**Sympatric Nesting Eastern Prairie Population (EPP) Canada Geese and Lesser Snow Geese on the Hudson Bay Lowlands:
Nest Depredation and Spatial Distribution**

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INTRODUCTION

Long-term monitoring (>25 years) of breeding Eastern Prairie Population (EPP) Canada geese (*Branta canadensis interior*) at Cape Churchill has documented a decline in nest density (Walter 1999, D. Andersen, Minnesota Cooperative Fish and Wildlife Research Unit, unpublished data). Walter (1999) identified nest depredation, particularly by arctic fox (*Alopex lagopus*), as the most consistent factor affecting EPP reproductive success and subsequent recruitment over 20 years (1976 – 1996). Currently, there is concern about the influence of increasing nesting light goose populations (lesser snow goose [*Chen caerulescens caerulescens*] and Ross's goose [*Chen rossii*]) on breeding Canada geese (Ankney 1996, Batt 1997, Walter 1999, Nack 2003, Nack and Andersen 2004, Gleason et al. 2004), and the potential interacting effects of predators and light goose abundance on Canada goose population dynamics in northern Manitoba.

Nesting lesser snow geese have expanded their distribution considerably during the last 20 years (Ankney 1996, Abraham and Jefferies 1997, Batt 1997) moving into areas where they did not previously occur, and that were traditionally used solely by nesting EPP Canada geese (Walter 1999, Nack and Andersen 2004). The detrimental impact that large populations of snow geese have on sub-arctic vegetation communities is well documented (Kerbes et al. 1990, Srivatava and Jefferies 1996, Jano et al. 1998, Jefferies and Rockwell 2002). Considerably less information exists on the direct or indirect effects of this growing population on other species, particularly sympatrically nesting Canada geese (Ankney 1996, Abraham and Jefferies 1997, Batt 1997). On Akimski Island in southern James Bay, Canada goose reproductive performance was reduced in the presence of sympatrically nesting lesser snow geese compared with when snow and Canada geese nested allopatrically (Gleason et al. 2004), yet the mechanisms

contributing to the observed difference are not clear. Large groups of snow geese may alter local predator-prey dynamics (Walter 1999), potentially influencing nest depredation of Canada geese. However, how dense nesting aggregations of lesser snow geese affect nest depredation on sympatrically nesting species is not known.

Herein, we report on research activities conducted in 2005 to further assess the potential impact of increased snow goose nesting aggregations on EPP Canada geese. We address the following questions:

1. How do nesting aggregations of lesser snow geese affect the probability of depredation of sympatric EPP Canada goose nests at 2 sites with different histories of snow goose nest presence?

2. How are sympatrically nesting Canada and snow geese arranged spatially relative to each other?

3. How are nesting EPP Canada geese distributed across the landscape and what factors influence the observed distribution?

To address the first objective, we collected data at Nestor One and the Broad River to model the probability of nest depredation and estimate the effect of multiple biological covariates (see Table 1). To address the second objective, we will use these data, data from near the Town of Churchill, and historical data from Nestor One to assess the spatial pattern of nest distribution and depredation, both in the presence and absence of nesting snow geese. To address the third objective, we will use existing breeding survey data. Breeding population surveys have been conducted annually for EPP Canada geese beginning in 1972 and continuing through 2004

(Malecki et al. 1981, Humburg et al. 2000, Raedeke et al. 2004). Nesting snow geese have been recorded on these aerial transects since 1981. These annual surveys summarize population trends used for long-term monitoring and harvest management (Malecki et al. 1981, Humburg et al. 1998, Humburg et al. 2000, Raedeke et al. 2003) but have not been used to quantify shifts in spatial distribution and density. With increasing numbers of lesser snow geese across the EPP Canada goose range (Abraham and Jefferies 1997), these data provide additional landscape-level information regarding their inter-specific relationship.

STUDY AREA

The EPP breeding range includes nearly 54,000 km^2 in northern Manitoba (Malecki et al. 1980). The highest density of breeding Canada geese is found along a strip of coastal habitat bordering Hudson Bay. The Nestor One study area (NO), just south of Cape Churchill and approximately 60 km east-southeast of the town of Churchill, Manitoba, Canada (Fig. 1), lies within this narrow strip of coastal tundra nesting habitat, characterized by low relief, continuous permafrost, poor drainage, beach ridges, coastal marshes, and coastal tundra vegetation (Wellein and Lumsden 1964, Didiuk and Rusch 1979). The core study area is ~ 48 km^2 and is located inside of Wapusk National Park (11,475 km^2). Coastal salt marsh, beach ridge/sedge meadow, and interior sedge meadow compose the major habitat types (Didiuk and Rusch 1979, Brook 2001). Prior to 2001, 0-2 snow goose nests were located annually during nest searching on the study area. However, from 2001 – 2003 there were 55, 6, and 94 snow goose nests, respectively.

The Broad River study area (NO) is located ~55 km south of NO in Wapusk National Park along Hudson Bay (Fig. 1). The core study area, just north of the river mouth, is ~20 km^2, and consists of the same general habitat types as NO (Brook 2001). Eight units have been searched for nesting Canada geese sporadically over the last 20 years. Annual aerial breeding

ground surveys document a roughly 200% increase in the number of snow goose nests near the mouth of the Broad River since 2000 (Raedeke et al. 2005).

The Churchill study area (CH) is located ~10 km east of the town of Churchill. We searched previously established study units (Walter 1999) of coastal tundra nesting habitat. Although the boreal forest is intermixed with tundra vegetation zones, in this area, we selected 3 units which generally resembled nesting habitat at NO and BR. The total area is ~7.62 km^2. Two nesting snow geese were reported in these units in 1993 (Walter 1999).

METHODS

Nest Depredation

Nest searching was conducted, 29 – 31 May 2005 at CH, 3 - 12 June 2005 at NO, and 3 – 7 June 2005 at BR. At all nests encountered, females were flushed and nest number, goose species, number of eggs present, incubation stage [(using candling and flotation methods) (Westerkov 1950, Weller 1956)], presence of predators, flush distance, nest site type (Type 1 = in sheet H$_2$O, saturated ground, sedge/H$_2$O; Type 2 = shore, point, island; Type 3 = beach ridge, upland, pressure ridge), and general nest condition were recorded on nest cards. Universal Transverse Mercator (UTM) coordinates of the nest location were determined with a Global Positioning System (GPS) unit (recording +/- [m] error values) and imported to a digital field map (Nack 2003). Nest locations were marked with a 7.5 cm x 12.5 cm plastic orange flag placed 10 m north of the nest bowl (Didiuk and Rusch 1979, Walter 1999). At NO, we observed nests from a distance of > 200m at regular intervals throughout the incubation period. If a female was present, we assumed that at least 1 egg was still intact and thus the nest was still active. If the female or male was not present we visited the nest to determine its fate. Based on a 28-day incubation period, we revisited nests at NO and BR at or subsequent to the predicted

hatch date to determine outcome (Didiuk and Rusch 1979). We categorized nests as (1) successful if at least 1 egg successfully hatched, identified by the presence of goslings or eggshells and intact membranes; or if a female was present at the final nest check, (2) depredated if few or no eggshell fragments were found in the nest, (3) abandoned if found with intact cold eggs, or (4) unknown. We assessed all depredated nests to identify the predator responsible. Holes in eggs or presence of eggshells are indicators of avian predation while missing eggs indicate mammalian predation (Walter 1999, Anthony et al. 2004). Identification of mammalian nest predators was made by the presence of key species-specific signs: scat, urine smell, or visual identification of individual.

We conducted ground-based arctic fox den surveys along beach ridges within NO and BR and visited all known den locations. We recorded den coordinates with a GPS and evaluated dens for occupancy by the presence of fox or fresh fox sign indicative of an active den (Macpherson 1969). We identified the presence of prey items (lemming carcasses, goose carcasses, etc.) around each den. We compared the proportion of den sites with fox to previous years as a rough index of relative annual arctic fox abundance at NO and BR. Because potential predator pressure likely varies with the proximity of an active fox den to a nest, it was measured as a separate variable, quantified as the distance (m) from each nest to the nearest active fox den.

We employed 2 methods to quantify local abundance of collared-lemmings (*Dircrostonyx richardsoni*); willow (*Salix* spp.) scar analysis and arctic fox scat-analysis. At Cape Churchill and the Broad River, collared-lemmings feed primarily on willow (*Salix* spp.). Surveys for scarring on willows provide a measure of local cycles of lemming abundance (Danell et al. 1981, Danell et al. 1999, Predavec et al. 2001). In 2004, we identified lemming population cycles at NO using this technique. In 2005, we collected scars near BR and used a dissecting microscope

to age scars based on the number of growth rings since the scarring event (Danell et al. 1981, Danell et al. 1999; see Reiter 2006 for a more thorough treatment of these methods and analysis). Arctic fox scat analysis can also provide an index of annual collared lemming abundance. We collected fox scat when encountered during nest searching and research activities and at fox dens. We aged each scat at the time of collection according to criteria in Macpherson (1969) and allowed scat to air dry until analyzed in the lab. We autoclaved samples, washed them with light detergent and water, and passed them through standard size (no. 5, 20 and 40) mesh sieves, until all component materials were separated. We dried samples at 55°C for 2 hours. We examined materials from each sample for 10 minutes to determine the presence or absence of lemming remains and other prey items (Macpherson 1969, Stickney 1991). If no lemming remains were identified after initial search, we conducted comparative hair analysis using both dissecting and compound microscopes (see Day 1966). The annual lemming abundance index for the study area is simply the proportion of scats containing lemmings. We used a chi-square test to examine differences in the proportion of fox scats containing lemming remains between 2004 and 2005 (Hollander and Wolfe 1999).

Investigator visits to nests can increase the probability of goose nest depredation (MacInnes and Misra 1972). We revisited a random subset of nests at NO the 1st or 2nd day post-discovery. During this visit, we observed the nest using a spotting scope or binoculars from > 200m and the female was not flushed. We noted the presence or absence of the male, female, or both geese, and we recorded all observed predators. If adult geese were not present for 2 consecutive days, we visited the nest to determine its status as active, depredated, or abandoned. We will use these data in a logistic exposure model (Shaffer 2004) to test for an observer effect on nest success of Canada geese. To account for potential effects of nest visitation, the number of times a female

was flushed from the nest was also calculated for each nest and will be included in nest survival models. .

Nest counts of both Canada goose and snow goose nests within 250m of each Canada goose nest and the distance (m) of each Canada goose nest to the nearest depredated nest were calculated using Arc View 3.3.

Variables considered in the analysis for all nests (Table 1) were tabulated and prepared for use in nest survival models. We will implement logistic exposure models developed by Shaffer (2004) using PROC GENMOD in SAS v.9.1 (The SAS Institute, Inc. © 2001) to estimate daily survival rate throughout incubation. Specifically we will examine how the density of lesser snow geese interacts with local predator dynamics to influence daily survival rate of Canada goose nests. We also will use these models to assess possible observer effects and nest age as variables influencing daily nest survival rates.

Spatial Distribution

To assess spatial patterns in the distribution of nesting Canada and snow geese, we will first analyze each species' distribution within each study area using the SPATSTAT 1.5-4 (Baddeley and Turner 2005) extension in the statistical software R v.2.1 (The R Foundation for Statistical Computing © 2005). This module allows spatial relationships to be modeled explicitly in regions that are inhomogeneous (i.e. events or nests cannot occur at any point within some region) and have irregular boundaries. Both single species and relative multiple species spatial distributions can be evaluated. In particular, we will conduct (1) a statistical based description of spatial patterns of Canada goose and lesser snow goose nests at NO, BR, and CH, (2) a bivariate analysis to test for spatial independence of Canada goose and lesser snow goose nests at NO and BR, and (3) univariate and bivariate analysis to explore spatial trends and

patterns in Canada goose nest depredation at NO and BR. We will employ univariate and

bivariate Ripley's K function analysis (Ripley 1976) to assess complete spatial randomness at

multiple spatial scales. In addition, we will fit other spatial point pattern models (Diggle 1983)

using this software. It may be possible to include these explicitly modeled spatial correlation

structures in a mixed model nest survival analysis. Currently, GPS data for spatial point pattern

analysis exist for NO from 1998 to 2005, the BR in 2005, and CH in 2005.

Landscape Distribution

   Model based geostatistics and mixed effects models provide a valuable tool for modeling

factors influencing landscape level spatial patterns and predicting population distributions over a

large range (Diggle and Tawn 1998). They allow for both spatial and non-spatial correlations to

be modeled. We will implement these techniques to (1) describe EPP Canada goose and lesser

snow goose nesting distributions throughout the survey region from 1981 until the present, (2)

model the effects inter- and intra-specific nest density, habitat type and spatial location on the

number of Canada goose nests observed at different points along each transect, and (3) model

changes in the distribution of Canada goose nests and snow goose nests in both space and time.

We intend to consider the results of local bivariate point pattern analysis and Canada goose nest

survival models, when developing landscape level models and testing hypotheses regarding the

landscape level influence of increasing nesting lesser snow geese across the EPP breeding range.

   Approximate densities (number of nests/ km^2) will be calculated for both Canada and snow

geese within each 1-minute recording interval area (Malecki et al. 1981) and plotted as fixed area

density blocks on a digital map. We will follow the suggestion of Humburg et al. (1998) and

include only single geese, pairs observed with a nest or brood, and birds initially observed as

singles but subsequently joined by another goose in nest density estimates. General habitat types

in each area will be quantified using the Brook (2001) vegetation map. We will include variables such as habitat type (using Brook 2001), lesser snow goose nesting density, and Canada goose nesting density in model development. Nest density prediction maps and corresponding prediction variance maps will be generated for all years using all models. We will employ cross-validation will be used to examine the accuracy of predictions from each model (Isaaks and Srivastava 1989), and incorporate model selection techniques to assess the most parsimonious model or set of models for predicting Canada goose nest density (Burnham and Anderson 2002).

RESULTS

Nest Depredation

Nestor One

Snow pack and spring phenology were roughly average near CH, NO, and BR in 2005 with ~ 50% snow cover in early June. EPP nest density at NO increased from 0.82 nests per 100 ha in 2004 to 9.43 per 100 ha in 2005. We discovered a total of 182 nests at NO (n = 165, active; n = 17, failed). On average, nests were 8.44 (SE = 0.33) days old at discovery. We made 791 nests observations on 165 nests that were active at initial discovery. We averaged 4.71 (SE = 0.15) days between nest observations. Of the 182 nest types, we classified 45.6% as Type 1 (n = 83), 34.1% as Type 2 (n = 62), and 20.3% as Type 3 (n = 37). Nest success for EPP based on daily survival rates (Mayfield 1975) also increased from 2004 to 0.51 in 2005 (Andersen et al. 2005). Mean distance from successful Canada goose nests to the nearest depredated nest (621.58 m; SE = 32.96) was larger than the nearest failed nest to another failed nest (505.10 m; SE = 76.01). Canada goose nest counts within 250m of each nest averaged 1.08 (SE = 0.09) nests and snow goose nest counts within 250m of Canada goose nests averaged 0.54 (SE = 0.13) nests. We discovered 70 snow goose nests at NO in 2005 and snow goose apparent nest success was

0.26. At least 1 predator species was observed during 281 (34.7%) of 809 total nest observations.

Broad River

On 3 June 2005, we initiated ground surveys for nesting geese at BR. We searched areas previously surveyed from 1987 – 1989 and 1993 - 1994. We discovered 404 Canada goose nests at BR in 2005. Nests averaged 9.06 (SE = 0.19) days old at discovery. In 2005, nest density (48.05 nests per 100 ha) at BR was much higher than at NO (9.43 nest per 100 ha) and also higher than the density of 24.97 nests per 100 ha observed in the same units at BR in the late 1980s and early 1990s. All nests that were active when discovered at BR were visited only 2 times due to logistical limitations. We classified 314 (78%) as Type 1, 31 (8.0%) as Type 2 and 58 (14%) as Type 3. Estimates of nest success based on daily survival rates (Mayfield 1975) were higher at BR (0.72) than at NO (0.51). Mean distance from each failed Canada goose nest to the nearest depredated nest was 138.01 (SE = 9.64) m which was larger than the mean distance from each successful Canada goose nest to the nearest depredated nest (102.42 m; SE = 5.60). The count of Canada goose nests within 250m of each other Canada goose nest averaged 11.93 (SE = 0.35) nests and snow goose nest counts within 250m of Canada goose nests averaged 5.95 (SE = 0.43) nests. We discovered 156 snow goose nests in 2005 and apparent nest success was 0.59 for snow geese. At least 1 predator species was observed at 152 (19.2%) of 790 total nest observations.

Churchill

On 30 May 2005, we initiated ground surveys for nesting geese at CH. We discovered 124 nests across 3 units and nest success based on daily survival rates (Mayfield 1975) was 0.82. We estimated nests density to be ~17 nests per 100 ha in 2005 which is similar to data from 1993

and 1994 (Walter 1999). We classified 74 (61%) of 121 nests as Type 1, 30 (25%) of 121 as

Type 2, and 17 (14%) as Type 3. We discovered no snow geese in these units.

We surveyed 22 arctic fox dens within and surrounding NO. We visited dens at least

twice to determine activity. Eight dens had sign of fresh fox activity during at least 1 visit ($p =$

0.37). This is well below the 12-year average (0.653 ± 0.06) and not captured in the 95%

confidence interval for the long-term mean (0.523, 0.783). However, only 1 (5%) of 22 dens

surveyed appeared to sustain activity throughout the goose breeding period. The mean distance

of Canada goose nests to the nearest active fox den was 3756.81 m (SE = 126.06), ranging from

617.62 m to 7232.34 m.

We surveyed 5 dens within and surrounding BR. We found sign indicative of an active

fox den at only 2 (40%) of 5 dens. However, 1 of these dens was used by a wolf (*Canis lupus*).

Overall, few fox were seem during research activities. The mean distance from Canada goose

nests to the nearest active fox (or wolf) den was 2408.44 (SE= 25.40) m and ranged from 965.62

m to 3645.97 m.

Willow stem scar ages (*n* = 238) ranged from 0 to 13 years. We fit non-linear models to

the observed scar-age frequency at BR and 2004 data from NO (see Reiter 2006 and Additional

Research Activities, below). Based on the distribution of scar ages, 2005 was a period of low

lemming populations at BR. The estimated relative lemming abundance for 2004 were similar

and long-term trends were synchronous between NO and BR. This is consistent with *ad hoc*

field observations during 2005 (D. Andersen, pers. comm.; M. Reiter, pers. comm.) and our fox

scat analysis data. These data were used to evaluate (1) historical trends in collared lemming

populations and the degree of landscape synchrony in the observed trend on the Hudson Bay

Lowlands and (2) the "bird-lemming" hypothesis as a mechanism influencing annual variation in

EPP Canada goose nest success at Cape Churchill from 1993 – 2004 (see Reiter 2006 and Additional Research Activities, below).

We collected arctic fox scats ($n = 48$) at NO and BR from 03 June to 10 July 2005. Based upon the crude scat aging classification of Macpherson (1969), the oldest sample was from late April and the most recent from early July. Because our willow scar data suggest lemming cycles are synchronous between NO and BR, we pooled scat samples from the 2 study areas together for analysis. In 2005, 23 (47.9%) of 48 arctic fox scats contained lemmings which is significantly less ($\chi^2 = 42.63$, $df = 1$, $P < 0.0005$) than 2004 when 91 (94.8%) of 96 arctic fox scats analyzed contained evidence of lemming remains. This further supports our willow scar analysis model which predicted lemmings to be much less abundant in 2005 than in 2004.

Spatial Distribution

In 2005, we began the process of hand digitizing the all study areas into the R software package. Canada goose and snow goose geospatial data for 1998 – 2003 from NO were proofed an organized into database format for use in R.

Landscape Distribution

In 2005, beginning and endpoints of flight transects during EPP breeding ground surveys were recorded by survey observers. These data were digitized and mapped using ArcView 3.3. Based upon endpoints, transects lines were constructed and a 200m buffer established on either side, representing the area over which geese are counted (Malecki et al. 1981, Humburg et al. 2000). In addition, we began to reenter the EPP aerial survey data by 1-minute intervals. We hope to complete this work by summer so that we can begin additional analyses using these data.

DISCUSSION and 2006 RESEARCH PLAN

We summarized and recorded variables of interest for each nest found in 2005 and we currently are developing formal models to be evaluated using logistic exposure nest survival analysis. Specifically, we hope model the effect of nest age, observer interactions, and the density of snow geese on the daily probability of Canada goose nest survival. Generally, in 2005, our data suggest that Canada goose nest success was average and both predator abundance (in particular, arctic fox) and the primary prey for predators (e.g. lemmings) were low. Nesting lesser snow geese were abundant at both NO and BR. We hope to gain further insight as to impact of these increasing densities of nesting snow geese and refine our predictions of both the local and landscape level impacts of increasing lesser snow geese on the distribution and success of nesting EPP Canada geese by employing point pattern analysis and modeling in SPATSTAT. In 2006, we also intend to initiate data analysis using the landscape level aerial survey data. In summer 2006, we will again search NO, BR, and CH for nesting geese and monitor nests and predator pressure throughout the incubation period.

ADDITIONAL RESEARCH ACTIVITIES

Currently, a draft of my M.S. thesis entitled "Historical Trends in Collared Lemming (*Dicrostonyx richardsoni*) Abundance and Nest Success of Eastern Prairie Population (EPP) Canada Geese (*Branta canadensis interior*) in Northern Manitoba: Evaluating the 'Bird-Lemming' Hypothesis" is in review and will be submitted to the EPP Technical Section, Mississippi Flyway Council upon its approval by my graduate committee. Data from this work were presented at the 2005 North American Arctic Goose Conference, the 2005 Minnesota Chapter of the Wildlife Society Meetings, and the 2005 Midwest Fish and Wildlife Conference. In 2006, we intend to submit both chapters from the thesis for publication.

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Figure 1: The Cape Churchill Region: Nestor One (NO), the Broad River (BR), and Churchill Study Areas
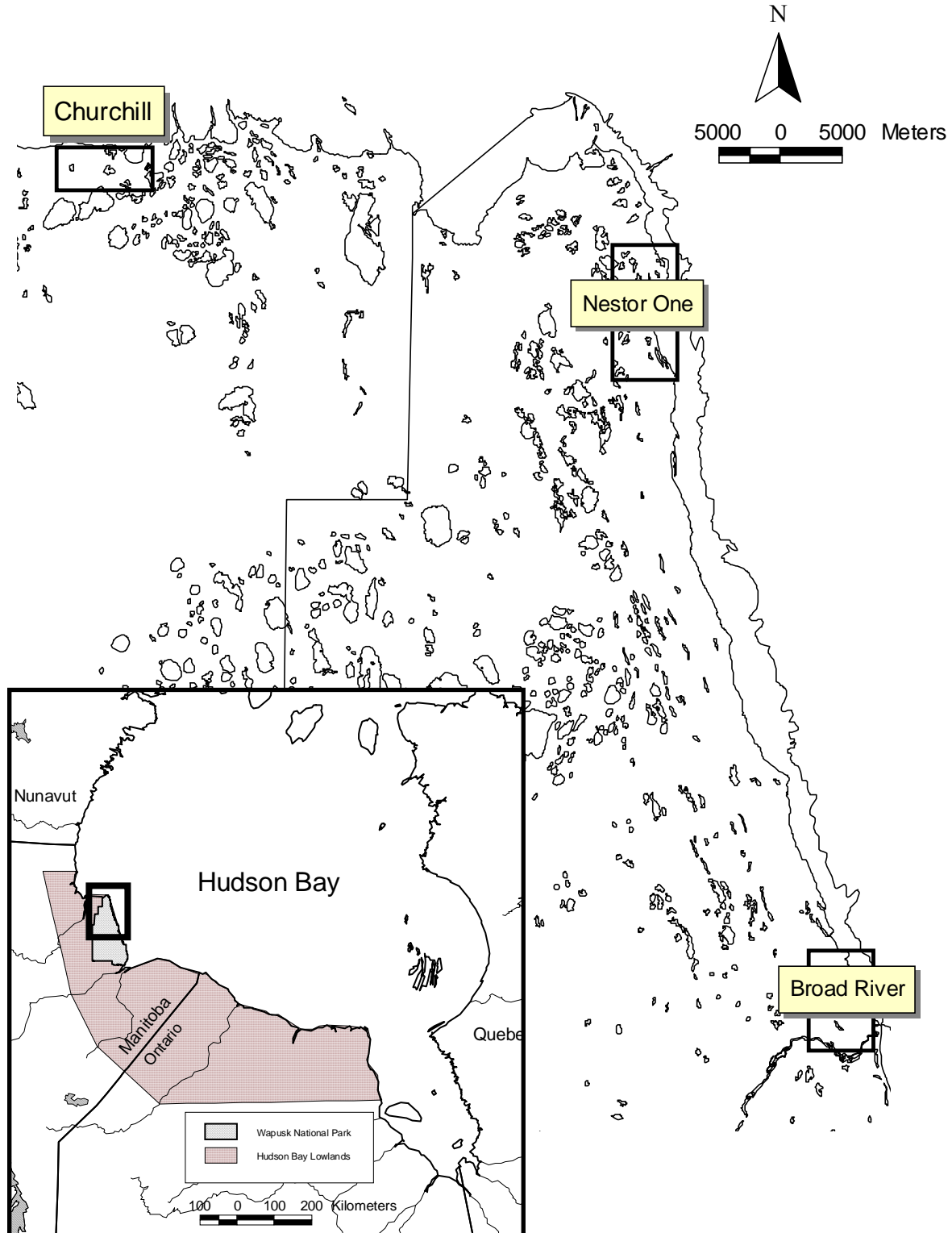
Table 1: Variables estimated from the data and included in model development and selection

Variable	Method of Estimation	Description
NEST EFFECTS CAGO proximity	Count of Canada goose nests within a 250m buffer around each nest	Index of competition and local prey abundance Measure of intra-specific effects
LSGO proximity	Count of lesser snow goose nests within a 250m buffer around each nest	Index of competition and local prey abundance Measure of inter-specific effects
Avian	Proportion of nest visits where an avian predator was observed	Index of predator pressure Specific predator effects
Mammal	Proportion of nest visits where mammal sign/ individual was observed	Index of predator pressure Specific predator effects
Fox	Distance (m) to nearest active fox den	Index of predator pressure Effect of local active fox dens
Proximity	Distance (m) to nearest depredated Canada goose or snow goose nest	Index of predator pressure Effect of opportunistic hunting
Nest type	One of 3 broad nest site characteristics (see Methods and Didiuk and Rusch 1979)	Index of defensive capability Measure of influence of nest type on nest depredation
Nest visitation	The number of times the female is flushed from the nest	Measure of effects of nest visitation
SITE EFFECTS Lemming	Proportion of arctic fox scat with lemming remains	Index of alternative prey abundance Effect of periodically abundant food resource on local predator pressure