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The effects on lowland habitat, breeding shorebirds and songbirds in the Banks Island Migratory Bird Sanctuary Number 1 by the growing colony of Lesser Snow Geese (*Chen caerulescens caerulescens*)

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Introduction

This investigation was driven by concerns arising elsewhere in the Canadian Arctic where the mid-continent population of Snow Geese has increased steadily over the past several decades to record-high numbers (Abraham et al. 1997; Canadian Wildlife Service Waterfowl Committee 2003; Kerbes et al. 2005). As a consequence of this unprecedented growth, some habitats important to both nesting and staging Lesser Snow Geese have become severely degraded (Kerbes et al. 1990; Abraham and Jefferies 1997). In particular, problems have been observed in the salt marshes along the western coast of Hudson Bay, where intense foraging has significantly altered the plant species composition and productivity, and soil salinity (Kerbes et al. 1990; Kotanen and Jefferies 1997; Jefferies and Rockwell 2002). Long-term and irreversible habitat damage could have detrimental effects not only on Snow Geese but also on other wildlife that share the same habitat (Gratto-Trevor 1994; Gratto-Trevor and Vacek 2001; Rockwell et al. 2003; Milakovic and Jefferies 2003).

The Snow Goose colony in the Banks Island Bird Sanctuary Number 1 (BIBS1) comprises more than 95 percent of the Western Arctic Population, which migrates through the Canadian prairies each spring and fall, and winters in the Pacific Flyway and western part of the Central Flyway. This population is distinct geographically from the mid-continent population and is only about one tenth of the size (570 500 in 2002). Despite the spatial separation and size difference in the two populations, the rates of growth (approximately five percent per annum) have been similar (Kerbes et al. 1999; Boyd 2000), leading us to hypothesize that habitat damage could also occur on Banks Island.

To help ensure effective management and conservation of the migratory birds of the western Canadian Arctic, we evaluated the potential impacts of increasing numbers of Lesser Snow Geese on the lowland habitats and breeding birds (primarily shorebirds and passerines) within and around the Snow Goose colony in BIBS1. The results of these studies are reported here as two main chapters. The first chapter describes the characteristics and abundance of broad habitat types present within BIBS1, and evaluates the current habitat conditions there. The second chapter examines the relationship between the Snow Goose colony in BIBS1 and the abundance of breeding birds in lowland habitats within and around the colony. The management implications of the work are also discussed, and additional information needs are identified.

The effects on lowland habitat in the Banks Island Bird Sanctuary Number 1, Northwest Territories, by the growing colony of Lesser Snow Geese (*Chen caerulescens caerulescens*)

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Abstract

The purpose of this study is to evaluate the current condition of lowland habitats in the Banks Island Bird Sanctuary Number 1 (BIBS1), Northwest Territories, in relation to potential overgrazing by the growing population of Lesser Snow Geese there. Using Landsat 5 Thematic Mapper (TM) imagery, we produced a habitat map of the 20 517 km^2 sanctuary. Overall, six terrestrial-cover classes and five subclasses were mapped. We describe the dominant vegetation and prevailing environmental conditions in each of the habitat classes. Two dominant classes, moist – wet lowlands dominated by grasses and sedges (the preferred habitat of geese) and dwarf shrub–herb barrens, together made up 80% of the land cover on the study area. Classification accuracy, determined from a sample of independent ground-truth data, ranged from 65–99% for the six terrestrial classes and was 94% overall. Considering land cover subclasses in the accuracy assessment reduced overall accuracy to 88% and increased the range in accuracy estimates to 32–99% for the classes/subclasses. A general reconnaissance of habitat conditions within BIBS1, carried out from 1992 to 2005, indicated that heavily grazed or degraded habitats were restricted mainly to the area in and around the main goose colony at Egg River and near the edges of most ponds and lakes throughout the sanctuary. Based on two different approaches, we estimated 0.8–5.6% of the graminoid dominated lowlands were overgrazed by geese. Indices of goose grazing intensity were collected at grazing exclosures (percent of standing crop eaten) and 1m^2 plots (percent of plot grubbed, percent of stems grazed, height of grasses and sedges, number of fecal droppings). These indices suggested that impact by Snow Geese on Banks Island ecosystems is much lower than that observed in some parts of the eastern Arctic and Subarctic. Nevertheless, the number of the Snow Geese nesting on Banks Island has grown at a rate similar to that reported for the mid-continent population. Thus, we agree with earlier recommendations that the population should be stabilized at current levels. Information requirements for successfully managing Snow Geese and their habitat on Banks Island are identified.

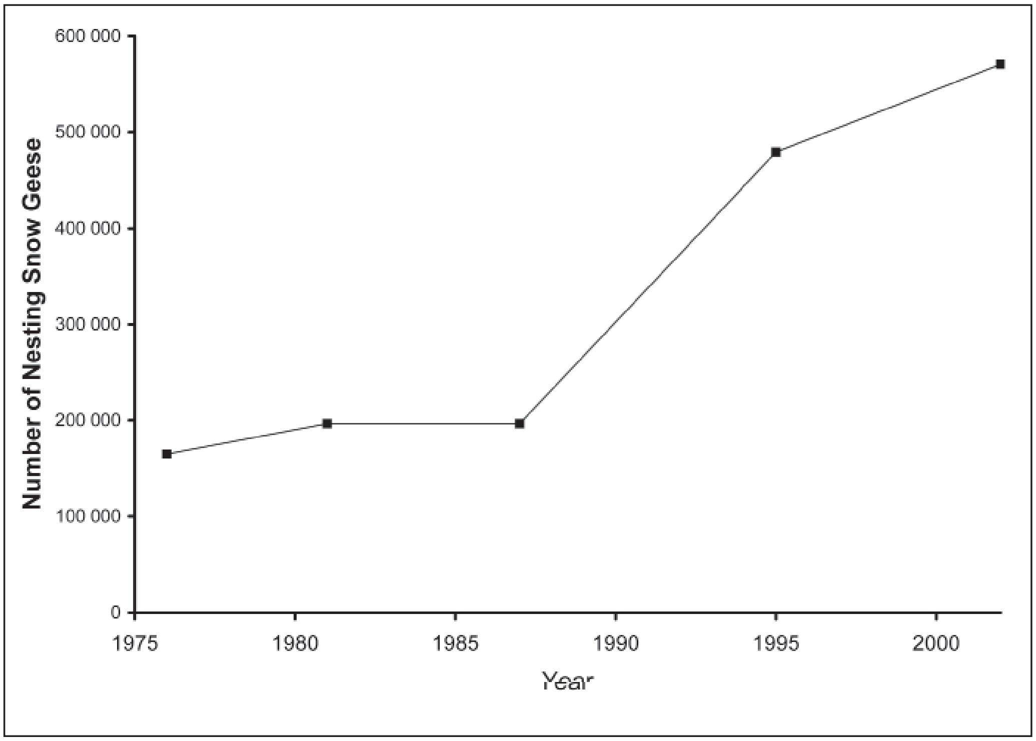
1. Introduction

Most populations of Lesser Snow Geese in North America have grown dramatically over the past several decades and are now at or near all-time record highs (Abraham et al. 1997; Canadian Wildlife Service Waterfowl Committee 2007; Kerbes et al. 2005). Numbers of Snow Geese have increased to the extent that the plant communities in some Arctic and Subarctic coastal lowlands have been destroyed or severely degraded by foraging geese (Kerbes et al. 1990; Ganter et al. 1996; Abraham and Jefferies 1997; Kotanen and Jefferies 1997). Ongoing loss of lowland habitat could put populations of geese and other species of wetland-dependent birds at risk.

The increased abundance of Lesser Snow Geese has become one of the most important and controversial problems facing wildlife conservation agencies in North America (Ankney 1996; Miller 2000). To date, research and management efforts dealing with the "overpopulation" issue have focused primarily on the growing colonies of Lesser Snow Geese in the central and eastern Canadian Arctic (collectively known as the mid-continent population). The growth of populations and degraded habitat conditions in some lowland breeding and staging areas near Hudson Bay and James Bay have been well-documented (Kerbes et al. 1990; Ganter et al. 1996; Abraham and Jefferies 1997; Kotanen and Jefferies 1997), and harvest-related prescriptions to reduce the size of the mid-continent population have been implemented (Rockwell et al. 1997; Boyd 2000; Canadian Wildlife Service Waterfowl Committee 2007).

The Lesser Snow Geese that return each spring to the Inuvialuit Settlement Region of the western Canadian Arctic make up a relatively distinct population that is much smaller than the mid-continent group of geese (Kerbes et al. 1999). Although widespread habitat destruction has not been observed in the western Canadian Arctic, numbers of Snow Geese nesting at the main colonies on Banks Island increased from 165 000 in 1976 to 570 500 in 2002 (Figure 1). Overall, the population has grown as fast (about 5% per annum) as the problematic mid-continent population. Continued population growth at this rate will inevitably result in extensive damage to the lowland tundra on which Snow Geese and many other species of wildlife depend. Damage to the tundra ecosystem could result in severe population declines of Snow Geese and Muskoxen (*Ovibos moschatus*), which would have important socio-economic consequences for the Inuvialuit of Sachs Harbour, Northwest Territories, as well as for other Inuvialuit communities that harvest large numbers of Snow Geese each spring (Anonymous 2003). Habitat loss could create conservation problems for other migratory bird species as well (Latour et al. 2010).

Figure 1
The numbers of Lesser Snow Geese nesting on Banks Island, Northwest Territories, 1976–2002, as determined by aerial photo surveys (Kerbes et al. 1999; Caswell and Meeres, unpublished data)



Habitat degradation caused by Lesser Snow Geese in the eastern and central Arctic is associated predominantly with coastal lowlands. The removal of grasses and sedges by foraging geese has led to increased evaporation, drying out of the now sparsely vegetated areas, and salinization of the soil. Most shrub and graminoid plants have difficulty in surviving or reproducing under the resulting hyper-saline conditions; however, a few species of salt-tolerant plants, some of which are not eaten by Snow Geese, have thrived (Abraham and Jefferies 1997). On Banks Island, salinization is an unlikely problem, as coastal salt-marsh habitat is very limited in extent (Porsild 1955). Most Snow Geese nest > 25 km inland from the coast (Kerbes et al. 1999) near the confluence of the Egg and Big rivers and, during July, broods and flocks of non-breeders and failed breeders disperse widely over a broad area of lowland tundra near freshwater lakes and ponds. Thus, the effects of heavy foraging by geese on the plant communities of Banks Island could be quite different than impacts observed in the coastal marshes of Hudson Bay.

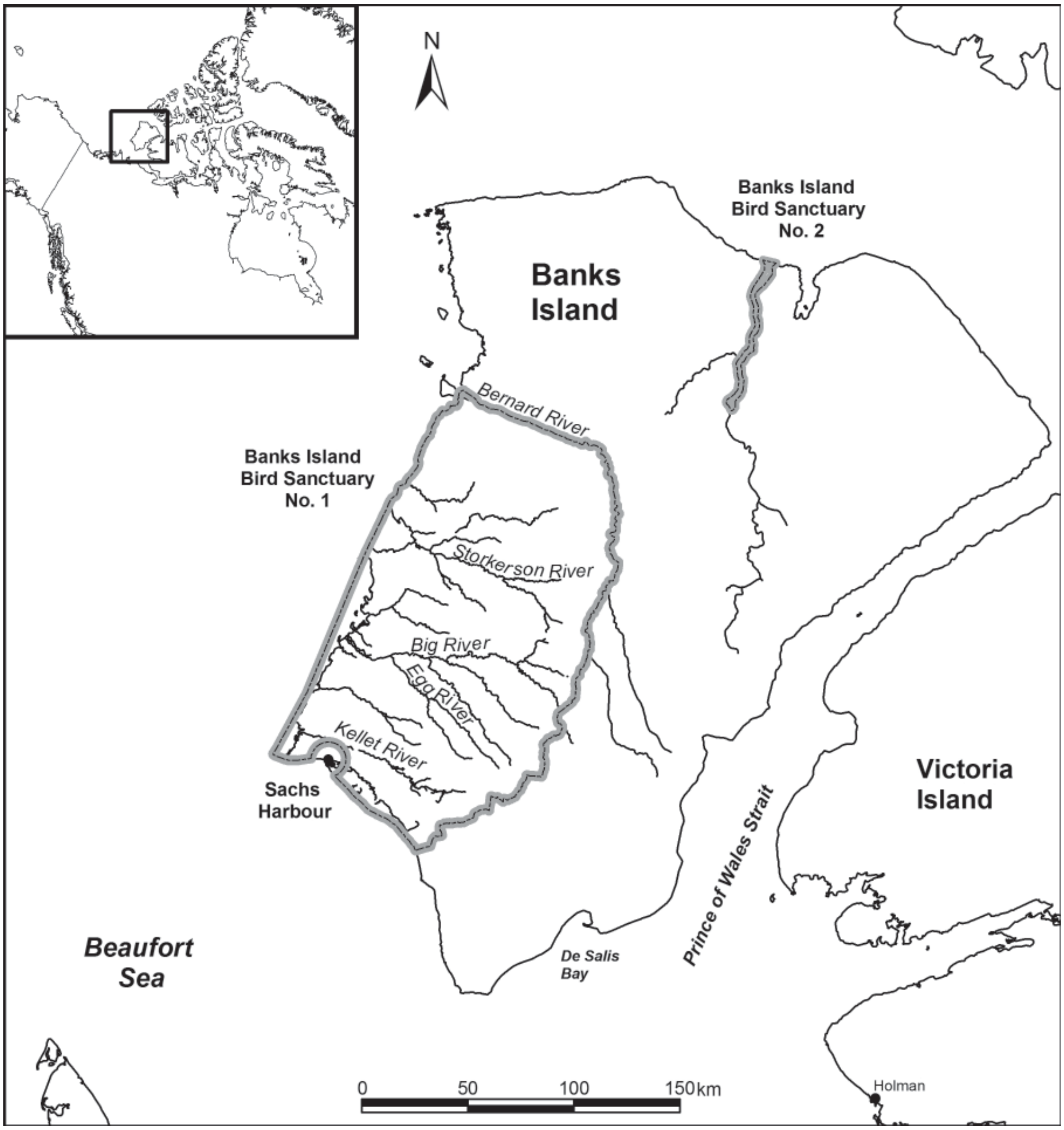
Given the growth of the Snow Goose population in the western Canadian Arctic and concerns about the effects of Snow Geese on ecosystems elsewhere in northern Canada, there is an urgent need to assess the condition of lowland habitat on Banks Island. In 1999, we initiated a study in BIBS1 with the following objectives: (1) map the major habitat types present in the sanctuary, (2) measure the availability of lowland habitat available for Snow Geese and other species, and (3) evaluate the broad impacts of the increasing numbers of geese on habitat quality. Here we describe the results of our investigation and discuss the management implications of the work.

2. Study area

Banks Island (60 165 km^2) is situated in the southwestern corner of the Canadian Arctic Archipelago in the Northwest Territories (Figure 2). The climate of the island is dry and cold. For example, in the community of Sachs Harbour, annual precipitation for the years 1955–90 averaged 127 mm and the mean daily temperatures for January and July were -30º C and 6º C, respectively (Environment Canada 2003).

BIBS1, where we carried out our fieldwork, is 20 517 km^2 in area. The sanctuary was created in 1961 to protect the colony of Lesser Snow Geese and the large numbers of other migratory birds that spend the summer on Banks Island (Canadian Wildlife Service 1992). Most of the sanctuary occurs in the Central Lowlands of Banks Island, a low plain (mostly within 150 m of sea level) characterized by rolling hills, shallow valleys, and alluvial flats (Fyles 1962). The Central Lowlands can be divided into coastal and interior regions, the former encompassing the drainages of many small rivers as well as the lower reaches of four major river systems: the Kellett, Big, Storkerson and Bernard (Figure 2). These rivers occupy broad shallow valleys and become highly braided as they near the Beaufort Sea. The wet valley bottoms feature large tundra polygons and rounded shallow lakes and ponds

Figure 2
The location of the study area, Banks Island Bird Sanctuary Number 1, in the western Canadian Arctic



(Fyles 1962). The interior of the Central Lowlands rises 250 m above sea level. Well-drained rolling hills, which are dissected by a network of broad, shallow river valleys and gullies, characterize the topography of the interior plateau (Fyles 1962).

The complex geological history of Banks Island (Vincent 1982) has resulted in widespread deposition of sand, silt and clay, which, with the presence of continuous permafrost, impedes drainage in lowland areas. These factors, along with the low to moderate relief, have led to nearly continuous lowland plant cover in many places, making Banks Island the most well-vegetated island in the Canadian Arctic Archipelago (Porsild 1955; Circumpolar Arctic Vegetation Mapping Team 2003). The island supports large populations of grazing animals including Muskoxen (Larter and Nagy 2001), which are present year-round, and Lesser Snow Geese (Kerbes et al. 1999), which are present from the end of May until early September.

3. Methods

Our study involved two main components: (1) mapping of the habitat types present within BIBS1, and (2) a general evaluation of habitat conditions in the sanctuary.

3.1 Habitat mapping

Mapping of land cover was carried out through a remote sensing analysis of digital data collected by the Landsat 5 TM. Habitat mapping followed the standard procedure of (1) preparing computer-enhanced satellite image maps of the study area; (2) undertaking fieldwork to assess what cover types were present and how they corresponded to the colour tones on the satellite image maps; (3) producing a digital land cover classification through a combination of supervised and unsupervised digital classification techniques; and (4) assessing classification accuracy to determine the reliability of the results.

Image processing was performed with PCI Geomatica image analysis software at the Northwest Territories Centre for Geomatics in Yellowknife. Two 185 x 172 km Landsat 5 TM scenes (pixel size of 25 x 25 m) were acquired for mapping the sanctuary. The southern two thirds of the sanctuary was covered by scene 60–09 (July 6, 1990), whereas the northern third of the sanctuary fell within scene 61–08 (August 12, 1995). A small area at the east-central edge, amounting to 0.1% of the sanctuary, was not covered by imagery. The satellite imagery was georeferenced to Landsat 7 ortho-images obtained from the Centre for Topographic Information in Sherbrooke, Quebec.

Field collection of land cover information was carried out during July of 1999–2002. Georeferenced satellite image maps, produced from Landsat bands 5 (short-wave infrared), 4 (near-infrared) and 2 (green) at 1:75 000 scale, were used to help select areas of relatively homogeneous colour tone for field sites. We visited 883 sites by helicopter and on foot, and recorded the general type of land cover present at each location. More detailed information on landforms, topography and soil moisture was recorded at 148 of the locations. From the field data, we were able to distinguish six major terrestrial cover types. In addition, we recognized three subclasses within one of the major cover types (moist – wet tundra) and two subclasses within another cover type (dry – mesic tundra).

Remote sensing analyses were based on the assumption that each cover type has a unique spectral signature (radiative surface) detectable by satellite. An unsupervised classification was used to map non-vegetated cover types that could be visually identified without the aid of field data. Classes were automatically generated based on natural clusters in the Landsat data. Those classes that could be identified as water, snow and ice, sparsely vegetated river and delta sediments, clouds, or shadows were labelled and eliminated from further analysis. The field sites of known land cover types were used as "training areas" on the imagery to calculate spectral signatures for each cover type from Landsat bands 2, 3, 4, 5 and 7. A supervised classification, using the spectral signatures generated from the field sites, assigned remaining image pixels to the land cover classes. Pixels could not be classified in relatively few instances. Our two satellite images were processed independently, using this combination of supervised and unsupervised image classification techniques. The land cover classification results from the northern and southern images were ultimately joined into one overall land cover image.

Following general methods recommended by Congalton (1991), we constructed error matrices for the reference and classified data, and then carried out an accuracy assessment of the classification. In this assessment, "producers' accuracy" indicated the probability that reference data (obtained in the field) had been correctly classified. Thus, it measured how well a certain type of area could be classified from the viewpoint of a map producer. In contrast, "users' accuracy" evaluated how accurately the classified map reflected the habitat conditions if visited on the ground. Both producers' and users' accuracies refer to individual land cover types. "Overall accuracy" applies to the classification as a whole, and is calculated by summing the correctly classified pixels for all classes and then dividing by the total number of pixels in the error matrix (Congalton 1991). To determine the reliability of the land cover maps at different levels of classification complexity, we carried out accuracy assessments for both the six broad-scale terrestrial classes and the three subclasses of moist – wet tundra. Data from 6415 pixels were saved from the field assessment of cover types for the purpose of evaluating classification accuracy (Congalton 1991).

3.2 Groundwork

The relative goose use and grazing pressure in different areas was assessed in several ways: (a) establishing grazing exclosures to determine amounts of graminoid vegetation being consumed; (b) counting goose fecal droppings; (c) assessing the degree of grazing and grubbing at a number of sites; (d) reviewing previous information on the distribution and abundance of geese throughout the sanctuary; and (e) conducting a broad reconnaissance of habitat conditions within the sanctuary.

(a) Grazing exclosures

During 1999–2001, we established 63 exclosures at 36 sites within the broad lowland area used by nesting, moulting and brood-rearing geese. Because of logistical and financial constraints related to aircraft support, exclosures were established only within 65 km of the primary goose nesting area at the junction of the Egg and Big rivers (Figure 3). Sites were located randomly within this sampled area and, for the purposes of our study, are thought to adequately represent lowland habitats elsewhere within the sanctuary.

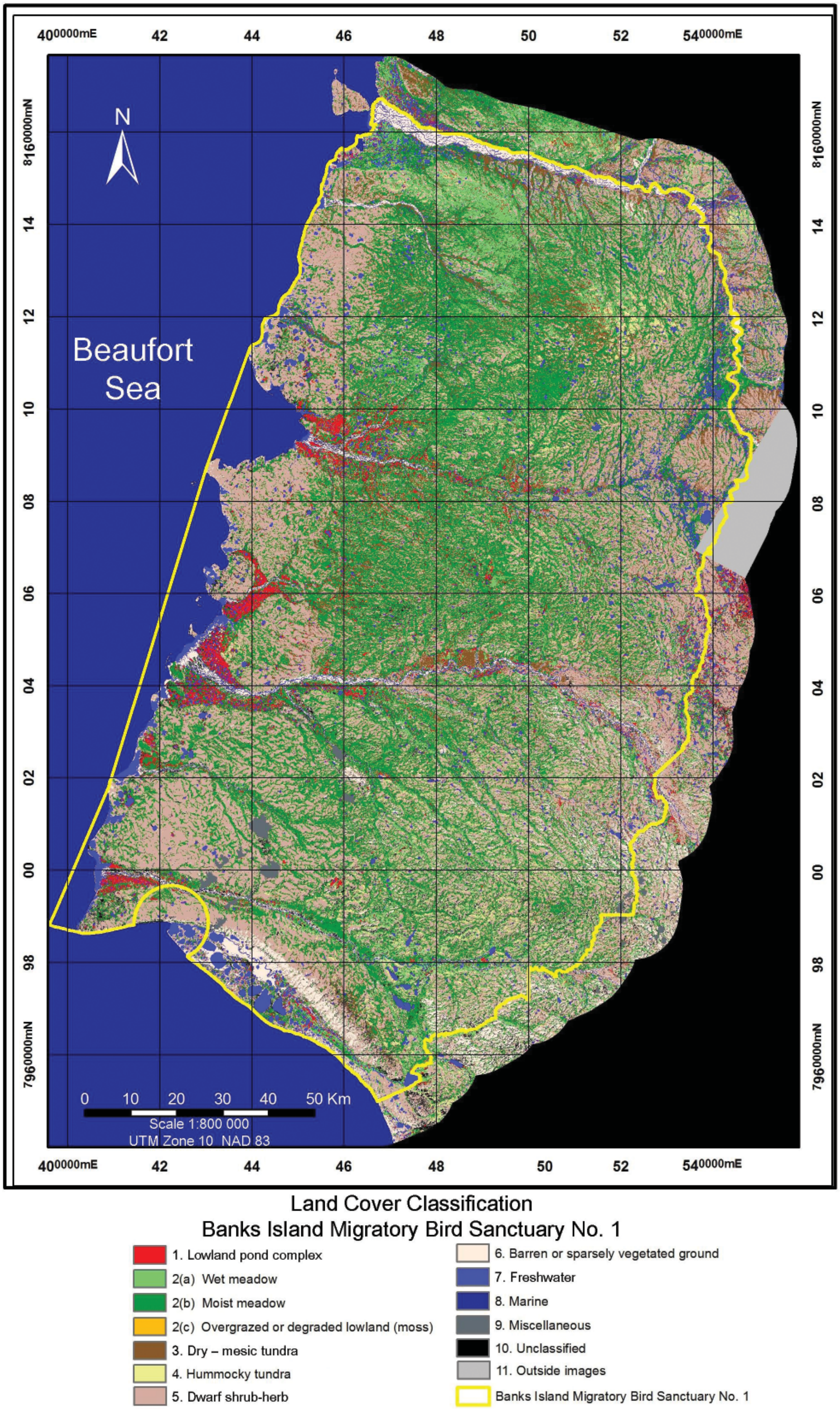
Each 30 cm–high, dome-shaped exclosure covered < 0.5 m^2. They were built with 14-gauge (1.6-mm diameter) chain link fencing and fixed to the ground with metal stakes. Several of the structures were flattened by Muskoxen or destroyed by flooding, and a few could not be relocated because of inaccuracies in Global Positioning System locations. Thus, data were collected at 50 of 63 possible exclosures.

Exclosures were set up in mid-July of a given year and revisited in mid-July of the following year. During the return visit, samples of grasses and sedges from within and outside the exclosure were collected. These biomass samples consisted of a circular core of turf (9.4 cm in diameter) collected within each exclosure, and a similar sample collected 1 m south of the structure. The two samples were referred to as "ungrazed" (during the preceding year) and "grazed," respectively. New green growth of grasses and sedges from each turf core was clipped off at ground level, oven-dried to constant mass, and weighed with an electronic balance.

(b) Counts of goose fecal droppings

We counted the number of "new" (from the current year) and "old" (from a previous year) droppings in 384 1-m^2

Figure 3
The nine land cover classes within BIBS1 mapped from Landsat 5 imagery



circular plots, as indicators of goose use of different areas (Kerbes et al. 1990; Jefferies and Abraham 1994). Counts were taken at 500-m intervals along bird survey transect lines (Latour et al. 2010) and at 100-m intervals at 39 other transects established in lowland habitats (i.e., lowland pond complex, moist – wet tundra). Each fecal fragment > 2.5 cm in length was treated as an individual dropping. Although transects could not be randomly placed throughout the sanctuary due to logistical and financial constraints, the plots were distributed in a manner that broadly sampled the area used by geese (Figure 3).

(c) Assessment of grazing and grubbing

A sub-sample (210) of the lowland plots noted above was used to assess the degree of grazing and grubbing, by estimating the percentage of the 1-m^2 plots that had been recently grubbed, the percentage of graminoid stems that had been grazed, and the height of graminoid plants.

(d) Previous surveys of goose distribution and abundance

A good index of goose use of different parts of BIBS1 in recent years can be derived from air photo surveys of nesting Snow Goose colonies conducted in mid-June (Kerbes et al. 1999; Caswell and Meeres, unpublished data), and aerial surveys of the distribution of broods and flocks of flightless moulting adults in mid to late July (Samelius et al. 2008). From the survey data, we calculated the average densities of geese in each of the following general areas within BIBS1: (1) the goose nesting colony near Egg River and the smaller satellite colony near Rotten Creek; (2) Kellet River; (3) Lennie River; (4) Big River and Sea Otter River Lowlands; (5) Storkerson River; (6) Satchik River; (7) Bernard River Delta; (8) Bernard River Valley (excluding the delta); and (9) the remainder of Banks Island Bird Sanctuary. The latter area, termed “the uplands” by Samelius et al. (2008), included abundant but less extensive patches of wetland habitat as well as drier upland vegetation. The Egg River area is used during both the nesting and brood-rearing periods (Samelius et al. 2008), whereas the other areas are used mainly after broods appear in early July.

(e) Reconnaissance of habitat conditions within BIBS1

During the course of fieldwork on the present and related projects since 1992 (Kerbes et al. 1999; Cotter and Hines 2001, 2005; Samelius et al. 2008; Latour et al. 2009), we had the opportunity to observe the general conditions of lowland habitat at many sites within BIBS1. Lowland habitats in those areas were classified as (a) overgrazed/degraded, (b) heavily grazed, (c) moderately grazed, or (d) lightly grazed based on the criteria presented in Table 1.

Table 1
Different categories of grazing pressure recognized during studies of Lesser Snow Goose habitat on Banks Island, 1999–2002

Grazing category	General characteristics
Overgrazed/degraded	Little sedge or grass cover remaining, with the few remaining graminoid plants clipped off near ground level; moss cover abundant, sometimes covering 100% of the ground; overgrazing indicator-species (*Senecio congestus* and *Petasites frigidus*) are common; dead willows sometimes present; goose droppings numerous (usually several per m^2).
Heavily grazed	Some sedge and grass cover remaining; most or all live shoots grazed but frequently of variable height; evidence of extensive grubbing; moss cover abundant but much less than 100%; *Senecio congestus* and *Petasites frigidus* present; goose droppings present.
Moderately grazed	Sedge and grass cover abundant; some shoots grazed but plants variable in height; moss cover much less than 100%; *Senecio congestus* and *Petasites frigidus* present; goose droppings not abundant.
Lightly grazed	Sedge and grass cover abundant; few shoots show signs of being grazed; moss carpet lacking; little or no evidence of grubbing; *Senecio congestus* and *Petasites frigidus* present; few goose droppings present.

4. Results

4.1 Land cover types

Nine land cover classes (including three subclasses) were recognized on the ground and mapped from Landsat imagery (Figure 3). A brief description of each cover type is given below and further details of dominant plants and environmental conditions prevalent within each cover class are presented in Table 2. A list of vascular plants encountered in the different cover classes is presented in Appendix 1.

(1) *Lowland pond complex* (designated class 1 in Figure 3) is a variable cover type occurring in low, wet areas with numerous ponds and small lakes. The community is dominant in the valleys of the major rivers of western Banks Island, particularly where the valleys broaden near the coast. Although the relief is low, the landscape is diverse and includes low-centered tundra polygons, frost boils, and other forms of patterned ground. Such features are difficult to map individually, or even identify, with Landsat TM imagery. Wet soil is a characteristic of all the constituent types of land cover and, in general, the vegetation is similar to that found in mesic – wet tundra described below. In many places, grass and sedge communities, which once existed near many ponds and lakes, have been significantly altered by goose grazing and have become a moss carpet.

(2) *Moist – wet tundra* (2, Figure 3) is one of the most common types of land cover. Sedges and grasses are dominant, especially in wetter areas, but dwarf shrubs are abundant in slightly-better-drained sites as well. Plant cover is continuous (100%) or nearly continuous. Three distinct subtypes of this cover class were recognized: 2(a) (Figure 3), a *wet meadow* type dominated by grasses and sedges; 2(b), a *moist meadow* community occurring on slightly higher or better-drained sites that contained dwarf shrubs as well as grasses; and 2(c), an *overgrazed mossy lowland* in which most of the grasses and sedges had been

Table 2
Characteristics of six broad terrestrial-cover classes present within BIBS1

Land cover class	Soil & moisture conditions	Topographic position	Vegetation cover (%)	Dominant or abundant plants
Lowland pond complex	Saturated, abundant moss and peat	Lowlands	75–100	*Carex aquatilis* var. *stans*, various other sedges and grasses, mosses, *Salix arctica*, *Senecio congestus*, *Petasites frigidus*, *Dryas integrifolia*
Moist – wet tundra (includes moist, wet and overgrazed subclasses)	Saturated or poorly drained, abundant moss and peat	Lowlands; low-centered polygons; lower, gentle to moderate slopes; alluvial terraces; near lakes and streams; below snowbanks	100	*Carex aquatilis* var. *stans*, *Eriophorum triste*, *Eriophorum scheuchzeri*, *Dupontia fisheri*, *Arctagrostis latifolia*, *Dryas integrifolia*, *Salix arctica*, *Senecio congestus*, *Petasites frigidus*, mosses
Dry – mesic tundra (includes overgazed subclass ["exposed peaty mounds"] that occurs within nesting area	Dry to mesic, moss and peat present (mainly on raised polygons)	Upland areas; slopes and hilltops; high-centered polygons; alluvial terraces well above water level	50–75	*Dryas integrifolia*, *Salix arctica*, various grasses and sedges (including *Carex membranacea)*, various herbs
Hummock tundra	Dry to moist gradient, mosses abundant between hummocks	Moderate to steep slopes	~50	*Dryas integrifolia*, *Salix arctica*, *Cassiope tetragona*, various herbs (including *Parrya arctica* and *Polygonum viviparum*)
Dwarf shrub–herb	Dry – mesic	Upper slopes; tops of hills, ridges and plateaus, other well-drained sites	25–50	*Dryas integrifolia*, *Oxytropis arctica*, *Saxifraga oppositifolia*, *Carex membranacea*, various other herbs
Sparsely vegetated or barren ground	Variable	Fluvial deposits, eroded areas, plateaus, ridges	< 10	Few plants

consumed by geese, thereby leading to the formation of an extensive moss carpet. The moss-dominated habitats usually occur near the edge of ponds and lakes throughout BIBS1 and throughout lowland areas within the core nesting area of the Egg River goose colony. Within the overall moist – wet tundra cover type, *Carex aquatilis* var. *stans* is dominant at the wetter sites but cotton grasses (*Eriophorum triste* and *E. scheuzeri*) and true grasses (*Dupontia Fisheri*, *Arctagrostis latifolia*) are common as well. Frequently occurring dwarf shrubs include *Dryas integrifolia* and *Salix arctica*. Two species (*Senecio congestus* and *Petasites frigidus*) are found frequently at degraded sites and their abundance, along with highly reduced graminoid cover and the existence of a moss carpet, were collectively considered to indicate overgrazed conditions.

(3) *Dry – mesic tundra* (3a, Figure 3) occurs in upland areas, on better-drained soils, and in areas of dry peat hummocks and high-centered tundra polygons. Ground cover, typically less than 75%, is sparser than in moist – wet tundra. Dominant plants include *Dryas integrifolia*, *Salix arctica*, graminoid plants (particularly *Carex rupestris*) and a variety of herbs. A local and degraded variation of this habitat type occurs near the Egg River, within the core part of the goose nesting colony. This overgrazed subclass, *"exposed peaty mounds",* features a dry surface layer of darkened peat, dead willows, and sparse ground cover.

(4) *Hummock tundra* (4, Figure 3) typically forms at the base of moderate to steep slopes in stone-free soils (Ferguson 1991). This cover type features hummocks up to 45 cm in diameter that have been formed by frost action (Pielou 1994). Dominant vegetation includes dwarf shrubs (primarily *Dryas integrifolia*, *Salix arctica* and *Cassiope tetragona*) and a variety of herbaceous plants, mosses, and lichens.

(5) *Dwarf shrub–herb* (5, Figure 3) predominate on hilltops, well-drained slopes, and other dry to mesic sites throughout BIBS1. Mountain avens (*Dryas integrifolia*) is the dominant plant in these areas. Other frequently occurring species include willows (primarily *Salix arctica*), sedges (especially *Carex membranacea*), mat-forming or cushion plants (*Saxifraga oppositifolia*, *Silene acaulis*), and numerous other flowering plants (Ferguson 1991, Appendix 1). Smaller patches of moisture-loving grasses and sedges occur in wetter depressions within the expansive *Dryas*-dominated landscape. Lichens are abundant in the dwarf shrub–herb barrens but moss cover is far less widespread than in the wetter forms of land cover described previously. Overall vegetation cover is typically < 50%.

(6) *Barren or sparsely vegetated ground* (6, Figure 3), characterized by < 10% plant cover, occurs under a wide range of moisture conditions, topographic positions and landform types (Ferguson 1991). Included in this land cover unit are sand and gravel deposits occurring near rivers and along exposed coastal shorelines, recently exposed sediments on former lake bottoms, eroded areas, and dry gravelly uplands.

(7) *Freshwater* occurs in lakes, ponds and rivers. It includes bodies of water that were covered by ice at the time the imagery was collected.

(8) *Marine* areas occur within the boundaries of BIBS1, along the western coast of the sanctuary.

(9) *Miscellaneous* cover types, including clouds, shadows and snow banks, make up a relatively small proportion of the map area.

(10) *Unclassified* areas could not be assigned to a particular land cover class by the computer algorithm and make up a small proportion of the image.

(11) A small area of the sanctuary, designated *outside images* in Table 3, fell outside the two Landsat images and could not be classified.

4.2 Habitat map and accuracy assessment

The distribution of cover types within BIBS1 is shown in Figure 3, and the area extent of each cover type is reported in Table 3. Dwarf shrub–herb and moist – wet tundra were the most extensive terrestrial habitat types present, each covering about 38% of the sanctuary. None of the other cover types made up more than 6% of BIBS1. Collectively, the lowland habitat types of primary importance to geese (lowland pond complex plus moist – wet tundra) made up about 40% of the land cover. We estimated that lowland habitats degraded by goose foraging covered 61 km^2 (0.3% of the sanctuary and 0.8% of the lowland habitat present). The other cover type thought to reflect degraded habitat (exposed peaty mounds, found only within the nesting colony) made up 1.9 km^2 or < 0.1% of BIBS1.

Matrices indicating the accuracy attained in mapping of terrestrial habitat types are presented in Table 4. Overall accuracy averaged 94% for the six major land cover classes and 88% if the land classification was looked at in greater detail by considering accuracy to the subclass level. Users' accuracy is particularly relevant to the application of the maps for management purposes. It ranged from 65–99% and averaged 86% for the major terrestrial habitat classes for which we had reasonable ground-truthing samples (> 100 contiguous pixels). When land cover subclasses were considered, users' accuracy still remained reasonably high (83%). The accuracy of the moist – wet tundra class, considered to be one of the most important habitat types for birds and other wildlife, is of particular interest. The users' accuracy for the wet meadow and moist meadow subclasses was relatively good, at 80% and 87%, respectively. The users' accuracy for the overgrazed or degraded lowland (moss) subclass was poor, at 44%. The error matrix showed that most of the errors in mapping individual moist-meadow subclasses were due to confusion with other moist-meadow subclasses and with the lowland pond complex class (Table 4).

4.3 Indicators of habitat conditions

(a) Grazing exclosures

A mixed two-way analysis of variance for paired samples (PROC MIXED procedure in SAS statistical software, Littell et al. 1996), using treatment type (inside or outside the exclosure) and year as factors, indicated that the standing crop of grasses and sedges in brood-rearing areas varied among years and between grazed and ungrazed samples ($P < 0.01$ for both tests; Table 5). Overall, the average plant biomass outside exclosures (6.8 $\pm$ SE 1.1 g/m^2) was 39% lower than the biomass within exclosures (11.2 $\pm$ SE 2.0 g/m^2).

Table 3
Area of different land cover classes in BIBS1 determined from Landsat 5 scene 60-09 (July 6, 1990) and scene 61-08 (August 12, 1995)

Class #	Class or subclass	Number of pixels	Area (km^2)	% of sanctuary[a]	% of classified area[b]
1	Lowland pond complex	1 060 873	663.0	3.3	3.4
2	Moist – wet tundra				
	2 (a) wet meadow	2 043 040	1276.9	6.3	6.5
	2 (b) moist meadow	9 622 134	6013.8	29.9	30.7
	2 (c) overgrazed or degraded lowland (moss)	102 268	63.9	0.3	0.3
3	Dry – mesic tundra	1 351 511	844.7	4.2	4.3
	– exposed peaty mounds	3004	1.9	< 0.1	< 0.1
4	Hummock tundra	752 484	470.3	2.3	2.4
5	Dwarf shrub–herb	11 916 365	7447.7	37.0	38.0
6	Barren or sparsely vegetated ground	1 433 875	896.2	4.5	4.6
7	Freshwater	1 781 457	1113.4	5.5	5.7
8	Marine	1 293 592	808.5	4.0	4.1
9	Miscellaneous[c]	162 875	101.8	0.5	-
10	Unclassified[d]	653 223	408.3	2.0	-
11	Outside images[e]	33 994	21.2	0.1	-
	Total	32 210 695	20 131.7	100.0	100.0

[a] Includes areas of unknown land cover (classes 9–11)
[b] Excludes areas of unknown land cover (classes 9–11)
[c] Clouds, shadows and snowbanks
[d] Pixels that could not be assigned to a land cover class
[e] Area of sanctuary not covered by either Landsat image

Table 4
Error matrix for accuracy-assessment pixels used in the supervised land cover classification of BIBS1. Land cover classes and subclasses are described in Table 3.

Land cover type	1	2a	2b	2c	3a	4	5	6	Total pixels	Users' accuracy
1. Lowland pond complex	104	23	16	17	0	0	1	0	161	64.6
2. (a) Wet meadow	9	461	92	12	0	0	0	0	574	80.3
2. (b) Moist meadow	1	214	1846	1	41	0	9	1	2113	87.4
2. (c) Overgrazed or degraded lowland (moss)	4	12	2	14	0	0	0	0	32	43.8
3. Dry – mesic tundra	0	0	15	0	355	0	100	0	470	75.5
4. Hummock tundra	0	0	5	0	0	76	0	0	81	93.8
5. Dwarf shrub–herb barrens	0	1	20	0	28	110	2403	3	2565	93.7
6. Barren or sparsely vegetated ground	0	0	0	0	0	0	4	415	419	99.0
Number of accuracy-assessment pixels	118	711	1996	44	424	186	2517	419	6415	
Producers' accuracy (%)	88.1	64.8	92.5	31.8	83.7	40.9	95.5	99.0		

Table 5
Biomass (g/m^2 dry weight) of lowland sedges and grasses within fenced exclosures where geese were prevented from feeding and from 1 m south of the exclosure (outside) where geese could feed, July 2000–2002. Also shown is the percentage difference between mean biomass inside and outside of exclosures.

Year	N[a]	Biomass (g/m^2) within exclosure	SE	Biomass (g/m^2) outside exclosure	SE	% difference
2000	13	19.3	5.7	12.6	3.4	34
2001	29	6.1	1.0	3.2	0.5	47
2002	8	16.5	5.3	10.5	2.3	36
Overall	50	11.2	2.0	6.8	1.1	39

[a] Number of exclosures

Table 6
Indices of grazing pressure recorded in 1-m^2 plots in lowland areas, BIBS1, 2000–2002

Variable	n	Mean	SE	Median	Range
Old droppings	834	2.4	0.2	1	0–115
New droppings	834	1.6	0.1	0	0–58
Total droppings	834	3.9	0.2	2	0–115
Height of graminoids (cm)	164	3.8	0.1	3.5	0–10
Area of plot grubbed (%)	210[a]	1.9	0.7	0	0–100
Stems grazed (%)[c]	164[b]	16.9	2.5	1	0–100

[a] 53 of 210 plots had been grubbed (25.2%)
[b] 75 of 164 plots had been grazed (45.7%)
[c] Trace mounts of grazing scored as 1%

(b) Counts of goose fecal droppings

Total counts of droppings ranged from 0–115 per 1-m^2 plot and averaged 3.9/m^2 overall (Table 6). Counts of "new" droppings deposited in the current year averaged 1.6/m^2 whereas the average for older droppings was 2.3/m^2. Most plots contained no droppings at all or relatively small numbers of either new or old droppings. Few plots had relatively large numbers of droppings (Figure 4).

(c) Measurements of goose grubbing and grazing

Only 25% of the plots showed signs of having been grubbed and 54% showed signs of having been grazed by geese. On average, less than 1.9% of the surface area of the plots had been grubbed and < 17% of the graminoid stems had been grazed (Table 6). Median values for the area grubbed (0%) and the proportion of stems grazed (1%) were even lower, but are possibly better indicators of goose grazing pressure given the skewed nature of the data (Table 6).

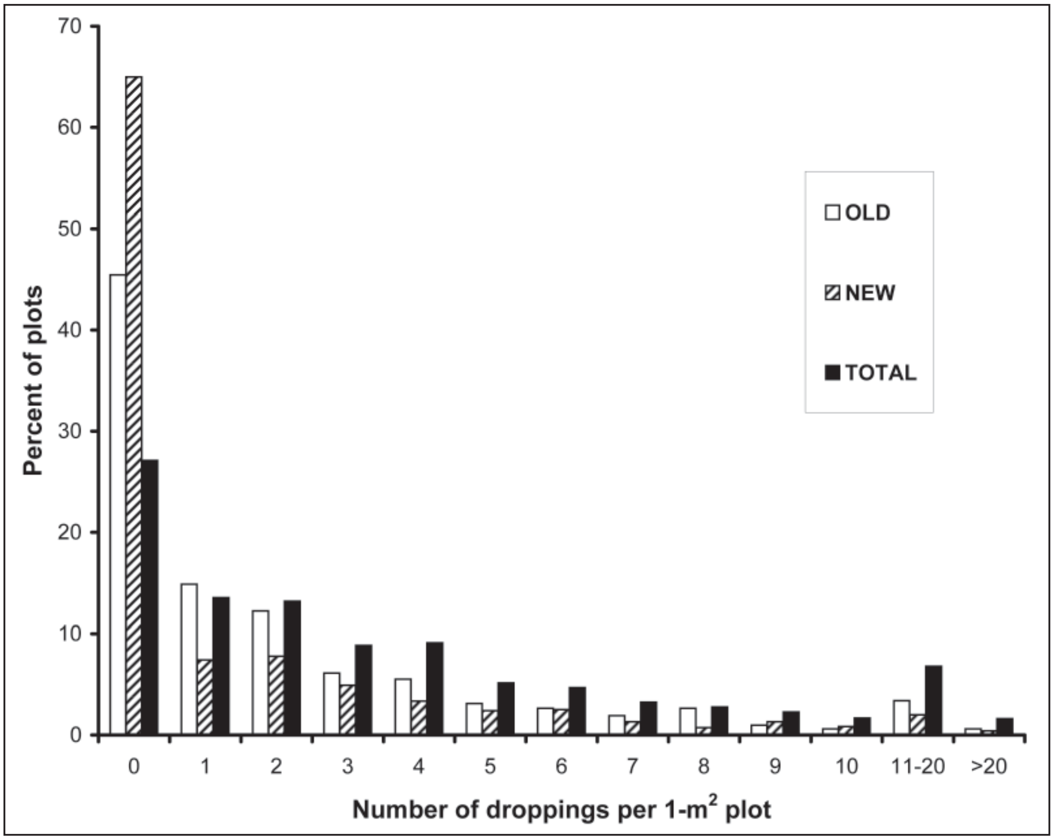
(d) Previous surveys of goose distribution and abundance

As determined by air photo surveys (Kerbes et al. 1999; Caswell and Meeres, unpublished data), the main goose nesting colonies at Egg River and the smaller satellite colonies near Rotten Creek and Lennie River supported densities of 1800–4280 geese/km^2 between 1987 and 2002. From 1995–98, Samelius et al. (2008) found that densities of geese in different brood-rearing and moulting areas ranged from 35–169 geese/km^2 and averaged about 40 geese/km^2 overall (Figure 5). Densities of geese were 45–107 times higher in nesting areas than in brood-rearing and moulting areas.

(e) Reconnaissance of habitat conditions within BIBS1

We visited many sites throughout southwestern Banks Island during this and other field studies from 1992 to 2005, and were able to evaluate the general habitat conditions throughout much of BIBS1 (Table 1). The following general observations of habitat conditions were obtained for the most important areas used by geese: (a) both the major colony near the junction of the Egg and Big rivers and the satellite colony near Rotten Creek are overgrazed; (b) the lowlands of the Big River valley between Egg River and the coast, a major brood-rearing and moulting area for Snow Geese, are heavily grazed in most places and overgrazed near wetlands; (c) the area near the mouth of the Lennie River, an important brood-rearing area, is heavily grazed in most places, and overgrazed near wetlands; (d) the lowlands of the Storkerson and Bernard rivers are lightly to moderately grazed in many places, heavily grazed at some sites, and overgrazed near most lakes and ponds; (e) with the possible exception of the northeastern part of the sanctuary, where we saw relatively low densities of geese, the wet lowland habitat within 20 m of most ponds and lakes in BIBS1 was heavily grazed or overgrazed, and a visible moss carpet was present within 5 m of most water bodies.

Figure 4
Number of Lesser Snow Goose fecal droppings counted in 834 1-m² circular plots located in BIBS1, 2000–2002



5. Discussion

5.1 Habitat mapping and accuracy assessment

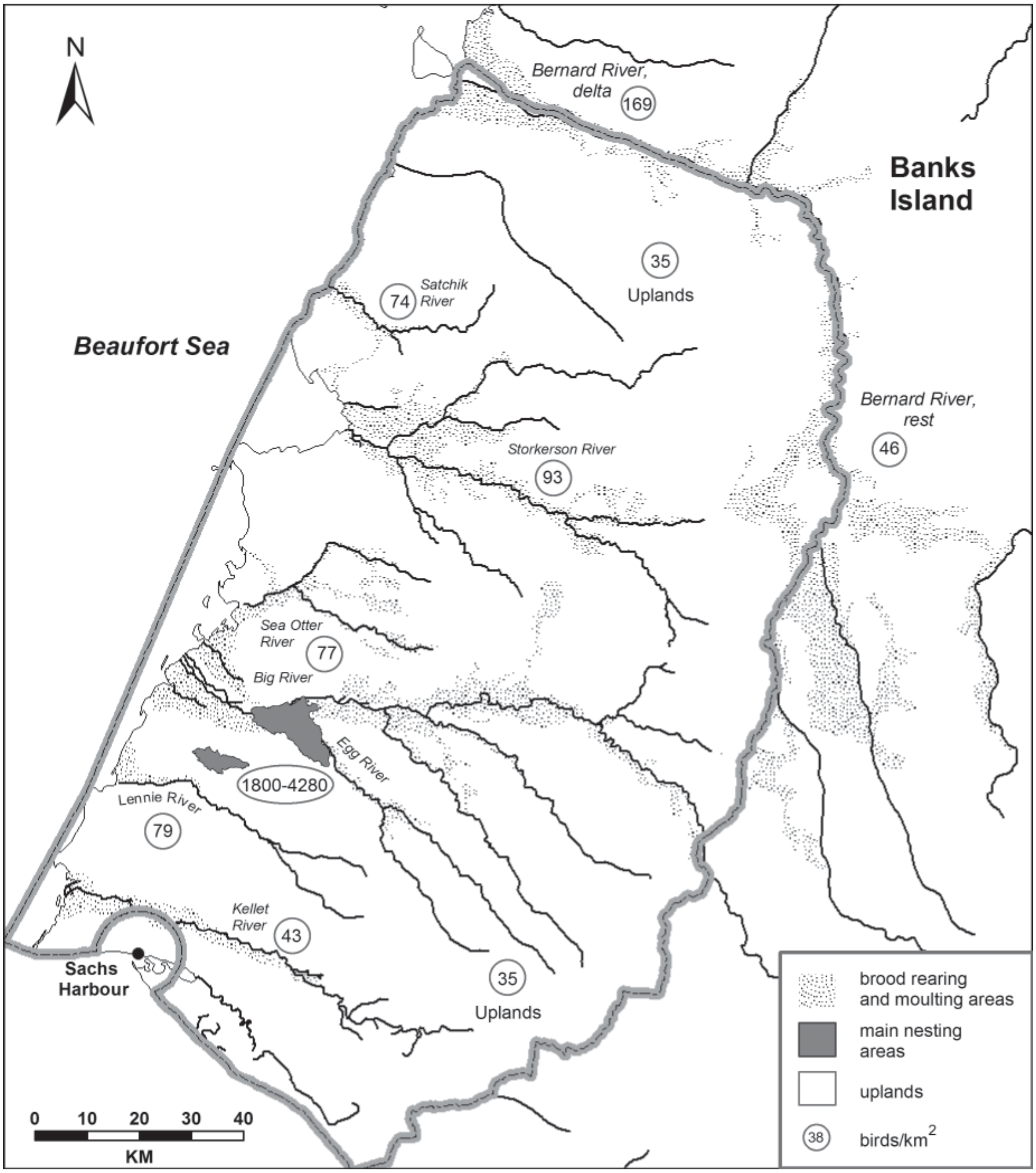
There were likely several reasons for the lower accuracy in mapping some land cover units. The few classes or subclasses with lower classification accuracy were not extensive and usually had only small numbers of pixels available for use as training areas or accuracy assessment samples. Thus, some of the apparent classification inaccuracy might reflect problems with small sample sizes. In the instance of the overgrazed, degraded, moss-dominated sites, the training sites tended to be small and located close to shoreline, within a Landsat pixel that was composed of part land and part water. It is not surprising that these pixels are almost as likely to be classified as wet meadow or lowland pond complex. Furthermore, the small size of the habitat patches (many were smaller than a 25 x 25 m pixel) would definitely limit the probability of their detection on Landsat imagery and thereby contribute to classification inaccuracy. In addition, the cover classes are not entirely discrete and one class, lowland pond complex, was composed in part of the three subclasses of moist – wet tundra. If, in doing the accuracy assessment (Table 4), the three subclasses and lowland pond complex are treated as being the same, users' accuracy for the combined class exceeds 99% (compared to 65% for lowland pond complex considered by itself). A more realistic estimate of classification accuracy for this group would fall between the 65% and 99% extremes.

Lowland habitats as a whole were identified quite well, but distinctions between the different wetland types were more difficult. Classification results suggest that overgrazed or degraded lowland is difficult to detect on the Landsat images at the current level of degradation (small patches, close to shorelines). Despite the limitations described above, we believe that the overall land cover classification is sufficiently sensitive for the future assessment of habitat conditions in BIBS1 in relation to goose grazing and subsequent management actions.

5.2 Impacts of goose grazing

Most species of Arctic-nesting birds depend on aquatic or wetland habitats (Snyder 1957), so the potential loss of lowland plant communities on western Banks Island to overgrazing by Snow Geese is a major concern. Assessing the impact of geese on the vegetation was an important objective of our study, but degraded lowland was a habitat type mapped with low users' accuracy (44%, Table 4). Therefore, as an independent estimate of the amount of goose-degraded habitat, we used a geographic information system (GIS) (Environmental Systems Research Institute, 1996) and our classified cover map to measure the area of lowland habitat (land cover classes 1 and 2) occurring within 20 m of freshwater. As noted previously, with the exception of the goose colonies where much of the lowland habitat had been degraded, overgrazed plant communities occurred mainly within the 20-m strip bordering ponds and lakes.

Figure 5
Densities of nesting Lesser Snow Geese in June, and geese found in brood flocks and moulting flocks of flightless adult geese in July



The GIS analysis indicated that approximately 361.2 km^2 of the lowland habitat within BIBS1 occurred within 20 m of ponds, lakes or streams (J. Leger, personal communication), and might therefore be considered as overgrazed. Adding this amount to the additional amount of lowland habitat within the goose colony (51.4 km^2—all considered to be degraded) yielded an estimate of 412.6 km^2 degraded by goose grazing. This estimate is larger than the area of degraded habitat measured directly from the land cover map but still represents only 5.2% of the lowland habitat within BIBS1.

None of the other indices of goose use or grazing intensity recorded within BIBS1 (densities of goose droppings, biomass measurements within and outside exclosures, frequency of grazing and grubbing, previous surveys of goose distribution and abundance, or the general reconnaissance of habitat conditions) provided strong evidence of widespread overgrazing in BIBS1 or that there was an "overpopulation" problem with Snow Geese. For example, the average density of fresh goose droppings (1.6/m^2, Table 6) on Banks Island was much lower than in intensively used salt marshes in the Hudson Bay region, where droppings can accumulate at rates of 40/m^2/week (Jefferies and Abraham 1994) and have averaged from 7–22/m^2/week (Jefferies and Rockwell 2002). However, estimated densities of fresh droppings reported for other Arctic breeding grounds are similar to the estimate for Banks Island. Data in Kerbes et al. (1990) indicated an average of 1.5 droppings/m^2 in the McConnell River area on Western

Hudson Bay. Similarly, in the high Arctic breeding area of Greater Snow Geese on Bylot Island, densities of droppings averaged about 2/m^2 in late July (Giroux et al. 1998). The population studied by Kerbes et al. (1990) had apparently exceeded the carrying capacity of the habitat, but that studied by Giroux et al. (1998) was thought to be below the carrying capacity.

Based on exclosure results, we estimated that, by mid-July, Snow Geese had consumed (at most) 34–47% of the standing crop of graminoids in the most heavily used nesting and brood-rearing areas on Banks Island. Other grazers, such as Muskoxen, were not frequently observed in the goose grazing area, but could have accounted for some of the consumption of the standing crop, meaning the above-noted percentages are maximum estimates. In contrast, Snow Geese were estimated to have consumed about 60% of the forage plant biomass in brood-rearing areas on Bylot Island (Giroux et al. 1998), and 90% of the above-ground biomass in salt marshes of the Hudson and James Bay region (Cargill and Jefferies 1984; Hik and Jefferies 1990; R. Jefferies, personal communication; K. Abraham, personal communication). Our estimates that 0–2% of the lowland area covered by study plots had been grubbed and 1–17% of the graminoid stems within plots had been grazed are consistent with the finding of a comparatively lower rate of biomass consumption by Banks Island Snow Geese.

On Banks Island, Snow Geese occur in the highest densities, and have the greatest potential to locally impact habitat, from late May until late June within the nesting areas of the Egg River valley and associated satellite colonies (4280 geese/km^2) (Figure 5). Population densities are substantially lower in late summer, when geese occur in family units or as flocks of flightless failed breeders or non-breeders (35–169 geese/km^2). After hatching, goose broods disperse from the colony, moving primarily to the lower valleys and deltas of the major rivers on western Banks Island and other well-vegetated sites within the sanctuary (Samelius et al. 2008). The observation from our reconnaissance survey that the colony has been heavily impacted by goose grazing and that nearby brood-rearing areas such as the Big River Valley were heavily grazed is consistent with our understanding of the summer distribution of geese within BIBS1 (Figure 5).

We estimated that 0.8–5.2% of the lowland area of the sanctuary had been overgrazed by geese. The proportion of the available lowland habitat degraded by grazing was much lower than that observed near the Hudson and James Bay region, where Abraham and Jefferies (1997) estimated approximately 35% of the salt marsh had been lost, 30% had been severely degraded and no longer provided a source of food for geese, and 35% had been heavily grazed. Thus, Snow Geese have affected the lowland habitats of Banks Island much less than in the Hudson and James Bay regions.

Despite the apparently low impact that geese have had so far on their lowland habitats on Banks Island, we believe a proactive approach to the management of the steadily growing population is advisable. Previously, Kerbes et al. (1999) recommended that stabilizing the population near its then-current level of about 600 000 adult geese was a suitable management goal for the western Arctic population. It was believed that a population of that size would be sufficiently large to optimize subsistence hunting opportunities for the Inuvialuit in the western Canadian Arctic while benefiting resource users living in parts of the Canadian prairies, western United States, and north-central Mexico (where Snow Geese are not nearly as abundant as in the mid-continent region). Increased growth of the Snow Goose population on Banks Island is not desirable, because of the unknown capacity of the lowlands to support large numbers of grazing animals (i.e., Snow Geese and Muskoxen), and the great difficulty of invoking successful harvest-related management actions if the goose population becomes too large. There is also evidence (Latour et al. 2010) that the Snow Goose colony is negatively affecting breeding shorebird numbers within 10 km of the colony. Therefore, continued expansion of the colony would likely broaden the area of influence on breeding birds in BIBS1.

Appendices

Appendix 1
Typical plants present in six different land cover types within BIBS1

1. Lowland pond complex

Scientific name[1]	Common name	Status
Carex aquatilis var. *stans*	Water Sedge	abundant (dominant)
Dryas integrifolia	Mountain Avens	abundant (sub-dominant)
Salix arctica	Arctic Willow	abundant (sub-dominant)
Salix polaris	Polar Willow	abundant
Androsace chamaejasme	Rock Jasmine	common
Carex misandra	Short-leafed Sedge	common
Draba alpina	Draba	common
Dupontia fisheri	Grass	common
Eriophorum scheuchzeri	Cotton Grass	common
Eriophorum triste	Cotton Grass	common
Juncus biglumis	Bog Rush	common
Melandrium apetalum	Bladder Campion	common
Pedicularis capitata	Capitate Lousewort	common
Pedicularis lanata	Woolly Lousewort	common
Phlox richardsonii	Richardson's Phlox	common
Senecio atropurpureus	Dark Purple Groundsel	frequent
Senecio congestus	Marsh Ragwort	frequent
Pleuropogon sabinei	Grass	occasional

2. Mesic – moist tundra

Scientific name[1]	Common name	Status
Carex aquatilis var. *stans*	Water Sedge	abundant (dominant)
Eriophorum triste	Cotton Grass	abundant (sub-dominant)
Eriophorum scheuchzeri	Cotton Grass	abundant (sub-dominant)
Salix arctica	Arctic Willow	abundant (sub-dominant)
Dryas integrifolia	Mountain Avens	abundant (sub-dominant)
Salix polaris	Polar Willow	abundant
Carex membranacea	Fragile-seed Sedge	abundant
Melandrium apetalum	Bladder Campion	common
Pedicularis capitata	Capitate Lousewort	common
Draba alpina	Draba	common
Arctagrostis latifolia	Grass	common
Dupontia fisheri	Grass	common
Senecio congestus	Marsh Ragwort	frequent
Petasites frigidus	Sweet Coltsfoot	frequent
Hierochloe pauciflora	Grass	frequent
Erigeron humilis	Low Fleabane	occasional

3. Dry – mesic tundra

Scientific name[1]	Common name	Status
Dryas integrifolia	Mountain Avens	abundant (dominant)
Carex membranacea	Fragile-seeded Sedge	abundant (dominant)
Salix arctica	Arctic Willow	common (sub-dominant)
Parrya arctica	Arctic Wallflower	common
Astragalus alpinus	Milk Vetch	common
Carex aquatilis	Water Sedge	common
Carex maritima	Sedge	common
Carex misandra	Short-leaf Sedge	common
Cassiope tetragona	Arctic White Heather	common

Scientific name[1]	Common name	Status
Draba alpine	Draba	common
Dupontia fisheri	Grass	common
Eriophorum triste	Cotton Grass	common
Melandrium apetalum	Bladder Campion	common
Pedicularis arctica	Arctic Lousewort	common
Pedicularis capitata	Capitate Lousewort	common
Pedicularis sudetica	Sudetan Lousewort	common
Salix polaris	Polar Willow	common
Stellaria longipes	Chickweed	common
Hierochloe pauciflora	Grass	frequent
Senecio atropurpureus	Dark Purple Groundsel	frequent
Armeria maritima	Thrift	occasional
Crepis nana	Hawk's-beard	occasional
Draba cinerea	Draba	occasional
Erigeron humilis	Low Fleabane	occasional
Luzula confuse	Wood Rush	occasional
Artemisia hyperborea	Wormwood	uncommon
Hierochloe alpina	Grass	uncommon
Vaccinium uliginosum	Alpine Blueberry	uncommon

4. Hummock tundra

Scientific name[1]	Common name	Status
Salix arctica	Arctic Willow	abundant (dominant)
Dryas integrifolia	Mountain Avens	abundant (dominant)
Cassiope tetragona	Arctic White Heather	abundant
Parrya arctica	Arctic Wallflower	abundant
Polygonum viviparum	Bistort	abundant
Alopecurus alpinus	Foxtail	common
Androsace chamaejasme	Rock Jasmine	common
Astragalus alpinus	Milk Vetch	common
Carex rupestris	Rock Sedge	common
Draba alpina	Draba	common
Eriophorum scheuchzeri	Cotton Grass	common
Festuca baffinensis	Fescue	common
Juncus biglumis	Bog Rush	common
Oxyria digyna	Mountain Sorrel	common
Pedicularis lanata	Woolly Lousewort	common
Pedicularis sudetica	Sudetan Lousewort	common
Phlox richardsonii	Phlox	common
Poa glauca	Blue Grass	common
Potentilla pulchella	Cinquefoil	common
Salix polaris	Polar Willow	common
Saxifraga cernua	Nodding Saxifrage	common
Saxifraga oppositifolia	Purple Mountain Saxifrage	common
Stellaria longipes	Chickweed	common
Agropyron violaceum	Wheat Grass	frequent
Caltha palustris	Marsh Marigold	frequent
Eutrema edwardsii	Mustard	frequent
Papaver radicatum	Arctic Poppy	frequent
Poa arctica	Blue Grass	frequent
Polemonium boreale	Jacob's Ladder	frequent
Senecio atropurpureus	Dark Purple Groundsel	frequent
Trisetum spicatum	Grass	frequent
Arnica alpinus	Arnica	occasional
Draba cinerea	Draba	occasional
Draba glabella	Draba	occasional
Draba nivalis	Draba	occasional
Luzula confuse	Wood Rush	occasional
Luzula nivalis	Wood Rush	occasional
Melandrium affine	Bladder Campion	occasional
Petasites frigidus	Sweet Coltsfoot	occasional
Silene acualis	Moss Campion	occasional
Potentilla hyparctica	Cinquefoil	uncommon

5. Dwarf shrub–herb

Scientific name[1]	Common name	Status
Dryas integrifolia	Mountain Avens	abundant (dominant)
Oxytropis arctica	Arctic Locoweed	abundant (sub-dominant)
Saxifraga oppositifolia	Purple Mountain Saxifrage	abundant (sub-dominant)
Carex membranacea	Fragile-seeded Sedge	abundant
Alopecurus alpinus	Foxtail	common
Carex maritima	Sedge	common
Carex rupestris	Rock Sedge	common
Cerastium beeringianum	Chickweed	common

Draba alpine	Draba	common
Dupontia fisheri	Grass	common
Eriophorum triste	Cotton Grass	common
Festuca brachyphylla	Fescue	common
Melandrium apetalum	Bladder Campion	common
Oxytropis borealis	Locoweed	common
Papaver radicatum	Arctic Poppy	common
Parrya arctica	Arctic Wallflower	common
Pedicularis capitata	Capitate Lousewort	common
Pedicularis lanata	Woolly Lousewort	common
Poa arctica	Blue Grass	common
Potentilla rubricaulis	Cinquefoil	common
Cardamine digitata	Bitter Cress	frequent
Hierochloe pauciflora	Grass	frequent
Pedicularis sudetica	Sudetan Lousewort	frequent
Phlox richardsonii	Phlox	frequent
Polemonium boreale	Jacob's Ladder	frequent
Potentilla pulchella	Cinquefoil	frequent
Salix arctica	Arctic Willow	frequent
Saxifraga cernua	Nodding Saxifrage	frequent
Saxifraga hirculus	Yellow Marsh Saxifrage	frequent
Artemisia richardsoniana	Wormwood	occasional
Draba corymbosa	Draba	occasional
Draba glabella	Draba	occasional
Draba oblongata	Draba	occasional
Draba subcapitata	Draba	occasional
Erigeron eriocephalus	Fleabane	occasional
Matricaria ambigua	Seashore Chamomile	occasional
Melandrium affine	Bladder Campion	occasional
Potentilla vahliana	Cinquefoil	occasional
Ranunculus gmelinii	Water-crowfoot	occasional
Ranunculus pedatifidus	Buttercup	occasional
Salix polaris	Polar Willow	occasional
Stellaria longipes	Chickweed	occasional
Taraxacum pumilum	Dandelion	occasional
Trisetum spicatum	Grass	occasional
Artemisia hyperborean	Wormwood	uncommon
Colpodium vahlianum	Grass	uncommon
Senecio atropurpureus	Dark Purple Groundsel	uncommon

6. Barren or sparsely vegetated ground

Scientific name[1]	**Common name**	**Status**
Artemisia richardsoniana	Wormwood	occasional
Draba lacteal	Draba	occasional
Draba oblongata	Draba	occasional
Equisetum variegatum	Horsetail	occasional
Juncus biglumis	Rush	occasional
Lesquerella arctica	Arctic Bladderpod	occasional
Saxifraga oppositifolia	Purple Mountain Saxifrage	occasional
Stellaria longipes	Chickweed	occasional
Taraxacum pumilum	Dandelion	occasional
Astragalus alpinus	Milk Vetch	occasional
Draba alpine	Draba	occasional
Potentilla pulchella	Cinquefoil	occasional
Saxifraga cernua	Nodding Saxifrage	occasional
Carex aquatilis var. *stans*	Water Sedge	occasional
Petasites frigidus	Sweet Coltsfoot	occasional
Salix arctica	Arctic Willow	occasional
Epilobium latifolium	Broad-leaved Willow-herb	occasional
Minuartia rossii	Sandwort	occasional
Poa glauca	Blue Grass	occasional
Cochlearia officinalis	Scurvy Grass	occasional
Erigeron compositus	Fleabane	occasional

[1] Scientific names after Porsild and Cody (1980)

Appendix 2
The plant species composition of three localized habitats that were too small in area to be mapped using Landsat TM imagery

Riparian areas

Riparian areas are defined here as habitats adjacent to rivers, creeks, lakes and beaches. Within BIBS1, riparian habitats typically occurred as thin ribbons along drainages. Most riparian areas were moist or wet, with the exception of beaches, which typically had more-rapid drainage and were drier. Ground cover varies greatly, from 100% vegetation cover on the wetter sites to 5% or less cover on beaches.

Scientific name[1]	Common name	Status
Carex aquatilis var. *stans*	Water Sedge	abundant
Polygonum viviparum	Bistort	abundant
Caltha palustris	Marsh Marigold	common
Carex misandra	Sedge	common
Carex subspathacea	Sedge	common
Epilobium latifolium	Broad-leaved Willow-herb	common
Eriophorum scheuchzeri	Cotton Grass	common
Eriophorum triste	Cotton Grass	common
Oxyria digyna	Mountain Sorrel	common
Pedicularis lanata	Woolly Lousewort	common
Salix polaris	Polar Willow	common
Saxifraga hirculus	Yellow Marsh Saxifrage	common
Cardamine digitata	Bitter Cress	frequent
Chrysosplenium tetrandrum	Golden Saxifrage	frequent
Festuca baffinensis	Fescue	frequent
Juncus biglumis	Bog Rush	frequent
Poa arctica	Blue Grass	frequent
Poa glauca	Blue Grass	frequent
Potentilla pulchella	Cinquefoil	frequent
Salix arctica	Arctic Willow	frequent
Saxifraga cernua	Nodding Saxifrage	frequent
Senecio atropurpureus	Dark Purple Groundsel	frequent
Senecio congestus	Marsh Ragwort	frequent
Artemisia richardsoniana	Wormwood	occasional
Astragalus alpinus	Milk Vetch	occasional
Cochlearia officinalis	Scurvy Grass	occasional
Draba alpine	Draba	occasional
Draba lacteal	Draba	occasional
Draba oblongata	Draba	occasional
Dryas integrifolia	Mountain Avens	occasional
Dupontia fisheri	Grass	occasional
Equisetum variegatum	Horsetail	occasional
Hippuris vulgaris	Mare’s Tail	occasional
Lesquerella arctica	Arctic Bladderpod	occasional
Matricaria ambigua	Seashore Chamomile	occasional
Melandrium apetalum	Bladder Campion	occasional
Minuartia rossii	Sandwort	occasional
Petasites frigidus	Sweet Coltsfoot	occasional
Pleuropogon sabinei	Grass	occasional
Ranunculus gmelinii	Water-crowfoot	occasional
Ranunculus pedatifidus	Buttercup	occasional
Saxifraga oppositifolia	Purple Mountain Saxifrage	occasional
Stellaria longipes	Chickweed	occasional
Taraxacum pumilum	Dandelion	occasional
Draba glabella	Draba	uncommon
Erigeron compositus	Fleabane	uncommon
Juncus balticus	Baltic Rush	uncommon

Snow patches

Snow patch communities typically occur near hillsides or other areas of relief where drifting snow accumulates and remains into the growing season later than in other nearby areas. The extra moisture from the melting snow greatly influences plant species' abundance, and snow patch communities typically possess high plant diversity and have 100% ground cover.

Scientific name[1]	Common name	Status
Dryas integrifolia	Mountain Avens	abundant
Polygonum viviparum	Alpine Knotweed	abundant
Salix polaris	Polar Willow	abundant
Astragalus alpinus	Milk Vetch	common
Carex rupestris	Rock Sedge	common
Cassiope tetragona	Arctic White Heather	common
Juncus bigulmus	Bog Rush	common
Oxyria digyna	Mountain Sorrel	common
Parrya arctica	Arctic Wallflower	common
Pedicularis capitata	Capitate Lousewort	common
Poa glauca	Blue Grass	common
Saxifraga cernua	Nodding Saxifrage	common
Saxifraga tricuspidata	Prickly Saxifrage	common
Androsace chamaejasme	Rock Jasmine	frequent
Oxytropis arctica	Arctic Locoweed	frequent
Oxytropis borealis	Boreal Locoweed	frequent
Papaver radicatum	Arctic Poppy	frequent
Potentilla nivea	Snow Cinquefoil	frequent
Salix arctica	Arctic Willow	frequent
Saxifraga oppositifolia	Purple Mountain Saxifrage	frequent
Stellaria longipes	Long-stalked Stitchwort	frequent
Arnica alpinus	Alpine Arnica	occasional
Draba cinerea	Draba	occasional
Luzula confuse	Wood Rush	occasional
Luzula nivalis	Wood Rush	occasional
Melandrium affine	Bladder Campion	occasional
Plantago canescens	Plantain	occasional
Salix reticulate	Net-veined Willow	occasional
Saxifraga tenuis	Saxifrage	occasional
Potentilla hyparctica	Cinquefoil	uncommon
Taraxacum pumilum	Dandelion	uncommon

Raptor perches and fox dens

Areas near raptor perches and fox dens are nutrient-enriched and provide suitable growing sites for nitrophilous plant species. Fox dens often occur on hillsides, whereas raptor perches are typically large rocks. These sites are very small and characterized by mesic moisture conditions with 100% vegetation cover and high plant diversity.

Scientific name[1]	Common name	Status	Comments
Dryas integrifolia	Mountain Avens	abundant	fox den
Oxytropis arctica	Arctic Locoweed	abundant	fox den
Salix arctica	Arctic Willow	abundant	fox den
Alopecurus alpinus	Foxtail	common	fox den
Androsace chamaejasme	Rock Jasmine	common	fox den
Astragalus alpinus	Milk Vetch	common	fox den
Cerastium beeringianum	Mouse-ear Chickweed	common	fox den
Pedicularis lanata	Woolly Lousewort	common	fox den
Polemonium boreale	Jacob's Ladder	common	fox den
Potentilla rubricaulis	Cinquefoil	common	fox den
Saxifraga cernua	Nodding Saxifrage	common	fox den
Saxifraga tricuspidata	Prickly Saxifrage	common	fox den
Stellaria longipes	Chickweed	common	fox den
Cardamine digitata	Bitter Cress	frequent	fox den
Draba glabella	Draba	occasional	fox den
Draba subcapitata	Draba	occasional	fox den
Ranunculus pedatifidus	Buttercup	occasional	fox den
Cerastium beeringianum	Mouse-ear Chickweed	common	raptor perch
Draba cinerea	Draba	occasional	raptor perch
Draba glabella	Draba	occasional	raptor perch
Saxifraga nivalis	Snow Saxifrage	uncommon	raptor perch

[1]Scientific names after Porsild and Cody (1980)

Appendix 3
Plant species found within BIBS1

Family	Scientific name[1]	Common name
Equisetaceae	*Equisetum variegatum*	Horsetail
Gramineae	*Agropyron violaceum*	Wheat Grass
Gramineae	*Alopecurus alpinus*	Foxtail
Gramineae	*Arctagrostis latifolia*	Grass
Gramineae	*Colpodium vahlianum*	Grass
Gramineae	*Dupontia fisheri*	Grass
Gramineae	*Festuca baffinensis*	Fescue
Gramineae	*Festuca brachyphylla*	Fescue
Gramineae	*Hierochloe alpina*	Grass
Gramineae	*Hierochloe pauciflora*	Grass
Gramineae	*Pleuropogon sabinei*	Grass
Gramineae	*Poa glauca*	Blue Grass
Gramineae	*Trisetum spicatum*	Grass
Cyperaceae	*Carex aquatilis*	Water Sedge
Cyperaceae	*Carex capillaris*	Hair-like Sedge
Cyperaceae	*Carex maritima*	Sedge
Cyperaceae	*Carex membranacea*	Fragile-seeded Sedge
Cyperaceae	*Carex misandra*	Short-leaved Sedge
Cyperaceae	*Carex rupestris*	Rock Sedge
Cyperaceae	*Carex scirpoidea*	Bulrush Sedge
Cyperaceae	*Carex subspathacea*	Sedge
Cyperaceae	*Carex ursina*	Sedge
Cyperaceae	*Eriophorum callitrix*	Cotton Grass
Cyperaceae	*Eriophorum scheuchzeri*	Cotton Grass
Cyperaceae	*Eriophorum triste*	Cotton Grass
Juncaceae	*Juncus balticus*	Baltic Rush
Juncaceae	*Juncus biglumis*	Bog Rush
Juncaceae	*Luzula confusa*	Wood Rush
Juncaceae	*Luzula nivalis*	Wood Rush
Salicaceae	*Salix arctica*	Arctic Willow
Salicaceae	*Salix glauca*	Gray Willow
Salicaceae	*Salix polaris*	Polar Willow
Salicaceae	*Salix reticulata*	Net-veined Willow
Polygonaceae	*Oxyria digyna*	Mountain Sorrel
Polygonaceae	*Polygonum viviparum*	Bistort
Caryophyllaceae	*Cerastium beeringianum*	Mouse-ear Chickweed
Caryophyllaceae	*Melandrium affine*	Bladder Campion
Caryophyllaceae	*Melandrium apetalum*	Bladder Campion
Caryophyllaceae	*Minuartia rossii*	Sandwort
Caryophyllaceae	*Silene acualis*	Moss Campion
Caryophyllaceae	*Stellaria longipes*	Chickweed
Cruciferae	*Draba alpina*	Draba
Cruciferae	*Draba cinerea*	Draba
Cruciferae	*Draba corymbosa*	Draba
Cruciferae	*Draba glabella*	Draba
Cruciferae	*Draba lactea*	Draba
Cruciferae	*Draba nivalis*	Draba
Cruciferae	*Draba oblongata*	Draba
Cruciferae	*Draba subcapitata*	Draba
Cruciferae	*Eutrema edwardsii*	Mustard
Ranunculaceae	*Caltha palustris*	Marsh Marigold
Ranunculaceae	*Ranunculus gmelinii*	Water-crowfoot

Family	Scientific name[1]	Common name
Ranunculaceae	*Ranunculus pedatifidus*	Buttercup
Ranunculaceae	*Ranunculus pygmaeus*	Buttercup
Papaveraceae	*Papaver radicatum*	Arctic Poppy
Compositae	*Cardamine digitata*	Bitter Cress
Cruciferae	*Cochlearia officinalis*	Scurvy Grass
Cruciferae	*Lesquerella arctica*	Arctic Bladderpod
Cruciferae	*Parrya arctica*	Arctic Wallflower
Saxifragaceae	*Chrysosplenium tetrandrum*	Golden Saxifrage
Saxifragaceae	*Saxifraga caespitosa*	Tufted Saxifrage
Saxifragaceae	*Saxifraga cernua*	Nodding Saxifrage
Saxifragaceae	*Saxifraga hirculus*	Yellow Marsh Saxifrage
Saxifragaceae	*Saxifraga nivalis*	Snow Saxifrage
Saxifragaceae	*Saxifraga oppositifolia*	Purple Mountain Saxifrage
Saxifragaceae	*Saxifraga rivularis*	Saxifrage
Saxifragaceae	*Saxifraga tenuis*	Saxifrage
Saxifragaceae	*Saxifraga tricuspidata*	Prickly Saxifrage
Rosaceae	*Dryas integrifolia*	Mountain Avens
Rosaceae	*Potentilla hyparctica*	Cinquefoil
Rosaceae	*Potentilla nivea*	Cinquefoil
Rosaceae	*Potentilla pulchella*	Cinquefoil
Rosaceae	*Potentilla rubricaulis*	Cinquefoil
Rosaceae	*Potentilla vahliana*	Cinquefoil
Leguminosae	*Astragalus alpinus*	Milk Vetch
Leguminosae	*Oxytropis arctica*	Arctic Locoweed
Leguminosae	*Oxytropis borealis*	Boreal Locoweed
Onagraceae	*Epilobium latifolium*	Broad-leaved Willow-herb
Haloragaceae	*Hippuris vulgaris*	Mare’s Tail
Ericaceae	*Cassiope tetragona*	Arctic White Heather
Ericaceae	*Vaccinium uliginosum*	Alpine Blueberry
Primulaceae	*Androsace chamaejasme*	Rock Jasmine
Plumbaginaceae	*Armeria maritima*	Thrift
Polemoniaceae	*Phlox richardsonii*	Phlox
Polemoniaceae	*Polemonium boreale*	Jacob’s Ladder
Scrophulariaceae	*Pedicularis arctica*	Arctic Lousewort
Scrophulariaceae	*Pedicularis capitata*	Capitate Lousewort
Scrophulariaceae	*Pedicularis lanata*	Woolly Lousewort
Scrophulariaceae	*Pedicularis sudetica*	Sudetan Lousewort
Plantaginaceae	*Plantago canescens*	Plantain
Compositae	*Arnica alpinus*	Arnica
Compositae	*Artemisia hyperborea*	Wormwood
Compositae	*Artemisia richardsoniana*	Wormwood
Compositae	*Crepis nana*	Hawk’s Beard
Compositae	*Erigeron compositus*	Fleabane
Compositae	*Erigeron eriocephalus*	Fleabane
Compositae	*Erigeron humilis*	Fleabane
Compositae	*Matricaria ambigua*	Seashore Chamomile
Compositae	*Petasites frigidus*	Sweet Coltsfoot
Compositae	*Senecio atropurpureus*	Dark Purple Groundsel
Compositae	*Senecio congestus*	Marsh Ragwort
Compositae	*Taraxacum pumilum*	Dandelion

[1]Scientific names after Porsild and Cody (1980)

The abundance of breeding shorebirds and songbirds in the Banks Island Bird Sanctuary Number 1, Northwest Territories, in relation to the growing colony of Lesser Snow Geese (*Chen caerulescens caerulescens*)

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Abstract

Surveys were conducted at varying distances from the growing Lesser Snow Goose colony within the Banks Island Bird Sanctuary Number 1 (BIBS1), Northwest Territories, to assess the effects of potential habitat degradation caused by geese on densities of breeding shorebirds and songbirds. Survey transects were 5–7 km long and 50 or 75 m wide. They were situated within homogeneous lowland vegetation types dominated by grasses and sedges located within, and 5–30 km from the edge of, the goose colony. The density of all shorebird species combined was inversely related to distance from the goose colony. The densities of shorebirds and songbirds considered as a group increased up to approximately 10 km away from the nearest colony. Independent of the goose colony, density of shorebirds also significantly declined as distance from the coast increased. Results for individual shorebird species were inconsistent, likely from low sample sizes. The breeding density of songbirds, primarily Lapland Longspur (*Calarius lapponicus*), was not strongly related to distance from the goose colony. Given the low densities of shorebirds on Banks Island, the relatively small area of shorebird nesting habitat so far impacted by goose grazing in BIBS1 and beyond, and the wide breeding range of all species of shorebirds present, we suspect the population-level impacts of habitat loss are currently negligible.

1. Introduction

In some areas of the Canadian low Arctic and sub-Arctic, feeding habitats important to both nesting and staging Lesser Snow Geese of the mid-continent population have become seriously degraded (Abraham and Jefferies 1997) as the numbers of geese have increased in North America over the last 30 years (Kerbes et al. 1999; Canadian Wildlife Service Waterfowl Committee 2004). The intense feeding on both the rhizomatous and leafy parts of grasses and sedges (Gramineae and Cyperaceae families, collectively referred to as graminoids) have significantly altered the species composition and annual productivity of coastal marshes in the James Bay and western Hudson Bay regions (Jefferies et al. 1979; Kerbes et al. 1990; Abraham and Jefferies 1997). These changes have been attributed directly to physical damage to the plants and loss of cover (Cargill and Jefferies 1984), and indirectly to salinization of soils after destruction of the vegetation mat (Srivastava and Jefferies 1996).

The Lesser Snow Goose colony on Banks Island increased from 200 000 breeding birds in 1976 to well over 500 000 breeding birds in 2002 (Kerbes et al. 1999; Hines et al. 2010; D. Caswell and K. Meeres, personal ommunication). This mid-Arctic colony accounts for almost the entire breeding population of the western Arctic population of Lesser Snow Geese. Unlike the Snow Geese of the mid-continent population, the Banks Island geese do not make extensive use of coastal marshes during the breeding season. The main breeding colony occurs inland on Banks Island in the Big and Egg River valleys (Kerbes et al. 1999). The surrounding habitat is primarily moist or wet meadow in low-lying areas and more sparsely vegetated uplands (Hines et al. 2010). The impacts of Snow Geese on sedge-dominated plant communities have been described for sites in the eastern Arctic (Giroux et al. 1994; Gauthier et al. 1996; Giroux et al. 1998) and for the area in and around the Banks Island colony (Hines et al. 2010).

Despite long-standing awareness of their impacts on Arctic and sub-Arctic plant communities, there is little information on the broader effects of overgrazing by Snow Geese on other wildlife. Milakovic et al. (2003) reported the effects of habitat loss on soil insects, while Rockwell et al. (2003, unpublished) have examined the effects of habitat loss on the bird community associated with coastal and near-coastal habitats along Hudson Bay. Sammler et al. (2008) described the effects of Snow Goose grazing on shorebirds and passerines in “sedge meadows” adjacent to these same coastal salt marshes. Thus far, however, no information has been obtained on bird communities associated with extensive inland, sedge-dominated communities in the mid-Arctic, such as Banks Island. Shorebirds represent the majority of birds present, and many shorebird species are experiencing population declines (Donaldson et al. 2000; Morrison et al. 2001, 2006). Reasons for these declines are unclear, but deterioration of northern nesting areas could be part of the problem.

In order to devise the best strategies for dealing with overabundant Snow Goose populations and the urgency of the strategies’ implementation, a more complete picture is required on the effect that intensive foraging by geese may be having on ecosystems in different parts of the Canadian Arctic. For example, management may be less urgent for Snow Goose populations not associated with the coastal marshes if their impact on important feeding habitats (and associated biota) used by these populations has not reached serious levels. The primary objective of this study, therefore, was to examine the relationship between the Banks Island Snow Goose colony and the abundance of breeding birds in sedge-dominated vegetation in and around the colony.

2. Study area

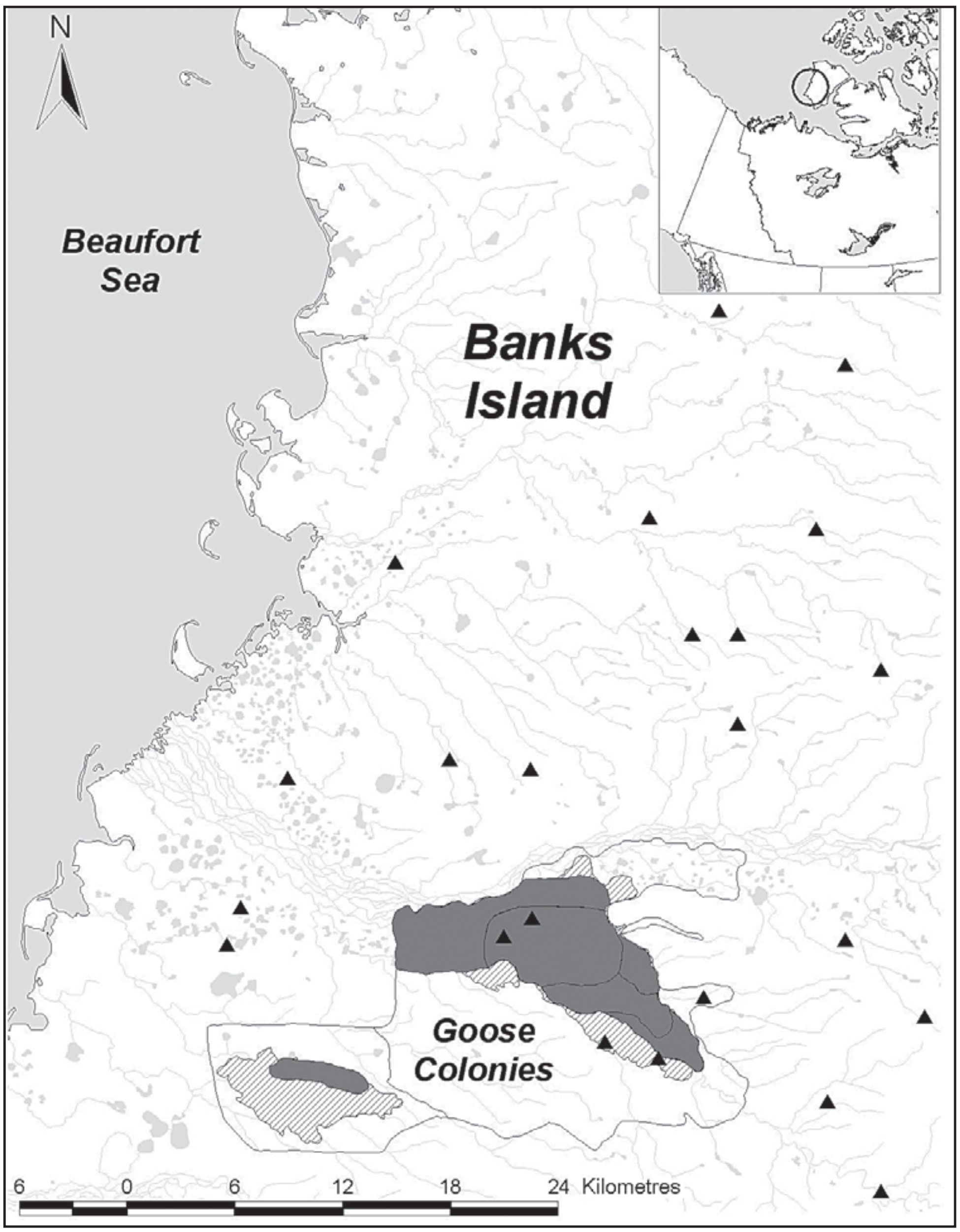
The study area (Figure 1) is situated in BIBS1 on southwestern Banks Island, Northwest Territories, centered about 72˚ 30' N, 124˚ 45' W. It includes the colony of Lesser Snow Geese located near the confluence of the Egg and Big rivers, but extends southwest to include part of the Lennie River, and an area within 50 km of the outer edges of the colony (Figure 1). Hines et al. (2010) provide a detailed description of the study area.

3. Methods

3.1 Survey methods

Shorebirds and songbirds were surveyed along 25 transects of 3–7 km in length. Twenty-three of those were surveyed both years (Figure 1), leaving two unpaired transects. The transects were located in: (1) patches of moist – wet tundra (wet habitat), (2) dry – mesic tundra

Figure 1
Study area and spatial extent of the Lesser Snow Goose colonies on southwestern Banks Island, Northwest Territories. Triangles mark the locations of the centres of bird transects. The goose colony is outlined in light and dark grey. The maximal size, encompassing the two areas of light hatched (> 1.6 geese/ha) and dark (> 28 geese/ha), was used as the colony boundaries for analyses. The open areas surrounding the colonies delineates areas of lower goose density referred to in the text.



and (3) dwarf shrub–herb (both dry habitat) identified on Landsat 5 Thematic Mapper (TM) imagery (Hines et al. 2010). They were located a maximum of 30 km from the outer edge of the Snow Goose colony. The former two land cover classes are known to be favoured by foraging geese, while dwarf shrub–herb were sufficiently common in the study area, and adjacent to preferred foraging habitat, such that sampling was done there also. Transects were linear, but occasionally had one bend (no more than 45˚) to keep the entire transect in a homogeneous land cover class. The starting point of each transect was located using a hand held Global Positioning System (GPS) unit. Each transect was surveyed by a team of two or three observers who walked at a slow pace (3–4 km/hr), spaced 25 m apart, scanning an area 12.5 m to their sides. Thus, transect width was 50 m when two observers were present and 75 m when three observers were present. One observer recorded all shorebirds and songbirds observed on the ground or flushed within the transect. All shorebirds and songbirds observed flying into the transect and landing were also treated as being present on the transects. Although all obvious male/female pairs were noted, it was not assumed that the presence of a territorial male meant a breeding pair was present. The presence of a breeding pair was assumed when an individual showed obvious distraction behaviour even if a nest was not found. Surveys were conducted from June 12–25, 2000, and June 13–24, 2001. We randomly assigned either two or three observers to transects. Consequently, surveyed area for a given transect varied among years. Plots were surveyed between 0900 and 1600 hrs during the peak breeding period for shorebirds and songbirds. Surveys were not conducted during periods of rain, strong winds (more than 30 km/hr) or restricted visibility (e.g., fog).

Table 1
Count of birds, by species, observed on 25 transects surveyed in 2000 and 2001 on Banks Island, Northwest Territories

	Year		
Species	2000	2001	Total
Baird's Sandpiper	8	12	20
Black-bellied Plover	62	38	100
Buff-breasted Sandpiper	13	3	16
Horned Lark	22	5	27
Lapland Longspur	547	399	946
American Golden-Plover	17	28	45
Pectoral Sandpiper	49	5	54
Red Phalarope	13	7	20
Ruddy Turnstone	23	8	31
Sanderling	1	1	2
Semipalmated Plover	2	3	5
Semipalmated Sandpiper	6	1	7
White-rumped Sandpiper	57	14	71
Total shorebirds	251	120	371
Total songbirds	569	404	973
Grand totals	820	524	1344
Area surveyed (km^2)	8.80	6.93	15.73

3.2 Data analyses

Density of birds was calculated by dividing the total count of each species by the surveyed area (km^2) in each year, then averaging across the two years. Although intraspecific variation was high (Table 1), within-species counts decreased in the second year more than expected based on the difference in area surveyed. For all shorebirds combined, this reduced density in 2001 versus 2000 was marginally significant (paired *t*-test $t = 1.83$, d.f. = 23, P = 0.08). Lapland Longspurs were considerably more abundant than other species. This meant that results of transect-level analyses would be primarily influenced by the response of Lapland Longspurs, with minor variation from the rest of the community. To account for this, the data were split into two groups: shorebirds (Semipalmated Plover, Black-bellied Plover, American Golden-Plover, Red Phalarope, Ruddy Turnstone, Sanderling, Semipalmated Sandpiper, White-rumped Sandpiper, Baird's Sandpiper, Pectoral Sandpiper and Buff-breasted Sandpiper) and songbirds (Horned Lark and Lapland Longspur).

As Snow Geese typically graze in wet, sedge-dominated habitat (moist – wet tundra) (Hines et al. 2010), we hypothesized that the shorebird species that prefer this habitat would be most impacted by the physical impacts of Snow Goose grazing. Shorebird species, therefore, were classified as either wet-habitat nesters (moist – wet tundra) (Hines et al. 2009) or dry-habitat nesters (dry – mesic tundra, dwarf shrub–herb barrens), based on the species' documented nesting habitat. The former category consisted of White-rumped Sandpiper, Pectoral Sandpiper, Red Phalarope (Parmelee 1992; Holmes and Pitelka 1998; Tracy et al. 2002). The latter consisted of Semipalmated Sandpiper, Buff-breasted Sandpiper, Black-bellied Plover, Ruddy Turnstone, Sanderling, Baird's Sandpiper, American Golden-Plover and Semipalmated Plover (Gratto-Trevor 1992; Lanctot and Laredo 1994; Paulson 1995; Nettleship 2000; Macwhirter et al. 2002; Moskoff and Montgomerie 2002; Johnson and Connors 1996; Nol and Blanken 1999). Wet-habitat nesters used the sedge wetlands along river and stream valley bottoms in the study area, while dry-habitat nesters used the less-vegetated hillsides and plateaus adjacent to the wetlands.

Abundance of shorebirds also varied more than tenfold among species, and rescaling was necessary to reduce the influence of a few abundant species (Krebs 1989). Due to the large annual differences noted above, the count within each species observed on a transect was divided by the maximum count observed on any transect in that year (e.g., if the highest number of White-rumped Sandpipers observed on a transect in one year was 14, the relative value calculated for that year was the count on each transect divided by 14). Within each year, therefore, all species had an adjusted value that ranged from zero to one. This rescaled value was divided by the transect area to produce a rescaled density to preserve differences in overall abundance between transects. These rescale densities were then summed across species to provide a rescaled value for shorebird density for either wet-nesting or dry-nesting species for each transect.

As with the rationale for splitting the data into shorebirds and songbirds, without rescaling of the shorebird data, results primarily would reflect trends in the two common Plover species, and variation in the other species would be lost. The alternative was to analyze individual species or small aggregations of species with similar densities, to determine responses. The latter approach would have very little power with our relatively small sample sizes.

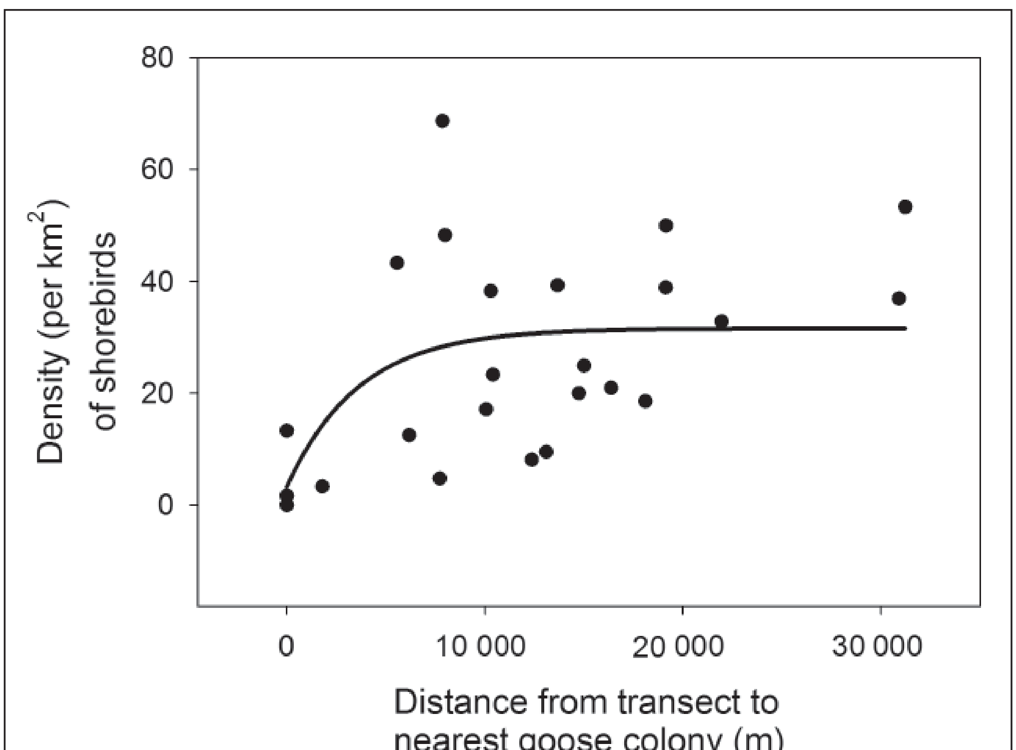
The size and shape of the Snow Goose colony on Banks Island has varied somewhat over the years (Kerbes et al. 1999; Samelius et al. 2008; Caswell and Meeres, unpublished data). The colony area identified for this study was the one observed in 1995, when intensive aerial surveys enabled demarcation of high (> 28 geese per hectare [ha]) and moderate (> 1.6 geese/ha) densities of geese (Figure 1) (Kerbes et al. 1999). Adjacent areas of lower densities have been observed over the years (Figure 1). For analysis, the goose colony was defined as the areas of high and moderate density. Defining the colony in this manner resulted in the major portion of the colony being centred around the confluence of the Big and Egg rivers, with another high-nesting-density area to the southwest of the main colony (Figure 1).

Previously, our general assessment of habitat conditions on Banks Island indicated that the habitat within the Snow Goose colony was overgrazed and degraded, and that much of the nearby lowland habitat within the valleys of the Big and Lennie rivers was heavily grazed (Hines et al. 2010). We therefore used distance from the goose colony as an index of grazing pressure (habitat conditions) on the survey transects. We predicted that if goose grazing was affecting the habitat of shorebirds or songbirds, densities should increase as distance from the colony increased. In addition, we predicted that at some point from the colony, grazing effects (if they existed) would no longer be discernible and the relationship would become asymptotic as shorebird and songbird numbers no longer increased with distance from the colony. Thus, curvilinear models were expected to produce best-fit lines. Each survey transect's position with respect to the colony was determined by the linear distance between the centre point of the transect and the nearest edge of the colony. The shortest distance from the transect mid-point to the west coast of Banks Island was also computed, owing to the study area's proximity to the west coast of Banks Island (Figure 2). Other studies on Arctic breeding grounds (Morrison 1997; TERA 1994) have found shorebird abundance to be positively correlated with distance to the nearest coastline.

A subjective, relative assessment of habitat value was applied to each homogeneous part of a transect (sub-transect). This was done to control for the possibility that any observed patterns in the data were from non-random distributions of higher- or lower-value habitats relative to the goose colony. Out of 10, barren ground was assigned a value of 0, dwarf-shrub / lichen-rock was assigned 2, lowland pond complex was assigned 6, and both graminoid / graminoid dwarf-shrub and wet sedge meadow were assigned 8. Sub-transect values were averaged at the transect level.

Relationships between bird density, distance to the Snow Goose colony, subjective habitat value, and distance to the coastline were examined using a repeated-measures general linear model (GLM) procedure (SPSS 17.0) with n = 23 (the two unpaired transects were omitted). Transect

Figure 2
Raw relationship between shorebird density (per km^2) and transect distance from the nearest goose colony, Banks Island, Northwest Territories, using unrescaled data (no correction for transect distance from coast, mean of 2000 and 2001 data). The best-fit regression was an exponential rise to maximum curve ([$y= \beta_0 + a(1-e^{-bx})$]) ($F_{2,23}$ = 4.76, P = 0.02, adjusted R^2 = 0.24).



is the subject in the GLM; two years of abundance data with two nesting preferences provide four within-subjects combinations. The three explanatory variables are entered as co-variates in this procedure. Models with all combinations of the three explanatory variables were run, and the most parsimonious model was selected using AIC_c criteria. Visual displays of the response patterns (plotting residuals to response variables to separate the effects for presentation) were made with best-fit curves that were chosen on the basis of increasing coefficient of determination values (adjusted R^2) in SigmaPlot 11.0. A Kolmogorov-Smirnov test was used to assess normality and the Levene Median test was used to assess homoscedascity to ensure regression results were reliable (not presented here).

As well as affecting species density, overgrazing of habitat could reduce species diversity. We calculated species richness for each transect using EstimateS (5.0.1) software (Colwell 1997). The "Sobs" (species observed) term was used as an indicator of species richness (Gotelli and Colwell 2001). This approach was chosen over the more traditional "count" of species method because of the inherent problems in comparing the number of species contained in an unequal sample of individuals (Gotelli and Colwell 2001). For example, by chance alone, one would expect to find more species in a sample of 100 individuals than in a sample of 50 individuals. Analyses are based on the complete data set of 730 records of 1344 birds.

4. Results

4.1 Count summary

Eleven species of shorebirds and two species of songbirds were counted in surveys, with Black-bellied Plover and Lapland Longspur being the most common (Table 1). Transects inside the goose colony had fewer species and fewer individuals than transects outside (Table 2). American Golden-Plover, Black-bellied Plover, and White-rumped Sandpiper were the only shorebird species found within the colony boundaries, but in comparatively low numbers, and no evidence of nesting was observed (Figure 1, Table 2).

4.2 Influence of the Snow Goose colony on bird density

Our raw shorebird-density data is presented in Figure 2, displaying the pattern evident without rescaled data or analyses that account for transect distance to the coast (i.e., the results below are not the result of rescaling the data). Shorebird densities showed a weak curvilinear relationship with the distance from the goose colony, as predicted.

Distance from the edge of the colony, combined with distance to the coast, best explained the observed pattern in the data based on AIC_c (Table 3) when data were rescaled and both effects were accounted for simultaneously in the GLM. The next best model, where all three variables were included, had "considerably" less support (Burnham and Anderson 2002).

Separately, there was a strong relationship between shorebird density and distance to the edge of the goose colony (GLM results: $F_{1,22} = 27.6$, $P < 0.001$; see Figure 3) when using rescaled data and the repeated-measures GLM to account for the influence of distance to coast. The most pronounced effect appeared within 10 km of the nearest colony, with little additional effect thereafter (Figure 3). The trend was not significantly different between the dry-habitat nesting shorebirds versus wet-habitat nesters (distance from colony by nesting preference interaction, $F_{1,22} = 0.50$, $P = 0.49$). However, plotting residuals and fitting curves revealed that most of the strength of the curvilinear relationship in the data in Figure 3 is from the dry-nesting species (Figure 4).

Using rescaled data, shorebird abundance declined as transect distance from the coast increased, independent of the effect of the goose colony (Figure 5). The inverse influence of the ocean coast on shorebird density was strong (GLM results: $F_{1,22} = 37.3$, $P < 0.001$), with the best-fit line following a negative, weakly curvilinear relationship.

Rescaled songbird density was unaffected by either the ditance to the nearest goose colony or the distance of each transect from the ocean (Figure 6); linear regressions: $P = 0.46$, $P = 0.79$, respectively (non-linear fits were not significant either).

Table 2
Mean density (birds/km^2) for birds observed on all 25 transects sampled on Banks Island, Northwest Territories. N is the number of transects surveyed in each group. Densities were calculated separately for each year, and then averaged because the area surveyed in each year was not identical. Categories were determined from results shown in Figures 2 and 3. Results are not corrected for distance to the coast of individual transects, and are not rescaled.

Species	Within colony N = 4	Near colony (0–10 km) N = 6	Away from colony (> 10 km) N = 15
Shorebirds			
American Golden-Plover	2.73	3.19	3.48
Black-bellied Plover	2.64	5.42	7.44
White-rumped Sandpiper	0.74	7.21	4.36
Ruddy Turnstone		4.65	1.65
Baird's Sandpiper		1.56	1.56
Buff-breasted Sandpiper		3.39	1.04
Red Phalarope		1.65	1.48
Sanderling		0.58	0.17
Semipalmated Plover		0.58	0.41
Semipalmated Sandpiper			0.62
Pectoral Sandpiper		4.71	
Songbirds			
Lapland Longspur	42.96	61.39	63.89
Horned Lark	0.82	1.74	1.88

Table 3
AIC_c results for linear regression models explaining the variation of relative shorebird density as a result of distance to edge of the Snow Goose colony, distance to the ocean (seadist), or habitat value (habval) of individual transects. N = 23.

Parameters	k	RSS	AIC_c	Δi	Weight
edge, seadist	4	58.273	96.9	0.0	0.83
edge, seadist, habval	5	57.885	100.0	3.2	0.17
seadist, habval	4	138.667	116.8	19.9	0.00
edge	3	166.971	118.1	21.3	0.00
edge, habval	4	150.940	118.8	21.9	0.00

Figure 3
Mean rescaled densities of shorebirds on transects compared to their distance from either goose colony when corrected for the effect of distance to coast. See text for explanation of how actual densities were calculated. The parameters for the best-fit line were $\beta_0 = -4.06$, a = 6.4378, b = 0.0001, $F_{2,23} = 4.76$, $P < 0.001$, adjusted $R^2 = 0.69$. Note that data for both years were averaged to produce this plot, so N = 25 instead of N = 23 for the repeat GLM procedure.

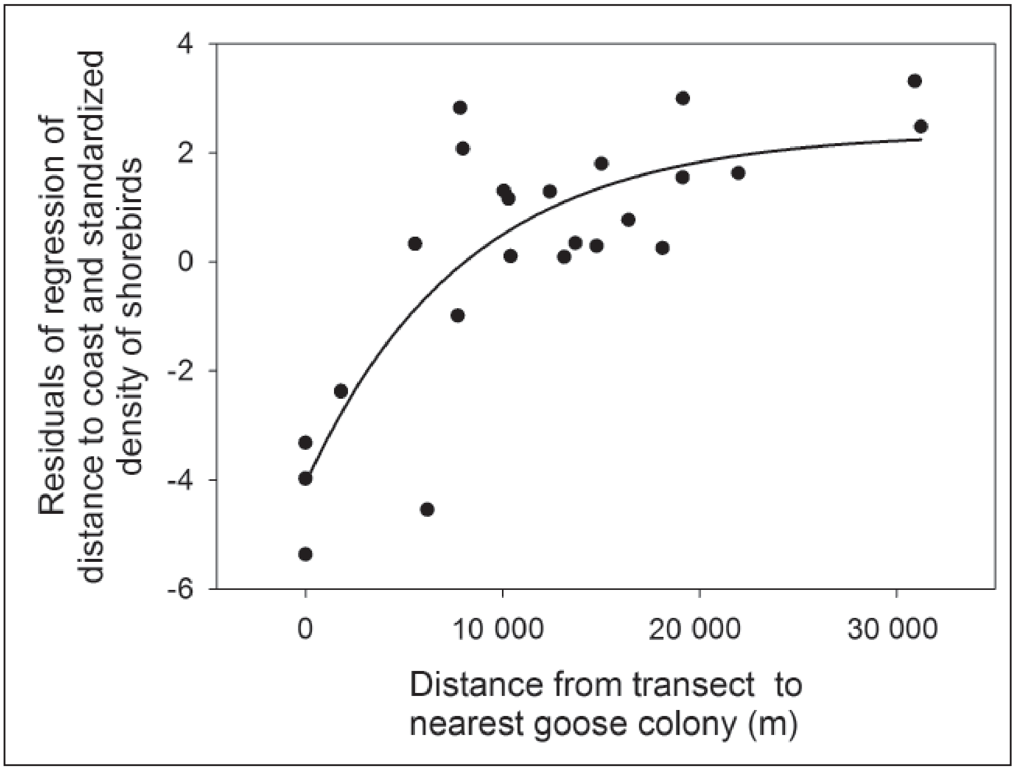


Figure 4
Differential response of dry-habitat nesters and wet-habitat nesters to increasing distance from the goose colonies. These are the same data from Figure 3 but are split into the two groups of birds described in the methods section.

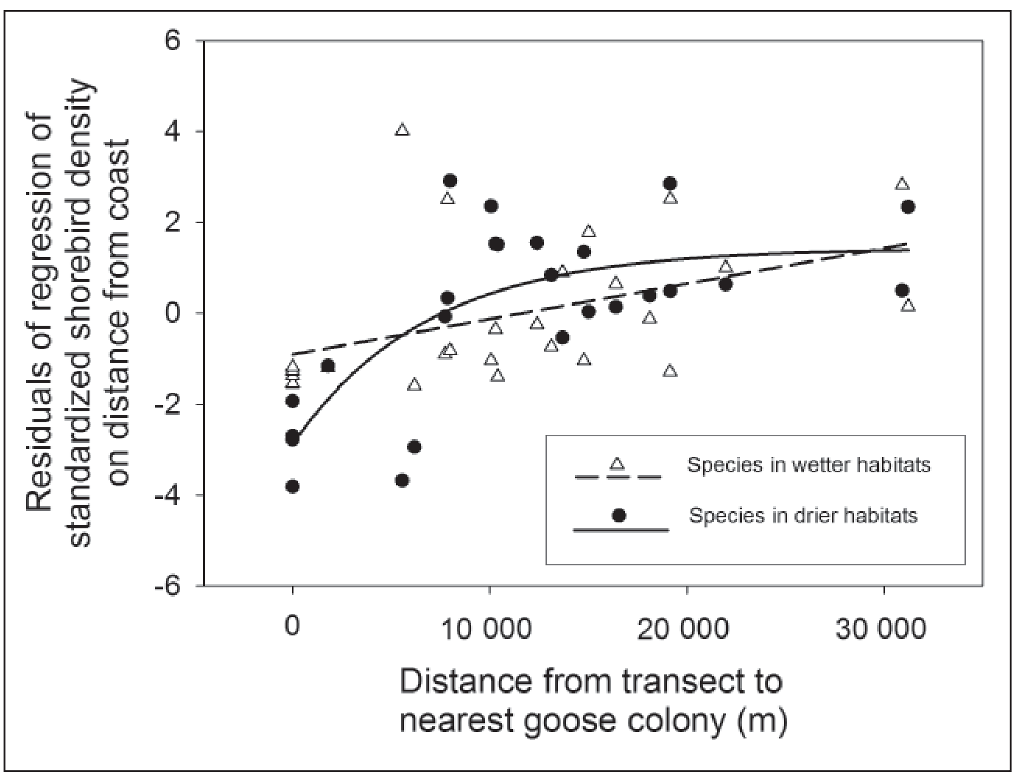


Figure 5
Corrected relationship between relative shorebird density and distance of the survey transect from the western coast of Banks Island, Northwest Territories, when the effect of the distance from the goose colony is removed. The best-fit line was an exponential decay function [$y = \beta_0 + ae^{-bx}$] with parameters of β_0 = -5.366, a = 11.634, b = 0.0000407.

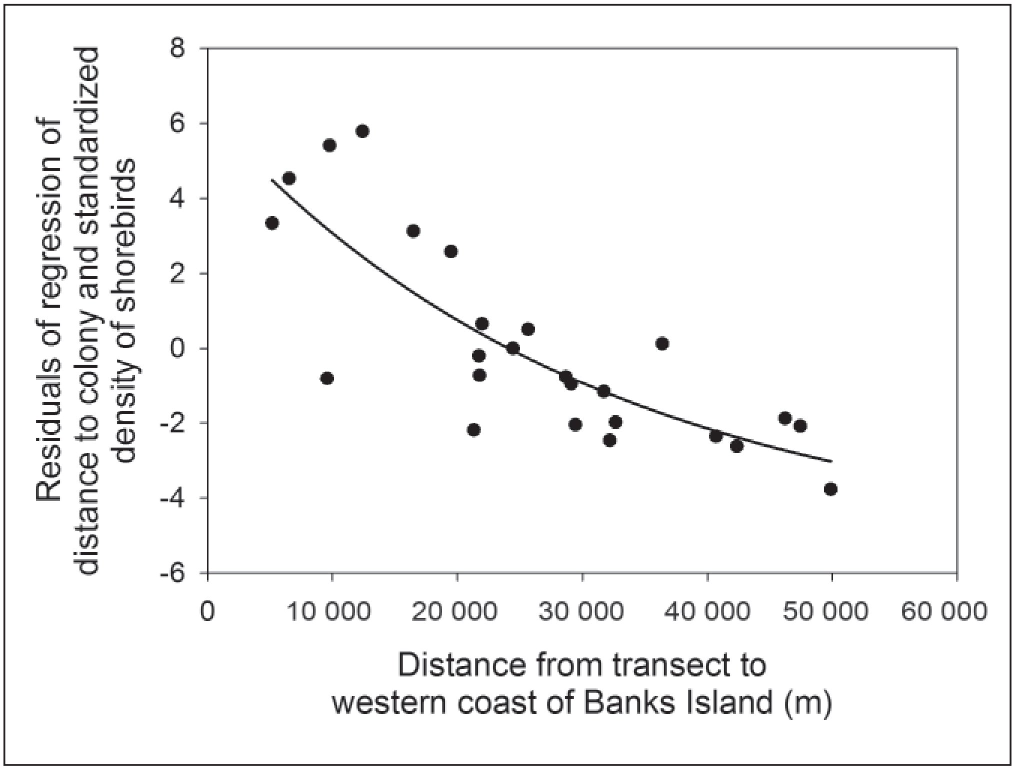
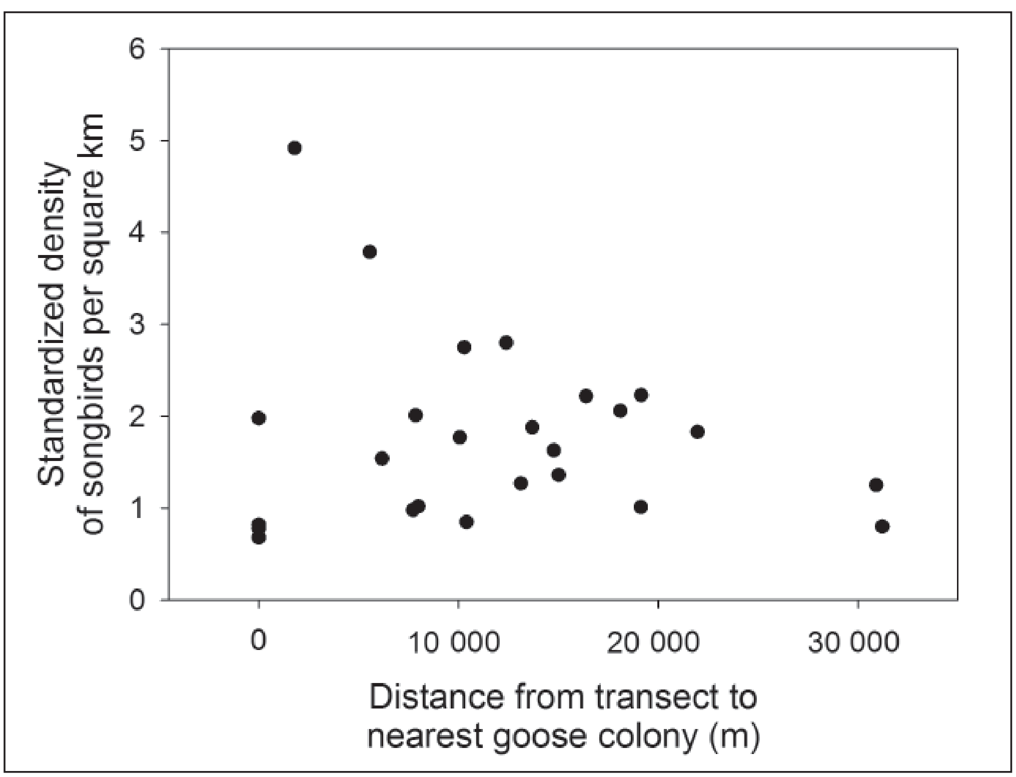


Figure 6
Relationship between the rescaled songbird density and distance to the edge of the Snow Goose colony. Linear and non-linear fits were not significant.



4.3 Response of individual species to the Snow Goose colony

The response of individual species to distance from the goose colony was modelled using the same repeat-GLM procedure and the best-fit model found for the community. Two species showed a significant relationship between the residuals and distance to the goose colony (Black-bellied Plover: $F_{1,22} = 6.37$, $P = 0.02$; Red Phalarope: $F_{1,22} = 8.352$, $P = 0.009$). It is assumed that there was insufficient power to detect a trend for most individual species.

4.4 Species richness

Species richness did not differ between transects close to the colony (< 10 km) and those farther away. There were 11 species (283 birds) on the closer transects and 12.0 ± 1.43 (95% confidence interval) for the equivalent number of birds on transects farther from the goose colonies. In both cases, the two most common species were Lapland Longspur and Black-bellied Plover. However, as noted above, it is obvious that transects inside the goose colony had a paucity of species (Table 2)

5. Discussion

The severe and long-term impacts of nesting and migrating Snow Geese on coastal salt marshes in the Canadian sub-Arctic has been well-documented. For example, along the west coast of Hudson Bay, physical damage and salination greatly altered the entire plant species composition and reduced overall biomass (Abraham and Jefferies 1997). In the mid-Arctic, Snow Geese depend more on inland sedge-dominated wetlands, both for feeding in and around colonies and for feeding away from colonies by broods, non-breeders, and failed breeders (Giroux et al. 1994; Giroux et al. 1998). These wetlands have not received the same amount of study as the low-Arctic wetlands, but some effects have been observed on biomass and productivity (Giroux et al. 1994; Giroux et al. 1998)—although the level of severity does not match that seen in the low Arctic (Abraham and Jefferies 1997).

Gratto-Trevor (1994), Hitchcock and Gratto-Trevor (1997) and Rockwell et al. (2003) reported marked declines in some shorebird and passerine species at a coastal wetland in the Hudson Bay lowlands. This was likely caused, at least in part, by habitat degradation attributable to Snow Goose grazing within and around the Snow Goose colony. Sammler et al. (2008) reported that shorebirds and tundra-nesting passerines, in a study area 15 km from the same Snow Goose colony, were at lower densities where sedge meadow habitat had been altered by goose grazing; however, they did not quantify this alteration.

In our study area, Hines et al. (2010) reported that, up to 2001, the Snow Goose colony on Banks Island had a low level of impact on lowland habitats compared to elsewhere (Abraham and Jefferies 1997). Of the affected habitat, only 5.2% was degraded, and this degradation was restricted mainly to a 20-m strip around ponds and lakes within the Snow Goose colony itself. The post-breeding dispersal and subsequent densities of Snow Geese on Banks Island (Samelius et al. 2008; Hines et al. 2009), and the habitat conditions reported by Hines et al., suggest similar impacts on vegetation both within and beyond 10 km from the colony. Nonetheless, we found that the numbers of nesting shorebirds increased up to approximately 10 km away from the colony of Snow Geese on Banks Island, then remained constant to at least 30 km from the colony. The limited spatial effect reported here and by Sammler et al. (2008) may reflect, in part, a degradation of habitat caused by Snow Goose grazing as well as other factors. For example, the spatial effect observed in our study was most pronounced when the influence of distance to coastline was removed from the analysis. As in some other studies of Arctic-nesting shorebirds, densities decrease with distance from the coast, but the reasons for this are unknown. The relationships between shorebird densities and distance to the goose colony on Banks Island, and perhaps elsewhere, probably involve a combination of distance from the colony, proximity to the coastline, and possibly other factors such as the greater numbers of predators that are attracted to the colony (Samelius and Alisauskas 2000).

Black-bellied Plover and American Golden-Plover were the only shorebirds regularly observed within the Snow Goose colony where grass sward was virtually non-existent, although they were not observed nesting in the colony. The absence of Pectoral Sandpiper (one of the more common shorebirds observed in this study) within 10 km of the Snow Goose colony suggests that they may be particularly sensitive to nest-cover requirements and impacts on wetland vegetation by foraging geese. Yet, the nesting habitat of Pectoral Sandpipers, consisting of wet tundra as well as drier grass – dwarf shrub tundra (Holmes and Pitelka 1998), does not suggest that they should be more sensitive than species such as White-rumped Sandpiper (Parmelee 1992).

Both Lapland Longspurs and Horned Larks were observed within and outside the Snow Goose colony with equal frequency, and Lapland Longspurs nested within the colony. These species do not depend on extensive grass sward development and readily use micro-relief for nest concealment (Hussell and Montgomerie 2002; Beason 1995). Furthermore, Lapland Longspurs and Horned Larks have a broader diet than shorebirds; it includes seeds and a range of invertebrate prey. In fact, the Snow Goose colony, with an abundance of goose nests, fecal material and carrion, may have more invertebrate prey available to Lapland Longspurs and Horned Larks than areas outside the colony.

The maximum densities of shorebird species observed in this study (i.e., either within or beyond 10 km from the Snow Goose colony) were considerably lower than those reported for the same species in the Mackenzie Delta (Gratto-Trevor 1996) and on the North Slope of Alaska (TERA 1993), the two areas of concentrated shorebird nesting that are closest to Banks Island. Densities in this study were also considerably less than those reported from mid-Arctic sites in northern Canada (Johnson and Gratto-Trevor 1999). The low densities of nesting shorebirds on Banks Island, the relatively small area of shorebird nesting habitat affected by the Snow Goose colony, and the wide breeding ranges of all species encountered in this study indicate that, at the species population level, impacts from the Snow Goose colony on Banks Island are negligible.

Sammler et al. (2008) concluded that shorebirds and passerines appeared to be negatively affected where habitat had been locally altered by grazing Snow Geese. However, there was not an effect at a larger spatial scale suggesting that habitat alteration needed to reach a threshold. The density of nesting songbirds (primarily Lapland Longspurs) was similar to that reported on the North Slope of Alaska (TERA 1994). Studies are required on species' nest-site requirements, food habits and availability, and feeding behaviour in relation to vegetation cover in and around the Snow Goose colony. These would provide a better understanding of the species-specific effects of the Banks Island and other mid-Arctic Snow Goose colonies, and the relationship at the population level between expanding Snow Goose populations and nesting shorebirds and songbirds.

Management implications of these findings, especially in relation to those of Hines et al. (2010), are addressed in the Conclusion (this volume).

Conclusions and management implications

1. Conclusions

The extensive damage by foraging Lesser Snow Geese at a variety of sites in the central Canadian Arctic and sub-Arctic did not appear to have occurred in the area around the Snow Goose colony in the Banks Island Bird Sanctuary Number 1 (BIBS1) in the western Arctic, up to at least 2001 (this study). Aside from within the colony, intensive foraging was restricted primarily to lowland pond complexes associated with the deltas of major rivers in the area, and areas immediately adjacent (within 5 m) to more-isolated ponds and small lakes. The heavily impacted area represented only 5.2% of the lowland habitat within BIBS1. This is in contrast to that found in areas in the low- and sub-Arctic, where two thirds of wetlands (primarily coastal salt marsh) were virtually destroyed (Abraham and Jefferies 1997). Despite the restricted nature of severe effects on vegetation resulting from Snow Goose foraging in and around the BIBS1 colony, this study provides evidence that the effects on the surrounding breeding bird community were more widespread. Wetland nesting shorebirds, in particular, occurred at lower densities in wetlands within 10 km of the outer bounds of the Snow Goose colony than beyond 10 km. These wetlands, however, are at higher elevation along secondary and tertiary stream valleys associated with the major drainages in the study area. This study found that, compared to the heavily impacted area, lowland pond complexes and lake edges, the higher-elevation wetlands received relatively light impact. Regardless, it is possible that wetland-nesting shorebirds may be sensitive to subtle changes in sward height and density caused by even light Snow Goose foraging and associated trampling. These higher elevation wetlands within 10 km of the Egg River snow goose colony, however, represent less than 3% of such wetlands within BIBS1. This, coupled with the low densities of shorebirds on Banks Island, the apparent lack of effect on passerines, and the widespread nature of the species observed (this study), suggests that there were no serious conservation concerns associated with a colony size of 500 000 Snow Geese (2002 size) in BIBS1 and its effects on the surrounding vegetation and breeding bird community.

2. Management implications

Although there does not appear to be a serious management concern with respect to the size of the Snow Goose colony in BIBS1 at its 2002 size, increased growth is not desirable. The lowlands surrounding the colony support other grazers, some of which have subsistence value to local Aboriginal people (e.g., Muskoxen, Peary Caribou, Arctic Hare). Furthermore, should the size of the Snow Goose colony increase, it would become difficult to use harvest-related management actions to bring the population down to the 2002 level, considering that current actions are likely working at their maximum effectiveness. We suggest that over the short to medium term, the following management approaches be continued or adopted:

- The Snow Goose colony in BIBS1 should be capped at 600 000 breeding individuals, given the evidence in this study for at least localized impacts on the surrounding vegetation and breeding bird community.
- The harvest rate of the western Arctic Lesser Snow Geese by northern Aboriginal hunters (6000 birds/year) is likely at the maximum, considering the numbers of hunters and other factors. Therefore, there should be continued efforts to maintain the current southern sport harvest. An evaluation of existing harvest, banding and population data is needed to determine harvest and survival rates, and potential harvest strategies for limiting population growth.
- Periodic (e.g., every five years) surveying of the goose colony is necessary, and additional banding of geese would be useful for evaluating the success of management measures (specifically, increased harvest) on population growth.
- Future monitoring of habitat conditions is needed. Photos taken periodically at the same lowland sites would be useful for monitoring gross changes in habitat, and the establishment of permanent grazing exclosures (which cannot be damaged by Muskoxen) is needed to evaluate goose foraging and the resiliency of plant communities to high grazing pressure.
- Future research should focus on the effects of Snow Goose foraging on the breeding bird community at the species level, in conjunction with more detailed examination of other ecological factors such as invertebrate prey abundance and availability, vegetation characteristics (particularly in higher-elevation sedge wetlands), and reproductive success of shorebirds and songbirds in spatial relation to the Snow Goose colony. This is especially true if surveys indicate the Snow Goose colony is maintaining its 2002 size.

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