ASSESSING THE IMPACT OF LESSER SNOW GOOSE AND CACKLING GOOSE COMPETITION ON BREEDING ATLANTIC BRANT

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the Master of Science in Wildlife Ecology

Summer 2016

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ACKNOWLEDGMENTS

Funding for this study was provided by the Canadian Wildlife Service and the United States Fish and Wildlife Service through the Arctic Goose Joint Venture, the Polar Continental Shelf Program of Natural Resources Canada, California Waterfowl through the Dennis Raveling Scholarship, Long Point Waterfowl in coordination with Delta Waterfowl through the Dave Ankney and Sandi Johnson Waterfowl and Wetlands Graduate Research Scholarship, the University of Delaware, and Trent University. The field work was conducted under permits from the Canadian Wildlife Service, Nunavut Water Board, Kivalliq Inuit Association, Nunavut Planning Commission, Nunavut Impact Review Board, and the Government of Nunavut.

I would like to thank all field technicians for their assistance and continued hard-work in the adverse conditions of our arctic field camp. It would not have been possible without the teamwork and mental fortitude displayed by all field crew members. Specifically, I would like to thank Jim Noble, Nick Docken, Will Weise, Lizzi Bonzcek, and Ashley Lutto for all their contributions to two successful field camps. This project would not have been possible without the advice and helping hands of Paul Smith, Grant Gilchrist, Chris Sharp, Mike Janssen, Christie MacDonald, Christine Eberl, and all others who assisted along the way. A special thank-you to Shannon Badzinski for generously providing housing for the field crew in Ottawa. Lastly, a special thank-you to both of the project investigators, Ken Abraham and Chris Williams, without whom this project

would not have been possible.

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ABSTRACT

Population estimates from Mid-Winter Survey Counts over the last half century show that Atlantic brant numbers have fluctuated over the course of this time period; however, between 2000 – 2016 the population has been showing a slow decline of ~20%. Additionally, the Mid-Winter Surveys (MWS) indicate a low percentage of young in flocks in recent years ($\leq$10% between 2013–2015), indicating breeding ground limitations in those years. Southampton Island's East Bay (located on the southern end of the Foxe Basin), supported a historic nesting colony of brant as well as a significant population of lesser snow geese (*Chen caerulescens caerulescens*) and a small population of cackling geese (*Branta hutchinsii*). However, range-wide, lesser snow geese populations have increased from a few million to ~15 million in the last few decades with consequences that resonate throughout the ecosystem, affecting other species sharing that ecosystem. Additionally, the MWS indicates the range-wide cackling goose population has also increased from ~400,000 to ~700,000 in the last 3 decades.

While East Bay historically supported a large nesting colony of Atlantic brant. Research crews in 2010 found that a local decline in brant nesting had occurred, though reasons for the decline were not resolved. The aim of my study was to begin to decipher the keys to understanding why a localized decline is occurring and to provide an update of the status of nesting Atlantic brant at East Bay. By means of nest searching, the careful

observation of brant pairs during incubation, and collection of habitat and nest site selection data, we now believe we have a better grasp on some of the factors limiting brant success at East Bay, Southampton Island.

Snow geese and cackling geese arrived 25 May 2014 and 21– 22 (respectively) May 2015. Brant arrived on 9 June in summer 2014 and 8 June in summer 2015. Snow melt in 2014 occurred much faster than snow melt in 2015. In 2014, snow cover reached 0% by 12 June, while in 2015 snow cover did not reach 0% until 28 June. The snow melt was much quicker in 2014, with 100% snow melt lasting only until ~23 May as compared to 2 June in 2015. The peak initiation for snow geese was 2 June in 2014, but 14 June in 2015. Following a similar pattern, the peak initiation for cackling geese was 6 June 2014 and 19 June 2015. Brant had a less pronounced difference between years, peaking on 18 June 2014 and 22 June 2015. Importantly, the late snow melt in 2015 also caused a significant reduction in initiated nests in cackling geese (from 570 in 2014 to 355 in 2015) and snow geese (from 230 in 2014 to 48 in 2015) and an increase in brant nests (from 44 in 2014 to 78 in 2015). Atlantic brant and lesser snow geese did not overlap in their nesting habitat in 1979, nor did they between 2010–2015 when their nesting habitat appeared to be segregated between the upland (snow geese) and the graminoid/moss zones (brant). By 2010–2015, cackling geese populations at East Bay increased and appeared to wedge between Atlantic brant and lesser snow geese populations, thus overlapping with brant nesting regions. In 1979, 88.5% of Atlantic brant had at least 2 other brant nests within 200 m of their nest. By 2010 that decreased to 18.4% and further declined to 13.6% in the 2014 breeding season, but rebounded slightly to 26.9% in the 2015 breeding season. In contrast, in 1979 only 5% of Atlantic brant had at least 2 or more cackling goose nests within 200 m of their nest. That increased to 46.1% by 2010 and to 40.9% in 2014. In 2015, due to the lower number of cackling goose nests, only 16.7% of brant nests included 2 or more cackling goose nests within 200 m. Even though there were a lower number of nesting cackling geese in 2015, I still found 39% of 2014 brant nest sites were occupied by a cackling goose nest (< 200 m) showing the strong overlap in preferred habitat.

Kruskal-Wallis tests revealed significant differences between male and female brant behaviors between 2014 and 2015. Male brant spent less time feeding as well as less time engaged in locomotive behaviors (swimming/walking) in 2014 than in 2015. Females on the nest spent more time alert more time engaged in nest construction behavior in 2014 than in 2015. Females off the nest spent less time feeding and less time flying in 2014 than in 2015, but more time alert and more time preening.

Mean island size, mean water depth, and mean water distance did not differ between cackling geese and Atlantic brant in summer 2015 when these data were collected for both species indicating brant and cackling geese prefer similar island nest sites. Water distance was defined as the distance from a nesting island to the nearest mainland body. This path was chosen by finding the shallowest water path, with the assumption that a fox will use the shallowest path to access an island. If islands were scattered across that path, then the water distance between those islands was measured and summed (i.e. distance to island #1, distance to island #2, etc.). Brant apparent nest success declined from a high of 86% in 1979 to 65% in 2010, 5% in 2014, and 17% in

2015. Cackling goose nest success dropped from 86% in 2010 to 61% in 2014 and to 2% in 2015. Snow goose nest success was lower (63%) in 2010 compared with 74% in 2014; but then dropped to 6% in 2015. The overwhelming majority of failures were due to arctic fox depredation, responsible for 82% of brant failures in 2014 and 73.3% of brant failures in 2015. I examined the impact of nest site selection on fox predation. The top model included year, maximum water depth, distance to a mainland (water distance), and whether or not the nest was located on an island. Both year and maximum depth had the greatest effect size within the top model. Brant daily nest survival was 0.828 (SE $\pm$ 0.029) in 2014 and 0.924 (SE $\pm$ 0.012) in 2015.

I conducted an artificial nest experiment and calculated Kaplan-Meier survival probabilities for artificial nests located in different density plots (high vs. low goose nest density) and found high density nesting plots to experience increased predation and decreased survival probability.

Preliminary evidence at East Bay reveals a complex system in which many factors are influencing the localized decline of brant nest success and local population. My results indicate that at least some level of four kinds of competition (exploitative, pre-emptive, interference, and apparent competition) is occurring at East Bay. Whether or not these forms of interspecific competition have larger implications for the brant population as a whole remains to be studied at other breeding locations. I also found weather to have a profound impact on the nesting success of geese and the level of competition displayed between different goose species at East Bay.The role that climate change may play in brant survival and reproduction in future decades is yet to be seen, but I believe the importance of weather and climatic variables in the success of East Bay brant indicates that it will play a large role in the future of all breeding brant colonies.

Chapter 1

INTRODUCTION

Background

Atlantic brant (*Branta bernicla hrota*), hereafter brant, is an arctic nesting goose species with the majority of its nesting occurring in the Foxe Basin. Southampton Island once contained a large portion of the nesting Atlantic brant population, although the current importance is unknown (Figures 1, 2). As well, it has had significant populations of lesser snow geese (*Chen caerulescens caerulescens)* for many decades and currently has high cackling geese (*Branta hutchinsii)* nesting numbers (Baldassarre 2014Batt 1997). Winter indicies of population size over the last half of a century show that brant numbers have fluctuated over the course of this time period (Batt 1997, Figure 3). At low points, midwinter surveys estimated the population at 50,000 brant. However, midwinter surveys since the mid 1980s suggest the population has recovered, and was estimated at around 151,300as recently as 2009 (Baldassarre 2014). More recent data suggest that brant may again be on the decline in the last decade, furthermore, selected breeding grounds show a significant decline in nesting pairs over the last 35 years (Abraham personal communication). Southampton Island, Canada supported a historic nesting colony with 455 nesting pairs of brant in 1979 (Figure 4). However, in 2013 only 70 nesting pairs were recorded (Abraham, personal communication) raising questions as to whether breeding ground limitations are occurring.

Lesser snow goose populations have increased at unprecedented rates the last few decades and consequences of such a growth rate resonate throughout other species. Current estimates show snow goose populations increasing at a rate of 5% of the annual population per year (Batt, 1997). Cackling goose numbers have also increased in the last decade according to midwinter surveys (USFWS 2015). The population explosion of these geese has led to the expansion to previously underused breeding grounds. Southampton Island has supported nesting pairs of lesser snow geese, cackling geese, and brant in recent decades (Abraham and Ankney 1986). Increased levels of snow geese and cackling geese may be detrimental to the later nesting brant. The Arctic Goose Joint Venture produced a strategic plan in 2008 that proposed that the Tall Grass Prairie Population of cackling geese be analyzed from a breeding ground perspective. The committee responsible for this document also recommended that work be conducted on brant breeding grounds to better understand any breeding grounds limitations (Batt 1997). It is unknown whether interspecific interactions between brant and other geese are affecting the breeding success of brant, but it could play a role in shaping how these geese distribute themselves on the nesting grounds (Newton 1998; Van Eerden 1984).

The key to understanding interspecific competition amongst brant, lesser snow geese, and cackling geese is to understand what specific types of competition is/are occurring. In theory, four types of competition could be occurring on the breeding grounds; pre-emptive competition, interference competition, exploitative competition, and apparent competition. I will first broadly define each of these types of competition. Pre-emptive competition occurs when one organism utilizes the territory or space that a different organism also desires. Interference competition occurs when one organism directly hampers the ability of a different organism to gain access to a resource. Exploitative competition occurs when one organism utilizes a resource to the point where it indirectly limits that resource for a different organism. Apparent competition occurs when the abundance of one species draws a shared predator that may be detrimental to a different species occurring in the same area.

Pre-emptive competition could be occurring if snow geese and cackling geese are displacing brant in the preferred nesting habitat prior to brant arrival (Figure 5). Geese are known to display aggressive behavior on their breeding grounds over nesting sites (Akesson and Raveling 1982, Hanson 1953, Gauthier and Tardif 1991, Sedinger and Raveling 1990). Competition, resulting from the acquisition of certain resources, might be the driving force of this aggression. Elevated hormone levels as the breeding season approaches may very well result in aggressive interactions between snow geese, cackling geese, and the later nesting brant (Akesson and Raveling 1982, Hirchenhauser et al. 2000). The key factor in this equation is the later nesting behavior of the brant. If snow geese and cackling geese establish nesting sites prior to the arrival of brant, the likelihood of interactions between the species increases.

Interference competition could occur if snow geese and cackling geese displayed aggressive behavior towards brant during the nesting period, including pre-laying and territory establishment (Figure 5). Baldwin et al. (2011) showed that aggressive behavior in colonies of Ross's geese showed evidence of affecting the nesting success of cackling geese in the same colony. A similar situation could be occurring to brant nesting inside pre-established snow geese or cackling geese colonies. Brant and cackling geese, unlike snow geese, are unable to complete the incubation period without feeding, and cannot rely on fat reserves to supplement feeding (Abraham and Ankney 1980, Eichholz and Sedinger 1999). More time spent off the nest in search of food may result in more detrimental encounters with nearby nesting snow geese or cackling geese.

Exploitative competition could be occurring if brant are nesting in areas that snow geese and/or cackling geese have overgrazed (Figure 5). The gregarious behavior of snow geese resulting in destroyed tundra habitat is well-documented and would be detrimental to other birds nesting in the same area, in this case, brant (Batt 1997; Alisauskas et al. 2012). If local nesting area is overgrazed, brant may stray farther from their nest during incubation to acquire the necessary nutrients to complete nesting. Unfortunately, this exposes the brant nests to greater risks of predation, and might also expose incubated eggs to longer periods of time at a lower temperature, therefore decreasing nesting success (Afton and Paulus 1992). Brant who choose nesting areas that are overgrazed or will be overgrazed throughout the course of nesting may be more prone to abandoning their nest as well.

The final type of competition that may be occurring is apparent competition. This could be occurring if an increase in the snow goose and/or cackling goose population increases predators that also prey on brant and their nests (e.g., shared predators include Herring Gulls, Parasitic Jaegers, and Arctic foxes; Figure 5; McKinnon et al. 2013). More recently, studies have shown that snow geese may be a more prevalent food item for polar bears as well (Iles et al. 2013, Gormezano & Rockwell 2013). If polar bears seek out these nesting birds, goose eggs, or molting birds, it is possible that they may have an effect on the brant populations as well. More predators drawn to molting geese may have an even greater effect on brant, which might still be nesting while other birds have begun to molt, and thus putting their whole clutch at risk.

Study Area

The implications of this study are wide ranging, and affect any and all of the nesting grounds shared by both brant, snow geese, and cackling geese in the eastern Arctic. However, due to limitations, we were only able to conduct work on one geographic location. Previous East Bay goose research was conducted by Thomas Barry (1957), in addition to Kenneth Abraham and C. Davison Ankney (1979, 1980), and Christopher Sharp (2010). As such, previous benchmarks existed regarding the status of geese at East Bay. Researchers in 2010 suggested that cackling geese had surpassed historical averages while Atlantic brant had declined drastically. Banding work began on Southampton Island, Nunavut, Canada in the year 2001, and efforts to assess the population have continued through (Baldassarre 2014, J. O. Leafloor personal communication). The AGJV committee recommended that work be conducted to determine why reproductive success is low on Southampton Island. This, compounded with the fact that Southampton Island hosts a large number of nesting snow geese and cackling geese, makes the island an ideal location for a breeding ground study. A significant percentage of the eastern Arctic population of snow geese nests on Southampton Island (Alisauskas et al 2012). Snow goose broods have been documented all the way from East Bay to the town of Coral Harbor (Batt 1997). However, the main nesting territory of snow geese, brant, and cackling geese that is of interest in my study spans across the East Bay region of the island. This is where I conducted my field work, out of a remote and temporary field camp. The lowland areas in close proximity to the coast are the prime focus of the study, as these areas are the preferential nesting spots of these goose species (Figure 2). I conducted my research in the East Bay Migratory Bird Sanctuary, Southampton Island, Nunavut, Canada, where previous goose studies have occurred (Barry 1956, 1962; Abraham and Ankney 1986). The area extended west to 82.03187°W and east to 81.77023°W (Figure 2). East Bay Migratory Bird Sanctuary is a habitat dominated by ponds and lakes. It includes four general zones: tidal, non vegetative (rock dominated), graminoid [*Carex subspathacea, Dupontia fisheri*] and moss vegetation), and upland (dominated by entire-leaved mountain avens [*Dryas integrifolia,*] and dwarf willow [*Salix reticulata*]) (Ken Abraham, personal communication). At the western limits of the study area, the pond and lake dominated zone extends further inland. The plant community here has been influenced by grazing and grubbing by both lesser snow geese and cackling geese in recent decades (Abraham et al. 2012).

Objectives

1. Document all nests initiated at East Bay, Southampton Island, Nunavut, Canada and compare the composition and density to historical averages from previous research at East Bay.
2. Plot nest locations of brant, cackling geese, lesser snow geese, and Ross's geese in GIS software to better understand how observed changes in density and composition might be introducing interspecific competition to breeding Atlantic brant.
3. Observe and develop time activity-budgets for male and female brant during the incubation period, including female brant on and off the nest. Averages can be compared to detect differences between years.
4. Document snow cover, snow melt, and nest timing/phenology for all goose species at East Bay. The results have implications for the level of competition occurring between East Bay geese and how climate change might impact the nesting phenology.
5. Record mean island size, water depth, and water distance for brant and cackling goose nesting islands at East Bay. Compare these covariates to detect differences in nest-site selection between brant and cackling geese which choose to nest on islands. The absence of nest-site differences may indicate the potential for increased competition between species.

6. Deploy nest cameras to record the fate of brant nests. Nest fates can be used in coordination with a set of covariates in program MCestimate to develop predictive models capable of generating nest-fate probabilities for brant nests.
7. Conduct an artificial nest experiment to assess depredation levels in high goose nest density plots, low goose nest density plots, and control plots (no nests). Develop Kaplan-Meier survival probabilities for geese nesting in these varying regions.
8. Monitor any new Ross's goose colonies as they provide a framework to improve survey methods in the eastern Arctic.
9. Chart the daily presence and absence of all East Bay bird species, including observed arrival and presumed departure.

Management Implications

Populations of Atlantic brant display long-term fluctuations and the current population counts estimate a lower than average brant population. While brant populations have declined in decades past, similar in the way they are declining now, new challenges face the brant that did not exist until recent decades. Populations of lesser snow geese and cackling geese have never been higher and the effect of competition with Atlantic brant is unknown. Arctic geese are dealing with competitors they have never dealt with before. Changing climate trends are altering the arctic landscape in addition to the timing of events such as sea ice melt and snow melt. The environment is changing more rapidly now than it ever has, and it remains to be seen how arctic geese, specifically struggling species like the brant can cope. They face new challenges ranging from increased predator abundance to increased competition from other geese. It is up to wildlife management agencies to unravel this story so they can better understand the vulnerability of the brant population and the factors that most limit the population. As such, it is our duty as field researchers to follow literature-based methods and establish novel methods to assess the breeding success and limitations of the Atlantic brant.

Figure 1 Satellite Imagery of Southampton Island. East Bay is located on the Southeast side of the island. Banding efforts take place on all parts of the island.

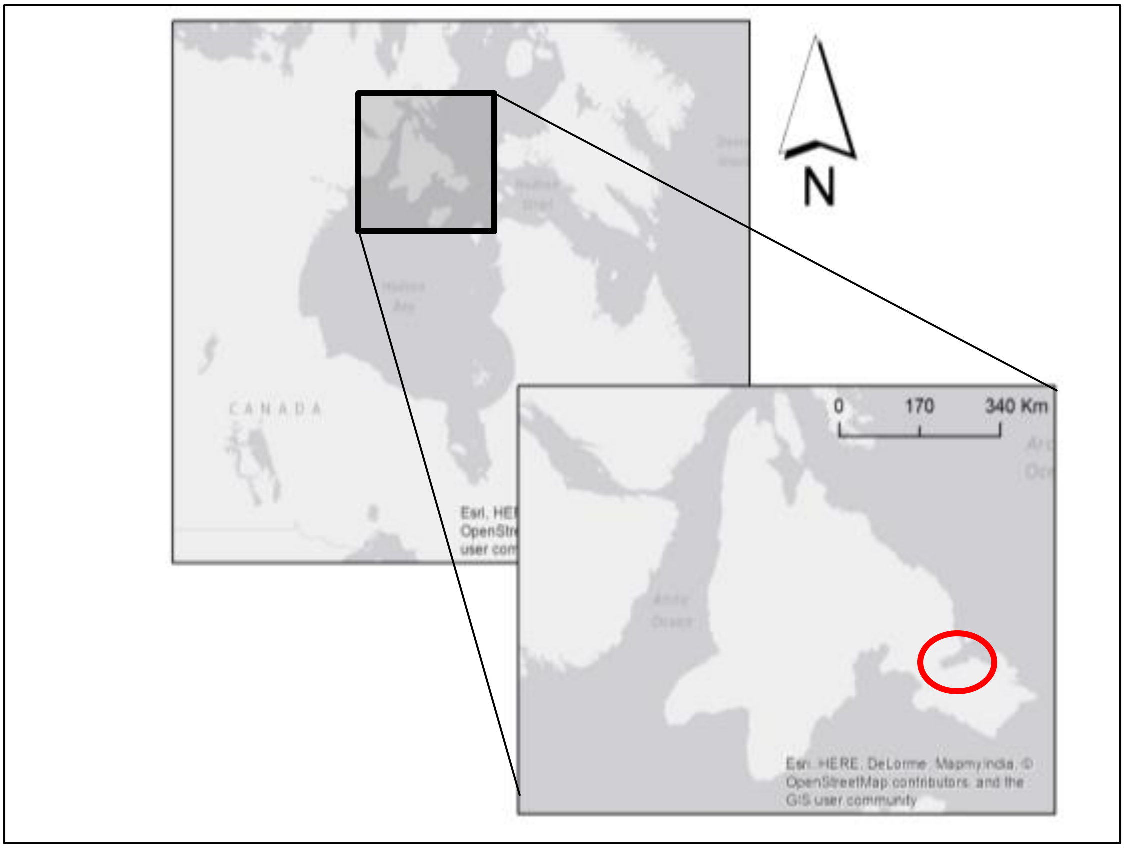


Figure 2 Map of the East Bay study site with a border around the searched nesting area. The border delineates the zone in which most geese nest in at East Bay (tidal line to 1.25 miles inland).

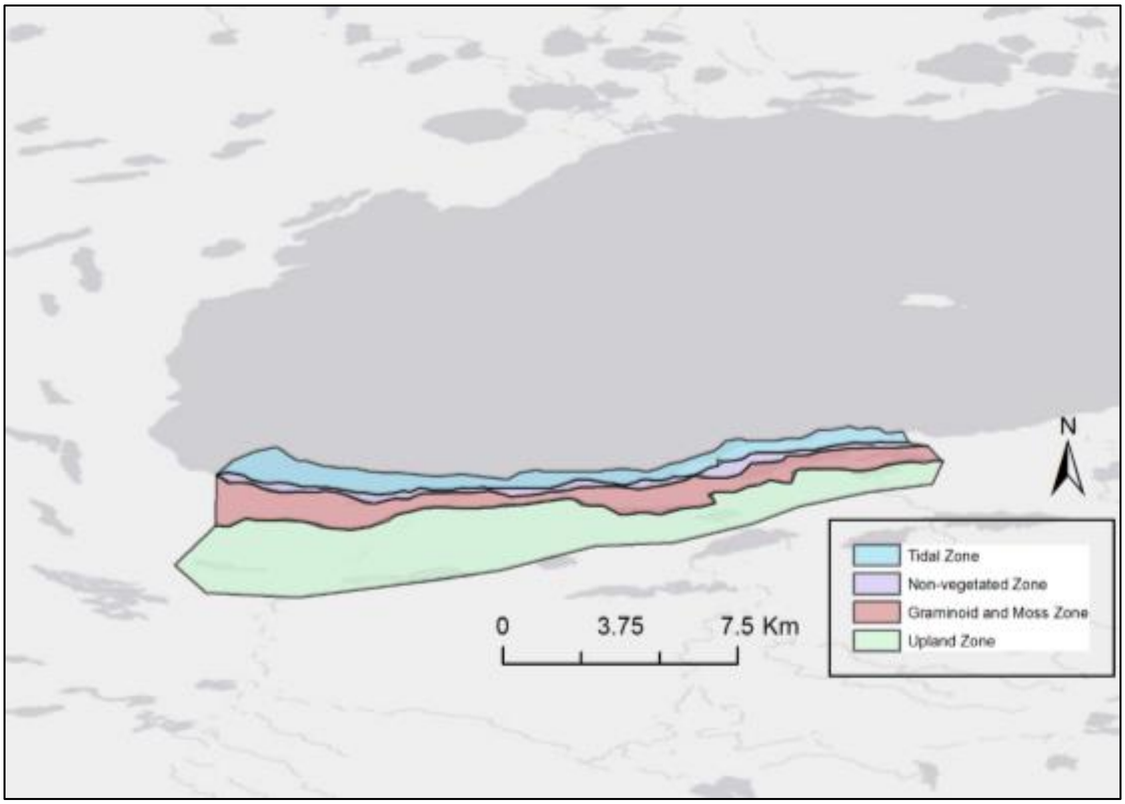


Figure 3 Brant mid-winter survey counts have fluctuated since the beginning of the surveys in 1955. The count reached a low point in 1980, but has since rebounded and remained steady around 140,000 brant.

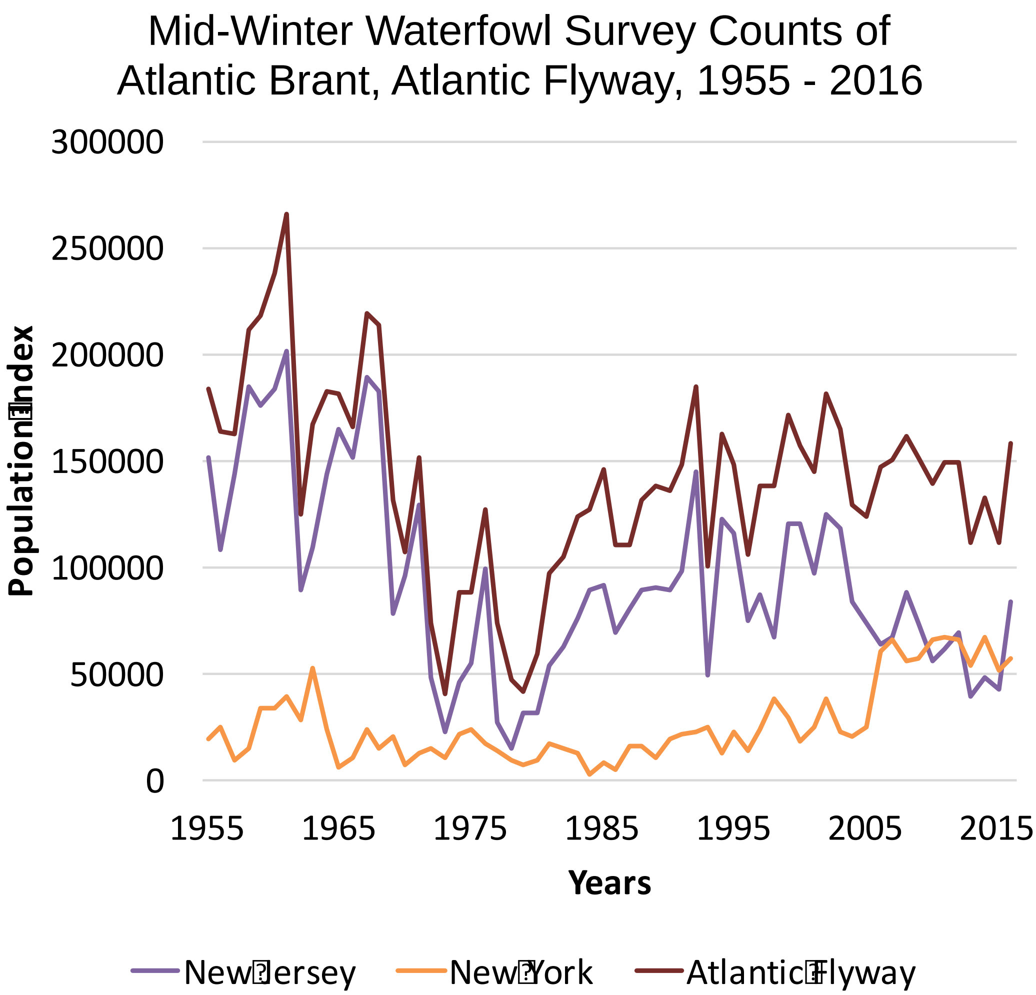


Figure 4 Nesting pairs of brant at East Bay, SHI have declined from a high of 455 in 1979 to a low of 44 in 2014.

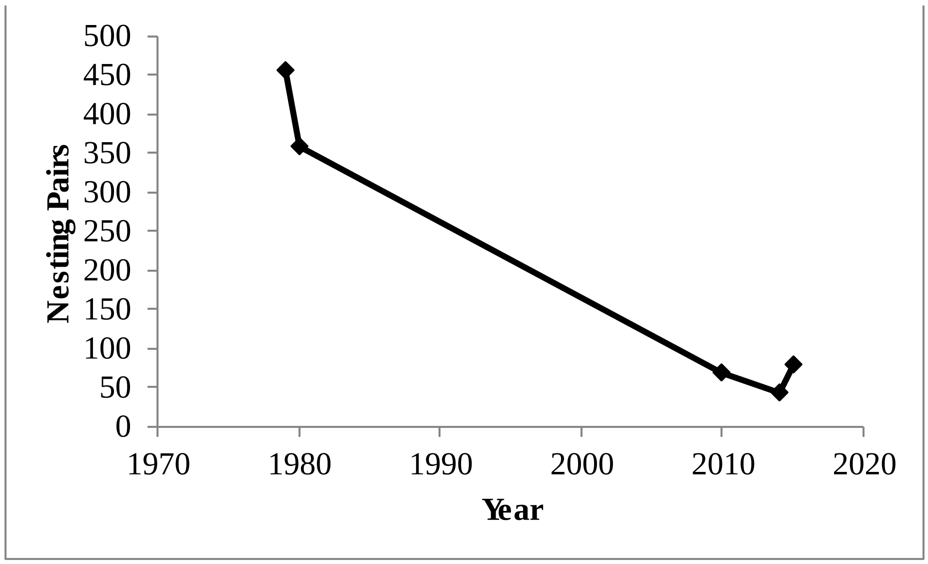
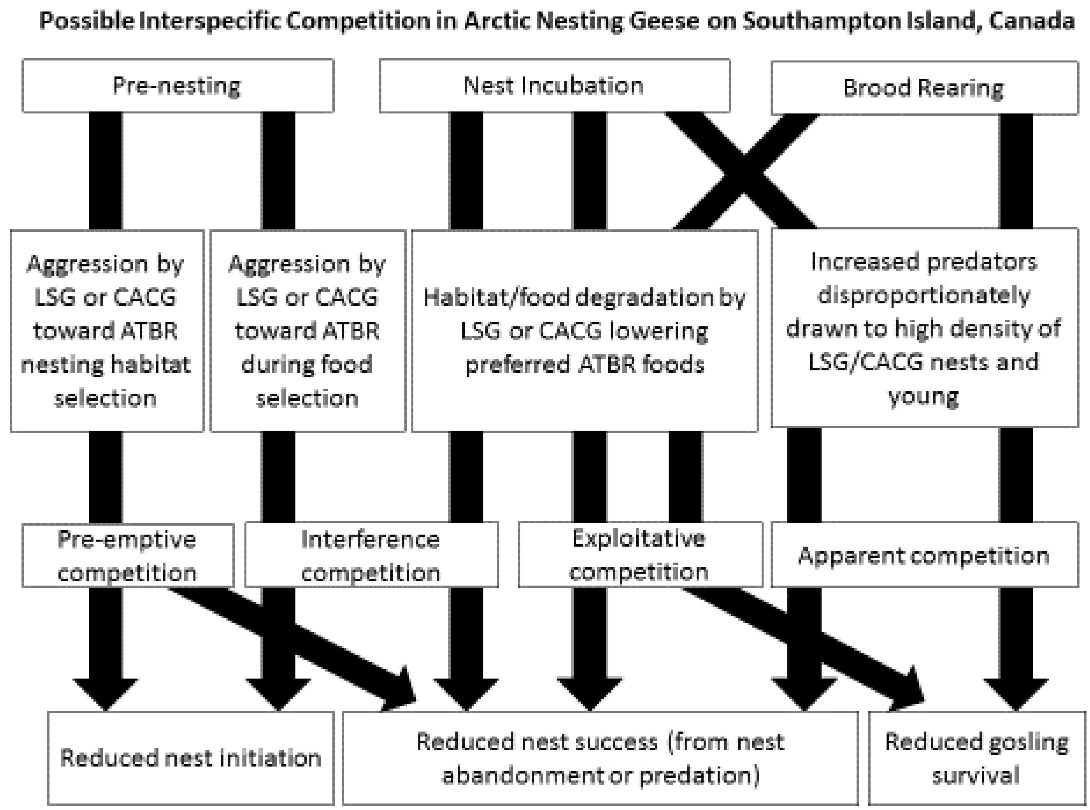


Figure 5 Potential forms of interspecific competition displayed by cackling geese and lesser snow geese with breeding Atlantic brant.



Chapter 2

COULD ARCTIC GOOSE INTERSPECIFIC COMPETITION BE AFFECTING THE NESTING BEHAVIOR OF ATLANTIC BRANT?

Introduction

Atlantic brant (*Branta bernicla hrota*), hereafter brant, is an arctic nesting goose species which primarily nest in the Foxe Basin, Nunavut, Canada and winter primarily in coastal New Jersey and New York, USA. Population estimates from Mid-Winter Survey Counts over the last half century show that brant numbers have fluctuated over the course of this time period (Figure 3); however, over the last 15 years the population has been showing a slow decline of ~20%. Additionally, the Mid-Winter Surveys (MWS) indicate a low percentage of young in flocks exist is recent years (<10% between 2013–2015), indicating breeding ground limitations (Paul Castelli, US Fish and Wildlife Service, personal communication). Moreover, research during the 2010 breeding season on East Bay, Southampton Island (at the southern end of the Foxe Basin) indicated that brant nesting densities were less than 1/5 of their 1979 nesting population (Abraham and Ankney 1986; Sharp personal communication).

Southampton Island's East Bay (located on the southern end of the Foxe Basin), supported a historic nesting colony of brant as well as a significant population of lesser snow geese (*Chen caerulescens caerulescens*) and a small population of cackling geese (*Branta hutchinsii*) (Sutton 1934, Barry 1962, Kerbes 1975, Abraham and Ankney 1986).

However, range-wide lesser snow geese populations have increased from a few million to ~15 million in the last few decades with consequences that resonate throughout other species (Batt 1997). Additionally, the MWS indicates the range-wide cackling goose population has also increased from ~400,000 to ~700,000 in the last 3 decades (USFWS 2015). The population explosion of these geese has led to the expansion on previously underused breeding grounds and raises questions as to whether breeding limitations are occurring in the Foxe Basin and on Southampton Island (Kerbes et al. 2006). Because of the negative correlation between increasing lesser snow geese and cackling geese populations and decreasing Atlantic brant populations, it raises a question as to whether interspecific competition could be affecting the nest site selection, distribution, and incubation success of brant (Newton 1984, van Eerden 1984)?

If interspecific competition is occurring among brant, lesser snow geese, and cackling geese, it is valuable to understand what specific types of competition could be occurring (i.e. pre-emptive, interference, exploitative, and/or apparent). Pre-emptive competition occurs when one species utilizes the territory or space that a different species also desires. Interference competition occurs when one species hampers the ability of a different species to gain access to a resource. Exploitative competition occurs when one species utilizes a resource to the point where it limits that resource for a different species (Schoener 1982). Apparent competition occurs when the abundance of one species attracts a predator that may be detrimental to a different species occurring in the same area with the same predator (McKinnon et al. 2013). Because nest site selection/distribution would most likely be driven be pre-emptive competition while incubation success would most likely be most driven by either direct interference or indirect exploitative competition, I will focus on these three forms in this paper (Madson and Mortensen 1987).

For pre-emptive competition to occur, it requires that one species has access to a resource prior to the other species gaining access to that resource. In the case of arctic nesting geese, nest sites are limited, highly coveted, and well-defended once established (Hanson 1953, Akesson and Raveling 1982, Sedinger and Raveling 1990, Gauthier and Tardif 1991). The arctic climate is highly variable and one year can be vastly different from the next year. These annual changes in seasonal timing often limit and control the timing and success of goose nesting for all species (Dickey et al. 2008). However, some species like lesser snow geese and cackling geese, exercise a risk-reward strategy during the breeding season. Historically, lesser snow geese are the first to arrive on the arctic breeding grounds (~late May, Barry 1956) and cackling geese arrive within a couple days of lesser snow geese (Sharp, personal communication). The risk of arriving early and potentially finding all nesting habitat covered in ice, is negated by the potential reward (if ice melt has occurred) of choosing the first nesting sites, gaining first access to foragable plants, and thus getting through the nesting cycle and migrating south before cold weather returns (Barry 1962, Cooke et al. 1984). Atlantic brant, arrive to the Foxe Basin approximately 2 weeks later due to their small size and multiple refueling stops along the migration. However, this evolutionary outcome creates its own risk-reward strategy that assures that brant will arrive with the majority of snow and ice melted to assure food is available upon landing. The negative consequence is they are the last geese to choose nesting sites. While snow geese prefer to nest in more upland habitat, cackling geese share similar coastal nesting habitat with brant (Nissley et al. 2016) thus increasing their likelihood of exhibiting pre-emptive competition on brant. It is likely that at one point, cackling geese did not overlap with brant nesting habitat at East Bay and may have occupied a preferred niche. However, expansions in the population at East Bay may have altered the ability of cackling geese to nest in their preferred niche-space. For this reason, we will consider cackling geese rather than snow geese when analyzing pre-emptive and interference competition at East Bay. Additionally, the 2-week gap between the arrival of cackling geese and brant allows the cackling geese to gain a selective advantage when choosing nest sites as long as site become available prior to brant arrival. However, if late snow/ice melt prohibits early arriving cackling geese from accessing nesting sites, then late arriving brant will have an increased chance of simultaneously finding melted nesting sites. This evolutionary gamble with the weather pays off in some years and not others for the cackling goose and Atlantic brant. If this logic is supported, the implications of increasing climate warming will theoretically harm the long-term success of the brant unless they shift their migration timing.

Direct interference competition could occur if cackling geese exhibit aggressive behavior towards brant during the nesting period. Baldwin et al. (2011) showed that Ross's Goose aggressive behavior in mixed colonies affected the nesting success of cackling geese in the same colony. A similar situation could be occurring to brant nesting inside pre-established cackling goose (or snow goose or Ross's goose) colonies.

Indirect exploitative competition could also be occurring if food resources are being reduced by the large goose colony (additively from all four species of locally nesting geese). Brant and cackling geese, unlike snow geese, are unable to complete the incubation period without feeding, and cannot rely solely on fat and protein reserves so they must supplement them by feeding (Ankney 1984, Eichholz and Sedinger 1999). More time spent off the nest in search of food may result in increased nest predation or stressful aggressive encounters with nearby nesting snow geese or cackling geese.

To measure pre-emptive competition, it is necessary to quantify nest site selection in the presence and absence of competing species. To measure interference and exploitative competition, it is necessary to quantify behaviors in the presence and absence of competing species is. Naturally, finding arctic goose colonies in isolation (thus quantifying a control "no-competition" system) is logistically challenging. However, between the summers of 2014 and 2015, the weather created a natural Before-After-Control-Impact (BACI) design to test for impacts of potential cackling goose/snow goose competition on Atlantic brant. In 2014, complete snow melt occurred by 12 June but in 2015, it did not occur until 28 June. Thus in 2015, early nesting snow geese and cackling geese struggled to establish nests (and it was noted some of the geese left the study area) thus potentially reducing competition with late arriving brant. Therefore, I had the opportunity to quantify nest site selection/distribution and nest incubation behaviors in an average or high abundance snow goose/cackling goose year (2014) versus a low abundance year (2015) to quantify how this could influence possible pre-emptive, interference, and exploitative competition with Atlantic brant. Additionally, abundance and nest distribution data were collected in 1979, 1980 and 2010 to also qualitatively evaluate possible long-term trends in pre-emptive competition (Abraham and Ankney 1986, Ken Abraham and Chris Sharp, unpublished data, personal communication). Correctly assessing and identifying the forms of competition occurring at East Bay is crucial to better understanding the potential breeding limitations apparently being experienced by brant on a local scale and possibly breeding range-wide scale.

Study Area

We conducted our research in the East Bay Migratory Bird Sanctuary, Southampton Island, Canada, where previous goose studies have occurred (Barry 1956, 1962, Abraham and Ankney 1986). The area extended west to 82.03187°W and east to 81.77023°W (Figure 6). East Bay Migratory Bird Sanctuary is a habitat dominated by ponds and lakes. It includes four general zones: tidal, Non vegetative (rock dominated), graminoid [*Carex subspathacea*, *Dupontia fisheri*] and moss vegetation), and upland (dominated by entire-leaved mountain avens [*Dryas integrifolia*,] and dwarf willow [*Salix herbacea*]) (Ken Abraham, personal communication). At the western limits of the study area, the pond and lake dominated zone extends further inland. The plant community here has been influenced by grazing and grubbing by both lesser snow geese and cackling geese in recent decades (Abraham et al. 2012).

In order to classify nesting habitat, we walked transects at the end of the 2014 field season to draw a distinction between the vastly different habitat types at East Bay. While the elevation gradient is minimal as one moves inland, it can have a profound effect on the vegetation community and surrounding habitat that occupies that nesting region (Abraham personal communication). To separate these different types of habitat, crew members walked a line at the transition zones between habitat types with the GPS units tracking their every step. These zones were then projected across the study region in ArcMap to better define the nesting regions at East Bay.

Methods

I arrived by means of a DeHavillan Twin Otter aircraft on skis in mid-late May 2014 and 2015 prior to the arrival of geese. I catalogued the arrival of all bird species throughout the field seasons. These lists can also be used to compare and contrast the phenology of geese with respect to changes in snow cover and nest habitat availability.

Quantifying Nest Site Selection

To determine goose densities at East Bay, I conducted nest searching once snow geese and cackling geese were ~4 days into incubation. The systematic nest searches were done first in upland regions where early nesting snow geese establish nest sites and slowly transitioned towards the coast where cackling geese and brant establish nest sites. Once an area was systemically searched using GPS technology to map and plot the study region, the searched area was not searched again for $\geq$ 1 week to limit disturbance. High density areas were often searched twice and areas with overlapping species (i.e. cackling geese, snow geese, and brant nesting in close proximity) were given priority in second pass search efforts. Historically, in 1979 and 1980, the study area was segmented into blocks and nests were searched without the aid of GPS technology (Abraham and Ankney 1986). Field crews in both 2014 and 2015 expanded the searched area from the head of East Bay stretching 12 km east to west and encompassing a 12 x 2 km study area (Figure 6).

When the crew located nests during the laying and incubation period, the crew marked the nest with a unique identifying number on a popsicle stick and placed it in the ground 1 m north of the nest. I recorded species, latitude/longitude, and habitat type (salt/brackish marsh, freshwater marsh, pond/stream/lake edge, upland). I also recorded information about the clutch including number of eggs, the maximum length and width of all eggs, and the age of the clutch via floating or candling (Cooper and Batt 1972). I collected clutch information on every brant nest but I was time and logistically constrained to collect only every forth cackling goose and snow goose nest. After I collected data in an efficient manner (to allow the female to return as soon as possible), I covered the nest with down to reduce chances of drawing the attention of nest predators.

Using ArcMap 10.2 (ESRI 2013), I digitized and mapped the nesting locations of all cackling geese and brant from 1979, 2010, 2014, and 2015. All marked nests with GPS coordinates were utilized in the analysis (Sharp personal communication). Behavioral scans indicated that brant are often willing to travel several hundred meters from their nests during incubation breaks; however, the average distance traveled revealed that females generally travel 100 m from their nest to feed. Assuming that cackling geese and snow geese on average travel shorter distances to satisfy energetic requirements, I created 200 m diameter buffers around each nest in ArcMap to replicate the ideal goose home-range. I therefore made the assumption that goose home ranges will overlap when nests are < 200 m of each other. This in turn allowed us to look at the proportion of brant nests that potentially shared home-ranges with both other brant in addition to cackling geese nesting in the region. Using ArcMap, and using the "nearest neighbor" tool (ESRI 2013), I generated home-ranges for all brant from the years 1979, 2010, 2014, and 2015. I then calculated the proportion of brant with cackling geese in their home-ranges for each year and the proportion of brant with other brant in their home-ranges each year. The resulting proportion represents an index of density of cackling geese and brant at East Bay. I further compared the proportion of brant with ≥ 2 brant nests within 200 m and the proportion of brant nests with ≥ 2 cackling goose nests within 200 m over the 4 time intervals.

In addition to calculating densities to understand how abundance and neighbor interactions may have changed over the last 35 years, I also used the data to generate a proportion of 2014 brant nest sites that were occupied by 2015 cackling geese. This was done in the same manner, assuming that brant home-ranges were ~200 m. I projected the 2015 cackling goose nests onto the 2014 Atlantic brant nests to determine what proportion of Atlantic brant home ranges were occupied by cackling geese in a sequential year.

Behavioral Scans

After the successful completion of nest searching, crew members focused on conducting incubation period behavioral scans beginning on 21 June in summer 2014 and

30 June in summer 2015. Scans were only conducted on incubating Atlantic brant. After a brant nest was discovered and processed, the nest was left alone for ≥ 4 days of incubation initiation before a blind was stationed near the nest for observation. Crew members placed 1.5m x 1.5m x 1.5m camouflaged pop up tent viewing blinds 150–300 m away from the brant nests depending on the visibility of the nest, proximity of neighboring nests, and the quality of the available optics. The blinds were secured with ropes and rocks and placed in a fashion that would effectively reduce any impact of the blind on brant feeding activity.

Observers arrived at a randomly pre-determined blind site, established or reoccupied the blind and allowed 30 minutes of acclimation by the nesting pair before initiating a focal scan. Additionally, observation periods were randomly distributed throughout the day, although most occurred between 06:00–18:00. Before the first scan, observers recorded temperature and weather conditions and also noted any weather changes throughout the scanning period. Observers always recorded the female's behavior first and then located and recorded the male's behavior. If the observer was only able to observe one of the birds in the pair, the observer would spend adequate time attempting to locate the other bird in the pair before beginning the scan with only the single mate. If both male and female were absent during the scan period, the scan was skipped and the birds were located in time to begin the next scan. Behaviors were recorded every 20 seconds within a 5-minute focal scan. When females were on the nest, the focal scans occurred every 15 minutes for variation in sampling. When females were off of the nest, the scans occurred continuously until the female returned to the nest. This was done because indirect exploitive competition is most likely going to affect the amount of forage available and thus the time it takes for the female to achieve caloric needs during the nest break. Thus paying extra attention to the behavior of females feeding off the nest is important, i.e. it was desirable to record full off-nest (recess) times and proportion of foraging time during each recess. If 15 minutes were allotted between scans, observers would likely have only captured only one focal scan while the female was off her nest thus not capturing a true representation of the behavior of the female during her incubation break. These scans were initiated as soon as the female brant left her nest, regardless of whether or not 15 minutes had passed from the time the previous focal scan had been conducted. Observers could choose from 10 behaviors: feeding, resting, walking, flying, swimming, alert, nest construction, preening, predator interaction, and agonistic. Behaviors were later combined into more broad categories to simplify the data for analysis. For male brant and female brant off the nest, swimming and walking were combined, and agonistic behavior was combined with predator interactions. Female brant on the nest did not require any combination of categories because of the limited behavior of females while incubating. Fifteen minute and off nest scans were continued until 2.5 hours had passed. The 2.5 hour observation period and was considered the sampling unit and behaviors were averaged within this period. If the next randomly identified nest focal scan was on the same nest as the previous scan, the observer waited 30 minutes before beginning the next scan to promote independence of scans. Once a scan session was completed, field crew members vacated the blind site, leaving only the blind behind.

To identify behavioral changes that may have occurred between the 2014 and 2015 breeding season, Iused a non-parametric Kruskal-Wallis test (α = 0.05) (SPSS). The Kruskal-Wallis test is appropriate because behavioral proportion data are non-normally distributed and exhibit skewness and kurtosis (Khan and Rayner 2003, Livolsi 2014). Three assumptions must be met in order for the Kruskal-Wallis test to be valid: 1) observations are independent from one another, 2) observations within treatment groups originate from the same population, and 3) treatment group populations have similar distributions (Kruskal and Wallis 1952). The only one of these assumptions in question is whether observations were independent of each other; however, the proportions of the same behavior between different scans is considered to be unrelated and thus this assumption is not violated. Our incubation behavioral scans satisfy both the assumption that observations within treatment groups originate from the same population and the assumption that the treatment groups have a similar distribution.

Results

Snow geese and cackling geese arrived 25 May 2014 and 21– 22 (respectively) May 2015. Brant arrived on 9 June in summer 2014 and 8 June in summer 2015 (Figure 7). Snow cover at East Bay was monitored daily in both 2014 and 2015 from the time of arrival until all snow had melted (Figure 7). Snow melt in 2014 occurred much faster than snow melt in 2015. In 2014, snow cover reached 0% by 12 June, while in 2015 snow cover did not reach 0% until 28 June. Thus there was a significant difference in nest initiation in summer 2015 compared to summer 2014 (Figure 7). The difference was more pronounced in early nesting snow geese and cackling geese. The peak initiation for snow geese was 2 June in 2014, but 14 June in 2015. Following a similar pattern, the peak initiation for cackling geese was 6 June 2014 and 19 June 2015. Brant had a less pronounced delay, peaking on 18 June 2014 and 22 June 2015 (Figure 7). To confirm that peak initiation dates were not a product of nest search effort, but a product of a delay in nest initiation by geese, I also calculated the peak hatch for all species and found similar results. Between 2014 and 2015, the peak hatch was 12 days later for snow geese and 11 days later for cackling geese (Figure 7). Similar to the smaller delay in peak initiation, the brant's delay in the peak hatch was only 5 days later in 2015 compared to summer 2014.

Results of nest searching in the summer of 2014 and 2015 showed a marked increase in cackling geese, a decrease in snow geese, and a large decrease in brant compared to 1979 (Table 1). Importantly, the significant reduction in initiated nests in cackling geese (from 570 in 2014 to 355 in 2015) and snow geese (from 230 in 2014 to 48 in 2015) and an increase in brant nests (from 44 in 2014 to 78 in 2015) was caused by a significantly later snow melt in 2015.Imapped the nests in ArcMap and projected them on the habitat zones as depicted by the transect lines (Figures 8 and 9). While Atlantic brant and lesser snow geese overlapped in their nesting habitat in 1979, between 2010–2015 their nesting habitat appeared to be segregated between the upland (snow geese) and the graminoid/moss zones (brant) (Figure 8). In 1979, cackling geese nesting sites overlapped with brant in the graminoid/moss zone, however there were only 35 cackling goose nests present. By 2010–2015, cackling geese populations at East Bay increased and appeared to almost drive a wedge between Atlantic brant and lesser snow geese populations thus overlapped with brant nesting regions and pushing snow geese further upland and to the west.

Using the identified nests, I calculated a proportion of nests within brant home-ranges (Figure 10). In 1979, 88.5% of Atlantic brant had at least 2 other brant nests within 200 m of their nest (assumed home-range overlap). By 2010 that number decreased to 18.4% and further declined to 13.6% in the 2014 breeding season, but rebounded slightly to 26.9% in the 2015 breeding season. In contrast, in 1979 only 5% of Atlantic brant had at least 2 or more cackling goose nests within 200 m of their nest. By 2010, that number increased to 46.1% and dipped slightly in 2014 to 40.9% overlap. In 2015, due to the lower number of cackling goose nests, only 16.7% of brant nests included 2 or more cackling goose nests within 200 m. Even though there were a lower number of nesting cackling geese in 2015, I still found 39% of 2014 brant home ranges were occupied by a cackling goose nest (< 200 m) showing the strong overlap in preferred habitat.

Kruskal-Wallis tests revealed significant differences between male and female brant behaviors between 2014 and 2015 (Table 2). Male brant spent less time feeding in 2014 vs. 2015 (23.3 ± 3.2% vs. 33.4 ± 3.1%, $P= 0.01$) as well as less time engaged in locomotive behaviors (swimming/walking) (1.2 ± 0.3% vs. 4.3 ± 0.9%, $P < 0.01$). Females were separated into two categories: females on the nest and females off the nest. Females on the nest spent more time alert in 2014 vs. 2015 (17.0 ± 3.0% vs. 4.1 ± 0.3%, $P < 0.01$). Females on the nest also spent more time engaged in nest construction behavior in 2014 vs. 2015 (2.3 ± 1.1% vs. 6.9 ± 0.2%, $P < 0.01$). Females off the nest in

2014 vs. 2015 spent less time feeding (73.8 ± 4.3% vs. 89.6 ± 1.4%, $P < 0.01$) and less time flying (1.4 ± 0.4% vs. 3.1 ± 0.6%, $P < 0.01$), but more time alert (11.7 ± 2.2% vs. 2.9 ± 0.6%, $P < 0.01$) and more time preening (5.4 ± 1.4% vs. 1.2 ± 0.4%, $P < 0.01$).

Discussion

With only 2 years of data collected at East Bay, it is difficult to definitively make conclusions about the level of pre-emptive, interference, and exploitative interspecific competition between Atlantic brant, cackling geese, and lesser snow geese. However, strong patterns emerged that seem to indicate certain types of interspecific competition have affected shifts in the density and distribution of geese at East Bay as well as affect the behavior of nesting Atlantic brant. Because of the fortuitous natural BACI design associated with late snow melt affecting nesting of lesser snow geese and cackling geese between 2014 and 2015, I was given the opportunity to observe brant nesting distributions and behavior in average vs. low cackling and snow goose population years.

One noticeable difference between summer 2014 and summer 2015 was the 2-week gap in nest initiation and peak hatch for the early nesting snow and cackling geese. This gap was driven by snow melt. In summer 2014, snow cover was already diminishing at a fast rate by the time the snow geese and cackling geese arrived at East Bay; but in 2015, the snow cover lasted significantly longer and early nesting geese were unable to nest upon arrival. These early nesting geese take a calculated gamble when making the choice to show up on the breeding grounds before other birds and gain access to the first available food and nesting resources (Barry 1962, Cooke et al. 1984). In 2015, when these geese arrived, they searched for any patch of available habitat to simply feed, utilizing fat and protein reserves to sustain themselves. This notable delay in snow melt and increased snow depth until nearly the second week of June 2015 resulted in disastrous nesting conditions and, as a result, many of these geese likely forewent nesting. Only 48 snow geese and 355 cackling geese successfully initiated nests within the study area in summer 2015 as opposed to 230 and 570, respectively, in summer 2014. Similarly, Abraham and Ankney (1986) observed a late summer in 1980 which resulted in an 88% reduction in nesting effort for lesser snow geese.

While early snow melt had positive consequences for snow and cackling geese, Atlantic brant become limited by their late nesting evolutionary strategy. In 2014, brant arrived at East Bay with hundreds of geese already having established nest sites and making it difficult to find high quality habitat that was not already being defended by cackling or snow geese. As a result, brant likely suffered from increased pre-emptive competition and reduced nest initiation. If these results were common across the Arctic breeding ground, then it is possible this affected the lower mid-winter survey population estimates in 2014-2015. However in 2015, when the other geese species were being limited by late season snow melt and nesting habitat conditions, the late arriving brant were less affected. Between years, brant experienced a short delay in nest initiation of only 4 days, holding out until the majority of snow had disappeared from the East Bay landscape. Not only were brant less impacted by the late snow melt, they also faced a nesting landscape with fewer neighbors to compete with. As a result, brant initiated 78 nests in summer 2015, nearly doubling their effort from the 2014 breeding season when densities of cackling geese and snow geese were high at East Bay. If these results were also common across the Arctic breeding ground, then it is possible this affected the higher mid-winter survey population estimates in 2015-2016.

In 1979, the risk/reward of arriving late may have had lower stakes for brant because lesser snow geese were the main competitor at East Bay (Abraham personal communication, Abraham and Ankney 1986). Lesser snow geese are nesting in upland locations (Nissley et al. 2016) and not exhibiting the same degree of pre-emptive or interference competition as a cackling goose might. Since the 1970's, cackling goose populations have risen across the continent on the wintering grounds and breeding grounds (USFWS 2015), and East Bay is no exception. These cackling geese increased in density in brant inhabited regions; consequently making the risk of arriving late to the breeding grounds much more costly for Atlantic brant. The evolutionary strategy of brant has not changed, but the density of cackling geese at East Bay has, thereby altering the interspecific competition dynamic brant must deal with on proximal scale, i.e. a yearly basis.

A complicating issue to the timing of nesting and weather conditions is the increasing global temperature trends (Solomon 2007) which may be exacerbating the breeding patterns and competition displays of these geese. If warming trends continue and global surface temperatures continue to increase, I hypothesize the implications will be felt by arctic nesting geese. Timing of arrival, nest initiation, and hatch is a risk/reward evolutionary strategy developed by these geese to deal with the extreme nature of the arctic and the limited window the geese have to breed. There are also advantages to be gained by nesting in the arctic, such as reduced predation during the pre-nesting, incubation, and brood-rearing periods (McKinnon et al. 2013). How these geese can adapt to global climate change and what plasticity in their nesting cycle they are capable of is yet to be seen for all arctic nesting species. However, our research at East Bay exemplifies the impacts that warm summers can have on the late nesting Atlantic brant. If early and warm summers increase, the brant will be forced to adapt or decline due to increased competition and a breeding strategy that is unfit for the changing environment. The brant, much like more iconic species (e.g. polar bears, Stirling et al. 1999), may very well be an indicator species for climate change. Recognizing the effects of this change on the brant population is imperative to understanding the short-term success of East Bay brant and long-term success of the entire Atlantic brant population.

In addition to the pre-emptive competition association with nest initiation and distribution, direct interference or indirect exploitative competition may be affecting brant success. Behavioral scans revealed that brant behave differently when cackling geese nest in high density as opposed to when cackling geese are at a lower density at East Bay. For male brant at East Bay, more time was spent feeding in a late year when there were fewer cackling goose neighbors. Males with more time to feed are likely more fit throughout the breeding season and more capable of defending the nesting female and her nest from predators and other geese. While the energetics of male brant have not been compared in such an instance, it may be a question that can be answered following a similar design protocol as Ankney (1984), in which brant are collected at critical points during the nesting season (i.e. pre-nesting, incubation, pre-molt, post-molt) to analyze the physiological composition (i.e. fat content, protein content, etc.), while also taking into account seasonal variability. In turn, incubating females on their nest spent less time alert when cackling geese were at a lower density and spent more time performing nest maintenance. This suggests that in low competition years, brant are possibly less stressed defending against predators and/or aggressive cackling geese (exhibiting interference competition) and can devote more time to maintaining their nest. These same females also spent more time flying and feeding when the cackling goose density was low. The home-range of these brant contained fewer cackling geese, meaning brant were less likely to infringe upon the home-range of cackling geese when venturing out on feeding breaks. In addition, when cackling geese were at a higher density, brant females spent more time alert when off of the nest. The behavioral changes in both male and female brant when cackling geese are at a higher density are behavioral changes indicative of stress and reduced fitness during a crucial period of the brant breeding cycle. While cackling goose density is the variable of interest, it cannot be solely implicated for the changes in brant nesting behavior. I can only speculate that these changes are in part due to the fluctuations in cackling goose density. While I do not feel I can tease apart interference and exploitative competition, if brant nesting behavior is largely dependent on cackling goose density, then it makes a very strong case that some combination of these factors is affecting brant success at East Bay.

Exacerbating the observed yearly interspecific competition, brant also exhibit high fidelity to their nesting sites and likely will return within a few hundred yards of the previous year's site (Lindberg and Sedinger 1997, Sedinger et al. 2008). Thus a negative feedback loop likely could drive brant to local extinctions. Even in summer 2015, when brant faced less competition from cackling geese, our efforts showed that cackling geese still occupied 39% of the 2014 brant nesting sites. Therefore, any brant returning to the same nest site as the previous summer faced the uphill battle of establishing a nest site within 200 m of an already established cackling goose nest. Not only could this spell disaster for brant in terms of competition, but it also means that cackling geese were very likely given choice to the preferred nesting habitat in that region. For brant, if they are relegated to second choice in nest sites and increased competition from cackling geese, even in a year evolutionarily tailored for the brant (i.e. 2015), they face steep challenges on the nesting grounds at East Bay.

One of the complicating factors in the East Bay competition story is the change in brant densities over the last 35 years (Abraham and Ankney 1986, Sharp personal communication) and the repercussions of the reduced densities of brant. East Bay brant once enjoyed high densities and potentially experienced benefits as a result of those high densities. Cooperative nest defense among brant to deter herring gulls during the laying period was likely among the greatest benefits (Barry 1956, Abraham personal communication). In 1979, 88.5% of brant had at least 2 other brant nests within 200 m of their nest. However, this number declined to 18.4% in 2010, 13.6% in 2014, and 26.9% in 2015. Brant are now scattered across the study zone, but do seem to nest in pockets. These pockets do not possess the density of the brant nesting establishments 35 years ago, and therefore cooperative nest defense is likely weak. As a result, brant are more susceptible to avian predation during the laying period and they are more susceptible to all predators looking for an uncontested fight while depredating a nest. Low nest density has been shown to be correlated with higher arctic fox depredation in goose colonies (Anthony et al. 1991). Brant nesting in small colonies (modern East Bay brant) are more susceptible to this arctic fox depredation than are those nesting in large colonies (1979 East Bay brant) (Raveling 1989).

The dynamics of nesting have changed at East Bay, but the evolutionary strategy of the Atlantic brant has not. I hypothesize that cackling geese have been a negative impact on East Bay brant, and mounting evidence supports this assertion. I encourage future researchers to identify other nesting colonies across the brant range that may have different densities of cackling goose before final conclusions implicating the cackling goose can be made.

Table 1 Number of goose nests found by species at East Bay, Southampton Island, Canada, 1979–2015.

Goose Species	**1979**	**2010**	**2014**	**2015**
Cackling goose	35	411	570	355
Lesser snow goose	605	259	230	48
Atlantic brant	455	76	44	78

Table 2 Non-parametric Kruskal-Wallis test used to test differences in incubation behavior between years in nesting Atlantic brant at East Bay, Southampton Island, Canada, 2014 and 2015. Mean values represent proportion of time spent on activity.

		2014		2015			
Sex	Behavior	Mean	SE	Mean	SE	H Statistic	P
Males	Feeding	0.233	0.032	0.334	0.031	6.654	0.010
	Resting	0.183	0.029	0.173	0.032	0.008	0.930
	Flying	0.011	0.003	0.010	0.002	0.152	0.696
	Swim/walk	0.012	0.003	0.043	0.009	20.946	<0.001
	Alert	0.496	0.036	0.409	0.034	1.762	0.184
	Agonistic/pred	0.019	0.004	0.012	0.003	0.652	0.419
	Preening	0.046	0.008	0.021	0.005	1.859	0.173
Females on nest	Feeding	0.020	0.016	0.001	0.000	1.835	0.176
	Resting	0.741	0.034	0.823	0.005	2.320	0.127
	Alert	0.170	0.030	0.041	0.003	21.074	<0.001
	Nest construction	0.023	0.011	0.069	0.002	24.861	<0.001
	Preening	0.045	0.008	0.065	0.002	2.262	0.133
Females off nest	Feeding	0.738	0.043	0.896	0.014	10.499	0.001
	Resting	0.001	0.001	0.003	0.002	0.834	0.361
	Flying	0.014	0.004	0.031	0.006	7.672	0.006
	Swim/walk	0.033	0.013	0.014	0.004	0.055	0.815
	Alert	0.117	0.022	0.029	0.006	15.490	<0.001
	Nest construction	0.037	0.024	0.012	0.005	0.037	0.848
	Agonistic/pred	0.005	0.004	0.002	0.001	0.002	0.966
	Preening	0.054	0.014	0.012	0.004	7.481	0.006

Figure 6 Study area located on East Bay, Southampton Island, Canada.

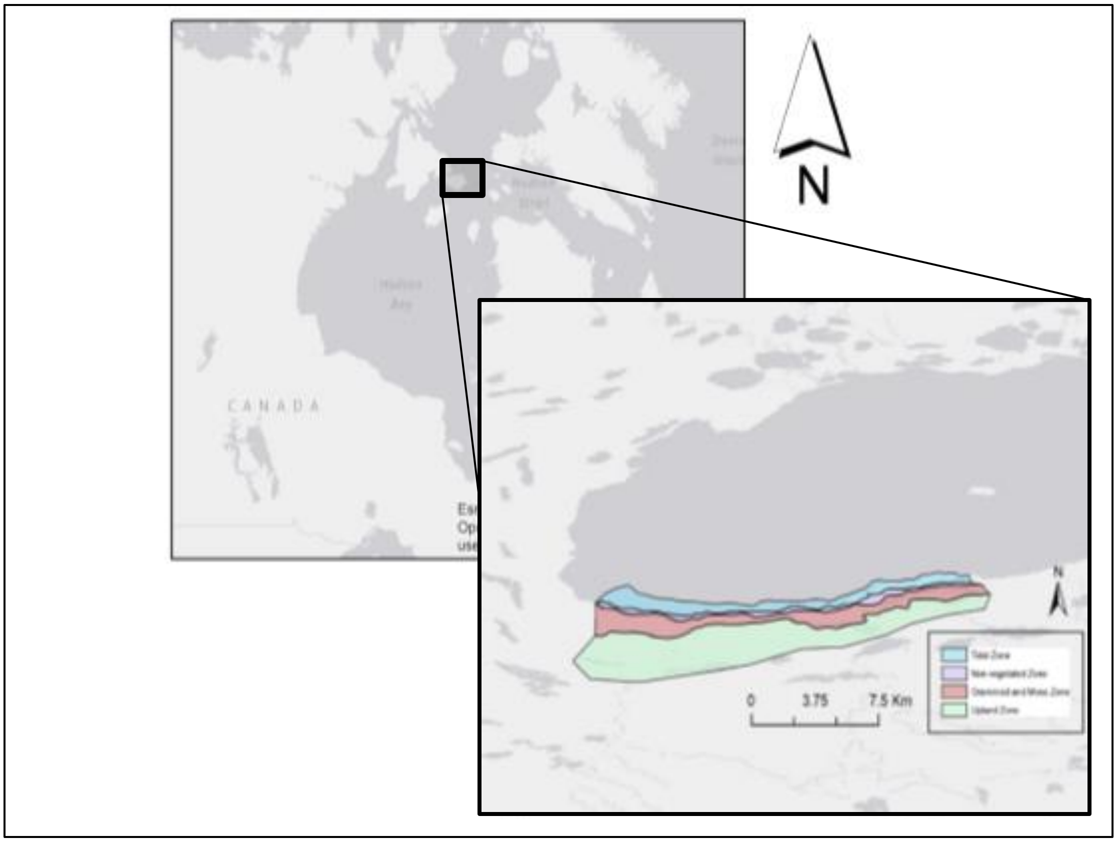


Figure 7 Snow cover, goose arrival, and peak nest initiation at East Bay Southampton Island, Nunavut, Canada in summer 2014 and summer 2015.

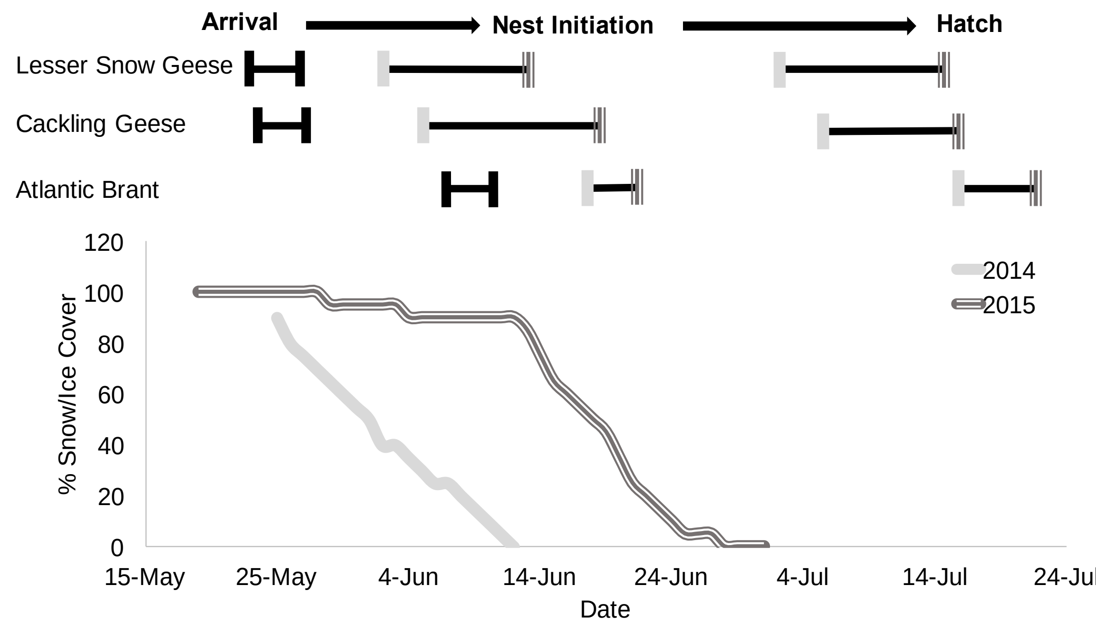


Figure 8 Atlantic brant (yellow) and lesser snow goose (blue) nests at East Bay, Southampton Island, Canada 1979–2015.

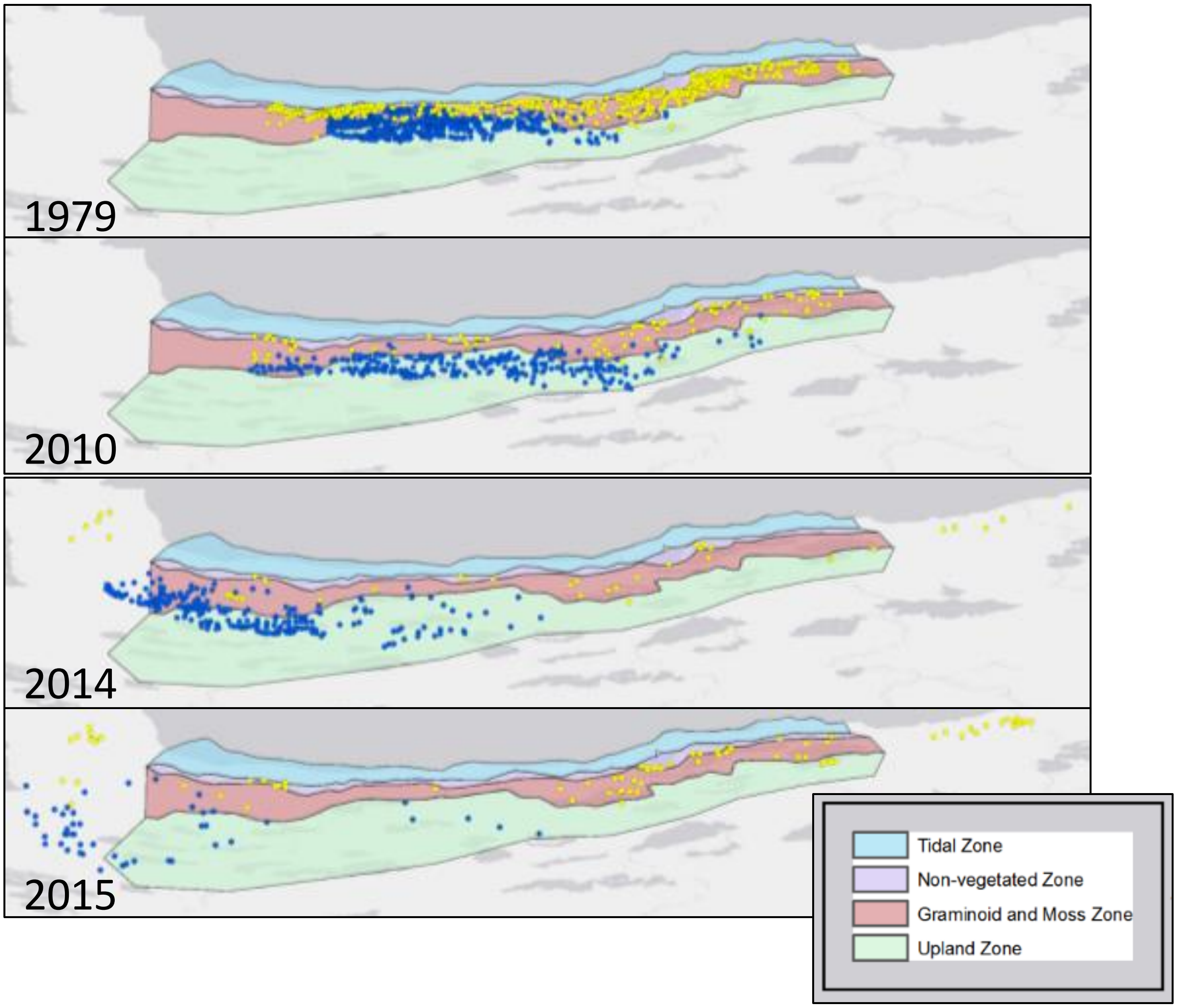


Figure 9 Atlantic brant (yellow) and cackling goose (green) nests at East Bay, Southampton Island, Canada 1979–2015.

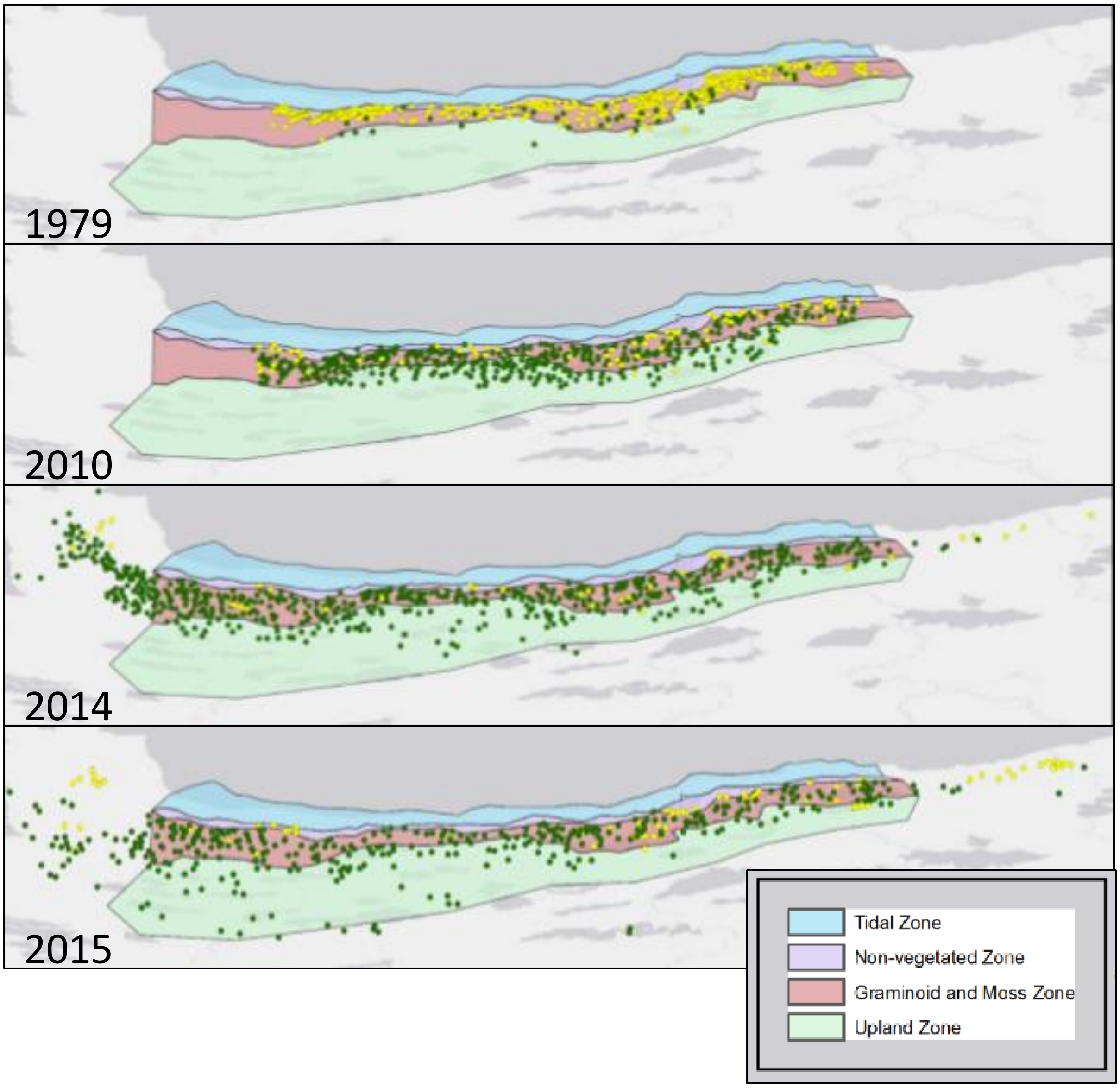
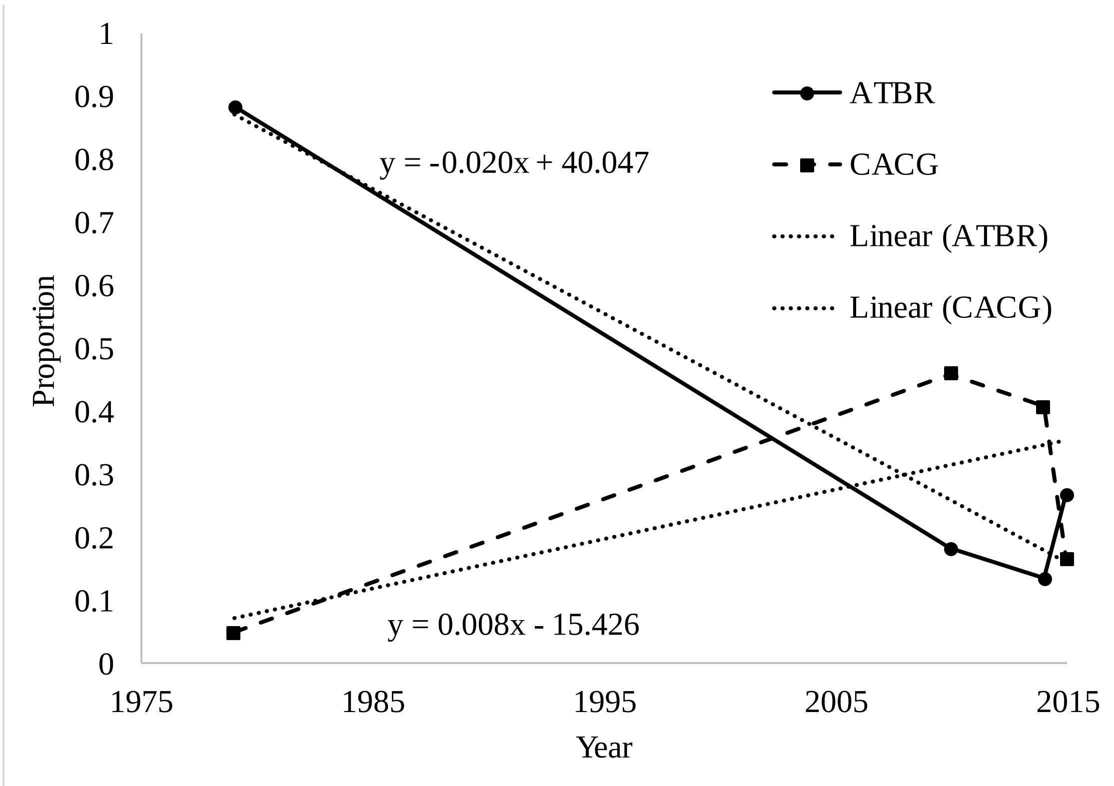


Figure 10 Proportion of brant with ≥ 2 brant neighbors and ≥ 2 cackling goose neighbors on East Bay, Southampton Island, Canada 1979– 2015. Associated trendlines are added to accentuate the increase in cackling goose densities at East Bay and the decrease in brant densities on the same spatial scale.



Chapter 3

NEST FATE PROBABILITIES AND FACTORS INFLUENCING THE NEST SUCCESS OF THE ATLANTIC BRANT

Introduction

Arctic goose nest success in coastal northern Canada is highly dependent on the level of nest depredation. Nest success varies yearly and is dependent on multiple stochastic factors (Barry 1956, 1962; Raveling 1989). Weather and nest timing play large roles in determining the fate of most nests (Barry 1962). During years when snow melts earlier in the summer, geese with early nesting strategies (e.g. lesser snow goose (*Chen caerulescens caerulescens)*, cackling goose (*Branta hutchinsii)*, and Ross's goose (*Chen rossi)*) are favored (Barry 1962). Alternatively, late melting summers favor geese with late nesting strategies such as the Atlantic brant (*Branta bernicla hrota*). Snow melt during the nesting season also can account for the level of depredation on these geese species. Coastal arctic nesting goose habitat is dominated by lakes and ponds with islands and small ridges defining the coastal habitat (Abraham 1986) and access to these islands is determined by the timing of snow melt. The more rapid the snow-melt, the sooner the islands are surrounded by a protective water barrier. This is important for cackling geese and Atlantic brant at East Bay, both of which a percentage nest on islands, ~25% and 75% respectively (Nissley 2016). The water depth varies for each individual island, and access to the islands is different for each predatory species.

Herring Gulls (*Larus argentatus*) and Parasitic Jaegers (*Stercorarius parasiticus)* are not limited by water and may prey on a nest regardless of surrounding water. In cases like this, avian predatory species are instead limited by goose nest density (Abraham personal communication). Cooperative nest defense may play a role in nest defense in high density goose colonies (Baldwin et al. 2011). The main predators include arctic fox (*Vulpes lagopus*) and an incidental predator is the polar bear (*Ursus maritimus*), both of which are land predators. Arctic foxes are short in stature (i.e. ~28 cm high; MacPherson 1969) and are generally not willing to swim through water to gain access to a goose nesting island (Abraham personal communication). Therefore, arctic foxes are limited by water depths which they can walk through. These depths can vary depending on the individual fox, but likely it would be around breast height (~20 cm). When snow cover lasts longer, frozen lakes and ponds provide ice access to islands into the laying period of some geese and do not restrict foxes from depredating nests. However, a late snow melt also means that once the ice melts, ponds and lakes will hold more water later into the nesting cycle which theoretically will benefit geese that rely on these islands as a safe-haven from arctic foxes. If there is little snowfall in the preceding winter and spring, even after snow melt, the ponds and lakes may be too shallow to protect goose nests from arctic foxes wading through shallow water.

Unfortunately for geese, polar bears are not limited by any such mechanism and can access nests at any point throughout the nesting cycle regardless of nest location or snow melt patterns. The timing of polar bear predation is more important because evidence shows that polar bears would rather spend time on the sea ice in search of their main food source: ringed seals (*Pusa hispida*) and bearded seals (*Erignathus barbatus*) (Derocher et al. 2002). When sea ice leaves water surrounding islands, the bears are more likely to swim to islands in search of alternative food sources. While it is relatively energetically inefficient for bears to chase and capture geese themselves or broods after hatch, it is more efficient for a polar bear to opportunistically consume eggs (Gormezano and Rockwell 2013). The efficiency increases as the density of goose nests increases. For example, East Bay on Southampton Island is known to support a high density of polar bears when the sea ice melts, and these bears are partially drawn to the area by East Bay Island, which supports a high density eider nesting colony (Mosbech et al. 2006). Single bears have been documented to wipe out the entire island of eider nests in a few days, providing a caloric bonus for the bear and a complete nesting failure for the eiders. The same is possible on a smaller scale for arctic nesting geese. Brant nest in pockets and if a polar bear opportunistically stumbles upon such a pocket, there is nothing limiting the bear from eliminating that segment of the brant nesting colony. This could become more of a factor as sea ice extent continues to diminish as a result of climate change.

Population estimates from Mid-Winter Survey Counts over the last half century show that brant numbers have fluctuated over the course of this time period (Figure 3); however, over the last 15 years the population has been showing a slow decline of ~20%. Additionally, the Mid-Winter Surveys (MWS) indicate a low percentage of young in fall flocks in recent years (<10% between 2013–2015), indicating breeding ground limitations (Paul Castelli, US Fish and Wildlife Service, personal communication). While snow geese prefer to nest in more upland habitat, cackling geese share similar coastal nesting habitat with brant (Nissley et al. 2016) thus increasing their likelihood of exhibiting pre-emptive competition on brant. Additionally, the 2-week gap between the arrival of cackling geese and brant allows the cackling geese to gain a selective advantage when choosing nest sites. However, if late snow/ice melt prohibits cackling geese from accessing nesting sites, then their early arrival can be detrimental to their nest initiation while benefiting the late arriving brant which have an increased chance of finding open nesting sites. In high competition years, earlier access to nesting islands for cackling geese can spell disaster for the later-arriving brant which are relegated to selecting from those islands that still remain. If any combination of factors (i.e. warm temperatures, low winter snowfall, increased competition for nesting islands) occurs during or prior to brant nesting, brant suddenly become more susceptible to water limited predators such as the arctic fox. The summers of 2014 and 2015 created a natural Before-After-Control-Impact (BACI) design allowing us to test for impacts of potential cackling goose/snow goose competition on Atlantic brant. Complete snow melt occurred significantly earlier in summer 2014 and resulted in a high density of early-nesting cackling geese and increased competition on brant. The opposite was observed in summer 2015, when complete snow-melt was delayed, reducing the nest-effort of cackling geese and decreasing competition on brant.

It is important for researchers to better understand the mechanisms that limit the late nesting brant nest success. That is, how do nest island size, water depth, water distance, and year affect the success of East Bay brant. Anecdotal evidence points to these variables as being some of the most significant in limiting brant success. With a better understanding of what is depredating brant nests and how those predators are limited, we can begin to assess what the proper measures are to improve brant breeding success in Arctic Canada.

Study Area

I conducted our research in the East Bay Migratory Bird Sanctuary, Southampton Island, Canada, where previous goose studies have occurred (Barry 1956, 1962, Abraham and Ankney 1986). The area extended west to 82.03187°W and east to 81.77023°W (Figure 6). East Bay Migratory Bird Sanctuary is a habitat dominated by ponds and lakes. It includes four general zones: tidal, Non vegetative (rock dominated), graminoid [*Carex subspathacea, Dupontia fisheri*] and moss vegetation), and upland (dominated by entire-leaved mountain avens [*Dryas integrifolia,*] and dwarf willow [*Salix herbacea*]) (Ken Abraham, personal communication). At the western limits of the study area, the pond and lake dominated zone extends further inland. The plant community here has been influenced by grazing and grubbing by both lesser snow geese and cackling geese in recent decades (Abraham et al. 2012).

To classify nesting habitat, I walked transects at the end of the 2014 field season to determine broad distinctions between the habitat types at East Bay. While the elevation gradient is relatively low as one moves inland (approximately 3-5m per km, Abraham, personal communication) it can have a profound effect on the vegetation community and surrounding habitat of that nesting region. To separate these different types of habitat, crew members walked a line at the transition zones between habitat types with the GPS units tracking their every step. These zones were then projected across the study region in ArcMap to better define the nesting regions at East Bay.

Methods

I conducted the majority of nest searching around day 4 of incubation for all species in an attempt to discover and mark as many nests as possible before depredation could occur. I collected nest habitat information on every brant nest but Iwere logistically constrained to collect only every forth cackling goose and snow goose nest. The crew marked each nest with a unique identifying number on a popsicle stick and placed it in the ground 1 m north of the nest. For each nest, I recorded species, latitude/longitude, and habitat type (salt/brackish marsh, freshwater marsh, pond/stream/lake edge, upland). I also recorded information about the clutch including number of eggs, the maximum length and width of all eggs, and the age of the clutch via floating or candling (Cooper and Batt 1972). A subset of nests had Reconyx HC 500 semi-covert cameras placed nearby. Each brant nest had a camera on it if a camera was available. Once a nest was depredated or abandoned, the camera could be moved to another nest as it became available. At times, all cameras were deployed (29) and they could not be deployed to newly discovered brant nests. Cameras were placed on high motion-detecting sensitivity, unless circumstances required that they be placed abnormally close to a nest, in which case they were placed on medium sensitivity. A camera was placed ~2 m from the nest it was monitoring. The cameras were surrounded by rocks to hold cameras in place, hide the cameras, and camouflage the cameras with the local habitat. The time-lapse function on the camera was set to take a picture every 1 minute for 24 hours each day. The motion-sensor was set to take a set of 3 pictures upon being triggered, with a separation of 1 second between pictures. The cameras were considered to be "semi-covert" meaning that in low-light situations, they used an infrared flash to take pictures. Cameras were checked periodically, typically every 4 days, to ensure proper functioning and sufficient battery power. These cameras collected details regarding the predators of brant and the timing of depredation events. The cameras also allowed for the differentiation between nest abandonment and nest depredation events. I collected nest data as quickly as was possible to reduce nest abandonment and I covered the nest with down to attempt to minimize detection by nest predators.

After a nest failed or chicks successfully fledged, I measured several defining variables of nest islands that were deemed to be important in the context of depredation: island size, water depth surrounding the island, and distance from that island to a mainland body. I took measurements on all brant nesting islands in summers 2014 and 2015, and on 30 random cackling goose nests in summer 2015. The size of each nest island was recorded by assuming that each nest island was rectangular in shape. This is not strictly true, but for ease of measurement and for standardization, I assumed that this was close enough for comparison between nesting islands. I measured the maximum width and maximum length of the island and then calculated the area of the island. I calculated the water depth by attempting to choose the shallowest path that a land predator (arctic fox) could take when accessing the island. However, because a predator must also travel through the deepest part of that shallowest path, I measured the deepest part along the shallowest path to collect an accurate measurement of the deepest water a predator must navigate when traveling to an island. I assessed the distance from each island to an area of mainland on the same navigational path as the water depth measurement was collected. If the shallowest path included multiple “island hops” to access the nest island, then the collected distance was cumulative in nature. For example, if access to the nest island involved island hopping along 3 different islands, then there would be 4 different stretches of water a predator must cross. The distances of these 4 stretches of water were summed and referred to as the distance to the mainland (water distance). I conducted independent t-tests ($\alpha = 0.05$) on each of these covariates to test for differences in nest island characteristics in brant and cackling goose islands.

I recorded the nest fate (success/fail) of each goose nest through systematic sampling during the field season. If a nest had a camera deployed on it, cause of nest failure could be determined. Nests were defined as successful if at least one egg hatched. If no eggs hatched, it was considered to have failed. Nests were checked on average every 4 days. There was no distinction between a failed nest that had been abandoned and one that had been depredated, as the two causes of failure are nearly impossible to distinguish without a camera on the nest. The reason for this discrepancy is that an abandoned nest will almost surely be depredated in the immediate future, and without hourly nest checks, it is not possible to differentiate between an abandoned nest that had been subsequently depredated and a nest that had simply been depredated. The number of eggs hatched was also collected by counting either the number of caps or the number of membranes in or around a nest. Sometimes it is difficult to get an accurate assessment of the total number of eggs hatched by this method, and thus our estimates for successful nests may be biased low. Egg shell membrane and cap presence can be compromised by wind and rain thereby making it difficult to properly recognize the number of hatchlings. If a nest was found to be depredated upon the initial discovery of the nest, I did not include these nests in our analysis of nest fate. While including these nests might have allowed for a more accurate measure of nest fate, it was sometimes difficult to differentiate between nest species in already depredated nests. Apparent nest success was defined as the proportion of successful nests and was calculated by simple division of successful nests/total nests (Beauchamp et al. 1996). Since I did not include already depredated nests in our apparent success calculations, our apparent nest success values are biased high, but I assume that bias was constant between species within each year.

Using program MCestimate (Etterson 2014), I developed a series of *a priori* competing models of brant nest fate probability as a function of nest microhabitat characteristics. The categorical variables included 1) whether or not a nest was on an island (yes/no), 2) year (2014/2015), and 3) whether the nest was surrounded by 20 cm or less of water (yes/no). The 20 cm was drawn from anecdotal observations that arctic foxes were somewhat unwilling to navigate deeper water than 20 cm. Ifurther included continuous variables: 4) the distance of that nest from a mainland (which was considered to be 0 if the nest was not located on an island) and 5) the water depth along the shallowest path leading to that nest (once again considered to be 0 if the nest was already located on a mainland body). The categorical and continuous water depth measurements (Covariates number 3 and 5 above) were never included in the same model as they would be correlated with one another. I compared 12 *a priori* models, including a null model, via Akaike Information Criteria corrected for small sample size (AICc, Burnham and Anderson 2004). Models to explain nest fate that had a ΔAIC $\leq$ 2 units of the top explanatory model were considered equally parsimonious. Program MCestimate generated a secondary AIC table to further break down which variables were of greatest importance based on the top model.

Results

Mean island size, mean water depth, and mean water distance did not differ between cackling geese and Atlantic brant in summer 2015 (Table 3) indicating brant and cackling geese chose similar island nest sites that year. However, a comparison of brant nest site characteristics between 2014 and 2015 showed that in 2014 (when cackling goose densities were higher), brant nests were surrounded by shallower water thus making them potentially more vulnerable to arctic foxes (Table 3).

Apparent nest success varied by species and between years. Brant apparent nest success declined from a high of 86% in 1979 to 65% in 2010, 5% in 2014, and 17% in 2015. Neither snow geese or cackling geese nest success rates were collected in 1979. Cackling goose nest success dropped from 86% in 2010 to 61% in 2014 and to 2% in 2015. Snow goose nest success increased from 63% in 2010 to 74% in 2014; but then dropped to 6% in 2015.

Using nest cameras, the exact cause of brant failure was determined for 28 nests in 2014 and 30 nests in 2015. The overwhelming majority of failures were due to arctic fox depredation; foxes were responsible for 82% of brant failures in 2014 and 73.3% of their failures in 2015. Polar bears were responsible for 5 depredated nests in 2015, a phenomenon not observed in 2014. Herring gulls were responsible for 14% of failures in 2014 but only 3.3% in 2015. Abandonment does not appear to be a significant cause of brant nest failure, with only 1 abandoned nest in 2014 and only 2 abandoned nests in 2015.

Because arctic foxes were the primary predator, I examined the relationship between nest site selection and fox predation. First I *a priori* examined a series of models examining combinations of the variables (Table 4). The top model included year, maximum water depth, distance to mainland, and whether or not the nest was located on an island. Program MCestimate generated a secondary AIC table to further break down which variables were of greatest importance (Table 5). Both year and maximum water depth had the greatest effect size within the top model. Therefore, I compared the nest fate probability of brant nests from year 2014 to 2015 while holding all other variables constant and found daily nest survival in 2014 equaled 0.828 (SE ± 0.029) and in 2015 equaled 0.924 (SE ± 0.012). Deeper water surrounding brant nests in both years was strongly associated with success (Figure 11). As water depth increases, fox depredation decreases and daily nest success rises (Figure 11). Probability of fox predation appeared to decrease significantly around 20 – 30 cm, suggesting that this may be the limiting water depth for arctic fox access to nest islands.

Discussion

Apparent nest success of brant at East Bay, Southampton Island has been lower in my two years of investigation than it was in 1979 and 1980. The decline is troublesome when paired with the steep decline in brant nest counts. The suspicion that brant might be having reduced reproductive success at East Bay was confirmed by research in summer 2010 (Abraham, personal communication). Nest searches showed that brant numbers had decreased and so had the apparent nest success of since 1979, but whether this was a one year outcome or a long term cumulative outcome was unknown. My results in 2014–2015 breeding seasons confirmed this trend. While cackling geese and lesser snow geese experienced a decline in apparent success in the 2015 breeding season due to the late snow melt (as was also observed across the arctic, R. Alisauskas and R. Rockwell, personal communication), it is clear that increasing pre-emptive, interference, and exploitative competition by cackling geese (Chapter 2 is having an impact on Atlantic brant.

Supporting the idea that pre-emptive competition is driving cackling geese and Atlantic brant nest site selection, I found brant share the same nest site characteristics as cackling geese including island size, water depth, and distance from mainland. While these comparisons are only for geese that establish nest-sites on islands, they are still important because they show an overlap of niche space in an environment where resources are highly limited. I show that brant nest success depends on the water levels at East Bay. In years of low water and few available deep water island nest-sites, it may benefit the brant to have open access to all nesting islands. The large number of cackling geese at East Bay may lead them to occupy deep water sites without it being a result of complete active selection or preference for these islands, just by sheer numbers and near saturation of suitable sites.

Tidal flooding loss and abandonment appear to be relatively minor causes, and herring gull and polar bear depredation play small roles depending on the year. Most herring gull depredation was during the laying period rather that during incubation and it is likely that this is the case because nest attendance is lower during laying, making the eggs more vulnerable. Arctic foxes and polar bears do not appear to be limited by the nesting phase and may be undeterred by nest attendance. Polar bear predation at East Bay is not well-studied in the goose colonies, but it is suspected that the bears opportunistically depredate nests rather than seeking out brant specifically. This makes polar bear depredation a concern where brant populations are low enough that a single bear could opportunistically depredate and wipe out the entire nesting colony with relative ease.

The majority of brant failures in both the 2014 and 2015 breeding seasons were a product of arctic fox depredation. Importantly, fox depredation appears to be limited by water levels surrounding the nest. When running MCestimate with respect to fox depredation, year effect (likely a surrogate for timing of snow melt, but also important in weather variation) appears to be the most important variable influencing our model, followed closely by the water depth. The 2015 breeding season had a later snow melt, more snow to melt, and subsequently higher water levels. The consequent higher water levels likely had the most to do with the increased brant nest success and decreased fox depredation in 2015. Daily nest survival was 10% higher in 2015 than 2014. This seems to implicate water levels as a limiting factor of brant success on the breeding grounds where arctic foxes are present.

It is possible that arctic fox depredation also varies with the presumed~3–4 year lemming cycles at East Bay. Lemmings are capable of population growth from a few individuals to several hundred individuals in a short period of time (Ims and Fuglei 2005, Ims et al. 2013). Arctic fox populations tend to have a one-year lag in response to years of high lemming populations (Ims and Fuglei 2005). However, as the lemming population falls into the low part of its cycle, the foxes must search for alternative prey including shorebird, duck, and goose eggs (Ims and Fuglei 2005). Arctic foxes are usually categorized as either feeding mainly on lemmings or mainly on seabirds and carrion (Ims and Fuglei 2005), but this may not be the case at East Bay where foxes enjoy the luxury of both lemming presence and nesting birds. Evidence of such a trend at East Bay is lacking support yet because lemming populations are only beginning to be monitored in the region. However, similar alternative prey cycles have been shown in other regions where arctic geese breed (MacInnes 1962, Summers 1986, McKinnon et al. 2013). There may have been a time when arctic fox populations were not as high on Southampton Island or when arctic foxes were not as dependent on goose eggs. It is also possible that arctic foxes are drawn to the East Bay region by the large and increasing lesser snow goose colony and then take advantage of the smaller East Bay brant colony (i.e. apparent competition).

With water levels acting as a limiting factor on brant nest success, I question how climate change may impact the nest success of East Bay brant. The topic is not well-studied, but I can begin to construct some hypotheses. The most likely changes are changes in phenology and timing of nesting (MacInnes 1962). As warming trends continue, geese will likely arrive to their breeding grounds earlier, exposing a potential mismatch in nutritional requirements of the geese and the peak growing season of the arctic vegetation (Clausen and Clausen 2013, Lepage et al. 1998, Van Der Jeugd et al. 2009). This mismatch could occur if either the vegetation or the geese adapt to the seasonal changes, while the other does not. Brant expose an interesting and unique problem because of their numerous migratory stopover sites on their way to the breeding grounds. If the stopover sites exhibit a lesser degree of climate change than their arctic breeding grounds, then the possibility of climatological mismatch is even greater (Clausen and Clausen 2013). What may not be as obvious is the impact that snowfall and snow cover can have on brant nest success. If warming trends continue, I can expect less snow accumulation over the winter months and an earlier snow melt. Arctic geese are shown to lay eggs earlier in the breeding season when there are high spring temperatures and less snow (Dickey et al. 2008). However, this speaks for greater snow geese (*Chen caerulescens atlantica*), which are capable of making the trip to the breeding grounds while utilizing fewer stopover sites, thus reducing the effects of climatic cues on their trek north. These climatic cues are often the greatest predictor of how long a species will spend at a stopover site (Bauer et al. 2008). In the same instance, geese benefitted from reduced predation in springs with above average rainfall (Dickey et al. 2008). These factors do not bode well for brant, which depend on winter snowfall and a late summer snow melt to provide sufficient deep-water nest islands. Additionally, earlier sea ice break-up and melt could increase the number of polar bears at East Bay, and increase the depredation of brant nests by bears looking for an opportunistic snack (Rockwell and Gormezano 2009, Gormezano 2013).

The overarching question left to be answered at East Bay is this, "how would brant success be altered if cackling geese were not present?" Would the brant suddenly take advantage of the available habitat and increased niche-space that was once solely theirs at East Bay? A future experiment excluding cackling geese from their East Bay nest sites or studying brant nest success in locations where cackling geese are absent may reveal the answer to this question.

Table 3 Mean island size, water depth, and water distance for brant nesting islands between 2014 and 2015 and between Atlantic brant and cackling goose nesting islands in 2015 on East Bay, Southampton Island, Canada.

		2014		2015		Statistical		
		Mean	SE	Mean	SE	comparison	t	P
Atlantic brant	Island Size (m^2)	61.88	10.95	66.10	9.26	2014 and 2015 Atlantic brant	0.28	0.78
	Water Depth (m)	11.95	1.14	19.59	1.52		4.02	<0.01
	Water Distance (m)	20.92	2.93	20.56	2.03		-0.1	0.92
Cackling Goose	Island Size (m^2)	-	-	101.97	23.29	2015 Atlantic brant and Cackling goose	-1.43	0.16
	Water Depth (m)	-	-	20.29	1.68		-0.29	0.78
	Water Distance (m)	-	-	20.93	1.68		-0.12	0.90

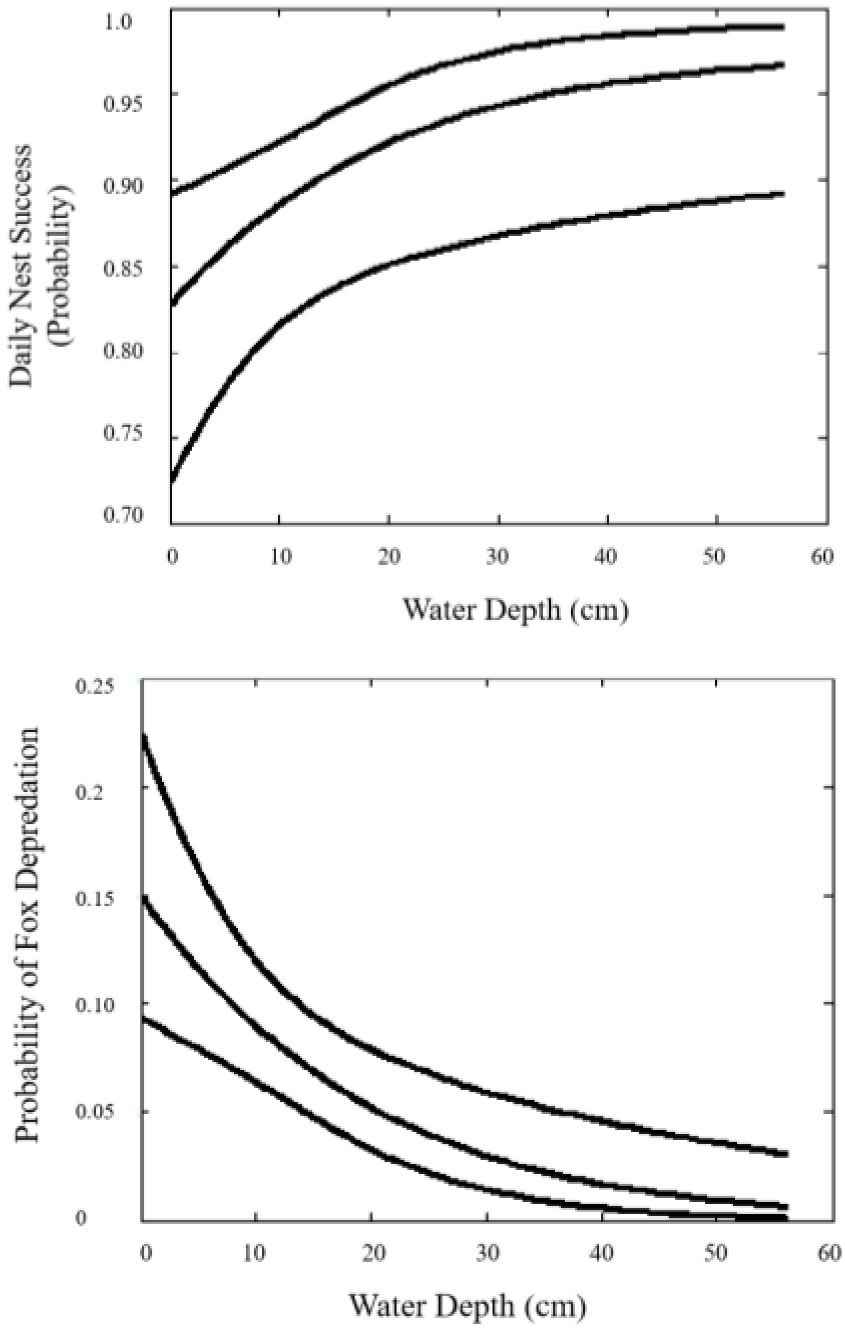
Table 4 AICc comparison of 12 *a priori* models to predict Atlantic brant nest-fate probabilities with respect to arctic fox predation on East Bay, Southampton Island, Canada, 2014 and 2015.

Model	**NLL**	**AICc**	**Δ AIC**	**Weight**	**K**
Fox(Year+Island+Max. Depth (cm)+Dist. To Mainland (m)+Date)	185.54	393.58	0	0.79	11
Fox(Island+ <20cm or mainland + Date)	189.00	396.33	2.74	0.20	9
Fox(Date)	194.44	403.09	9.50	0.01	7
Fox(Year)	199.92	414.05	20.47	0	7
Fox(Max. Depth (cm))	200.56	415.32	21.74	0	7
Fox(Island+ <20cm or mainland)	200.25	416.77	23.19	0	8
Fox(Island+Max. Depth (cm)))	200.49	417.25	23.66	0	8
Fox(Island+Max. Depth (cm)+Dist. To Mainland (m))	199.89	418.11	24.53	0	9
Fox(Dist. To Mainland (m))	203.18	420.56	26.98	0	7
Fox(Island+Dist. To Mainland (m))	202.68	421.63	28.05	0	8
Fox(Island)	204.25	422.71	29.13	0	7
Null	206.76	425.68	32.1	0	6

Table 5 MCestimate AICc comparison of 4 variables from top model to predict brant nest-fate probabilities with respect to fox predation, on East Bay, Southampton Island, Canada, 2014 and 2015.

Model	**NLL**	**AICc**	**Δ AIC**	**Weight**
Fox(Year)	185.54	393.58	0	0.79
Fox(Max Depth (cm))	189.00	396.33	2.74	0.20
Fox (Dist. To Mainland (m))	194.44	403.09	9.50	0.01
Fox(Island)	199.92	414.05	20.47	0

Figure 11 Modeled a) daily nest success and b) daily fox depredation rate of Atlantic brant in relation to water depth at East Bay, Southampton Island, Nunavut, Canada in 2014 and 2015.



Chapter 4

ANTHROPOGENIC INDUCED WILDLIFE POPULATION RELEASE INCURS APPARENT COMPETITION CONSEQUENCES

Introduction

Mid-continent lesser snow geese (*Chen caerulescens caerulescens*) have increased from a few million to ~15 million in the last few decades with consequences that resonate throughout other species (Baldassarre 2014). Current estimates show snow geese populations increasing at a rate of 5% of the annual population per year (Leafloor et al. 2012). The Federal midwinter waterfowl survey indicates the mid-continent cackling goose (*Branta hutchinsii*) population has also increased from ~400,000 to ~700,000 in the last 3 decades (USFWS 2015). Ross's goose populations too are on the increase, with recent estimates totaling well over 1 million Ross's geese as a conservative estimate (Kerbes et al. 2014). The population explosion of these goose species has led to the expansion to previously underused or unused breeding grounds. For example, the number of cackling geese nesting at East Bay has increased at an astounding rate, from 35 in 1979 to 400–600 nests by 2015. Ross's goose range has expanded into the eastern arctic (Moser 2001, Kerbes et al. 2006, Caswell 2009, Alisauskas et al. 2012). The increase in all these species (snow, cackling, and Ross's geese) is due to a combination of trophic shifts to agricultural byproducts in migration and winter, increased survival, lower harvest rates, and climate change, releasing these geese from their historic wintering grounds limitations (Batt 1997, Abraham et al. 2011). The negative implications of population expansions on vegetation communities in their arctic nesting grounds are well-studied (Abraham and Jefferies 1997, Abraham et al. 2012).

Atlantic brant (*Branta bernicla hrota*), hereafter brant, is an arctic nesting goose species with the majority of its nesting range in the Foxe Basin, Nunavut, Canada and its wintering area centered around coastal New Jersey and New York, USA. Population estimates over the last half of a century show that brant numbers have fluctuated over the course of this time period (Baldassarre 2014). At low points, midwinter surveys estimated the population at 50,000 brant. While the population recovered from that low, over the past decade data suggest that brant populations may be on the decline (USFWS 2015). Furthermore, selected breeding grounds show a significant decline in nesting pairs over the last 35 years. Southampton Island's East Bay, on the southern end of the Foxe Basin, supported a historic nesting colony with 455 nesting pairs of brant in 1979 as well as a significant population of lesser snow geese and a small population of cackling geese (Abraham and Ankney 1986, Batt 1997, Baldassarre 2014). However, in 2014 and 2015 only 44 and 78 nests were discovered (Chapter 3) opening questions as to whether cumulative breeding limitations are occurring on the island.

Recently, I found increased levels of snow geese and particularly cackling geese may be detrimental to the later nesting brant through pre-emptive, interference, and exploitative competition. What has not been well-explained is whether lesser snow geese and cackling geese nesting populations could subsidize mesocarnivores on the arctic breeding grounds and effectively reduce the population of other species of birds (e.g., brant or shorebirds) via apparent competition. To determine if apparent competition could be a functional mechanism for brant limitations, I conducted an artificial nest depredation trial. I established artificial goose nests in high goose density plots, low goose density plots, and control plots on East Bay, Southampton Island, Nunavut , Canada to if apparent nest success was related to density of co-occurring goose species.

Study Area

I conducted our research in the East Bay Migratory Bird Sanctuary, Southampton Island, Canada, where previous goose studies have occurred (Barry 1956, 1962, Abraham and Ankney 1986). The area extended west to 82.03187°W and east to 81.77023°W (Figure 12). East Bay Migratory Bird Sanctuary is a habitat dominated by ponds and lakes. It includes four general zones: tidal, non-vegetative (rock dominated), graminoid [*Carex subspathacea*, *Dupontia fisheri*] and moss vegetation), and upland (dominated by entire-leaved mountain avens [*Dryas integrifolia*] and dwarf willow [*Salix reticulata*]) (Ken Abraham, personal communication). At the western limits of the study area, the pond and lake dominated zone extends further inland. The plant community here has been influenced by grazing and grubbing by both lesser snow geese and cackling geese in recent decades (Abraham et al. 2012).

In order to classify nesting habitat, I walked transects at the end of the 2014 field season to draw a distinction between the vastly different habitat types at East Bay. While the elevation gradient is minimal as one moves inland, it can have a profound effect on the vegetation community and surrounding habitat that occupies that nesting region (Abraham personal communication). To separate these different types of habitat, crew members walked a line at the transition zones between habitat types with the GPS units tracking their every step. These zones were then projected across the study region in ArcMap to better define the nesting regions at East Bay.

Methods

Following the Arctic Wildlife Observatories Linking Vulnerable EcoSystems artificial nest monitoring protocol (McKinnon et al. 2010), I conducted an artificial nest experiment at East Bay, Southampton Island, Nunavut, Canada between 2–11 July 2015. Nest searching was conducted prior to the start of the experiment so goose nest densities were known. Using Garmin program Basecamp (Garmin licensed software), I established artificial nests in high density ($\geq$ 30 nests per km^2), low density (5–10 nests per km^2), and control (1-2 nests per km^2) plots throughout the study area (based on already established 2015 goose nests). These densities are regionally high or low and do not represent high or low goose densities elsewhere on the island. The plots were scattered across the aforementioned nest habitat types at East Bay. However, a the general pattern was that high density plots featured in the more coastal moss and graminoid nest zone, and the density (high vs. low) of plots generally decreasing as their placement moved inland (Figure 12). All plots measured 1 km^2 and each plot was separated from all other plots by $\geq$1 km. There were 9 total plots, with 3 replicates per treatment. Using program

Basecamp, I generated 10 random points per plot. These points served as artificial nest locations. Artificial nests were established on day one of the experiment and were checked after 12 hrs, 24 hrs, 72 hrs, 6 days, and 9 days or until 90% of the nests had failed. To construct a nest, field crew members located the randomly generated nest location on a GPS and then used local vegetation to construct a simulated (realistic) goose nest. Two chicken eggs were placed in each nest. Latex gloves were worn during the construction and daily checks of the nests to attempt to minimize human scent around the nest locations. Researchers were also instructed not to kneel at the nest or do anything that could lead to the deposition of human scent. A labeled popsicle stick was placed 5 m north of each artificial nest and the latitude and longitude of the nest were logged on a GPS. At each nest check, the level of depredation was recorded as partial, complete, or none; as well as any relevant details regarding the nest. Partial depredation was defined as 1 egg missing from the artificial nest. Complete depredation was defined as both eggs missing from the artificial nest. No depredation was recorded when both eggs were still present during a nest check. It was possible for partial depredation to be recorded during one check and complete depredation to be recorded at the next nest check if 1 egg was taken between checks. If the nest was fully depredated, the popsicle stick was removed and the nest was no longer included in nest checks. Nest survival probabilities were calculated via Kaplan and Meier (1958) using nest success (had 1 or 2 eggs) or failure (had 0 eggs) and the timing of complete depredation. I compared pairwise survival across treatments using a log rank Mantel-Cox Chi-square test ($\alpha \leq 0.05$).

Results

The survival probability of nests after the 12-hour check were 0.567 (high density), 0.833 (low density), and 0.90 (control) (Figure 13). The 24-hour check yielded survival probabilities of 0.467 (high), 0.833 (low), and 0.767 (control). The 72-hour check yielded similar results, with the control probability slightly higher than the low density plots; 0.133 (high), 0.3 (low), and 0.367 (control). Associated probabilities for the 6-day check were 0.033 (high), 0.2 (low), and 0.1 (control). By the 9-day check, the survival probability of high density plots was 0, as no nests remained; whereas the low density and control plots both had survival probabilities of 0.033. Because fewer than 10% of artificial nests remained at 12 days, a final check was not conducted. While the majority of nests across all plots failed by day 9, the speed by which the high density nests failed was significant. The control and low density treatment cumulative nest survival was not different (χ^2= 0.17, P = 0.68). However, the high density treatment cumulative nest survival was significantly lower than both the low density (χ^2= 8.82, P < 0.01) and control plots (χ^2= 7.21, P < 0.01).

Discussion

The East Bay snow goose colony has grown significantly in the last 30 years and continues to grow (Nissley Chapter 2, Sharp personal communication). While they nest in fundamentally different habitat than the Atlantic brant, there are potentially indirect effects on brant. In addition to the increased snow goose population, Ross's geese are thought to have increased their eastern arctic range with an estimated 50,000 – 75,000 nesting on Southampton Island (Leafloor, personal communication), with small pockets documented at East Bay (Nissley 2016). These Ross's geese at East Bay are nesting at similar densities as the lesser snow geese and the cackling geese, if not at a higher density (Nissley et al. 2016). Cackling geese at East Bay experienced a similar boom in population, with only 35 nests documented in 1979 but nearly 600 nest attempts documented in the 2014 breeding season. While the number of attempted cackling goose nests was down slightly in the 2015 breeding season, it is very likely that the number will rebound, as the slight dip can most likely be credited to a late summer in the 2015 breeding season (Nissley 2016). Unlike lesser snow geese and cackling geese, Atlantic brant are unable to take advantage of changed agricultural practices and are still confined to coastal salt marshes on the Atlantic coast. Food availability in these coastal salt marshes has been analyzed and is currently not a limiting factor for wintering brant (Laden 2013). However, because there has been a lower percentage of young in mid-winter survey population counts (Paul Castelli, personal communication), there has been concern that limitations occur on the arctic breeding grounds. While found evidence that pre-emptive, interference, and exploitative competition could be influencing brant nest success (Chapters 2, 3), there has been no experimental evidence that increased predator pressure related to density variation among heterospecific geese could be a contributing factor (i.e. supporting an hypothesis of apparent competition).

Nissley (2016) found arctic foxes are the primary predator of Atlantic brant eggs. Success of the brant breeding is highly dependent on the density of arctic foxes, with low fox abundance boding well for brant success (Anthony et al. 1991). While foxes rely on the eggs of nesting geese for food during the summer and it is likely that the geese and their eggs (cached by foxes) act as a subsidy in low lemming years. Lemmings are an important part of the arctic fox diet in most arctic locations (Ims and Fuglei 2005). However, when lemmings are absent foxes are known to rely on arctic breeding birds as their primary food source, and this includes the eggs of many of these species (Ims and Fuglei 2005, McKinnon et al. 2013). While no lemming trapping was performed in summer 2014 or 2015, anecdotal evidence supports the claim that lemming abundance was higher in 2014 than 2015. While lemmings and their winter nests were observed in summer 2014, no lemmings were observed by field crews conducting shorebirds research in summer 2015 (Paul Smith, Canadian Wildlife Service, personal communication). It is reasonable to predict that arctic foxes experienced relative boom in breeding success in summer 2014, as would follow a year of high lemming abundance and optimal breeding conditions (Ims and Fuglei 2005). The alternative prey hypothesis would suggest that a down year in lemming abundance (e.g., summer 2015) would bode poorly for breeding geese and their eggs (Ims and Fuglei 2005, MacInnes 1962, Summers 1962). It is quite possible that increased fox populations from a successful 2014 breeding season wreaked havoc on the nest success of the large goose colonies at East Bay.

Apparent competition is shown to be a driving force in ecological systems and has been shown to play a role in shaping other communities (Bonsall and Hassell 1997, Holt and Kotler 1987). This could be occurring at East Bay if an increase in the snow goose, Ross’s goose, cackling goose, or a combination of all three populations increases predators that prey on brant and their nests (Herring Gulls, parasitic jaegers, Arctic foxes; Figure 5; (see McKinnon et al. 2013). The 2014 brant breeding season indicated a low apparent nest success due mostly to high depredation, possibly indicative of apparent competition. Apparent competition is difficult to detect because it is tough to implicate one population or multiple populations for the local increase in predators, without a presence/absence experiment where habitat conditions are the same and density is the only variable. I was able to control for habitat and site variation, and thus establish t variation in densities within artificial nest plots. The evidence found in this study provides a missing link between high goose densities and increased depredation via apparent competition. This study provides a look at how depredation can vary inside of a goose colony. Baldwin et al. (2011) showed increased nest defense when Ross's geese nested inside of a snow goose colony, but what happens to geese nesting on the fringe of the snow goose colony? The Atlantic brant fit this profile due to their inability to nest in the same upland environment as snow geese. Additionally, low density brant colonies are known to experience higher rates of depredation (Raveling 1989); thus the reduced brant densities at East Bay make it a prime candidate for increased depredation due to the increase in other nearby nesting geese (i.e. apparent competition). With lesser snow geese potentially attracting and subsidizing local arctic fox populations, the brant face continued tough breeding conditions. Our results show a clear link between increased nest density, increased probability of depredation, and thus a decreased survival probability.

Figure 12 Map of the historic East Bay study site with a border around the searched nesting area. The border delineates the zone within the study area in which most geese nest on the south shore of East Bay (tidal line to 1.25 miles inland). Color zones reflect habitat types: light blue – tidal, purple – non-vegetated, red – moss dominated, and green – upland. Squares represent high density (orange), low density (yellow), and control plots where artificial nests were placed.

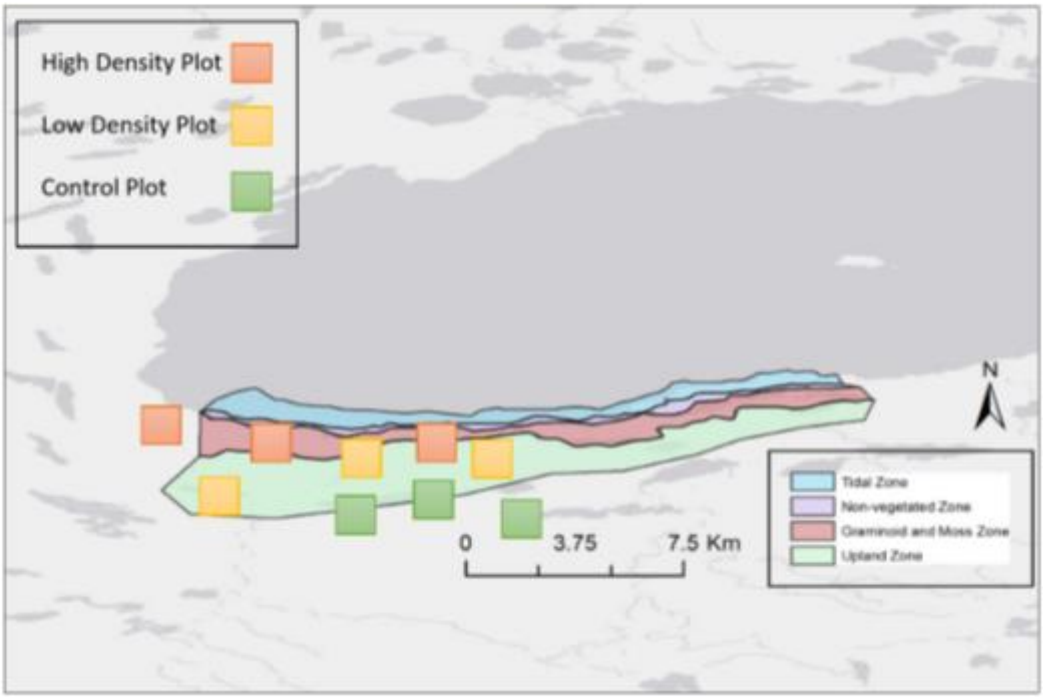
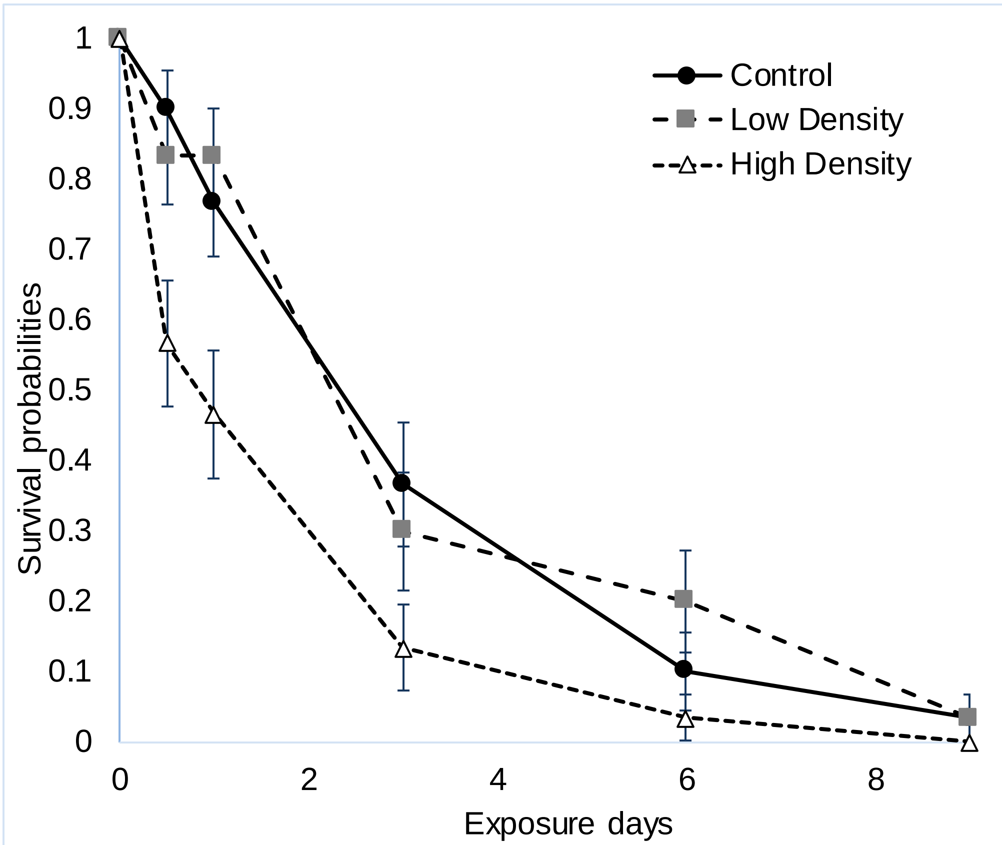


Figure 13 Survival probabilities for high density, low density, and control artificial goose nest plots up to 9 days after the construction of the nests on East Bay, Southampton Island, Canada 2–11 July 2015.



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Appendix A

ROSS'S GOOSE (*CHEN ROSSI)* NESTING COLONY AT EAST BAY, SOUTHAMPTON ISLAND, NUNAVUT

Nissley, C. A., C. K. Williams, and K. F. Abraham. 2016. Ross's Goose (*Chen rossi*) nesting colony at East Bay, Southampton Island, Nunavut. Canadian Field-Naturalist 130:22–24.

Most Ross's Geese (*Chen rossi*) nest in the central arctic of North America, but the range has expanded eastward in the last two decades. In summer 2014, we discovered a cluster of 48 nesting pairs of Ross's Geese at East Bay Migratory Bird Sanctuary, Southampton Island, Nunavut. The Ross's Goose colony was between an upland Lesser Snow Goose (*Chen caerulescens caerulescens*) nesting area and a low-lying Cackling Goose (*Branta hutchinsii*) and Atlantic Brant (*Branta bernicla*) nesting area, in a zone dominated by ponds and lakes and interspersed with areas of moss and graminoids. Our discovery documents a previously unknown level of nesting of Ross's Geese at East Bay and corroborates unpublished evidence of growing numbers of the species on Southampton Island and expansion of its breeding range.

Introduction

Field studies and aerial surveys have documented large populations of nesting Lesser Snow Geese (*Chen caerulescens caerulescens*), Atlantic Brant (*Branta bernicla hrota*), and Cackling Geese (*Branta hutchinsii*) on Southampton Island, Nunavut (Sutton 1932; Barry 1962; Kerbes 1975; Abraham and Ankney 1986; Kerbes et al. 2006, 2014).

The largest numbers occupy portions of East Bay Migratory Bird Sanctuary, the Harry Gibbons Migratory Bird Sanctuary, and other lowland areas. In contrast, evidence of nesting by Ross's geese (*Chen rossi*) comes from finding three nests prior to 1980, two in 1957 (Barry and Eisenhart 1958) and one suspected nest in 1979 (Abraham and Ankney 1986), but mainly from the capture of locally hatched young during the banding of molting geese in late summer in the last two decades (Abraham and Ankney 1986; Canadian Wildlife Service, unpublished data).

Study Area

In summer 2014, we conducted a goose study in the East Bay Migratory Bird Sanctuary at the same East Bay area of earlier studies (Abraham and Ankney 1986). The area extended west to 82.03187°W and east to 81.77023°W (Figure 1). East Bay Migratory Bird Sanctuary is a habitat dominated by ponds and lakes. It includes four general zones: tidal, rock dominated (minimal vegetation), pond and lake dominated (moss and graminoid vegetation), and upland (dominated by Entire-leaved Mountain Avens, *Dryas integrifolia*-Vahl, and Dwarf Willow, *Salix herbacea* L.) dominated). At the western limits of the study area, the pond and lake dominated zone extends further inland. The plant community here has been influenced by grazing and grubbing by both Lesser Snow Geese and Cackling Geese in recent decades (Abraham et al. 2012).

Methods

Searching for nests was done systematically on foot, using multiple searches of the entire study area during the incubation period to ensure that we found late-nesting and re-nesting geese. We recorded latitude, longitude, and microhabitat measurements at each nest. Nests were identified by observing the incubating female. To confirm that the nests were those of Ross's Geese rather than Lesser Snow Geese, we measured egg size using calipers (to the nearest ±0.1 mm) following Alisauskas et al. (1998). We candled a sample of eggs to determine development stage. We estimated the various forms of ground cover within 1 m of nests, and water within 10 m selecting from 25%, 50%, 75%, or 100%. We also classified dominant vegetation or ground cover within 10 m of each nest, as moss, graminoids, willow, dead moss, bare ground, or rock. We obtained banding records of Ross's Geese and Lesser Snow Geese from the Canadian Wildlife Service (J. O. Leafloor, personal communication).

Results

We found a small colony of 48 nesting pairs of Ross's Geese at the head of East Bay (Figure 1). Nine Ross's Goose nests were discovered on 26 June and an additional 39 were found on 2 July. All nests discovered or re-visited on 2 July were either hatching or in the last 4 days of incubation. The average clutch size at the time of discovery was 3.1 eggs. We measured 110 eggs from 34 Ross's Goose nests. Average egg length was 72.46 ± 2.27 mm and average width was 48.45 ± 1.37 mm (compared with 71.8 ± 3.2 mm long by 48.4 ± 1.6 mm wide) corroborating our visual identification of the females and pairs as Ross's Geese and not Lesser Snow Geese whose egg size is reported as 78.4 ± 3.2 mm long by 52.7 ± 1.6 mm (Alisauskas et al. 1998).

Ross's Geese nested chiefly in the pond and lake dominated zone, sandwiched between an upland nesting area mostly occupied by nesting Lesser Snow Geese, and a low-lying area mostly occupied by nesting Cackling Geese and Atlantic Brant geese.

Conspecific inter-nest distances were lower for Ross's Geese (mean = 30.41 ± 2.62 m, n = 48) than Lesser Snow Geese (mean = 83.52 ± 4.96 m, n = 228) or Cackling Geese (mean = 99.37 ± 2.62 m, n = 578).

The average vegetation composition within a 1-m radius of the nest was 48% live moss, 35% graminoid (mainly Hoppner's Sedge, *Carex subspathacea* Wormskjold), 11% dead moss, 4% rock, 2% willow, and <1% bare ground. Nest material was a combination of down, moss, graminoids, and willow. The dominant form of vegetation within 10 m of the nest was moss for 18 of the nests and graminoids for 29. In addition, on average, 52% of the area within a 10 m radius of the nests was water.

Discussion

North American Ross's Geese nest mostly in the Queen Maud Gulf Sanctuary but growing numbers are nesting in the western Hudson Bay region and numbers are reported to be increasing in the Foxe Basin region on Baffin Island and on Southampton Island (Moser 2001; Kerbes et al. 2006; Caswell 2009; Alisauskas et al. 2012). Although this is the first documentation of a Ross's Goose nesting colony on Southampton Island, the number and regularity of Ross's Goose captures during annual banding by the Canadian Wildlife Service suggest that it may be just one of many similar small colonies or clusters of Ross's Geese scattered among the much more numerous Lesser Snow Geese nesting on the island. Current estimation techniques for "light geese" on Southampton Island do not include separate estimates of Ross's Geese as in some other nesting areas (e.g., West Hudson Bay, cf. methods outlined in Kerbes et al. 2006, 2014).

We recommend more detailed monitoring on Southampton Island to allow discovery and enumeration of other nesting clusters of Ross's Geese. This is a necessary precursor to understanding their use of habitat in relation to that of other nesting goose species and their relation to habitat alterations that have occurred.

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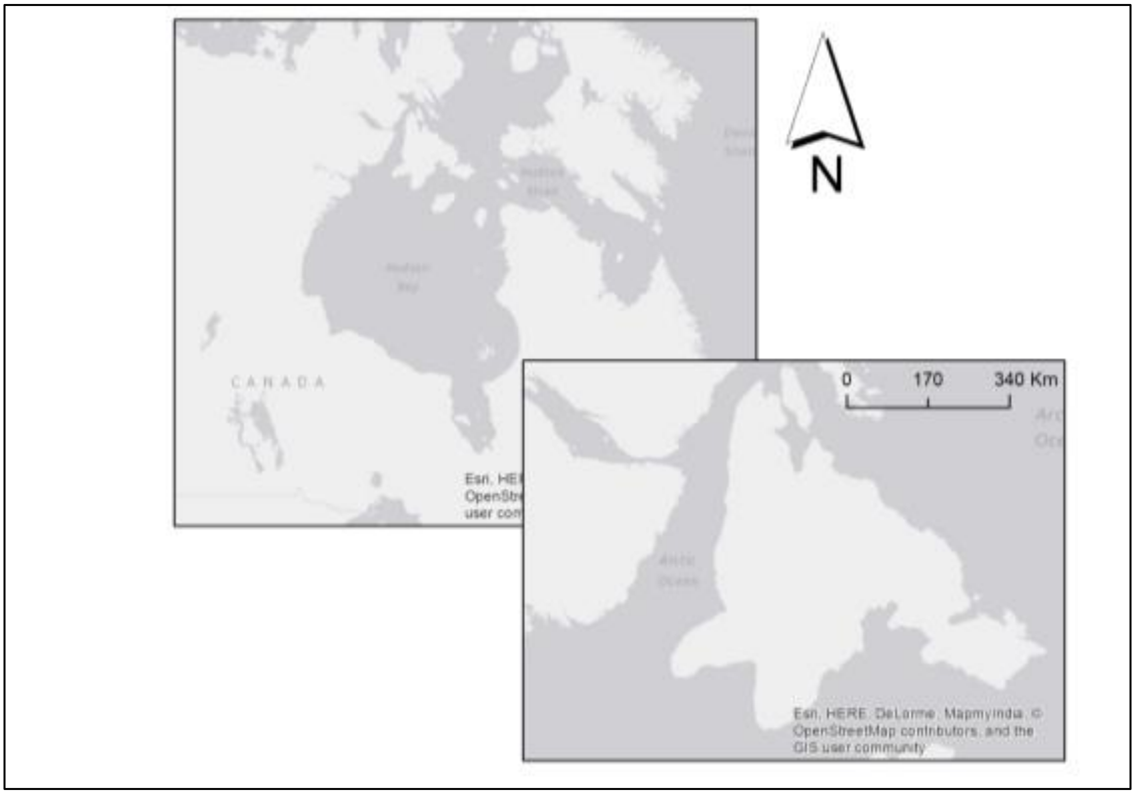
FIGURE 1. Map of Southampton Island and East Bay, Nunavut, including the previously unknown Ross's Goose (*Chen rossi*) colony.



Appendix B

EAST BAY, SOUTHAMPTON ISLAND, NUNAVUT, CANADA SPECIES LIST

Species Code	Common Name	2014	2015		
		First Observed	First Observed	Last Observed	Prop. Days Observed
SNGO	Snow Goose	25-May	22-May	25-Jul	1.00
CACG	Cackling Goose	25-May	21-May	25-Jul	1.00
ATBR	Atlantic Brant	9-Jun	8-Jun	25-Jul	0.96
ROGO	Ross's Goose	28-May	13-Jun	22-Jul	0.79
CANG	Canada Goose	25-Jun	22-Jun	11-Jul	0.42
GWFG	Greater White-Fronted Goose	30-May	31-May	31-May	1.00
KIEI	King Eider	28-May	27-May	25-Jul	0.78
COEI	Common Eider	1-Jun	13-Jun	25-Jul	0.93
NOPI	Northern Pintail	31-May	1-Jun	25-Jul	0.54
LTDU	Long-Tailed Duck	1-Jun	15-Jun	23-Jul	0.76
RBME	Red-Breasted Merganser	9-Jun	16-Jul	22-Jul	0.33
TUSW	Tundra Swan	27-May	27-May	22-Jul	0.54
PALO	Pacific Loon	5-Jun	8-Jun	25-Jul	0.94
RTLO	Red-Throated Loon	7-Jun	13-Jun	25-Jul	0.83
SACR	Sandhill Crane	31-May	5-Jun	13-Jul	0.18
HERG	Herring Gull	25-May	21-May	25-Jul	0.98
GLGU	Glaucous Gull	25-May	28-May	17-Jun	0.20
SAGU	Sabine's Gull	31-May	11-Jun	22-Jul	0.93
THGU	Thayer’s Gull	14-Jun	-	-	-
ARTE	Arctic Tern	1-Jun	14-Jun	18-Jul	0.74
SNBU	Snow Bunting	27-May	19-May	23-Jul	0.66
LALO	Lapland Longspur	3-Jun	5-Jun	25-Jul	0.66
HOLA	Horned Lark	1-Jun	22-May	5-Jul	0.27
WRSA	White-Rumped Sandpiper	30-May	16-Jun	25-Jul	0.90
SESA	Semi-Palmated	UNK	10-Jun	3-Jul	0.52

	Sandpiper				
PESA	Pectoral Sandpiper	-	5-Jul	5-Jul	1.00
PUSA	Purple Sandpiper	-	5-Jul	5-Jul	1.00
LESA	Least Sandpiper	9-Jun	-	-	-
SAND	Sanderling	-	20-Jun	20-Jun	1.00
DUNL	Dunlin	1-Jun	7-Jun	23-Jul	0.39
RUTU	Ruddy Turnstone	5-Jun	7-Jun	22-Jul	0.69
REKN	Red Knot	30-May	8-Jun	9-Jul	0.32
REPH	Red Phalarope	30-May	16-Jun	21-Jul	0.69
WHIM	Whimbrel	26-Jun	29-Jun	19-Jul	0.25
CORA	Common Raven	UNK	22-May	22-Jul	0.08
SNOW	Snowy Owl	-	11-Jun	11-Jun	1.00
SEPL	Semi-Palmated Plover	UNK	12-Jun	25-Jul	0.47
BBPL	Black-Bellied Plover	5-Jun	5-Jun	23-Jul	0.54
AMGP	American Golden Plover	30-May	5-Jun	20-Jul	0.22
RLHA	Rough-Legged Hawk	-	7-Jun	18-Jun	0.36
PAJA	Parasitic Jaeger	27-May	8-Jun	25-Jul	0.89
LTJA	Long-Tailed Jaeger	UNK	25-Jun	25-Jun	1.00
PEFA	Peregrine Falcon	26-Jun	28-May	11-Jul	0.16
ROPT	Rock Ptarmigan	-	1-Jun	1-Jun	1.00