gagnon in different aspects of her study. Every year, Philip Panneak was also hired as a translator during our community workshop and public presentation. In 2007, our field assistants included Daniel Ootoova, Joassie Otoovak, Bernie Kilukishak, Terry Killikty and Samuel Arreak.

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

Our analysis confirmed empirically that the region of Bylot Island has been experiencing a strong warming trend over the last three decades. These trends were mostly visible during the spring, summer and especially the fall season as the mean air temperature has warmed by 2.1 to 4.5^{o}C during this period. Our monitoring has started to reveal some impact of this warming on the ecosystem. Here are the most significant changes detected over the last two decades on Bylot Island.

- Plant production in wetlands of Bylot Island has almost doubled over the period 1990-2007 with an 84% increase. This is likely a direct consequence of climate warming as our detailed analysis revealed that temperature and precipitation were the most influential factors on plant production.

- Climatic variations appear to be the most important driver of the annual production of several migratory birds. This is best exemplified by Greater Snow Geese as our long-term record showed a very close association between the breeding phenology (i.e. laying date) or their breeding effort (i.e. nest density) and climatic factors, primarily air temperature.

- As the summer temperature and plant production both increase, one could think that this would have beneficial effects on herbivorous species like geese. However, our analysis also revealed some unexpected negative effect of warm temperature on geese, as gosling growth was reduced in years with warm spring temperature and early snow-melt. A possible explanation is that warm, early springs may lead to a mismatch between the peak in plant quality and hatching date of goslings, resulting in poor feeding conditions for them.

- We found evidence that the 3 to 4-year cycle of lemming abundance may have been disrupted, as recent peaks of abundance were much weaker than previous ones. Although many factors could affect lemming abundance, the strong warming trend detected in the fall could be one explanation for the low abundance of lemmings because some studies have shown that poor snow condition and an increased frequency of freeze-thaw cycles at the onset of winter may increase winter mortality of lemmings and prevent population build-up. If proven to be real, this phenomenon could have far-reaching impacts on the whole tundra food webs as lemmings are the primary prey of most tundra predators and play a key role in the population dynamics of these species.

- We found evidence that the proportion of fox dens with reproductive activity has decreased over the years. This could be a consequence of the low abundance of lemmings recorded recently during peak years of abundance, and clearly shows how change in prey abundance due to climatic factors could affect predators higher up along the food chain.

- Our Traditional Ecological Knowledge study pertaining to snow geese and foxes has shown that Elders knowledge can provide complementary information to our monitoring program. For instance, we found that traditional knowledge on foxes expanded the spatial and temporal scales of our current scientific knowledge. However, according to Elders, changes observed in their local environment are not necessarily considered a trend or permanent. These changes are to be expected and many informants did not seem concerned about the physical changes they had observed in the surrounding area of Pond Inlet.

8.2 RECOMMENDATIONS

- The environment of Bylot Island is changing, and we presented several examples of it. Detecting these changes was only possible because our work on Bylot Island has been ongoing for almost two decades. We thus recommend that long-term monitoring effort of this ecosystem is maintained in future years. In particular, the recent addition of some significant ecosystem components (e.g. shorebirds, avian predators) will likely require many more years of monitoring before significant changes in these groups can be detected.

- Everybody would like to be able to forecast how the abundance and distribution of animals will change in response to climate change. However, our long-term studies revealed how this may be a complex task. In particular, the snow goose example shows that climate change may have both positive and negative impacts on this species. Therefore, despite the large amount of knowledge acquired on this ecosystem, we are still unable to accurately predicting how it will evolve in response to climate change. We thus recommend that intensive, detailed studies be pursued in parallel to monitoring in order to improve our understanding of the ecosystem, and especially of the trophic interactions among species.

- We are highly satisfied with the success of the TEK component of our project. Support from the community was very high and many positive feedbacks were expressed from community members throughout the project. We have shown that the integration of TEK and scientific knowledge is possible and can serve as a powerful tool to get a clearer picture of the Bylot Island ecosystem. We recommend that partnership with the community of Pond Inlet continues in the future and that resources are allocated to maintain and even strengthen this partnership. Indeed, unlike the NEI program, traditional funding sources for university researchers do not specifically allow funds for community workshops or interactions. Thus, we are clearly in need of such programs to maintain these important partnerships.

- We have made considerable efforts to establish close collaborations with people responsible to manage this ecosystem and the exploitation of species inhabiting it (e.g. Parks Canada, Canadian Wildlife Service). We thus recommend that main findings of our work are integrated in the management plan developed by these governmental agencies, especially for exploited species like snow geese or foxes.

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APPENDIX A. Climatic metadata for the seven weather stations on Bylot Island, Nunavut.

STATION	CLIMATIC VARIABLE	TIME PERIOD
Bylot S1	Ground surface temperature (at 2 cm)	August 1996 – July 2007
Bylot S2	Air humidity	March 1994 – August 2007
	Air temperature (at 2 m)	March 1994 – August 2007
	Soil temperature (at 2 and 10 cm)	March 1994 – August 2007
	Net solar radiation	March 1994 – July 2005
	Photosynthetic active radiation	March 1994 – July 2005
	Wind speed (at 3 m)	March 1994 – August 2007
	Wind direction	March 1994 – August 2007
	Snow depth	October 2001 – August 2007
Bylot S3	Air humidity	July 2005 – August 2006
	Air temperature (at 2 m)	July 2005 – August 2006
	Soil temperature (at 2 and 5 cm)	July 2005 – August 2006
	Wind speed (at 3 m)	July 2005 – August 2006
	Wind direction (at 3 m)	July 2005 – August 2006
	Snow depth	July 2005 – August 2006
Bylot SILA	Air humidity	July 2004 – July 2007
	Air temperature (at 5 m)	July 2004 – July 2007
	Soil temperature (at 5 and 10 cm)	July 2004 – July 2007
	Wind speed (at 10 m)	July 2004 – July 2007
	Wind direction (at 10 m)	July 2004 – July 2007
	Snow depth	July 2004 – July 2007
	Solar radiation – far infrared	July 2005 – July 2007
	Solar radiation – PAR	July 2005 – July 2007
	Solar radiation – albedo	July 2005 – July 2007
	Solar radiation – UV-B	July 2005 – July 2007
	Net solar radiation	July 2004 – July 2005
	Barometric pressure	July 2004 – July 2005
Bylot PB	Soil temperature (at 0, 10, 20, 30, 40, 80, 120, 160, 200, 300 cm)	June 1999 – July 2007
Bylot PD	Soil temperature (at 0, 10, 20, 30, 40, 80, 120, 160, 200, 300 cm)	June 1999 – July 2007
Bylot PP	Soil temperature (at 0, 60, 100, 200, 300, 500 , 800, 1000, 1100 cm)	July 2000 – July 2007

APPENDIX B. Air temperature recorded at the Environment Canada weather station of Pond Inlet from 1976 to 2007.

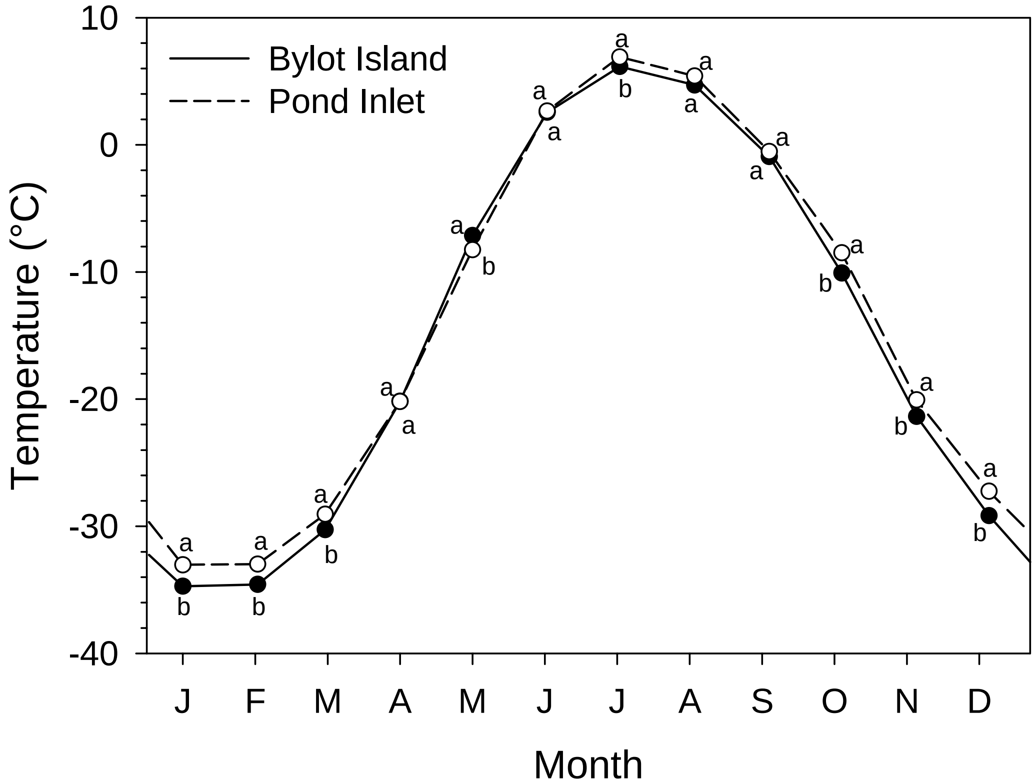


Figure B1. Comparison of average monthly air temperatures on Bylot Island and Pond Inlet from 1994 to 2007. Months with the same letters are not significantly different ($P > 0.05$) between sites (interaction site × month: $F_{11, 311} = 7.58$, $P < 0.001$).

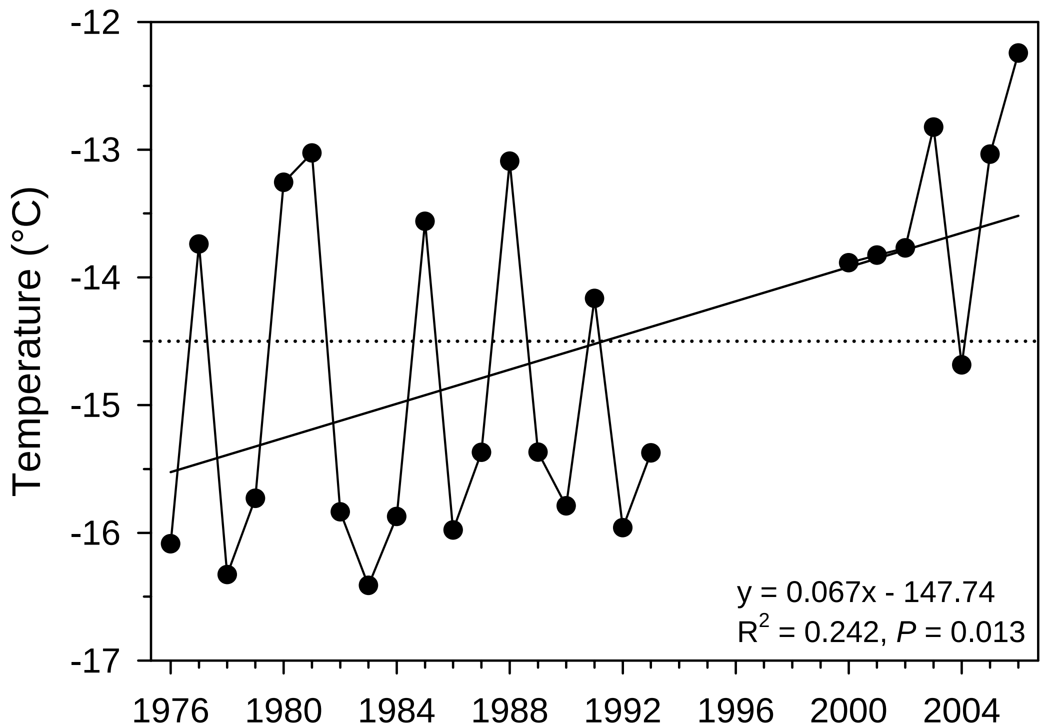


Figure B2. Average annual air temperature recorded at the Environment Canada weather station of Pond Inlet from 1976 to 2006 (from www.cen.ulaval.ca/bylot/). The dotted line shows the mean for the whole period. The significant temporal trend is represented by a solid line ($P < 0.05$).

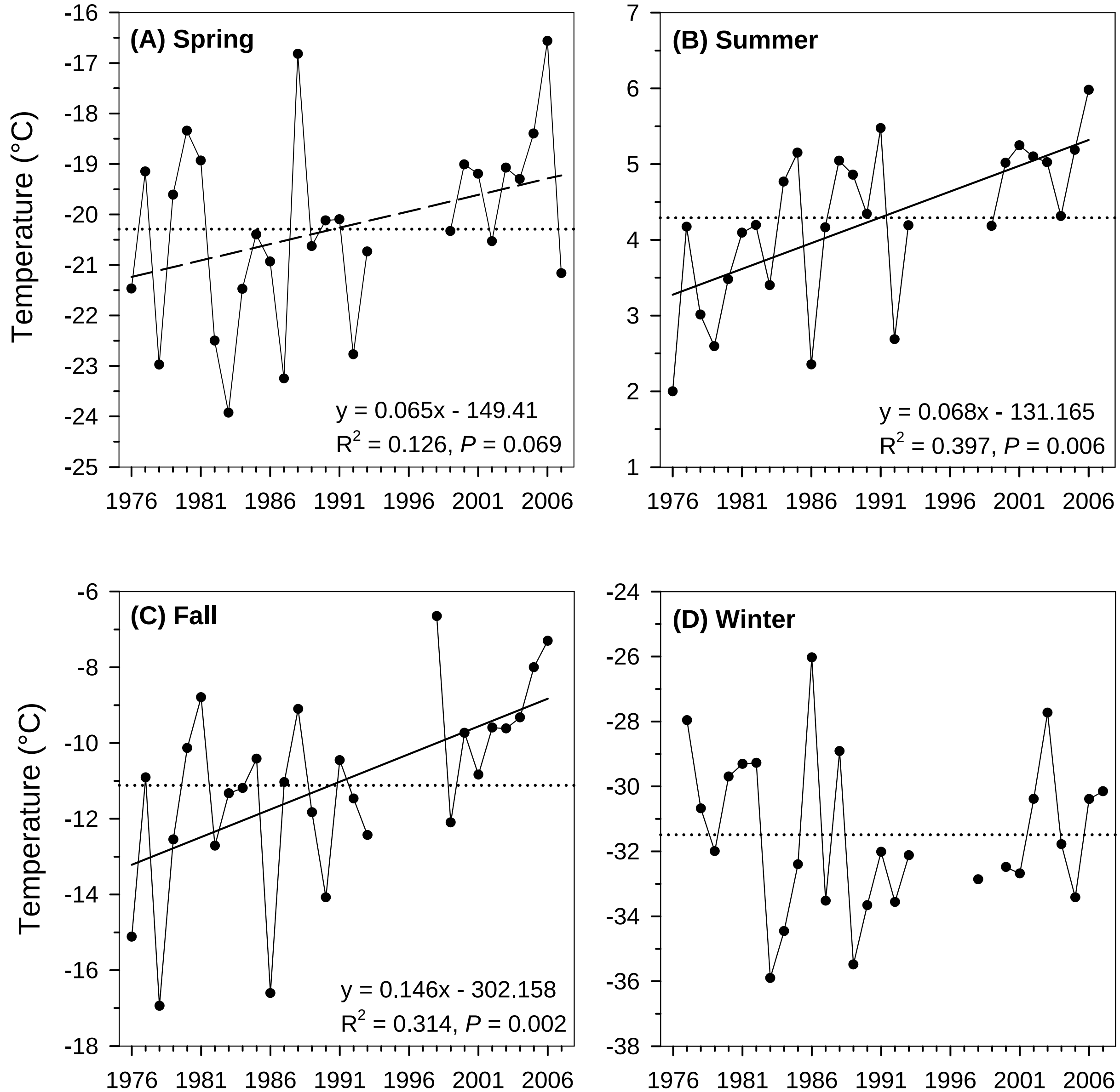


Figure B3. Average air temperature recorded at the Environment Canada weather station of Pond Inlet from 1976 to 2007 (from www.cen.ulaval.ca/bylot/) for (A) spring (March to May), (B) summer (June to August), (C) fall (September to November) and (D) winter (December to February). The dotted line shows the mean for the whole period. Temporal trends are represented by a solid line when significant ($P < 0.05$) and by a dashed line when approaching significance ($0.05 < P < 0.15$).

APPENDIX C. Questionnaire used during the interviews for the Traditional Ecological Knowledge project (from Gagnon 2007).

INTERVIEWEE PERSONAL DATA

1. Where were you born?
2. What year where you born?
3. Have you lived in this area for a long time?
4. Did you live somewhere else and for how long?
5. Are you still going on the land for hunting and camping? If yes how often and at what time of the year?
6. If no when did you stop going on the land and for how many years did you go before you stopped?
7. Can you tell me in which area you spend the most time when you go out on the land (if applicable)? Which area do you know the most?

SNOW GEESE (KANGUQ, QAVII, KANGUARA)

Hunting
1. Do you harvest snow geese?
2. Can you show me on the map where? (as a young adult compared to now)
3. How frequently do you hunt geese? What time of the year?
4. Did you hunt geese more or less in the past?
5. Can you comment on the method you use to harvest geese?
6. Is the method similar or different than methods use in the past?
7. I heard of people driving geese on the ice to kill them, have you heard of this method?
8. Have you heard of geese fences made of rocks?
9. What kind of geese are the best for hunting. Do they have young with them? What I mean is there are groups with young and it seems there are groups without.

Eggs
1. Do you gather goose eggs?
2. Can you show me on the map where? (as a young adult compared to now)
3. How frequently do you gather eggs, what time of the year?
4. Did you gather eggs more or less frequently in the past?

Migration
1. Can you show me on the map where you see geese arriving first in the spring?
2. When do you see geese leave the area?
3. What happen at that moment, do they leave all at the same time?
4. Can you show me their travel routes?
5. Do you remember times when migration was unusually early or late?

Nesting
1. Where have you seen geese nesting? Where are the large groups?
2. In your lifetime, have you seen geese nesting in the same areas or have they moved to other areas? (as a young adult compared to now)

3. Do you have knowledge about where your parents, grand-parents and other Elders use to see large geese nesting areas?
4. Do these areas have names?
5. I have heard of a place called Qaversisit? Have you heard of this place? Can you tell me about his place? Is it a nesting place for geese?

Molting
1. When do the geese start to molt their feathers? Do they all molt at the same time?
2. Do you know where geese go to molt their feathers? Those that have nest and goslings? Those that do not have nests?
3. On your lifetime, have you observed that geese (those that do not have young) always go to molt their feathers in the same place?
4. Do you have knowledge about where your parents, grand-parents and other Elders use to see geese molting?

Numbers
1. Have you noticed any similarities or change in the number of geese you see today compared to before? (as a young adult compared to now)
2. Do you remember any exceptional years when you did see very many or very few geese? What was special in that/those year(s) that could have affected the geese?

Geese health
1. Have you noticed if geese are healthier, same or less healthy than now than they were before (as a young adult compared to now)
2. Do you remember anything that stands out that you have noticed concerning the health of geese?

Community use and values
1. Can you please comment on why are geese important to you, to your culture or to your children and grand-children?
2. Do the people use geese now the same way that they use to a long time ago?

Final comment about the geese
1. Do you have any other comment or old stories you would like to share regarding the geese?

ARCTIC AND RED FOXES (TIRIGANNIAQ, QIANGAQTUQ, KAJUQTUQ)

Hunting
1. Do you trap or hunt Arctic and/or Red Foxes?
2. If you still hunt or trap foxes on a regular basis, how frequently do you go out to trap them?
3. If you don't trap them now, have you trap them in the past, how many years?
4. Can you show me on the map where you trap foxes? (as a young adult compared to now)
5. Are the areas different for the Arctic Foxes and the Red Foxes?
6. Do you know of other places used by trappers to get foxes?
7. Did you go out to trap foxes more or less in the past
8. What time of the year do you trap foxes?

9. Can you comment on the method you use to trap foxes?
10. Is the method similar or different than methods use in the past?
11. What are the best foxes to trap?

Molting
1. At what time of the year do you see the white fur appearing on the Arctic Foxes?
2. At what time of the year the fur of the Arctic Foxes start to be completely white?

Red Foxes
1. Have you always seen Red Foxes in the area? If not, when did you see them for the first time?
2. Did you ever hear your parents, grandparents or other Elders talking about the first time they saw Red Foxes? When did they see them for the first time?
3. What happened after the arrival of the Red Fox?
4. How did people react when they saw Red Foxes for the first time?
5. Have you ever seen Arctic and Red Foxes at the same time? What were they doing?

Differences between arctic and red foxes
1. What are the major differences between Red and Arctic Foxes?
   (behavior, food, intelligence, relation to humans)

Reproducing habitat
1. Can you show me on the maps areas that are good for the foxes to reproduce, to build a den? Why are these areas good?
2. Can you show me places where you have seen fox dens. Can you show me dens that are:
   a. old
   b. new (last ten years)
   c. are these dens occupied by Arctic or Red Foxes?
3. Are some areas better for the Red Fox than the Arctic Fox?
4. Do you know of dens that were abandoned, or Arctic Fox dens taken over by Red Foxes?

Feeding habitat
1. Can you show me on the maps areas that are good for foxes to feed?
2. Are the good areas the same for the Arctic and Red Foxes? Why?
3. During the winter, where do you most often see the Arctic Fox? Do you see them on the land or on the ice?
4. And what about the Red Fox?
5. When you see Arctic Foxes during the winter, what are they generally doing?
6. When you see Arctic Foxes eating a carcass, the carcass of what animal do they eat more generally (seals and what kind, walruses, whales)?
7. When Arctic Foxes are eating a carcass, do they eat the fat or the meat or both?

Temporal and spatial trends in distribution and abundance
1. Do you know of any places where you used to see Arctic and/or Red Foxes and where you do not find them anymore? Or where there are less?
2. Do the number of foxes you see today similar or different compared to when you were younger?

3. Are there places where your parents, grandparents or other Elders used to see many Arctic and Red Foxes that are different than today? Can you show me these places on the maps?

Fox health
1. Do foxes are always the same, or have you seen changes in their health from time to time? What are the signs that tell you that their health has change?
2. Have you seen foxes that are particularly in bad health?

Threats and disturbance
1. Can you describe any threat to foxes that you know off?
2. Do you think foxes avoid places where you find humans?

Community use and values
1. Can you please comment on why foxes are important to you, to your children and grand-children?
2. Do the people use foxes now the same way that they used to a long time ago?
3. What do you use the foxes for today?

Final comment about the foxes
1. Do you have any other comment you would like to make regarding the foxes, any old stories or interesting thing?

APPENDIX D. List of attendees to the Bylot Island Research and Monitoring Workshop and public consultation on 5 March 2008 at the conference room of the Nattinak Visitor Center, Pond Inlet.

Name	**Affiliation**	**Workshop**	**Public meeting**
Debbie Jenkins	Dept Environment, Gov. Nunavut, Pond Inlet	X	
Gregor Hope	Dept Environment, Gov. Nunavut, Pond Inlet	X	
David Qamaniq	Joint Park Management Committee, Pond Inlet	X	X
Gesoni Killiktee	Joint Park Management Committee, Pond Inlet	X	
Qavavauq Issuqangituq	Joint Park Management Committee, Pond Inlet	X	
Mike Richards	Pond Inlet Senior Administration Officer	X	
Andrew Maher	Parks Canada, Pond Inlet	X	X
Brian Koonoo	Parks Canada, Pond Inlet	X	
Carey Elverum	Parks Canada, Pond Inlet	X	X
Israel Mablick	Parks Canada, Pond Inlet	X	
Bernie Kilukishak	Field assistant – Goose camp 2007	X	
Terry Killiktee	Field assistant – Goose camp 2007	PM	
Daniel Ootova	Field assistant – Goose camp 2007	X	
Isidore Quasa	Inuit knowledge research assistant 2005	AM	
Andrew Sangoya	HTO - Community initiatives	AM	
Sheatie Tagak	HTO	PM	X
Elijah Panipakoochoo	HTO		X
James Atagootak	HTO		X
Darlene Willie	JPMC - Arctic Bay mayor		X
Tommy Tattatuapik	Joint Park Management Committee, Pond Inlet		X
Katy Hanson	Parks Canada, Iqaluit		X
Gary Mouland	Parks Canada, Iqaluit		X
Paul Ashley	Parks Canada, Iqaluit		X
Richard Carbonnier	Architect, Pond Inlet		X
Philip Panneak	Inuit Qikiktani Association, translator	X	X
Esther Lévesque	Professor, Université du Québec à Trois-Rivières	X	X
Catherine A. Gagnon	MSc student, University Quebec Rimouski	X	X
José Gérin-Lajoie	Research assistant, Université du Québec à TR	X	X
Jean-François Therrien	PhD student, Université Laval	X	X

APPENDIX E. Schedule of the workshop and public presentation on ecological monitoring on Bylot Island, Sirmilik National Park, Pond Inlet, 5 March 2008.

WORKSHOP ON ECOLOGICAL MONITORING ON BYLOT ISLAND, SIRMILIK NATIONAL PARK

POND INLET, 5 March 2008 – Nattinak Visitor Centre

WEDNESDAY, 5 March	
9:00-10:15	**Esther Lévesque (Université du Québec à Trois-Rivières)** Welcome word –Ecological research on Bylot Island with emphasis on plant research
10:15-10:35	Coffee Break
10:35-11:30	**Jean-François Therrien (Université Laval)** Research on birds on Bylot Island with emphasis on snowy owls (Ookpik)
11:30-12:00	**Jean-François Therrien (Université Laval)** Consultation on Hunter Harvest Survey
12:00-13:30	LUNCH TIME
13:30-15:00	**Esther Lévesque & José Gérin-Lajoie** New research initiatives on Bylot Island
15:00-15:20	Coffee Break
15:20-17:00	Discussions between researchers, JPMC members, Parks Canada people, HTO members and other people interested to discuss specific issues/topics related to the Bylot Island ecological monitoring

PUBLIC PRESENTATION ON ECOLOGICAL MONITORING ON BYLOT ISLAND, SIRMILIK NATIONAL PARK

POND INLET, 5 March 2008 – Nattinak Visitor Centre

19:00 – 19:10	**Esther Lévesque, Jean-François Therrien & José Gérin-Lajoie** Welcome word to the public evening session
19:10 – 21:00	**Public presentation of research performed on Bylot Island** Ecological research on Bylot Island Research on Arctic birds and on vegetation on Bylot Island Presentation of plants collected on Bylot Island

APPENDIX F

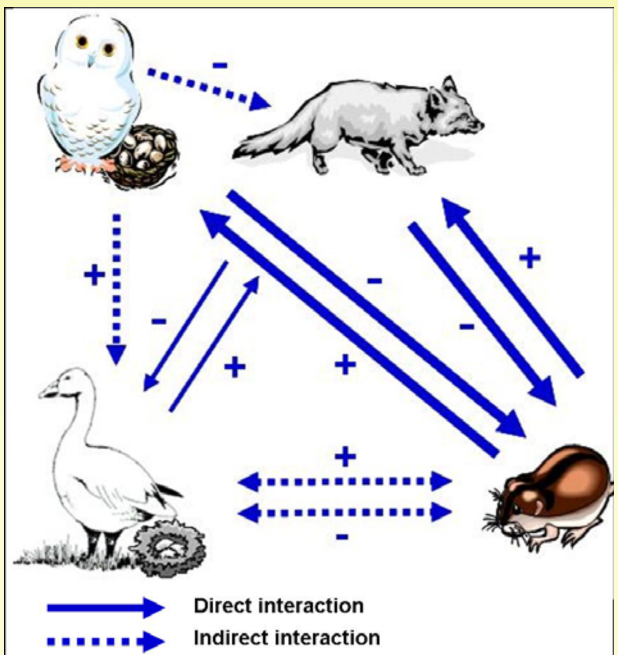
Pamphlet on the snowy owl study on Bylot Island, Sirmilik National Park
distributed to the participants at the workshop

ᓱᒻᒪᑦ ᖃᐅᔨᓴᖅᑕᐅᕙᑦ ᐅᑉᐱᒃᔪᐊᑦ?

Why study Snowy Owls?

ᐅᑉᐱᒃᔪᐊᑦ ᐱᒻᒪᕆᐅᓛᖑᖃᑕᐅᔪᖅ ᖁᕙᓯᑦᑐᓂ ᓂᕿᑐᖃᑦᑕᖅᑐᖅ ᐅᑭᐅᑕᖅᑐᒥᑦ ᐊᕙᑎᖓᓂᑦ ᐊᒻᒪ ᐃᓚᒋᓪᓗᐊᑕᕆᓪᓗᓂᐅᒃ ᑲᑎᖓᑎᐊᕐᓂᖓᓂᑦ. ᑭᓯᐊᓂᓕ ᖃᐅᔨᒪᑦᑎᐊᖏᓐᓇᑦᑕ ᓇᒧᖓᖃᑦᑕᕐᓂᖏᓐᓂᑦ, ᐅᓄᕐᓂᖏᓐᓂ ᐊᒻᒪ ᖃᐅᔨᓴᖅᑕᐅᓂᖏᑦ ᐊᒥᓲᓂᖏᑦ. ᐊᑦᑕᓇᖅᑐᒦᒍᓐᓇᕐᒥᔪᑦ ᓯᒪᐅᑉ ᐊᓯᔾᔨᕐᓂᖓᓄᑦ ᐅᐱᓐᓇᕐᓂ ᐊᔾᔨᐅᓐᓇᓂ ᓂᕿᑐᖃᑦᑕᖅᑐᖅ ᓄᓇᒥᐅᑕᐅᓪᓗᓂ.

Snowy Owls are one of the most important top predator of the arctic ecosystem and a key component of its integrity. However we know little about its movements, abundance and demography. They are also vulnerable to climate change because it is a specialist predator well adapted to the tundra.



ᐊᐱᖅᑯᑎᒃᓴᖃᕈᕕᑦ? ᐅᕙᑦᑎᓐᓂ ᑐᑭᓯᒋᐊᕆᒃᓯ!

Questions? Contact us!

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ᖁᔭᓐᓇᒦᒃ! Thank you!

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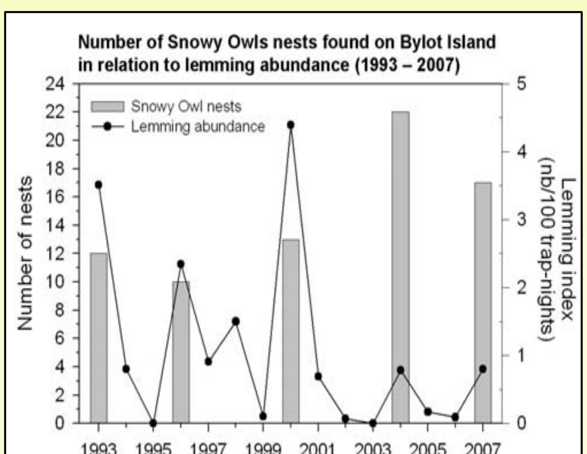
ᐅᑉᐱᒃᔪᐊᓂᑦ ᖃᐅᔨᓴᕐᓂᖅ ᒥᑦᑎᒪᑕᓕᐅᑉ ᐊᑭᐊᓂ

Snowy Owl studies on Bylot Island

ᐱᕈᐅᖃᖃᑦᑕᕐᓂᖏᑦ ᖃᐅᔨᓴᖅᑕᐅᓂᖏᑦ
Breeding biology

ᑖᓐᓇ ᐊᖏᔪᖅ ᐅᑭᐅᑕᖅᑐᒥᑦ ᐅᐸᒃᔪᐊᖅ ᐱᕈᐅᖃᖃᑦᑕᖅᑐᑦ ᓄᓇᐃᓐᓇᕐᒥᑦ ᓯᓚᕐᔪᐊᒥ ᐅᑭᐅᑕᖅᑐᒥᑦ. ᐊᒥᓱᒐᓚᐃᑦ ᐅᐸᒃᔪᐊᑦ ᐱᕈᐅᖃᖅᐸᑦᑐᑦ ᒥᑦᑎᒪᑕᓕᐅᑉ ᐊᑭᖓᓂ ᑭᓯᐊᓂ ᐊᕐᖀᒍᖏᓐᓂ ᐊᕕᓐᖓᐃᑦ ᐊᒥᓲᑎᓪᓗᒋᑦ. ᐊᕕᓐᖓᖃᑦᑎᐊᖏᑦᑐᖅ ᕿᑭᖅᑕᒥᑦ ᐊᓯᖏᓐᓂ ᐊᕐᖀᒍᖏᓐᓂ.

This large northern owl breeds in the open tundra of the circumpolar Arctic. Numerous Snowy Owls breed on Bylot Island but only in years when there is a high abundance of lemmings. There are almost absent from the island in other years.



ᒫᓐᓇᐅᔪᒥᑦ ᖃᐅᔨᓴᕐᓂᐅᔪᖅ ᓯᕐᒥᓚᒃ ᒥᕐᒍᐃᓯᕐᕕᒻᒥᑦ
Current research in Sirmilik National Park

ᐅᐸᒃᔪᐊᑦ ᖃᐅᔨᒪᔭᐅᔪᑦ ᓇᒧᑐᐃᓐᓈᕈᓐᓇᕐᓂᖏᓐᓂ. ᑖᓐᓇ ᖃᓄᐃᓘᕐᓂᖓ ᐃᓱᒪᒋᔭᐅᔪᖅ ᐊᓯᔾᔨᖃᑦᑕᕐᓂᖏᓐᓄᑦ ᐊᕕᓐᖓᐃᑦ ᐊᒥᓲᓂᖏᑦ. ᑖᓐᓇ ᑎᒻᒥᐊᖑᔪᖅ ᑕᑯᔭᐅᖃᑦᑕᖅᑐᑦ ᖃᓪᓗᓈᑦ ᓄᓇᖓᓂ ᑲᓇᑕᒥ ᐅᑭᐅᒃᑯᑦ, ᐅᑎᖅᑕᖃᑦᑕᕐᕕᒋᕙᑦᑕᖏᑦ ᐊᕐᕿᒍᑕᒫᑦ ᖃᐅᔨᒪᔭᐅᑦᑎᐊᖏᑦᑐᑦ. ᐊᑐᖅᑐᒍᑦ ᖃᖓᑦᑕᖅᑎᑕᐅᓯᒪᔪᒃᑯᑦ ᖃᐅᔨᓴᕈᑎᒥᑦ ᐅᖓᓯᑦᑐᓄᑦ ᓇᒧᖓᖃᑦᑕᕐᓂᖏᑦ ᐅᐸᒃᔪᐊᑦ ᐊᒻᒪ ᐊᑦᑐᐊᓂᖃᖅᑎᓪᓗᒋᑦ ᐊᕕᓐᖓᐃᑦ ᐊᒥᓲᓂᖏᑦ.

Snowy Owls are known for their erratic movements. This behaviour is believed to be related to fluctuations in the abundance of its main prey, the lemming. Although this bird is seen in southern Canada during winter, its seasonal and annual movements are largely unknown. We are using satellite telemetry to track long-distance movements of owls and to relate them to lemming abundance.

ᐅᖓᓯᑦᑐᒨᖃᑦᑕᕐᓂᖏᑦ
Long-distance movements

ᖃᐅᔨᓴᖅᑕᐅᓃᑦ ᑎᓴᒪᑦ ᐅᐸᒃᔪᐊᑦ ᐱᕈᐅᖃᖅᑐᑦ ᓇᓄᓇᐃᒃᑯᓯᖅᓯᒪᔪᑦ ᒥᑦᑎᒪᑕᓕᐅᑉ ᐊᑭᖓᓂ ᐱᒋᐊᖅᑐᒍ ᔪᓚᐃ 2007 ᑎᑭᑦᑐᒍ ᕕᕗᐊᕆ 2008. ᑖᒃᑯᐊ ᑎᓴᒪᑦ ᑎᒻᒥᐊᑦ ᐊᔾᔨᒌᖕᖏᑦᑐᒻᒪᕆᓐᓂ ᓇᔪᖅᑐᑦ ᐊᒻᒪ ᑕᑯᒃᓴᐅᑎᑦᑎᔪᑦ ᓇᒧᑐᐃᓐᓈᕈᓐᓇᕐᓂᖏᓐᓂ ᑎᒻᒥᐊᑦ.

Tracking of 4 Snowy Owl breeding females marked on Bylot Island from July 2007 to February 2008. These 4 birds followed very different paths and illustrate the erratic movements of the species.

APPENDIX G

Leaflet introducing the berry project initiated in Nunavik in 2007
distributed to the participants at the workshop

Climate change impacts on berry ecology in Canadian arctic tundra: linking local ecological knowledge with science

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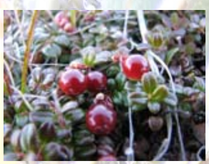
PROJECT OBJECTIVES

Berry picking is an important activity in Northern communities and berries are a good source of vitamins and antioxidants. The main objective of this project is to link local ecological knowledge (LEK) obtained by interviewing Inuit Elders, with scientific data on inter-annual variations in productivity (biomass/m^2) of commonly used berries.


Kimminaq
(*Vaccinium vitis-idaea*)


Paurngaq
(*Empetrum nigrum*)


Kigutangirnaq
(*Vaccinium uliginosum*)


Arpiq
(*Rubus chamaemorus*)

Local ecological knowledge (LEK) will address questions such as:

1) Where did berry picking take place in past decades?

2) Where is this activity still practiced today?

3) What is the perception of Inuits of climate change and its effects on climate *per se* (wind, rain, snow, ice, temperature), but also on plants, animals and human activities?

Scientific approaches will be used to:

1) Document natural variability in distribution and abundance of berry producing species.

2) Measure environmental factors affecting berry productivity such as exposition, slope, ground temperature, snow cover.

3) Measure biotic interactions such as shrub and tree covers, presence of pollinating insects, etc.

In the early phase of this project, the proposed objectives are discussed with communities in order to insure that community needs are addressed concurrently with basic scientific issues.

STUDY SITES

In 2007, two sites were established in Nunavik (N. Quebec):

Kangirsujuaq

Kangirsualujjuaq

At least two others are planned for 2008, in Nunavut : Pangnirtung and Pond Inlet.

METHODOLOGY

LEK

Semi-structured interviews, with an interpreter, are used to collect Inuit knowledge and perception about vegetation changes, berry ecology and climate change. These interviews also serve to address their preoccupations in relation to these changes. Old photographs have been used to help the interviewees relocate certain sites, to evaluate vegetation changes and to facilitate story-telling. Interviews are transcribed and analysed.

Some of the Elders interviewed in the project:


Susie Morgan


Nappaaluk Arnaituk


Alasie Koneak


Pitiulaq Pinguatuk

SCHOOL PROJECT

Two northern teachers and their students of Ulluriaq School, in Kangirsualujjuaq, and Arsaniq School, in Kangirsujuaq, are collaborating in the survey of berry productivity. Six to ten small monitoring quadrats (25cm x 25cm) have been marked for each species inside permanent plots of 50 – 150 m². All fruits inside the quadrats are collected annually, weighed and counted. Snow height is also measured by northern students alongside the vegetation plots and snow transects. Some classes are also involved in recording meteorological and ecological observations in specially designed calendars (see example below).


Ammak Annanack and Sandy Emudluk

BERRY ECOLOGY

The ecology of berry producing shrubs will be studied in permanent plots in a range of microhabitats by characterizing species cover, vegetation height, plant phenology, berry productivity and biophysical parameters. In 2008-2009, we plan to return to a few sites identified by elders or berry pickers to evaluate the status of berry production and identify potential causes of changes. A field experiment simulating low-level warming with open-top chambers (OTCs) and increased shrub growth by shading will be installed to quantify the impact on berry producing shrubs.

WHAT WAS DONE AND WHAT NEXT!

During the summer of 2007, eight interviews have been completed with elders of Kangirsualujjuaq (3 men and 5 women) and eleven with elders of Kangirsujuaq (4 men and 7 women) in Nunavik. Analyses are in progress.

Students, guided by their teacher, harvested three species of berries growing in the monitoring quadrats, then weighed, counted and shipped them to the scientific team for different analyses (*e.g.* antioxidants).

In 2008-2009, we will survey berry sites during the picking season to gather berries with community members, especially elders and youth, and to realize other interviews.

We are developing protocols in collaboration with all partners in order for the school monitoring program to be expanded to other parts of the Canadian North (South/North and East/West axes) and be integrated in monitoring networks such as CANTTEX and PlantWatch. Other communities are already interested in using a similar approach: Nain in Labrador and Kugluktuk in the Northwest Territories.

ACKNOWLEDGEMENTS

This project is part of the Climate Change impacts on Canadian Arctic Tundra program (CiCAT) initiated under the International Polar Year (IPY). We thank the communities of Kangirsujuaq and Kangirsualujjuaq for their support, especially the Elders, interpreter, school teachers and students. Their enthousiasm and commitment are essential to the success of this project.