

BYLOT: Long-term abundance time-series of a High Arctic terrestrial vertebrate community

Authors:

Louis Moisan^{1,2}, Azenor Bideault^{2,3}, Pierre Legagneux^{3,4}, Gilles Gauthier⁵, Éliane Duchesne¹, Marie-Christine Cadieux³, Dominique Berteaux¹, Dominique Fauteux⁶ and Joël Béty¹

Author Affiliations:

¹ Chaire de Recherche du Canada en Biodiversité Nordique, Centre d'Études Nordiques, Centre de la science de la biodiversité du Québec, Département de biologie, chimie et géographie, Université du Québec à Rimouski, Rimouski, QC, Canada

² Chaire de Recherche du Canada en Écologie Intégrative, Centre d'Études Nordiques, Centre de la science de la biodiversité du Québec, Département de Biologie, Université de Sherbrooke, Sherbrooke, QC, Canada

³ Chaire de Recherche Sentinelle Nord sur l'impact des migrations animales sur les écosystèmes nordiques, Centre d'Études Nordiques, Centre de la science de la biodiversité du Québec, Département de Biologie, Université Laval, Québec, QC, Canada

⁴ Centre d'Études Biologiques de Chizé (CEBC-CNRS), Université de La Rochelle, France

⁵ Centre d'études nordiques, Département de Biologie, Université Laval, Québec, QC, Canada

⁶ Centre d'études nordiques, Centre de connaissance et d'exploration de l'Arctique, Musée canadien de la nature, Ottawa, ON, Canada

Corresponding Author:

louis.moisan.bio@gmail.com

joel_bety@uqar.ca

Abstract

Arctic ecosystems present unique opportunities for community-wide monitoring, in part due to their relatively low species richness. However, conducting research in these remote environments poses significant logistical challenges, resulting in long-term monitoring being exceedingly rare. Here, we focus on the long-term, intensive ecological monitoring efforts conducted on the south plain of Bylot Island (almost 400 km², Nunavut, Canada), which has generated a remarkable dataset spanning up to 30 years, a rarity in tundra ecosystems. Our goal is to synthesize this dataset and upscale vertebrate abundance data at the landscape level, a prerequisite to conduct community-level analyses. We have standardized data obtained with different field methods to provide readily usable long-term time series of abundance for 35 vertebrate species (30 birds and 5 mammals) present in the study system. Monitoring data includes intensive capture-mark-recapture density estimates of lemmings on trapping grids, systematic or opportunistic nest monitoring conducted across the entire study area or within specific plots for all bird species, transects of vertebrate counts distributed throughout the study area, daily incidental observations of vertebrates and satellite tracking of fox movements. Annual abundance of species was estimated at the landscape level, accounting for spatial variations. Furthermore, we provide body masses for each species, derived from

empirical onsite measurements for 18 species and from the literature for the remaining species. Body mass is essential to convert species abundance into biomass for studies of trophic fluxes and ecosystem processes. Our dataset provides a unique opportunity for holistic empirical studies of ecological communities, allowing a deeper understanding of community structure and dynamics. Considering that the study site is a pristine and protected area that has experienced minimal anthropogenic impact, it can also provide an ideal baseline for investigating the impacts of global changes on high-latitude terrestrial ecosystems.

Introduction

The composition of ecological communities, defined as the abundance of each species within a given community, is fundamental for understanding patterns and processes in community ecology. Community composition can help to detect spatial patterns linked to environmental variations (Kemp et al., 1990), assess temporal trends of different groups of species after disturbances (Philippi et al., 1998; Magurran, 2007), and understand food web structures (Cohen et al., 2003). Additionally, community composition is essential for modeling the dynamics of ecological communities. Dynamic community modelling allows addressing important issues and questions in ecology, such as: determining the relative strength of top-down versus bottom-up forces in communities (Krebs et al., 2003; Legagneux et al., 2014), assessing the ecological resilience of communities under climate change (Griffith et al., 2019) and evaluating the cascading effects of invasive species in food web (David et al., 2017; Goto et al., 2020). Dynamic community modelling can also be applied to address practical challenges, including fishery management (Plagányi, 2007) and the planning of protected areas (Okey et al., 2004; Dahood et al., 2020).

Modeling ecological communities requires adjusting trophic flows based on species' functional responses, which necessitates time series data on the abundance of all species within a community. However, accurately determining the abundance of all species is rarely achievable. Consequently, empirical community models often reduce taxonomic resolution by grouping species into large functional or taxonomic categories. Additionally, food webs consist of species with varying body sizes depending on their trophic level, with top-level species often being highly mobile and having large home ranges (McCann et al., 2005). Therefore, community models must use landscape-wide estimates of species abundance to accurately represent trophic fluxes. Due to these constraints, empirical datasets with high taxonomic resolution that cover entire communities at broad spatial and temporal scales are rare and often include incomplete or rough estimates.

The composition of ecological communities is influenced by various factors acting at different temporal and spatial scales, leading to noisy data and emphasizing the need for long-term data sets (Magurran et al., 2010; Lindenmayer et al., 2012). Species abundances are influenced by stochastic effects (Hubbell, 2001), environmental changes (e.g., climate warming), and species interactions, contributing to data variability. For instance, a community composition could be driven simultaneously by the intra-annual seasonal variations in the environment, the multi-year dynamics of small mammals cycles and a relatively slow but directional climate warming. Therefore, to untangle the relative effects of diverse abiotic and biotic factors on community composition, long-term data sets are required (Magurran et al., 2010; Lindenmayer et al., 2012).

Arctic environments are highly valuable systems for studying community patterns and processes due to their relatively low species richness (Payer et al., 2013; Legagneux et al., 2014). However, logistical challenges in the Arctic limit the number of long-term biodiversity monitoring programs. Hence, the small number of Arctic communities with long-term monitoring serve as highly valuable sites for holistic and

empirical community studies. Datasets on terrestrial communities are notably scarce, and this scarcity extends to Arctic communities as well (Ims et al., 2013).

Within terrestrial Arctic sites, the south plain of Bylot Island in the Canadian High Arctic (**Figure 1**) hosts one of the longest and most intensive biodiversity monitoring programs (Gauthier et al., 2024b). Monitoring on Bylot Island began in 1989 with a focus on the snow goose and it gradually expanded to other species over time. Currently, the program encompasses all significant vertebrate species in the community with continuous monitoring spanning more than a decade (Gauthier et al., 2024b). Monitoring is also conducted at multiple spatial scales, including intensive and systematic observations conducted across a landscape spanning approximately 400 km². This approach allows the scaling of local density measurements to the landscape level when required and facilitates the estimation of abundance for less common and rare species.

Previous work based on the tundra community of Bylot Island has already produced several influential papers (Gauthier et al., 2011; Legagneux et al., 2012, 2014; Hutchison et al., 2020; Duchesne et al., 2021; Gauthier et al., 2024a). These studies showed that tundra communities may experience stronger top-down regulation than bottom-up regulation (Legagneux et al., 2012, 2014). They also revealed a heterogeneous response of trophic levels to climate warming (Gauthier et al., 2013) and highlighted the effects of indirect trophic interactions on the occurrence of species across the landscape (Duchesne et al., 2021). However, those earlier papers were built on data from relatively short time series, they were not always scaled at the landscape level, and some species or functional groups were lacking abundance estimates. With over a decade of additional community-wide monitoring compared to earlier studies, our goal is to synthesize and upscale the data collected on the Bylot Island community since the 1990s to the landscape level. This synthesis aims to provide readily accessible annual time series (or mean values in some cases) of abundance and biomass for all vertebrate species in a tundra landscape, covering approximately 400 km².

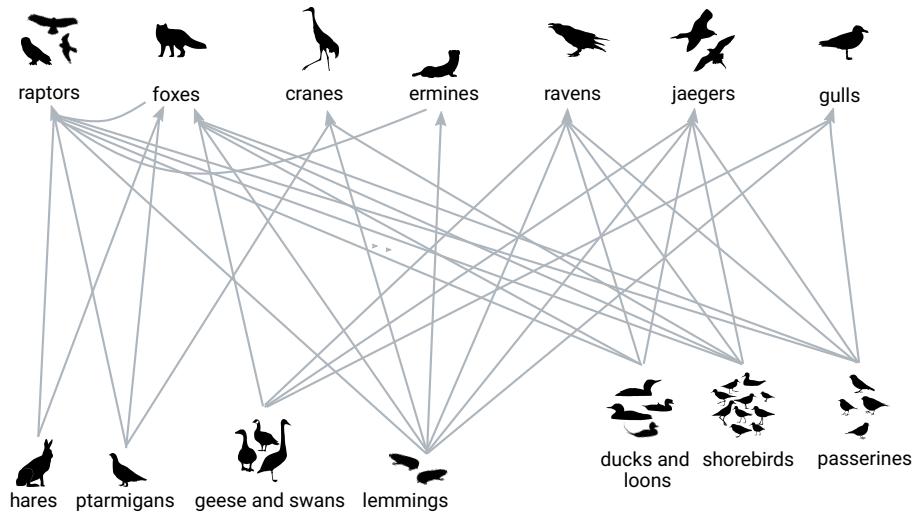


Figure 1: Synthetic vertebrate food web of the south plain of Bylot Island (figure adapted from Gauthier et al. (2011)).

Objective

Our objective is to provide readily accessible, long-term time series of annual abundances of all vertebrate species within the Arctic terrestrial community of Bylot Island during the breeding season (May to August). This includes both breeding and non-breeding individuals that stay in the study area for a

significant period of time, but excludes non-breeding individuals that stop for only a few days during their migration. Additionally, our focus extends to estimating abundances at the landscape scale, enabling the study of community and ecosystem dynamics, trophic interactions and the impacts of global changes on high-latitude environments.

1 Study area

The study area (389 km^2) is located on the south plain of Bylot Island, Nunavut, Canada. It comprises a combination of mesic tundra mainly on hills (64 %), upland plateaus of sedimentary rock with drier/rockier habitat at higher elevation (20 %), low-lying wetlands interspersed with ponds (10 %) and larger bodies of water such as lakes and rivers (6 %). Wetlands were delineated by photo-interpretation of high-resolution satellite images (30 cm; Ouellet, unpublished data), whereas lakes were delineated with aerial photos and rivers with google satellite images, resulting in a coarser delineation. The mean temperature in July is 6°C , and the area typically remains free of snow from mid-June to late September (Gauthier et al., 2013). An important biological characteristic of the area is the presence of a large snow goose (scientific names of most vertebrate species can be found in **Table 1**) colony of around 25 000 breeding pairs (Reed et al., 2002) spanning approximately 70 km^2 . The vertebrate community within the study area comprises 30 bird species, with 29 of them being migratory or partially migratory, along with 5 mammal species (**Table 1**; Moisan et al. (2023); Gauthier et al. (2024b)). The study area experiences significant temporal fluctuations in the population of small mammals (lemmings), which in turn impact the occurrence and abundance of their avian and mammalian predators such as snowy owls, rough-legged hawks, long-tailed jaegers, ermines and Arctic foxes (Legagneux et al., 2012). We exclude occasional visitors, namely: i) species lacking confirmed breeding occurrences on the study site, ii) species observed solely within a single year, and iii) species primarily breeding and foraging in nearby marine or coastal habitats (Moisan et al., 2023). The case of the red fox (*Vulpes vulpes*) was ambiguous. While the presence of a breeding pair has been confirmed in the study area (Lai et al., 2022), the extent of the population's establishment remains unclear, and sightings are rare, therefore, we decide to exclude this species.

The study area is divided into 9 zones based on the sampling method and the level of field effort applied in each zone (**Figure 2**). Long-term monitoring of the community began in the 1990s in the Qarlikturvik valley (Gauthier et al., 2013, 2024b), which represents the zone of the study area with the highest annual sampling effort. Within the Qarlikturvik valley, the sampling is concentrated on the southern side of the glacial river, where the main research infrastructure is situated. Another zone with extensive sampling efforts is Camp 2, located at the core of the snow goose colony, where the primary focus is to monitor snow goose nests. However, nests of many other avian species are also monitored within and around the colony in this zone. Camp 3, Pointe Dufour, Goose Point, and Malaview are zones where intensive sampling efforts are conducted annually, albeit for a relatively brief period (approximately one week) during the breeding season of most species (Gauthier et al., 2024b). The upland zones in the study area (defined as areas approximately 300 meters above sea level or more) are the Black Plateau, Southern Plateau, and Camp 3 Plateau. These zones are primarily visited to assess raptor nesting activity (Beardsell et al., 2016). The zone between the Qarlikturvik valley and Camp 3 received very little sampling effort and is therefore excluded from the study area.

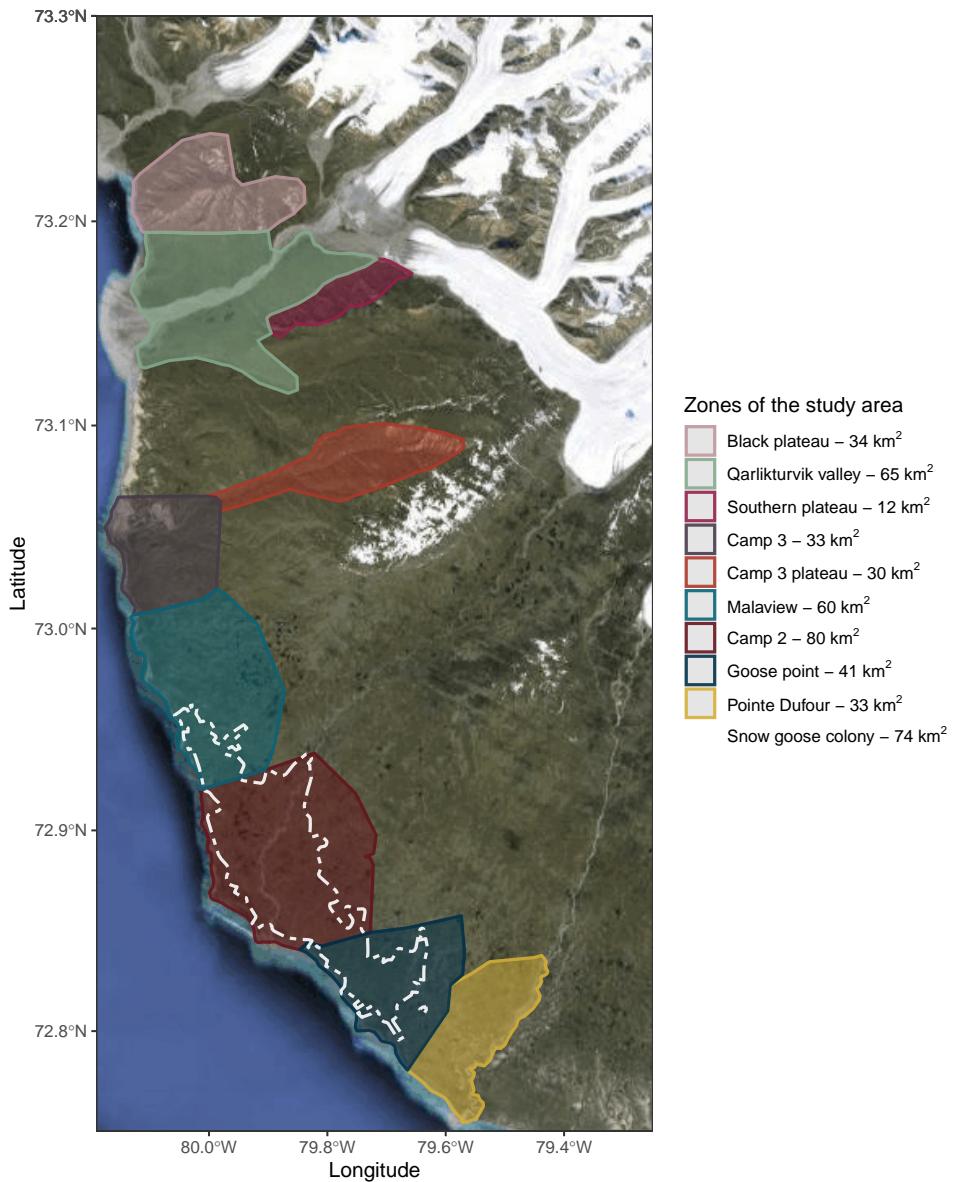


Figure 2: Map of the different zones (colored polygons) of the 389 km² study area located on the south plain of Bylot Island, Nunavut Canada. The perimeter of the snow goose colony is delineated by white dashes; we highlighted the perimeter in 2017 since it represents the average colony area.

Table 1: Species composition of the vertebrate community of Bylot Island with the corresponding annual cycle strategy (i.e., resident, partial migrant, migrant).

Functional group	Scientific name	Name	Annual cycle strategy
ducks and loons	<i>Somateria spectabilis</i>	king eider	migrant
ducks and loons	<i>Clangula hyemalis</i>	long-tailed duck	migrant
ducks and loons	<i>Gavia pacifica</i>	Pacific loon	migrant
ducks and loons	<i>Gavia stellata</i>	red-throated loon	migrant
geese and swans	<i>Branta hutchinsii</i>	cackling goose	migrant
geese and swans	<i>Anser caerulescens</i>	snow goose	migrant
geese and swans	<i>Cygnus columbianus</i>	tundra swan	migrant
raptors	<i>Buteo lagopus</i>	rough-legged hawk	migrant
raptors	<i>Falco peregrinus</i>	peregrine falcon	migrant
raptors	<i>Bubo scandiacus</i>	snowy owl	migrant
ptarmigans	<i>Lagopus muta</i>	rock ptarmigan	resident
cranes	<i>Antigone canadensis</i>	sandhill crane	migrant
shorebirds	<i>Pluvialis dominica</i>	American golden-plover	migrant
shorebirds	<i>Pluvialis squatarola</i>	black-bellied plover	migrant
shorebirds	<i>Charadrius hiaticula</i>	common-ringed plover	migrant
shorebirds	<i>Arenaria interpres</i>	ruddy turnstone	migrant
shorebirds	<i>Calidris canutus</i>	red knot	migrant
shorebirds	<i>Calidris melanotos</i>	pectoral sandpiper	migrant
shorebirds	<i>Calidris bairdii</i>	Baird's sandpiper	migrant
shorebirds	<i>Calidris fuscicollis</i>	white-rumped sandpiper	migrant
shorebirds	<i>Calidris subruficollis</i>	buff-breasted sandpiper	migrant
shorebirds	<i>Phalaropus fulicarius</i>	red phalarope	migrant
gulls	<i>Larus hyperboreus</i>	glaucous gull	migrant
jaegers	<i>Stercorarius longicaudus</i>	long-tailed jaeger	migrant
jaegers	<i>Stercorarius parasiticus</i>	parasitic jaeger	migrant
ravens	<i>Corvus corax</i>	common raven	partial migrant
passerines	<i>Eremophila alpestris</i>	horned lark	migrant
passerines	<i>Anthus rubescens</i>	American pipit	migrant
passerines	<i>Calcarius lapponicus</i>	Lapland longspur	migrant
passerines	<i>Plectrophenax nivalis</i>	snow bunting	migrant
lemmings	<i>Lemmus trimucronatus</i>	brown lemming	resident
lemmings	<i>Dicrostonyx groenlandicus</i>	collared lemming	resident
hares	<i>Lepus arcticus</i>	Arctic hare	resident
ermes	<i>Mustela richardsonii</i>	ermine	resident
foxes	<i>Vulpes lagopus</i>	Arctic fox	partial migrant

2 Data collection

2.1 Avian nest monitoring

Avian nest monitoring was conducted annually except in 2020 and 2021 due to logistical constraints imposed by the COVID-19 pandemic. Systematic nest monitoring refers here to a systematic sampling approach aimed at documenting all nests within a specified area. Monitoring is considered opportunistic when there is a chance that some nests might not have been detected within a specific area. Nest densities derived from nest sampling could be underestimated due to early nest failure (i.e., failure that happened before our sampling period).

Table 2: Summary of vertebrate species monitoring in the Bylot Island study area. In this paper, we excluded certain years for specific species due to reduced sampling efforts. As a result, duration of times series presented here may differ slightly from those in Gauthier et al. (2024b).

Species	Zone	Years	Monitoring	References
snow goose	camp 2	1999-2019, 2023	systematic	Gauthier et Cadieux, 2020
rough-legged hawk	qarlikt., black & south plat.	2007-2019, 2022	systematic	Gauthier et al., 2020
peregrine falcon	qarlikt., black & south plat.	2007-2019, 2022	systematic	Gauthier et al., 2020
snowy owl	qarlikt., black & south plat.	1996-2019, 2023	systematic	Gauthier et al., 2020
Baird's sandpiper	qarlikturvik (2x1 km plot)	2005-2019, 2022-2023	systematic	Béty, 2020
Lapland longspur	qarlikturvik (2x1 km plot)	2005-2019, 2022-2023	systematic	Gauthier and Béty, 2020
king eider	qarlikturvik (4x2 km plot)	2005-2019, 2022	opportunistic	unpublished data
long-tailed duck	qarlikturvik (4x2 km plot)	2005-2019, 2022	opportunistic	unpublished data
rock ptarmigan	qarlikturvik (4x2 km plot)	2005-2019, 2022	opportunistic	unpublished data
sandhill crane	qarlikturvik (4x2 km plot)	2005-2019, 2022	opportunistic	unpublished data
brown lemming	qarlikturvik (trapping grids)	1995-2019, 2021-2022	systematic	Gauthier, 2020
collared lemming	qarlikturvik (trapping grids)	1995-2019, 2021-2022	systematic	Gauthier, 2020
Pacific loon	qarlikturvik valley	2004-2019, 2022	systematic	unpublished data
red-throated loon	qarlikturvik valley	2004-2019, 2022	systematic	unpublished data
cackling goose	qarlikturvik valley	2004-2019, 2022-2023	systematic	unpublished data
tundra swan	qarlikturvik valley	2004-2019, 2022	systematic	unpublished data
glaucous gull	qarlikturvik valley	2004-2019, 2022	systematic	Gauthier et al., 2020
long-tailed jaeger	qarlikturvik valley	2004-2019, 2022	systematic	Gauthier et al., 2020
parasitic jaeger	qarlikturvik valley	2004-2019, 2022	systematic	unpublished data
Pacific loon	whole study area	2017-2019, 2022	systematic	Duchesne et al., 2021
red-throated loon	whole study area	2017-2019, 2022	systematic	Duchesne et al., 2021
cackling goose	whole study area	2017-2019, 2022-2023	systematic	Duchesne et al., 2021
tundra swan	whole study area	2017-2019, 2022	systematic	Duchesne et al., 2021
rough-legged hawk	whole study area	2013-2019, 2022	systematic	Gauthier et al., 2020
peregrine falcon	whole study area	2013-2019, 2022	systematic	Gauthier et al., 2020
snowy owl	whole study area	2012-2019, 2022-2023	systematic	Gauthier et al., 2020
common-ringed plover	whole study area	2015-2017	systematic	Béty, 2020
glaucous gull	whole study area	2017-2019, 2022	systematic	Gauthier et al., 2020
parasitic jaeger	whole study area	2009-2019, 2022	opportunistic	unpublished data
common raven	whole study area	2013-2019, 2022	systematic	unpublished data
ermine	whole study area	1993-2019	opportunistic	Bolduc et al., 2023
Arctic fox	whole study area	2008-2016	systematic	Dulude-de Broin et al., 2023

2.1.1 Systematic nest monitoring

Pacific loon, red-throated loon, cackling goose, tundra swan and glaucous gull

Since 2004, systematic searches of wetland areas has been conducted on the southern side of the glacial river in the Qarlikturvik Valley, and since 2017, in other zones of the study area. This sampling aimed to find all nests of the cackling goose and the glaucous gull. Nest locations of other large wetland-nesting species, including the tundra swan, the red-throated loon and the Pacific loon, were also noted, as these species nest in the same habitat (Duchesne et al., 2021; Gauthier et al., 2024b). Each year, all known or potential nesting sites were revisited. Observers detected nests by walking and scanning around ponds and lakeshores to identify any active nesting sites. These large species can be seen from a relatively long distance sitting on the nest or when flushing from the nest. Most of them (geese, swans and gulls) can also reveal their presence with alarm calls or nest defense displays. We are confident that nest detection probability was high for these species given the open landscape.

Snow goose

Snow geese nest in a large colony in the study area (**Figure 2**), but also in small aggregations distributed on the island, especially in years when snowy owls are nesting (Lepage et al., 1996; Reed et al., 2002). Since 1994, goose nests were systematically monitored on a 0.24 km^2 wetland at the center of the colony. Since 1999, nests were also systematically monitored on a variable number of plots, measuring 0.01 km^2 in wetland habitat and 0.04 km^2 in mesic habitat, randomly distributed throughout the goose colony (Gauthier and Cadieux, 2020b). The total area covered by the randomly distributed plots averaged $0.79 \pm 0.37 \text{ km}^2$ per year. From 2010 onwards, except in 2020 and 2021, we traced the approximate boundary of the goose colony using a GPS receiver aboard a helicopter flying along the colony border (Duchesne et al., 2021).

Rough-legged hawk, peregrine falcon and common raven

Peregrine falcons, rough-legged hawks and common ravens nest on cliffs, near ravines, and on large rocky outcrops and tend to reuse the same nesting sites from one year to the next (Beardsell et al., 2016). Systematic monitoring of every known or potential nesting site has been carried out in the Qarlikturvik valley, Black plateau and Southern plateau since 2007 and throughout the study area since 2013 (Beardsell et al., 2016; Gauthier et al., 2020). Observers walked along ridges and scan surrounding areas from vantage points to detect nesting birds. These large species can be seen from a relatively long distance sitting on the nest or when flushing from the nest. They can also reveal their presence with alarm calls or nest defense displays. We are confident that nest detection probability was high for these species. Each year the observers use slightly different paths to sample the areas, but locate the nests in the same positions, which supports a high probability of detection for these species. Most nesting sites were located in the upland zones of the study area, which are the Black Plateau, Southern Plateau and Camp 3 Plateau.

Snowy owl

Snowy owls predominantly nest in habitats similar to other raptors, favoring ridges in mountainous or hilly regions, although they can occasionally be found nesting on mounds in lowland areas (Seyer et al., 2020). Since 1996, searches for snowy owl nests have been conducted concurrently with searches for other raptor nests in the Black and Southern plateaus, as well as during searches for jaeger nests on the southern side of the glacial river in the Qarlikturvik Valley. Additionally, since 2012, nests have been recorded across the entire study area by scanning the landscape from hills and ridges during the nesting period (Duchesne et al., 2021). Given that snowy owls nest on elevated mounds, exhibit contrasting

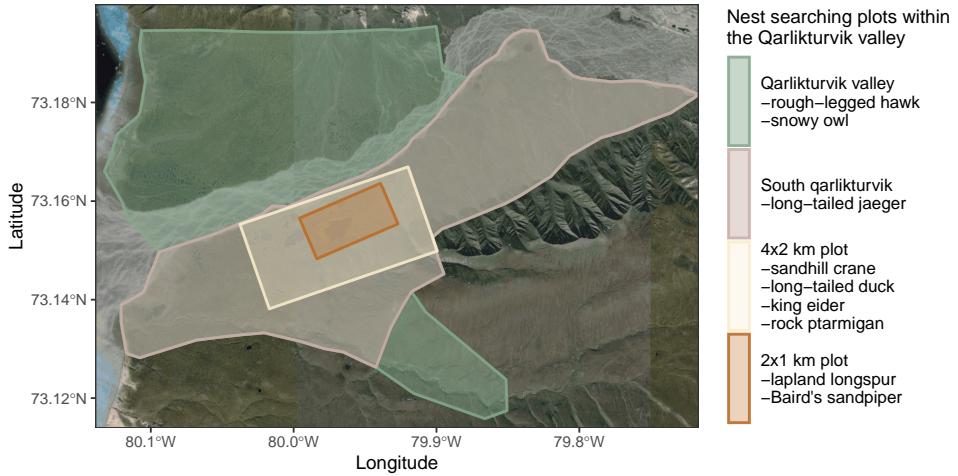


Figure 3: Intensive nests searching plots (8 km^2 and 2 km^2) located in the Qarlikturvik valley.

colors with the landscape, emit alarm calls, and display defensive behaviors, active nesting sites have a high probability of detection.

Long-tailed jaeger and parasitic jaeger

Since 2004, observers have walked parallel transects spaced 400 meters apart, covering the entire southern side of the glacial river in the Qarlikturvik Valley (33 km^2 ; **Figure 3**), during the nesting period. The aim of those transects was to record nests of long-tailed jaegers, parasitic jaegers, and sandhill cranes. Observers listened for alarm calls to detect territorial birds, and then located nests by observing the birds returning to their nests from elevated vantage points. We consider the sampling to be systematic for long-tailed and parasitic jaeger, since those species tend to leave their nest relatively far from the observer to perform mobbing behavior, and thus increasing their detection probability. We do not consider the sampling to be systematic for sandhill cranes as they only display defensive behaviors near their nests at relatively short distances.

Common-ringed plover

Between 2015 and 2019, observers conducted surveys of the primary nesting areas of the common-ringed plover. The survey involved walking in stony and sandy shores and gravel bars with scarce vegetation along rivers. Nests were found by detecting individuals exhibiting reproductive behaviors, such as incubation, alarm calls, or distraction displays. The sampling effort was particularly intensive between 2015 and 2017. Small areas along the coast or on the banks of smaller rivers that could potentially serve as nesting sites may have been overlooked.

Lapland longspur and Baird's sandpiper

Since 2005, nests of passerines and sandpipers have been extensively monitored across an 8 km^2 ($4 \times 2 \text{ km}$) area in the Qarlikturvik valley. We considered the sampling to be most systematic within a core 2 km^2 ($2 \times 1 \text{ km}$) plot in this area (**Figure 3**). An observer conducted systematic searches of this plot during the

entire breeding season to locate and monitor as many passerine and shorebird nests as possible. Assuming this observer can detect all nests within 5 or 10 meters, this single observer sampled annually at minimum an area of 0.72 ± 0.12 or $1.09 \pm 0.17 \text{ km}^2$ ($n= 3$). Additionally, several other observers conducting related field work in the same zone reported all passerine and shorebird nests found opportunistically. We excluded relatively large water bodies (0.26 km^2) to calculate nest density in the plot due to the presence of a large lake, which leaves an area of 1.74 km^2 available for nesting.

Table 3: Annual nest density (nests/km²) of selected avian species estimated on different zones of Bylot Island.

Species	Zone	Mean \pm SD	Number of years
Baird's sandpiper	qarlikturvik (2x1 km plot)	5.000 ± 3.558	17
Lapland longspur	qarlikturvik (2x1 km plot)	13.559 ± 5.849	17
king eider	qarlikturvik (4x2 km plot)	0.115 ± 0.138	16
long-tailed duck	qarlikturvik (4x2 km plot)	0.092 ± 0.138	16
rock ptarmigan	qarlikturvik (4x2 km plot)	0.031 ± 0.055	16
sandhill crane	qarlikturvik (4x2 km plot)	0.161 ± 0.087	16
long-tailed jaeger	qarlikturvik valley	0.362 ± 0.380	17
Pacific loon	whole study area	0.005 ± 0.004	4
red-throated loon	whole study area	0.082 ± 0.019	4
cackling goose	whole study area	0.177 ± 0.064	5
tundra swan	whole study area	0.001 ± 0.001	4
rough-legged hawk	whole study area	0.157 ± 0.151	8
peregrine falcon	whole study area	0.053 ± 0.007	8
snowy owl	whole study area	0.022 ± 0.058	10
common ringed plover	whole study area	0.070 ± 0.012	3
glaucous gull	whole study area	0.091 ± 0.011	4
parasitic jaeger	whole study area	0.010 ± 0.004	12
common raven	whole study area	0.003 ± 0.003	8

2.1.2 Opportunistic nest monitoring

Since 2005, we also noted the nest location of any other bird species encountered opportunistically during travel or while carrying out the protocols for the previously described species. The sampling was particularly intensive in the defined 8 km² (2x4 km plot) area in the Qarlikturvik valley. The accuracy of nest monitoring in this plot thus depends on the species detection probability. We are confident to obtain a realistic order of magnitude for the number of nests present for relatively large bodied species in this area (i.e., sandhill crane, rock ptarmigan, long-tailed duck and king eider). Additionally, starting in 2009, a significant effort has been made each year, though not systematically, to visit known nesting territories of parasitic jaegers throughout the study area.

2.2 Observation of individuals

2.2.1 Vertebrate count transects

From 2010 to 2023, observers walked 500-meter linear transects where all vertebrate individuals observed within 150 meters on either side were counted (146 to 320 transects per year). Transects were distributed across all lowland zones of the study area, typically in mesic habitats, and were carried out during the nesting period (between June 21 and July 14; Duchesne et al. (2021); **Figure 4**). Furthermore, specifically for American golden-plovers, we measured the distance of each observed individual to the transect path.

2.2.2 Snow goose point count

At the start, middle, and end of each vertebrate count transect, a point count with a radius of 125 meters was conducted to determine the number of snow goose breeding pairs. On average, 613 ± 142 point counts were sampled each year, covering an area of 30 ± 7 km².

2.2.3 Incidental observations

Since 2007, observers have recorded all vertebrate species observed opportunistically during field work and tallied the total number of individuals at the end of each day (Gauthier and Cadieux, 2020a; Gauthier et al., 2024b). The number of hours spent in the field served as a proxy for the sampling effort. We used the number of individuals observed per hour spent in the field calculated by Gauthier et al. (2024b) as an index of relative abundance for each species. However, we separated observations made in lowland from those in upland zones to have a relative abundance of each species in each of these two broad categories (**Table 4**). Given that incidental observations lacked georeferencing, we opted to extract upland observations by focusing on observations made during visits to rough-legged hawk nests, which are mostly located in uplands.

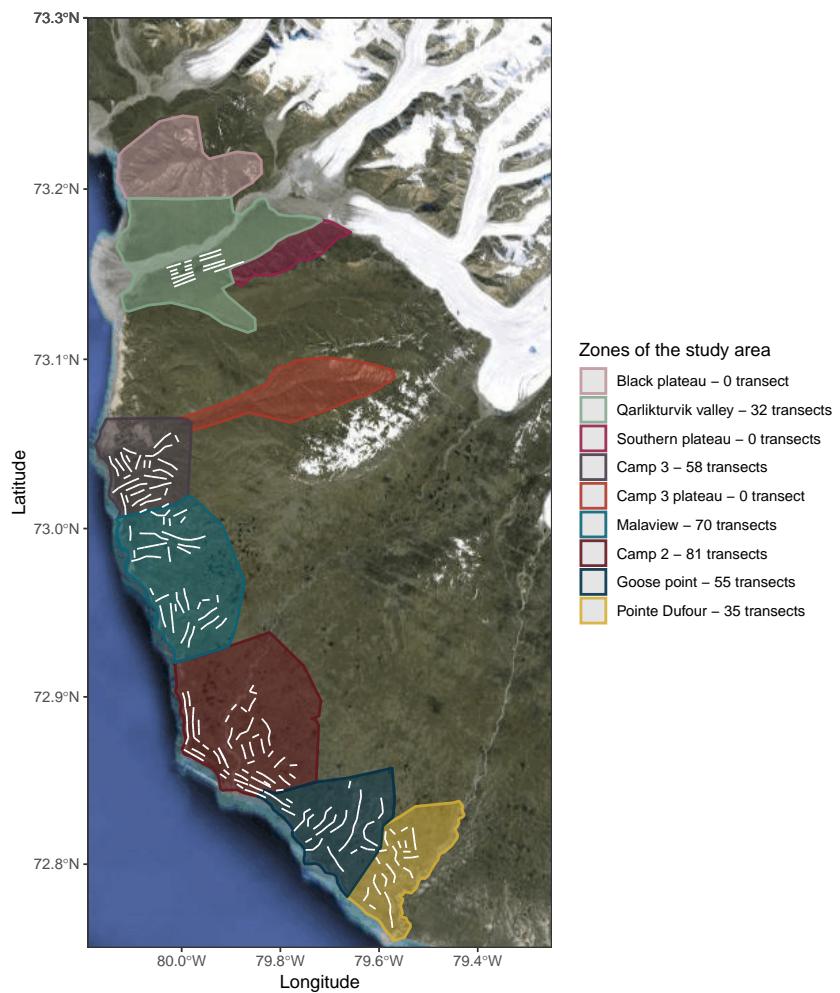


Figure 4: Spatial distribution of vertebrate count transects (white lines) on the south plain of Bylot Island (146 to 320 transects per year).

Table 4: Index of relative abundance (i.e., number of individuals observed per hour) derived from incidental daily observations for selected vertebrate species in lowland (i.e., Qarlikturvik valley, Camp 3, Malaview, Camp 2, Goose point and Pointe Dufour) and upland (i.e., Black plateau, Southern plateau and Camp 3 plateau) zones of the Bylot Island study area. The ratio compares relative abundance indexes between these two types of zones, calculated by dividing the upland by the lowland index of relative abundance.

Species	Individuals/hour		
	Upland	Lowland	Ratio
rock ptarmigan	0.03	0.03	1
sandhill crane	0.42	0.287	1.5
American golden-plover	0.26	0.394	0.7
black-bellied plover	0.02	0.032	0.6
ruddy turnstone	0.01	0.007	1.3
red knot	0.00	0.033	0
pectoral sandpiper	0.02	0.034	0.6
Baird's sandpiper	0.31	0.32	1
white-rumped sandpiper	0.04	0.137	0.3
buff-breasted sandpiper	0.00	0.001	0
red phalarope	0.01	0.038	0.2
horned lark	0.24	0.154	1.6
American pipit	0.34	0.024	14.2
snow bunting	0.59	0.092	6.4
Arctic hare	0.02	0.009	2

2.2.4 Testimonials of ermine sightings

There was no direct estimation of ermine abundance on Bylot Island as they are quite difficult to obtain. The density estimates for ermine were derived from an annual abundance index established by Bolduc et al. (2023), which relied on testimonials provided by observers across the whole study area from 1993 to 2019. The testimonials provided by observers were used to create an abundance index ranging from 0 to 3 (Bolduc et al., 2023). In this index, a score of 0 corresponds to the absence of ermine sightings, 1 indicates a single sighting of a lone individual, 2 represents multiple sightings of lone individuals, and 3 signifies at least one sighting of a family group. Scores of individual participants were averaged annually as detailed in Bolduc et al. (2023).

2.3 Capture of individuals

2.3.1 Lemming trapping

Since 2004, brown and collared lemmings were live-trapped 3 times during the summer (mid-June, mid-July, and mid-August) in two 11 ha grids. Each grid is made of 144 traps separated by 30 m according to a cartesian plane, one in mesic habitat and the other in wet habitat, located in the Qarlikturvik valley (Fauteux et al., 2015; Gauthier, 2020). Density of each species was estimated at each occasion using spatially explicit capture-recapture methods (see Fauteux et al. (2015) for details). From 1995 to 2016 snap-trapping was performed once a year (mid-July) along 2 groups of transects located in the same habitats than the trapping grids (Gruyer et al., 2008). Index of abundance derived from snap-trapping were transformed in density estimates in each habitat for the period 1995-2003 using the equation provided by Fauteux et al. (2018) based on the period of overlap between the two sampling methods (2004 to 2016).

2.3.2 Arctic fox movement tracking

Between 2008 and 2016, 109 Arctic foxes were fitted with Argos Platform Transmitter Terminals mounted on collars (Lai et al., 2015; Christin et al., 2015; Dulude-de Broin et al., 2023). Foxes were captured between May and August across the study area, within and outside the goose colony (Dulude-de Broin et al., 2023). Sampling of animal locations was set for an interval of 1 or 2 days and only locations

between May 1 and October 30 were retained (Dulude-de Broin et al., 2023).

2.3.3 Parasitic jaeger banding

In 2009, a significant effort was made to band as many parasitic jaegers as possible within the study area. This effort resulted in the banding of 17 adult individuals (Therrien and Gauthier, unpublished data).

2.4 Species body mass

All vertebrate individuals captured for marking purposes were systematically weighed (snow goose (unpublished data), snowy owl (Therrien et al., 2012; Robillard et al., 2018), American-golden plovers (Lamarre et al., 2021), common-ringed plovers (Léandri-Breton et al., 2019), other shorebirds (Béty, unpublished data), glaucous gulls (Gauthier et al., 2015), long-tailed jaeger (Seyer et al., 2019), parasitic jaegers (Gauthier and Therrien, unpublished data), Lapland longspurs (Gauthier and Béty, unpublished data), lemmings (Gauthier, 2020), ermine (Bilodeau and Bolduc, unpublished data) and Arctic foxes (Lai et al., 2015)). Mean body mass of vertebrate species was determined in priority with measurements from Bylot Island. When not available, we extracted mean body mass from the literature (Wilman et al., 2014).

Table 5: Average adult body mass (g) of the vertebrate species from Bylot Island measured directly at the study area or extracted from the literature (Wilman et al., 2014).

Species	Body mass (g)		Literature
	Study area	(n)	
king eider			1617
long-tailed duck			871
Pacific loon			2251
red-throated loon			1486
cackling goose			2812
snow goose	1487	(6231)	2636
tundra swan			6378
rough-legged hawk			950
peregrine falcon			760
snowy owl	2169	(29)	2029
rock ptarmigan			535
sandhill crane			4296
American golden-plover	170	(164)	151
black-bellied plover	210	(6)	250
common-ringed plover	86	(118)	64
ruddy turnstone			136
red knot	145	(1)	142
pectoral sandpiper	88	(2)	80
Baird's sandpiper	72	(6)	41
white-rumped sandpiper			43
buff-breasted sandpiper	92	(2)	62
red phalarope			56
glaucous gull	1500	(10)	1529
long-tailed jaeger	298	(138)	288
parasitic jaeger	461	(24)	444
common raven			928
horned lark			33
American pipit			21
Lapland longspur	28	(86)	28
snow bunting			42
brown lemming	45	(6405)	70
collared lemming	47	(679)	54
Arctic hare			4405
ermine	134	(NA)	119
Arctic fox		(NA)	3584

3 Data preparation

We estimated the abundance of breeding individuals for most species, but there were a few exceptions. For common ravens, parasitic jaegers, long-tailed ducks, and king eiders, we suspect the presence of a significant number of non-breeding individuals in the study area. Therefore, the estimates we provided for these species include both breeding and potentially non-breeding individuals. Additionally, we did not distinguish between breeding and non-breeding individuals for mammals such as brown and collared lemmings, Arctic fox, ermine, and Arctic hare. The methods used for each species are summarized in (**Table 6**).

R software (version 4.3.2) was used to process the data on a linux-gnu machine. Most of data manipulation was carried out with the *dplyr* (Wickham et al., 2023) and *sf* packages (Pebesma et al., 2018). All codes are available in the Dryad repository XXXXXXXXXXXXXXXX.

Table 6: Summary of the methods and spatial scales used to estimate the density of each vertebrate species on Bylot Island, and how abundance was extrapolated at the landscape scale.

Species	Sampling method	Reference species	Sampling scale	Spatial extrapolation
king eider	nest sampling		4x2km plot	wetlands
long tailed duck	nest sampling		4x2km plot	wetlands
king eider	relat. abund. (incidental obs.)	red-throated loon	study area	
long tailed duck	relat. abund. (incidental obs.)	red-throated loon	study area	
Pacific loon	nest sampling		study area	
red-throated loon	nest sampling		study area	
cackling goose	nest sampling		study area	
snow goose	nest sampling		camp 2	goose colony
snow goose	vertebrate count transects		lowland	goose colony
snow goose	snow goose point counts		lowland	goose colony
tundra swan	nest sampling		study area	
rough-legged hawk	nest sampling		study area	
peregrine falcon	nest sampling		study area	
snowy owl	nest sampling		study area	
rock ptarmigan	nest sampling		4x2km plot	all habitats
sandhill crane	nest sampling		4x2km plot	transects
American golden-plover	distance sampling		lowland	transects
black-bellied plover	relat. abund. (transects)	A. golden-plover	lowland	transects
black-bellied plover	relat. abund. (incidental obs.)	A. golden-plover	study area	
common-ringed plover	nest sampling		study area	
ruddy turnstone	relat. abund. (transects)	Baird's sandpiper	lowland	transects
ruddy turnstone	relat. abund. (incidental obs.)	Baird's sandpiper	study area	
red knot	relat. abund. (transects)	Baird's sandpiper	lowland	transects
red knot	relat. abund. (incidental obs.)	Baird's sandpiper	study area	
pectoral sandpiper	relat. abund. (transects)	Baird's sandpiper	lowland	transects
pectoral sandpiper	relat. abund. (incidental obs.)	Baird's sandpiper	study area	
Baird's sandpiper	nest sampling		2x1km plot	transects
white-rumped sandpiper	relat. abund. (transects)	Baird's sandpiper	lowland	transects
white-rumped sandpiper	relat. abund. (incidental obs.)	Baird's sandpiper	study area	
buff-breasted sandpiper	relat. abund. (transects)	Baird's sandpiper	lowland	transects
buff-breasted sandpiper	relat. abund. (incidental obs.)	Baird's sandpiper	study area	
red phalarope	relat. abund. (transects)	Baird's sandpiper	lowland	transects
red phalarope	relat. abund. (incidental obs.)	Baird's sandpiper	study area	
glaucous gull	nest sampling		study area	
long-tailed jaeger	nest sampling		qarlikturvik	mesic habitat
parasitic jaeger	maximum banded individual		study area	
parasitic jaeger	nest sampling		study area	
common raven	nest sampling		study area	
common raven	relat. abund. (incidental obs.)	Parasitic jaeger	study area	
horned lark	relat. abund. (transects)	lapland longspur	lowland	transects
horned lark	relat. abund. (incidental obs.)	lapland longspur	study area	
American pipit	relat. abund. (transects)	lapland longspur	lowland	transects
American pipit	relat. abund. (incidental obs.)	lapland longspur	study area	
lapland longspur	nest sampling		2x1km plot	transects
snow bunting	relat. abund. (transects)	lapland longspur	lowland	transects
snow bunting	relat. abund. (incidental obs.)	lapland longspur	study area	
brown lemming	capture marking recapture		two 11 ha grids	wet and mesic hab.
collared lemming	capture marking recapture		two 11 ha grids	wet and mesic hab.
arctic hare	incidental observations	Arctic fox	study area	
ermine	relat. abund. (testimonials)		study area	
arctic fox	home range (movement track.)		study area	

3.1 Pacific loon, red-throated loon, cackling goose, tundra swan and glaucous gull

Based on the systematic and intensive search for the glaucous gull, cackling goose, tundra swan, red-throated loon and Pacific loon nests in wetlands, we are confident that we have found nearly all nests across the study area from 2017 to 2019 and in 2022. We transformed the number of nests to abundance of individuals by multiplying it by a factor of two.

We observed a relatively strong correlation between the nest density of glaucous gulls in the Qarlikturvik valley and the nest density across the entire study area ($R^2 = 0.84$, $p = 0.16$, $n = 4$). Consequently, we estimated the density of glaucous gulls at the scale of the study area between 2004 and 2016 based on the nest density in the Qarlikturvik valley ($y = 0.12406x + 0.13775$). However, we did not observe such strong relationships for loons and swans and thus we did not extend the time series. Regarding cackling geese, we observed signs of an exponential increase over time based on the annual number of nests found in various zones of the study area and the indices of relative abundance (i.e., daily incidental observations and transects). We thus fitted an exponential model using the number of nests found annually over two distinct periods: in 1996 when the first nest was discovered, and then from 2017 to 2023 when sampling effort was systematic across the whole study area (**Figure 5**). We used the fitted model to estimate abundance between 1996 and 2016 when monitoring was less systematic, which could potentially underestimate observed abundance as seen on **Figure 5**. We multiplied nest density by two to obtain the abundance.

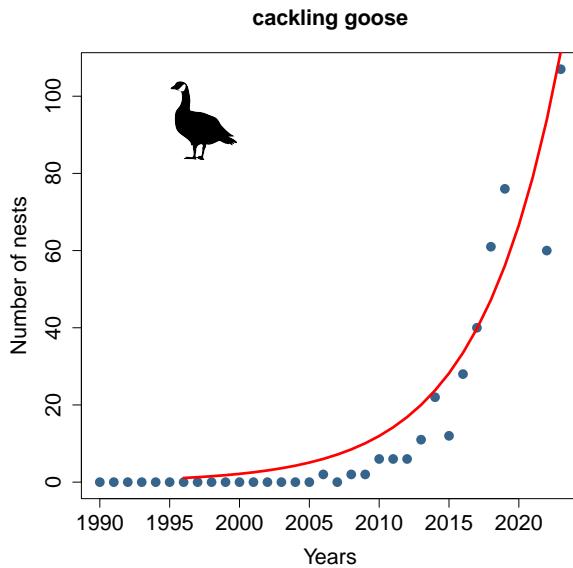


Figure 5: Number of cackling goose nests found across the study area over time. The red line represents the fitted model over the period 1996–2023 ($y = e^{0.1717x - 342.684}$), which was used to estimate the annual abundance of cackling goose between 1996 and 2016. The model presents a strong fit with the number of nests found between 2017 and 2023, when nest monitoring was systematic across the study area ($R^2 = 0.74$, $p = 0.15$, $n = 5$).

3.2 Snow goose

Between 1999 and 2023, we assessed the abundance of snow geese in the study area through a multi-step process. We calculated the mean annual density of snow goose nests separately in the mesic and wetland habitats of the area occupied by the goose colony annually. We made slight adjustments to

the goose colony perimeter defined from helicopter surveys to include all snow goose point counts where at least one breeding pair had been observed (**Figure 6**). To determine the mean density of nesting geese in wetlands, we divided two times (assuming two individuals per nest) the total number of nests found during systematic nest searches by the total area of wetlands sampled. The density of geese nesting in mesic habitat, a less preferred nesting habitat (Lecomte et al., 2008), was averaged from three independent methods: systematic nest searches, vertebrate count transects, and snow goose point counts. Systematic nest searches were highly precise, but covered a relatively small area, whereas transects and snow goose point counts were less precise but covered larger areas. For each method, we calculated the mean density of breeding individuals in mesic habitat by dividing the number of birds (or nests) recorded by the area sampled. Despite methodological differences, the three approaches showed similar inter-annual variations, supporting the use of a mean values to estimate nest density in mesic habitat (**Figure 7**). Lastly, to transform the densities in total abundance, we determined the annual proportion of wetland and mesic habitats within the goose colony and multiplied the area of each habitat by the density of breeding individuals. For the period 1999 to 2009, we used the average limits of the colony over the period 2010 to 2023 because we did not conduct aerial survey of the colony. Moreover, nest density in the mesic habitat was derived from a single method (**Figure 7**).

In 1993, 1998, 2003, and 2008, the Canadian Wildlife Service conducted aerial surveys over the southern plain of Bylot Island during the brood-rearing period to estimate the abundance of breeding snow geese (Reed et al., 2002). We corrected these estimates with the annual nesting success, as these surveys were conducted after the hatching period. For 2003 and 2008, we used in priority estimates of abundance derived from aerial surveys instead of nest sampling.

3.3 King eider and long-tailed duck

We estimated the abundance of both king eiders and long-tailed ducks based on the annual nest density of each species found in the 8 km² extensive nest search area located in the Qarlikturvik valley. We extrapolated the mean nest density in the wetlands of the Qarlikturvik valley to the wetlands of the study area (38.35 km²). We transformed nest density to abundance of breeding individuals by multiplying it by a factor of two. We acknowledge that the opportunistic monitoring of these species likely underestimated their true nest density. However, considering the extensive sampling effort deployed annually within this area, we are confident to obtain a realistic order of magnitude for the number of nests present. Because duck sightings are frequent, yet only a few nests are found, we believe there may be non-breeding individuals. Therefore, we employed an additional method to estimate the overall duck populations without differentiating between breeding and non-breeding individuals.

As an alternative approach, we estimated the abundance of ducks based on the indices of relative abundance (i.e., the number of individuals observed per 100 hours) presented by Gauthier et al. (2024b). We assumed that the ratios between relative and actual abundance are the same (i.e., similar detection probability) in duck and loon species. We therefore derived the absolute abundance of long-tailed ducks and king eiders from their relative abundances using the ratio between relative and absolute abundances of red-throated loons as a reference.

3.4 Rough-legged hawk, peregrine falcon and snowy owl

We estimated the abundance of breeding rough-legged hawks, peregrine falcons and snowy owls based on systematic nest monitoring conducted throughout the study area for these species. To convert the number of nests into breeding abundance, we multiplied it by two. For snowy owls, we extended the time series from 1996 to 2011 based on a linear regression between nest density in the Qarlikturvik

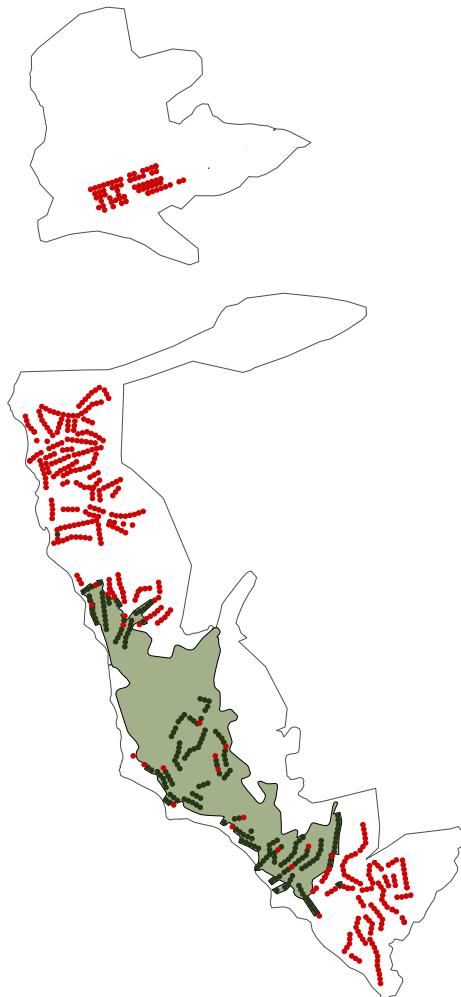


Figure 6: Map showing the region occupied by the snow goose colony in 2017 (green polygon) as an example. The perimeter was first defined from a helicopter surveys and then slightly adjusted to include all snow goose point counts where at least one breeding pair had been observed in that year (green dots). Snow goose point counts where no breeding geese were observed in that year are presented as red dots.

valley and nearby plateaus (Black and Southern plateaus) and nest density across the entire study area ($y = 0.68867x - 0.00173$; $R^2 = 0.99$; $p < 0.0001$, $n = 10$). We used the same approach for rough-legged hawks ($y = 0.49851x$, $R^2 = 0.99$, $p < 0.0001$, $n = 8$) to extend the time series from 2007 to 2012. We did not extend the time series for peregrine falcons because the correlation is not as strong ($R^2 = 0.44$, $p = 0.27$, $n=8$).

3.5 Rock ptarmigan

We estimated the abundance of rock ptarmigans based on the annual nest density measured in the 8 km² extensive nest search area of the Qarlikturvik valley. While we acknowledge that the opportunistic monitoring of this species likely underestimates nest density, the extensive sampling effort deployed annually within this area gives us confidence in obtaining a realistic number of nests. We then extrapolate the density to the whole study area, without distinction between mesic, wetland and upland habitats (**Table 4**). Among the 6 nests found in the study area, 4 were located in mesic habitat, while one nest was found in a wetland and another in an upland habitat. To convert the number of nests into breeding

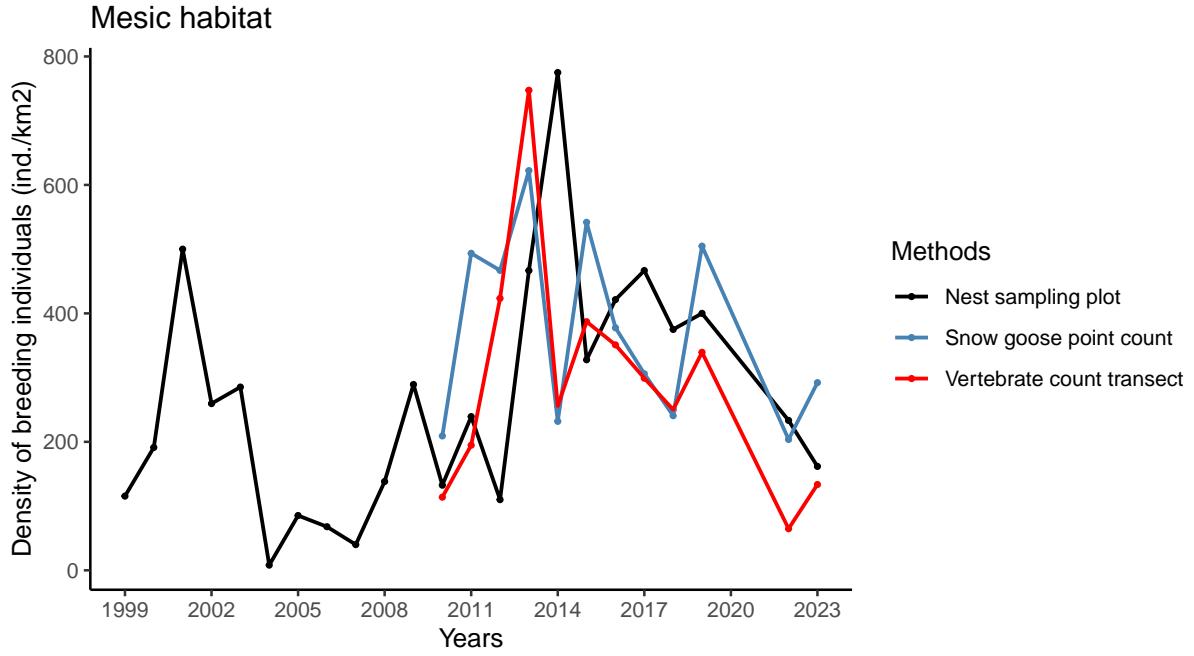


Figure 7: Estimates of breeding goose density in mesic habitat of the Bylot Island study area using three independent methods: Nest sampling plot, Snow goose point count, Vertebrate count transect.

abundance, we multiplied it by two.

3.6 Sandhill crane

We estimated the mean abundance of sandhill cranes in the lowland zones of the study area based on a regression between nest density and the number of individuals observed per transect (**Figure 8**). In this relationship, nest density and transect observations come from the 8 km^2 area of the Qarliktuvik valley where extensive nest search is performed. We acknowledge that the opportunistic monitoring of this species likely underestimated the true nest density. However, considering the extensive sampling effort deployed annually within this area, we are confident in obtaining a realistic order of magnitude for the number of nests present. Number of individuals observed along transects in each lowland zone was converted into nest density using the regressions, and then in total number of individuals in each zone by multiplying by the area of the zone and a factor 2. We estimated the density in the upland zones by applying a correction factor to the annual mean density in lowland zones. This correction factor was determined based on the relative abundance ratio between the upland and lowland zones (**Table 4**).

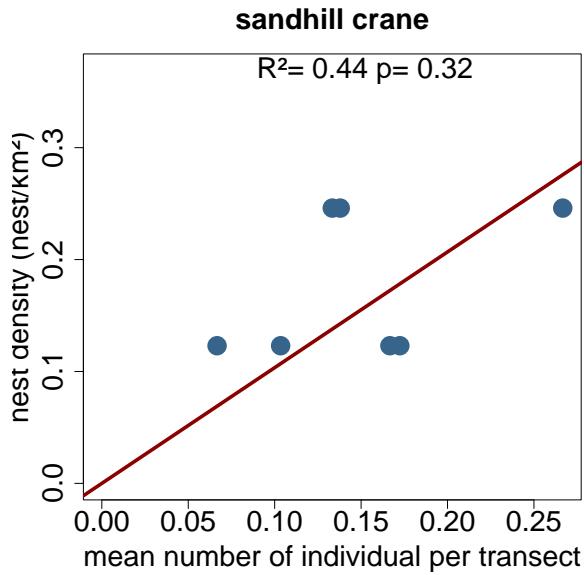


Figure 8: Linear regression between the nest density of sandhill cranes and the number of individuals observed per transect (nest density = $1.12 \times$ number of individuals per transect; regression was forced to pass through the origin). The fit (R^2 and p value) of the regression (red line) with the empirical data from the Qarlikturvik valley is presented (blue dots). Data points represent annual values.

3.7 American golden-plover and black-bellied plover

We applied a distance sampling approach to the observations of American golden-plovers made along vertebrate count transects to estimate the abundance of individuals in the mesic habitat of the study area between 2014 and 2023. We used perpendicular distance between detected individuals and transect ($n= 1015$) to estimate a detection function with the *ds* function from the *Distance* package (Miller et al., 2019). We applied a truncation distance of 150 m (i.e., maximum distance on either side of the observer where observations have been considered). We selected the model with the lowest AIC, which included a "hn" key and a single "cos" adjustment term. We excluded observations of more than four individuals, as these likely indicated groups of non-breeders passing through the area. We did not estimate abundance in wetland habitat because American golden-plovers nest almost exclusively in mesic habitat (Parmelee et al., 1967). We estimated the abundance in the upland zones (i.e., plateaus) by applying a correction factor to the abundance in lowland zones. This correction factor was determined based on the relative abundance ratio between the upland and lowland zones (**Table 4**).

To determine the abundance of black-bellied plovers, we used the mean number of black-bellied plovers and American golden-plovers observed per transect as an index of relative abundance. We assumed that the ratios of between relative and actual abundance are the same (i.e., similar detection probability) among those species. This assumption is realistic as those species present similarities in size, color, and reproductive behavior. We therefore derived the absolute abundance of black-bellied plovers from their relative abundance using the ratio between relative and absolute abundances of American golden-plover as a reference.

As an alternative approach to determine black-bellied plover abundance, we used the same approach as previously described, but with the indices of relative abundance presented by Gauthier et al. (2024b), which was derived from incidental daily observations.

3.8 Common-ringed plover

To estimate the abundance of common-ringed plovers in the study area, we relied on the total number of nests recorded annually from 2015 to 2017, during which the primary nesting sites underwent intensive sampling. We multiplied the total nest count by two to represent the abundance of breeding individuals.

3.9 Lapland longspur and Baird's sandpiper

We estimated the mean abundance of Lapland longspur in the different lowland zones of the study area based on a regression between nest density and the number of individuals observed per transect (**Figure 9**). For Baird's sandpiper, we employed a similar approach, but instead of using the mean number of individuals observed per transect, we used the mean proportion of transects where at least one individual was detected. We made this adjustment because this species was less frequently observed. In this relationship, nest density for these two species came from the intensive nest sampling conducted within the core 2 km² area of the Qarlikturvik valley and observations of individuals from transects carried out in the larger 8 km² area in which the core area was located. This approach allowed us to incorporate a larger sample size from the transects while focusing on a measure of nest density determined systematically. Transects observations in lowland were then converted into nest density using the regressions, and then in total number of individuals by multiplying by the area and a factor 2. We estimated the density of both species in the upland zones by applying a correction factor to the annual mean density in lowland zones. This correction factor was determined based on the relative abundance ratio between the upland and lowland zones (**Table 4**). We acknowledge that the regression for Baird's sandpiper is weak; however, it offers some refinement compared to assuming a uniform density throughout the study area.

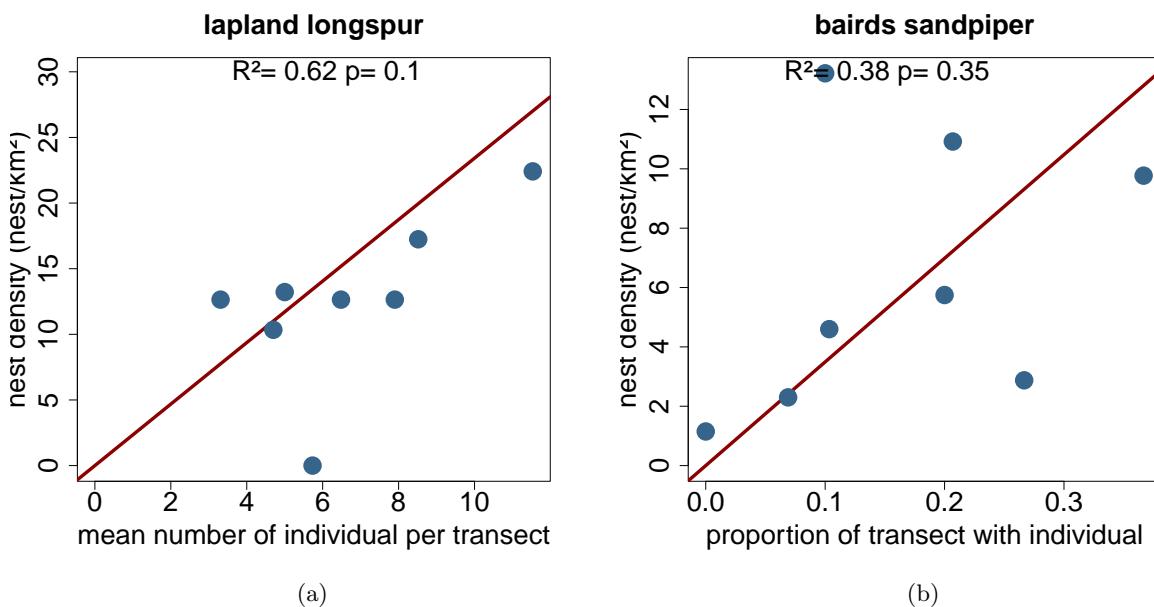


Figure 9: a) Linear regression between the nest density of Lapland longspurs and the number of individuals observed per transect (nest density= 2.3422 x number of individuals per transect; regression was forced through the origin). The fit (R^2 and p value) of the regression (red line) with the empirical data from the Qarlikturvik valley is presented (blue dots). Data points represent annual values. b) Linear regression between the nest density of Baird's sandpiper and the proportion of transect with at least one individual observed (nest density= 34.9248 x proportion of transects with at least one individual; regression was forced through the origin). The fit (R^2 and p value) of the regression (red line) with the empirical data from the Qarlikturvik valley is presented (blue dots). Data points represent annual values.

3.10 Other passerines and sandpipers

We estimated the abundance of other passerines (horned lark, American pipit, and snow bunting) in the lowland zones of the study area with the regression equation between number of individuals per transect and nest density of the Lapland longspur (see section 3.9). We assumed here a similar detection probability for all species. We used the same approach for other sandpiper species (white-rumped sandpiper, pectoral sandpiper, buff-breasted sandpiper, red knot, ruddy turnstone and red phalarope) based on the regression equation for the Baird's sandpiper (see section 3.9). For all these species, we estimated the density in the upland zones by applying a correction factor to the mean density in lowland zones. This correction factor was determined based on the relative abundance ratio between the upland and lowland zones (**Table 4**). Nest density was then converted in number of individuals by multiplying by the area and a factor 2.

As an alternative approach, we estimated the abundance of other passerines and sandpipers based on the indices of relative abundance (i.e., the number of individuals observed per 100 hours) presented by Gauthier et al. (2024b). We assumed that the ratios between relative and actual abundance are the same (i.e., similar detection probability) among both passerine and sandpiper species. We therefore derived the absolute abundance of other passerine and sandpiper species from their relative abundances using respectively, the ratios between relative and absolute abundances of Lapland longspur (passerines) and Baird's sandpiper (sandpipers) as references.

3.11 Long-tailed jaeger

We determined the annual nest density of long-tailed jaegers from the systematic nest sampling between 2004 and 2023 on the southern side of the glacial river in the Qarlikturvik valley. We determined nest density by dividing the annual number of nests recorded by the area of the surveyed zone (33 km^2). As long-tailed jaegers typically nest in mesic habitat (Andersson, 1971), we multiplied the area occupied by mesic habitat across the study area by the nest density obtained in the surveyed zone and by two to obtain the total abundance of breeding individuals.

3.12 Parasitic jaeger

Based on the opportunistic nest monitoring of parasitic jaegers across the study area, an average of 3.75 nests is found annually, a small number considering that parasitic jaegers were frequently observed at the study site (Gauthier et al., 2024b). This suggests that there may be non-breeding individuals present at the study site, or alternatively, individuals may regularly travel long distances, potentially from outside the study area, to forage during the breeding season. Due to limited data availability for estimating the abundance of non-breeding parasitic jaegers, we relied on the maximum number of adults banded during a single year (17 individuals in 2009; Therrien, unpublished data) as the minimum abundance on the study area. This corresponds to a density of 0.04 individuals/ km^2 . For comparison, Taylor (1974) measured a density of 0.06 individual/ km^2 on Bathurst Island.

3.13 Common raven

Despite the intensive nest searches for raptors in upland zones, we never found more than one common raven nest each year, a small number considering the frequent raven observations at the study site (Gauthier et al., 2024b). This indicates the potential presence of non-breeding individuals or individuals that breed outside the study area but use it for foraging. Therefore, we opted for alternative approaches based on individual counts to estimate the abundance of both breeding and non-breeding ravens.

As a first approach, we based our estimate of ravens on the number of glaucous gulls observed per transect.

We assumed that the ratios between relative and actual abundance are the same (i.e., similar detection probability) among those species. This assumption is reasonable as those species present similarities in size and foraging strategy. We therefore derived the absolute abundance of common ravens from their relative abundance using the ratio between relative and absolute abundances of glaucous gulls as a reference.

Independently, we estimated the abundance of common ravens with the same approach but using the indices of relative abundance presented by Gauthier et al. (2024b), which was derived from incidental daily observations, rather than observations from the transects.

3.14 Brown and collared lemming

Between 1995 and 2003, we used the density estimates derived from the snap-trapping indices obtained in late July in each habitat. Between 2004 and 2007, annual abundance of each lemming species was based on the late-July density estimates on trapping grid in wet and mesic habitats. However, starting from 2008, estimates were derived from the mean density recorded in mid-July and mid-August, except for two instances: 2019 and 2021. In 2019, due to an exceptionally early snowmelt and thus an early decline in lemmings during the summer, we only retained value from mid-July. In 2021, we relied solely on data gathered in August because it was the only trapping period carried out that year. To scale the estimated densities from the wet and mesic grids to the entire study area, we used the proportions of mesic habitats (64%) and wet habitats (10%) measured within the study area.

3.15 Arctic hare

Arctic hares are primarily observed in the upland zones of the study area, where sampling effort is limited. We thus derived abundance of hares from the estimated abundance of Arctic foxes based on indices of relative abundance presented in (Gauthier et al., 2024b), which were derived from incidental daily observations. We doubled the density of Arctic hares in the upland zones (i.e., plateaus), as twice as many individuals were observed per hour of fieldwork there compared to lowland zones (**Table 4**). However, it is worth noting that assuming a similar detection probability between foxes and hares might lead to an overestimation of hare detection probability due to behavioral differences between the species. Therefore, we most likely underestimate the actual abundance of Arctic hares in the study area.

3.16 Ermie

We estimated the annual abundance of ermines by transforming the annual index of relative abundance provided in Bolduc et al. (2023) into individual density. Annual values ranged from 0, indicating no ermine sighting, to 2.88, which signifies that nearly all observers observed at least one family group during their field season. We independently obtained measures of minimum (0.02 ind./km²) and maximum (0.4 ind./km²) ermine density, which were determined from estimates of individual home range obtained from radio-tracking data, observations on Bylot Island, and existing literature (Legagneux et al., 2012; Bilodeau, 2013). We associated the minimum and maximum scores of relative abundance with the minimum and maximum density of individuals, respectively. Ultimately, we calculated the ermine density by linearly interpolating between these two density extremes using the annual index of relative abundance.

3.17 Arctic fox

We estimated the abundance of Arctic foxes in the study area based on their estimated home range size inside and outside the goose colony. We used the data and methodologies outlined in Dulude-de Broin

et al. (2023) to estimate home range size. However, here, we did not account for annual variations in lemming density as presented in Dulude-de Broin et al. (2023) in order to obtain mean fox home range. Given that foxes are territorial and exhibit an average spatial overlap with adjacent territories of 18% (Clermont et al., 2021), we converted home range size into individual density using the following formula: $\text{density of individuals} = \frac{2}{0.82 \times \text{home range}}$. We used two as numerator because we assumed each territory was held by a pair of fox, either breeding or non-breeding fox pair, without accounting for potential nomadic or transient individuals. We used values of 12.26 km² to represent the mean home range of foxes within the goose colony and 20.02 km² for foxes outside the goose colony. We estimated the mean density of foxes in each zone of the study area according to the mean proportion of the zone covered by the goose colony. We derived the mean annual proportion of each zone covered by the goose colony from the colony outline between 2010 and 2023. We estimated a mean density of 0.14 individuals/km² for the study area. Previously, the minimum density of foxes in the study area was estimated to be between 0.03 and 0.13 individuals per km² based on camera traps (Royer-Boutin, 2015).

4 Species abundance

4.1 Uncertainty on estimates

We did not quantitatively assessed uncertainty on each estimate of species abundance. However, we provide a qualitative measure of uncertainty based on the level of confidence derived from field experts, and in some cases, the fit of statistical models to estimate density (**Table 7**).

Table 7: Confidence level on the various estimates of annual or mean abundance of vertebrate species on Bylot Island.

Species	Estimate	Confidence	Reason
king eider	mean	moderate	Intensive, but opportunistic nest monitoring (8 km2)
long-tailed duck	mean	moderate	Intensive, but opportunistic nest monitoring (8 km2)
Pacific loon	2017-2019, 2022	high	Intensive study area-wide nest monitoring (389 km2)
red-throated loon	2017-2019, 2022	high	Intensive study area-wide nest monitoring (389 km2)
cackling goose	2004-2016	moderate	Extrapolation from exponential model of growth (R2=0.74, p=0.15, n=5)
cackling goose	2017-2019, 2022-2023	high	Intensive study area-wide nest monitoring (389 km2)
snow goose	1999-2009	low	Density based only on nest monitoring and uncertainty on goose colony area (mean)
snow goose	2010-2019, 2022-2023	high	Intensive study area-wide monitoring based on several methods and annual colony outline
tundra swan	2017-2019, 2022	high	Intensive study area-wide nest monitoring (389 km2)
rough-legged hawk	2007-2012	high	Extrapolation from intensive nest monitoring (111 km2, R2=0.99, p<0.0001, n=8)
rough-legged hawk	2013-2019, 2022	high	Intensive study area-wide nest monitoring (389 km2)
peregrine falcon	2013-2019, 2022	high	Intensive study area-wide nest monitoring (389 km2)
snowy owl	1996-2011	high	Extrapolation from intensive nest monitoring (111 km2, R2=0.99, p<0.0001, n=10)
snowy owl	2012-2019, 2022-2023	high	Intensive study area-wide nest monitoring (389 km2)
rock ptarmigan	mean	low	Intensive, but opportunistic nest monitoring (8 km2) and prime nesting habitat not well sampled
sandhill crane	mean	moderate	Extrapolation from intensive nest monitoring (8 km2) and uncertain relation with large scale indices
American golden-plover	2014-2019, 2022-2023	high	Distance sampling throughout lowland (313 km2)
black-bellied plover	mean	moderate	Derived from the abundance estimate of another species
common-ringed plover	2015-2017	moderate	Nest monitoring on the main breeding sites
ruddy turnstone	mean	low	Derived from the abundance estimate of another species
red knot	mean	low	Derived from the abundance estimate of another species
pectoral sandpiper	mean	low	Derived from the abundance estimate of another species
Baird's sandpiper	mean	moderate	Extrapolation from intensive nest monitoring (2 km2) and uncertain relation with large scale indices
white-rumped sandpiper	mean	low	Derived from the abundance estimate of another species
buff-breasted sandpiper	mean	low	Derived from the abundance estimate of another species
red phalarope	mean	low	Derived from the abundance estimate of another species
glaucous gull	2004-2016	high	Extrapolation from intensive nest monitoring (111 km2, R2=0.84, p=0.16, n=4)
glaucous gull	2017-2019, 2022	high	Intensive study area-wide nest monitoring (389 km2)
long-tailed jaeger	2004-2019, 2022	high	Extrapolation based on intensive nest monitoring (33 km2)
parasitic jaeger	mean	low	Opportunistic nest monitoring and uncertainty about number of non-breeding individuals
common raven	mean	low	Low density and uncertainty about number of non-breeding individuals
horned lark	mean	moderate	Derived from the abundance estimate of another species

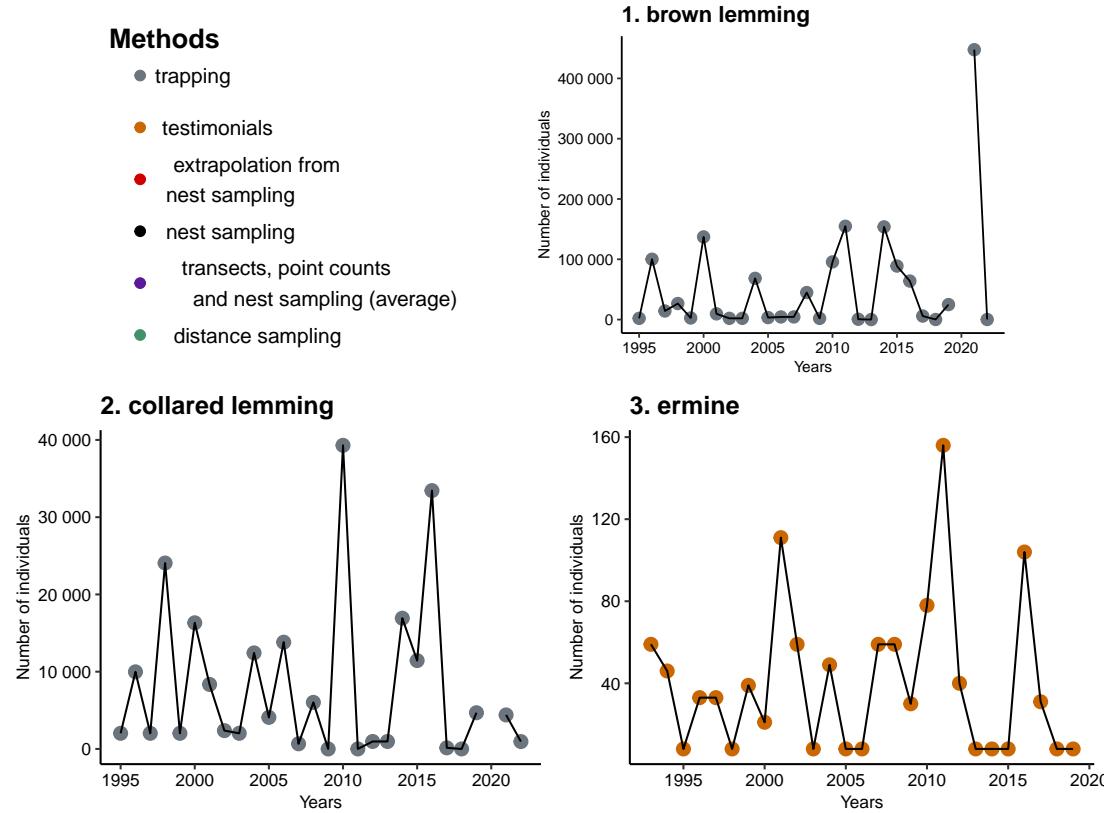
American pipit	mean	low	Derived from the abundance estimate of another species and prime nesting habitat not well sampled
Lapland longspur	mean	moderate	Extrapolation from intensive nest monitoring (2 km ²) and uncertain relation with large scale indices
snow bunting	mean	low	Derived from the abundance estimate of another species and prime nesting habitat not well sampled
brown lemming	1995-2019, 2021-2022	moderate	Rigorous density estimates but at a small spatial scale (0.22 km ²)
collared lemming	1995-2019, 2021-2022	moderate	Rigorous density estimates but at a small spatial scale (0.22 km ²)
Arctic hare	mean	low	Prime habitat not well sampled
ermine	1993-2019	moderate	Based on indirect indices and uncertainty on ermine home range size estimates
Arctic fox	mean	moderate	Derived from extensive fox home range size studies (n=109)

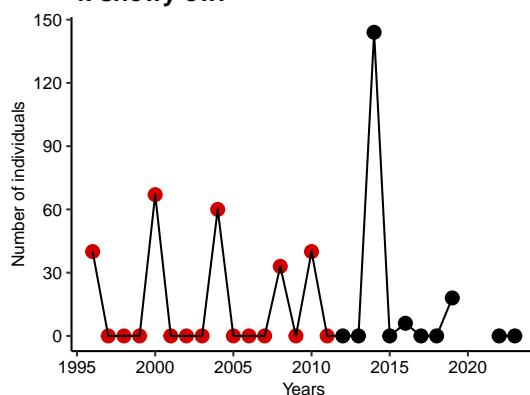
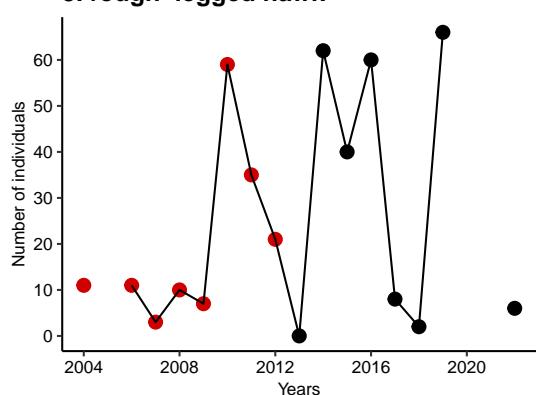
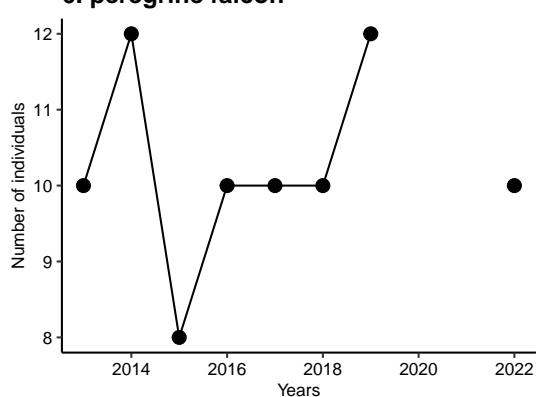
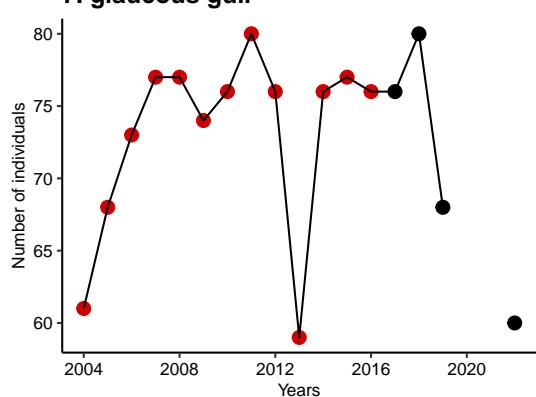
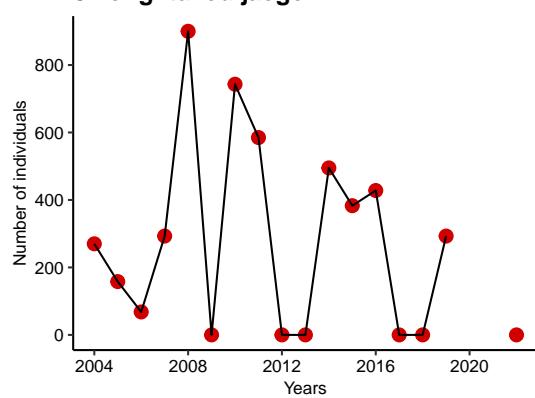
4.2 Abundance estimates

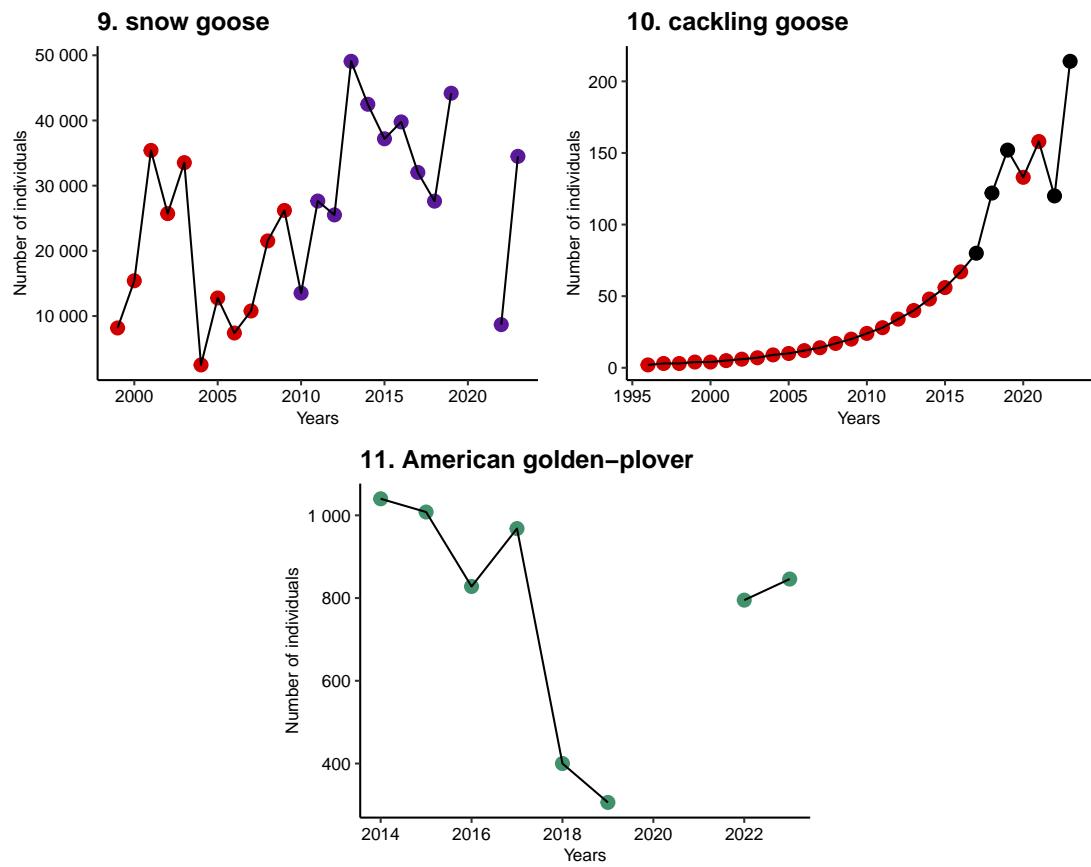
Table 8: Mean (\pm standard deviation) and minimum and maximum (when available) annual abundance of vertebrate species for the whole Bylot Island study area (389 km²). In some cases, several independent approaches have been used to estimate the abundance of a species as a proxy for uncertainty.

Species	Method	Mean \pm sd	n	Minimum	Maximum
king eider	nest sampling (extrapolation habitat)	25			
king eider	incidental observations (relative abundance)	106			
long-tailed duck	nest sampling (extrapolation habitat)	20			
long-tailed duck	incidental observations (relative abundance)	191			
Pacific loon	nest sampling	4 \pm 3	4	0	6
red-throated loon	nest sampling	64 \pm 15	4	42	76
cackling goose	nest sampling	50 \pm 59	28	2	214
snow goose	combined methods	25289 \pm 13327	23	2505	49076
tundra swan	nest sampling	1 \pm 1	4	0	2
rough-legged hawk	nest sampling	25 \pm 24	16	0	66
peregrine falcon	nest sampling	10 \pm 1	8	8	12
snowy owl	nest sampling	16 \pm 33	26	0	144
rock ptarmigan	nest sampling (extrapolation habitat)	24			
sandhill crane	nest sampling (extrapolation transects)	34			
American golden-plover	distance sampling	774 \pm 275	8	306	1040
black-bellied plover	transects (relative abundance)	22			
black-bellied plover	incidental observations (relative abundance)	61			
common-ringed plover	nest sampling	55 \pm 9	3	44	62
ruddy turnstone	transects (relative abundance)	40			
ruddy turnstone	incidental observations (relative abundance)	54			
red knot	transects (relative abundance)	64			
red knot	incidental observations (relative abundance)	237			
pectoral sandpiper	transects (relative abundance)	79			
pectoral sandpiper	incidental observations (relative abundance)	260			
Baird's sandpiper	nest sampling (extrapolation transects)	2495			
white-rumped sandpiper	transects (relative abundance)	1135			
white-rumped sandpiper	incidental observations (relative abundance)	1156			
buff-breasted sandpiper	transects (relative abundance)	41			
buff-breasted sandpiper	incidental observations (relative abundance)	8			
red phalarope	transects (relative abundance)	156			
red phalarope	incidental observations (relative abundance)	276			
glaucous gull	nest sampling	73 \pm 7	17	59	80
long-tailed jaeger	nest sampling	272 \pm 285	17	0	900
parasitic jaeger	banding	17			
parasitic jaeger	nest sampling	8			
common raven	transects (relative abundance)	14			
common raven	incidental observations (relative abundance)	31			
horned lark	transects (relative abundance)	362			
horned lark	incidental observations (relative abundance)	411			
American pipit	transects (relative abundance)	53			
American pipit	incidental observations (relative abundance)	87			
Lapland longspur	nest sampling (extrapolation transects)	7110			
snow bunting	transects (relative abundance)	18			
snow bunting	incidental observations (relative abundance)	276			
brown lemming	trapping	54043 \pm 93530	27	0	447630
collared lemming	trapping	8128 \pm 10334	27	0	39302
Arctic hare	incidental observations (relative abundance)	6			
ermine	testimonials	40 \pm 37	27	8	156
Arctic fox	individual home range	53			

The following figures present the time series of species abundances. If different methods were used, we present the estimates derived from each method with different colors (see **Table 7** for the corresponding method and confidence in estimates).



4. snowy owl**5. rough-legged hawk****6. peregrine falcon****7. glaucous gull****8. long-tailed jaeger**



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