

EVALUATION OF SPECIAL MANAGEMENT MEASURES FOR MIDCONTINENT LESSER SNOW GEESE AND ROSS'S GEESE

Report of the Arctic Goose Habitat Working Group



*A Special Publication of the Arctic Goose Joint Venture of the
North American Waterfowl Management Plan*

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EXECUTIVE SUMMARY

Unprecedented management actions were initiated in 1999 to reduce damage caused to arctic and subarctic ecosystems by the foraging activities of increasing numbers of midcontinent lesser snow geese and Ross's geese. Coincident with these management actions, monitoring programs were established or expanded to evaluate changes in habitat, harvest, survival and productivity of the geese, as well as potential changes in their abundance and distribution in response to management actions.

Harvest of lesser snow geese and Ross's geese increased substantially before and during the period of conservation actions, but after initial increases in the early years, the take by hunters has declined. Harvest rates (i.e., the proportions of each population that are harvested annually) have continued to decline following implementation of conservation measures, as the harvest by hunters has not kept pace with increases in population size. We found evidence of declining survival of adult lesser snow geese from the southern-most nesting colonies, but survival of arctic-nesting snow geese, constituting 90% of the midcontinent population, remained high and overall survival rates remained above the level required to induce a population decline. Increased harvest has not resulted in reduced survival of Ross's geese, whose numbers have continued to increase at a higher rate than have lesser snow geese since the start of conservation actions in 1999. There was no indication that increased disturbance caused by conservation harvest reduced productivity of midcontinent lesser snow geese,

and continued expansion and productivity of agro-ecosystems and the nutritional subsidy that they provide may further increase survival rates and productivity of these geese.

Indices of abundance and estimates of population size also suggest that growth of midcontinent lesser snow goose and Ross's goose populations has continued, though perhaps at a reduced rate. Use of banding and harvest data to estimate population size suggested that population size of midcontinent light geese may be much higher than previously thought, and this likely explains why increased harvest has not led to expected declines in population size. Surveys on nesting areas suggest that growth of midcontinent populations has been uneven, but that most recent growth for both species appears to be occurring in the central arctic, where there may be room for considerably more expansion. We predict continued growth of lesser snow goose and Ross's goose populations where favorable habitat conditions still exist, particularly in the central and western arctic.

Evidence suggests that damage to staging and nesting habitats in coastal areas along James and Hudson Bay has continued, and that the area affected by foraging activities of the geese continues to expand. Much of the salt marsh habitat along this coast has been severely degraded, and impacts to adjacent freshwater marshes are continuing as birds move inland to feed, away from the most severely degraded coastal areas. Our knowledge of habitat conditions farther north, where most of the midcontinent populations of lesser snow geese and Ross's geese nest, remains inadequate. However, observations suggest that many light geese that nest north of 60° N latitude do so at inland locations, and rely much more on freshwater marshes than salt marshes compared to those in the southern subarctic stratum. There is evidence from at least some northern nesting areas, such as those on Southampton Island and near large colonies in the Queen Maud Gulf region, that habitat damage has occurred there also, and that Ross's geese contribute to the degradation where they exist in large numbers. We have limited knowledge of the use of staging habitats north of agricultural regions in prairie Canada, and this limits our ability to document and/or predict habitat degradation caused by lesser snow geese and Ross's geese as their distribution expands and abundance increases over time.

To date, management actions have not been successful in reducing populations of midcontinent lesser snow geese and Ross's geese, though there is some evidence that growth rates may have slowed over the past decade. It is clear that even with regulatory changes aimed at increasing harvest of midcontinent lesser snow geese and Ross's geese, the goal of reducing their numbers is not likely to be achieved through increased harvest by hunters alone, at least with current hunter numbers. Reducing these populations to levels that could be controlled through hunting in the future will likely require implementation of a large scale direct control program. The existence of agricultural subsidies in the form of waste grain is beyond the ability of wildlife management agencies to control, and other species benefit from those subsidies besides geese. Thus, the underlying conditions that have led to runaway growth of these populations are expected to remain in place well into the future. In the 1970s, much lower populations of both species underwent dramatic growth, so aggressive harvest

management policies would still be required to maintain population sizes at manageable levels even after population control actions were implemented.

In the absence of drastic population control measures, continued increases in population size of midcontinent lesser snow geese and Ross's geese are expected, and are likely to lead to more destruction of arctic wetland habitats used by geese and other species. The difficulty of reducing migratory goose populations once they have reached such a large size points to the need for earlier, more aggressive harvest management policies when goose populations exceed objectives and/or show signs of sustained growth over time. Our collective experience suggests that it is likely easier to recover goose populations that reach low levels than to reduce them after they experience runaway growth.



Photo credit: Chris Benson

INTRODUCTION

Arctic-nesting geese in general have increased due to a series of anthropogenic factors such as changes in agricultural practices, the establishment of wildlife refuges, declines in hunter numbers and hunting pressure, and climate change (Ankney 1996; Batt 1997, 1998; Moser 2001; Gauthier et al. 2005). Snow goose (*Chen caerulescens*) and Ross's goose (*Chen rossii*) populations in particular have benefitted from these developments, and have increased to such levels that they are now considered overabundant in Canada and the United States. In fact, snow and Ross's geese have experienced such dramatic increases over the last four decades that they have created an unprecedented challenge for North American wildlife managers, who have traditionally been focused on recovery of depleted populations or maintenance of healthy ones.

In 1996, a group of arctic goose specialists, sponsored by the Arctic Goose Joint Venture (AGJV) of the North American Waterfowl Management Plan (NAWMP), convened to analyze the patterns, causes, and implications of increases in the number of lesser snow geese. The working group concluded that some populations of arctic-nesting geese, and in particular the midcontinent population of lesser snow geese, had caused major damage to arctic and subarctic ecosystems upon which they and other species depended. Habitat degradation was characterized by a trophic cascade, following destructive foraging by geese that created soil salinity and moisture conditions that

eventually led to desertification of the affected landscapes (Batt 1997). Habitat damage was increasing in extent and was unlikely to be reversed, given the continued increase in population size of geese at the time. The working group predicted that the most likely outcomes of continued population increase would be either that the population could remain at high levels for a longer period of time, with individuals in ever-worsening physiological condition, leading to the ultimate destruction of habitats on which several species depended, or that it would experience a sharp population decline due to density-dependent effects. In reality, the large population size, high survival rate, and long life span of these geese makes them capable of expanding their numbers even in the face of declining recruitment, and we have seen instead that snow geese and Ross's geese continue to invade and exploit new habitats, further spreading the trophic cascade across the landscape. The group made 8 recommendations regarding management of the species, including: "The responsible public agencies in Canada and the U.S. should implement proactive population reduction measures to reduce mid-continent white goose populations to a level of about 50% of current numbers by the year 2005" (Batt 1997).

The Trilateral Committee for Wildlife and Ecosystem Conservation and Management, representing the United States, Canada, and Mexico, declared midcontinent lesser snow geese to be overabundant in 1999. In the ensuing years, the United States and Canada implemented unprecedented conservation actions to increase the harvest of snow and Ross's geese, as well as other management actions. Several of the management changes that were identified by Johnson (1997) (e.g., legalization of unplugged shotguns, no bag or possession limits, longer seasons, electronic calls, shooting until ½ hour after sunset, and harvest after the legislated framework date of March 10th) were implemented in one or both countries. In addition to liberalized regulations intended to increase harvest using previously prohibited methods, a variety of habitat management practices were implemented on National Wildlife Refuges that were designed to increase exposure of snow geese and Ross's geese to more harvest pressure. Shortly afterward, another working group explored alternative strategies, beyond the new hunting and habitat management practices that had been implemented, that could be used in the event that increased mortality through harvest was insufficient. This assessment provided a broad array of possible additional steps that could be taken, and highlighted the need for experimental work to reduce key uncertainties related to implementation and potential impact of these direct control measures (Johnson and Ankney 2003).

Special conservation measures in Canada and the United States have been in place since 1999. In the 13 years of management efforts to reduce population size, an assessment of its effectiveness on greater snow geese was completed (Reed and Calvert 2007). The present working group was charged with reviewing the most up-to-date information and assessing the current status of midcontinent lesser snow geese and Ross's geese and their arctic and subarctic habitats. This evaluation builds on a series of publications over those 13 years (e.g., Abraham et al. 2005, Jefferies et al. 2006, Kerbes et al. 2006) and most recently on analyses of the effects of increased hunting opportunity on adult survival and population growth rate of midcontinent lesser snow geese (Alisauskas et al. 2011) and Ross's geese (Alisauskas et al. 2006).

Increasing numbers of snow geese and Ross's geese and their impacts on North American habitats have been the subject of many scientific papers, regulatory documents, and public interest articles over the last 20 years. During this time, several similar terms have been used to describe different aggregations of geese, often leading to confusion (e.g., midcontinent population of lesser snow geese vs. midcontinent light geese). Here, we define these terms and explain their origin in an attempt to reduce misunderstanding. Specifically, we address two species of geese in this report; snow geese and Ross's geese. In situations such as aerial surveys, the two species (Ross's geese and snow geese) often cannot be differentiated, and the geese are sometimes referred to in aggregate as "light geese" in this report (also "white geese" in some previous publications). Snow geese are further divided into two subspecies, the greater snow goose of eastern North America, and the lesser snow goose, which predominates in the western two-thirds of the continent.

Snow and Ross's geese have also been further geographically defined as management units or "populations," based on their historical presence on shared wintering grounds, and on their shared breeding areas. The traditional definition of the "Midcontinent Population" of lesser snow geese and Ross's geese includes geese that winter primarily in the Mississippi Flyway and eastern portion of the Central Flyway. They nest mainly in areas east of 115°W longitude, including on Baffin Island, Southampton Island, along the western and southern coasts of Hudson Bay, and west to the Queen Maud Gulf region of the central arctic of Canada. "Western Central Flyway Population" snow and Ross's geese winter in the western part of the Central Flyway, and nest from Banks Island in the western arctic region of Canada to the Queen Maud Gulf region, where they overlap with birds from the midcontinent population. Geese from these two wintering populations are often considered together and referred to as midcontinent light geese, or Central/Mississippi Flyway light geese (U.S. Fish and Wildlife Service 2007), or individually as midcontinent lesser snow geese and midcontinent Ross's geese. All of these descriptors refer generally to lesser snow geese and/or Ross's geese that nest in northern Canada and winter in the midcontinent region of the United States and parts of Mexico.

Most North American goose biologists currently favor management of goose populations based on breeding aggregations rather than wintering aggregations. Thus, at times we have defined aggregations of snow and/or Ross's geese that are based on breeding ground affiliations (e.g. chapter 4) that may not coincide exactly with traditional population definitions based on wintering areas. At other times, we continue to use traditional wintering population definitions because we rely on previously collected winter aerial survey counts or harvest estimates that do not differentiate between light goose species, or because data are more easily compiled at the state level than according to goose population boundaries. Readers should note differences among authors in describing the population and species data that they summarize in their respective chapters, but also that winter indices of abundance suggest that the Western Central Flyway wintering population comprised only about 6% of all midcontinent light geese from 2001 through 2010. Thus, trends in harvest, abundance, and survival data are expected to be virtually identical regardless of which definition of midcontinent snow geese or Ross's geese is used.

We present the assessment in six chapters. The first updates the available information on changes to habitat in arctic and subarctic ecosystems, and the role of both species in contributing to the degradation of arctic and subarctic vegetation communities. While the short-term management goal was to reduce the population by one-half, the ultimate measure of program efficacy should be based on recovery of impacted habitats. Chapter 2 assesses state and federal surveys that measure the harvest of geese by hunters in both traditional hunting seasons and as part of conservation actions implemented since 1999, and provides information on levels of harvest before and after implementation of management actions. Increased harvest, if high enough, was expected to decrease adult survival rates sufficiently to result in population decline. It was unknown whether a decline in adult population size could have relaxed density dependence enough to lead to a compensatory increase in production of young. The third chapter assesses the effects of conservation actions on survival and productivity of the midcontinent population of lesser snow geese and Ross's geese. Chapter 4 summarizes available information about population size, and trends in numbers of midcontinent light geese before and after conservation actions were initiated in 1999. Some of these surveys have been in place for many years, while other estimation methods have been implemented since the beginning of the new management programs. New data and approaches are available to help forecast the outcome of future management programs using new population models. This is the subject of chapter 5, which explores the effects of stochastic variation in survival and reproduction on population trajectory, the importance of metapopulation structure and momentum on population dynamics, and evaluates management alternatives through elasticity analysis. The Ross's goose has been central to the monitoring and management programs instituted in both Canada and the United States since 1999, although information about their population status and impact on habitats was less well-developed when the new management programs were implemented. The final chapter, by all members of the working group, summarizes the conclusions from all chapters and offers suggestions as to how agencies might address the continued management challenges of overabundant midcontinent light geese.

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NORTHERN WETLAND ECOSYSTEMS AND THEIR RESPONSES TO HIGH DENSITIES OF LESSER SNOW GEESE AND ROSS'S GEESE

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Introduction

Following the publication of *Arctic Ecosystems in Peril* in 1997 (Batt 1997), federal, state and provincial governments in North America undertook actions intended to reduce populations of lesser snow geese (*Chen caerulescens caerulescens*) and Ross's geese (*Chen rossii*), particularly the midcontinent populations which are responsible for much of the acknowledged impact of geese on arctic and subarctic vegetation. This review incorporates information that has become available since that report was published. The primary focus is the relationship of lesser snow geese and to a lesser extent, Ross's geese with the northern habitats where they breed or stage. This includes the

coastal zones of James Bay, southern, western and northern Hudson Bay, the islands and coasts of Foxe Basin and the central arctic (Figure 1). Wherever possible, primary literature sources in peer-reviewed journals are referenced, but some relevant information is unpublished. A recent report documented key terrestrial habitats used by migratory birds, including many geese, in the Northwest Territories and in Nunavut (Latour et al. 2008). Separate reports have already appeared on the greater snow goose (*C. c. atlantica*) (Batt 1998, Reed and Calvert 2007), but they are not included in this assessment.

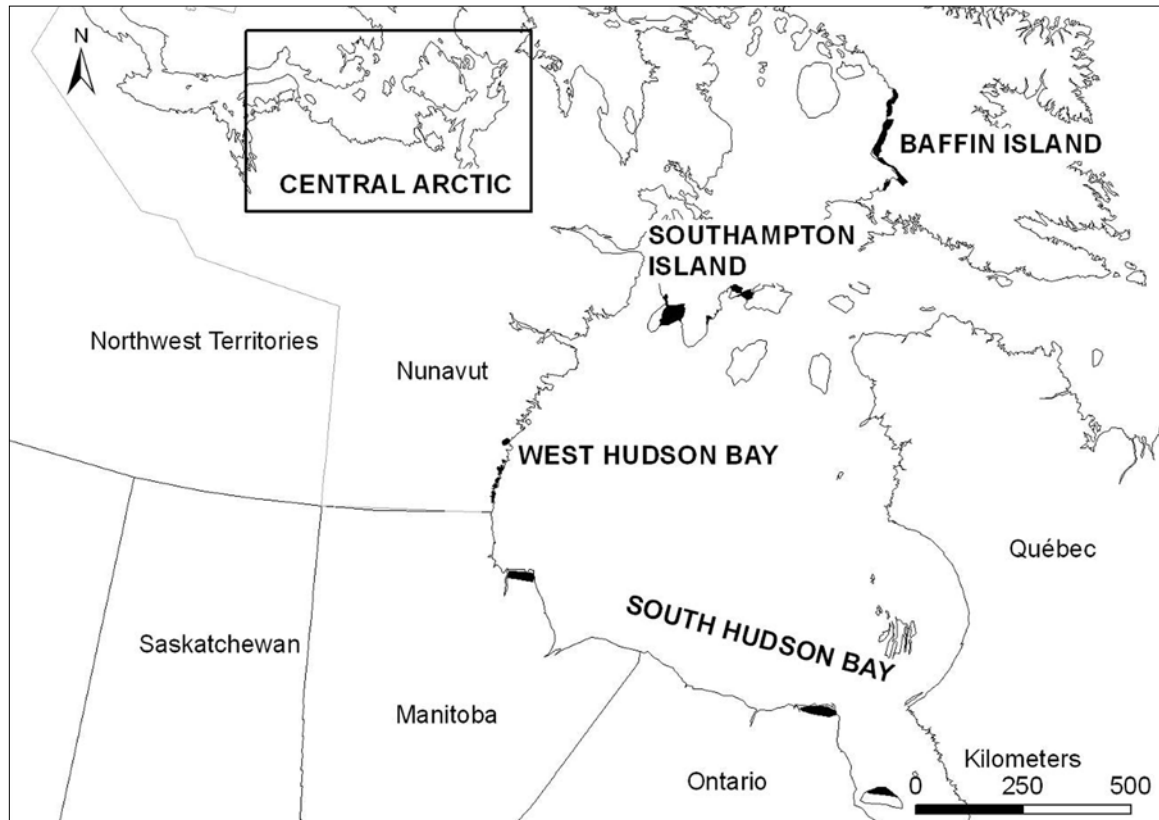


Figure 1. Nesting regions of Lesser Snow and Ross's Geese in the Eastern Canadian Arctic and Central Canadian Arctic (from Kerbes et al. Draft MS).

Summary of the First Assessment and a Preamble to this Assessment

We begin with a summary of the main conclusions of the earlier publication (Abraham and Jefferies 1997) which forms a basis for reviewing recent research findings. The summary statements pertain primarily to changes on the Cape Churchill Peninsula, Manitoba, owing to the state of knowledge at that time. However, other sites in the Canadian arctic have been studied in detail during the intervening years, hence some additional comments have been made where appropriate in this summary to give a wider perspective.

1. A combination of direct and indirect anthropogenic factors is at the root of the twentieth-century increase in arctic geese, both in North America and Europe. However, one of the major influences, modern agricultural practices, is not the responsibility of wildlife management agencies. As long as the cultivation of cereal grains and pulses that are used by geese is economically profitable and agricultural practices remain relatively unchanged, the production of these crops probably will sustain continued growth of goose populations that winter in terrestrial habitats on the two continents. Whether the arctic can continue to be a source of suitable forage for expanding populations of geese during the post-hatch period is uncertain as its carrying capacity is unknown. A nutrient and energy subsidy derived from foraging in agricultural croplands and the expanded migration and winter ranges has been a major influence enabling geese to increase in numbers in recent decades. Expected density-dependent effects, such as increasing mortality in late winter, fail to operate because of the subsidy.
2. It is not only the large numbers of lesser snow geese and Ross's geese but also their colonial or gregarious behaviour on the migration and breeding grounds that result in locally high densities. Additionally, their faithfulness to breeding areas ensures that they nest repeatedly in the same northern areas over decades. Together, these behaviours have caused substantial changes to northern plant assemblages both in coastal salt marshes and freshwater sites far inland. Although nesting birds are highly concentrated, family groups disperse widely along coasts dominated by salt marsh but also can rely on freshwater sedge meadows far inland during the post-hatch period. In parts of their range, higher densities of light geese are found in intertidal salt marshes than in adjacent freshwater habitats. In others areas, light geese use freshwater habitats almost exclusively over coastal salt marsh throughout their entire summer residence in the arctic. This movement behaviour during the post-hatch period ensures that some birds no longer forage in traditionally used sites that have been degraded. As a consequence, local populations avoid some density-dependent regulation.
3. The different foraging activities of the geese in the intertidal marshes of Hudson Bay and James Bay, that include grubbing of below-ground biomass and shoot pulling of graminoids at thaw followed by grazing during the snow-free season, have resulted in vegetation loss and exposure of the underlying marine sediments. Increased evaporation from these sediments results in hypersalinity in summer together with other deleterious changes to the sediments, such that plants are unable to re-establish easily either from seed or by clonal growth. The few plants that do establish are quickly removed by the geese. The hypersalinity also kills mature willow bushes present in the upper intertidal and supratidal marshes.
4. Where the loss of intertidal vegetation has occurred in the Hudson Bay Lowland, lesser snow geese have moved inland and they forage in freshwater sedge meadows (mesotrophic or calcareous mires) primarily on graminoids. In spring, a considerable amount of shoot-pulling of sedges is evident in these meadows followed by grazing of leaf tips of *Carex* and other graminoid species in

summer. The continual foraging year after year leads to the death of graminoids and exposure of the underlying peat that gradually erodes, revealing glacial silt and gravels where soils are drained. This change alters the successional trajectory and eroded sites may be colonized by shrubs. In poorly drained areas, moss carpets develop on the surface of the peat. Seedling establishment by *Carex spp.* in moss carpets or on eroded peat is difficult or impossible as they require mineral or other non-organic substrates, so degraded freshwater sites are likely to resist revegetation.

5. Loss of freshwater and heath vegetation as a result of foraging and nest building leads to exposure of surface peat and has been reported at other sites in the arctic frequented by lesser snow geese and Ross's geese, including west Hudson Bay and Karrak Lake, Nunavut. The long term effects of grazing and shoot pulling on loss of sedges in brood rearing areas are less clear, although detectable with exclosures. Grazing rather than grubbing is the predominant foraging activity in these freshwater brood rearing areas that leads to a reduction of biomass. Increasing numbers of nonbreeding light geese, however, can resort to shoot-pulling early in the summer in brood-rearing areas before goslings and their adults arrive from natal colonies. Such non-breeding adults switch to grazing later in the summer.
6. The area of intertidal salt marsh between the Maguse River, Nunavut on the west coast of Hudson Bay and Attawapiskat, Ontario on the west coast of James Bay is estimated at 54,800 hectares, of which 35,600 hectares are no longer productive and the remaining areas of salt marsh swards are heavily utilized. Similar data for the more extensive sedge meadows in freshwater habitats farther inland in this region are unavailable. These estimates are based on the application of remote sensing techniques and the monitoring of vegetation losses along transects in intertidal marshes. Although restoration of vegetation is possible on a small scale experimental basis (1 m²), large scale restoration of denuded areas in intertidal marshes is impractical.
7. The overall conclusion is there is no evidence of a decline in the rate of habitat degradation either in intertidal habitats or inland freshwater habitats along south Hudson Bay since the initial report was written (Abraham and Jefferies 1997). With or without reduction of goose numbers, secondary processes within the soil, such as hypersalinity, anaerobic conditions, loss of organic matter and the seed bank, and development of moss carpets or eroded and dried exposed peats, will largely control re-colonization by plants in the short to medium term (ca. 20 years).

Crop Production, Fertilizer Use, and the Growth of the Midcontinent Population of Lesser Snow and Ross's Geese

During the last decade, there have been significant advances in our understanding of the biology of the midcontinent population of lesser snow geese and other goose populations that breed in the arctic, that justify some changes to the paradigm presented in the earlier report (Abraham and Jefferies 1997). It has become increasingly evident that both in North America and in Europe the

growth of different species of arctic nesting geese is heavily affected by agricultural policy. Thus, we begin with a discussion of events on the wintering grounds and along the flyways that have affected waterfowl populations and, in turn, wetland habitats in northern latitudes linked via the migratory connectivity of the birds (Webster et al. 2002).

Geese feed on waste grains such as corn, rice and wheat and pulse crops, and green cover such as alfalfa, but consume little or no soybean (Alisauskas et al. 1988, Alisauskas and Ankney 1992, Alisauskas 1998, Alisauskas 2002, Krapu et al. 2004). Total land area planted with corn and wheat has shown little change during the last 50 years (Abraham et al. 2005a), although the area planted with corn may increase again with the demand of corn for ethanol production (c.f. Sanderson 2006). Data on the total area planted with corn mask agricultural changes among states during this period. For example, growers in Louisiana increased corn plantings at the expense of rice production in the last two decades. The total area devoted to rice in the United States approximately doubled from 1954 to 1975, but has not increased further. Again, this stability masks state-specific changes, e.g., substantial declines in Louisiana but substantial increases in Arkansas. In contrast, the area of soybean production increased three-fold between 1954 and 2002 (Krapu et al. 2004, Abraham et al. 2005a). Variation in weather patterns during the growing season also strongly influences the availability of grain for geese, e.g. yields of wheat were variable during 2006 and 2007, particularly in Canada where increased dryness of prairie soil, late spring frosts and a declining acreage lowered yields by as much as 20% in 2007-08 compared with 2006 (Klaassen 2008). Overall, where the midcontinent population winters or visits on migration, the area of agricultural land planted with corn is approximately double that of rice. Krapu et al. (2004) provided a useful land use map of crop production for the Central and Mississippi Flyways.

The yields, as distinct from the area under cultivation, of corn, rice, wheat and soybean have increased substantially in the last 50 years in the Central and Mississippi Flyways. Increases are of the order of 3.5-fold for corn, 2.5-fold for rice, 2-fold for wheat and 6.5-fold for soybean. This is the outcome of the introduction of high-yielding varieties and the application of nitrogenous (N) fertilizers. In 1990, about 40% of the total N fertilizer used in crop production in the US was on agricultural land in the north central states and Texas and much of this fertilizer was (and is) used for corn production (Lanyon 1995). These states are situated along the Central and Mississippi Flyways, and hence it is not surprising that spilled corn continues to be one of the primary food sources of lesser snow geese (Frederick and Klaas 1982, Alisauskas and Ankney 1992). Post-harvest waste corn averaged 2.6% and 1.8% of yield in 1997 and 1998, respectively, providing ample food for many species of migratory and resident wildlife over the past 60 years (Krapu et al. 2004).

Changes in patterns of crop production result in a behavioural response by geese that leads to rapid adjustments in their winter foraging habits and migration routes (Krapu et al. 1995, Jefferies et al. 2004a). In recent years, pulse crops (legumes) have been grown in the Great Plains of the northern United States and southern Canada, particularly in North Dakota and Saskatchewan, where the

length of the growing season is adequate. The crops include field (dry) pea, lentil, field bean and chickpea, which are playing a much greater role in the diversification of cropping systems in the northern Great Plains (Miller et al. 2002). Showing opportunism and adaptability, geese are now feeding on spilled pulses in these croplands (Pearse et al. 2010, 2011). In 2005-2006 (August to July crop year), 5.6 million acres of pulse crops were harvested in Canada (the majority in Saskatchewan; Saskatchewan Agrivision Corporation 2002) and 1.29 million acres were harvested in the United States (the majority in North Dakota; Janzen et al. 2006).

Land Use and Refuges

Changes in land use are expected to influence goose movements within the region. Examination of the distribution and density of the midcontinent population of lesser snow geese on the wintering grounds indicates that there is little evidence of a northward shift in wintering during the last 20 years beyond the area occupied in the early 1980s, which represented the culmination of a period of 30 years of geographical expansion (Abraham et al. 2005a). However, densities of birds have increased substantially within this area, particularly in rice-growing areas in the southern Mississippi River alluvial valley and in the northern corn-belt. Although a predictable food source is readily available over a wide geographic area along the Central and Mississippi flyways, there is a coincident contributing factor that accounts for the growth of the midcontinent population of lesser snow geese. The extensive network of U.S. National Wildlife Refuges, both on the wintering grounds and along the migration routes of this population, is over 1.5 million hectares and 59% of the reserves were established after 1954. Numerous additional reserves administered by state and private agencies also were established at a time that was broadly coincident with the major changes in agricultural practices and land use outlined above. Refuges provide safety from hunters and food for the birds in landscapes that often include large wetland complexes adjacent to agricultural fields (USFWS 2007). At some refuges, goose movements between agricultural land and refuges are jointly controlled by agricultural and wildlife officers, following guidelines that meet farming and wildlife conservation interests, as well as hunting and tourism (Taylor and Kirby 1990).

Before the establishment of agriculture in the midcontinent of North America, annual weather variations, including drought, likely rendered the availability and nutritional quality of natural food sources on migration routes and on the wintering grounds unpredictable in time and space (Alisauskas and Ankney 1992). Today, there is a network of agricultural landscapes and refuges along the flyways that provide suitable habitats and food that were previously unavailable. The birds are able to exploit differences in the annual and seasonal phenologies of snow melt, water conditions, agricultural crops, grain availability and weeds with less energy expenditure than previously because of the geographical proximity of sites (Frederick and Klaas 1982, Alisauskas and Ankney 1992). Increased flexibility in movements of birds, accelerated by land use changes since the late 1980s, has led to shifts in migratory pathways. This has resulted in more frequent stopovers between wintering

and breeding areas. Consequently, midcontinent lesser snow geese are less vulnerable to unpredictable climatic vicissitudes than when they migrated over longer distances to fewer staging or wintering sites (Alisauskas 2002, Abraham et al. 2005a and references therein). This stepping stone model describes the northward movement of the birds in spring as they follow the retreating snowline in a series of stopovers. The flexible tactics enable birds to acquire resources for reproduction in addition to migration. The extensive network of refuges, many of which are located in agricultural areas, in effect provide multi-channel migration routes with numerous fueling stations, enabling birds to switch routes depending on local circumstances (Jefferies et al. 2006a). Using a stochastic dynamic model to generate spatially and temporally explicit predictions of stopover site use, Bauer et al. (2008) showed that pink-footed geese (*Anser brachyrhynchus*) follow a risk-averse strategy during migration, favouring sites with highly predictable food supplies and low energy expenditure. With a changed climate, these geese leave the wintering grounds earlier but extend their staging times in Norway, arriving on the breeding grounds no earlier than in previous years (Bauer et al. 2006, 2008), a situation analogous to midcontinent snow geese (Abraham and Jefferies 1997).

Prebreeding Nutrient Acquisition

To exploit the short arctic growing season, geese acquire energy and nutrients from lower latitudes and use it in early stages of reproduction to shorten the length of the breeding season and improve the chances of reproductive success. Birds that import nutrients and energy to the arctic breeding site in this way have been called “capital” breeders, as they utilize these body stores to subsidize the costs of laying and incubation (Ryder 1970, Drent and Daan 1980, Meijer and Drent 1999, Schmutz et al. 2006). However, the extent to which migratory birds that winter in southern biomes but breed in the arctic rely on residual body stores for egg production is not fully resolved, although the importance of reserves for incubation is well recognized (Klaassen et al. 2006). The amount of reserves available will be influenced by body size (more prevalent in larger birds; Klaassen 2003), increased energetic and predation costs associated with carrying large stores, distances between staging sites and the location of breeding grounds within the arctic. Birds rarely fly directly to the breeding grounds and extensive feeding by migrants may occur in the arctic, even within a few kilometers of the breeding sites as the birds track the retreating snowline. Birds are thus able to store resources necessary for egg laying and incubation at local or regional scales. It is important to distinguish between local capital breeding and distant capital breeding, in terms of understanding the importance of contributions from various habitats and sites, and the impact of millions of staging geese on wetland ecosystems at northern latitudes. The extent to which a bird is characterized as a distant capital or an income breeder not only varies between species but also between individuals and seasons (Klaassen et al. 2006, Drent et al. 2007).

Originally, the distinction between capital and income breeding was based on the deposition of energy and protein in eggs (Drent and Daan 1980), but more recently all reproductive investment

up to the time of hatch has been included in the assessment. The energy content of a clutch of bird's eggs is only one-fifth to one-quarter of the energy costs of migration (Jenni and Jenni-Eiermann 1998) and migratory fuel stores do not have the same protein to fat ratio as eggs. On a dry weight basis, eggs contain approximately 60% protein (Sotherland and Rahn 1987) which is much higher than the 6-20% protein found in migratory food stores (Jenni and Jenni-Eiermann 1998, Klaassen et al. 2006). Fat stored in adipose used in migration contains virtually no water, whereas protein is associated with as much as 77% water (Blaxter 1989). Because of this high water content, large protein stores for egg synthesis would add considerably to a bird's weight at the start of migration. It is generally assumed that energy costs per unit of flight distance increase sharply with an increased fuel load (Pennycuik 1989, Alerstam and Lindstrom 1990, Weber et al. 1998). In spite of this, "capital breeders" must be able to meet protein demands for egg laying and to a lesser extent for body maintenance during incubation on the breeding grounds (Allan and Hume 2001).

Given the body size of many geese, the group has often been identified as capital breeders (c.f. Klaassen et al. 2006 and references therein). However, many goose species feed intensively on arrival at the breeding grounds indicating that not all are strictly capital breeders. In an early study of migrating lesser snow geese, Wypkema and Ankney (1979) noted that the fat reserve index of females did not change between staging sites and breeding grounds along the coast of Hudson Bay, a distance of 1,800 km. In contrast, the protein index increased, indicating that the birds were feeding en route. In excess of 60% of the protein needed to meet demands from arrival to hatch was acquired in the Hudson Bay Lowland rather than the northern prairies. This protein demand during late spring migration has driven the process of goose induced habitat degradation on the southern Hudson Bay coast, and intensive foraging may continue at some breeding locations. Ganter and Cooke (1996) reported that lesser snow geese at La Pérouse Bay, Manitoba, foraged intensively in many years and thus appeared not to be fully capital breeders. Similarly, Gloutney et al. (2001) reported that female Ross's and lesser snow geese spent considerable time foraging on mosses, chickweed and sedges at Karrak Lake during the pre-laying and laying periods, although the actual consumption of food was low indicating that results from studies that do not directly measure intake rates are equivocal. The larger greater snow goose on Bylot Island, Nunavut, obtains most of its fat and protein requirements for egg production after arrival on the breeding grounds (Choinière and Gauthier 1995, Gauthier et al. 2003). Feeding does not appear to be directly related to goose size, as even within a species different patterns of foraging are evident depending on the location, and travel distance is a key factor (Hobson et al. 2011). Additionally, those birds arriving late on the breeding grounds are more likely to use endogenous rather than exogenous reserves for egg production than birds arriving early, irrespective of the size of the bird (Klaassen et al. 2006).

Recently, stable isotope analysis has been applied to determine sources of egg production in arctic breeding birds (Gauthier et al. 2003, Morrison and Hobson 2004, Hobson 2006, Klaassen et al. 2006, Sharp 2010, Traylor 2010, Hobson et al. 2011). Gauthier et al. (2003) found no shift in the isotopic ratio of eggs of the greater snow goose on Bylot Island within a clutch. They showed that

reserves formed a constant proportion of nutrients placed in eggs over the entire laying period. The percentage contribution of endogenous reserves to egg protein was only 27 % to 33 % and egg lipid was less than 25% for greater snow geese nesting on Bylot Island, and there was very little variation in these values between years. By contrast, Hobson et al. (2011) showed that lesser snow geese at La Pérouse Bay had endogenous protein contributions to eggs of about 30%, similar to the greater snow geese, but endogenous lipid contributions were about 55%, over twice that of the larger greater snow geese. Annual variation in the carbon isotope ratios of hatching down of goslings of lesser snow geese on Akimiski Island (Nunavut) in James Bay indicates that the dependency of adult females on both lipid and protein stores derived from C₄ plants (endogenous reserves derived from corn) varies annually (Klaassen et al. 2006). Examination of down isotopic signatures among goslings within a family indicated similar isotopic ratios, irrespective of hatching order. Sharp (2010) found that lesser snow geese on Akimiski Island relied less on endogenous resources for egg production (15% for albumen, 30% for yolk protein, and 27% for yolk lipid) than did sympatric Canada geese, and that the proportion of endogenous resources varied among years. These percentages for lesser snow geese are low relative to other studies at higher latitudes. Traylor (2010) found that Ross's geese nesting at Karrak Lake displayed greater reliance on stored reserves than did snow geese, though both used endogenous reserves (> 62% of yolk protein, > 48% of albumen, and > 73% of yolk lipid) for clutch formation. Ross's and snow geese experienced declines of 28% and 23% in body masses from arrival to post-laying but also until hatch demonstrating that endogenous reserves are the main nutrient sources for incubation at Karrak Lake. Still, Traylor (2010) suggested that constraints of small size forced Ross's geese to use a mixture of local food plants and reserves for incubation metabolism.

We contend that reliance by arctic geese upon stored nutrient reserves is a flexible strategy which is dependent, in part, on species, body size, food quality (protein) and variation in its relative abundance along the migration route and at different breeding areas (Gloutney et al. 1999, Klaassen et al. 2006, Hobson et al. 2011). Migrating lesser snow geese track the receding snow line and feed at coastal and inland sites where sufficient thaw has occurred. Feeding stops can occur at distances of tens of kilometers from the breeding grounds rather than just at hundreds of kilometers (characteristic of the migration distance) from southern agricultural lands to northern staging wetlands. Migration patterns within the subarctic and arctic allow the birds to lay down endogenous reserves as little as 10 km from the nesting site (Jefferies et al. 2003, Hupp et al. 2006). Hence, the distinction between capital and income breeding requires qualification with respect to the geographic origin of the capital along the migration route from the wintering grounds to the breeding site (c.f. Drent and Jefferies 2006, Drent et al. 2007). Historically, a majority of midcontinent snow geese migrated through James Bay and southern Hudson Bay, staging and acquiring nutrients on the coastal marshes of the Hudson Bay Lowland (Curtis 1976, Gauthier et al. 1976, Wypkema and Ankney 1979). Concurrent with population growth and changes in agricultural practices across the flyways, spring migration has shifted to the west and a large portion of the population is now thought to migrate from prairie staging areas more directly north. The current proportion of the population using the Hudson Bay Lowland coast during either spring or fall migration is unknown. Further, very

few snow geese marked in arctic nesting areas, i.e., north of 60°N latitude, since 1988 are recovered at any time along the southern Hudson Bay coast and in James Bay, in comparison to the snow geese that originate from colonies south of 60°N (Alisauskas et al. 2011). Little is known about important areas for nutrient acquisition by snow and Ross's geese that might travel directly north from prairie staging ground to breeding areas in the central arctic.

Linked to the acquisition of resources along the migratory pathway is the impact of the spring hunt on migratory populations (Mainguy et al. 2002). Féret et al. (2003) concluded that in the Gulf of St. Lawrence, the conservation order hunt for greater snow geese was the most important factor explaining the low fat and protein storage of geese in the springs of 1999 and 2000. Hunting disturbance likely reduced nutrient storage of geese for reproduction because of decreased feeding activity and increased flying time. This may have resulted in compensatory feeding later in migration or at breeding areas. Information on the physiological impact of the conservation order hunts in the midcontinent region on lesser snow geese is lacking, although baseline information has been established by Alisauskas (2002), and Leafloor and Alisauskas (unpublished data) monitored levels of nutrient reserves in lesser snow geese during spring 2002-2006 on the Canadian prairies. Traylor (2010) found that both Ross's and snow geese showed long term declines (from 1993 to 2008) in the amount of protein with which they arrive to breed at Karrak Lake in the central arctic, despite the absence of a long-term change in body size over the same time span. There was substantial evidence for a curvilinear decline in protein reserves with increasing size of the local nesting population, a pattern of decline consistent with increased competition for food resources on northern staging areas. Although declines occurred in both species, an interaction between species and population size suggested that declines in protein reserves of snow geese were steeper than those of Ross's geese. Models which included density dependent effects on protein reserves at arrival fit the data better than a competing model with inclusion of an effect of the conservation order. Long-term patterns of change in fat reserves of Ross's and snow geese arriving at Karrak Lake varied strongly by species; from 1993 to 2008, abdominal fat values of female snow geese predicted from the best model declined from about 87g to 65g, representing a long-term decline of 25%. However, abdominal fat of female Ross's geese increased from 55 g to 60 g. Thus the long-term reduction in fat reserves occurred only in snow geese, and may explain why Ross's geese generally have higher nest success, probably higher breeding propensity, and higher rates of local population growth, than do snow geese at Karrak Lake (Alisauskas et al. 2012). It remains equivocal if the long-term decline in snow goose fat reserves was attributable to density dependence or the conservation hunt, as models with either effect did not fit the data as well as a simple linear trend (Traylor 2010).

Distribution and Habitat Use During Brood Rearing by Lesser Snow and Ross's Geese

Many of the largest snow goose colonies, particularly in the eastern arctic and subarctic, were established in coastal areas, on or near salt marsh habitats that provided high quality forage plants for brood rearing. Though coastal salt marsh habitats are often favored, snow and Ross's geese can use either salt marsh or freshwater wetland habitats (e.g., Slattery and Alisauskas 2007, Samelius et al. 2008, Winiarski et al. 2012). Freshwater habitats include wet sedge meadows associated with lowlands that support large expanses of graminoids such as *Eriophorum angustifolium* and *E. vaginatum*, *Carex aquatilis*, *Dupontia fisheri*, *Festuca brachyphylla* and *Arctophila* spp. Slattery and Alisauskas (2007) studied habitat selection by snow and Ross's goose adults with their goslings in a large 5,000 km² brood-rearing area used by geese originating from the Karrak Lake colony south of Queen Maud Gulf. They used GIS to compare the proportion of light geese in specific habitat polygons mapped and defined by Didiuk and Ferguson (2005) for the entire 63,000 km² Queen Maud Gulf Bird Sanctuary. Slattery and Alisauskas (2007) determined that lowland sites composed of wet sedge meadows, hummocky graminoid tundra, tussocky graminoid tundra, and freshwater waterbodies, were selected by light geese proportionally more than their availability on the landscape. Exposed substrates such as those associated with solifluction along major rivers and coastal mudflats that support *Puccinellia* spp, *Carex subspathacea*, or *C. ursine*, where these composed up to about 80% of the ground cover, were used in proportion to their presence. Habitats avoided by geese during brood-rearing included shrub thickets, exposed peat, low shrub tundra, marine waters along the north coast of the sanctuary, moss-lichen tundra, bedrock and boulder fields, and lichen heath tundra, the last 3 found mostly in upland habitats. Most families from the Karrak Lake breeding colony dispersed up to 70 km northward toward the coast, where Slattery and Alisauskas (2007) found that density of birds was greatest, presumably because freshwater terrestrial habitats preferred by light geese there were more common in that direction than in any other direction from the colony.

Methods used by Slattery and Alisauskas (2007) were somewhat constrained by the 30 m resolution of Landsat imagery (Didiuk and Ferguson 2005) in which riparian habitat was not readily distinguishable. Such riparian habitat that can extend far inland along river valleys, however, is important judging from a separate study by Slattery (2000); he used dropping density as an index of goose use, and found such densities to be 3 times higher in riparian habitats, than in favoured wet sedge meadows, and 6 times higher than in exposed substrates which included coastal *Puccinellia phryganodes* mud flats. This was probably because protein content of plants generally was higher in riparian habitats than in either wet sedge meadow or hummock graminoid tundra.

Samelius et al. (2008) estimated abundance of adult snow geese and goslings during brood-rearing on a 18,055 km² study area bounded by the west coast of Banks Island, and extending ~190 km eastward from the coast between the Bernard River on the north and east, and the Kellett River on the south boundary. They found lower densities of lesser snow geese/km² in upland habitats compared to

river valleys. However, the large 14,435 km² expanse of such uplands represented about 80% of the area and so contained absolutely more geese than the smaller 3,620 km² area composed of preferred habitats within river valleys. For example, uplands contained 76% of 297,000, 42% of 92,000 and 58% of 288,000 snow geese estimated on this area in 1996, 1997, and 1998, respectively. Thus, adult snow geese can subsist and goslings can develop in habitats far inland from coastal areas, and freshwater habitats support large numbers of geese at all major nesting areas in recent decades.

Impacts of the Midcontinent Population of Lesser Snow and Ross's Geese on Subarctic and Arctic Ecosystems

Runaway growth of the lesser snow goose and Ross's goose populations seems to have occurred largely because of wide-scale application of industrial fertilizer to agro-ecosystems, which elicited a growth response of crops via a bottom-up effect. However, a primary effect of the increased numbers of geese is an apparent cascade of complex top-down effects on northern wetland ecosystems that are a great distance from the source of the agricultural food subsidy. The resilience of these northern ecosystems is particularly sensitive to the density of lesser snow and Ross's geese, which can result in two different outcomes to the vegetation on which they are feeding. At moderate-high densities, forage plants exhibit over-compensatory growth of above-ground biomass in response to grazing which sustains local goose production, but at high to very high densities, over-compensatory growth gives way to lack of resilience and with the addition of grubbing of below ground plant parts, results in sward destruction and near irreversible changes in soil properties. In extreme cases, the result of this "migratory connectivity" (Webster et al. 2002) has been a catastrophic shift in ecosystem functioning as a result of biotic exploitation which in turn has led to the alternative stable-state of exposed sediments in salt marshes (Henry and Jefferies 2008) and moss carpets, exposed peat or dried mosses in freshwater systems.

Coastal sites (up to 5 km from the shore line including intertidal salt marsh and adjacent freshwater wetlands) on the boundary between the subarctic and the arctic are particularly vulnerable to disturbance by the geese, because they are both breeding and staging sites, and this effect is emphasized in western and southern Hudson Bay and James Bay. Different species and populations of geese use these boundary regions; some of the geese breed locally, while others breed at higher latitudes. The combination of high densities of birds, (particularly when snow persists farther north, delaying migration), together with the intensive feeding in recently thawed wetlands with little or no above-ground growth of vegetation, and repeated annual use is a recipe for habitat degradation (Jefferies and Rockwell 2002, Jefferies et al. 2006b). In at least two cases (La Pérouse Bay, MB and Akimiski Island, NU), there is documentation of disproportionate concentrations of spring staging geese that trigger the cascade of effects (Jefferies and Rockwell 2002); one possibility is that after such severe episodes of degradation, it takes only a relatively small number of geese to maintain the damage that was created, thus inhibiting recovery.

Although the loss of intertidal vegetation is triggered by lesser snow geese and Ross's Geese, subsequent abiotic changes in summer, including the development of hypersaline sediments, loss of organic matter and nitrogen, sediment compaction and increased aridity of the upper layers of sediment limit the potential for re-colonization of exposed soil (McLaren and Jefferies 2004). Biotic factors further constrain the re-vegetation process, examples being the loss of the seed bank in exposed sediments (Chang et al. 2001) and the loss of propagules of one of the dominant salt marsh graminoids, *Puccinellia phryganodes*; as it is a sterile triploid in North America, it reproduces only by clonal reproduction and the removal of the majority of plants reduces the number of leaf and root remnants that would otherwise grow vegetatively in soft sediments. The other dominant graminoid, *Carex subspathacea*, sets seed very infrequently, particularly in grazed swards. The alternate stable state of exposed sediment is characterized by an ascending spatial scale over time (Henry and Jefferies 2008). Initially intertidal swards undergo fragmentation as a result of grubbing and under its cumulative impact exposed patches of sediment coalesce over the years into larger units. This process is marked by the development of the adverse soil conditions described above and the inability of the vegetative units of these graminoids to re-establish in the compacted sediments (McLaren and Jefferies 2004). Experimental studies indicate that micro-patches of exposed sediment only 20 cm in diameter can become hypersaline within a growing season, limiting establishment of graminoid tillers (McLaren and Jefferies 2004). The sequences of change resulting in vegetation loss in the intertidal and adjacent coastal marshes of the Hudson Bay Lowland and the establishment of an alternate stable state are described in detail in Handa et al. (2002), Jefferies et al. (2003, 2004b) and Henry and Jefferies (2008).

With the loss of intertidal vegetation, the geese are increasingly foraging in adjacent freshwater sedge meadows (mesotrophic or calcareous mires) in the coastal wetlands of the Hudson Bay Lowland in both early spring and during the post-hatch period in summer. The dominant species of these wetlands is the sedge, *Carex aquatilis*, which may grow 50 cm or more in height. At spring thaw, staging and breeding geese feed heavily on the shoots of this graminoid. They pull up the shoot early in the growing season and eat the basal portion, which is rich in soluble carbohydrates and nitrogen (Gadallah and Jefferies 1995a, Kotanen and Jefferies 1997). The remainder of the shoot is discarded and the cumulative effect of this shoot-pulling over the years is the death of the sedge plants and exposure of the peat substrate. Large wind rows of pulled shoots collect at the edge of transient melt water ponds in spring (Kotanen and Jefferies 1997); the subsequent vegetation changes depend on the hydrological regime and the relative role of shoot-pulling versus grazing isn't completely clear. Where the peat drains, or where it dries out in summer, the organic layer erodes as a result of chemical oxidation, physical erosion and biological decomposition of the peat. This can result in exposure of glacial gravels and marine clays that reflect the earlier history of the site; subsequently willow and other shrubs can colonize these eroded sites. However, where the peat remains waterlogged, a moss carpet often grows on the surface of the exposed peat, embedded in which are vascular plant species, such as *Potentilla palustris*, *Triglochin palustris*, *T. maritima* and *Petasites sagittatus* (these are species that often occur around lake margins together with *Eleocharis acicularis*). Because of the loss of much

of the intertidal vegetation, the birds now nest in larger numbers at moderate densities in the sedge meadows and also spend a considerable amount of time foraging in this habitat during the post-hatch period. Although adults are able to feed on shoot tips of *Carex aquatilis*, young goslings are physically incapable of reaching leaves of these shoots. In experimental field trials, goslings either lost weight or did not gain weight when they were given chopped leaves of *C. aquatilis* (Gadallah and Jefferies 1995b). Recent examination of the gut contents of goslings feeding in these sedge meadows soon after hatch has revealed that the four important gosling forage species are *Equisetum variegatum*, *Triglochin palustris*, *Festuca rubra* and *Dupontia fisheri* (Jefferies, unpublished data). While present, all of these occur at lower densities in dense *Carex* meadows than the equivalent plant forms/forage types in intertidal salt marshes. Hence, family groups must forage over a wide area for the goslings to acquire sufficient forage during the early days of life, in contrast to the intertidal salt marshes where family groups graze intensively on the grazing lawns of the small-leaved salt marsh graminoids. As goslings increase in size, they are able to forage on *Carex aquatilis*, but family groups are widely dispersed relative to intertidal areas. A wide dispersion (low density) of geese in the freshwater sedge communities results in relatively low average defoliation of shoots by grazing of individual plants during the brood-rearing period. However, if the birds are strongly clustered, the resulting higher amount of defoliation is likely to lead to substantial loss of above ground biomass, as it does in the central arctic and on Bylot Island, in greater snow goose breeding areas. Unlike *Puccinellia phryganodes*, the shoots of *C. aquatilis* appear to have relatively little ability to re-develop following defoliation. Leaf production and extension do increase after grazing, just not nearly as much as in *Puccinellia* (Kotanen and Jefferies 1989). If defoliation occurs over successive years, below-ground reserves are challenged in the absence of photosynthetic tissue, resulting in the death of the plant.

In other lesser snow goose and Ross's goose breeding areas, such as Baffin Island, similar pulling of shoots of *Eriophorum* spp. occurs (Hudson Bay Project, unpublished data). On Akimiski Island, *Festuca rubra* is the target of spring grubbing in supratidal areas. It flowers abundantly, but this does not seem to lead to much seedling establishment, a situation analogous to the lack of seedling production in the intertidal *C. subspathacea*.

There are nutritional differences between the intertidal marshes and the freshwater marshes of the Hudson Bay Lowland (Jefferies et al. 2003, Ngai and Jefferies 2004). Growth of salt marsh vegetation is primarily nitrogen limited, although when nitrogen is added to experimental plots, the vegetation quickly becomes phosphorus limited. In contrast, growth of vegetation in freshwater marshes adjacent to La Pérouse Bay is phosphorus limited and addition of nitrogen, in contrast to phosphorus, does not produce an increase in above-ground biomass within the season (Ngai and Jefferies 2004). More recent studies of the nutritional status of other freshwater marshes on the Cape Churchill Peninsula have shown that vegetation is either nitrogen or phosphorus limited, or co-limited by both nutrients (Edwards 2010). Phosphorus limitation may contribute to the small size of goslings if birds feed extensively in nutrient-poor mires. The selection of forage plants in spring and summer on the Cape Churchill Peninsula in both freshwater and saltwater marshes is strongly linked to the presence of

high amounts of soluble carbohydrates in tissues in addition to the levels of N and P (Jefferies and Edwards 2008). When the sugar content fell as a result of shoot development or leaf senescence, the geese switched to alternative sources of forage (Jefferies and Edwards 2008). Earlier studies by Thomas and Pevett (1980, 1982), Sedinger and Raveling (1984), Coleman and Boag (1987), Beaulieu et al. (1996), and Hupp et al. (2001) also have established a link between the selection of forage species and the soluble carbohydrate content of plants.

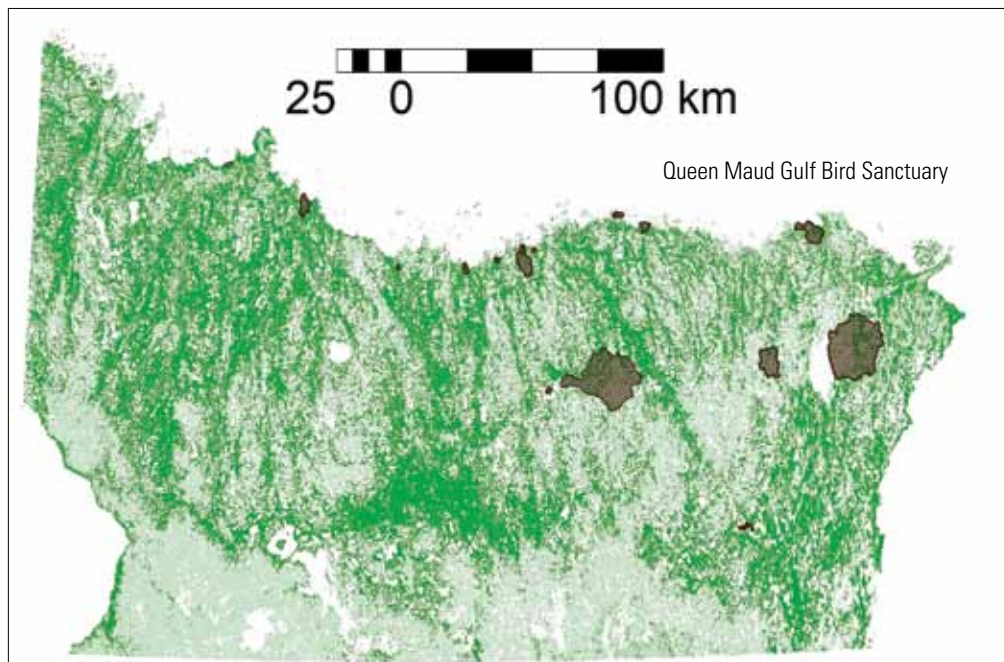


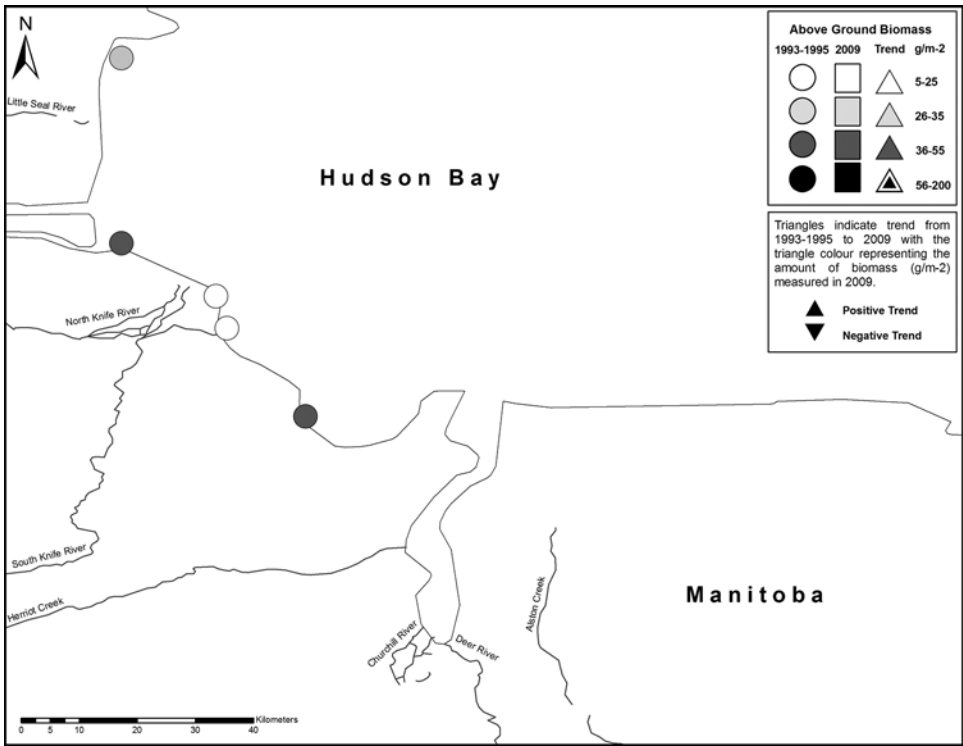
Figure 2. Distribution of 13,370 km² of habitats (darker green) preferred by Ross's and lesser snow geese during brood rearing (Slattery and Alisauskas 2007) in the Queen Maud Gulf bird sanctuary in the Canadian central arctic. Habitat map derived from Didiuk and Ferguson (2005). Also shown is known distribution of light geese nesting on mainland colonies (stippled) surrounding freshwater lakes between 2000 and 2011 (Kerbes et al. 2006, Alisauskas unpubl. data). Not shown are smaller insular colonies confined to islands in freshwater lakes.

We suggest that during the post-hatch period, net primary production of the freshwater meadows is driven by bottom-up processes in contrast to net primary production of intertidal vegetation where top-down processes (e.g., large faecal nitrogen input from high densities of foraging geese) formerly modulated growth. A similar conclusion has been reached by Slattery (2000) for the freshwater marshes of Queen Maud Gulf. At freshwater sites adjacent to the coastal salt marshes (within about 10 km) and in the vicinity of thermokarst ponds where densities of staging and locally breeding geese may be high in early spring, the incidence of shoot-pulling is of sufficient intensity to produce strong top-down effects as described above. Hence, there is a spatial and temporal continuum in these coastal wetlands of the Hudson Bay Lowland of strong top-down to strong bottom-up effects on net primary production that reflects the interaction between goose numbers, phenology and growth habit and availability of the forage species.

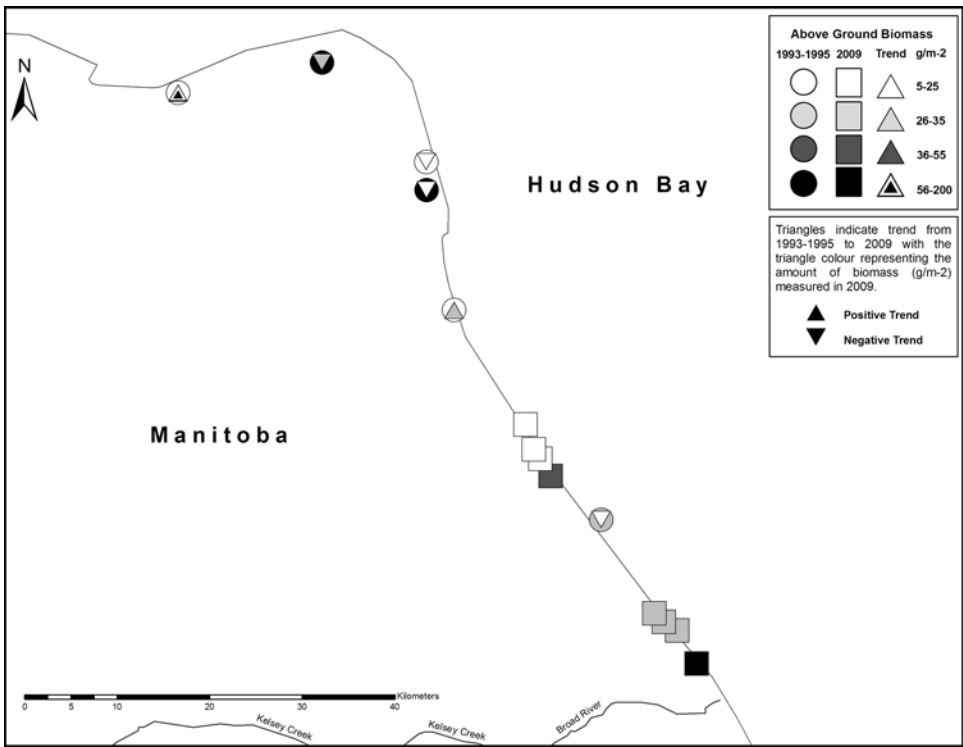
Documentation of the impact on northern ecosystems has now been accumulated from several staging areas and nesting colony sites of the midcontinent population of lesser snow goose and Ross's goose that breed in the Hudson Bay Lowland of Ontario, Manitoba and Nunavut, as well as west Hudson Bay, Queen Maud Gulf and Southampton Island, Nunavut. All have been shown to contain adversely affected salt and/or freshwater wetland plant assemblages and hummock graminoid communities and their associated soils at a large spatial scale (Kerbes et al. 1990, Kotanen and Jefferies 1997, Jefferies et al. 2003, O et al. 2005, Alisauskas et al. 2006, Slattery and Alisauskas 2007). Nevertheless, in some parts of the arctic there appear to be large areas of suitable habitat favoured by geese in other areas that as yet remain largely unoccupied. Slattery and Alisauskas (2007) found that areas surrounding freshwater lakes were selected far more often by brood-rearing snow and Ross's geese compared to the surface area represented by freshwater. The terrestrial habitats preferred by snow and Ross's geese at this time of year, including wet sedge meadow, hummock and tussock graminoid tundra, cover 13,370 km² in the Queen Maud Gulf sanctuary and large contiguous expanses of such habitats extend 150 km inland from the coast (Figure 2). The known major colonies that occupy mainland areas that surround freshwater lakes as well as associated brood-rearing areas, are found largely in the eastern half of the sanctuary (Figure 3). Thus, highly favoured freshwater wetlands and associated lowland tundra habitats found in the western half of the sanctuary, are largely unexploited by snow and Ross's geese, so far as is known.

On the other hand, almost all intertidal marshes of the Hudson Bay Lowland (Maguse River on the west coast of Hudson Bay to Moosonee in southern James Bay) have been severely disturbed by the effects of goose foraging (Abraham and Jefferies 1997, Jefferies et al. 2006b, Hudson Bay Project, unpublished data). The loss of vegetation reported in the first assessment (Abraham and Jefferies 1997) has continued during the conservation order (Figure 3). The changes to the vegetation can be detected with the use of LANDSAT imagery (Jano et al. 1998, Didiuk and Ferguson 2005, Jefferies et al. 2006b, Fontaine and Mallory 2011). Using remote sensing techniques, vegetation loss was quantified in nine small study areas in southern Hudson Bay to assess the timing of the events. Up to 43 % of the loss in these study sites occurred since 1996 (range 2.4-43.3%), and there is no evidence of any recovery of intertidal vegetation within the region as a whole (Jefferies et al. 2006b).

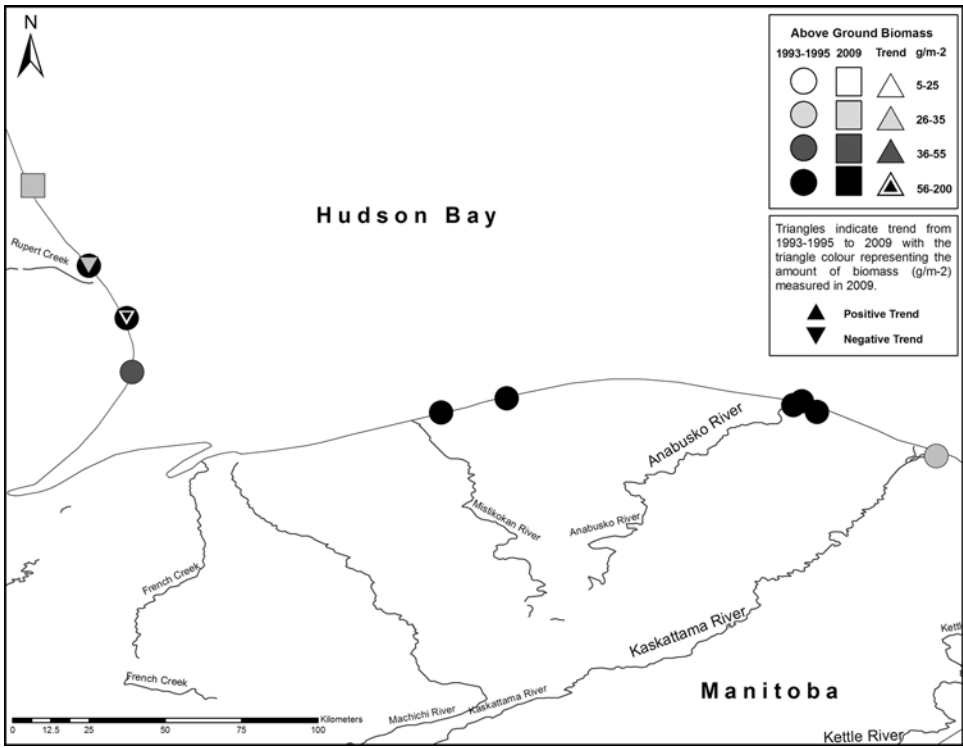
Damage and loss of vegetation are not confined to the intertidal marshes but have also occurred in the supratidal marsh where tidal inundations are infrequent (2-3 occasions every two years) and other coastal habitats, such as beach ridges, riverine wetlands and freshwater fens and marshes (Abraham et al. 2005b). Grubbing in spring of roots and rhizomes of the two graminoids mentioned above and of *Festuca rubra* (O et al. 2005) and *Calamagrostis deschampsiioides* in supratidal marshes leads to the death of willow bushes because of the resulting soil hypersalinity (Jefferies et al. 2006b). The loss of ground vegetation and the death of willow bushes have led to a decline in the breeding population of savannah sparrows (*Passerculus sandwichensis*) at La Pérouse Bay, reflecting the loss of nesting sites (Rockwell et al. 2003) and a decline in the invertebrate fauna, particularly numbers of spiders and beetles (Milakovic and Jefferies 2003). Similarly, there has been a decline in the species richness of



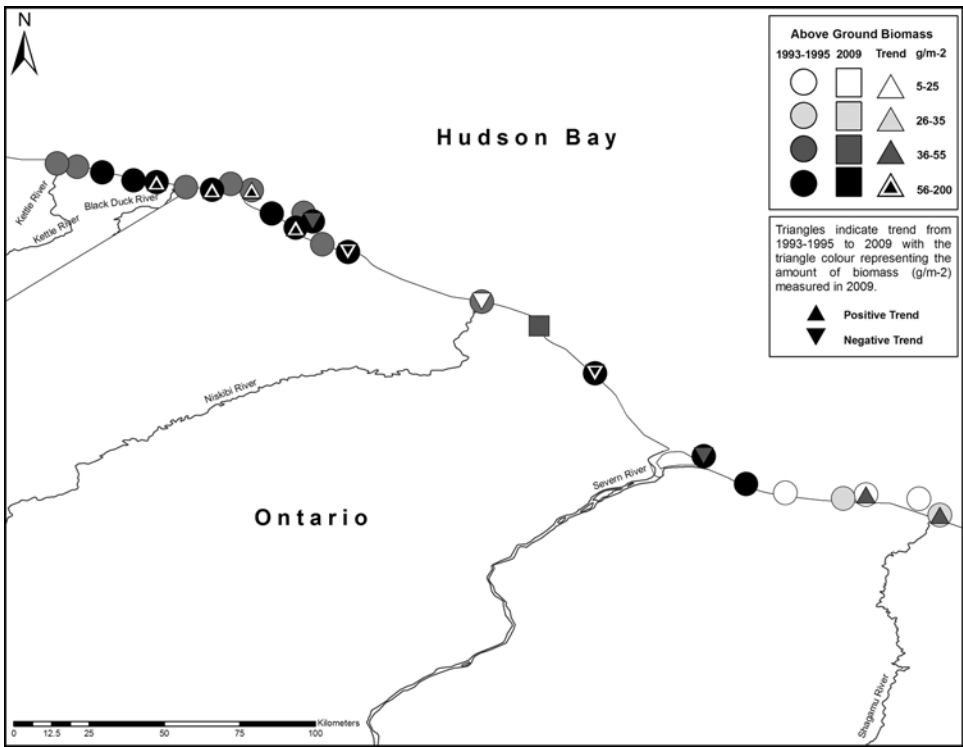
(A)



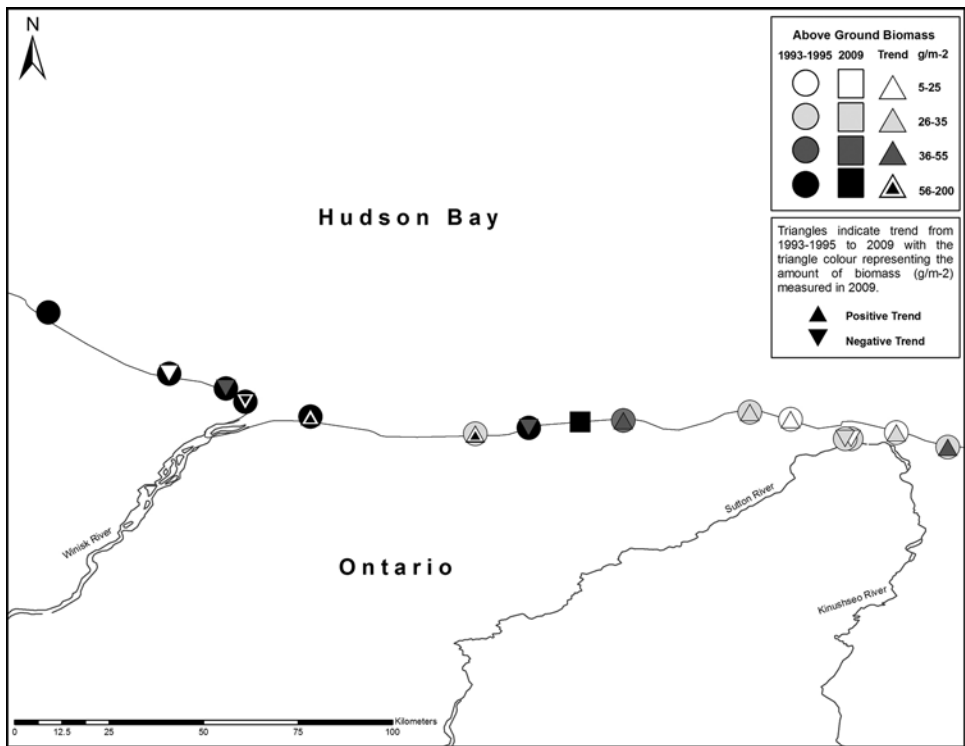
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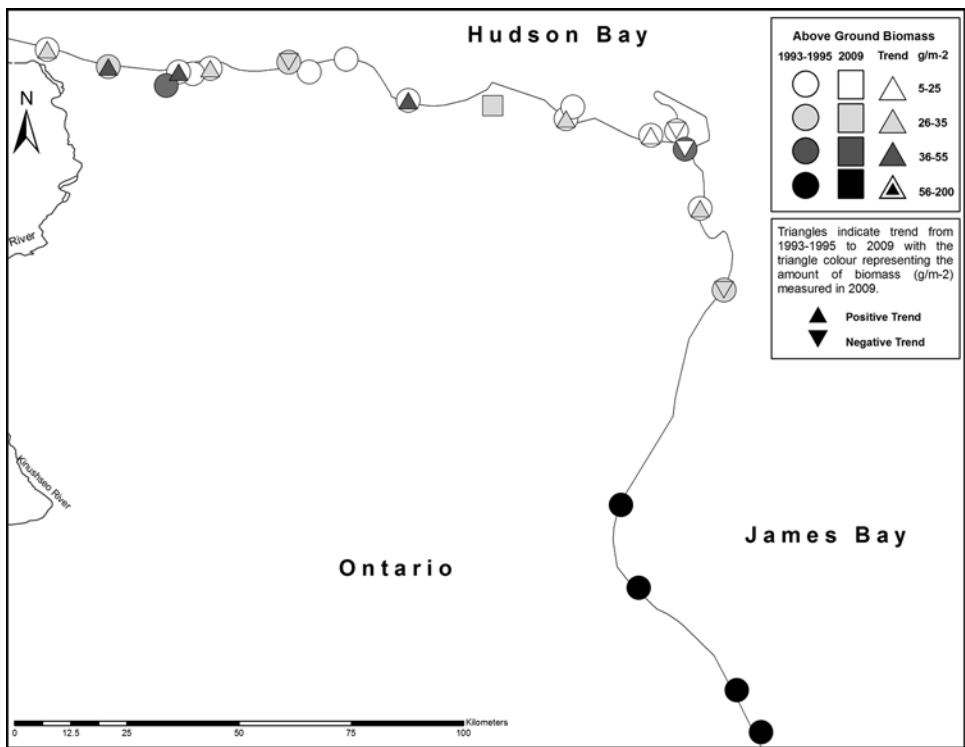
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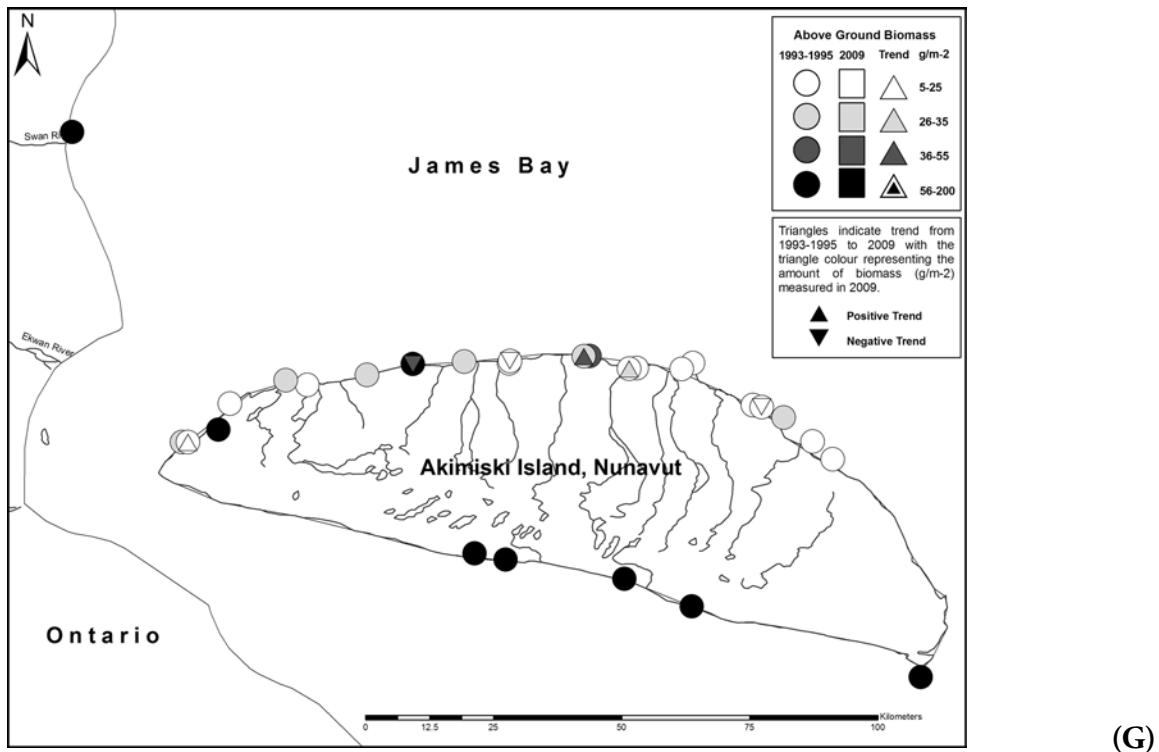


Figure 3. Snow goose grazing levels on the salt marshes in southern Hudson Bay and James Bay from north (A) to south (G). Shading refers to the grams per square metre of aboveground biomass in July as an index of habitat condition (White = overgrazed and heavily damaged, pale grey = overgrazed and moderately damaged, dark grey = grazed but not damaged, black = little or no grazing). Symbols refer to the year of the estimate (circles are 1993-1995, squares are 2009) and triangles superimposed on circles refers to sites sampled in both time periods, with the 1993-1995 estimate as shaded in the circle and the 2009 estimate as shaded in the triangle; upward triangle = increased biomass in 2009 compared to 1993-1995, downward triangle = decreased biomass over that period (source, Hudson Bay Project).

chironomids in vernal ponds in the supratidal marsh with the increasing salinity associated with vegetation loss (Milakovic et al. 2001). Sammler et al. (2008) reported scale dependent changes in breeding birds on Cape Churchill over a span of 16 years during which lesser snow geese increased significantly. At the scale of the habitat patch, they found that passerines and shorebirds were less abundant in altered versus intact habitats, but at a broader scale these small bodied species did not decline over time. In contrast, larger bodied ground nesting species declined in abundance. In soils where loss of vegetation has occurred, microbial activity has declined in the absence of living plants (Buckeridge and Jefferies 2007).

At Karrak Lake, Nunavut, where populations of Ross's geese and lesser snow geese have grown geometrically over the last three decades, there is strong evidence of loss of vegetation cover in areas where geese have nested the longest (Didiuk et al. 2001, Didiuk and Ferguson 2005, Alisauskas et al. 2006). In wet areas, moss carpets have developed, similar to wet sites in freshwater sedge meadows on

the lower Hudson Bay coast that have lost vascular plant cover. In addition to wetland ecosystems, drier upland lichen-heath pastures have also been affected but in a limited way, e.g., at Karrak Lake where both species may use the lichen-heath pastures for walking between wetlands (Slattery and Alisauskas 2007) or as assembly points where a limited amount of foraging may occur but prior to snow melt in lower-lying sites (c.f. Gloutney et al. 2001). Alisauskas et al. (2006) found that the proportion of land covered with vegetation was lowest where the geese had nested for more than 20 years. They detected decreases in the proportions of *Cassiope tetragona*, lichens, grasses and sedges in plant communities in areas with a longer occupancy by geese. In areas with just 10 years of nesting history, there was more exposed mineral substrate, surface peat and *Senecio congestus* (an indicator of disturbance) compared with comparable sites with no nesting. *Senecio congestus* is also common in disturbed sites on the Cape Churchill Peninsula, Cape Henrietta Maria and Akimiski Island, where the basal leaves are eaten extensively by the geese in early spring. Several colonies of lesser snow geese and Ross's geese have nesting densities in excess of 2,000 nests per km² (Kerbes et al. 2006), however, at Karrak Lake, average densities of about 3,400 nests per km² occur and locally higher densities are not uncommon, consequently considerable impact from grubbing of vegetation may be expected on the breeding grounds in early spring (Alisauskas et al. 2006, Samelius and Alisauskas 2009). The geese use the graminoids and other plant material both as forage and as nesting material. The reduction in graminoid biomass by the geese has reduced small mammal abundance (lemmings and voles) by about an order of magnitude compared with areas outside the nesting colony (Samelius and Alisauskas 2009). The authors suggest that the decline in small mammal abundance is driven by both low food availability and increased predation pressure. All these responses of different taxa to the catastrophic changes ultimately are driven by the apparent trophic cascade.

Habitat degradation affects lesser snow and Ross's geese as well. Where intertidal and supratidal habitats have been degraded, the behaviour of family groups attempting to feed has changed (Pezzanite et al. 2005). Adults spend more of their total time in motor activities and less time in vigilance and comfort behaviours, and goslings spend less time foraging. However, the pecking rate of both adults and goslings has increased while feeding. These changes have not allowed the birds to keep pace with the loss of vegetation, and the size of goslings has continued to decline in these degraded sites (Pezzanite et al. 2005). Canada geese have been adversely affected on shared range at Cape Churchill, where traditional brood rearing areas of Canada geese are now dominated by snow geese (Nack and Andersen 2006). They have also been affected on Akimiski Island, where nesting densities and reproductive performance are lowest (Gleason et al. 2004), and where body size and survival of goslings is lower (Hill et al. 2003) in areas of poorest vegetation within the snow goose colonies.

On Southampton Island, Nunavut, Fontaine and Mallory (2011) have examined the impact on vegetation of breeding lesser snow geese and Ross's Geese. The breeding population of Lesser snow geese rose from 155,800 in 1973 to 721,200 in 1997 and 652,500 in 2004 (Kerbes et al. 2006, Draft MS). Fontaine and Mallory (2011) examined the impact of the geese at 74 sites and carried out an aerial reconnaissance at an additional 1,425 sites. They report heavy damage to graminoid meadows

both in the interior and along the coast leading to shoot loss and at some sites the development of moss carpets with a sparse cover of vascular plants. In many areas, such as between East Bay and Native Bay, they observed exposed peat with dead and dying moss, similar to sites in the Hudson Bay Lowland. Lichens have also disappeared from most upland ridges and sedge habitats within these low-lying areas and the lichen-heath communities within goose nesting areas at East Bay, Southampton Island have changed dramatically over the past 3 decades, with loss of plant species diversity and vigor, including lichens, extensive drying and very low graminoid populations (KFA and P. Kotanen, Hudson Bay Project unpublished data). A confounding factor on Southampton Island is the impact of a significant increase in the caribou population from 1968 to the present (Ouellet et al. 1993, Gunn and Russell 2011).

On Akimiski Island in James Bay, intertidal marshes have been extensively grubbed by snow geese, giving rise to exposed sediments (O et al. 2005, 2006). Annual measurements of above ground biomass near the peak of the growing season between 1997 and 2010 indicate a declining trend in biomass of the primary forage species (*Puccinellia phryganodes*, *Carex subspathacea*, *Festuca rubra*) within the area occupied by both snow geese and Canada geese. Measurement of permanent transects at 5 sites along the north shore between 1998 and 2008 indicate significant changes in the distribution of both forage and non-forage species in plant communities of the supratidal, upper and lower intertidal marshes (Kotanen and Abraham, unpublished data). Although they observed some recovery of forage species, the magnitude was small and most of the ground surface is still mud. Overall, forage species were less frequent within the snow goose colony than outside it in both years, whereas non-forage species were abundant both inside and outside of the colony. However, between 1998 and 2008, forage species increased significantly within the colony although the cover remained low. Both forage and non-forage species exhibited changes in position relative to the sea or the freshwater marshes between 1998 and 2008, but with no obvious pattern. The response of forage species could indicate slow recovery from historically higher grazing pressure or a rare event (Curtis 1976). The lack of response by non-forage species is not unexpected.

These top-down effects of geese on plants and indirectly on other components of the ecosystems have occurred despite the potential top-down effects of hunting and predation on the geese themselves. Harvest rates of both species have dropped dramatically over the past 4 decades, including the period of the conservation order (Alisauskas et al. 2011, 2012). Predation has been similarly out-paced in their subarctic and arctic breeding habitats (Jefferies et al. 2003, 2004b). However, the presence of large numbers of birds has resulted in a bottom-up effect on predators, particularly arctic foxes (*Vulpes lagopus*) that respond to the pulsed resources (eggs), e.g. at Karrak Lake and Banks Island (Samelius et al. 2007). Likewise, predatory Herring Gulls (*Larus argentatus*) increased significantly at the landscape scale on Cape Churchill (Sammler et al. 2008).

Outside the range of the midcontinent populations, rates of growth of the western arctic lesser snow goose colony on Banks Island, NWT, have also been high, and the nesting population there tripled

between 1975 and 2005, raising similar concerns about the impact on habitats and other species. Studies indicate that habitat degradation due to geese is lower on Banks Island than in the eastern arctic and subarctic, but that within the Egg River colony most ecosystems show signs of overgrazing, particularly near wetlands, lakes and streams (Hines et al. 2010). Similar studies of greater snow geese on Bylot Island (Giroux et al. 1998) have documented the impact of herbivory of a growing population on plant communities in freshwater tundra. The situation on Bylot Island may be a model for predicting future impacts on the large, currently unoccupied expanses of freshwater tundra in the central and eastern arctic.

Unresolved Issues: Re-vegetation of Southern Hudson Bay Habitats and Limited Knowledge About the More Northern Nesting Areas

The conservation order was implemented with an objective of not just decreasing the size and growth rate of the lesser snow goose and Ross's goose populations, but with the objective of releasing northern wetland ecosystems from the intense foraging pressure, and eventually a re-vegetation or "recovery" of these systems. At this point, there is little evidence of natural recovery of vegetation from the effects of extreme goose foraging in the southern staging and breeding range (i.e., the Hudson Bay Lowland) or elsewhere. Hypersalinity, drying and other soil changes have precluded re-vegetation in most intertidal and supratidal areas. In one location at La Pérouse Bay, there is evidence of a system shift, with re-vegetation by species associated with elevated salinity, but not recovery to the former condition. There is also some evidence of re-growth potential within experimental enclosures, but only in sites with suitable freshwater conditions, and where vegetative fragments provided a nucleus for clonal propagation in the exposed organic sediments. At Akimiski Island, there is some evidence of colonization of lower intertidal marshes and increase in cover of forage species. However, overall, the available information from systematic studies and opportunistic surveys points to a continued disturbance and loss of vegetation in coastal habitats (Jefferies et al. 2006).

Re-establishment of vegetation in hypersaline compacted sediments of poor nutritional status is long-term, especially given the reproductive biology of the salt marsh graminoids. Nevertheless, it is possible to restore swards of *Puccinellia phryganodes* at a scale of 1 m² by planting soil plugs containing tillers of the sterile grass in degraded intertidal sediments and adding a mulch of organic matter laced with inorganic nutrients (Handa and Jefferies 2000). However, these techniques are very labour intensive and are cost prohibitive at a larger spatial scale. Under natural conditions, colonization occurs more rapidly in unconsolidated soft sediments, which are a consequence of stream and lacustrine sediment deposition, and locally also are a consequence of erosion of hypersaline consolidated sediments exposed by grubbing activity. Recently, studies have been conducted at freshwater sites near Thompson Point, about 60 km south of Cape Churchill, Manitoba, and close to a lake about 10 km south of the La Pérouse Bay Field Station (Rockwell et al., Hudson Bay Project,

unpublished data). At the first site, vegetation loss and the development of soil hypersalinity is similar to that in the coastal marshes of La Pérouse Bay. At the second site, *Puccinellia phryganodes* has re-established by clonal growth in exclosures where plant fragments still remained following grubbing. In spite of this evidence of re-growth potential in experimental sites, no evidence of recovery on the broader landscape has been found. Effectively, the alternative stable state is the culmination of the loss of an ecological sere (the intertidal marsh). While high densities of geese continue to be present, long term establishment of forage graminoids is unlikely to occur. We still do not know what level of reduced foraging pressure will be necessary to achieve re-vegetation of damaged habitats, if it can be achieved at all.

There is less information from habitats on the northern portion of the breeding range than those in the southern portion and thus the habitat conditions there remain less clear with the exception of Queen Maud Gulf. Systematic studies of some kind have been conducted at Kent Peninsula (J. Hines, unpublished data), Banks Island (Samelius et al. 2008, Hines et al. 2010), and Southampton Island (Fontaine and Mallory 2011). Additional work on Southampton Island in 2010 (Hudson Bay Project, unpublished) revealed a seriously degraded environment compared to information from the 1970s and 1990s. However, except at Karrak Lake (Slattery 2000, Alisauskas et al. 2006, Samelius et al. 2007), there are few systematic studies of the vegetation over long periods in these northern areas where lesser snow geese breed. A remote sensing analysis of the Great Plains of the Koukdjuak on Baffin Island, Nunavut was undertaken in the late 1990s. Photographic and anecdotal information from Baffin Island during that work clearly indicates that some loss of vegetation is occurring, but there is a need to build up benchmark quantitative data on the extent and intensity of this loss within local ecosystems for long term monitoring. It would be especially important to get benchmark data from areas not already degraded, such as Queen Maud Gulf where new colonies continue to appear, and perhaps on Baffin Island. The question of the capacity of arctic freshwater tundra habitats to accommodate the continually increasing population is still open; an estimate of available suitable habitat, as well as the net above-ground primary productivity of preferred goose plants in respective habitats, is required to estimate the carrying capacity of various areas of Canada's arctic and subarctic. Ideally such estimation should focus primarily in the zone of postglacial marine transgression, which tends to contain the surficial geology of marine sands and silts conducive to supporting preferred tundra habitat such as wet sedge meadows.

Resolving this question of the condition of northern colonies has become urgent because of changes that have occurred during the last several decades. For example, the anomalous cold area in late winter and early spring in the north Hudson Bay region, Ungava and south Baffin Island that persisted in the 1970s and 1980s (Skinner et al. 1998), has since disappeared. As a consequence, ice break-up in Baffin Bay, Foxe Basin, Davis Strait and west Hudson Bay has occurred earlier in spring in the last decade (Stirling and Parkinson 2006). Similarly, in the southwest region of Hudson Bay and the northwest region of James Bay, ice has been breaking up earlier in recent years at a rate of at least 3 days per decade, consistent with increased spring temperatures in the region (Gough et

al. 2004). This region of low temperatures at the onset of the breeding season delayed migration of lesser snow geese because of the presence of snow and ice cover (Boyd and Madsen 1997, Skinner et al. 1998). In extreme late years, this led either to frequent breeding failures in arctic colonies or to birds stopping short of their natal or former arctic breeding sites to nest in more southern localities; the nesting colonies of snow geese at West Hudson Bay, Cape Churchill, Cape Henrietta Maria and Akimiski Island all appear to have originated from such events (Hanson et al. 1972, Geramita and Cooke 1982, Abraham et al. 1999, Cooch et al. 2001). While we have relatively detailed monitoring data for staging habitats in coastal areas of the Hudson Bay Lowlands, we know much less about the location of habitats used in arctic staging areas during spring and fall migration, and the extent of habitat degradation that may be occurring there.

What is the Potential for Range Expansion by Snow and Ross's Geese in the Arctic?

Within the subarctic, the early spring foraging is destructive in salt marshes; the birds grub for roots and rhizomes of grasses and sedges provided the ground has thawed. The cumulative effect is the destruction of their summer grazing pasture. In the freshwater sedge meadows where they also increasingly feed in subarctic areas and which provide the majority of habitat in arctic areas, the birds pull up living shoots of sedges and only eat the base that is nutrient-rich and discard the remainder. Individual sedge plants are weakened over successive years of shoot-pulling and in time they die, exposing the underlying peat. These changes to wetland vegetation are not restricted to coastal marshes but also occur hundreds of kilometers inland where breeding colonies of the geese are present in some areas, e.g., the central arctic. Recovery of the areas where there has been loss of vegetation and exposure of soil is long-term, partly because there are adverse changes to soils (hypersalinity, loss of organic matter and drying out of soil) and partly because the residual seed pool in the soil is poor or non-existent. These disturbed wetlands can be detected using LANDSAT remote sensing imagery and over the last two decades the area of vegetation adversely affected has grown in coastal marshes around the shores of Hudson Bay as well as at Karrak Lake, south of Queen Maud Gulf (Nunavut) and elsewhere, where geese breed. There is no sign of abatement of the ongoing damage and little evidence of revegetation or recovery of damaged habitats. Most intertidal and coastal freshwater marshes along southern and western Hudson Bay and James Bay are adversely affected, leading to loss of habitat function for many species. The adverse effects extend beyond the geese and their forage plants. All components of the food web are deleteriously affected from the soil microbes to the top predators to the aboriginal people who consume geese.

However, it is also clear that there remain large areas of freshwater wetlands, and graminoid tundra communities in the Canadian arctic that appear not to have been exploited by snow and Ross's geese as yet. Such areas likely will contribute to further expansion of breeding range and perhaps population growth, if current survival and recruitment remain unchanged. In fact, recruitment may recover after previously documented long-term declines if these geese abandon degraded habitats and

pioneer currently unoccupied habitats, thereby temporarily escaping current density-dependence in recruitment. Given the vastness of the arctic and subarctic areas, it remains possible that currently there are areas already recently colonized, of which we are unaware. At present, it appears that the damage will continue for the foreseeable future, so long as populations continue to expand in abundance and range.

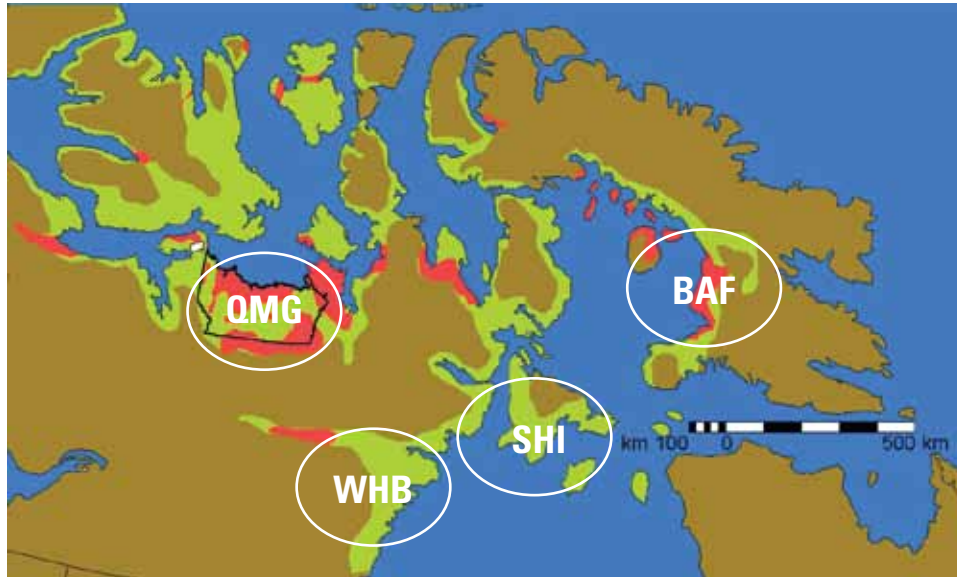


Figure 4. Zone of postglacial marine transgression in Canada's central and eastern arctic (after Bird 1967) with (red) without (green) extensive deposits of marine sands and silts. Note that most known areas important to snow and Ross's geese are contained within this zone.

Expansion in use of both coastal saltmarsh and freshwater wetlands and graminoid tundra is likely to be contained above the tree-line to areas within the zone of post-glacial marine transgression (Figure 4) based on the fine silts deposited in such regions after deglaciation, flooding and deposition by marine waters; such surficial geology is conducive to supporting the fens and meadows that support graminoid food plants favoured by snow and Ross's geese when they are in the arctic. However, there are vast expanses of heath tundra within this zone that might support both non-breeding and breeding geese. The potential for expansion will depend on the extent to which density-dependence might impinge on (1) prebreeding feeding and conditioning by adults in subarctic and arctic staging areas, as well as (2) gosling growth and probability of fledging. An important need in that regard, is estimation of carrying capacity in (i) regions with existing populations and associated brood-rearing areas (such as south and west coasts of Hudson Bay, south of Queen Maud Gulf, Southampton Island, and the Great Plain of the Koukdjuak on Baffin Island), (ii) areas within these same regions that support extensive habitats currently unoccupied by snow and Ross's geese, but favoured by them elsewhere and, if possible, (iii) areas of drier tundra such as lichen-heath tundra less dominated by graminoids than favoured habitats, but with documented use (Slattery and Alisauskas 2007), which covers about 33% of the terrestrial habitat in the Queen Maud Gulf bird sanctuary (Didiuk and Ferguson 2005), and about 42% on Southampton Island (Fontaine and Mallory 2011). As on Banks

Island (Samelius et al. 2009), these expanses in central and eastern regions of Canada's arctic could contain sufficient graminoid vegetation to support a large number of geese during brood rearing.

Mapping of vegetation communities on a wide scale such as has been done from LANDSAT imagery south of Queen Maud Gulf (Didiuk and Ferguson 2005), Southampton Island (Fontaine and Mallory 2011), or is in progress for the Great Plain of the Koukdjuak on Baffin Island (Didiuk, pers. comm.), is valuable in formulating a sampling frame for estimation of potential carrying capacity. Such imagery can be used in stratification of sampling for estimation of the net above ground primary productivity (NAPP), by plant species, in specific habitat themes within each area of interest. Matched sampling of the August standing crop from inside and outside of vegetation exclosures deployed before hatch (in June or July) in each stratum would provide estimates of NAPP, and biomass removed by grazers, respectively. Covariates might include distance from and size of nearest light goose colony to measure potential and realized exploitation by light geese. Such habitat-specific estimates of NAPP and biomass (kg/ha) removed, could then be weighted by area (km²) to provide estimates for regions known to be important to light geese as well as regions which they are not known to have exploited yet. Such estimation of arctic carrying capacity could provide important inferences about current regional constraints to local population growth by light geese as well as the potential for range expansion and further growth in abundance of the midcontinent population of lesser snow geese, and Ross's geese in North America.

Summary

Lesser snow geese and Ross's geese have increased over the last several decades as a result of feeding in agricultural fields on the wintering grounds and along the migratory corridors between their arctic breeding sites in Canada and the southern United States and Mexico. The birds feed on spilled corn, rice and pulses (legumes) but other crops are also eaten. Formerly, the geese wintered in the salt marshes of the Gulf States but the agricultural food has provided the birds with an abundant food source across a large area of the continent. This, together with a network of reserves, likely was the cause of increased survival, and has meant that multiple migration routes are possible and the birds are no longer constrained to traditional flyway routes. Beyond the agricultural lands, the birds fly northwards in spring following the retreating snowline in a stepping stone fashion, feeding enroute in marshes, although little is known about where light geese migrate through the interior boreal, taiga, and tundra areas north of the Canadian Prairies.

This assessment is based on changes that have occurred in the midcontinent population of lesser snow geese and Ross's geese since 1997, and the effect of these changes on vegetation, soils and different groups of organisms. The population continues to be in a dynamic state as a result of the agricultural subsidy and there is no evidence of an overall decline in numbers, although population growth may have slowed and some local populations have declined (e.g. Cape Henrietta Maria, Ontario). Migrating birds take advantage of new crops that are not located on traditional routes. This has

resulted in a spatial expansion of migration routes, both in the spring and fall. Similarly, depending on the weather conditions in any one year, birds feed at different subarctic and arctic staging sites along a geographical continuum, exploiting plant reserves to meet nutritional requirements for migration and egg-laying in the spring, so that the distinction between exogenous and endogenous reserves is blurred. Much of the vegetation loss in the subarctic and arctic that occurs in spring brings about changes in soil conditions and in the foraging habits of the geese. With more frequent freeze-thaw cycles earlier in the year associated with increases in air temperature, it is expected that birds will have earlier access to plants, and that plant growth and productivity will change. This has implications for the relationship between nest timing and later, for gosling growth and condition. Already geese are nesting earlier (e.g. the onset of incubation of snow geese at La Pérouse Bay has advanced 0.16 days/year over the past 35 years (Rockwell and Gormezano 2009, Rockwell et al. 2011).

From an ecological perspective, the processes leading to loss of vegetation and changes in soil conditions as a result of goose foraging described by Abraham and Jefferies (1997) have changed little in the intervening decade, although our understanding of underlying mechanisms has increased substantially. Additionally, the rapidly increasing Ross's goose population in the midcontinent region contributes increasingly to the damage, and other localities beyond the Hudson Bay Lowland, such as West Hudson Bay, the lowlands south of Queen Maud Gulf and Southampton Island in Nunavut have lost vegetation as a result of goose grubbing and foraging. Warming temperatures and shifting precipitation regimes in all of these northern areas interact with plant growth dynamics to affect recovery potential, forage availability and carrying capacity. There are no indications of large-scale recovery of damaged swards at any site. It is also evident that there are deleterious cascade effects that influence other groups of organisms besides geese and vegetation. Damage is present throughout the arctic wherever large populations of breeding or staging geese occur. However, the lack of adequate surveys carried out by professional plant ecologists severely limits our ability to provide a comprehensive spatial and temporal assessment of these ongoing changes. As a result, predictions of likely landscape changes beyond the handful of intensively studied sites continue to evade us and are only detected when irreversible damage has occurred.

Recommendations

1. Complete the 1999-2000 report on habitat classification of West Baffin Island within 1 year.
2. Identify areas of high(est) potential for breeding expansion using remote sensing methods.
3. Estimate carrying capacity of arctic breeding habitat for current areas and areas of high(est) potential for breeding expansion.
4. Conduct ground evaluations of habitat of west Baffin Island within 5 years.
5. Conduct ground evaluations of habitat on Southampton Island within 5 years.

6. Conduct ground evaluations of the west coast of Hudson Bay within 5 years.
7. Continue to conduct evaluation of Southern Hudson Bay coast with emphasis on recovery assessment.

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ASSESSMENT OF HARVEST FROM CONSERVATION ACTIONS FOR REDUCING MIDCONTINENT LIGHT GEESE AND RECOMMENDATIONS FOR FUTURE MONITORING

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Introduction

The winter index of midcontinent light geese (MCLG, consisting of lesser snow (*Chen caerulescens caerulescens*) and Ross's geese (*C. rossii*) more than doubled from less than 800,000 birds in 1970 to nearly 2 million by the mid-1980s (U.S. Fish and Wildlife Service 1999). Hunting regulations for these birds were liberalized gradually during that period to allow increased hunting opportunity and harvest as MCLG populations grew (Kruse et al. 2009). Increasing awareness of the continuing growth of MCLG populations led to even more liberal hunting regulations in the Central and Mississippi Flyways, beginning in 1989. However, these increases in bag limit and season length and expansions of season date frameworks during the regular hunting season did not increase harvest to a level that reduced population growth, and the mid-winter index of MCLG increased to nearly 3 million by 1998.

A report by the Arctic Goose Habitat Working Group (AGHWG) of the Arctic Goose Joint Venture (Batt 1997) provided new information about the impacts of overabundant light geese on arctic habitats and included recommendations for reducing numbers. This analysis of impacts to arctic habitats demonstrated that damage was much more serious than had been previously reported. A primary recommendation of the AGHWG to address problems caused by overabundant MCLG was to increase harvest by hunters (Batt 1997). The report called for reducing the population growth rate of MCLG from the estimated rate of 1.05 to an annual level between 0.85 and 0.95. The recommended means of accomplishing this was by increasing the kill by hunters to a level that tripled the harvest of these birds.

Light geese are subject to hunting on nesting, staging and wintering grounds. Subsistence harvest on arctic breeding grounds is not well documented, but likely comprises a very small proportion of the total kill. Harvest on prairie staging grounds in southern Canada and northern United States, and on wintering grounds in the southern United States, in contrast, is well documented and results in large numbers of geese being taken each year. However, it was clear that despite liberal MCLG hunting regulations in both Canada and the United States, MCLG numbers were still increasing. The failure to reduce population size and growth rates through regular hunting seasons led to implementation of special conservation measures in Canada and the Light Goose Conservation Order (LGCO) in the United States, which were the most recent management attempts to increase harvest. This report evaluates the efforts to increase annual harvest of MCLG during the past several decades.

Measurement of harvest is one of the principal ways that wildlife agencies monitor game populations and the effects of hunting seasons. Harvest of migratory game birds is generally measured through either band recoveries of hunter shot birds or by harvest surveys consisting of mail questionnaires directed at hunters and requests that hunters provide parts (i.e., wings or tail feathers) from the birds they bag. These harvest surveys provide a statistically robust measure of the total number of birds killed over the entire range over which species are harvested and across all species, something that

would be difficult to attain and prohibitive in terms of costs with banding studies. In addition, harvest surveys provide a wealth of information that cannot be collected otherwise and that are useful in the management of hunted populations or species. Among other things, they allow species-specific estimates of age and sex (for some species) of the birds taken, the temporal and geographic distribution of the harvest, and information on hunting effort, hunter success, wounding loss, and in some cases use of various methods by hunters. The Canadian Wildlife Service (CWS) collects information annually on migratory game bird hunter activity and harvest in Canada during both the fall hunting season and the spring conservation snow goose harvest. In the United States, the U.S. Fish and Wildlife Service (USFWS) collects that information for the regular waterfowl hunting season, whereas participating states are responsible for obtaining harvest information pertaining to the LGCO.

States are required to keep records of activities carried out under the provisions of the LGCO including: 1) the number of birds taken; 2) the methods by which they were taken; and 3) the dates they were taken. A report summarizing this information must be submitted by the end of August to the USFWS. However, there are no “standardized” methodologies recommended or required that are used by states when generating these estimates. Thus, the suitability and comparability of these estimates for measuring LGCO harvest have been questioned.

The purpose of this report is to review the progression of MCLG hunting regulations, describe the harvest surveys used by the USFWS, the CWS and states in the Central and Mississippi Flyways to measure annual light goose hunting activity and harvest, report the results of those surveys, and examine the efficacy of liberalized hunting regulations as a means of increasing MCLG harvest. Herein, we use the term midcontinent light geese to describe Ross’s geese and lesser snow geese that are harvested in Manitoba, Saskatchewan, and northern Ontario, as well as those harvested in all states of the Central and Mississippi Flyways. This is consistent with the term midcontinent light geese used for regulatory purposes in the United States, and includes harvest areas of the Midcontinent Population and Western Central Flyway Population of wintering lesser snow geese and Ross’s geese.

History of Light Goose Hunting Regulations

Migratory bird hunting seasons in both Canada and the United States are limited by provisions specified in the Migratory Bird Treaty (known as the *Migratory Birds Convention* in Canada; hereinafter Treaty). Hunting of migratory game birds may only occur from 1 September through 10 March, and seasons are limited to a maximum of 3½ months; the latter stipulation is interpreted as 107 days. Thus, the MCLG season may not exceed 107 days in any zone of any province in Canada or state in the United States. The Treaty does not specifically limit daily bag or possession limits.

Canada

The federal government, represented by the CWS, consults with provincial governments and stakeholders and then establishes annual migratory bird hunting seasons for each province, and, where applicable, zones within provinces. Nearly all of the MCLG harvest in Canada occurs in Manitoba and Saskatchewan, with northern Ontario, Nunavut and eastern Alberta accounting for little additional harvest. Thus, we concentrate our attention on regulations and harvest in Manitoba and Saskatchewan.

Fall season length in Canada is constrained by weather and most MCLG migrate south out of Canada before a fall and winter season of up to 107 days could be completed. Therefore Canada primarily uses daily bag and possession limits to regulate goose harvest. Manitoba's season lengths have remained stable since the 1970s, ranging from about 60-85 days depending on the zone, and Saskatchewan's have ranged from 74-111 days, also varying by zone (Table 1; NOTE: all tables for this chapter can be found with the other appendices at the end of the report). Note that the few seasons that were longer than 107 days in length occurred at a time when Canada used the maximum 3 ½ month season length limit as prescribed in the Treaty, instead of the more recent interpretation of this clause to not exceed 107 days. Daily MCLG bag limits in Canada were moderately low throughout the 1970s and 80s, with some variation among provinces (Table 1). In Manitoba, the bag limit was increased from 5 to 8 birds in 1978. The next modification occurred in response to the rapid growth of the population in 1996, when the possession limit was doubled to 32 birds, though the daily bag limit remained at 8 birds. The following year, the bag limit was increased to 10 and the possession limit to 40. In 2000, the bag and possession limits were substantially increased again to 20 and 80 birds, respectively. Saskatchewan's limits followed a similar pattern. Until 1994, the bag limit was 5 birds, although in some locations 8 birds were permitted after the first or second week of October. Then there was a series of bag and possession limit increases starting in the mid-1990s (Table 1). Since 1999, 20 birds have been allowed in the bag, with a possession limit of 60 birds.

Although substantial changes have been made to the regular fall harvest season to encourage the take of overabundant species, the most drastic regulatory change, by way of an amendment to the Migratory Birds Regulations, occurred through the implementation of special conservation measures concerning overabundant species; a spring conservation harvest was permitted starting in 1999 in Manitoba and in 2001 in Saskatchewan and Nunavut. Spring take in Manitoba was initially allowed from 1-21 May and 10 April – 21 May, depending on the zone, but by 2002, all zones were open to harvest between 1 April and 31 May. Since 1999, an early fall take (15-31 August) has also been in place in northern Manitoba. In Saskatchewan, spring harvest was allowed each year from 1 April until early- or late-May, depending on year and zone. Finally, spring harvest was allowed in Nunavut from 1 May to 7 June in all years. Electronic snow goose calls were also allowed, and during the earlier years only decoys representing white phase snow geese were allowed. This restriction on decoy coloration, originally introduced to reduce the unintended harvest of other species, was removed in 2004 after it was demonstrated that dark geese were not attracted by electronic snow goose calls

irrespective of decoy color (Caswell et al. 1999). Daily bag limits during conservation harvest periods were the same as those for the regular season. Only snow geese could be harvested during special conservation seasons in Canada.

United States

The federal government establishes frameworks and rules within which states may permit the take of migratory game birds, including light geese. Currently, light geese may be taken during regular fall and winter hunting seasons and during the LGCO. The USFWS annually establishes frameworks for regular hunting seasons that include the outside season dates, maximum season length, and the maximum bag and possession limits. The USFWS has also established the rule under which states may participate in the LGCO. States, operating principally through state wildlife agencies, establish hunting seasons and LGCOs within their borders within the restrictions set by the USFWS. The USFWS also establishes basic regulations that implement a variety of restrictions on the manner of taking, tagging and transportation, and disposition of migratory game birds. Basic regulations are rarely changed.

Regular Seasons

Kruse et al. (2009) summarized U.S. hunting regulations for light geese from 1918-1960 and reported in detail the annual federal frameworks for light goose hunting in the Central and Mississippi flyways since then. In the early 1960s, states in the Central and Mississippi flyways could establish light goose hunting seasons up to 60-75 days in length, with daily and possession limits both set at 5 birds (Table 2). The earliest allowable season opening date was on or about 1 October, and the latest allowable season-ending date was in early to mid-January. As in Canada, seasons were expanded gradually for the next 2 decades; by the late 1970s, federal frameworks allowed 70- to 93-day seasons, and in the 1980s the possession limit was increased to 10 birds (Table 2). Season closing dates were extended further into the winter during that period as well. As it became clear that MCLG populations were increasing to undesirable levels (Batt 1997), season lengths and limits increased more rapidly throughout the 1990s, culminating with 107-day seasons (the maximum allowed under the Migratory Bird Treaty), 20-bird daily bag limits and no possession limits (Table 2). Near the end of the decade, the USFWS published an Environmental Assessment addressing overabundant light geese that recommended implementing additional measures to control MCLG (U.S. Fish and Wildlife Service 1999).

Regulations based on the Environmental Assessment allowed states to permit special harvest provisions during the regular season for light geese, provided that all other waterfowl and crane hunting seasons, excluding falconry, were closed (Federal Register 64(30):7517-7529). These special harvest provisions allowed the use of electronic calls, unplugged shotguns (i.e., shotguns capable of firing more than 3 times without reloading) and hunting until one-half hour after sunset. Initially, 4 Central Flyway states (Colorado, Kansas, Nebraska and South Dakota) and 5 Mississippi Flyway states (Arkansas, Illinois, Iowa, Kentucky and Missouri) employed special provisions (i.e., electronic calls and/or unplugged

shotguns) during regular light-geese seasons in late February and early March of 1999. Over the next 2 years, all states except Colorado stopped using special provisions during regular seasons, and replaced that option with LGCOs that started earlier; Colorado followed suit in 2002-03.

Light Goose Conservation Order

The LGCO was first offered to states in the Central and Mississippi flyways in February, 1999. The LGCO was not a hunting season as defined by the USFWS; rather, it was a management action designed to address the problem of overabundant light geese. This management action allowed harvest of light geese to occur after 10 March, even when the 107 days of hunting allowed under the Treaty had been used. Both Ross's and snow geese could be harvested under the LGCO whereas only snow geese could be harvested under Canada's special conservation measures. Use of special methods (electronic calls, unplugged shotguns, and hunting until ½ hour after sunset) was also allowed within the LGCO. In addition, there were no daily bag limits or federal Migratory Bird Hunting and Conservation Stamp (hereafter federal duck stamp) requirements during the LGCO. The LGCO allowed states to "without permit, kill or cause to be killed" MCLG "when all waterfowl and crane hunting seasons, excluding falconry, are closed" (Federal Register 64(30): 7517-7529). Similar to regular hunting seasons, states could be more restrictive, but not more liberal than allowed by federal law.

Following implementation of the first LGCO during February of 1999, it appeared unlikely that a LGCO would be available in 2000. The Humane Society of the United States filed for an injunction to stop the 1999 LGCO and also filed a lawsuit to prohibit the LGCO in the future. The injunction was denied, but the judge ruled that issuance of the LGCO was a major federal action that required an Environmental Impact Statement (EIS) rather than the less detailed Environmental Assessment that the USFWS had prepared. Rather than allow the issue to proceed in court, the USFWS rescinded the LGCO on 17 June, 1999 and issued notification of its intent to produce an Environmental Impact Statement. This process was expected to take at least 18 months, which would have precluded issuing LGCOs for spring 2000 and probably 2001. As a result, Congress passed the Arctic Tundra Habitat Emergency Conservation Act. This bill, signed into law by President Clinton in November 1999, directed the LGCO to continue during preparation of the EIS. The LGCO has continued annually since that time. The final EIS was published in June 2007, and the final rule and notice regarding the LGCO was published on 5 November, 2008 (Federal Register 73(205): 65926-65955).

In the first year (1999) that the LGCO was available, 11 states participated: Colorado, North Dakota, Oklahoma, South Dakota and Texas in the Central Flyway and Arkansas, Illinois, Iowa, Louisiana, Mississippi and Missouri in the Mississippi Flyway. In 2000, Indiana, Kansas, Kentucky, Minnesota, Nebraska and New Mexico also implemented the LGCO, and Wyoming began participation in 2001. All 18 of these states have participated annually since 2001. Few light geese pass through Alabama, Michigan, Montana, Ohio, Tennessee and Wisconsin in spring, therefore those states have not elected to participate.

States attempt to implement the LGCO during the period when light geese are most likely to be in the state and when it does not conflict with regular waterfowl or crane hunting seasons. Light goose spring migration chronology is strongly influenced by weather and snow and ice conditions, and thus it is highly unpredictable. Therefore, states often open their LGCO well in advance of normal migration periods (e.g. mid-February in North Dakota). Federal LGCO rules do not restrict bag or possession limits of light geese and there are no restrictions on either species, therefore both snow and Ross's geese may be taken in unlimited numbers.

Kruse et al. (2009) reported in detail the annual state-specific LGCO regulations (opening and closing dates, daily bag and possession limits, special provisions employed); we use the 2006 LGCO as an example to illustrate how the participating states implement the LGCO (Table 3). In the Central Flyway in 2006, starting dates for the LGCO ranged from 29 January (east zone of Texas) to 24 February (Colorado), and ranged in length from 38 days in New Mexico to 88 days in South Dakota (Table 3). Closing dates ranged from 10 March (New Mexico) to 8 May (South Dakota). States in the Mississippi Flyway had opening LGCO dates that ranged from as early as 1 October (Mississippi) to as late as 5 February in Arkansas. The duration of the LGCO ranged from 49 days in the west zone of Louisiana to 91 days in Iowa, with closing dates from 10 March (Mississippi) to 30 April (Minnesota and Missouri). Louisiana had a season split with two segments in each of its two zones and Mississippi had three splits with four segments in LGCO dates statewide (Table 3).

Only 3 states established daily bag limits for light geese in 2006; South Dakota, Wyoming and Iowa allowed a daily bag limit of 20 birds per day. Possession limits were not restricted by any state in either flyway (Table 3). With only two exceptions, all states that implemented the LGCO in 2006 permitted hunting until ½ hour after sunset and allowed the use of electronic calls and unplugged shotguns; unplugged shotguns were not permitted in Colorado and Wyoming (Table 3).

History and Methodology of Harvest Surveys

CWS Surveys

The purpose of the Canadian National Harvest Survey is to provide reliable estimates of the harvest of migratory game birds in Canada. The National Harvest Survey is the joint name for two surveys sent annually to a sample of purchasers of the Migratory Game Bird Hunting Permit (MGBHP). This permit was introduced by the federal government in 1966 to provide a register of hunters who could be asked to participate in either the Harvest Questionnaire Survey (HQS) or the Species Composition Survey (SCS). The SCS is sent early in the hunting season, and the HQS is sent at the end of the season. An additional spring harvest survey was initiated in 1999 in Manitoba and 2001 in Saskatchewan in response to the introduction of the spring conservation hunt.

Migratory Game Bird Hunting Permit.

The permits are sold primarily at post offices across Canada. The postal office clerk is responsible for completing the information requested on the permit stub, which is returned by mail to CWS. A file is generated that includes permit number, date of sale, the identifying number of the issuing post office, the name, address and date of birth and residency of the permit purchaser, whether the individual hunted migratory birds during the previous year and whether he/she bought a permit that year. Permit-issuing post offices are linked to one of 23 geographic zones (see below) so that permit records can be assigned to a zone of purchase for subsequent sample selection. Hunters who indicate that they bought a permit in the previous year are termed “renewals” and those who did not are “non-renewals.”

Harvest Questionnaire Survey.

The HQS is a country-wide mail questionnaire (Appendix 1) sent at the beginning of December (with a reminder mailing sent in February to non-respondents) to a sample of MGBHP purchasers. The HQS asks hunters questions on whether they hunted that season, how many days they hunted for waterfowl and non-waterfowl migratory game birds, and the total number of ducks, geese and other migratory game birds that they harvested. In addition, there are questions on the location of each hunt and a calendar to record the number of waterfowl killed and retrieved during each day of hunting. The information on duck and goose harvest is recorded on the front and back sides of the survey instrument, respectively. Latitudes and longitudes of hunting locations are subsequently generated based on the location information provided by the respondent.

The survey provides estimates for broad species groupings, e.g., ducks, geese, and other non-waterfowl game birds. The HQS also enables the calculation of other variables such as the number of active and successful hunters, their average daily and seasonal bag and average number of days spent hunting. The HQS was first conducted in 1967; the year after the MGBHP was introduced. The survey was refined over the next few years (1967-1974) (Cooch et al. 1978) and has since been conducted annually. Due the changes in methodologies and calculations, harvest estimates presented in this report will be restricted to years after 1974. The survey design has been described previously (Cooch et al. 1978, Smith 1975) but we provide a brief summary of the major aspects here.

Although the survey sample is selected from the MGBHP database, the current year permits are not captured in sufficient time to allow selection and mailing of the survey. Historically, 70% of the permit holders in any year are renewals (i.e., they purchased a permit the previous year). Hunters who identify themselves as having purchased a permit in the previous year are labelled renewals; a distinction is made between “renewals” and “non-renewals” because the renewal group is considered persistent hunters who tend to hunt more often and kill more birds than do novice or intermittent hunters (i.e., non-renewals). The renewals are sampled from the previous year’s permit file. This approach allows renewal hunters to be further subdivided into those who purchased the MGBHP for the last two years and those who purchased the permit the previous year but not the year prior to that. This allows a more effective stratification of experience which improves the survey precision,

and is also aimed at reducing a significant bias in hunting activity and kill that was apparent during the early years of the survey. The current year permit file is generated as permit stubs are received and a sample of “non-renewing” hunters is selected from this file in November of the current year. By this time, usually 150,000 permits will have been entered and the sample is considered to include a sufficient portion of the non-renewing hunters.

The country is partitioned into 23 geographic strata (Figure 1); there are from 1 to 3 geographic strata, or hunting zones, in each province and territory. The HQS sampling is also partitioned into 4 hunter types, based on the renewal history (described above) and residency. Non-resident hunters are assigned to a separate stratum, irrespective of their purchasing history. The combination of geographic and hunter-type strata produces 84 sampling strata.



Figure 1. Canadian harvest survey sampling zones.

Species Composition Survey.

The SCS is also a country-wide mail survey sent to a sample of MGBHP purchasers. The selected permit holders are requested to mail in one wing from each duck and the tail feathers from each goose that they kill and retrieve. The hunter is asked to provide on the wing and tail envelope (Appendix 2) his or her name and address, current permit number, and the location and date of the

kill. The results of the survey are used to partition the estimated kill from the HQS among species, age and sex.

Operational constraints prevent the SCS from being a representative sample survey of the current year MGBHP holders. First, the mailing for the survey must take place prior to the hunting season so that the selected hunters have wing and tail envelopes in their possession from the first day of hunting. In order to meet this deadline the hunters are selected from the previous year's permit file. Second, due to the difficulty of mailing waterfowl parts across the border, the survey is restricted to Canadian residents. Third, mailing out a package of wing and tail envelopes is expensive and there is a strong incentive to reach hunters who will participate by returning parts. To achieve this goal the sampling is biased towards sampling hunters who have previously cooperated. A letter and a screening card are sent to all potential participants in July. Hunters do not participate in the SCS for more than two consecutive years.

Similar to the HQS, the SCS is stratified into 23 geographic zones and hunters in the previous years permit file are stratified into 5 categories: 1) SA: respondent to the SCS in previous year, 2) SC: respondent to HQS in previous year who shot more than 5 waterfowl, 3) SD: respondent to HQS in previous year who shot 1 to 5 waterfowl, 4) SE: renewal hunter in the previous year not eligible for SA, SC or SD and 5) SF: non-renewal hunter from the previous year not eligible for SA, SC or SD. Hunters who respond to the SCS in categories SC, SD, SE and SF are placed in category SA the next year. Hunters in category SA are not selected the next year. This is done to provide a balance between response burden and the need to select hunters who will respond to the survey. Approximately 30% of MGBHP purchasers in any given year did not purchase a permit the previous year. The geographic zone of purchase can also change between one year and the next. Thus, the responding hunters are asked to provide their current MGBHP number in order to classify the responding hunters into the correct geographic strata for that year. The responding hunters are assumed to be a simple random sample within the current year geographic strata.

Combining HQS and SCS Surveys.

The HQS provides estimates of the total harvest for the season from all species groups, whereas the SCS data are used to estimate species-specific harvest by calculating the proportion of parts received per species. However, a disproportionate number of parts were received from birds killed early in the hunting season. To reduce this bias, the SCS data are used to partition the season into periods so that in each period there are enough parts to determine the proportion of harvest by species for each zone. Periods are groups of weeks with at least 5% of the total parts as well as at least 5 parts. The HQS calendars are then used to partition the total harvest into time periods by allocating the total harvest using the proportion reported in each period. Within each time period, the total harvest is partitioned among species using the species reported in the time period. Finally, the harvests by species within periods are summed across periods to give an estimate of the total harvest by species for each zone. Standard error is also calculated for each harvest estimate, as described by Smith

(1975) and Collins and Gobeil (2003). Unlike the USFWS harvest survey, there are no corrections applied to the Canadian harvest estimates. Various sources of bias, including non-response and response (prestige and memory) bias have previously been acknowledged and assessed to some degree (described in Cooch et al. 1978). These biases are likely to vary spatially and temporally as well as with hunter experience. However, until more accurate and comprehensive data become available, these correction factors are not applied to the Canadian harvest survey.

Sample Allocation.

The sampling approach used for the survey is based on “optimal allocation” procedure (Cochran 1977) described by Sen (1976) for its application to this survey. Essentially, the objective is to achieve a coefficient of variation of the harvest estimates of 5% for provinces and 8% at the zone level. Using this sampling approach, the current sample sizes for the HQS and SCS are approximately 40,000 and 33,000 hunters, respectively.

Harvest Survey of Special Spring Conservation Harvest.

The CWS undertook a special harvest survey to quantify the annual take of MCLG during the spring conservation harvest. Survey sampling methods and coverage were modified during the initial years of the survey. The first survey, conducted in Manitoba in 1999, benefited from a spring harvest registration system that facilitated the sampling process. In 2000, the federal registration system was dropped and Manitoba hunters were sampled using the list of purchasers of the provincial hunting license, because the beginning of the provincial license sale period coincided with the onset of the spring conservation measures (hunters were required to possess a provincial small game hunting permit in addition to the federal Migratory Game Bird Hunting Permit). The mail survey was dropped in Manitoba after 2000, due to low rate of participation by hunters in the spring conservation measures (only 288 hunters registered for the provincial permit that spring) resulting in a small harvest.

The harvest survey of the Saskatchewan spring harvest was initiated in 2001. The sample was stratified in two groups: 1) fall MGBHP purchasers and 2) spring MGBHP purchasers. In 2002, a third stratum was added to split the fall MGBHP purchasers into residents and non-residents. The proportion of active hunters and the average kill per hunter were substantially different between the fall and spring strata. However, the spring stratum was dropped after 2002 due to very low permit sales during that period. Since then, the survey sampling has been conducted on two strata, Saskatchewan residents and non-Canadian residents, with the exception of 2005, when a third stratum was added to sample Canadian resident MGBHP purchasers in southern Alberta. That stratum was discontinued after one year due to very low participation of Albertans in the Saskatchewan spring harvest. The Saskatchewan questionnaire is mailed to 2,000 hunters in late April and a reminder is sent to non-respondents approximately one month later. In 2005, 500 additional questionnaires were sent to Albertans. Spring surveys provide estimates of the number of active and

successful hunters, the number of hunting days, and the total harvest of light geese. There is no SCS for the spring harvest and thus no information is collected on the age structure of the harvest. No survey is conducted in Nunavut because very few permits are sold there.

USFWS Surveys

The USFWS estimated the annual light goose harvest in the United States from a national waterfowl harvest survey that has been conducted since the 1952 hunting season. From 1952-2001, the annual survey was conducted on a sample of all the people who purchased a federal duck stamp that year. All waterfowl hunters ≥ 16 years old were required to possess a federal duck stamp when they hunted waterfowl; thus, the survey's sample frame was nearly complete. An agreement between the USFWS and the U.S. Postal Service, whose post office clerks sold most of the federal duck stamps, provided the survey's sampling mechanism (Carney 1984).

The survey instrument, called the Mail Questionnaire Survey (MQS), was a self-administered form that, in the 1950s, asked waterfowl hunters to report how many of each duck and goose species they harvested. When it became apparent that some hunters could not identify waterfowl species accurately, the USFWS developed and established the waterfowl Parts Collection Survey (PCS) to correct that problem (Carney 1984). The PCS provided samples of duck wings and goose tails that, combined with estimates of total duck harvest and total goose harvest obtained from the MQS, enabled the USFWS to estimate species-specific harvest more accurately. The USFWS began collecting duck wings nationwide in 1961, and the PCS was expanded to include goose tail feathers in 1962 (Martin and Carney 1977).

Although federal duck stamp purchasers provided a nearly complete sample frame for the waterfowl harvest survey, the USFWS lacked sample frames upon which it could base harvest surveys of other migratory game bird hunters. Furthermore, the MQS's sampling mechanism deteriorated as cooperation from post office clerks waned, and as duck stamp sales gradually shifted from post offices to private vendors who were even less cooperative (Tautin et al. 1989). As a result, the potential for non-response bias increased as more and more U.S. waterfowl hunters were excluded from the MQS (Barker et al. 1992). This led to calls for a new sample frame for migratory bird harvest surveys (Tautin et al. 1989, Barker et al. 1992).

In response, state wildlife agencies and the USFWS established the national, cooperative Migratory Bird Harvest Information Program (HIP) in 1992 (Elden et al. 2002). This cooperative state-federal program was designed to provide annually an appropriate sample frame for national surveys of licensed migratory bird hunters, including those who hunt species for which adequate harvest information was lacking. The HIP requires licensed migratory bird hunters to identify themselves as such annually to the state licensing authority, provide the state their name, address and date of birth, and carry evidence of their compliance whenever they hunt migratory birds in that state. States collect this information from each licensed migratory bird hunter, provide him or her with proof of compliance, and ask a series of screening questions about his or her hunting success the previous

year. States must provide all of this information to the USFWS within 30 days of collection, and the USFWS is responsible for using those data to conduct annual national hunter activity and harvest surveys for all migratory game birds.

A two-year pilot phase of the HIP was conducted in 1992 and 1993 in California, Missouri and South Dakota (Elden et al. 2002). More states entered the program each year from 1994-1997 and all remaining states except Hawaii implemented the HIP in 1998. The first nationwide HIP migratory game bird harvest surveys were conducted during the 1999 hunting season. MQS and HIP surveys were conducted concurrently from 1999-2001, and in 2002 the HIP waterfowl harvest survey replaced the MQS permanently.

MQS Sample Frame and Sample Selection.

The U.S. Postal Service provided an annual report to the USFWS that indicated how many federal duck stamps were sold the previous year at each of the approximately 16,000 post offices that sold the stamps. The USFWS stratified the post offices by state and post office size, and randomly selected 3,000-4,000 of them for the sample each year (Voelzer et al. 1982, Geissler 1990). Clerks at each selected post office were asked to hand out a postage-paid name and address form to each person who bought a federal duck stamp, and ask the purchaser to fill out the form and mail it to the USFWS (Martin and Carney 1977). Thus, each sampled post office was a cluster sample of federal duck stamp purchasers (Geissler 1990). The name and address forms included a tear-off portion for the recipients to keep, notifying them that they would be asked to report on their waterfowl hunting at the end of the season. The tear-off portion also provided a small diary on which recipients were asked to record their hunts during the season, so that they could report their hunting activity and harvest accurately (Geissler 1990). Duck stamp purchasers who filled out and mailed in the name and address forms constituted the MQS's sample of hunters.

MQS Survey Methodology.

At the end of the waterfowl hunting season, each hunter in the sample was sent a self-addressed, postage-paid questionnaire that asked about his or her hunting activity for the season (Martin and Carney 1977). About a month after that mailing, a second request and survey was sent to those hunters who had not responded. From 1952-1961, hunters were asked to report their goose harvest by species, with separate categories for white- and blue-phase snow geese. Beginning in 1962, PCS participants were asked to provide goose tail feathers for species identification, and the species-specific goose harvest questions were removed from the revised MQS form soon thereafter.

MQS Analysis.

The proportion of duck stamp purchasers that hunted waterfowl and shot at least one goose (successful goose hunters), and the mean number of geese harvested (retrieved kill) and geese knocked down but not retrieved (unretrieved kill) per hunter were estimated at the state level, directly from

survey responses (Martin and Carney 1977, Geissler 1990). Those estimates were multiplied by the number of duck stamps sold in each state, yielding raw estimates of the number of successful goose hunters, geese harvested and unretrieved kill. The raw estimates of harvest and unretrieved kill were then adjusted to compensate for coverage and response biases, using flyway-specific adjustment factors (Voelzer et al. 1982). Raw estimates were adjusted upward to account for active hunters <16 years old, who were not covered by the sample frame because they were not required to purchase duck stamps. These “junior adjustment factors” were derived from special surveys conducted in the 1960s specifically to estimate the harvest of junior hunters (Voelzer et al. 1982). The resulting junior-adjusted estimates were then reduced to account for response biases (i.e., memory bias and prestige bias). Total response bias was estimated and flyway-specific bias correction factors were derived using the methods of Atwood (1959). Both junior and response-bias adjustment factors were treated as constants that did not vary from year to year.

HIP Sample Frame and Sample Selection.

The annual HIP sample frame consisted of hunters who identified themselves as potential migratory bird hunters when they purchased state hunting licenses. People who hunted migratory birds in more than one state had to comply with the HIP requirement in each state in which they hunted, thus, the HIP sample frame was specific to each state. Some states required everyone who hunted migratory game birds to obtain HIP certification, including people who were otherwise exempt from state license requirements (e.g., juniors, seniors, disabled veterans and landowners hunting on their own property), but in most states migratory bird hunters who were exempt from state hunting-license requirements were also exempt from the HIP requirement.

The sample frame was stratified by hunter type and experience, thereby allowing the USFWS to improve precision of goose harvest estimates by sampling primarily goose hunters, especially those who were highly successful. As part of the HIP certification process, states asked each migratory bird hunter, “How many geese did you shoot last season: none, 1 to 10 or more than 10?” This prior-year information was used as a predictor of current-year hunting activity and success. The USFWS assigned each hunter to a success stratum based on his/her responses to that question. The stratification maximized sampling efficiency by sampling the small group of very successful goose hunters at a high rate, the larger group of less successful goose hunters at a lower rate, and the very large group of migratory bird hunters who rarely, if ever, hunted geese at a very low rate. Sampling rates were state-specific, and they were established prior to the first sample selection in August.

HIP Survey Methodology.

The HIP survey form was a daily hunting diary designed to reduce memory and prestige bias, both of which result in overestimation of harvest (Atwood 1956). Hunters selected for the surveys were asked to record the date of each goose hunt, the state and county where they hunted that day, and how many geese they personally bagged that day. They were also asked to report the total number of

days they hunted for geese, the total number of geese they bagged and the total number of geese they knocked down but were unable to retrieve during the entire season. This enabled hunters to provide useful information even if they forgot to record their daily hunting information, or if they did not receive the form until after the hunting season began. Hunters needing additional space were asked to place a toll-free telephone call to the USFWS and request additional forms.

The survey was conducted using Dillman's Total Design Method for mail surveys (Dillman 1978, Dillman 1991), a survey implementation method that is designed to maximize survey response rates and ensure quality and timely responses. The survey packet consisted of the diary-format survey form (Appendix 3), a personalized cover letter and a postage-paid envelope for returning the survey to the USFWS at the end of the hunting season. Soon after the initial batch of names and addresses was received from a state, stratified samples were selected according to predetermined sampling rates. Each selected hunter was sent a survey packet within 2 weeks after his or her name was received. The sample selection and initial mailing process continued with each subsequent batch of names and addresses (roughly twice per month), with the last initial mailing occurring on or shortly after the closing date of the state's last waterfowl hunting season. For all hunters who received their initial packets before the hunting season ended, reminder postcards were sent at the close of the season asking hunters to return their completed survey forms. For hunters who received the initial packet after the close of the hunting season, reminder postcards were mailed approximately one week after the initial packet. Two to 3 weeks after the reminder postcard, follow-up packets were sent to the non-respondents. Finally, 3 to 4 weeks later, an additional follow-up packet was mailed to the remaining non-respondents.

HIP Survey Analysis.

Each hunter's record was summarized as the total number of days afield, number of geese bagged (retrieved kill) and number of geese knocked down but not retrieved (unretrieved kill) for the entire season in the sample state. Those state-specific season totals were used to obtain estimates of goose and hunter activity and harvest, using standard analysis methods for stratified samples (Cochran 1977, Steel and Torrie 1980). Proportion of active hunters (hunted geese at least once), mean number of days hunted, mean retrieved kill and mean unretrieved kill and their respective variances were estimated for each stratum. Then, state-level totals for days afield, retrieved kill and unretrieved kill and their variances were estimated by combining the stratum-specific means and variances with the number of HIP-certified people in each stratum. State-level totals of active goose hunters and their variances were also estimated by combining the stratum-specific proportions with the number of people in each stratum. Details of these analyses were described in Padding et al. (2006).

Waterfowl Parts Collection Survey.

The USFWS has conducted a PCS annually in cooperation with the state wildlife agencies to estimate the species, age and sex composition of the duck harvest since 1961 and the species and

age composition of the goose harvest since 1962 (Martin and Carney 1977). Goose hunters who agreed to participate in this survey were provided large, postage-paid “wing envelopes” (Appendix 4) and were asked to send in the tail feathers and primary feather tips from each goose they shot throughout the hunting season. They were also asked to report the state, county and date of harvest for each specimen they submitted. After the waterfowl hunting seasons ended, teams of federal and state biologists examined the specimens to determine the species and age (young-of-the-year or adult) of the birds. Blue-phase snow geese were identified from the color and markings on their tail feathers. Adult white-phase snow goose and Ross’s goose tail feathers are similar in appearance, and were distinguished from each other primarily by central rectrix length and coloration (for juveniles) (Johnson et al. 2007). Age determination for both species was based on coloration and shape and wear patterns of the tail feathers. Hybrid snow/Ross’s geese appear to be increasing in abundance (Robert Rockwell, pers. comm.) and we know of no reliable way to distinguish these birds from either snow or Ross’s geese from the PCS samples. Thus, the PCS provided state-specific estimates of the species and age composition of the light goose harvest.

Species-Specific Harvest Estimates.

From 1962-2001, annual species composition estimates derived from the PCS were combined with goose harvest estimates from the MQS to calculate species-specific goose harvest estimates (see Martin and Carney 1977 and Geissler 1990 for computational details). The PCS also made it possible to estimate harvest by location of harvest rather than by the state in which the duck stamp was purchased. Furthermore, county information provided by PCS participants provided the means for apportioning the MQS harvest estimates for Colorado, Montana, New Mexico and Wyoming into flyway-specific (i.e., Central and Pacific flyways) light goose harvests. When HIP surveys were initiated in 1999, similar methods combining HIP and PCS results were used to obtain species-, state-, and flyway-specific light goose estimates (Padding et al. 2006).

Bias Corrections.

The direction and magnitude of the overall bias (i.e., from coverage, response and nonresponse biases combined) in MQS and HIP goose harvest estimates was estimated by comparing MQS and HIP estimates of the harvest of banded geese (DMBM, unpublished data) with goose band recovery reports. Recent reward-band studies indicate that current band reporting rates for mallards (*Anas platyrhynchos*; Royle and Garrettson 2005), black ducks (*A. rubripes*; P. R. Garrettson, unpublished data), wood ducks (*Aix sponsa*; P. R. Garrettson, unpublished data) and Canada geese (*Branta canadensis*) (Zimmerman et al. 2009) in the United States are nearly identical. Based on this finding, and assuming that previous reporting rates were also similar across species, Padding (in review) used past estimates of mallard reporting rates (Nichols et al. 1995) and a recent estimate of the Canada goose reporting rate (Zimmerman et al. 2009) to estimate annual Canada goose band recoveries in the United States. The number of Canada goose band recoveries reported to the Bird Banding

Laboratory (R), adjusted for reporting rate (r), provided unbiased estimates of the number of banded Canada geese that were shot in the United States each year (H_t^{BBL}) from 1971-2009:

$$H_t^{BBL} = \frac{R_t}{r_t}$$

Comparison of those unbiased estimates (H_t^{BBL}) with annual MQS and HIP estimates of the total number of banded Canada geese (H_t^{MQS} and H_t^{HIP} , respectively) showed the direction and magnitude of overall bias in annual MQS and HIP estimates of the harvest of banded Canada geese (B_t^{MQS} and B_t^{HIP} , respectively) and, by extension, estimates of all goose harvest, including light geese:

$$B_t^{MQS} = \frac{H_t^{MQS}}{H_t^{BBL}}, \text{ for } t=1971-2001$$

$$B_t^{HIP} = \frac{H_t^{HIP}}{H_t^{BBL}}, \text{ for } t=1999-2009$$

The resulting multiplicative bias correction factors (C) were the reciprocals of the average annual estimated biases:

$$C^{MQS} = \left(\frac{\sum_{t=1971}^{2001} B_t^{MQS}}{n} \right)^{-1}$$

$$C^{HIP} = \left(\frac{\sum_{t=1999}^{2009} B_t^{HIP}}{n} \right)^{-1}$$

Although this method did not offer insights into the types and causes of biases, it did provide the basis for developing bias correction factors that were applied to the MQS and HIP estimates of total goose harvest.

Like Canada's SCS, the PCS has long been suspected of a temporal response bias that results in overestimating the harvest of species that are mainly shot early in the hunting season, and underestimating species that are mainly shot late in the season (Martin and Carney 1977). The underlying hypothesis is that some hunters run out of postage-paid envelopes and fail to request more, and others tire of participating before they stop hunting, either of which would result in a temporally-biased sample. The USFWS conducted a study over the last 20 years of the MQS that estimated the direction and magnitude of bias that this imposed on harvest estimates for each goose species (E. M. Martin, unpublished data). The MQS questionnaire form employed during

that period (Appendix 5) asked participants to report their harvest by month, thereby enabling the USFWS to estimate goose harvest by month. Coupled with date-specific PCS responses, those monthly harvest estimates yielded weighted, species-specific goose harvest estimates that corrected for any temporal response bias in the PCS. That study's results provided the basis for species- and flyway-specific correction factors for light goose harvest estimates, which were applied after the correction factors described above.

Another source of bias in light goose harvest estimates has arisen since the advent of the LGCO. The MQS, and later the HIP survey, was expected to estimate light goose harvest during the hunting season, whereas individual state harvest surveys were implemented to estimate harvest during the LGCO. However, the timing of both MQS and HIP survey mailings enabled some hunters to report their LGCO harvest on the USFWS survey form, thereby inflating the USFWS estimates of regular-season light goose harvest. The date and county-of-harvest information provided by PCS participants who shot light geese was used to eliminate birds shot during the LGCO from each state's MQS-derived light goose harvest estimate. A different approach was taken to correct HIP survey estimates. Date and county information that respondents provided on their hunting diaries was used to estimate the proportion of each state's goose harvest that occurred during the LGCO, and that harvest was subtracted from the total goose harvest. Species composition was then estimated from the PCS, using only parts from geese shot during the regular hunting season.

State LGCO Surveys in the United States

States that participate in the LGCO are required by the USFWS to obtain and keep records of hunter activities and harvest during the LGCO period. These records include: the number of participants, total harvest, and harvest with the aid of each of the special provisions that are allowed (electronic calls, unplugged guns, and harvest during the period from sunset to ½ hour after sunset). No information is collected by states on the age or species composition of the LGCO harvest. A report summarizing this information must be submitted annually by the end of August to the Division of Migratory Bird Management (USFWS). Procedures for acquiring, compiling and analyzing these data were left entirely to the discretion of individual states. The USFWS has not provided any guidelines or directives regarding procedures for obtaining this information, correcting for biases or analyzing and reporting the results. The result was that states developed harvest assessment methodologies independently, usually within their operational survey processes and within the capability of their existing harvest survey procedures and infrastructure.

Under the federal rules that established the LGCO, this take of light geese is not officially a hunting season. However, each state that implements a LGCO essentially treats it like any other hunting season. Thus, states that have mechanisms in place to assess the harvest of migratory game species by hunters, likely use these same or similar mechanisms to obtain the information required for the LGCO. Other states, especially those that do not have survey mechanisms in place, had to establish new or revised procedures for obtaining the required information.

Assessing harvest through a hunter survey begins with establishing a sample universe. This is usually done by sampling names and addresses obtained through required licenses or permits. License and permit requirements for participation in the LGCO vary considerably among states, ranging from full licensing (small game plus state and federal duck stamps) to free registration via a 1-800 telephone call. Therefore, the sample frames from which states assess LCGO harvest range from all license buyers to only those who register specifically to participate in the LGCO. Post-harvest survey questions can also differ greatly among states. There were flyway coordinated attempts to “standardize” a set of core questions, but these questions were often delivered using different survey instruments, including mail surveys, telephone surveys and web-based surveys. Differences also exist within similar survey types, such as the proportion of participants surveyed and the type and number of follow-up contacts. We recognize that differences in methodologies can have profound effects on results that may make comparisons among states difficult.

To determine how the various states assessed LGCO harvest, we developed a questionnaire that we sent to state waterfowl biologists in the Mississippi and Central flyways during winter 2006-07. We asked each biologist to provide information on LGCO regulations in their state, including licensing requirements (i.e., criteria for participation in the LGCO); the LGCO harvest survey methods and procedures their state uses; and any programs they established to inform hunters about the LGCO or provide assistance to increase hunting success.

Of the 17 states completing our questionnaire, all but two states collected LGCO harvest information through a mail questionnaire survey; Colorado used a telephone survey, and Oklahoma used a web-based survey system.

Mail Questionnaire Surveys.

Fifteen states (7 in the Central Flyway and 8 in the Mississippi Flyway) reported that they used mailed questionnaire surveys to estimate LGCO harvest and activity. HIP names and addresses were used to derive a sampling base by 6 states. Five states (Wyoming, Arkansas, Indiana, Minnesota and Mississippi) issued special permits or required special registrations to participate in the LGCO. Four states (New Mexico, Texas, Louisiana and Missouri) based their sampling frame on regular season license holders.

Sampling frame sizes were highly variable (Table 4) due to the different methods states used to obtain the names and addresses of potential LGCO hunters (e.g., sampling all license holders vs. sampling only those issued special LGCO permits). Sample frame size is related to the number of licensed waterfowl hunters and their opportunity to pursue light geese during the LGCO. In the case of HIP registrations, some states (e.g., North Dakota and Kansas) reduced the size of the sampling frame by selecting only those HIP registrations that occurred from the end (or near the end) of the regular waterfowl season until the end of the LGCO.

The total number of hunters sampled by mail questionnaires ranged from 103 in Indiana to 10,000 in Texas and 11,000 in Missouri. Most states sent follow-up mailings to hunters who did not respond to the first questionnaire mailing. Five states sent 1 follow-up mailing and 4 states sent 3 follow-up mailings. Nebraska and New Mexico did not send follow-up mailings to non-respondents. Seven states (Nebraska, Texas, Wyoming, Iowa, Illinois, Minnesota and Mississippi) corrected for non-response bias in some fashion. Nebraska used a phone survey for non-response bias correction. We did not collect details on how non-response bias corrections were made. Two states corrected for memory/prestige bias; North Dakota calculated and applied a correction based on Atwood (1959) and Texas used a regression technique to generate a corrected harvest estimate.

States reported that LCGO harvest survey procedures have changed very little during the 1999-2007 period (Table 4). Kansas, Texas and Iowa report improvements in how their sampling universe was established. Missouri reported that they had some minor modifications in question structure.

Telephone and Web-based Surveys.

One state, Colorado, used a telephone survey to assess LGCO harvest and hunting activity in 2006. The survey was based on a sample of 2,704 out of approximately 25,000 2005-06 HIP registrants. Attempts were made to contact each person in the sample 3 times. If contact was not made, they were dropped from the sample. There were no additional follow-ups. Fifty-six percent of the sample registrants were successfully contacted to obtain survey information.

Oklahoma reported using web-based surveys to obtain LGCO harvest and hunter activity information. Oklahoma has web-based registration for LGCO hunters. They sampled all of the 200 to 500 annual registrants to obtain the required harvest and hunter activity information, and conducted follow-ups to obtain information from non-respondents.

Hunter Activity and Harvest

Continental Harvest

The annual harvest of MCLG during the regular fall and winter seasons varied greatly and peaked at 912,557 birds in 1998 (Figure 2). The annual regular season harvest of midcontinent light geese in the United States and Canada averaged 428,630 birds for the 1962-1997 period and 471,654 birds for the 1962-2007 period. Coincident with implementation of conservation actions in the United States and Canada in the spring of 1999, annual harvest during the regular season has declined fairly steadily to 458,140 birds in 2007, the lowest regular season harvest since 1993. The take of MCLG in the United States and Canada increased significantly during the period of conservation actions (1998-2007). Harvest during this period averaged 1,300,244 geese, an increase of 154% over the average of the previous 10 year period (1988-1997) when only regular seasons were in place.

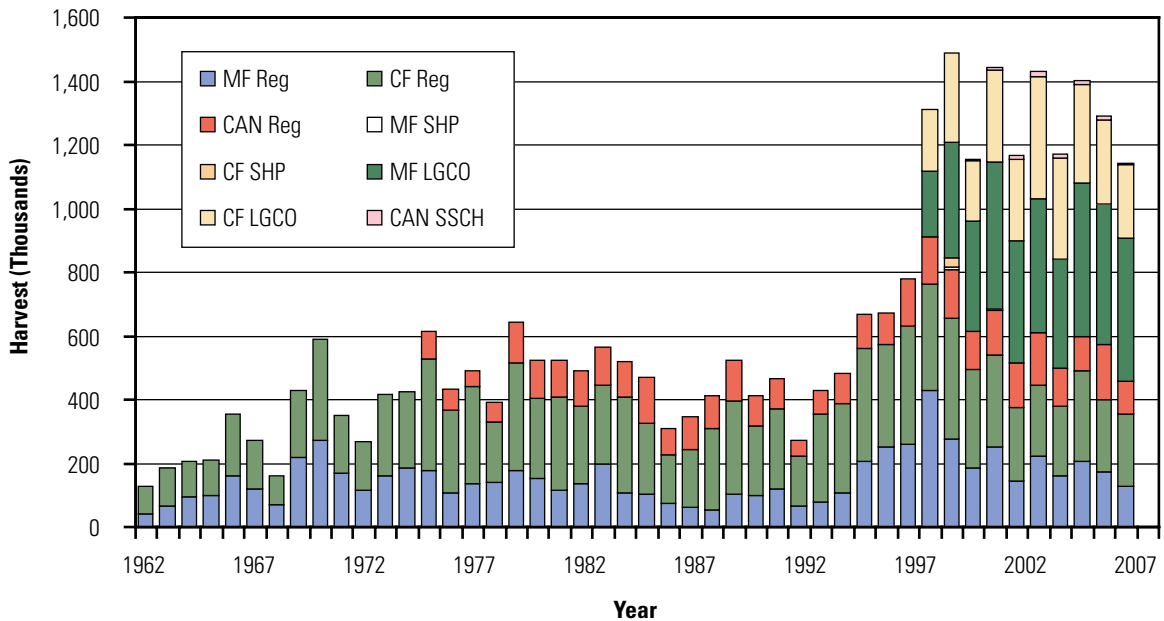


Figure 2. Midcontinent light goose harvest from regular hunting seasons (Reg), seasons with special harvest provisions (SHP) and conservation harvest in the Central (CF) and Mississippi (MF) Flyway states (LGCO) and Canada (CAN) (SSCH), 1962-2007. MF and CF regular hunting season harvests derived from MQS (1962-1998) and HIP Survey (1999-2007). Data for a year (e.g. 1998) includes harvest for the fall of that year (1998) plus that from the winter and spring of the following year (1999).

A further indication of the change in the size of the harvest during the conservation action period is the total birds taken over time. The total estimated take of light geese in the United States and Canada for all 46 years (1962-2007) combined was 28.43 million birds. This estimate does not include any harvest estimates from Canada from 1962 to 1974 when they did not have an operational harvest survey. Of this total, 15.43 million birds were taken in the 36 years (1962-1997) prior to conservation harvest actions. During 1998-2007, when conservation actions were in place in the United States and Canada, a total of 13.0 million was taken through regular hunting seasons and conservation harvest. Thus, the 10 years with conservation actions in place accounted for 45.7% of all light geese taken from 1962 to 2007. During the LGCO period (1998-2007), 48.2 % (6.27 million birds) were taken during regular seasons and 51.8% (6.74 million birds) were taken as conservation season harvests in the United States and Canada. Special harvest provisions, used by only 4 states in 1999 and 1 state in 2000 and 2001, resulted in the take of only 42,000 additional geese.

The proportion of adult snow geese in the midcontinent regular season harvest has trended upward since 1975 (Figure 3) The harvest of adult snow geese peaked in 1999 at 608,067 birds and has declined since then to 384,993 birds in 2007 (Figure 4). There was not a significant correlation between the proportion of adult snow geese in the harvest and the total regular season midcontinent snow goose harvest ($R^2 = 0.004$, $P > 0.05$) (Figure 5) nor with the harvest of immature snow geese

($R^2 = 0.077$, $P > 0.05$) (Figure 6). Age-specific harvest data for midcontinent snow geese and Ross's geese are provided in Appendices 6 and 7.

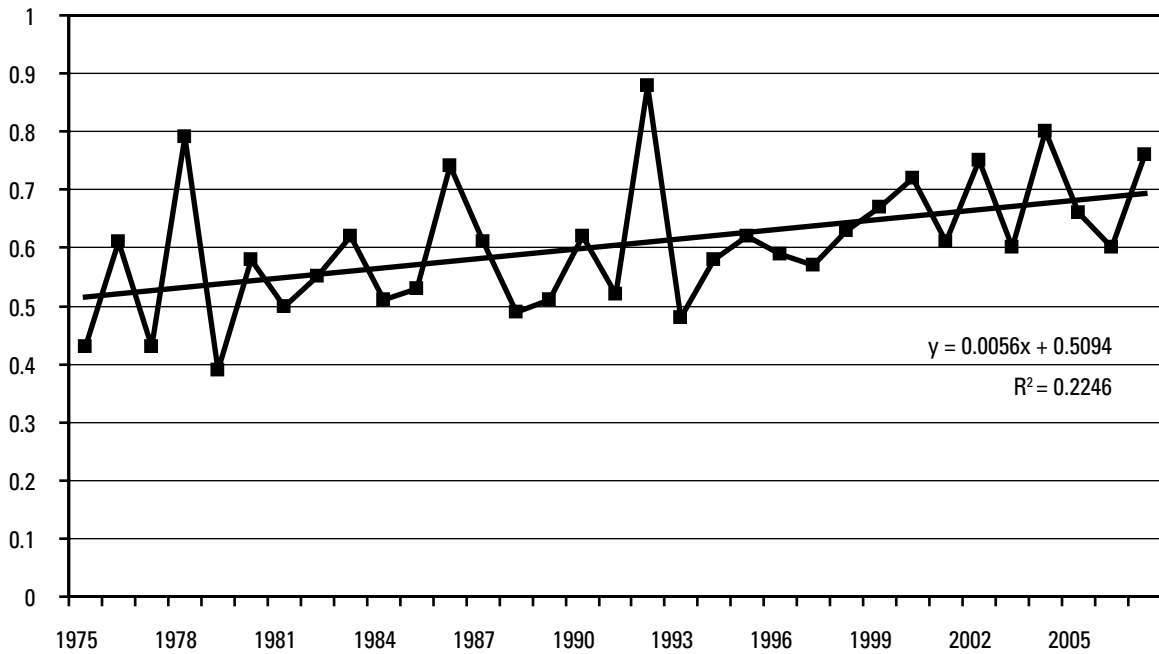


Figure 3. Proportion of adults in the midcontinent snow goose regular season harvest in the United States and Canada, 1975-2007

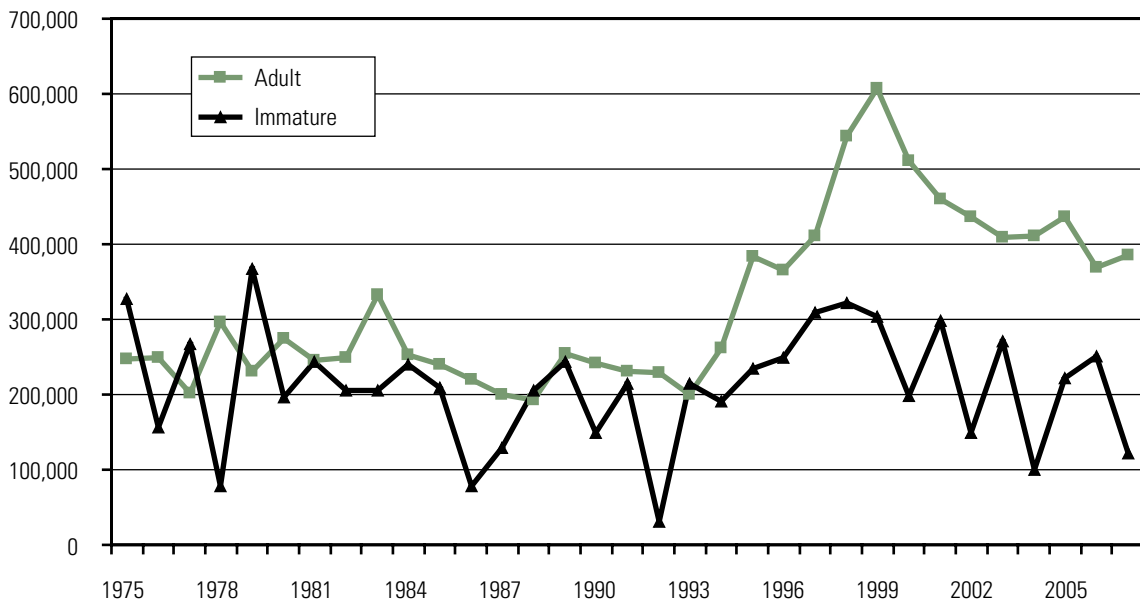


Figure 4. Adult and immature midcontinent snow goose harvest from regular seasons in the United States and Canada 1975-2007.

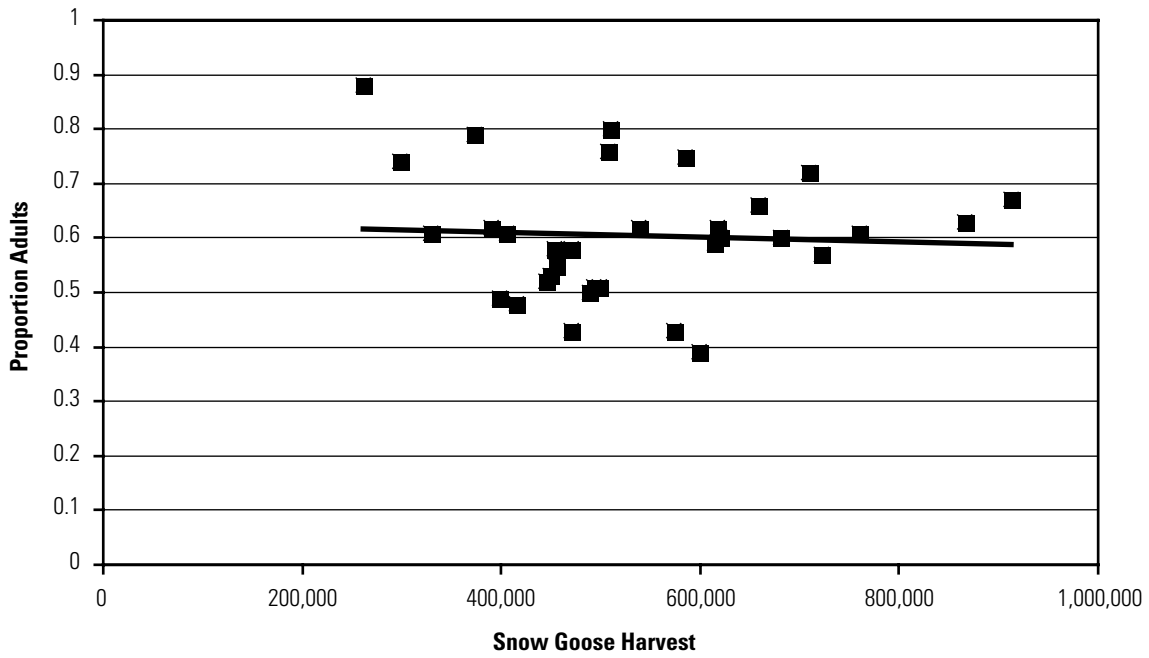


Figure 5. Relationship between total harvest and the proportion of adults in harvest of midcontinent snow geese in regular seasons in the United States and Canada, 1975-2007.

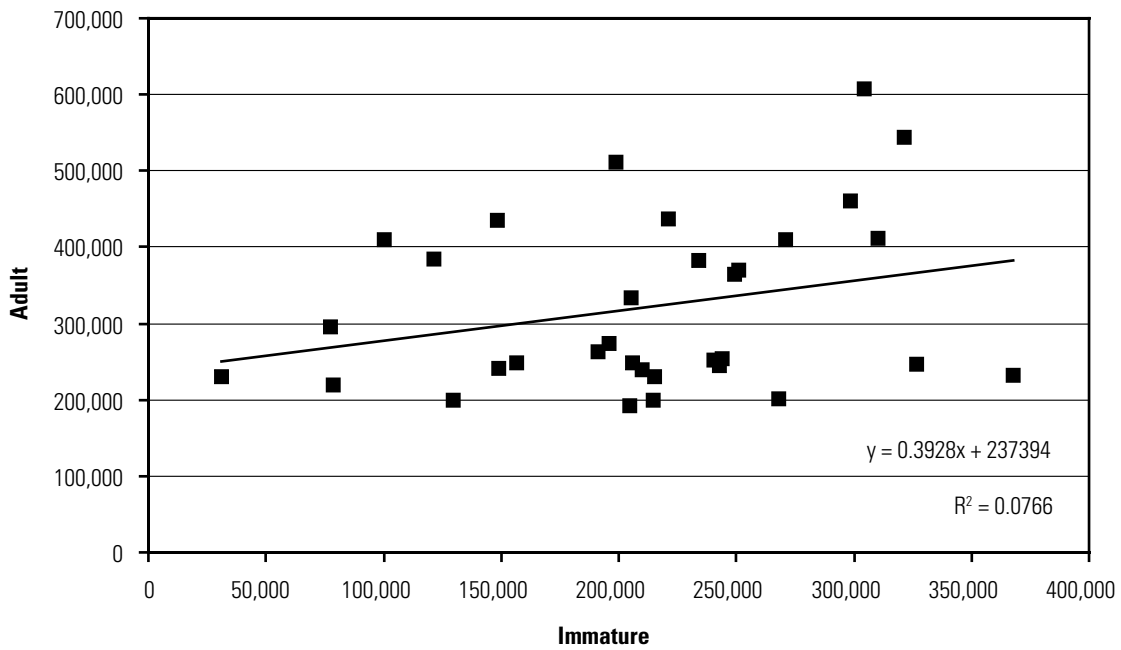


Figure 6. Adult versus immature midcontinent snow goose harvest in the United States and Canada, 1975-2007.

Regular Seasons in Canada

Number of Hunters.

MGBHP sales show different patterns in hunting activity among provinces. Hunter numbers in Manitoba peaked in 1978 and then declined consistently and precipitously until 2001, after which they stabilized (Figure 7). In Saskatchewan, the number of hunters declined sharply from 1976 until 1988 and it has since remained relatively stable due to a combination of a reduced rate of decline by Saskatchewan residents and an increase in non-Canadian hunters (Figure 8). Indeed, the number of permits sold to non-Canadians increased by 2.5 times from 1994 to 2000 and since 2003, more permits have been sold to non-Canadians than to Saskatchewan residents. The increase in non-Canadian permits sales is likely due, in part, to the increase in hunting opportunities from increasing populations of geese, and additional hunting opportunities during the special conservation measures. Estimates of successful goose hunters have also declined over the years but the ratio of successful goose hunters to permit sales has considerably changed since the mid-1970s (Figures 7 and 8). For example, less than half of permit purchasers were successful goose hunters in the mid-1970s while that proportion increased to more than 85% in recent years. This suggests that hunters have improved their success rate and/or more (formerly duck-only) hunters have started hunting geese. Regardless, this increase in goose hunting likely reflects the increase in hunting opportunities stemming from increase in light and dark goose populations.

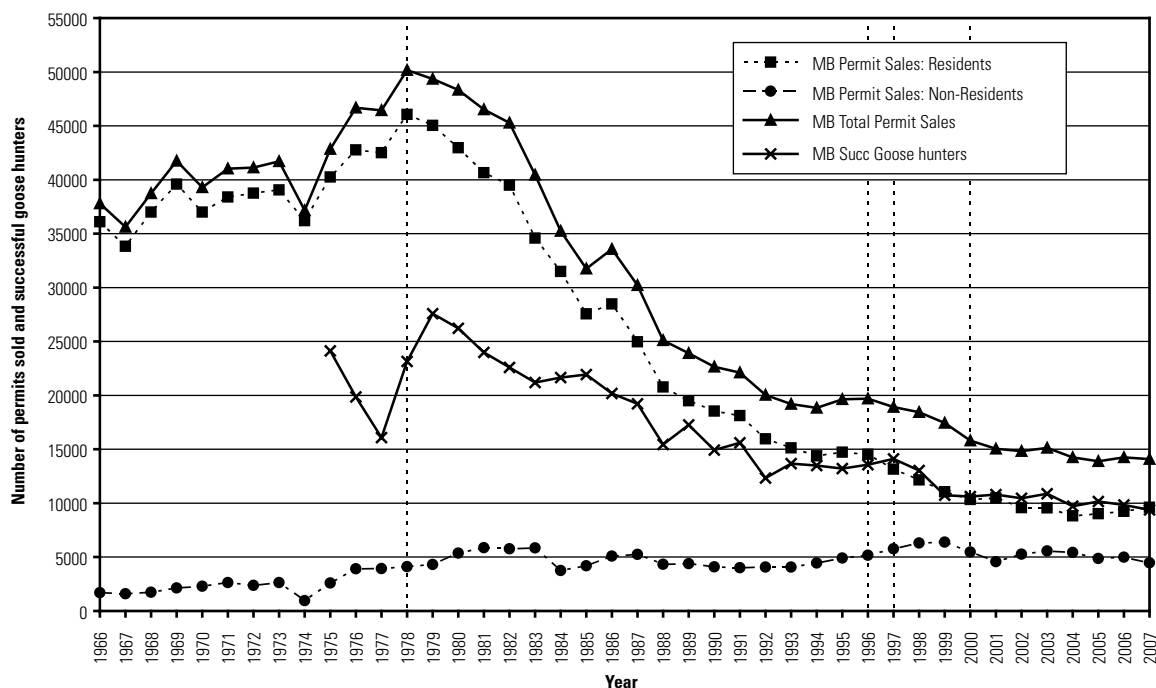


Figure 7. Estimated number of successful goose hunters and migratory game bird hunting permit sales for residents and non-residents in Manitoba from 1966 to 2007. Vertical dashed lines indicate a regulatory change in bag and/or possession limits.

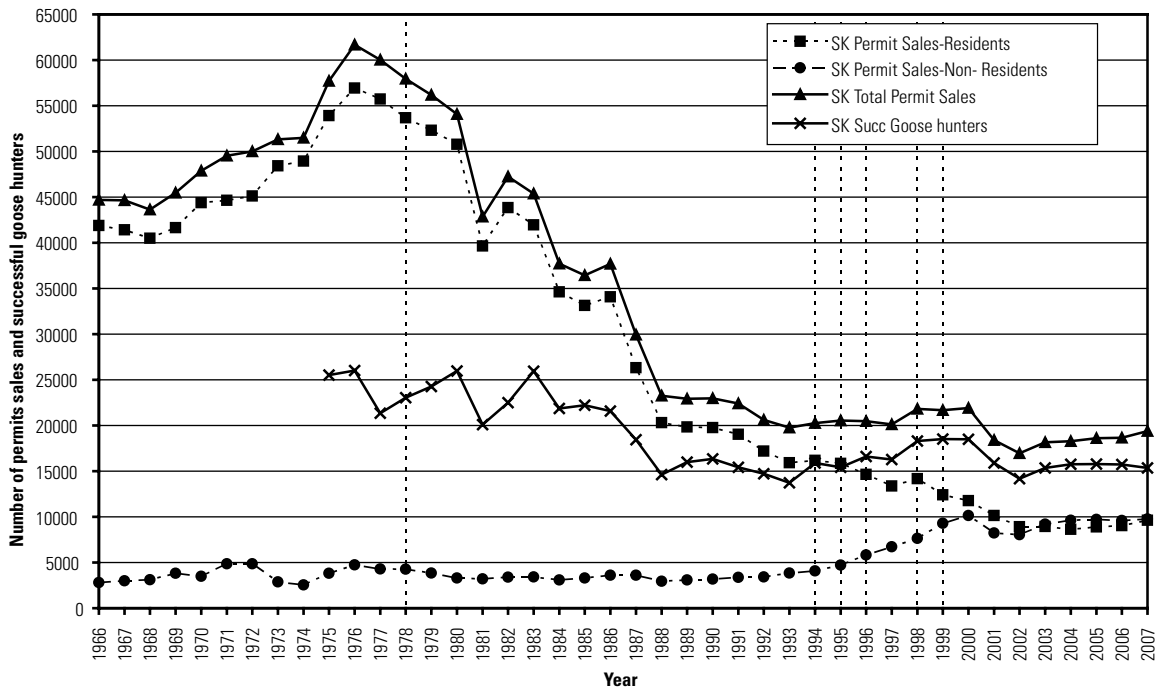


Figure 8. Estimated number of successful goose hunters and migratory game bird hunting permit sales for residents and non-residents in Saskatchewan from 1966 to 2007. Vertical dashed lines indicate a regulatory change in bag and/or possession limits.

Harvest.

Total fall regular season harvest of light geese varied considerably between 1975 and 2007, with significant reductions in the late 1970s and early 1990s (Figure 9). However, over that whole period, harvest increased only slightly (slope = 1643 geese per year, $R^2 = 0.27$, $P < 0.01$; Table 5). That trend was almost equally partitioned between increases in Ross's goose harvest (slope = 718 geese per year, $R^2 = 0.61$, $P < 0.001$) and snow goose harvest (slope = 925 geese per year, $R^2 = 0.12$, $P = 0.05$). During that period, the proportion of snow geese in the light goose harvest has declined from approximately 95% in the 1970s to approximately 85% in the 2000s. There was no evidence that regular season light goose harvest increased following the implementation of special conservation measures (one-tailed t-test of residuals of the 1975-2007 relationship between 1975-1998 and 1999-2007, $t = 0.70$, $df = 31$, $P = 0.5$).

Temporal patterns in harvest and hunter effort and success during the fall regular season varied considerably among provinces. In Saskatchewan, despite the decrease in permits sales since the late 1970s, harvest remained relatively stable up to the mid-1990s (Table 5), most likely due to a gradual increase in hunter success (i.e., light goose daily and seasonal bag per waterfowl hunter) (Figures 10 and 11). When changes to regulations were initiated in the mid-1990s, the combination of a continued increase in hunter success (seasonal bag nearly quadrupled over 10 years) and the stabilization in permit sales resulted in harvest levels that are currently about 3 times greater than levels prior to regulatory changes. Also, prior to the mid-1990s, the number of days afield per waterfowl hunter had been declining. The regulatory changes may have stabilized that pattern for a few years although it appears that the number of days afield is once again declining.

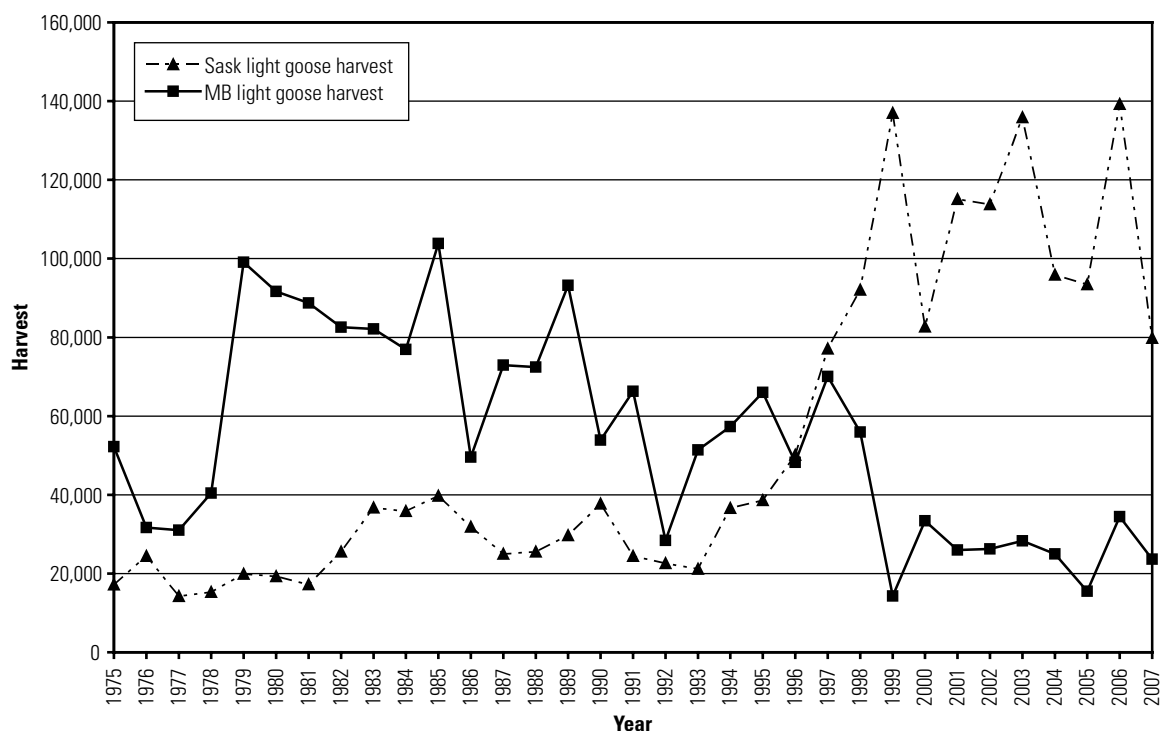


Figure 9. Estimated regular-season light goose harvest in Manitoba and Saskatchewan, 1975-2007.

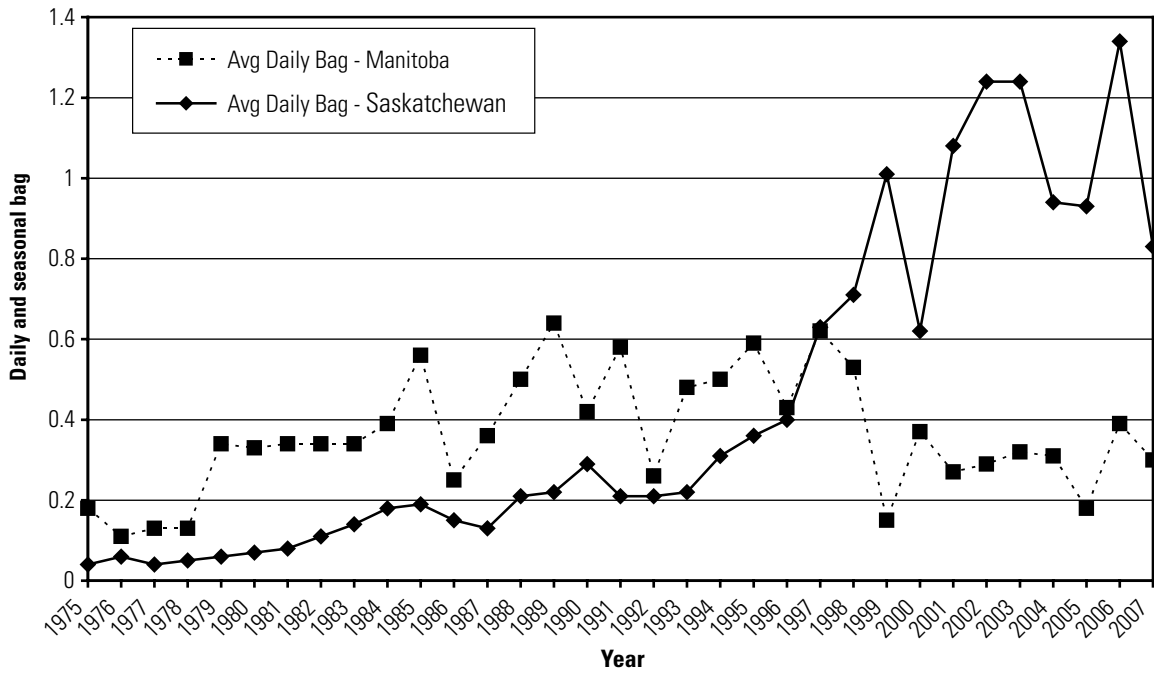


Figure 10. Estimated average daily light goose harvest per hunter in Manitoba and Saskatchewan from 1975 to 2007.

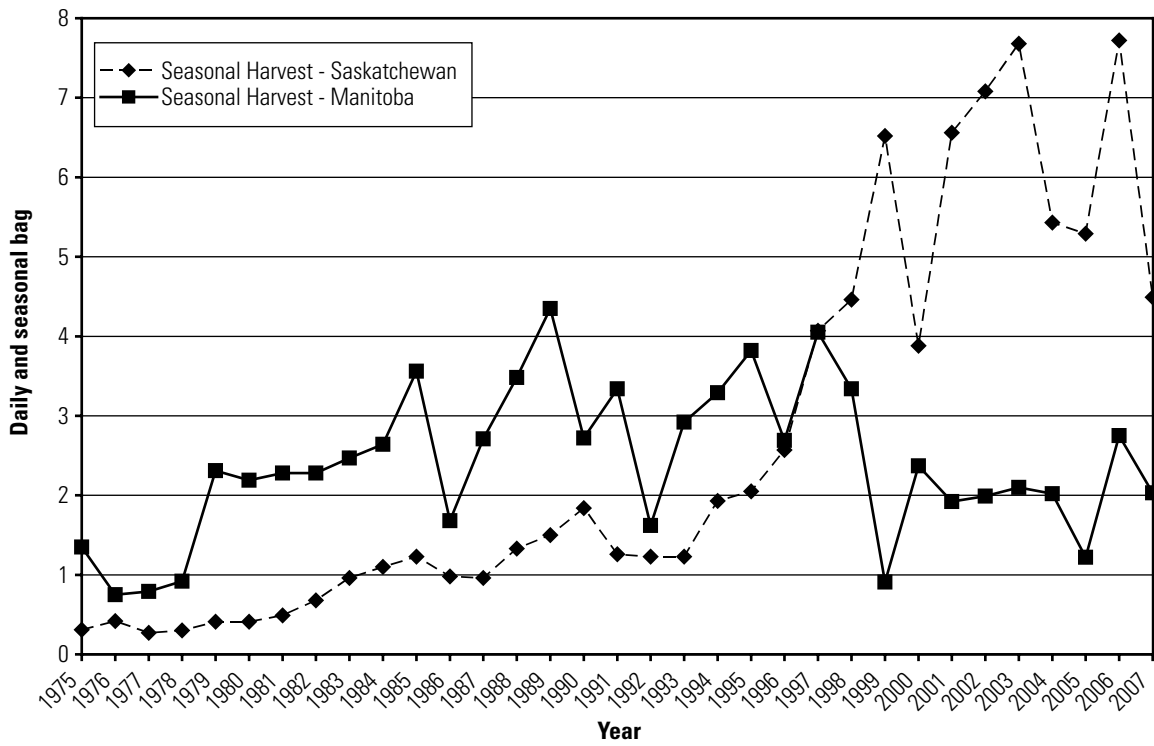


Figure 11. Estimated average seasonal light goose harvest per hunter in Manitoba and Saskatchewan from 1975 to 2007.

The trends in Manitoba were quite different. Harvest in that province was fairly high in the late 1970s and early 1980s, with levels above 80,000 birds (Table 5). Harvest started to drop along with the decline of permit sales and has stabilized over the last few years at about 25,000 birds killed annually. However, there is no indication that the increase in hunting opportunities in Manitoba has resulted in an increase in harvest or hunter success and effort. In fact, the average daily and seasonal bags have been lower in recent years (Figures 10 and 11). This pattern is opposite of the trend for Canada geese in Manitoba; harvest of Canada geese has increased, despite the loss of about 75% of waterfowl hunters since 1978. The decline in snow goose harvests is likely related to a westward shift in the fall distribution of snow geese, with fewer birds overall staging in Manitoba.

MCLG harvest in the rest of Canada (i.e., northern Ontario) is very low (Table 5). In fact, harvest and hunter success (i.e., daily and seasonal bags) have declined despite regulatory changes that increased daily bag and possession limits. This suggests that waterfowl hunters have not responded to the liberalized regulations and/or that goose migration patterns changed in that area.

We examined the relationship between the proportion of adult snow geese and the harvest of snow geese in MB and SK regular season harvest. Goose harvest tended to be higher when there were proportionately more juveniles in the harvest (Figure 12). Thus, assuming that harvest age ratios provided a reliable index to annual population age structure, it appears that harvest increased somewhat when young-of-the-year birds made up a greater proportion of the population, likely because young-of-the-year birds are more vulnerable to hunting than are adults. The proportion of adults in the harvest increased over time for snow geese, but declined for Ross's geese (Figure 13). The regular season harvest of adult snow geese peaked in 1999 at 80,280 birds and then declined to 52,545 birds in 2007 (Appendix 6). The harvest of adult Ross's geese peaked in 1998 at 11,030 birds and again in 2004 at 10,757 birds (Appendix 7).

Spring Conservation Harvest in Canada

For the spring conservation harvest, the Saskatchewan survey suggests that overall participation has been low, particularly over the last couple of years (Table 6). For example, during spring 2008, an estimated 430 out of 7,755 (5.5%) of Saskatchewan residents who were MGBHP holders participated in the harvest, while 80 out of 7,052 (1.1%) of non Canadian residents who purchased their MGBHP in Saskatchewan were active. To develop a better understanding of the low participation rate, an additional question was added to the 2009 questionnaire asking the survey respondents to indicate the reason(s) for not participating in the spring conservation harvest. Of the 900 responses received specific to that question, reasons for not participating in the spring conservation harvest included a lack of time (27%), not interested or hunter traditionally hunts in the fall (27%), distance to hunting location (17%; many respondents were non-residents), lack of geese where they live (8%), lack of money (8%), were not aware of the hunt (4%), personal reasons (3%), don't enjoy snow goose hunting (3%), logistical issues (2%), and difficulty in identifying Ross's geese when hunting (1%).

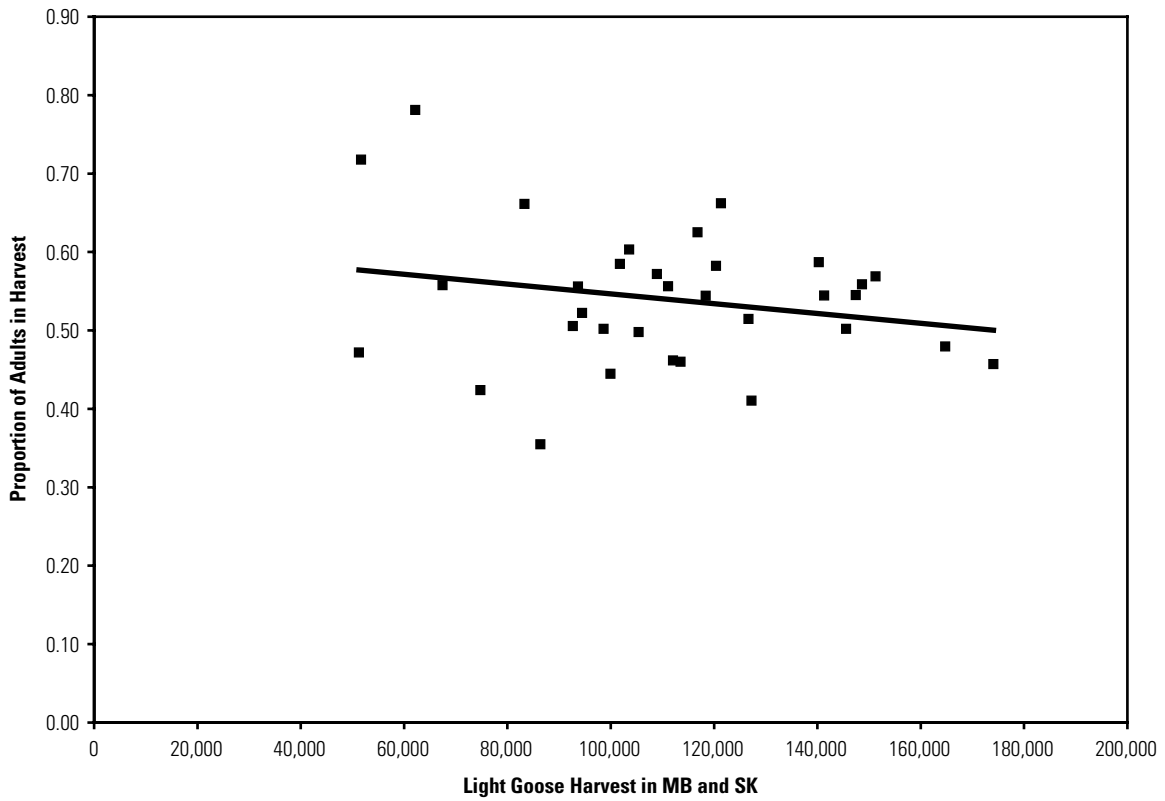


Figure 12. Relationship between the number of birds harvested and the proportion of adults in the harvest of snow geese harvested during regular seasons in Canada, 1975-2007.

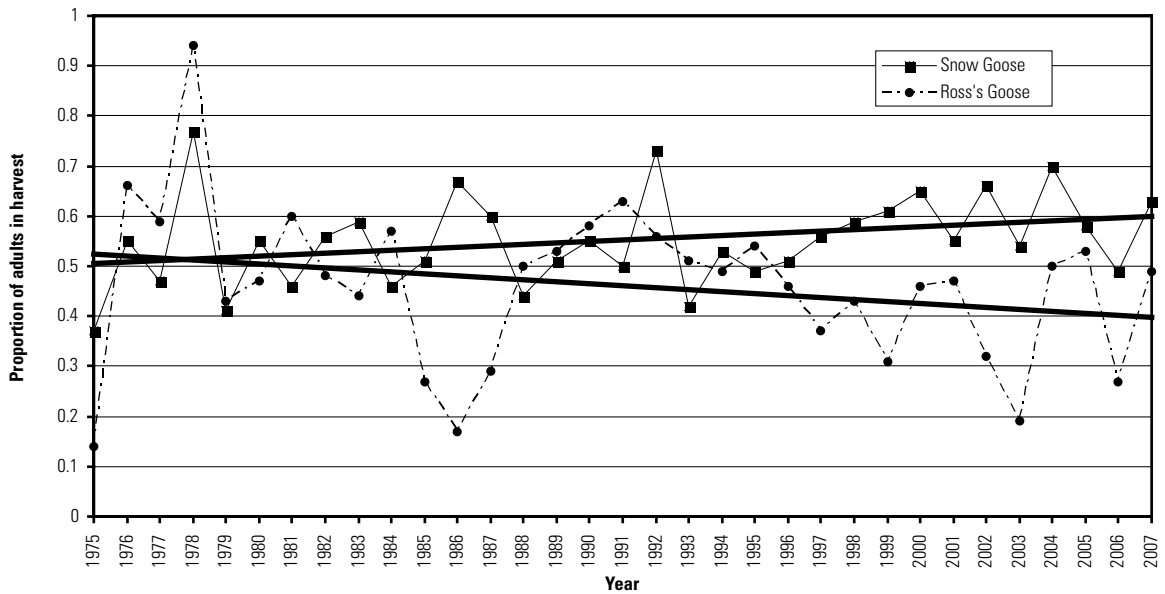


Figure 13. Proportion of adults in the harvest of midcontinent light geese during regular seasons in Canada, 1975-2007.

Regular Seasons in the United States

Number of Hunters.

MQS estimates of successful goose hunters were not directly comparable to HIP estimates of active goose hunters, but data from the 3 years during which both surveys were conducted nationwide (1999-2001) provided a link. The ratio of MQS successful hunters to HIP active hunters was similar for each year of survey overlap, and that ratio was used to convert the HIP estimates to the MQS scale, i.e., successful goose hunters. However, most of the goose harvest in midcontinent United States is comprised of Canada geese (e.g., Moore et al. 2007), and likely most goose hunters in the region primarily hunt Canada geese. Long MCLG hunting seasons, large bag limits, and seasons that continued well after duck and other goose hunting seasons were closed may have resulted in greater MCLG hunter success than other goose hunters experienced, particularly in the 1990s and early 2000s. Nonetheless, we assume that the trend in the number of successful goose hunters reflects the trend in the number of successful MCLG hunters. The estimated number of successful goose hunters in the Mississippi and Central flyways increased from 1963 until the mid-1970s, leveled off from the late 1970s to the early 1990s, then increased again for several years, but has declined since the late 1990s (Figure 14).

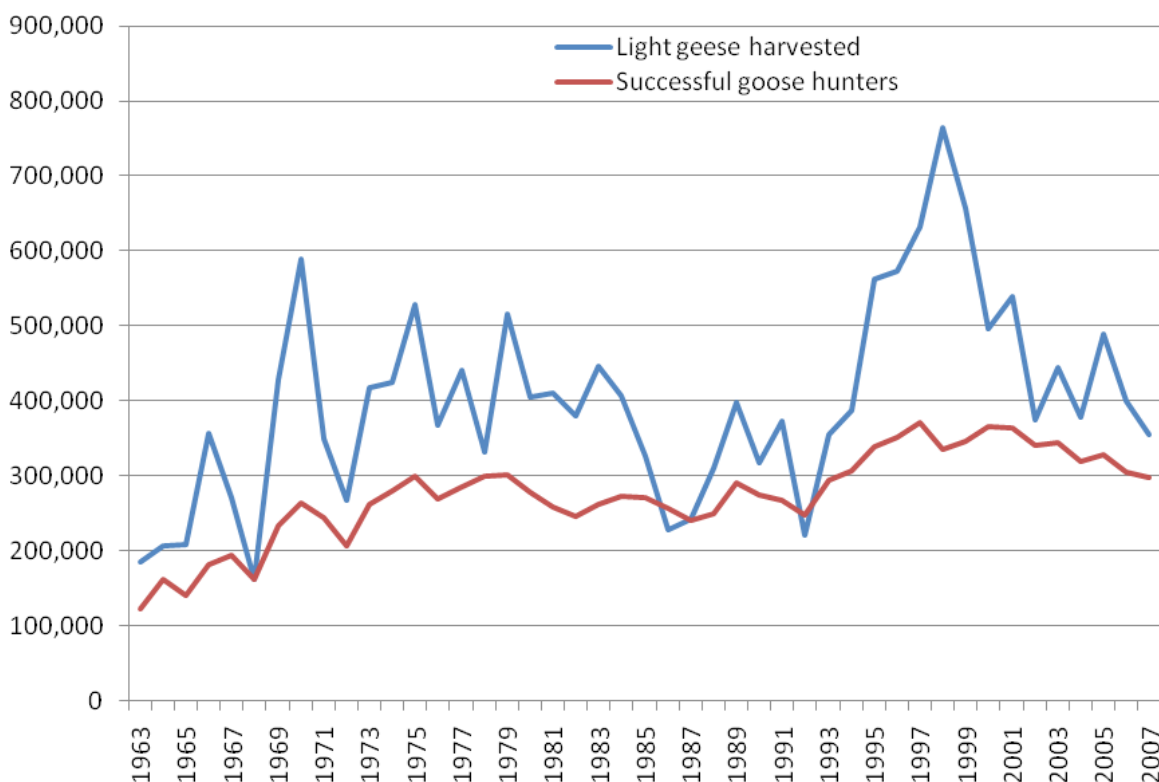


Figure 14. Estimated number of successful goose hunters and total regular-season light goose harvest in the Central and Mississippi Flyways, 1963-64 – 2007-08.

Bias Corrections.

Removal of LGCO harvest from the 1998-2007 estimates resulted in reductions of estimated regular-season harvest. The accuracy of this adjustment may be slightly compromised some years because several states (e.g., Louisiana and Texas) set zone-specific dates for their LGCOs. County was the finest level of resolution that both the PCS and the HIP diaries provided for harvest data, but zone boundaries did not always correspond with county boundaries. In those cases, counties were assigned to the zone in which most of the county was located.

Temporal bias in the PCS was species- and flyway-specific. In the Mississippi Flyway, temporally-weighted estimates were 4.6%, 6.8%, and 7.0% greater than the estimates shown in Appendix 8 for white-phase and blue-phase snow geese and Ross's geese, respectively (E. M. Martin, unpublished data). However, the mean difference between the 2 sets of Central Flyway estimates was <1% for each of the light geese, and none of the differences were significant. Thus, multiplicative adjustment factors of 1.046, 1.068, and 1.070 were applied to the estimates for each Mississippi Flyway state, but estimates for Central Flyway states were not adjusted.

Although MQS estimates were originally adjusted for junior hunting and memory and prestige bias, additional bias was evident from comparisons of estimated harvest of banded Canada geese based on harvest surveys versus recoveries of banded Canada geese from 1971 to 2009. MQS estimates were an average 1.50 times greater than the estimates based on reported recoveries adjusted for band reporting rates (Padding, *in press*). HIP goose harvest estimates were also biased high, but the magnitude was larger; HIP estimates were an average 1.68 times greater than the adjusted total number of band recoveries. Based on those findings, multiplicative adjustment factors (*C*) of 0.67 and 0.60 should be applied to annual, state-specific, MQS and HIP light goose harvest estimates, respectively. Since the CWS harvest estimates and the state LGCO estimates were derived from similar survey and analysis methodology, we suspect that those estimates are also biased high to a similar degree. However, we have no way of confirming that suspicion. Therefore, to maintain as much comparability among estimates as possible, we did not apply the adjustment factor to the harvest estimates reported here.

Harvest.

The harvest estimates reported here may differ from those previously reported in USFWS Administrative Reports (e.g., Martin et al. 1991, Moore et al. 2007), flyway data books, and other USFWS reports (e.g., Kruse et al. 2009) because of the bias adjustments that we applied. Annual flyway- and species-specific harvest estimates for the 1952-53 through 2001-02 seasons were obtained from the MQS (Table 7), and HIP surveys yielded estimates for the 1999-00 through 2007-08 seasons (Table 8). Regular-season light goose harvest followed a pattern similar to that of successful goose hunters, but showed more marked changes since the implementation of special provisions during regular light-geese-only hunting seasons (i.e., use of electronic calls and/or unplugged shotguns) and the LGCO (Figure 14). Nine states employed special provisions during regular light-geese seasons in late February and early March of 1999, and that probably contributed to the peak

harvest of about 764,000 light geese that occurred during the 1998-99 season (Figure 14). As those states reduced their regular seasons and replaced them with LGCOs, regular-season harvest declined in 1999-2000, 2000-01, and 2001-02, but stabilized at an average of about 406,000 birds per year since then (Figure 14). State-specific MQS harvest estimates for the Mississippi and Central flyways are given in Appendices 8 and 9, respectively, and HIP survey estimates for the 2 flyways are given in Appendices 10 and 11, respectively.

There was a weak relationship between the magnitude and age composition of the regular season snow goose harvest; total harvest tended to be greater when young-of-the-year birds made up a greater proportion of the harvest (Figure 15). Thus, assuming that harvest age ratios provided a reliable index to annual population age structure, it appears that harvest increased somewhat when young-of-the-year birds made up a greater proportion of the population, likely because young-of-the-year birds are more vulnerable to hunting than are adults. The proportion of adults in the harvest has increased over time for both snow geese and Ross's geese (Figure 16).

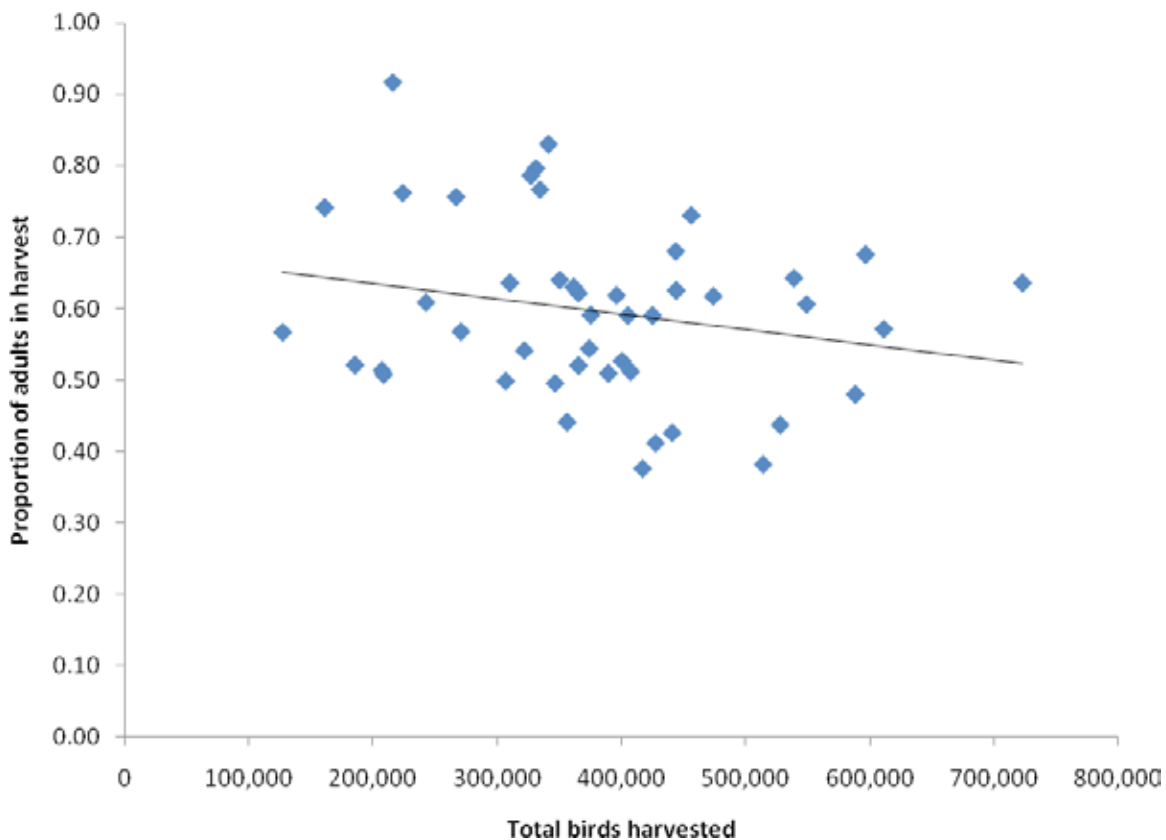


Figure 15. Relationship between the number of birds harvested and the proportion of adults in the harvest of midcontinent snow geese harvested during regular seasons in the United States, 1962-63 – 2007-08.

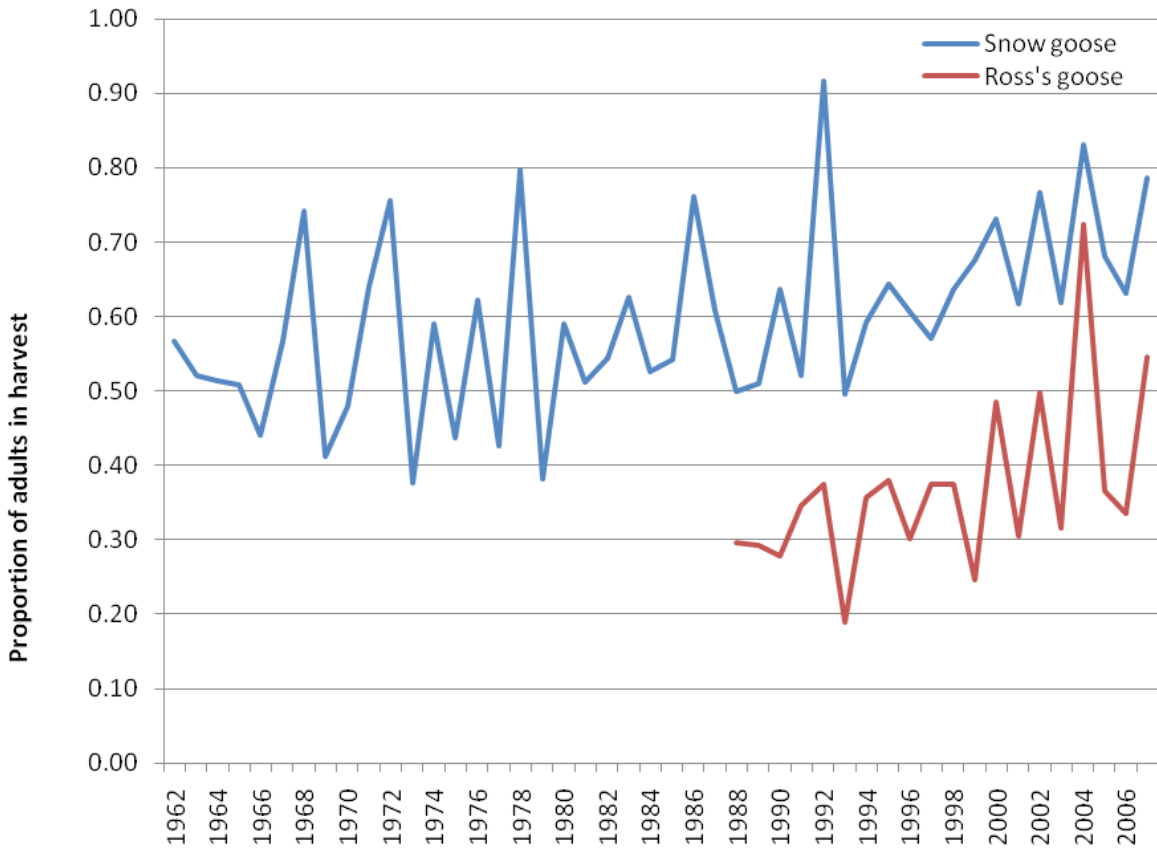


Figure 16. Proportion of adults in the harvest of midcontinent light geese during regular seasons in the United States, 1962-63 – 2007-08.

Unretrieved Kill.

Estimates of unretrieved kill (crippling loss) obtained from harvest surveys should be viewed as indices, because they are based on individual hunters' interpretations of their observations in the field (Schulz et al. 2006). The reported unretrieved kill of geese, expressed as the percent of the total kill [unretrieved / (retrieved + unretrieved)], declined from about 15% in the 1950s to about 13% in the mid-1980s, then increased during the period when nontoxic-shot regulations were implemented in the United States, then declined to about 11.7% by the early 2000s (Schulz et al. 2006).

LGCO in the United States

Number of Hunters.

The estimated number of hunters pursuing light geese during LGCOs in Central and Mississippi flyway states from 1999 through 2006 have ranged from 41,163 in 1999 to 75,727 in 2000 (Table 9). Hunter numbers have since declined to 44,734 in 2008 (Figure 17). There were only 3,571 more hunters in 2008 for all 18 states participating in the LGCO than in the first year (1999) when only 10 states held LGCOs. Hunter numbers in the Central Flyway averaged 33,399 but have declined to

19,844 in 2008 from the peak of 49,047 in 2000. Hunter numbers in the Mississippi Flyway have averaged 24,375 and have remained relatively stable, ranging between 23,401 and 28,888 since 2000. Within individual states, hunter numbers have ranged from 23 in Indiana in 2000 to 27,882 in Texas in 2000. The average number of hunters per state (averaged over years with LGCO seasons between 1999 and 2007) ranged from 55 hunters in Indiana to 11,729 in Texas.

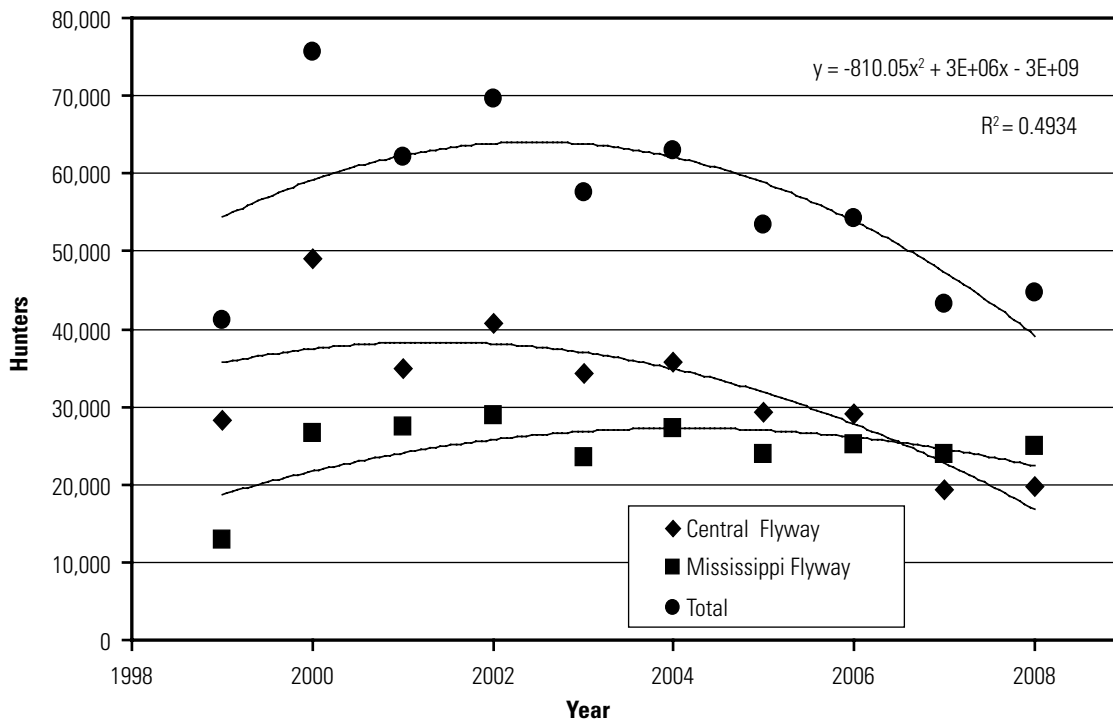


Figure 17. Estimated number of hunters participating in the Light Goose Conservation Order in Central and Mississippi Flyway states, 1999-2008.

Hunter Effort and Success.

The LGCO has provided for an estimated 2.53 million hunter-days since 1999. Mississippi Flyway states estimated a total of 1.48 million hunter-days (58%) and Central Flyway states estimated 1.05 million hunter days (42%) from their 10 years of harvest survey results. The top 5 states (in order of importance) were Louisiana, Missouri, South Dakota, Nebraska and Illinois, accounting for 1.66 million hunter-days or 65.7% of the total LGCO hunter-days. Estimated hunter-days appear to have peaked during 2002 to 2004 and are trending downward in both the Mississippi and Central flyways and in all states combined (Figure 18).

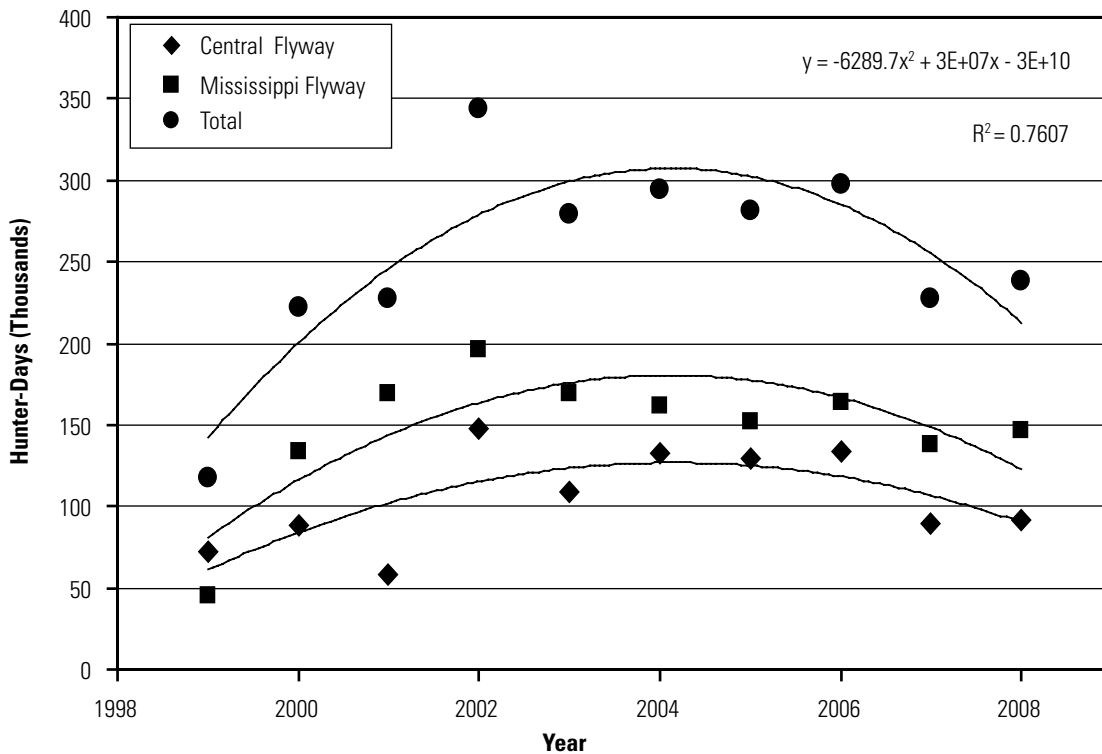


Figure 18. Estimated number of hunter-days during the Light Goose Conservation Order in Central and Mississippi Flyway states, 1999-2008.

Harvest per hunter-day averaged 2.61 birds overall and 2.58 birds in the Central Flyway and 2.64 birds in the Mississippi Flyway. Among the states, the average harvest per hunter-day ranged from 0.66 in Minnesota to 5.46 in Arkansas. Harvest per hunter-day was highest in the first year (1999) at 3.38 but declined to 2.18 in 2002 and appears to be trending upward since then to an overall average of 3.10 in 2007 and 2.85 in 2008 (Figure 19).

The overall average harvest per hunter in LGCOs is 11.71 birds and has ranged from 8.50 in 2000 to 16.31 in 2007. The average was higher in the Mississippi Flyway (15.94) than in the Central Flyway (8.48). Average harvest per hunter has been trending upwards in both flyways ranging from 5.46 (2001) to 13.68 (in 2007) (slope = 0.8445 geese per year, $R^2 = 0.82$, $P < 0.001$ in the Central Flyway and from 12.65 (in 2001) to 19.13 (in 2006) (slope = 0.4812 geese per year, $R^2 = 0.47$, $P < 0.03$) in the Mississippi Flyway (Figure 20). Estimates of annual harvest per hunter have ranged from 1.17 in Indiana in 2000 to 52.72 in Arkansas in 2006. Arkansas hunters consistently report the highest average annual harvest per hunter (38.23), ranging from 30.12 in 2001 to 52.72 in 2006. In the Central Flyway, Kansas hunters had the highest average annual harvest per hunter (13.48).

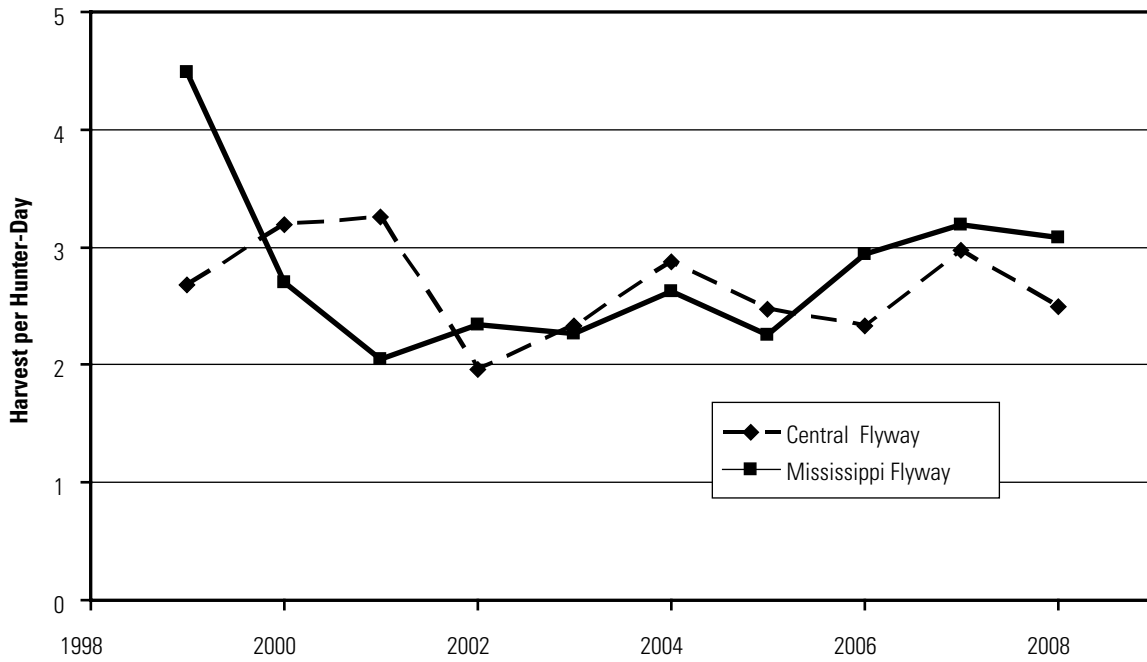


Figure 19. Estimated average daily light goose harvest per hunter during the Light Goose Conservation Order in Central and Mississippi Flyway states, 1999-2008.

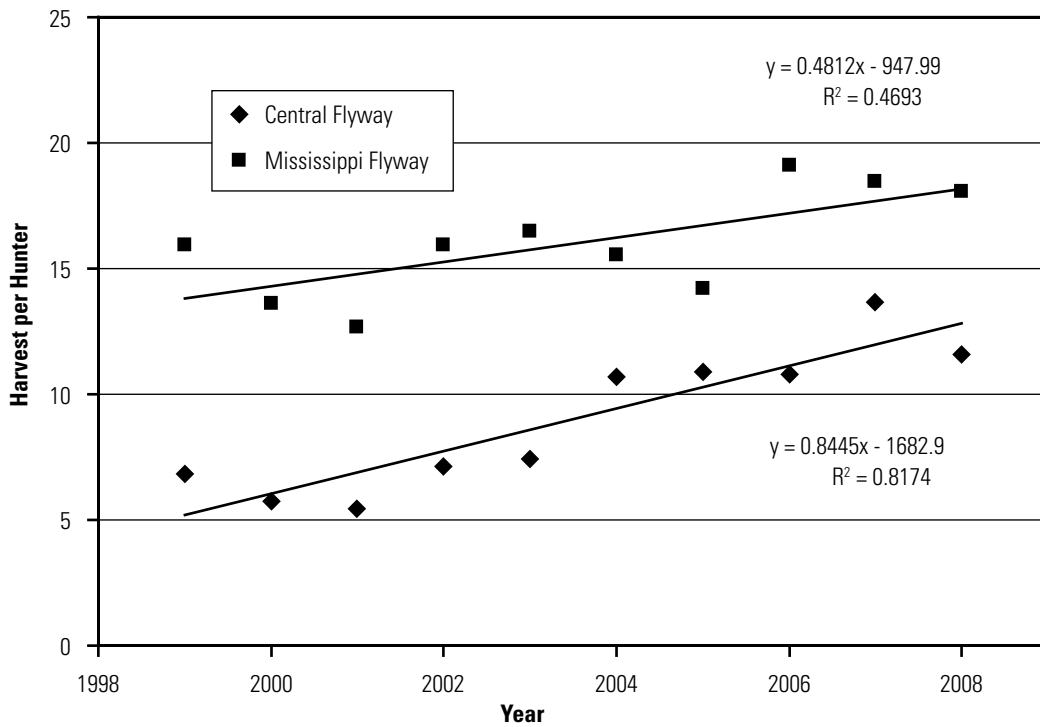


Figure 20. Estimated average total light goose harvest per hunter during the Light Goose Conservation Order in Central and Mississippi Flyway states, 1999-2008.

Harvest.

State survey estimates indicate that 6,612,513 light geese have been taken by hunters during LGCOs from 1999 through 2008 (Table 10). Fifty-nine percent (3.89 million birds) of this harvest was taken in the Mississippi Flyway and 41% (2.72 million birds) was taken in the Central Flyway. The top five harvest states (in order of importance) were Missouri, Arkansas, Louisiana, South Dakota and Nebraska. These states accounted for 73.4% of the total LGCO harvest since 1999. Hunters in Missouri reported a take of 1.23 million birds or 18.6% of the total harvest in LGCO states. Indiana had the lowest average harvest at 199 birds, with a total take of 1,988 light geese over the 9 years it held LGCOs.

Annual harvest for all states combined ranged from 398,455 in 1999 to 805,583 in 2004. The average annual harvest across states and years was 661,251 birds. LGCO harvest in the Mississippi Flyway has consistently exceeded that of the Central Flyway (Figure 21); Mississippi Flyway states averaged a harvest of 389,459 birds annually, while Central Flyway states averaged 271,792 birds. Harvest in both flyways combined has trended upward since 1999, but appears to have peaked in 2004 and is now stable to declining at around 700,000 birds annually (Figure 21).

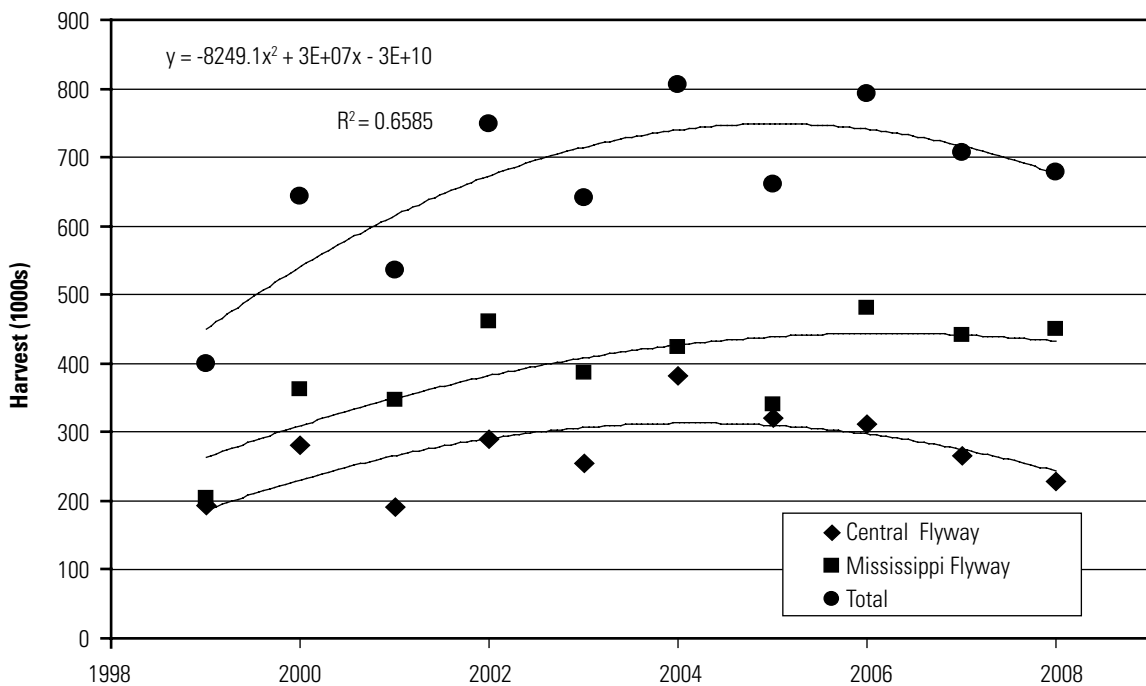


Figure 21. Estimated light goose harvest in the Central and Mississippi Flyways during the Light Goose Conservation Order, 1999-2008.

Hunter Assistance Programs in the United States

Because the LGCO is a management effort to reduce the number of midcontinent light geese, many states make efforts to provide hunters with information that will help them find concentrations of these birds during their late winter and spring migrations. Information is provided to hunters

through phone hotlines, news releases or websites (Table 11). Seven states reported that they conduct population or migration surveys to monitor the migration of light geese. Two states operate a light goose migration information 'hotline.' This is a phone number that hunters can call to hear a recorded message with the latest migration information that is available to the agency. Ten states reported that they issue news releases to inform hunters about the LGCO. However, not all of these appear to provide regular migration information, but rather are intended to provide information about the dates, licenses, regulations and other information. Twelve states reported using web-based information sources to provide information to hunters. At least some web information outlets provide current population and migration information. In addition to these regular information sources, state wildlife agencies respond to numerous phone calls, personal visits and web-based inquiries from hunters requesting information on when, where and how to best hunt light geese during the LGCO.

Discussion

As MCLG populations increased in the 1970s, 1980s and early 1990s, both Canada and the United States responded by establishing increasingly liberal hunting regulations to provide more hunting opportunity and harvest. In the mid- and late 1990s, a growing understanding that MCLG were overabundant, and concern about the ramifications for arctic and subarctic habitats (Ankney 1996; Batt 1997), led both countries to implement unprecedented measures in an attempt to control MCLG population growth. These measures included regulatory changes that allowed hunters to use electronic calls, use unplugged shotguns while hunting MCLG in the United States and hunt them until ½ hour after sunset in areas that normally did not allow it, provided that all other migratory bird hunting seasons were closed. Both countries also adopted rules that allowed hunters to take MCLG outside of the normal hunting period allowed by the Migratory Bird Treaty, that is, between 10 March and 1 September. As a result, MCLG are now harvested in some portion of their range during every month except July. In the United States and Canada, regular hunting seasons occur in the fall and early winter as allowed by the Treaty. Conservation harvests take place outside the regular hunting seasons during late summer, starting in mid-August in northern Manitoba and include spring harvests that run through May in the United States and prairie Canada and early June in Nunavut.

The CWS establishes annual regulations for Canada's regular seasons and the spring conservation harvest in consultation with provincial agencies. In the United States, the USFWS and state agencies each have roles in setting annual regular season regulations, whereas states set annual regulations for the LGCO under the guidelines of the federal rules that established the LGCO (Federal Register 64(30):7517-7529 and Federal Register 73(205): 65926-65955). With the exception of the special harvest provisions allowed, state regulations implementing the LGCO are generally consistent with their regulations for regular (fall/winter) waterfowl hunting seasons. Because states have unique geography, habitats, climates, hunting opportunities, hunter behaviors, cultural, economic and

political situations, regulations among states are highly variable. Season dates, season lengths, bag and possession limits, zones, manner of taking and other regulations are set to take advantage of the opportunities that migrating light geese present during spring, fall and winter. These regulations are all balanced against the cultural, social, economic and political demands of hunters, landowners and the general public.

Monitoring hunter activity and the harvest of light geese is critical to maintaining these hunting and population management programs. In Canada, the CWS monitors both the regular season and the spring conservation harvest of light geese through its harvest survey programs. These surveys provide estimates at zone, province and management-unit scales. The USFWS monitors regular season harvest in the United States through the HIP survey system. Like the CWS surveys, HIP surveys use a standardized method across the country and thus provide reliable and consistent estimates among states and flyways and across years. While development of the HIP sampling frame has had its problems (Shroufe 2004), significant efforts to correct these problems have taken place or are ongoing (K. D. Richkus, USFWS, pers. comm.).

The MQS, HIP and HQS surveys are all affected by biases common to self-administered mail surveys: coverage, response, and non-response bias. Coverage bias occurs when a survey's sample frame excludes some segment(s) of the target population (Lessler and Kalsbeek 1992, Dillman 2007). In harvest surveys, incomplete coverage omits the harvest of the excluded segment(s), thereby causing a negative bias in estimates of total harvest. Response bias results from inaccurate reporting that is generally attributed to 2 causes in harvest surveys: imperfect memory (memory bias) and exaggeration (prestige bias) (Atwood 1956, Filion 1980). Both types of response bias result in overestimating harvest. Non-response bias occurs in harvest surveys when hunting activity and harvest differs between survey respondents and non-respondents. Non-response bias is thought to result in overestimation of harvest (Wright 1978, Barker 1991).

The harvest of light geese during the LGCO in the United States is monitored by the states. Because states have the legal authority to regulate hunting within their borders, the conservation harvest actions could not be implemented in the United States without the cooperation of and action by the states. What is different about monitoring the annual LGCO harvest, compared to the CWS and USFWS survey programs, is that the USFWS mandates that the states measure the number of participants, total harvest and harvest by the special provisions. The USFWS provides no funding for monitoring harvest under the LGCO and there are no guidelines or requirements for the methods states must use to collect and analyze this important information. Most states routinely collect information on hunting activity and harvest for most of their resident game species that are hunted or trapped (i.e., big game, game birds, small game and furbearers). Because of this, states are able to incorporate some type of harvest survey for the LGCO into their annual harvest survey processes. State reports summarizing hunter participation and harvest data are submitted to the USFWS, which

then compiles these data to produce estimates of total MCLG hunter activity and harvest in the United States under the LGCO.

Required state licenses, permits and HIP registrations provide the sampling data base for harvest surveys within states. However, licensing and permitting structures and prices are highly variable among states with each having evolved over decades of legislative or commission driven laws and regulations to meet the needs of funding state agencies and regulating and monitoring hunting activity. Additionally, each state has implemented different licensing structures and license costs for resident and non-resident hunters. Thus, highly variable harvest management and monitoring systems among states provide an inconsistent mechanism for measuring harvest across all the states participating in the LGCO. This is analogous to the situation faced by the states and the USFWS for many years in attempting to develop a common and consistent harvest survey for migratory game birds across the United States. The end result was the creation of the HIP, a system that provides a common name and address data base of migratory game bird hunters and allowed for creation of the current operational harvest survey for all migratory game birds (Elden et al. 2002).

Special or new hunting opportunities, like the LGCO, often attract larger numbers of hunters during the first years of implementation, after which interest wanes. As examples, such shifts in hunter activity have been observed following implementation of and changes to sandhill crane (*Grus canadensis*) and tundra swan (*Cygnus columbianus*) hunting seasons in the United States, as well as with the implementation of special measures for greater snow geese (*Chen caerulescens atlantica*) in Canada (Sharp 1993, Vaa et al. 1999, Calvert et al. 2007). It also appears that hunters responded positively to the new opportunities and increased interest in light goose harvest when the United States began allowing special provisions during light-geese-only regular seasons and Canada's spring conservation harvest and the LGCO were established, all of which occurred in 1998-99. The number of hunters participating in the spring conservation measures has since declined by approximately 20% in Canada. In the United States, just over 41,000 hunters took part in the first LGCO in 1999, when only 11 states participated. This increased to nearly 76,000 hunters in 2000 with the addition of 7 additional states. However, most of the increase in hunter numbers in 2000 occurred in the states that had also held a LGCO in 1999. Since 2000, hunter numbers have declined and in 2008 hunter participation was only 8.7% higher than in 1999 (Table 9, Figure 17). This decline in hunter numbers is also reflected in the estimates of hunter-days that peaked in 2002 and have since declined to a level similar to that of 2000 and 2001 (Figure 18).

There are likely several reasons for this decline in hunter activity. For many hunters, the novelty of a spring hunting opportunity faded, or they discovered the high level of effort required to pursue light geese in the spring. Additionally, there is evidence that greater snow geese responded to the spring conservation harvest and the LGCO by changing migration patterns (Béchet et al. 2003), or altering their behavior to avoid hunters and hunting situations (e.g. Lemoine 2003), and MCLG may have as well. Thus, many hunters may have become frustrated or have simply lost interest and no longer take part in the conservation harvest opportunities.

Hunters that continue to participate in the spring conservation harvest and the LGCO are most likely those that are more skilled and more aggressive at pursuing light geese. This is demonstrated by the continuing increase in the harvest per hunter in Saskatchewan and the United States. While hunter numbers have decreased, those that continue to participate are more successful and thus the average harvest per hunter has increased consistently (Figure 20). This trend toward higher success is also reflected, but to a lesser extent, in the estimates of daily light goose harvest per hunter (Figure 19).

Although many states have taken actions to provide information to hunters to help increase the conservation action take, the harvest of MCLG from both regular seasons and conservation actions remains well below the desired level and appears to be declining. Additional increases in hunter participation and harvest seem unlikely unless federal and state management agencies take further actions to increase hunter participation and success as examined by Johnson and Ankney (2003).

Among the recommendations of the Arctic Goose Habitat Working Group to address the overabundance of MCLG was a call to increase the harvest rate of these birds by a factor of 3 (Batt 1997). The total annual take by hunters, that is the harvest from the regular seasons plus the conservation harvests, is an important measure of the success of efforts to increase the harvest of light geese. Our analysis examines only harvest and does not consider harvest rates, i.e. the proportion of the population that is harvested annually.

Although differences among state and the 2 federal survey programs may cast some doubt on the validity of direct comparisons and summation of the harvests, summing the estimates across all surveys is a useful approach for evaluating the effects of regulations on harvest and the effects of harvest on MCLG populations. Furthermore, as the methods have remained mostly consistent over time, the information derived from trends in harvest estimates provides a good indicator of the pattern of hunting response to regulatory changes.

It is clear that the harvest of light geese has increased significantly during the period of conservation harvest actions (1998-2007) (Figure 2). The average annual harvest (United States and Canada) during the 10 years with conservation actions in place (1998-2007), 1,300,244 light geese, was about 2.54 times that of the previous 10 years (511,491 light geese). Our examination of the harvest data from regular season and conservation actions combined indicates the U.S. plus Canada regular season harvest peaked at 912,557 geese in 1998-99 and the conservation harvest peaked in 2003 at 822,464 birds. The highest combined regular season plus conservation action harvest occurred in 1999-2000 with 1,488,434 geese being taken.

Since implementation of conservation actions, the regular season harvest has declined to a level similar to that prior to 1995. The combined U.S./Canadian average annual harvest in 2005-06 through 2007-08 (1,300,244 geese) was only 1.81 times greater than the average annual harvest (706,473 geese) of the 1995-98 period, the 3 years just prior to implementation of conservation actions.

While the average harvest of MCLG during the period of conservation actions was 2.54 times greater than 10 years prior to implementation of conservation actions (1988-1997), what cannot be ascertained from the harvest data is the degree of additivity of the conservation harvest relative to the regular season harvest that would have occurred with conservation actions. If conservation action harvest is not completely additive to that of the regular hunting season, then the impacts of conservation actions on the population are reduced. Conservation harvest can be completely additive to the regular season only if the take during the regular season is not reduced because of changes in the behavior of geese that reduces their vulnerability to harvest or changes in the behavior and/or success of hunters. Learned avoidance behavior by geese subjected to annual hunting pressure from August through June could reduce their susceptibility to harvest in the fall and winter regular hunting seasons. In addition, if hunters replace some of their annual fall hunting effort with spring hunts, then conservation harvest will not be completely additive to that of the regular season.

Regular season harvest was trending upward, significantly, just prior to implementation of conservation actions. The average annual regular season harvest in three years (1995-96 through 1997-98) prior to the conservation actions had increased 65% over the previous 5 years, likely due to season liberalizations in both the Central and Mississippi flyways (Batt 1997). Regular season harvest peaked the same year that conservation actions were implemented and has since trended downward and in 2007 was at the lowest level since 1993.

Despite declining hunter numbers and hunter activity, increased success of active hunters resulted in an increase in the annual spring conservation and LGCO harvests the first 4 years of conservation actions in the United States. However, spring conservation harvests in Saskatchewan and LGCO harvests in the Central Flyway have declined since 2004, while LGCO harvest in the Mississippi Flyway appears to have stabilized since 2006. The overall annual spring harvest in Canada and the two U.S. flyways combined appears to be declining since peaking in 2003, and is currently about 685,000 birds (2007). Annual MCLG harvest during regular seasons seems to have stabilized at about 500,000 birds (Canada and United States combined) after peaking in the 1998-99 season at 912,000 birds and then declining to current levels. Thus, the total continental harvest of MCLG is currently stable or declining slightly.

Rockwell et al. (1997) demonstrated that the most effective way to reduce the population growth rate and thus reduce the population of MCLG is to reduce adult survival. To do this, Batt (1997) recommended increasing the kill by hunters by about a factor of 3. Immature snow geese are more vulnerable to hunters than are adults (Boyd et al. 1982). Adult geese are more difficult for hunters to take because they are more experienced than juveniles and thus more wary of hunters, decoys and hunting situations. In addition, light geese are long-lived with many birds living 10 to 20 years (U.S. Bird Banding Laboratory database) and some past 30 years (Rockwell, pers. comm.). Cooke et al. (1995) reported that adults appear to have a reduced probability of being shot when unaccompanied by young. Indeed, it is common knowledge among light goose hunters that hunting over decoys is

much more successful in years with higher numbers of juvenile birds in the fall flight. Juvenile birds will decoy much more readily than adults. This behavior appears to lead more adult birds in range of hunters, thus increasing their vulnerability.

We have harvest age ratio information only for the regular hunting seasons in the United States and Canada. Neither Canada nor the states collect information on the age of geese harvested during conservation actions. To collect reliable age data from the conservation harvest would require a parts collection survey similar to that carried out for the regular seasons. Snow goose regular season harvest from the United States, Canada, and for both countries combined demonstrates an increasing trend in the proportion of adults since 1975 (Figures 16, 13, and 3). U.S. and Canadian harvest estimates show a weak negative relationship between the proportion of adult snow geese in the harvest and the total snow goose harvest (Figures 15 and 12), but there is not a significant relationship between the midcontinent adult snow goose harvest and the total midcontinent snow goose harvest (Figure 6). The harvest of adult snow geese (in 2007) is about double that of the early 1990's. The adult snow goose harvest increased substantially during the period of increased liberalizations of light goose hunting regulations (1994-1999), peaking at about 3 times that of 1993. The largest portion of the light goose harvest is now taken during conservation actions and this proportion of the harvest is increasing (Figure 2). Because there are no age data available for the conservation harvest, it is not possible to assess the effects of the recent (1998-2007) harvest activities on adult versus juvenile birds from harvest data.

MCLG harvest includes both snow geese and Ross's geese during both the regular seasons and the conservation actions in the United States, whereas special conservation measures apply only to snow geese in Canada. Estimates of the harvest of snow geese versus Ross's geese are available only for the regular hunting seasons (Tables 5, 7, 8). Despite the fact that a large portion of waterfowlers in Saskatchewan are non-residents, mostly from the United States, and non-residents are not sampled in the SCS, it appears that, based on a recent analysis using band recoveries, the goose species composition in the harvest by Canadians appears to be similar to that by non-residents except perhaps for Ross's geese in Saskatchewan which may be biased low (Ray Alisauskas, pers. comm.). Thus, the potential bias from not sampling non-residents in the Canadian SCS specific to the MCLG population appears to be low. Neither Canada nor the states conduct parts collection surveys to assess the species composition of the conservation harvests. Therefore, conservation action harvest data do not provide information on the harvest of snow geese versus Ross's geese.

There is likely a high degree of variability in the consistency and comparability of LGCO estimates among states. State surveys differ in survey methods (mail questionnaire, telephone and web-based surveys), survey instruments, sampling rates, follow-up contacts with non-respondents and bias corrections. An important point to consider when looking at the LGCO harvest estimates is that these are a combination of state surveys with differing methodologies and minimal to no bias corrections. Thus, these estimates are likely inflated by an amount similar to the regular season

harvest estimates as described in this report. Atwood (1956; Atwood 1959) suggested that a lack of memory and prestige bias correction to mail survey harvest estimates can result in over-estimates of harvest by at least 30%. The analysis of harvest estimation bias here indicates that U.S. regular season goose harvest estimates are inflated by about 50% (MQS) or 68% (HIP), depending on which survey system (MQS or HIP) was used to obtain the estimates. If this is the case, then the U.S. 1998-2007 average annual regular season harvest would be 299,018 light geese, rather than the current estimate of 489,451 light geese (based on the MQS estimate for 1998, and HIP estimates for 1999-2007). If CWS and LGCO estimates are similarly biased, the combined CWS and LGCO average annual conservation harvest for this same period is either 404,222 or 451,381 light geese, depending on whether the MQS or HIP bias correction is applied, compared to the current harvest estimate of 673,703 light geese without the bias correction.

To adequately monitor light goose harvest, it is critical to have a survey program that measures the harvest of alight geese, including species and age distributions in the harvest, across all seasons and jurisdictions in which harvest occurs. A valid and consistent estimate of the hunter activity and harvest that occurs during the LGCO is an important part of monitoring the success of efforts to manage the light goose overpopulation problem. This is especially true since our current survey efforts indicate that more than 50% of the light goose harvest occurs during the LGCO. It seems highly unlikely that an accurate and consistent “nationwide” estimate of LGCO harvest and hunter activity can be obtained by rolling up the results from 18 disparate state-run surveys. We believe that a single survey conducted by the USFWS, as is done with regular migratory game bird hunting seasons, would be the most appropriate method for annually monitoring the harvest and hunter activity of the LGCO. This could be accomplished through the existing HIP registration system; LGCO states would provide the sample frame by requiring all LGCO participants to “register” for the LGCO by answering an additional HIP question, and the USFWS would use that sample frame to conduct an annual LGCO hunter activity and harvest survey. In addition, valid estimates of the age and species distributions within the harvest cannot be obtained without implementing a PCS that samples the LGCO harvest.

Recommendations

- The USFWS and the states should continue the cooperative HIP survey and PCS programs to assess light goose harvest during regular hunting seasons. These surveys provide quality hunter activity and harvest information, including estimates of the age and species distributions within the harvest.
- The CWS should continue its HQS and SCS surveys to assess light goose harvest during regular hunting seasons. These surveys provide quality hunter activity and harvest information, including estimates of the age and species geographic distributions within the harvest.

- The USFWS should publish the bias-corrected harvest estimates for light geese and apply improved memory, prestige and non-response bias corrections to historic and future harvest estimates. These bias corrections provide harvest estimates that are much reduced from previous harvest estimates.
- The CWS should investigate improved bias correction procedures for the HQS and develop improved harvest estimates that incorporate appropriate corrections for bias. Improved bias corrections would provide harvest estimates that would more accurately reflect the true harvest.
- The USFWS should improve the assessment of light goose harvest during the LCGO in the United States by expanding both the HIP survey and the PCS to cover the LGCO harvest. To do this, states will need to cooperate in providing the names and addresses of LGCO hunters by requiring HIP registration and adding a LGCO participation question to their HIP registration process. This will provide more reliable estimates of harvest of light geese, the harvest of adults and juveniles and the harvest of snow geese and Ross's geese from conservation actions in the United States.
- The CWS should consider expanding the SCS in Canada to include regular hunting season non-resident waterfowl hunters. The CWS could consider alternatives for collecting tail fans from non-resident goose hunters that do not involve shipping these parts across the border. Such alternatives could include drop-off points at border crossings or having parts shipped to collection points in the United States where they could be processed at U.S. wing bees or shipped in bulk back to Canada for processing. Alternatively, an appropriate study could be conducted to determine if the harvest of light geese in Canada is adequately measured without sampling non-resident waterfowl hunters. Periodic reassessments of the representativeness of the resident versus non-resident harvest measures should be conducted to ensure that changes have not occurred.
- The CWS should expand the SCS in Canada to include the spring conservation harvest or develop an alternative method to obtain a measure of the age distribution in the spring harvest.
- The CWS should investigate the participation rate by Canadian residents living outside of Saskatchewan in the spring conservation harvest and, if deemed necessary, develop annual estimates of the participation and harvest for that group.
- The USFWS and CWS should develop/improve techniques for distinguishing between Ross's goose and snow goose tail fans that are examined in the wing bees in both countries.

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TEMPORAL VARIATION IN SURVIVAL AND PRODUCTIVITY OF MIDCONTINENT LESSER SNOW GEESE AND SURVIVAL OF ROSS'S GEESE AND ITS RELATION TO POPULATION REDUCTION EFFORTS

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Introduction

A major recommendation of the Arctic Goose Habitat Working Group (Batt 1997) was that proactive measures be taken to reduce the size of the midcontinent lesser snow goose (*Chen caerulescens caerulescens*; hereafter “snow goose”) population by approximately 50% within a suggested time-frame of 3-7 years. It was recognized that such a reduction would require considerable change in the population growth rate (λ), which was estimated at the time to be 5% per annum ($\lambda = 1.05$), and it was suggested that λ be reduced to a value between 0.85 and 0.95 (5-15% population reduction per year) in order to achieve population goals. Because population modeling based on midcontinent lesser snow goose data had indicated that the growth rate of the population should be most sensitive to changes in adult survival (Rockwell et al. 1997), the Working Group recommended that management efforts be directed towards increasing adult mortality. Further, because hunting mortality is generally additive to natural mortality in geese (e.g., Rexstad 1992; Gauthier et al. 2001; Alisauskas et al. 2006), it was argued that the most effective way to bring about a change in adult survival would be to increase the annual harvest. In keeping with these conclusions and recommendations, snow goose management has operated under a guiding principle of increased harvest since the introduction of new regulatory measures in 1998-1999.

In an effort to explore the potential efficiency of various management scenarios, Rockwell et al. (1997) developed a matrix projection model for midcontinent lesser snow geese and analyzed changes in age-specific survival and reproductive success and corresponding effects on population growth rate. Assuming an adult annual survival rate of 0.88 (the most recent estimate available at the time) and an initial population growth rate of $\lambda = 1.05$, the authors predicted that to achieve even modest population reduction ($\lambda = 0.95$), adult survival would need to be reduced to a value of 0.795. To achieve $\lambda = 0.85$, it was estimated that adult survival would need to be reduced to a value of between 0.71 and 0.73. Rockwell et al. (1997) concluded further that a 2- to 3-fold increase in the annual harvest, relative to mean harvest levels at the time, would be required to achieve these rates of survival and population growth. Cooke et al. (2000) challenged this last conclusion as being too conservative, arguing that the model used by Rockwell et al. (1997) was based on inappropriate estimates of key parameters. Using updated estimates of these parameters, Cooke et al. (2000) predicted that no less than a 4.5-fold increase in harvest (and as high as a 7.3-fold increase) would be required to achieve $\lambda = 0.85$. Rockwell and Ankney (2000) subsequently revised projections of the original model and estimated that a fixed annual harvest of approximately 1.4 million snow geese (adult and young) would be sufficient to achieve population goals.

As is evident from above, much of the debate surrounding management of overabundant snow goose populations has centered on the level of harvest necessary to achieve population reduction. By contrast, there has been little disagreement that the most effective management actions would target a reduction in adult survival via increases in hunter harvest. In this chapter, we review available information on temporal changes in harvest and survival of midcontinent lesser snow geese as they

pertain to the introduction of special conservation measures (spring harvest and liberalized fall/winter hunting regulations) beginning in 1998-1999. Our specific objectives were to: (1) quantify the relationship between annual survival and annual harvest; (2) assess whether survival rates have responded to increases in harvest brought about by the introduction of increased hunting opportunities; and (3) assess whether any observed declines in survival have been sufficient to effect changes in snow goose abundance. In meeting these objectives, we rely heavily on analyses of both short-term and long-term banding data from several regions of the eastern and central Canadian arctic. Our primary focus is on temporal changes in adult annual survival because adult survival is the demographic parameter that holds the most potential for altering the growth rate of the midcontinent lesser snow goose population (Rockwell et al. 1997; Rockwell et al. 2012), and because all management action to date has been aimed at increasing adult mortality (Alisauskas et al. 2011).

Although changes to light goose harvest regulations initiated in 1998-1999 were aimed primarily at reducing populations of midcontinent lesser snow geese, snow geese and closely related Ross's geese (*Chen rossii*) are managed in aggregate due, in part, to hunter difficulty in distinguishing the two species (Alisauskas 2001, Moser and Duncan 2001). As such, harvest regulations for Ross's geese in the Central and Mississippi Flyways have been liberalized in concert with those for snow geese since the mid-1980s, raising questions about impacts on Ross's goose survival and other population parameters. For instance, Alisauskas et al. (2006) analyzed hunter recoveries of Ross's geese captured and marked in the Queen Maud Gulf region and found that survival of adults had declined during the period 1994-2000, reaching a low of approximately 0.80, apparently in response to concurrent increases in harvest. The authors noted, however, that during this same time period, the Ross's goose population at one of the largest known breeding colonies in the Queen Maud Gulf region had shown sustained growth, suggesting that an adult survival rate of 0.80 was unlikely to have negative consequence for continental Ross's goose populations. Since 2001 (the last year that Alisauskas et al. 2006 considered), continental harvest of adult Ross's geese has apparently stabilized and harvest rates have actually declined (Alisauskas et al. 2009, 2012). Thus, a reassessment of annual survival seemed timely and warranted. A secondary aim of the present chapter was to update the analysis of Alisauskas et al. (2006) to provide baseline information on temporal changes in survival of adult Ross's geese for the period 1989-2010. In addition to using the most recent time series of banding data available, our update is significant in that it incorporates information both from Ross's geese banded in their traditional nesting range in the Queen Maud Gulf region, as well as those banded in more recently occupied areas of the eastern Canadian arctic (Alisauskas et al. 2012, Figure 3).

While the new regulatory measures introduced in 1998-1999 were explicitly aimed at reducing adult survival, it is possible that some measures have had additional, unintended consequences for other light goose vital rates. In particular, there is growing interest in the possibility that spring harvest in Canada and the United States has had a negative impact on annual productivity and recruitment of young. This interest stems from the recognition that increased disturbance of geese by hunters during spring migration might influence nutrient acquisition by adults and so impede productivity

via reduced breeding propensity and other components of reproduction (Alisauskas 2002). The greater snow goose (*Chen caerulescens atlantica*) population, which has also been subject to spring harvest since the late 1990s, is a case in point. Recent studies of greater snow geese nesting on Bylot Island, Nunavut, in combination with studies conducted on fall and spring staging areas in Quebec, have documented delayed nesting, reduced breeding propensity, and reductions in clutch size and other productivity indices since the introduction of spring harvest in 1999 (Mainguy et al. 2002; Bêty et al. 2003; Reed et al. 2004; see also Reed and Calvert 2007 and references therein). Additional evidence suggests a direct link between these reductions in breeding performance and energetic costs associated with increased disturbance on spring staging areas (Mainguy et al. 2002; F  ret et al. 2003). Unfortunately, in the case of midcontinent lesser snow geese, detailed information on specific components of recruitment is largely unavailable, at least with respect to changes in recent years. In the absence of this information, one avenue for evaluating large-scale changes in recruitment is to assess changes in the proportion of young in the fall population, as indicated by annual age ratios in the fall harvest (e.g., Sheaffer 1998; Alisauskas 2002). Our final aim in this chapter was to provide such an analysis for midcontinent lesser snow geese, with the specific objective of comparing fall age ratios among years prior and subsequent to the implementation of spring conservation harvest. For this analysis, we rely on harvest age ratio data from the Canadian Species Composition Survey (Gendron and Collins 2007), corrected for differential harvest vulnerability among age classes, to estimate the proportion of young in the fall population. We limit our consideration of fall age ratios to snow geese because Canadian harvest age ratio data for Ross's geese were largely unavailable or insufficient for analysis for most years prior to the introduction of increased harvest opportunities.

Temporal Changes in Harvest and Survival of Snow Geese

Background and Data Sources

The midcontinent lesser snow goose population, as operationally defined in this report, comprises lesser snow geese that nest east of 110°W longitude in the eastern and central Canadian arctic. The largest known breeding aggregations occur in Nunavut south of Queen Maud Gulf (QMG) and on Southampton Island (SOU) and Baffin Island (BAF; Kerbes et al. 2006). Other important colonies include those at West Hudson Bay, Nunavut (WHB), La P  rouse Bay, Manitoba (LPB), and Cape Henrietta Maria, Ontario (CHM; Kerbes et al. 2006). Snow geese that nest in these regions are harvested primarily in Saskatchewan, Manitoba, and northern Ontario in Canada and throughout the Central and Mississippi Flyways in the United States (Alisauskas et al. 2012, Figures 1, 2).

Annual survival rate estimation requires banding data and information from corresponding hunter recoveries. For arctic-nesting geese, the most efficient banding methods involve mass capture and marking of geese on molting areas during the flightless period in late summer. Since 1989, snow geese have been captured and marked in varying numbers, either continuously or periodically (and beginning in different years), at all six major breeding areas mentioned above, as well as on Akimiski

Island, Nunavut (AKI), and the Rasmussen Lowlands of the central arctic (RAS). As detailed below, our focus here is on adult (after-hatch-year) snow geese, and we limit our consideration to birds marked with legbands only (i.e., birds marked with neckbands are excluded). Subject to these constraints, the most significant banded samples derive from QMG and LPB, where snow geese have been marked in large numbers annually or near annually since 1989 (Table 1). Continuous annual banding of snow geese has occurred at AKI and CHM since 1995 and 2000, respectively, and in 2003, concerted banding efforts were initiated at BAF and SOU (Table 1). Only limited occasional banding has occurred at either WHB or RAS (Table 1). In sum, consistent long-term banding data, encompassing years both before and after the introduction of additional harvest opportunities in 1998-1999, exist only for QMG and LPB. Expanded banding efforts in recent years have resulted in good representation of the midcontinent population for the period 2003-2006.

Table 1. Number of adult (after-hatch-year) lesser snow geese marked with legbands only at each of eight locations (breeding areas) in Canada's eastern and central arctic, 1989-2006. Breeding areas include Akimiski Island (AKI), Baffin Island (BAF), Cape Henrietta Maria (CHM), La Pérouse Bay (LPB), Queen Maud Gulf (QMG), Rasmussen Lowlands (RAS), Southampton Island (SOU), and West Hudson Bay (WHB). Data from Alisauskas et al. (2011).

Year	Breeding area							
	AKI	BAF	CHM	LPB	QMG	RAS	SOU	WHB
1989	8	5	0	1191	796	0	0	0
1990	2	46	0	1650	580	0	0	0
1991	0	35	0	1981	279	0	24	3
1992	0	36	3	3295	549	0	0	0
1993	0	0	0	2397	267	5	0	0
1994	0	0	216	1512	769	32	0	0
1995	185	0	0	870	601	15	0	55
1996	438	0	0	0	155	0	0	0
1997	457	35	0	0	1132	0	0	24
1998	705	10	0	1777	2181	0	0	37
1999	674	79	0	1945	1450	0	0	2
2000	456	63	1129	7657	1378	0	0	0
2001	541	77	1238	4213	1255	0	88	37
2002	582	64	1066	3778	1673	0	1	0
2003	213	1095	1597	2364	2897	0	1604	0
2004	579	791	2003	3667	3356	0	1799	0
2005	482	1816	2021	2798	3168	0	1998	200
2006	652	1098	2172	2195	1994	0	2056	0
Total	5974	5250	11445	43290	24480	52	7570	358

Quantifying the relationship between adult survival and harvest requires annual estimates of the size and age-composition of the kill. In Canada, regular season harvest estimates are obtained via the Hunter Questionnaire Survey (HQS; Gendron and Collins 2007) administered annually by the Canadian Wildlife Service (CWS). These estimates are weighted using age ratio data from the Species Composition Survey (SCS; Gendron and Collins 2007) to obtain harvest estimates for each age class (young-of-the-year vs. adult). Until recently, regular season harvest in the United States was estimated by the U.S. Fish and Wildlife Service (USFWS) using the Mail Questionnaire Survey (MQS), analogous to the HQS in Canada. In 2002, the MQS was phased out and replaced by the Hunter Information Program (HIP), which had been in place since 1999 (USFWS 2003; see also Johnson et al. 2012). For purposes of the present chapter, U.S. regular season harvest estimates for the period 1989-1998 derive from the MQS, whereas estimates for 1999-2006 are from HIP. As well, USFWS is currently revising their harvest estimates to address issues of survey bias (Johnson et al. 2012), but because bias-adjusted estimates are preliminary, we rely on historical estimates here. Age composition of the U.S. harvest is measured annually by the waterfowl Parts Collection Survey (PCS), the U.S. equivalent of the Canadian SCS. Harvest during special provisions in the United States (1999-2000) was captured by the sampling frame of HIP, but age-specific estimates of spring harvest (Canada) and conservation order harvest (United States) cannot be obtained directly from harvest survey data, because the age-composition of that portion of the harvest is unknown. However, age-specific estimates of spring / conservation order harvest can be obtained through joint use of regular season harvest estimates and band-recovery data (details below).

Using the most recent banding data and harvest estimates available, Alisauskas et al. (2011) provide a detailed and comprehensive assessment of harvest levels and distribution, migration phenology, and survival rates of midcontinent lesser snow geese for the period 1989-2006. What follows is a summary description of key analyses and results of that assessment as they pertain to the effectiveness of population reduction efforts. Unless otherwise stated, all survival and harvest analyses reported here are from Alisauskas et al. (2011), and we refer the reader to that paper for details.

Temporal Changes in Harvest

Given that one of our goals was to quantify the relationship between survival and harvest, it is instructive to consider how harvest levels have changed over time and, in particular, in response to the introduction of increased hunting opportunities in 1998 (note that here and elsewhere, in accounts pertaining to harvest, 1998 refers to the 1998-1999 hunting season and includes spring harvest and conservation order harvest that occurred, in this example, in the spring of 1999). Alisauskas et al. (2011) estimated annual, age-specific harvest of midcontinent snow geese for the period 1989-2006, and partitioned these estimates according to (1) regular season harvest, (2) special provisions harvest, and (3) U.S. conservation order and Canadian spring harvest. Age-specific estimates of regular season harvest were obtained in the conventional manner by weighting harvest survey data (HQS in Canada and MQS or HIP in the United States) by corresponding age ratios from respective parts surveys (SCS and PCS). Age-specific estimates of conservation order / spring harvest were obtained following

Alisauskas et al. (2006) using regular season harvest estimates and age- and season-specific band-recovery data. In short, this approach involves weighting the regular season harvest estimate for year i (R_i) by the quotient of hunter recoveries obtained during conservation order / spring harvest (c_i) and those recovered during regular seasons (r_i). Assuming equal band reporting rates among seasons, conservation order / spring harvest (C_i) is given by

$$C_i = [c_i/r_i] \cdot R_i$$

(see Alisauskas et al. 2006, 2009, 2011 for details).

Annual adult harvest estimates for the period 1989-2006 are given in Figure 1. A general pattern of increased total harvest following the introduction of special conservation measures in 1998 is evident, although increases in harvest were apparently underway beginning in 1994 (Figure 1). Still, the initial impact of increased hunting opportunities was considerable. Between 1997 and 1998, total adult harvest rose from ~422,000 to ~623,000 geese, an increase of 48%. Since that time, conservation order and spring harvest has been highly variable, ranging from ~103,000 adults in 1998 to ~350,000 adults in 2001. Nevertheless, contributions from conservation order / spring harvest, in combination with regular season harvest (1998-2006), have resulted in total harvest estimates that have consistently exceeded annual harvest estimates for the period 1989-1997 (Figure 1). Overall, total annual harvest has averaged ~650,000 adults since the introduction of special conservation measures, compared to an average of ~290,000 adults during the period 1989-1997. Thus, adult harvest levels have clearly responded to recent management efforts. It is worth noting, however, that conservation order / spring harvest did not exceed regular season harvest in any year and that total adult harvest has yet to approach 1 million birds (Figure 1).

Geographic Variation in Survival

From a population management perspective, the observed increases in harvest are significant only to the extent that they have resulted in corresponding decreases in adult survival and population growth. Assessing whether adult survival has responded to the increases in harvest requires band-recovery data collected both before and after the introduction of special harvest provisions in 1998-1999. For lesser snow geese, such data exist only for QMG and LPB (Table 1). Further, there is some uncertainty as to whether survival and other demographic parameters from either of these two regions is representative of the midcontinent population as a whole, or indeed whether heterogeneity in survival among snow geese from different breeding areas should preclude such generalizations (Cooke et al. 2000). Thus, an important first step in assessing the relationship between harvest and survival, as it pertains to the midcontinent population, was to evaluate geographic (i.e., inter-colony) variation in survival to the extent possible based on available data.

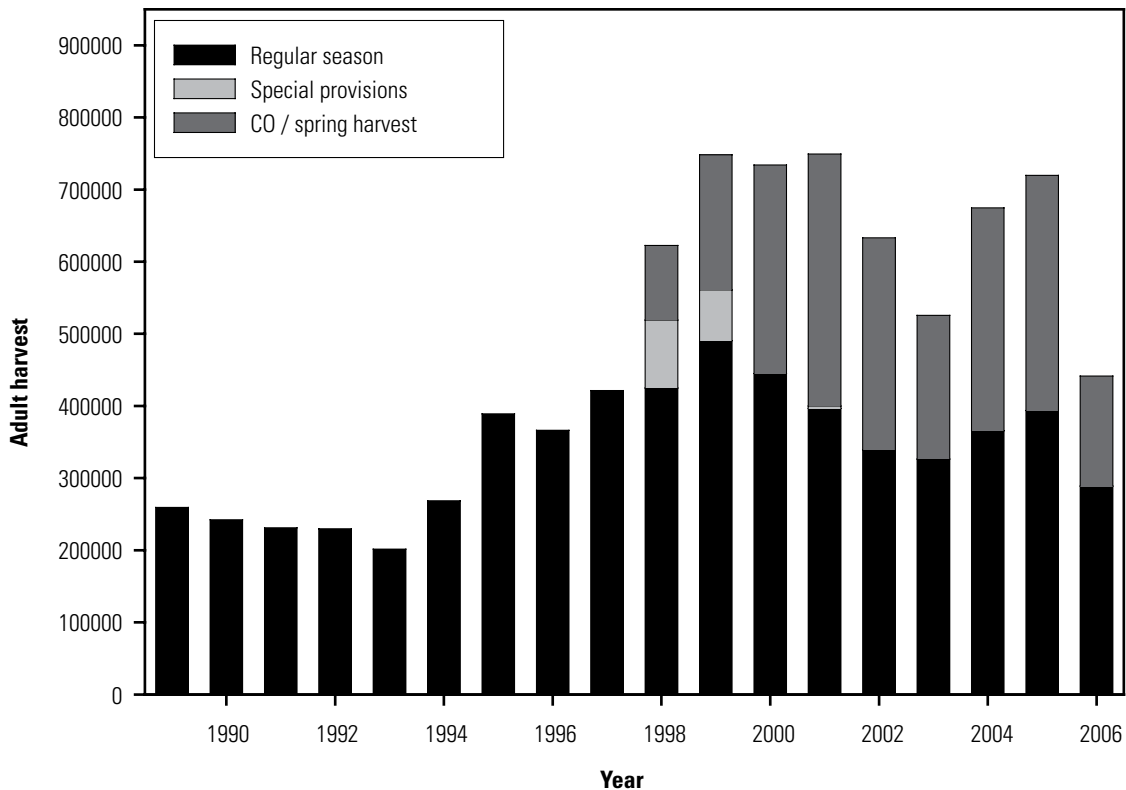


Figure 1. Estimated annual harvest of adult midcontinent lesser snow geese partitioned according to regular season harvest, special provisions harvest, and US conservation order (CO) and Canadian spring harvest, 1989-2006. Modified from Alisauskas et al. (2011).

Although the breeding distribution of the midcontinent snow goose population is widespread, especially with respect to latitude, Alisauskas et al. (2009) postulated the existence of two large subpopulations with potentially differing population dynamics: (1) a northern (arctic) subpopulation consisting of geese nesting north of 60°N latitude (including birds from Queen Maud Gulf, West Hudson Bay, Southampton Island, and Baffin Island); and (2) a southern (subarctic) subpopulation comprising geese nesting south of 60°N latitude at La Pérouse Bay, Cape Henrietta Maria, and Akimiski Island. This suggestion was based in part on analyses of hunter recoveries indicating that geese from the southern colonies migrate southward (and encounter greater harvest pressure) approximately two weeks earlier, on average, than those from the northern colonies (Alisauskas et al. 2011; Figure 2). Alisauskas et al. (2009) noted further that, based on the most recent available photo-survey data (Kerbes et al. 2006), snow geese nesting north of 60°N latitude account for approximately 90% of the midcontinent population. Alisauskas et al. (2009) reasoned that the interplay of these two factors should result in higher harvest rates among geese originating from southern breeding areas. Consistent with this prediction, harvest rates of snow geese marked at La Pérouse Bay, Cape Henrietta Maria, and Akimiski Island during the period 1998-2004 were found to be generally higher than corresponding harvest rates for snow geese marked at Queen Maud Gulf (Alisauskas et al. 2009).

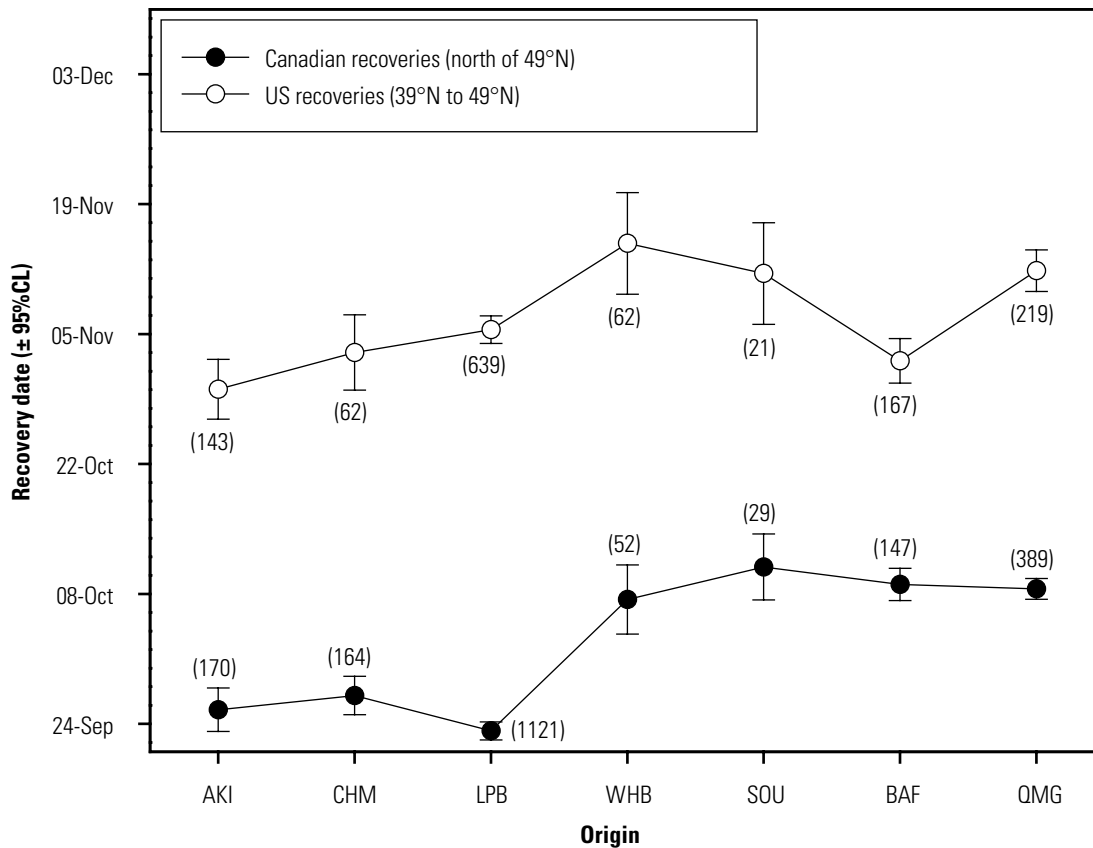


Figure 2. Mean date of hunter recovery for lesser snow geese captured and marked at each of seven breeding areas in Canada's eastern and central arctic, 1989-2006. Breeding areas include (in ascending order of latitude north) Akimiski Island (AKI), Cape Henrietta Maria (CHM), La Pérouse Bay (LPB), West Hudson Bay (WHB), Southampton Island (SOU), Baffin Island (BAF), and Queen Maud Gulf (QMG). Mean dates are shown for both recoveries that occurred in Canada (north of 49°N) and those that occurred in the US between 39°N and 49°N latitude. Modified from Alisauskas et al. (2011).

Given these patterns of variation in migration phenology and harvest probabilities, Alisauskas et al. (2011) predicted that survival and recovery rates of snow geese marked at QMG should be generally representative of the larger northern stratum of the nesting distribution (i.e., geese nesting north of 60°N latitude), whereas those of snow geese marked at LBP should be representative of the southern stratum. A formal test of this prediction was made possible by the initiation in 2003 of concerted banding efforts on Baffin Island and Southampton Island, areas of two of the largest known breeding aggregations (Kerbes et al. 2006) and the only northern sites, other than Queen Maud Gulf, where snow geese have been banded in numbers sufficient for survival estimation (Table 1). Along with banding efforts initiated somewhat earlier at CHM and AKI and continued banding at QMG and LPB, availability of these data permitted a survival analysis based on six reference areas for the period 2003-2006. Given only four years of banding data, it was expected that survival rate estimates would lack precision, but that such an analysis might nevertheless yield useful insights regarding population structure as it pertains to adult survival.

Input data for this initial analysis consisted of recovery matrices for snow geese marked at each of three northern reference areas (QMG, BAF, and SOU) and three southern reference areas (LPB, CHM, and AKI) during the period 2003-2006. Because the goal of population reduction efforts was to reduce adult annual survival, the analysis was restricted to birds marked as after-hatch-year (AHY) individuals. Additionally, because survival rate estimates obtained from analyses of geese marked with neckbands tend to be biased low (Alisauskas and Lindberg 2002, Alisauskas et al. 2006; cf. Menu et al. 2000), the analysis was limited to birds marked with metal legbands only. Recovery data were obtained from the USGS Bird Banding Laboratory and, for purposes of analysis, included only those birds reportedly shot by a hunter or taken under permit. The resulting sample comprised 44,415 marked individuals, of which 2,268 were subsequently recovered (i.e., shot, retrieved, and the band reported).

We estimated adult annual survival (S) and recovery (f) probabilities using the open population models of Brownie et al. (1985) as implemented in program MARK (White and Burnham 1999). The candidate model set for this analysis included models that recognized additive and multiplicative effects of time (i.e., annual variation, denoted t) and banding location (i.e., reference area, denoted g) on both survival and recovery probability, as well as models that assumed constancy and/or no area differences in these parameters. To address the specific prediction that survival might be structured according to northern and southern regions of the nesting distribution, the candidate set also included models (denoted S_{NS} with respect to survival) that contrasted survival estimated from the three northern reference areas (QMG, BAF, and SOU) with that estimated based on data from the three southern reference areas (LPB, CHM, and AKI). Model selection was based on minimization of Akaike's Information Criterion, corrected for overdispersion and small sample bias ($QAIC_c$; Burnham and Anderson 2002). To facilitate model comparisons, we also computed AIC-based model weights, which sum to unity and provide a measure of the weight of evidence in favor of a particular model, given the data (Burnham and Anderson 2002). Finally, because model selection uncertainty was evident (i.e., no one model was uniquely supported by the data; see below), we report model-averaged parameter estimates obtained by averaging over all models in the candidate set after weighting each estimate by the appropriate model weight (Burnham and Anderson 2002).

Model selection based on AIC indicated that the most parsimonious model was one in which survival was stratified according to northern and southern regions of the nesting distribution (model $S_{NS, f_{g+t}}$; Table 2). A north-south structure on survival probability (S_{NS}) was common to the three most parsimonious models, and these models collectively embraced approximately 88% of the total support among the candidate models considered (cumulative model weight = 0.88; Table 2). Point estimates obtained under the AIC-selected model indicated that geese from the northern stratum survived at an appreciably higher annual rate (0.962; 95% CI = 0.765-0.995) than did geese from the southern stratum (0.828; 95% CI = 0.750-0.885). Likewise, model-averaged survival rate estimates (computed separately for each reference area in each year of study) were consistently higher for geese marked at northern locations (QMG, BAF, and SOU; range = 0.951-0.968) than for geese marked at southern locations (LPB, CHM, and AKI; range = 0.827-0.846; Table 3). As expected, survival rate

estimates were imprecise (Table 3) owing to the limited time series available for this analysis (i.e., only four years of marking). Nevertheless, model selection results and model-averaged parameter estimates clearly support the existence of a north-south structure on survival probability. An implication of this result is that survival rate estimates based on snow geese marked at QMG should be generally representative of snow geese from northern (arctic) nesting areas, whereas estimates based on data from LPB are more likely to reflect those of snow geese nesting south of 60°N latitude.

Table 2. Summary output from competing band-recovery models developed to estimate annual survival (S) and recovery (f) probabilities for adult lesser snow geese captured and marked at six breeding areas in Canada's eastern and central arctic, 2003-2006. Breeding areas include Queen Maud Gulf (QMG), Baffin Island (BAF), Southampton Island (SOU), La Pérouse Bay (LPB), Cape Henrietta Maria (CHM), and Akimiski Island (AKI). Only those models having QAICc weights ≥ 0.01 are shown.

Model ^a	Number of parameters	ΔQAIC_c^b	QAIC _c weight ^c
S_{NS}, f_{g+t}	11	0.00	0.41
S_{NS}, f_{NS+t}	7	0.23	0.37
S_{NS^*t}, f_{NS+t}	9	2.75	0.10
S_g, f_{g+t}	15	3.77	0.06
S, f_{g+t}	10	5.90	0.02
S_{NS}, f_{NS+T}	5	7.13	0.01
S_{g+t}, f_{g+t}	17	7.37	0.01

- a Model notation follows Lebreton et al. (1992); t = time-dependency (annual variation), g = group differences (differences among breeding areas), T = linear-logistic time trend, no subscript = constancy. NS represents survival or recovery probability stratified according to northern (QMG, BAF, and SOU) and southern (LPB, CHM, and AKI) regions of the nesting distribution.
- b Difference between QAICc of the current model and the minimum observed value, where QAICc is Akaike's Information Criterion with adjustments for overdispersion ($\hat{c} = 1.3674$) and small-sample bias (Burnham and Anderson 2002).
- c Normalized Akaike weight (Burnham and Anderson 2002).

As a check on our interpretation above, we expanded our “six reference areas” analysis to explore the possibility that adult survival might be more strongly structured according to eastern and western segments of the midcontinent population than according to northern and southern nesting strata. Such a situation might arise, for instance, as a result of flyway differences in harvest pressure and/or differences in habitat quality along spring migration routes (Rockwell et al. 2012). Thus, we developed six additional (*a posteriori*) models of the form S(EW) in which adult survival was contrasted between banding origins east and west of 95°W longitude. The basis for this particular split was that it assigned all geese of the Hudson Bay lowlands region (LPB, CHM, AKI) and areas east of there (BAF, SOU) to a single eastern segment, consistent with known migration routes and patterns (Rockwell et al. 2012). Conversely, snow geese nesting at QMG were assigned to the western segment. Alternative parameterizations for recovery probability paralleled those used under our

original north-south classification scheme (Table 2). Results of the expanded analysis supported our original conclusion. For instance, the most parsimonious model incorporating an east-west structure on survival probability was ranked 9th among the candidate models considered and had a model weight of only 0.002. More generally, the cumulative model weight for models incorporating an east-west structure on survival was <0.01, more than an order of magnitude lower than the corresponding value for models structured according to northern and southern nesting strata (i.e., 0.89; Table 2). In short, information on adult survival was generally much more consistent with a north-south metapopulation structure, as hypothesized by Alisauskas et al. (2009), than with a structure based on eastern and western regions of the nesting distribution.

Table 3. Model-averaged survival rate estimates (\hat{S}) for adult lesser snow geese captured and marked at six breeding areas in Canada's eastern and central arctic, 2003-2006.

Breeding area	Year	\hat{S}^a	95% CI
Queen Maud Gulf	2003	0.960	0.720 – 0.996
	2004	0.951	0.702 – 0.994
	2005	0.961	0.716 – 0.996
Baffin Island	2003	0.961	0.695 – 0.996
	2004	0.951	0.681 – 0.994
	2005	0.961	0.689 – 0.996
Southampton Island	2003	0.968	0.724 – 0.997
	2004	0.958	0.697 – 0.996
	2005	0.968	0.723 – 0.997
La Pérouse Bay	2003	0.829	0.721 – 0.901
	2004	0.828	0.727 – 0.897
	2005	0.842	0.701 – 0.923
Cape Henrietta Maria	2003	0.828	0.717 – 0.901
	2004	0.827	0.722 – 0.898
	2005	0.840	0.695 – 0.924
Akimiski Island	2003	0.834	0.684 – 0.921
	2004	0.833	0.686 – 0.919
	2005	0.846	0.671 – 0.937

a Probability of survival from year i to year $i+1$.

Temporal Changes in Survival and Recovery Rates, 1989-2006

Key questions surrounding the effectiveness of management actions introduced in 1998-1999 are (1) whether survival rates of adult snow geese have declined in response to increases in annual harvest, and (2) whether such declines have been sufficient to effect changes in population growth. As described above, long-term banding data spanning both pre- and post-management periods exist only

for QMG and LPB. However, the apparent existence of two distinct segments of the midcontinent population (arctic and subarctic), as evident from the preceding analysis of geographic variation in adult survival, suggested an opportunity to integrate long-term banding data from QMG and LPB with more recent data from other breeding areas. Analysis based on this integrated data set would make full use of available banding data and maximize precision of parameter estimates. Accordingly, for survival and recovery rate estimation for the period 1989-2006, Alisauskas et al. (2011) used band-recovery data from all eight breeding areas (Table 1), stratified according to northern and southern regions of the nesting distribution. The northern stratum included geese marked at QMG, BAF, SOU, RAS, and WHB (i.e., geese marked north of 60°N latitude), whereas the southern stratum included geese marked at LPB, CHM, and AKI. Input data for this analysis were recovery matrices for northern and southern strata involving 37,710 and 60,732 marked adults, respectively. Collectively, these individuals contributed 8,626 hunter recoveries (2,632 from the northern sample and 5,994 from the southern sample).

As with the preceding analysis, annual survival (S) and recovery (f) probabilities were estimated using the models of Brownie et al. (1985) as implemented in program MARK (White and Burnham 1999). The candidate model set for this analysis included models that recognized additive and multiplicative effects of time (i.e., year, denoted t) and breeding stratum (north vs. south, denoted $strat$) on both survival and recovery probability, as well as models that assumed constancy and/or no differences between strata in these parameters. With respect to survival, we also considered models that allowed annual estimates to vary as a linear-logistic or quadratic function of time (i.e., linear or quadratic time trend models, denoted S_T and S_{T2} , respectively). To evaluate the relationship between survival and harvest, we included total adult harvest estimates (Figure 1) as a time-varying group covariate (H) in the analysis. Finally, as a direct test of the effectiveness of special conservation measures, the candidate set included models (denoted S_{CO}) that contrasted survival between periods before (1989-1997) and after (1998-2006) the implementation of such measures in 1998. We again used AIC-based model selection and model-averaged parameter estimates as the primary basis for our inferences.

An initial assessment of 40 *a priori* candidate models suggested that effects of conservation measures, harvest, and time trends on survival all varied by breeding stratum (i.e., models structured according to $S_{strat*CO}$, $S_{strat*H}$, $S_{strat*T}$, or $S_{strat*T2}$ were highly ranked). Thus, to explore the nature of these interactive effects, Alisauskas et al. (2011) developed an additional 12 models of the general form $S_{NORTH(SOUTH)}$, in effect modeling survival separately by northern and southern strata (Table 4). Among the most parsimonious models in this expanded candidate set was a model that recognized an effect of conservation measures on survival rates of southern geese, but no such effect among northern geese (model $S_{NORTH(SOUTH(CO))}$, $f_{strat*t}$; Table 4). Under this model, which received substantial support based on AIC ($\Delta QAIC_c = 1.13$), annual survival for the northern stratum was structured as constant for the period 1989-2006 and was estimated at 0.870 (95% CI = 0.858-0.882). For southern geese, survival was estimated at 0.883 (95% CI = 0.871-0.894) before the introduction of special conservation measures (1989-1997), but declined to a value of 0.829 (95% CI = 0.815-0.842) following the

introduction of these measures (1998-2006). Survival rate estimates obtained by averaging over all models in the candidate set (after appropriate weighting) showed a similar pattern of no systematic temporal change or trend in adult survival among northern geese, but declining adult survival among southern geese corresponding to introduction of special conservation measures in the 1998 season (Figure 3). Overall, results of the analysis supported the existence of a survival response among snow geese nesting south of 60°N latitude. At the same time, however, results provided no evidence to suggest a parallel response among snow geese nesting north of 60°N latitude, where (as noted above) approximately 90% of the midcontinent snow goose population is assumed to reside during the breeding season.

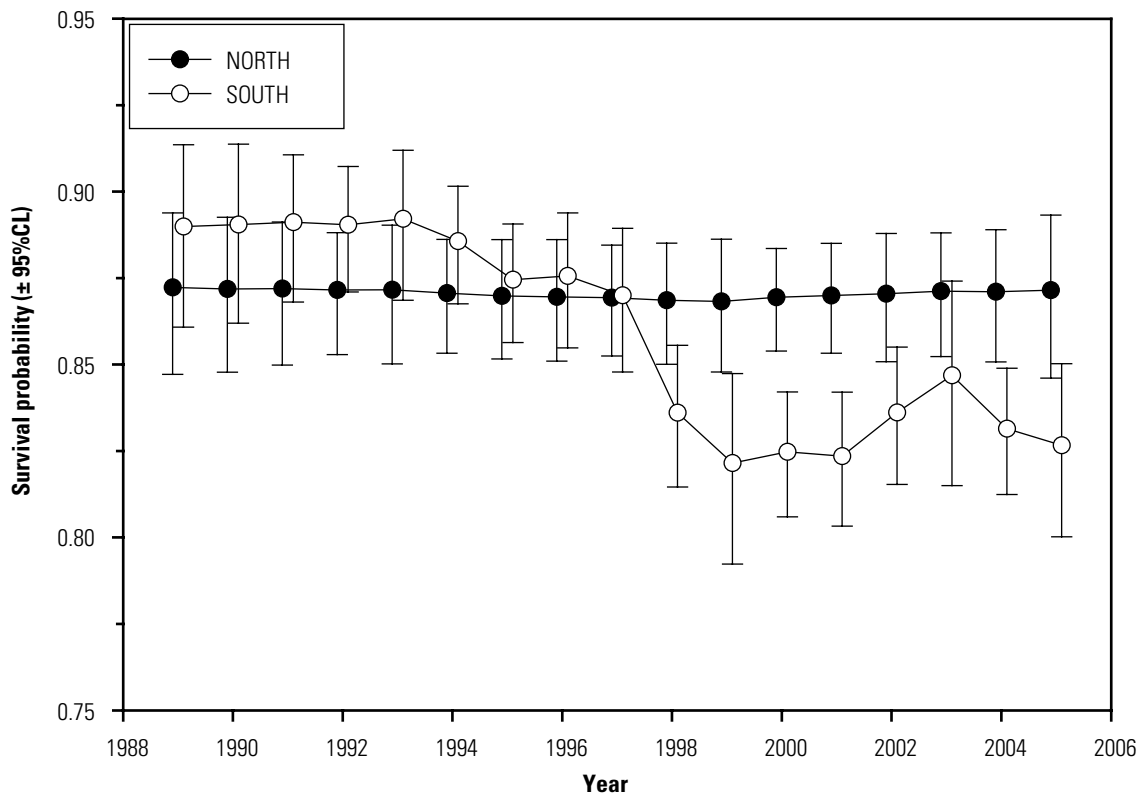


Figure 3. Model-averaged survival rate estimates (\hat{S}) for adult lesser snow geese captured and marked either north of 60°N latitude (NORTH) or south of 60°N latitude (SOUTH) in Canada's eastern and central arctic, 1989-2006. Modified from Alisauskas et al. (2011).

Table 4. Summary output from competing band-recovery models developed to estimate annual survival (S) and recovery (f) probabilities for adult lesser snow geese captured and marked at eight breeding areas in Canada's eastern and central arctic, 1989-2006. Breeding areas north of 60°N latitude (northern stratum, denoted NORTH) include Queen Maud Gulf, Baffin Island, Southampton Island, Rasmussen lowlands, and West Hudson Bay. Breeding areas south of 60°N latitude (southern stratum, SOUTH) include La Pérouse Bay, Cape Henrietta Maria, and Akimiski Island. Only those models having QAICc weights ≥ 0.01 are shown. Data from Alisauskas et al. (2011).

Model ^a	Number of parameters	ΔQAIC_c^b	QAIC _c weight ^c
$S_{\text{NORTH}(.)\text{SOUTH}(H)}, f_{\text{strat}+t}$	22	0.00	0.32
$S_{\text{NORTH}(.)\text{SOUTH}(CO)}, f_{\text{strat}+t}$	22	1.13	0.18
$S_{\text{NORTH}(.)\text{SOUTH}(R+C)}, f_{\text{strat}+t}$	23	1.45	0.16
$S_{\text{strat}^*H}, f_{\text{strat}+t}$	23	1.85	0.13
$S_{\text{strat}^*CO}, f_{\text{strat}+t}$	23	3.13	0.07
$S_{\text{strat}^*R+C}, f_{\text{strat}+t}$	25	4.07	0.04
$S_{\text{strat}^*T2}, f_{\text{strat}+t}$	25	4.36	0.04
$S_{\text{NORTH}(.)\text{SOUTH}(T)}, f_{\text{strat}+t}$	22	4.38	0.04
$S_{\text{NORTH}(.)\text{SOUTH}(C)}, f_{\text{strat}+t}$	22	5.91	0.02
$S_{\text{strat}^*T}, f_{\text{strat}+t}$	23	6.34	0.01

- a Model notation follows Lebreton et al. (1992); t = time-dependency (annual variation), strat = breeding stratum (NORTH vs. SOUTH), T = linear-logistic time trend, T2 = quadratic time trend, H = total adult harvest, R = regular season harvest, C = conservation order harvest, (.) = constancy. CO denotes a contrast corresponding to the introduction of special conservation measures in 1998 (1989-1997 vs. 1998-2006).
- b Difference between QAICc of the current model and the minimum observed value, where QAICc is Akaike's Information Criterion with adjustments for overdispersion ($\hat{c} = 1.058$) and small-sample bias (Burnham and Anderson 2002).
- c Normalized Akaike weight (Burnham and Anderson 2002).

Based on the model-averaged parameter estimates derived above, the most recent available adult survival rate estimates (corresponding to the interval 2005-2006) for northern and southern snow geese, respectively, were 0.872 (95% CI = 0.846-0.893) and 0.827 (95% CI = 0.800-0.850). Notably, both point estimates exceed the original target values for adult survival recommended for population reduction (i.e., ~0.80 and 0.72 corresponding to population growth rates of $\lambda = 0.95$ and 0.85, respectively; Rockwell et al. 1997). Further, given the disproportionate contributions of northern and southern snow geese to the midcontinent population, it seems prudent to weight inferences according to the respective proportions of the midcontinent population belonging to each of these two segments. Assuming proportions of 0.90 and 0.10 for arctic and subarctic segments, respectively (Kerbes et al. 2006), and applying these proportions as weights to the most recent survival rate estimates obtained above, this suggests a composite weighted estimate of adult survival for the midcontinent population of $S_{2005} = 0.868$. Again, this estimate is well above stated goals for reductions in adult survival intended to achieve negative population growth.

Implicit in our interpretation of the above results is the expectation that the relationship between adult survival and harvest differs between northern and southern segments of the midcontinent population. Model selection results and parameter estimates based on band-recovery data were consistent with this expectation. Indeed, the most parsimonious model in the candidate set recognized an inverse relationship between adult survival and total adult harvest for southern geese, but no such relationship among northern geese (model $S_{\text{NORTH}(.)\text{SOUTH}(H)}, f_{\text{strat}+t}$; Table 4). The slope of the relationship between survival of southern geese and total adult harvest, on a logit scale, was -1.15 (95% CI = -1.56 to -0.74). Model-averaged survival rate estimates, when plotted against annual estimates of total adult harvest, also suggested a strong inverse relationship between survival and harvest for southern geese but no such relationship among northern geese (Figure 4). The negative relationship between survival and harvest among southern geese is consistent with hunting mortality being additive to non-hunting mortality for this segment of the midcontinent population. However, the absence of such a relationship among northern geese suggests that harvest mortality for much of the midcontinent population may have been below threshold levels necessary for such additivity to occur.

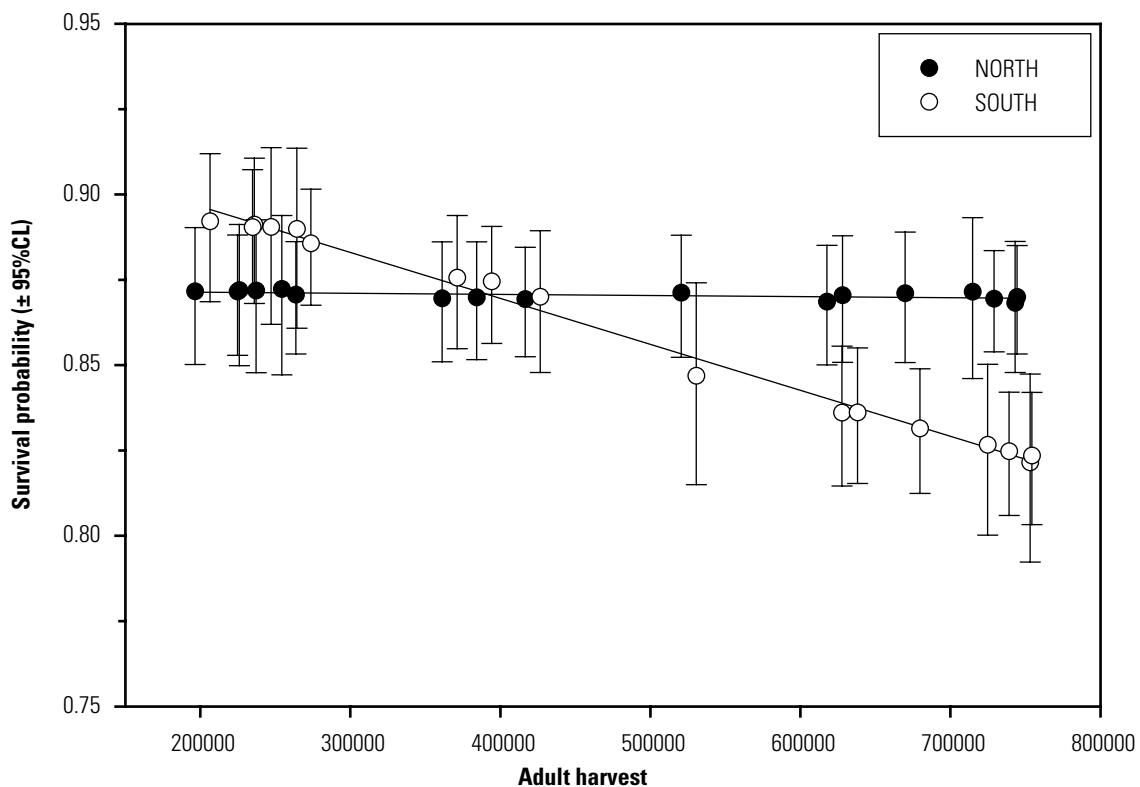


Figure 4. Model-averaged survival rate estimates (\hat{S}) for adult lesser snow geese captured and marked either north of 60°N latitude (NORTH) or south of 60°N latitude (SOUTH), relative to annual estimates of adult harvest, 1989-2006. Lines represent simple linear regressions conducted separately by stratum and are included for illustrative purposes only. Modified from Alisauskas et al. (2011).

Recovery probability was best modeled as showing parallel annual variation among geese from northern and southern regions of the nesting distribution (parameterization $f_{\text{strat}+t}$ with respect to recovery; Table 4). For both groups, recovery probability exhibited a modest increase beginning in 1995 (Figure 5), presumably the result of increased reporting rates associated with the introduction of legbands carrying a toll-free telephone number for reporting purposes. Recovery rates for both groups rose sharply following the introduction of additional harvest opportunities in 1998-1999, but exhibited a general decline thereafter (Figure 5), reaching post-management lows of 0.019 and 0.024 for northern and southern strata, respectively, in the final year of the analysis (2006). Overall, recovery rate estimates for southern geese were approximately 25% higher than corresponding estimates for northern geese (Figure 5). Assuming comparable band-reporting rates for geese from northern and southern regions of the nesting distribution, this last result implies higher harvest rates among geese marked south of 60°N latitude.

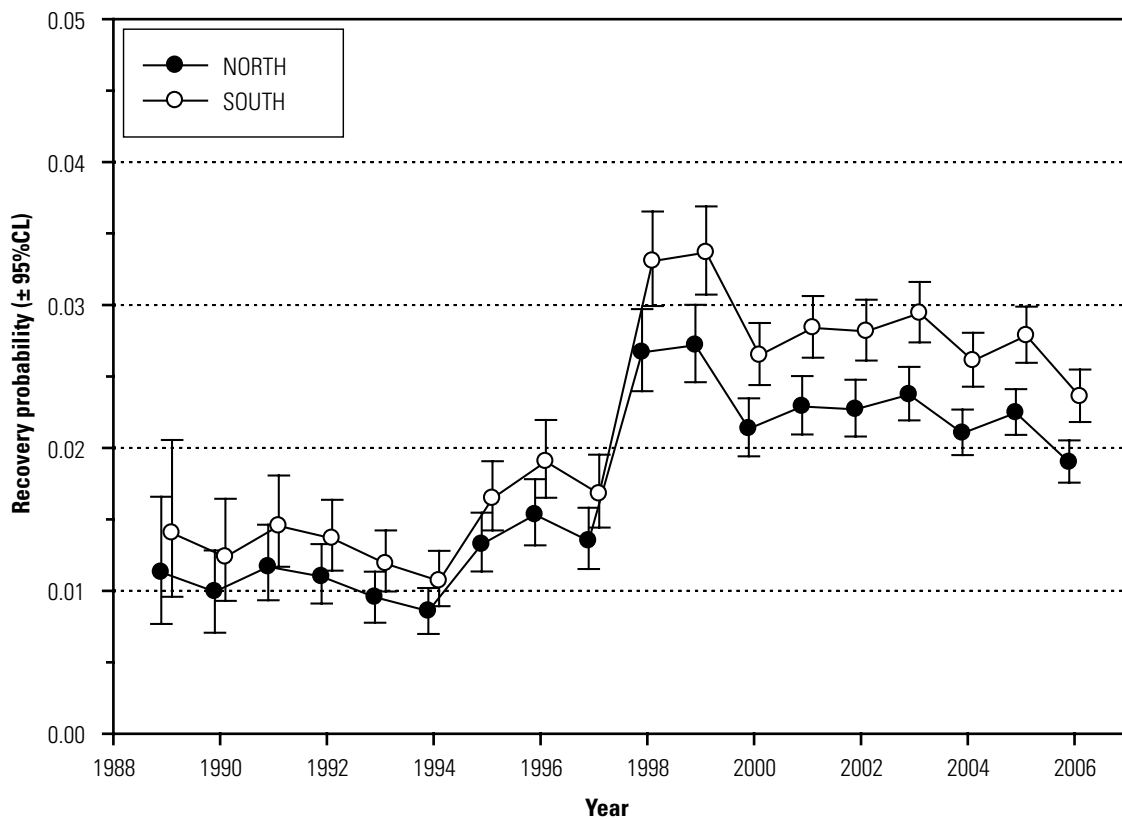


Figure 5. Model-averaged recovery rate estimates (f) for adult lesser snow geese captured and marked either north of 60°N latitude (NORTH) or south of 60°N latitude (SOUTH) in Canada's eastern and central arctic, 1989-2006. Modified from Alisauskas et al. (2011).

Temporal Changes in Survival of Ross's Geese

As mentioned earlier, a secondary aim of the present chapter was to explore temporal changes in survival of Ross's geese, with a view towards determining whether declines in adult survival observed during the 1990s have continued since implementation of special harvest regulations. We began our analysis of Ross's goose survival by assembling all banding data on Ross's geese captured and marked east of 110°W longitude in the eastern and central Canadian arctic since 1989. Banding data were obtained from USGS Bird Banding Laboratory and the CWS Bird Banding Office. As with snow geese, our focus was on adult (after-hatch-year) birds and we restricted our analysis to birds marked with standard metal legbands only (i.e., birds marked with neckbands or reward bands were excluded). By far the largest banded samples of Ross's geese derive from the Queen Maud Gulf (QMG) region in the central arctic, where adults have been marked each year since 1989 (Table 5), and where more than 90% of the continental Ross's goose population is thought to reside during nesting and brood-rearing (Kerbes et al. 2006). Lesser numbers of Ross's geese have been banded in areas of the eastern arctic (Table 5), although banding efforts have increased in recent years, coincident with an eastward expansion of the species' breeding range (Moser 2001). Specifically, since 1989, periodic banding of Ross's geese has occurred at West Hudson Bay (11,125), Southampton Island (2,061), Baffin Island (1,518), La Pérouse Bay (444), Cape Henrietta Maria (53), and Akimiski Island (2). Individually, we considered these samples insufficient for survival estimation because (1) none of the banded samples from the eastern arctic represented an uninterrupted time series spanning 1989-2010, and (2) only limited banding occurred at any eastern site prior to 2002 (Table 5). Collectively, however, banded samples from the eastern sites appeared adequate. Thus, for our purposes, we combined data from all six eastern banding areas and contrasted survival of Ross's geese marked in the eastern arctic with that of birds marked in the Queen Maud Gulf region. In support of this decision, we note that a recent analysis indicated that recovery distributions of Ross's geese banded in different areas of the eastern arctic were statistically indistinguishable and were largely restricted to the midcontinent, whereas those of birds banded in the Queen Maud Gulf region were distinct and included a significant number of recoveries from the Pacific Flyway (Alisauskas et al. 2012, Figure 3).

Input data for this analysis were recovery matrices involving 43,737 marked individuals from the Queen Maud Gulf region and 15,203 individuals from the eastern arctic, the latter treated in aggregate. Recoveries included only those birds reportedly shot by a hunter. At the time of analysis, information on hunter recoveries was current to 9 June 2011 and thus included birds recovered during the 2010-2011 hunting season (late-reported recoveries notwithstanding). Total recovered sample sizes were 2,621 and 1,215 for the QMG region and the eastern arctic, respectively.

Table 5. Number of adult (after-hatch-year) Ross's geese marked with legbands only at each of seven locations in Canada's central and eastern arctic, 1989-2010. Locations include Queen Maud Gulf (QMG) in the central arctic and Akimiski Island (AKI), Baffin Island (BAF), Cape Henrietta Maria (CHM), La Pérouse Bay (LPB), Southampton Island (SOU), and West Hudson Bay (WHB) in the eastern arctic.

Year	Central Arctic		Eastern Arctic				
	QMG	AKI	BAF	CHM	LPB	SOU	WHB
1989	162	0	0	0	2	0	15
1990	304	0	0	0	0	0	0
1991	161	0	0	0	6	26	50
1992	156	0	3	0	5	0	0
1993	36	0	0	0	5	0	0
1994	185	0	0	0	36	28	30
1995	187	0	0	0	5	0	0
1996	3	0	19	0	0	0	5
1997	932	2	8	0	0	0	161
1998	1494	0	0	0	1	0	214
1999	1165	0	0	0	3	0	2
2000	1442	0	0	3	0	0	119
2001	965	0	0	4	1	0	22
2002	1056	0	0	42	19	209	967
2003	2607	0	2	3	0	0	2200
2004	3411	0	0	1	17	0	1599
2005	3756	0	0	0	113	0	3241
2006	4818	0	200	0	125	501	2500
2007	5721	0	332	0	5	227	0
2008	5825	0	91	0	11	598	0
2009	3803	0	452	0	0	262	0
2010	5548	0	411	0	90	210	0
Total	43737	2	1518	53	444	2061	11125

Similar to snow geese, we estimated rates of annual survival (S) and recovery (f) of adult Ross's geese using band-recovery models (Brownie et al. 1985) as implemented in program MARK (White and Burnham 1999). With respect to survival, we considered models that recognized effects of both time (i.e., year, denoted t) and banding location (QMG vs. other, denoted g) with interaction ($S_{g \cdot t}$), models that recognized temporal parallelism between the two groups ($S_{g \cdot t}$), and models that assumed constancy and/or no group differences in survival (S_g , S_t , and S). To evaluate systematic changes (trends) in survival over time, we also included models that allowed survival to vary as a linear (T) or

quadratic (T2) function of calendar year, with and without interactive or additive effects of banding location (S_{g^*T} , S_{g+T} , S_T , and S_{g^*T2} , S_{g+T2} , S_{T2} , respectively). With respect to recovery probability, we considered models that recognized full group- and time-dependency (f_{g^*t}), parallel variation between the two groups (f_{g+t}), and simple time dependency (f_t). As with snow geese, we selected among competing models using AIC and rely heavily on model-averaged parameter estimates in drawing our inferences.

Model selection based on AIC indicated that the most parsimonious model was one in which survival varied as a quadratic (curvilinear) function of time (model S_{T2} , f_{g^*t} ; Table 6). Under this model, annual survival declined from 0.897 (95% CI = 0.789-0.953) to a low of 0.827 (95% CI = 0.801-0.850) during the period 1989-1997, then increased steadily from 1998 onward, reaching a high of 0.950 (95% CI = 0.899-0.976) in 2009. Survival rate estimates obtained by model-averaging showed a similar pattern of declining survival during the 1990s and a subsequent increase between 1999 and 2009 (Figure 6). Model-averaged estimates of annual survival for birds marked in the QMG region were slightly higher than corresponding estimates for birds marked in areas of the eastern arctic, but broad overlap of confidence intervals suggested that these differences were statistically negligible (Figure 6). For Ross's geese marked in both the QMG region and in the eastern arctic, model-averaged survival rate estimates exceeded 0.90 each year from 2006 onward. For the interval 2009-2010 (the final interval of the time series), survival rate estimates for these two groups were 0.942 (95% CI = 0.863-0.977) and 0.940 (95% CI = 0.852-0.977), respectively.

Table 6. Summary output from competing band-recovery models developed to estimate annual survival (S) and recovery (f) probabilities for adult Ross's geese captured and marked at Queen Maud Gulf (QMG) and six other breeding areas in Canada's eastern and central arctic, 1989-2010. Other breeding areas (treated in aggregate) include Baffin Island, Southampton Island, West Hudson Bay, La Pérouse Bay, Cape Henrietta Maria, and Akimiski Island. Only those models having QAIC_c weights ≥0.01 are shown.

Model ^a	Number of parameters	ΔQAIC _c ^b	QAIC _c weight ^c
S_{T2}, f_{g^*t}	47	0.00	0.58
S_{g+T2}, f_{g^*t}	48	1.84	0.23
S_T, f_{g^*t}	46	3.87	0.08
S_{g+T}, f_{g^*t}	47	5.62	0.04
S_{g^*T2}, f_{g^*t}	50	5.71	0.03
S_{g^*T}, f_{g^*t}	48	7.58	0.01

a Model notation follows Lebreton et al. (1992); t = time-dependency (annual variation), g = group differences (QMG vs. other), T = linear-logistic time trend, T2 = quadratic time trend, no subscript = constancy.

b Difference between QAIC_c of the current model and the minimum observed value, where QAIC_c is Akaike's Information Criterion with adjustments for overdispersion ($\hat{c} = 1.0855$) and small-sample bias (Burnham and Anderson 2002).

c Normalized Akaike weight (Burnham and Anderson 2002).

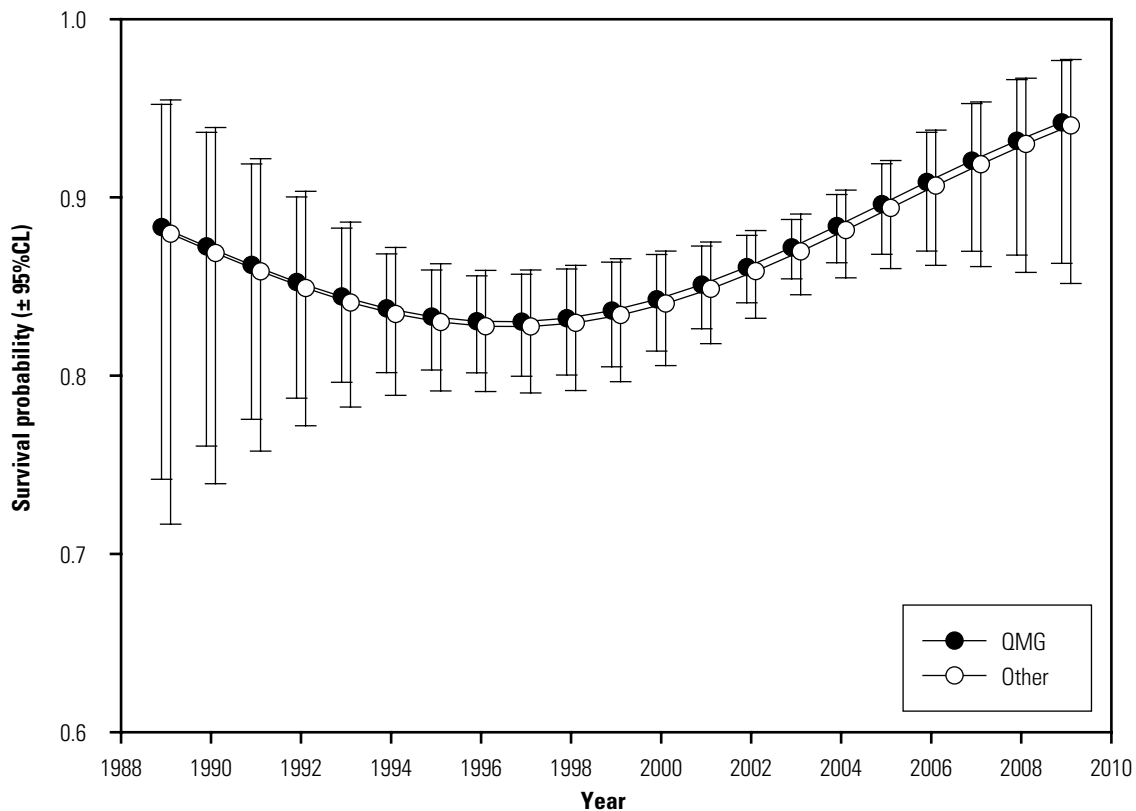


Figure 6. Model-averaged survival rate estimates (\hat{S}) for adult Ross's geese captured and marked at Queen Maud Gulf (QMG) and six other breeding areas in Canada's eastern and central arctic, 1989-2010. Other breeding areas (treated in aggregate) include Baffin Island, Southampton Island, West Hudson Bay, La Pérouse Bay, Cape Henrietta Maria, and Akimiski Island.

Recovery probability of Ross's geese was best modeled to include interactive effects of banding location (QMG vs. other) and time (i.e., year; Table 6). Although variable among years, model-averaged recovery rate estimates rarely exceeded 0.03, or in the case of QMG birds, 0.02 (Figure 7). For both groups, there was some suggestion of a general increase in recovery rates during the 1990s and a subsequent decline from 2000 onward, when special conservation measures were in place (Figure 7). However, imprecision of recovery rate estimates precluded strong inferences about these temporal trends. We note also that recovery rate estimates for 2010 (the last year considered) are likely biased low due to incomplete information at the time of analysis on birds recovered during the 2010-2011 hunting season.

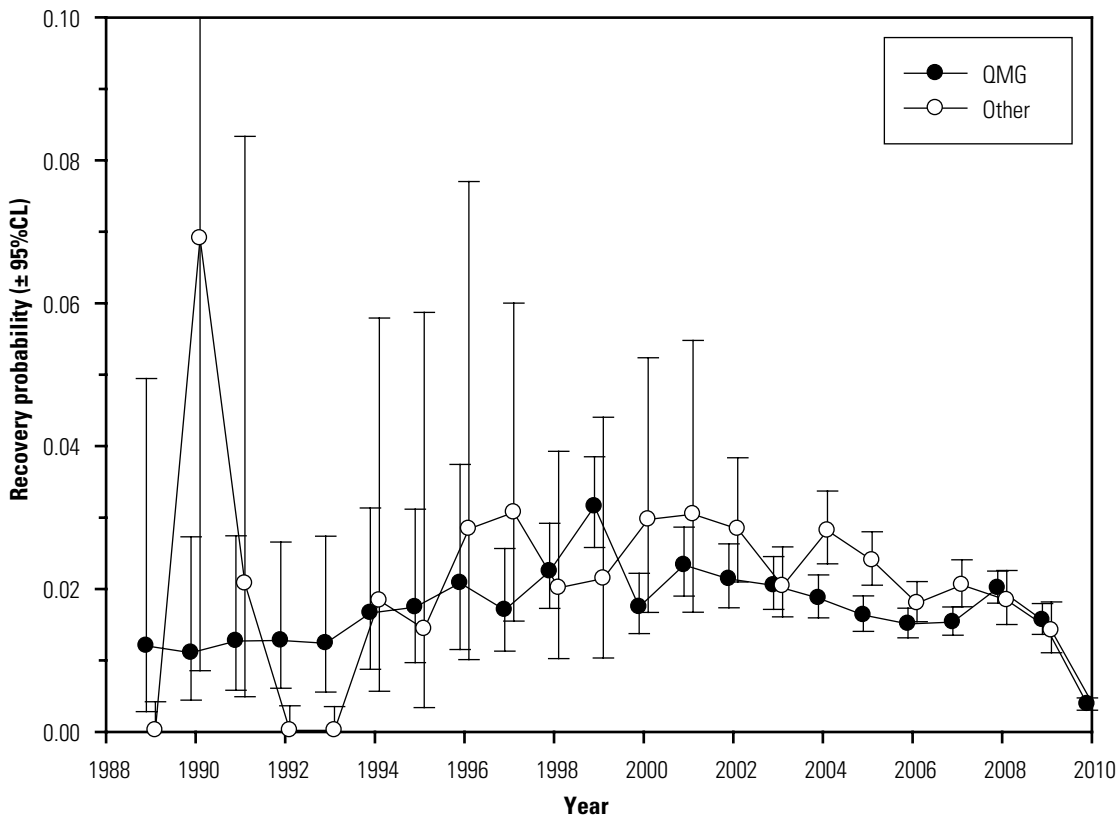


Figure 7. Model-averaged recovery rate estimates (f) for adult Ross's geese captured and marked at Queen Maud Gulf (QMG) and six other breeding areas in Canada's eastern and central arctic, 1989-2010. Other breeding areas (treated in aggregate) include Baffin Island, Southampton Island, West Hudson Bay, La Pérouse Bay, Cape Henrietta Maria, and Akimiski Island.

Temporal Changes in Snow Goose Productivity

Although the goal of management action introduced in 1998-1999 was to control snow goose numbers via reductions in adult survival, the new regulatory measures may have had unintended consequences for snow goose productivity and recruitment. In particular, flock disturbance during spring harvest activities in Canada and the United States has potential to disrupt nutrient acquisition and increase energy expenditure among staging geese (Alisauskas 2002), which in turn might impact subsequent breeding propensity and performance (Ebbing 1989; Alisauskas 2002; Reed et al. 2004). As mentioned earlier, such appears to have been the case with greater snow geese: following the introduction of spring conservation harvest in 1999, hunting disturbance on spring staging areas in Quebec apparently resulted in reductions in greater snow goose body condition, breeding effort, and production of young (reviewed by Reed and Calvert 2007). Thus, an examination of long-term trends in lesser snow goose productivity seemed warranted. In this section, we address temporal changes in productivity of midcontinent lesser snow geese via analyses of changes in annual age ratios in the Canadian regular season harvest. Although care must be taken in interpretation, harvest age ratios,

when corrected for differential harvest vulnerability among age classes, provide a summary measure of annual productivity that integrates several components of recruitment, including breeding propensity of adults, clutch size, nest success, gosling survival, and juvenile survival between fledging and the time of harvest.

We obtained harvest age ratio data from the Canadian Species Composition Survey (SCS; Gendron and Collins 2007) for the period 1975-2006. We elected to analyze changes in age ratios in the Canadian regular season harvest (as opposed to the continental harvest) to (1) minimize complicating effects of changing harvest vulnerability of juvenile geese during southward migration (see, for instance, Calvert et al. 2005), and (2) avoid related problems associated with changes in annual hunting dates and season lengths in the United States (Kruse et al. 2007). We initially considered age ratios of lesser snow geese harvested in Ontario, Manitoba, and southeastern Saskatchewan (National Harvest Survey SK zone 3; Gendron and Collins 2007), areas where most midcontinent snow geese are harvested in Canada. We subsequently focused our analyses on harvest age ratio data from Manitoba and southeastern Saskatchewan because parts samples from Ontario were generally inadequate for computing age ratios (following Gendron and Collins 2007, we considered sample sizes of <20 individuals insufficient for analysis). Blue and white phase snow geese were pooled in analysis because previous work had established that harvest age ratios were unrelated to color phase (Alisauskas 2002). Where possible, harvest age ratios were adjusted for differential harvest vulnerability among age classes (as detailed below) to yield annual indices of the proportion of young in the fall population.

Arctic-nesting geese typically show pronounced annual variation in productivity, and much of this variation can be attributed to the severity of weather conditions on arctic nesting areas (e.g., Boyd et al. 1982; Alisauskas 2002; Reed et al. 2004). Thus, studies of temporal changes in productivity should seek to account for severity of arctic spring weather in analysis. Following Alisauskas (2002), we developed an annual index of spring severity based on weather data assembled from three Environment Canada arctic weather stations for the period 1975-2006: Baker Lake (64°18'N, 96°05'W), Coral Harbour (64°12'N, 83°22'W), and Hall Beach (68°47'N, 81°15'W), Nunavut. Weather variables included mean June temperature (°C), snow depth on the last day of May (cm), and snow depth on the last day of June (cm). To reduce the dimensionality of the weather data for analysis, we averaged June temperature values and summed May and June snow depth values across the three stations and conducted principal components analysis (PCA) on the correlation matrix of the resulting three variables. The first principal axis (PC1) accounted for 70.4% of the total original variance and was characterized by component loadings of -0.87, 0.82, and 0.83 corresponding to mean June temperature, May snow depth, and June snow depth, respectively. High positive scores along the first principle axis (PC1 scores) described years of severe spring temperature and snow pack conditions, so we interpreted PC1 scores as measures of spring severity on arctic nesting areas.

We conducted two separate analyses of annual variation in harvest age ratios. In the first analysis, we assessed changes in age ratios over a 32-year period spanning 1975-2006. Because we lacked

information on age-specific harvest vulnerability for the first 15 years of this time series (see below), age ratios were not adjusted for differential harvest vulnerability and, as such, reflect age ratios in the fall harvest. Harvest age ratio (A_{harv}) in this analysis was computed simply as the ratio of immature to adult parts received by the SCS, i.e.,

$$A_{\text{harv}} = (\text{number of immatures} / \text{number of adults}).$$

For purposes of analysis and following Sheaffer (1998), A_{harv} was converted to the proportion of young in the fall harvest (Y) using

$$Y = A_{\text{harv}} / (A_{\text{harv}} + 1).$$

Thus, hereafter, “age-ratio” and proportion of young in the fall harvest are synonymous, except where specifically indicated.

In the second analysis, we assessed changes in age ratios over a 17-year period spanning 1990-2006, after first adjusting age ratios for differential vulnerability of young and adult geese to harvest. Differential harvest vulnerability was estimated using pre-season banding data and corresponding hunter recoveries assembled for immature and adult snow geese marked in the Queen Maud Gulf Migratory Bird Sanctuary over this same time period (banding data for immature geese were available only from 1990 onward, hence the need to use raw age ratios in the analysis involving the longer time series above). Banding data were restricted to geese marked with legbands only, and recoveries included only those birds reportedly shot by a hunter or taken under permit. Harvest vulnerability of young geese relative to adults (V_{diff}) was estimated for each year as the quotient of the direct recovery rate for immature geese (f_{imm}) and that computed for adults (f_{ad}), i.e.,

$$V_{\text{diff}} = f_{\text{imm}} / f_{\text{ad}}.$$

Harvest age ratios were then adjusted for V_{diff} to yield annual estimates of age ratio in the fall population (A_{pop}) according to

$$A_{\text{pop}} = A_{\text{harv}} / V_{\text{diff}}.$$

Finally, in keeping with the preceding analysis, adjusted age ratios were expressed as proportions of young in the fall population (Y'), i.e.,

$$Y' = A_{\text{pop}} / (A_{\text{pop}} + 1).$$

For each of the two analyses, we developed a suite of alternative general linear models (GLMs) to describe annual variation in Y or Y' as a predictable function of one or more explanatory variables. Explanatory variables in each instance included severity of arctic spring weather (PC1 score), province where shot, year treated as a continuous predictor (i.e., linear time trend models), and a contrast corresponding to the implementation of spring conservation harvest in 1999 (i.e., pre- vs. post-

management periods). Each candidate set also included a null (intercept only) model. Similar to our analyses of adult survival, we used AIC-based model selection and model weights (Burnham and Anderson 2002) to evaluate the performance of competing models.

Harvest Age Ratios, 1975-2006

The proportion of young in the Canadian regular season harvest varied widely among years, ranging from 0.16 in 1992 (Saskatchewan) to 0.63 in 1984 (Manitoba). Model selection based on AIC indicated that annual age ratios varied as a predictable function of severity of arctic spring weather (PC1 score) and province where shot (Table 7). These two explanatory variables were common to the three most parsimonious models, and these models collectively embraced all of the AIC-based support among the candidate models considered (cumulative model weight = 1.0; Table 7). Under the AIC-selected model, there was a pronounced inverse relationship between harvest age ratio (proportion immature) and spring severity ($\beta = -0.051 \pm 0.007$ SE; Figure 8), and harvest age ratios from Manitoba exceeded corresponding age ratios from Saskatchewan (Figure 8). By contrast, there was little evidence to suggest a systematic change or trend in harvest age ratio over time (cumulative model weight for models incorporating a linear trend = 0.29; $\beta = -0.001 \pm 0.001$ SE from the most parsimonious linear trend model; Table 7), nor was there evidence of a decline in harvest age ratio following the introduction of spring conservation harvest in 1999 (cumulative model weight = 0.21; $\beta = 0.007 \pm 0.010$ SE; Table 7).

To further explore patterns of temporal variation in harvest age ratios, while controlling variation attributable to spring weather severity, we computed weather-adjusted age ratios for each year of study and examined changes in these adjusted age ratios over time. Adjusted values (Y_{adj}) were computed based on residuals from the regression equation describing the relationship between harvest age ratio and PC1 score as

$$Y_{adj} = (Y_{obs} - Y_{exp}) + \bar{Y}_{obs},$$

where Y_{obs} is the observed age ratio, Y_{exp} is the expected value computed from the regression equation, and \bar{Y}_{obs} is the mean observed age-ratio computed over all observations in the sample. When adjusted age ratios were plotted against year, there was some suggestion of a decline in recent years among geese harvested in Manitoba (Figure 9), but quantitative evidence to support this suggestion was weak to nonexistent (quadratic regression: $r^2 = 0.13$, $n = 32$, $P = 0.14$) and the pattern was not evident among geese harvested in Saskatchewan (Figure 9). Thus, overall, there was little evidence to suggest that harvest age ratios have changed in response to the new regulatory measures introduced in 1999.

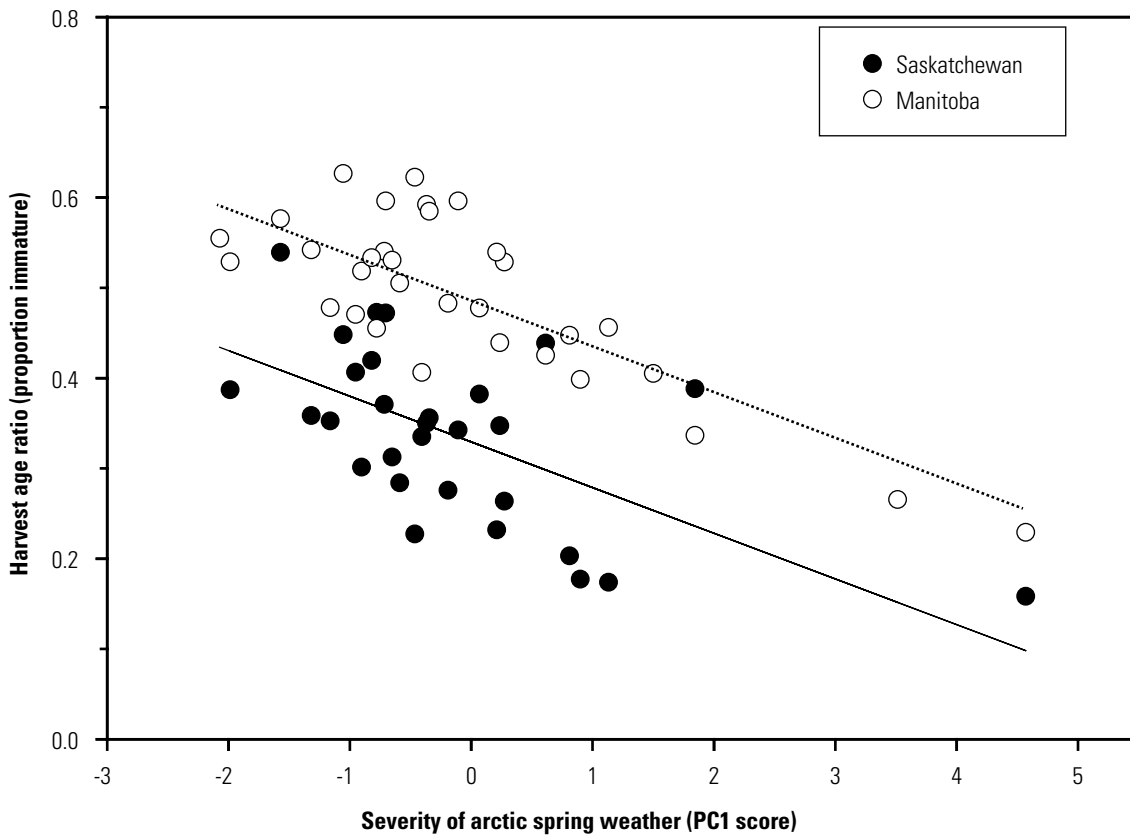


Figure 8. Relationship between annual age ratio (proportion immature) in the fall harvest of midcontinent lesser snow geese and an index of severity of spring weather on arctic nesting areas. Lines represent predicted values from a general linear model evaluating harvest age ratio relative to spring severity (PC1 score, see text) and province where shot (Prov, Saskatchewan [-1] vs. Manitoba[1]): $\hat{Y} = 0.41 - 0.051(PC1) + 0.079(Prov)$.

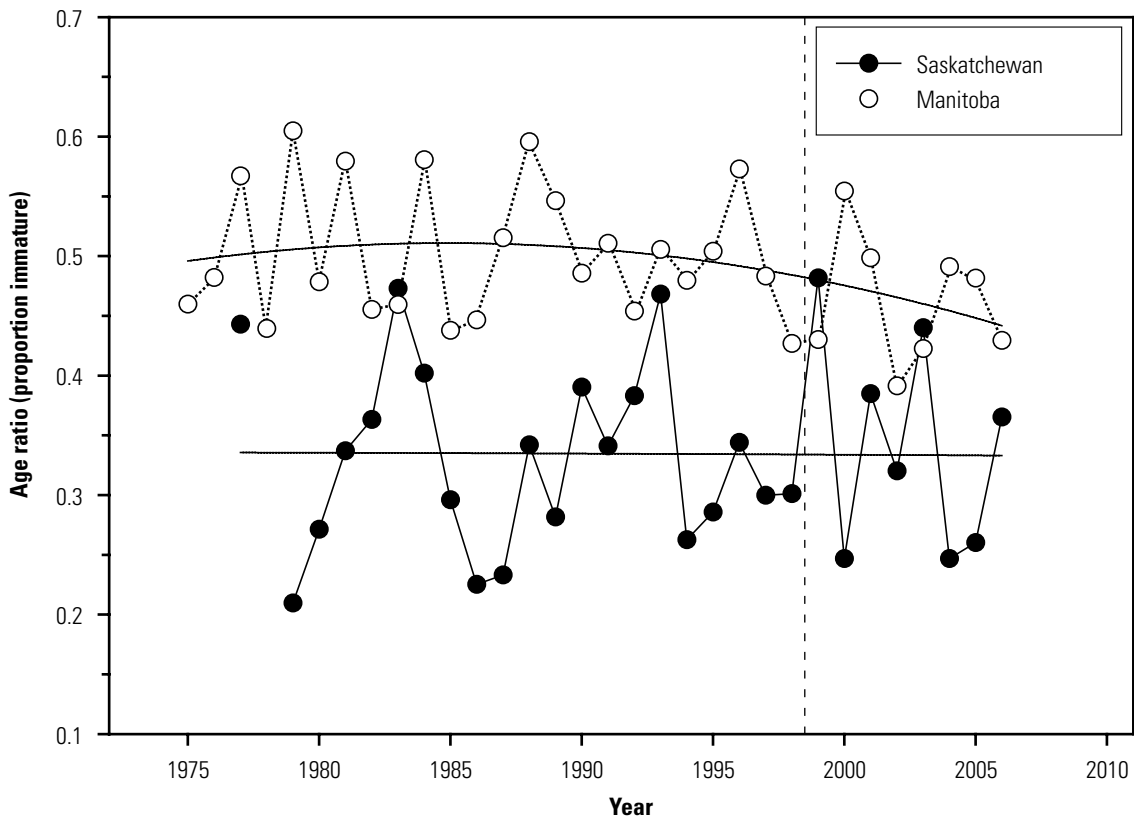


Figure 9. Annual age ratios (proportion immature) of midcontinent lesser snow geese in the Canadian fall harvest, 1975-2006. Age ratios are adjusted for variation in severity of arctic spring weather (PC1 score) based on residuals from the regression equation $\hat{Y} = 0.41 - 0.048(PC1)$, standardized to the overall mean (see text for details). Curves represent quadratic regressions conducted separately by province (Saskatchewan, $\hat{Y} = -4.36 + 0.0048(X) - 1.2 \times 10^{-6}(X^2)$, $r^2 = 0.00$; Manitoba, $\hat{Y} = -608.23 + 0.6134(X) - 0.0002(X^2)$, $r^2 = 0.13$). The vertical dashed line indicates the introduction of special conservation measures.

Table 7. Summary output from competing general linear models evaluating annual variation in age ratios of midcontinent lesser snow geese in the Canadian regular season harvest, 1975-2006. Explanatory variables include severity of arctic spring weather (Weather), province where shot (Prov, Saskatchewan vs. Manitoba), linear time trend (Linear, i.e., year treated as a continuous predictor), and a contrast corresponding to the introduction of special conservation measures in 1999 (CM, 1975-1998 vs. 1999-2006). Null denotes a model with no explanatory variables (i.e., intercept only).

Model ^a	Number of parameters	DAIC _c ^b	AIC _c weight ^c	R ²
Weather, Prov	4	0.00	0.51	0.70
Linear, Weather, Prov	5	1.14	0.29	0.70
CM, Weather, Prov	5	1.81	0.21	0.70
Prov	3	39.76	0.00	0.40
CM, Prov	4	41.72	0.00	0.40
Linear, Prov	4	41.96	0.00	0.40
Weather	3	51.22	0.00	0.27
Linear, Weather	4	52.10	0.00	0.29
CM, Weather	4	53.07	0.00	0.28
Null	2	68.42	0.00	0.00
Linear	3	70.22	0.00	0.01
CM	3	70.29	0.00	0.01

a Models are identified by the explanatory variables included in each.

b Difference between AIC_c of the current model and the minimum observed value, where AIC_c is Akaike's Information Criterion with small-sample bias adjustment (Burnham and Anderson 2002).

c Normalized Akaike weight (Burnham and Anderson 2002).

Fall Population Age Ratios, 1990-2006

A limitation of the preceding analysis is that age ratios were not adjusted for differential harvest vulnerability among age classes and, as such, they do not necessarily represent age ratios in the fall population at large. However, when we adjusted harvest age ratios to account for age differences in harvest vulnerability over the period 1990-2006, we obtained very similar results. Specifically, model selection based on AIC provided strong evidence for effects of both spring severity (cumulative model weight = 0.996; $\beta = -0.035 \pm 0.009$ SE) and province where shot (cumulative weight = 0.999; $\beta = 0.059 \pm 0.013$ SE) on the proportion of young in the fall population. However, there was little evidence to suggest either a declining trend in fall population age ratio over time (cumulative weight = 0.150; $\beta = 0.001 \pm 0.003$ SE) or a difference in fall population age ratio between years before (1990-1998) and after (1999-2006) the implementation of spring conservation harvest (cumulative weight = 0.283; $\beta = -0.014 \pm 0.013$ SE). Similar results were obtained when harvest age ratios were adjusted for both age differences in harvest vulnerability *and* severity of arctic spring weather (Figure

10). Thus, in common with our analysis of unadjusted age ratios above, there was little evidence to suggest an impact of spring conservation harvest on the proportion of young in the fall population.

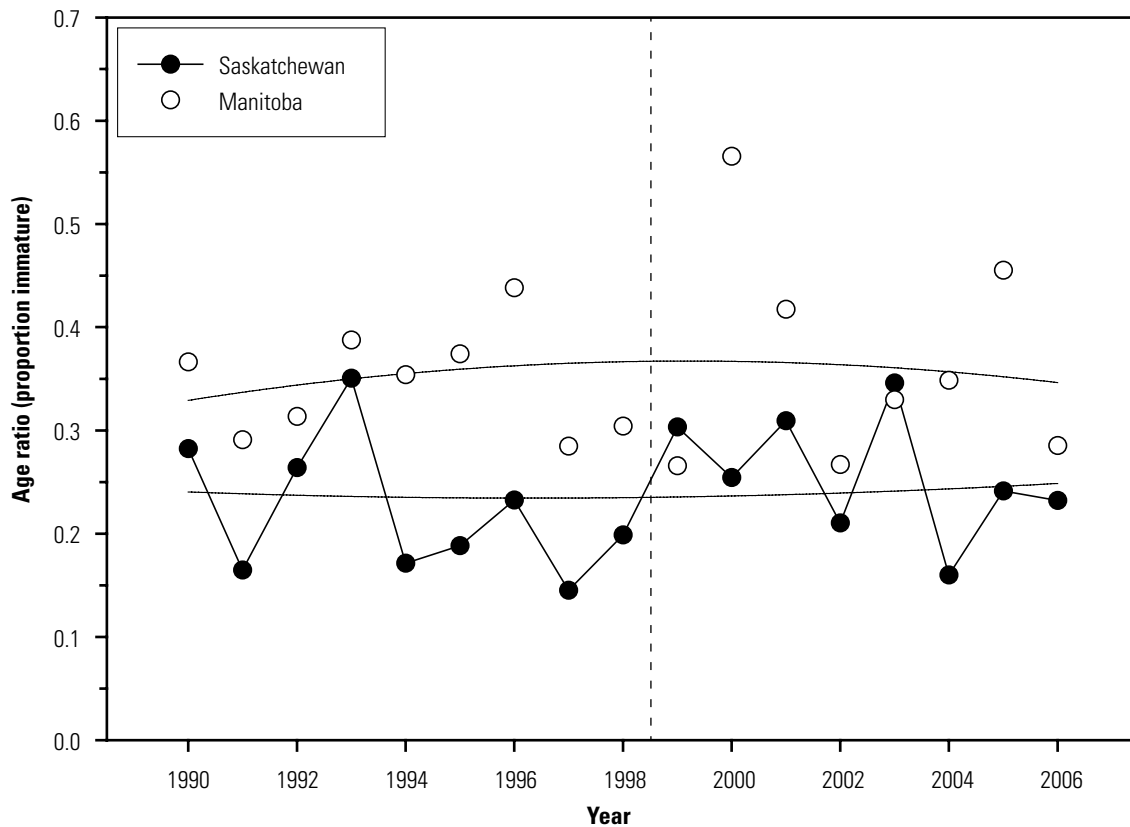


Figure 10. Annual age ratios (proportion immature) of midcontinent lesser snow geese in the Canadian fall harvest, 1990-2006. Age ratios are adjusted for annual variation in both severity of arctic spring weather and differential harvest vulnerability among age classes (see text for details). Curves represent quadratic regressions conducted separately by province (Saskatchewan, $\hat{Y} = 600.76 - 0.6016(X) + 0.0002(X^2)$, $r^2 = 0.00$; Manitoba, $\hat{Y} = -1801.15 + 1.8022(X) - 0.0005(X^2)$, $r^2 = 0.02$). The vertical dashed line indicates the introduction of special conservation measures.

Summary and Conclusions

The new regulatory measures introduced in 1998-1999 were put in place with intent to (1) increase the annual harvest of midcontinent lesser snow geese, especially that of adults, in order to (2) effect a reduction in adult annual survival, and (3) stabilize growth of the midcontinent population and, ultimately, reverse the growth trajectory to reduce snow goose numbers to sustainable levels (Batt 1997). Results presented in this chapter suggest that while harvest levels have apparently increased in response to the new regulatory measures, these increases have been generally insufficient to result in substantive changes to adult survival and, hence, population growth rate. In particular, analyses of band-recovery data for the period 1989-2006, stratified according to northern and southern regions

of the nesting distribution, provided no indication that survival rates of adults nesting north of 60°N latitude have declined since the introduction of increased harvest opportunities in 1998-1999. Significantly, snow geese nesting north of 60°N latitude are thought to account for approximately 90% of the midcontinent population (Kerbes et al. 2006). In contrast to the pattern seen among northern geese, snow geese nesting south of 60°N latitude showed an apparent survival response to increases in harvest, with adult survival rates declining from approximately 0.89 to 0.83 following the introduction of special conservation measures. Notably, however, even among southern geese, the most recent survival rate estimates still exceed the original target values for population reduction (i.e., ~0.80 and 0.72 corresponding to population growth rates of $\lambda = 0.95$ and 0.85, respectively). Thus, overall, it appears that attempts to control snow goose numbers via increases in hunter harvest have been unsuccessful in achieving management goals as they pertain to adult survival.

In keeping with the temporal patterns described above, band-recovery analysis revealed a strong inverse relationship between adult survival and total adult harvest among southern snow geese, suggesting that harvest mortality is likely additive to non-hunting mortality for this segment of the midcontinent population. Conversely, there was no evidence of a similar relationship among snow geese nesting north of 60°N latitude, which is consistent with the lack of survival response among northern geese to the regulatory changes implemented in 1998-1999. These results also lend further support to the suggestion that the midcontinent lesser snow goose population is comprised of two distinct subpopulations with differing migration phenologies, harvest characteristics, and survival prospects (Alisauskas et al. 2009). Specifically, available evidence indicates that snow geese nesting in subarctic regions (south of 60°N latitude) tend to migrate to major harvest areas significantly earlier than snow geese nesting in arctic regions (Figure 2), and previous work has demonstrated that southern snow geese are subject to higher harvest rates (Alisauskas et al. 2009). Results of our analysis involving six reference areas for the period 2003-2006 extend these findings by suggesting a north-south structure on adult survival probability, with adults from northern regions (i.e., Queen Maud Gulf, Baffin Island, and Southampton Island) surviving at consistently higher annual rates than adults nesting at more southerly latitudes (La Pérouse Bay, Cape Henrietta Maria, and Akimiski Island).

Although recovery rates of snow geese initially rose in response to the introduction of additional harvest opportunities in 1998-1999, analyses suggest that recovery rates have since declined to levels only slightly higher than those observed just before concerted efforts to increase harvest. This is especially true of the arctic-nesting (northern) segment of the population, for which the most recent recovery rate estimate was less than 2% (i.e., 0.019; Figure 5). Alisauskas et al. (2011) adjusted direct recovery rate estimates for changing reporting rates and examined the resulting harvest rate estimates in an historical context. The authors concluded that harvest rates of midcontinent snow geese have declined in recent years and are currently very low relative to estimates obtained for the 1970's. Moreover, abundance estimates based on band-recovery data and continental harvest estimates suggest that the midcontinent population has shown continued growth since 1998 (albeit at a reduced rate relative to 1990-1998), and that the current midcontinent population (estimated in August of each

year) probably exceeds 15 million adults (Alisauskas et al. 2011). It seems likely that the increases in snow goose harvest realized by management efforts have been outpaced by concurrent population growth, resulting in little change (and possibly a decline) in the per-capita rate of harvest over time. Clearly, additional increases in harvest are required if growth of the midcontinent population is to be stabilized through increases in harvest rate and consequent reductions in adult survival.

With regard to Ross's geese, our results indicate that survival rates of adults, which were in decline during the 1990s (Alisauskas et al. 2006, this study), have not only stabilized since the introduction of special regulatory measures for light geese in 1998-1999, but have in fact increased to levels as high as those of the late 1980s - early 1990s (i.e., >0.90 ; Alisauskas et al. 2006, Traylor et al. 2012). Notably, this reversal of the survival trajectory occurred in the face of some of the highest annual harvest levels estimated for adult Ross's geese since 1989 (Alisauskas et al. 2012, Figure 16). At the same time, multiple lines of evidence support the inference that Ross's goose populations have continued to grow, both in the central arctic and at the continental level (Alisauskas et al. 2009, 2012). Collectively, these observations suggest that, like snow geese, increases in harvest of Ross's geese have been outpaced by concurrent increases in abundance, diminishing the effects of harvest on adult survival. Consistent with this suggestion, harvest rates of both juvenile and adult Ross's geese have declined steadily since the introduction of special regulatory measures, and by 2009, harvest of adults occurred at a rate of only 2% (Alisauskas et al. 2012). Regardless, current harvest levels clearly pose no threat to continental Ross's goose populations, and it seems likely that Ross's goose populations could sustain further increases in harvest without realizing population decline.

Unlike the situation apparent in greater snow geese, our results offer little support for the suggestion that spring harvest in Canada and conservation order harvest in the United States has had a negative impact on lesser snow goose productivity or recruitment. Specifically, analyses of annual age ratios in the Canadian regular season harvest provided little compelling evidence to suggest that the proportion of young in the fall harvest has declined over time or in response to the implementation of spring conservation harvest in 1999. This was true regardless of whether harvest age ratios were adjusted for age differences in harvest vulnerability to yield indices of the proportion of young in the fall population. We caution, however, that there are limitations inherent in the use of fall age ratios to monitor changes in productivity. In particular, fall age ratios tend to exhibit pronounced annual variation, and some of this variability may be unrelated to changes in productivity on arctic nesting areas. For instance, changes in the relative vulnerability of young geese during the course of the hunting season, differences in timing of peak harvest among years, and shifts in migration patterns and staging distributions all have potential to influence harvest age ratios independently of changes in productivity. To the extent that these sources of variation are not controlled in analysis, this variation remains as unexplained error variation in the model, thus compromising the investigator's ability to detect subtle changes in productivity *per se*. Nevertheless, our finding that harvest age ratios continue to be correlated with spring weather conditions on arctic nesting areas (Alisauskas 2002) provides

some reassurance that age ratios, as used in the present investigation, provide a reasonable metric of annual variation in productivity.

As noted above, there is some indication that the growth rate (λ) of the midcontinent snow goose population has declined since the approximate onset of special harvest incentives. Specifically, Alisauskas et al. (2011) analyzed changes in λ among four time periods collectively spanning 1971-2006 using abundance estimates inferred from (1) midwinter survey data for the Central and Mississippi flyways (Kruse 2007) and (2) joint analysis of band-recovery data and continental harvest estimates (i.e., Lincoln's [1930] estimator; Alisauskas et al. 2009). Both analyses indicated that the population growth rate was lower following the introduction of special conservation measures (1998-2006) than during the preceding equivalent time period (1990-1998), although neither analysis provided evidence of population decline (i.e., $\lambda < 1.0$). For instance, estimates of population growth rate derived from Lincoln estimates of adult abundance declined from $\lambda = 1.14$ during the period 1990-1998 to a value of $\lambda = 1.05$ during 1998-2006, when special conservation measures were in place (Alisauskas et al. 2011). At present, we can only speculate as to the causes of this attenuation in the rate of population growth. One possibility is that annual recruitment of young has declined in recent years as a result of density-dependant processes acting on arctic breeding grounds, as has been inferred on a local scale at La Pérouse Bay (Cooch et al. 1991; Francis et al. 1992) and more recently at Karrak Lake in the central arctic (Traylor 2010). Alternatively, increased disturbance of geese by hunters on spring staging areas may have precipitated declines in breeding propensity and performance as described earlier. Although neither of these hypotheses is supported by our analysis of harvest and fall population age ratios, both would seem to warrant further study. It appears clear, however, that the apparent reduction in population growth rate was not brought about by large-scale changes in adult survival related to increases in continental harvest.

It is apparent that further increases in harvest and harvest rate will be required if growth of the midcontinent population is to be stabilized via reductions in adult survival. To provide some perspective on levels that may be necessary, we offer the following examples of minimum rates of hunting mortality (i.e., kill rates) required to reduce adult survival to a value below 0.80 (cf. Rockwell et al. 1997). The most recent available evidence indicates that midcontinent snow geese are currently harvested at an annual rate of only 2% (Alisauskas et al. 2011, 2012). Assuming a retrieval rate of 0.80 (Rockwell et al. 1997), this represents a kill rate (i.e., hunting mortality) of 2.5%. Assuming complete additivity of hunting and non-hunting mortality, a reduction in adult survival rate from 0.87 (Alisauskas et al. 2011, this study) to below 0.80 would require an annual kill rate of at least 9%, representing a harvest rate of about 7.2%. Likewise, if only 2% of adult Ross's geese are harvested annually (Alisauskas et al. 2012), then a reduction in survival rate from over 0.90 (this study), to below 0.80 would require a kill rate of at least 12%, or a harvest rate of about 9.6%, again assuming a retrieval rate of 0.80. This represents an approximate 3.6-fold and 4.8-fold increase in harvest rate relative to current estimates for snow and Ross's geese, respectively. Given uncertainties in (1) retrieval rates assumed above, and (2) the threshold where kill rate becomes additive to natural

mortality, we emphasize that these increases beyond the most recent estimates in harvest rate are likely *minimum levels* that would need to be attained in order to achieve desired reductions in survival. Since harvest rates of both species are declining (Alisauskas et al. 2011, 2012), it seems clear that the goal of population reduction through increased hunting mortality will not be attained using measures currently in place.

Several research and monitoring needs are suggested. First, we strongly recommend continued annual banding of midcontinent snow geese and Ross's geese at multiple locations throughout the eastern and central arctic. Banding efforts will be central to future long-term management of the midcontinent population, as such efforts will permit (1) continued monitoring of potential changes in adult annual survival, (2) further assessment of geographic (inter-colony) variation in survival, (3) continued monitoring of changes in harvest rate, and (4) estimation of snow and Ross's goose abundance via use of Lincoln's estimator based on band-recovery data and continental harvest estimates. In particular, we encourage continuation of the recent emphasis on obtaining representative samples of banded geese from important northern areas (especially Queen Maud Gulf, Baffin Island, and Southampton Island), where the bulk of the midcontinent snow goose population is assumed to reside during nesting and brood-rearing. At the same time, we recommend continued banding at La Pérouse Bay, as snow geese from that area appear to be representative of the southern segment of the nesting population, and because La Pérouse Bay represents the longest running source of historical banding data. Second, we recommend that harvest age ratio data continue to be collected and evaluated as a surrogate for annual productivity. Where possible, this information should be supplemented by targeted research aimed at estimating specific components of recruitment (e.g., breeding propensity, nest success, gosling and juvenile survival) at selected colonies representing both arctic and subarctic subpopulations. Accurate and robust estimates of these parameters will be critical to projecting future population growth and to evaluating management options. Third, in view of the potential for localized differences in population growth among segments of the midcontinent snow goose population, we encourage investigators to adopt a metapopulation approach to modeling and estimation. A full understanding of the metapopulation structure of the midcontinent population will require, among other things, accurate estimates of snow goose abundance in each segment, as well as knowledge of the levels of juvenile and adult dispersal between segments. In this regard, we suggest that a mark-recapture approach involving multiple breeding colonies and modern capture-recapture methods (Williams et al. 2002) would pay large dividends towards increasing our understanding of the dynamics of the midcontinent population.

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POPULATION STATUS OF MIDCONTINENT LESSER SNOW GEESE AND ROSS'S GEESE FOLLOWING SPECIAL CONSERVATION MEASURES

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Introduction

The midcontinent population of lesser snow geese is the largest population of geese in North America, and was the first to be considered as overabundant and managed for population reduction (Alisauskas et al. 2011a), under recently revised regulations in the United States and Canada. Abraham and Jefferies (1997) provided a comprehensive review of available information about abundance of midcontinent lesser snow geese and the continental population of Ross's geese up to the mid-1990s. Their review included an examination of available data from a variety of surveys that had been conducted over several decades. Abraham and Jefferies (1997) compared these measures of abundance with historical evidence based on anecdotal reports from winter areas (e.g., McIlhenny 1932, Bent 1962), and concluded that most snow goose populations had increased over much of the 20th century to unprecedented levels. Several reports have shown that Ross's goose numbers have grown at similarly high rates (Abraham and Jefferies 1997, Moser 2001, Alisauskas et al. 2006).

Despite the availability of several indices of abundance, no survey method in recent use has provided an estimate of total population size for the midcontinent population of lesser snow geese or Ross's geese. The sheer size, widespread distribution, and remote nesting locations of these populations makes abundance estimation very challenging when using conventional survey techniques (Alisauskas et al. 2009). Abraham and Jefferies (1997) suggested that the midcontinent population of lesser snow geese probably numbered about 6 million adult birds in the mid-1990s, and this seemed to be a reasonable estimate based on available data. Based partly on the assumptions about population size at the time, Rockwell et al. (1997) concluded that with an increase in harvest and harvest rate of 2-3 times contemporary estimates, a reduction in abundance of 50% would require 3-7 years.

A primary goal of recent management action directed at lesser snow and Ross's geese (collectively referred to as 'light geese') in the midcontinent and eastern North America was population reduction (Batt et al. 1997). Specifically, recommendation 3 of the Arctic Goose Habitat Working Group (Batt et al. 1997:124) stated:

“The responsible public agencies in Canada and the U.S. should implement proactive population reduction measures to reduce midcontinent white [light] goose populations to a level of about 50% of current numbers by the year 2005. This requires that the population growth rate be reduced to an annual level of between 0.85 and 0.95 (5% - 15% reduction in total numbers per year) from the current growth rate of about 1.05 (5% growth per year). Because the main force driving population growth rate is adult survival and because most of the specific population reduction recommendations relate to increasing the kill by hunters, the harvest rate should be increased to about 3 times the current level.”

Regardless of the technique used to estimate abundance in a given area, successful implementation of population reduction measures was expected to result in declines in the various indices of population size.

Abundance estimation of wildlife populations seems like an indispensable prerequisite for making informed decisions about how to manage their exploitation in a sustainable manner. Estimates of abundance at specific times t , \hat{N}_t , permit estimation of population growth rate,

$$\hat{\lambda}_t = \frac{\hat{N}_{t+1}}{\hat{N}_t},$$

usually at the interval of 1 year. Thus, in conjunction with abundance, $\hat{\lambda}$ can be a useful metric for understanding whether population growth rates are compatible with management goals.

This chapter reviews existing and potential methods for monitoring abundance of midcontinent lesser snow geese and Ross's geese at multiple temporal and spatial scales, updates information on the status of the populations, and makes comparisons among available monitoring techniques. Midwinter counts, photographic surveys on nesting colonies (e.g., Kerbes et al. 2006), and pre-season banding in the arctic have been the primary tools used to monitor the status of the midcontinent population of lesser snow geese and Ross's geese over the last several decades. In addition to these efforts, other types of surveys, some of them proposed or experimental, have periodically been done to estimate numbers of snow geese or Ross's geese. Methods that have been used include: (1) systematic ground surveys on nesting colonies (e.g., Alisauskas 2001, Samelius et al. 2008), (2) aerial transect surveys on nesting colonies (e.g., Hines et al. 2003, Ross et al. 2003), (3) aerial transect surveys of post-breeding flocks (e.g., D. Caswell, unpublished data), (4) photographic surveys of post-breeding flocks (e.g., Reed and Chagnon 1987, Samelius et al. 2008), and (5) Lincoln-Peterson estimates of population size based on band recovery data and harvest estimates (Boyd 1976; Boyd et al. 1982; Alisauskas et al. 2009).

Each of these methods has limitations and biases, but with the exception of the midwinter survey, all of these techniques employ some form of statistical sampling framework, and are designed to estimate the number of geese within a defined area. We refer to midwinter surveys as counts because they are not based on a statistical sampling framework, and the relationship between the counts and actual population size is unknown. Thus, we differentiate between counts, C , and estimates of population size, \hat{N} ; the two are related as $\hat{N} = C/\hat{p}$, where \hat{p} is an estimate of detection probability (see Nichols 1992). Detection probability is not always considered in survey design, but with a statistical sampling framework at least, it is theoretically possible to estimate \hat{N} . We discuss the relative strengths and weaknesses of various techniques in terms of their ability to provide useful information about the status of midcontinent snow geese and Ross's geese.

Delineation of the Midcontinent Population of Lesser Snow Geese and Ross's Geese

We defined the midcontinent population of lesser snow geese, based on common distribution of recoveries of birds banded on breeding areas, as those nesting east of 110°W longitude in Canada (Figures 1 and 2). The term midcontinent lesser snow geese refers to geese traditionally defined by North American waterfowl managers according to their distribution during winter in the Central and Mississippi Flyways. Although the midcontinent winter area is composed largely of snow geese from

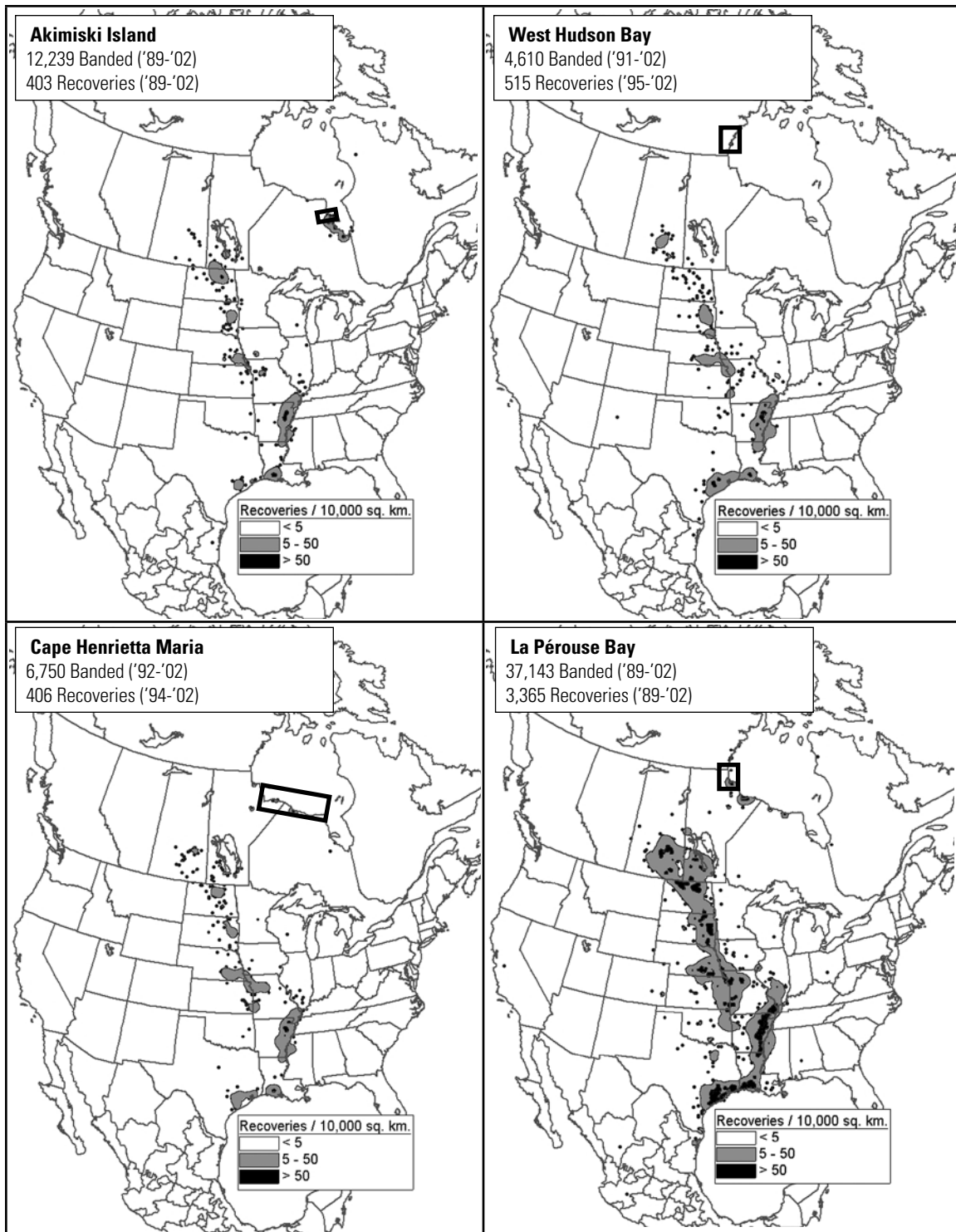


Figure 1. Band recovery distribution of lesser snow geese banded at several colonies in the western and southern Hudson Bay region.

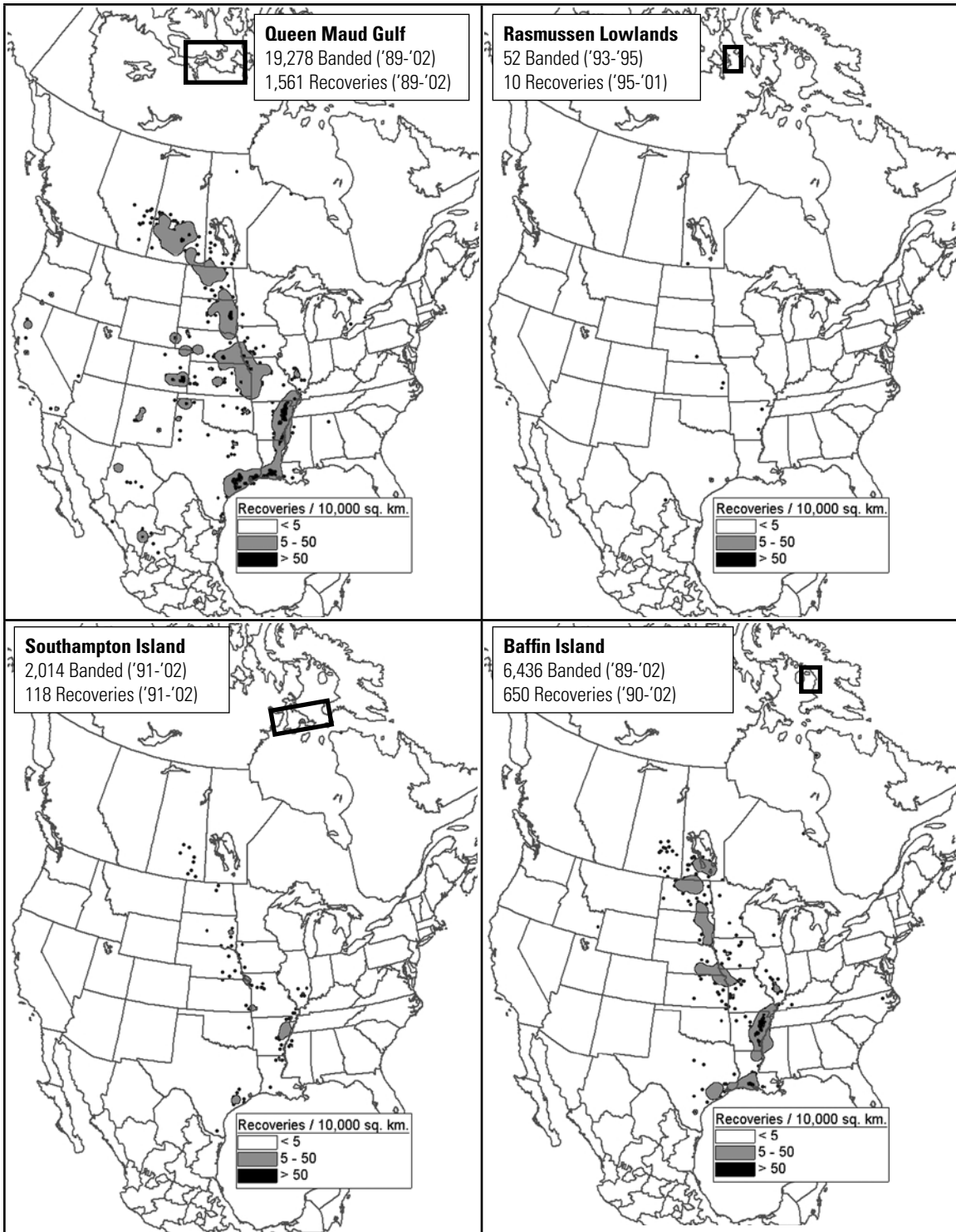


Figure 2. Band recovery distribution of lesser snow geese banded north of Hudson Bay and south of Queen Maud Gulf from 1989 to 2002.

Canada's central and eastern arctic and subarctic regions (Alisauskas et al. 2011), it also includes those from Canada's western arctic, which seem to be shifting eastward in winter range. For example, of 166 snow geese banded from 1987 to 1989 in the western arctic and recovered in the United States during winter, 4 (2.4%) were from the midcontinent, and 14 (8.4%) were from the West Central Flyway (Hines et al. 1999). We believe that the midcontinent definition may be convenient, but that affiliations based on breeding areas are more biologically meaningful than those on wintering grounds. Accordingly, readers should note that our treatment includes geese of both of these previously defined management populations.

Midcontinent Ross's geese co-occur with midcontinent lesser snow geese throughout the annual cycle, though a sizeable proportion of Ross's geese from the central arctic of Canada (i.e., the Queen Maud Gulf [QMG] region) also winter with snow geese from the western arctic and Wrangel Island, i.e., they winter west of the midcontinent in the Pacific Flyway (Figure 3). We tested for differences in distributions by flyway [Atlantic, including Canadian recoveries from Quebec eastward (n = 9), Mississippi including Ontario and Manitoba (n = 1,896), Central including Alberta and Saskatchewan (n = 5,123), Pacific including B.C. (n = 1,909), and Mexico (n = 65)], of Ross's goose recoveries including those with neckbands in relation to where they were initially marked from 1989 to 2010 in 6 regions [Baffin Island (n = 166), Cape Henrietta Maria (n = 8), La Perouse Bay (n = 94), Queen Maud Gulf (n = 5,391), Southampton Island (n = 182), and West Hudson Bay (n = 3,161)] of Canada's central and eastern arctic and subarctic. Overall, recovery distributions of adult Ross's geese from QMG differed from those banded at all other locations (NONQMG) in Canada (likelihood ratio $\chi^2 = 1923.6$, $df = 4$, $P < 0.0001$), mainly due to a higher proportion of recoveries of QMG geese from the Pacific Flyway, and a lower proportion of recoveries from northern Canada (Figure 3). However, flyway distributions of recoveries from all NONQMG Ross's geese were not different among those 5 regions (likelihood ratio $\chi^2 = 26.0$, $df = 16$, $P > 0.05$). Nonetheless, most recoveries of Ross's geese from all 6 sites combined (> 75%) occurred in the midcontinent region.

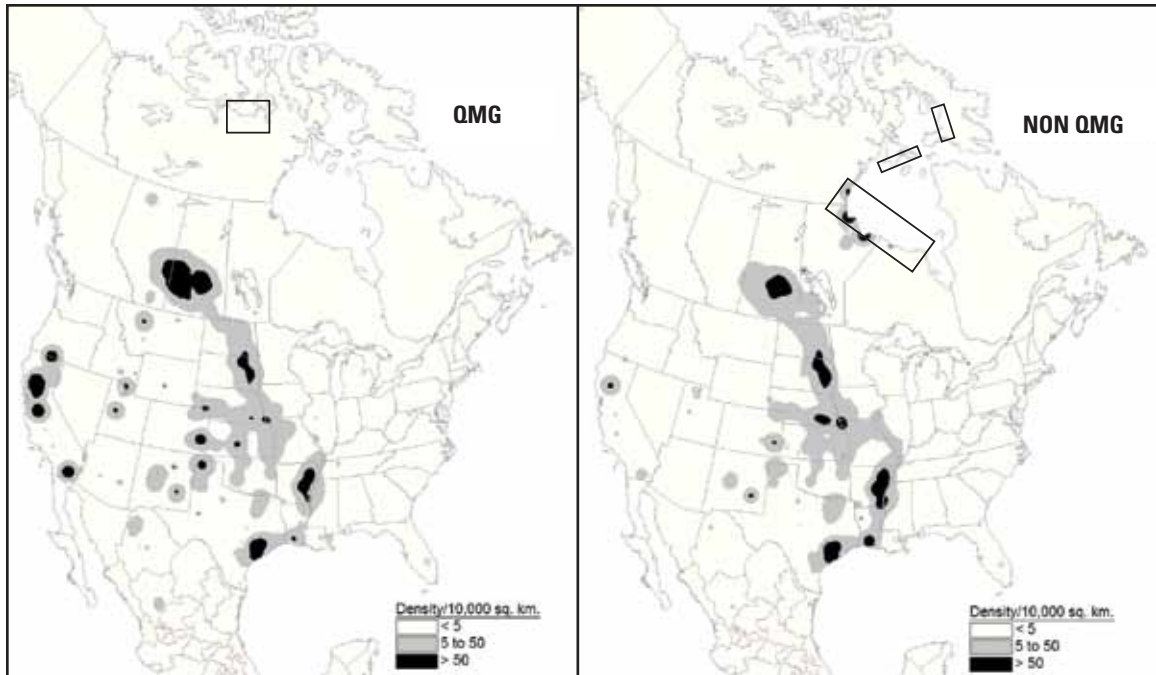


Figure 3. Band recovery distribution of Ross's geese banded in the Canadian arctic from 1989 to 2010. Map on the left shows recoveries of Ross's geese from their traditional nesting range in the Queen Maud Gulf (QMG) region of the central arctic, while the map on the right shows recoveries of Ross's geese banded in more recently occupied areas of the eastern arctic in Canada.

Important colonies of light geese include Colonies 3, 9, 10, and 46 in the Queen Maud Gulf region of the central arctic (Figure 4); and those at Cape Henrietta Maria, Ontario; La Pérouse Bay, Manitoba; the west coast of Hudson Bay, Southampton Island, and Baffin Island in Nunavut (Figure 5). In Canada, midcontinent light geese are harvested mainly in Nunavut, northern Ontario, Manitoba, and Saskatchewan. In the United States, most harvest occurs in ND, SD, NE, KS, CO, IA, MS, MO, AR, LA, and TX (Figures 1-3).

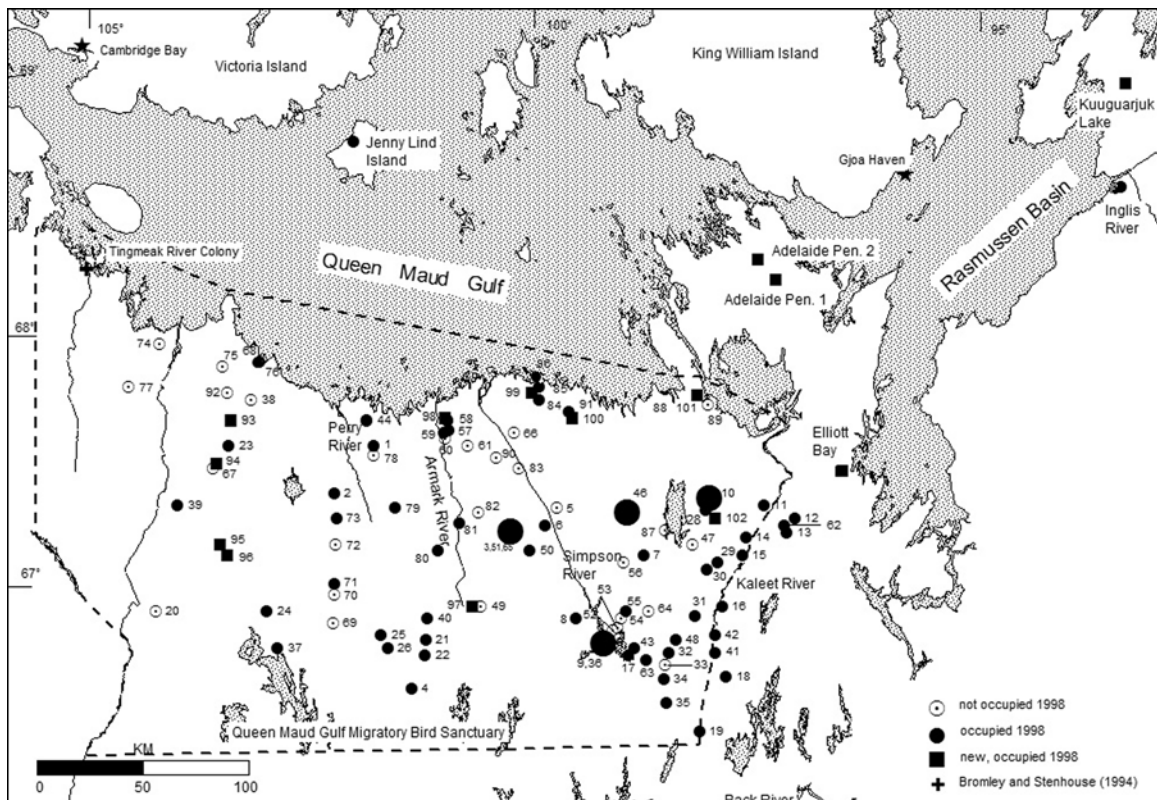


Figure 4. Locations of known nesting colonies of lesser snow geese in the Queen Maud Gulf region of Canada's central arctic. Colonies 3, 9, 10, and 46 accounted for most nesting snow geese tallied in the 1998 photo inventory (from Kerbes et al. 2006).

Midwinter Surveys

Midwinter waterfowl counts, W , have been conducted in the United States since the 1950s with the intention of providing a long-term database for detecting change in populations of different species or groups of species (Roth Eggeman and Johnson 1989). These counts of light geese (Ross's and snow geese combined) do not include information about age structure. Light geese are counted in the midcontinent (north of the Gulf of Mexico in the eastern part of the Central Flyway and Mississippi Flyway) and in the western part of the Central Flyway. Boyd et al. (1981) used winter counts in a review of midcontinent snow goose populations from 1964-1979. Abraham and Jefferies (1997) noted that midwinter indices of light geese in the midcontinent region had increased from about 800,000 birds in 1969 to about 2.7 million by 1994, an approximate 3.4-fold increase in 24 years.

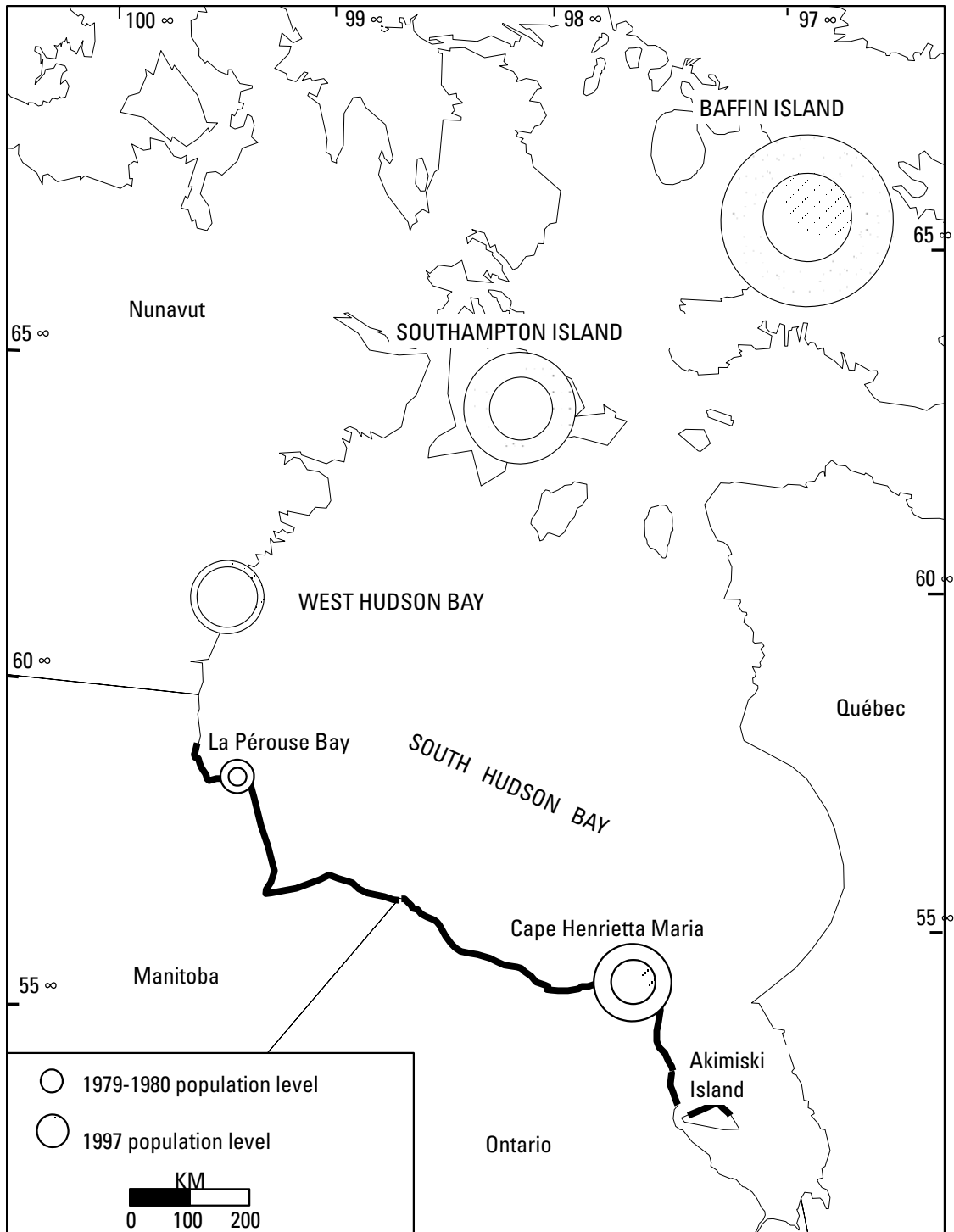


Figure 5. Location of important nesting colonies of lesser snow geese in the eastern Canadian arctic (from Kerbes et al. 2006).

Rockwell et al. (1997) estimated that midwinter counts had increased by about 5% each year over the period 1969-1994. Since then, midwinter counts of midcontinent light geese peaked in 1998 at

nearly 3 million birds, but then showed a general decline during the conservation order from 1998 to 2006. However, with the conservation order still in place, midcontinent counts generally increased again from 2006 to 2010 (Figure 6A).

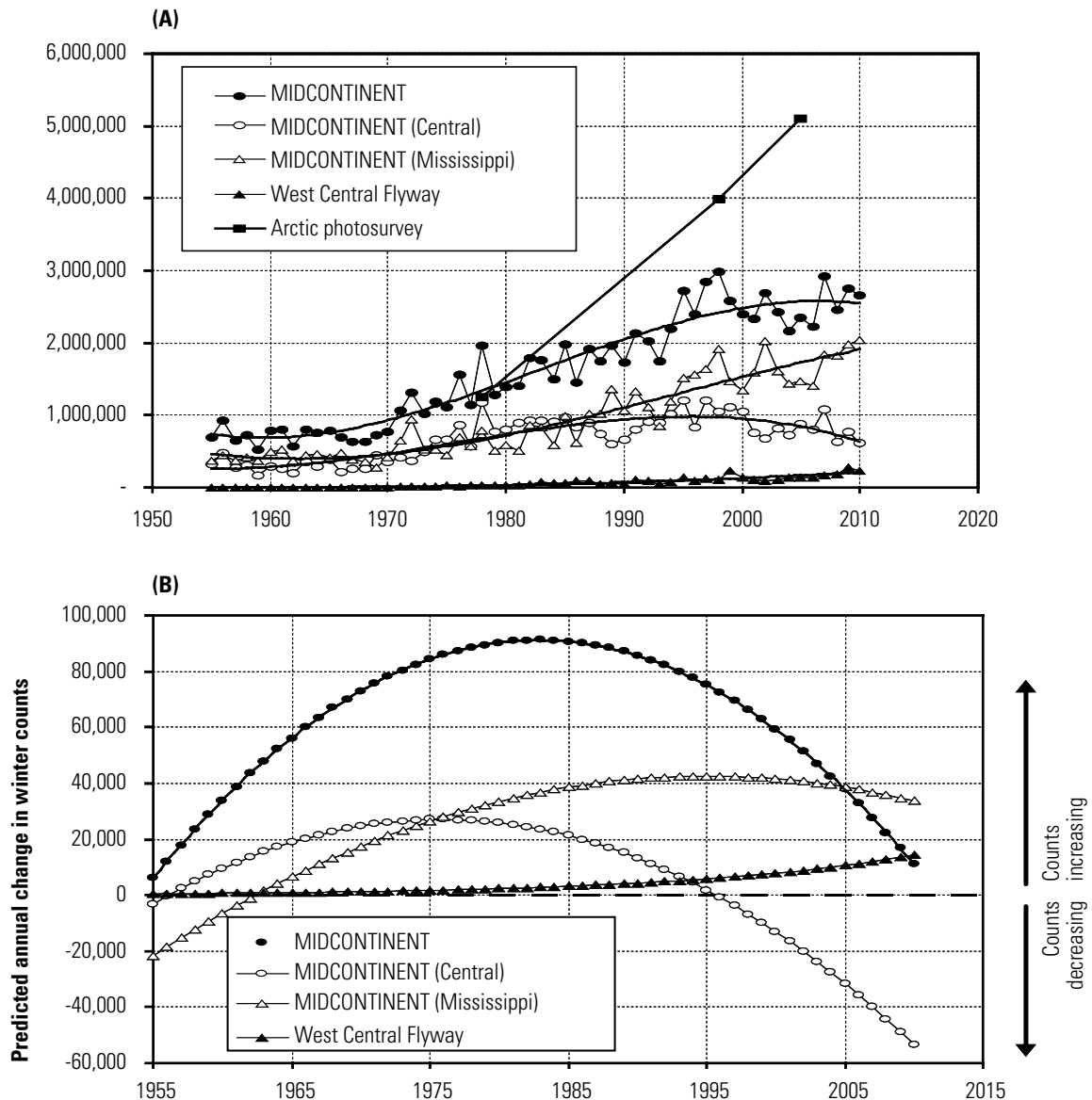


Figure 6. (A) Light geese (lesser snow and Ross's geese) counted during midwinter (December or January) in the Central Flyway, Mississippi Flyway and West Central Flyway. Midcontinent counts exclude West Central Flyway counts. Also shown are estimates (filled squares) of nesting geese at known colonies from aerial photographs: 1978 covers 1976-1980, 1998 covers 1997-1998, and 2005 covers 2003 to 2006 (Kerbes et al. 2006 and Kerbes et al. in prep). (B) Annual change in numbers of light geese counted as predicted from best models (Table 1) fit to data in Figure 6A.

Alisauskas et al. (2011a) fit various models to the time series of midcontinent W to determine which trajectory over the long term (1955-2008) was best supported. They concluded that a polynomial cubic model fit the data best, and suggested that counts had not declined overall during

the conservation order but instead had leveled off. Here, we repeated model fitting on the updated (1955-2010) midwinter counts using data supplied by Kruse et al. (2009). We considered linear models, exponential models, logistic models to accommodate sigmoidal growth with an asymptote, and cubic polynomial models to accommodate sigmoidal growth followed by decline. Rank order of models was the same as reported by Alisauskas et al. (2011a) for 1955-2008 data, although weight of the top model (cubic) increased from 0.73 to 0.89, and that of the logistic model increased somewhat from $w = 0.06$ to 0.10 (Table 1). Nevertheless, the cubic model was unequivocally the best fit to count data in both time series, and supported the inference that \hat{W} increased from 1955 to 2010. The first derivative of the best model

$$\hat{W} = 768696 - 30821t + 3153.899t^2 - 36.373t^3 \quad \text{Eq. 1}$$

(Figure 6A), is

$$\frac{\partial \hat{W}}{\partial t} = -30821 + 6307.798t - 109.119t^2 \quad \text{Eq. 2}$$

and this gives the annual change in count at time t (where $t = \text{year} - 1954$, Figure 6B). The maximum annual increase in \hat{W} was about 91,000/year in 1983 and has declined since, but at no time was there a decline in the predicted value of \hat{W} over the time series considered. In fact, \hat{W} predicted from the best model increased by about 20,000 from 2008 to 2009. Thus, although winter counts appear to be leveling off (Figure 6A), there has not been a detectable decline over the time series (Figure 6B) using the models considered.

Table 1. Model selection between patterns of annual change in numbers of light geese counted during midwinter (Figure 6A) from 1955 (winter of 1954-1955) to 2010 (winter of 2009-2010).

Region	Model	n	ΔAIC	K	Weight
Midcontinent	<i>Cubic</i>	56	0.00	5	0.89
	<i>Logistic</i>	56	4.39	4	0.10
	<i>Linear</i>	56	9.16	3	0.01
	<i>Exponential</i>	56	22.25	3	0.00
Midcontinent (Central Flyway only)	<i>Cubic</i>	56	0.00	5	0.98
	<i>Logistic</i>	56	7.88	4	0.02
	<i>Linear</i>	56	27.44	3	0.00
	<i>Exponential</i>	56	35.88	3	0.00
Midcontinent (Mississippi Flyway only)	<i>Cubic</i>	56	0.00	5	0.56
	<i>Exponential</i>	56	1.67	3	0.24
	<i>Logistic</i>	56	2.12	4	0.19
	<i>Linear</i>	56	17.27	3	0.00
West Central Flyway	<i>Exponential</i>	56	0.00	3	0.73
	<i>Cubic</i>	56	1.95	5	0.27
	<i>Linear</i>	56	19.48	3	0.00
	<i>Logistic</i>				Model would not converge

Underlying the general continuation of increase in midcontinent counts of light geese, there appear to have been different trajectories in different parts of the midcontinent. For example, counts in the Central Flyway portion of the midcontinent, $W_i^{Central}$, have been in decline since about 1995, after reaching a predicted maximum of about 1 million. On the other hand, counts in the Mississippi Flyway portion, $W_i^{Mississippi}$, have continued to increase according to a cubic fit (Figure 6A), suggesting some attenuation in growth after about 1995. Part of this could be the result of redistribution in wintering light geese northeastward from Texas into Louisiana and Arkansas. In any event, if declines in the Central Flyway portion of the midcontinent were linked to increased harvest associated with the conservation order, there appeared to be no such effect in the Mississippi Flyway.

We also examined midwinter counts of light geese in the western portion of the Central Flyway (largely New Mexico), outside of the midcontinent range. This group of light geese includes snow geese from Banks Island in Canada's western arctic, as well as Ross's geese and lesser snow geese from Canada's central arctic. Midwinter counts of these geese continue to increase exponentially (Figure 6A) by over 10,000 annually since 2005 (Figure 6B).

Arctic Photo Survey of Nesting Colonies

Photographic surveys have been used to estimate the number of lesser snow geese nesting at specific colonies or regions in Canada's arctic since the 1970s (Kerbes 1975). Photographic surveys of nesting lesser snow geese and Ross's geese were conducted at known colonies in the eastern and central arctic in 1997 and 1998, just before concerted efforts were made to reduce the population of snow geese in the midcontinent region (Table 2). Those surveys resulted in estimates of ~ 3.8 million nesting snow geese and ~ 542,000 nesting Ross's geese (Kerbes et al. 2006). Compared to similar surveys in the eastern arctic in 1979-80 and the central arctic in 1982, this represented an approximate 6.4-fold increase in about 20 years.

Table 2. Estimates of snow geese nesting at the time of arctic photosurveys in Canada's central and eastern arctic and subarctic (Kerbes et al. 2006, 2010) before (1997, 1998) or after (2003, 2004, 2005, 2006) start of the conservation order in March 1999.

Year	Ross's geese from Central arctic				Snow geese					
	Central Arctic		Eastern Arctic		Subarctic		South Hudson Bay			
	Queen Maud Gulf Bird Sanctuary	Other areas	Queen Maud Gulf Bird Sanctuary	Other areas	Baffin Island and Foxe Basin	Southampton Island	West Hudson Bay	South Hudson Bay		
1997	- ^a	-	-	-	1,733,500	721,200	211,600	408,700		
1998	495,086	24,196	651,700	88,841	-	-	-	-		
2003	-	-	-	-	-	-	261,080	-		
2004	-	-	-	-	-	652,546	-	-		
2005	-	-	-	-	1,318,560	-	-	307,100		
2006	1,280,883	45,462	971,007	492,781	-	-	-	-		
Variable										
N_0	495086	24196	651,700	88,841	1,733,500	721,200	211,600	408,700		
N_t	1280883	45462	971,007	492,781	1,318,560	652,546	261,080	307,100		
t	8	8	8	8	8	7	6	8		
r^b	0.119	0.079	0.050	0.214	-0.034	-0.014	0.035	-0.036		
$e^r = \lambda$	1.126	1.082	1.051	1.239	0.966	0.986	1.036	0.965		

a No survey.

b Estimated from $N_t = N_0 \bullet e^{rt}$ or $r = 1/n(N_t/N_0) \bullet t^r$.

Additional photographic surveys were conducted along the west coast of Hudson Bay in 2003, at Southampton Island in 2004, at Baffin Island in 2005, and at Queen Maud Gulf Migratory Bird Sanctuary (QMGBS) in 2006 (Table 1). Preliminary results (Kerbes et al., in prep.) indicated that the number of nesting snow geese photographed increased by about 22% (from 212,000 to about 261,000 birds) at west Hudson Bay since 1997. On Southampton Island, the estimated number of nesting snow geese was ~ 10% lower in 2004 (652,000) compared to 1997 (721,000). On Baffin Island and Foxe Basin, estimates were 1,734,000 in 1997 and 1,319,000 in 2005, a decline of about 24%. In the central arctic, there were 1,464,000 nesting snow geese estimated from aerial photographs in 2006, almost double the number estimated in 1998. At the same time, estimates of nesting Ross's geese in the central arctic region rose from 519,000 in 1998 to about 1,326,000 in 2006, an increase of more than 150% in less than a decade. In addition, at least 60,000 Ross's geese were photographed at McConnell River, on the west coast of Hudson Bay, with unknown numbers on Baffin and Southampton Islands. Overall, the minimum number of nesting midcontinent population snow geese estimated from photo surveys increased about 13% between the two most recent surveys in all known colonies combined, while nesting Ross's geese increased by more than 150% in areas where they were tallied separately (Kerbes et al. in prep.).

The time interval between surveys at specific sites was variable, making comparisons of changes over time among areas difficult, because inferences about change are highly sensitive to only 2 estimates separated by several years. Nevertheless, annual rates of change can be estimated if we account for variation in the number of years, t , between surveys at each colony (Table 2). Estimates of nesting Ross's geese increased from 1998 to 2006, corresponding to an average rate of increase of 12.6% per year in the QMGBS, and 8.2% per year in other areas of the central arctic. Comparably, snow geese increased over the same interval at an average annual rate of 5.1% and 23.1% respectively. Several of the nesting areas in Canada's central arctic, but outside of QMGBS, were first discovered during systematic aerial surveys designed for other species, concurrent with the conservation order (e.g. Erebus Bay, Alisauskas 2006). Outside of the central arctic, abundance increased after start of the conservation order only on the west coast of Hudson Bay, corresponding to a 3.6% increase per year.

Overall, the latest available estimates of nesting snow geese and Ross's geese from photo surveys suggest that both species have continued to increase during the period of conservation harvests. These surveys also suggest that there has been a continuing shift in the distribution of both snow geese and Ross's geese; the number and proportion of the midcontinent population of lesser snow geese that nests in the central arctic continued to increase, while the number and proportion nesting in the eastern arctic appeared to have declined. The central arctic continues to be the main center of abundance for nesting Ross's geese, and estimates there have increased at a high rate over the past decade. Ross's geese appear to be increasing in the eastern arctic also.

Aerial Transect Surveys During Nesting

Ross et al. (2004) described a method using a helicopter for counting goose nests along 100 m wide strip transects, at 30 meters altitude, in areas where snow geese were known to nest in 4 colonies along the southern coast of Hudson Bay. They found that the density of geese estimated to be associated with counted nests was essentially equal to densities calculated from geese counted from photos of the same areas by Kerbes et al. (2006). Estimated densities of nesting birds/km² were 898 at Cape Henrietta Maria (CHM), 482 at La Pérouse Bay, 821 at Pen Island and 152 at Shell Brook (Ross et al. 2004).

Helicopter transect surveys were conducted at the Cape Henrietta Maria snow goose colony in 9 years between 1996 and 2009 (Figure 7). In the two survey years (1996 and 1997) before conservation measures were enacted, the estimated number of nesting geese at CHM averaged ~340,000. The average of 5 surveys conducted since that time was only ~230,000 geese (we excluded 2009 results, because this was an exceptionally late spring, and few geese nested that year), and no estimates exceeded those from the 1996 and 1997 surveys. However, log-linear regression of nesting pair estimates for 1996 to 2007 provided an estimate of $\hat{\lambda} = 0.957$ (95%CI: 0.89,1.03). Although consistent with reduced survival of adults from the southern colonies since the late 1990s (Alisauskas et al. 2011a, Dufour et al. 2012), annual estimates of nesting geese from these surveys suggest that numbers of snow geese nesting at CHM have declined, yet we could not detect a declining trend statistically. This may have been related to the low power associated with few years ($n = 7$), and in particular to only 2 years before the start of efforts at population reduction in February, 1999.

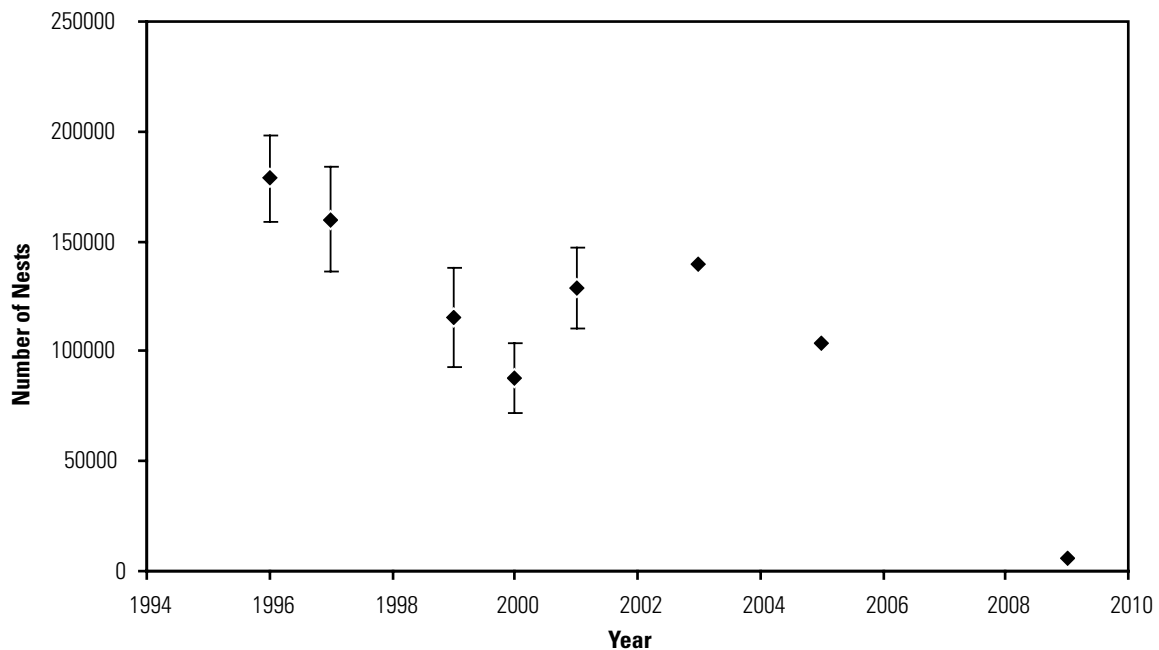


Figure 7. Number of lesser snow goose nests (\pm SE) at Cape Henrietta Maria colony, 1996-2009, estimated from helicopter transects.

Helicopter or fixed-winged aircraft strip transects also have the potential to provide information about widely dispersed nesters, and associated nonbreeders. In fact, this approach has been widely used for estimating distribution and abundance of cackling geese, white-fronted geese, and other non-colonial species of waterfowl in the arctic (e.g. Hines et al. 2006). Wiebe Robertson and Hines (2006) estimated numbers of both nesting and nonbreeding snow geese from an altitude of about 230 m. Over 6 years, densities of nesting snow geese/km² averaged 12 at Anderson River and 9 at Kendall Island; densities of nonbreeders were 15 and 12, respectively, showing that most (55%) snow geese were failed nesters or those that did not attempt to nest. It is noteworthy that densities at these two colonies were <10% of those reported by Ross et al. (2004). While this method shows promise for abundance estimation at nesting colonies of low density, it is likely of little utility in colonies of high density, such as those in QMGBS, where annual densities ranged between ~4,000 to ~8,000 geese/km² during 1993 to 2009, based on ground surveys (see below). For this reason, aerial transect surveys of nesting geese are not considered further.

Helicopter Transects During Brood-Rearing

Helicopter transect surveys were conducted on western Baffin Island in early August of each year, from 1996 to 2009. Transects were flown perpendicular to the coast of western Baffin Island at intervals equal to 2° of latitude between the Koukdjuak River and Cape Dominion, and at intervals of approximately 5° north and south of that (Figure 8). Coordinates for the start and end of each transect were entered into a Global Positioning System (GPS) that was used to navigate each line. Surveys were flown at 35m AGL at speeds that varied from 80-160 km/h, depending on goose density. Two rear seat observers recorded species, breeding status (breeding birds had young, non-breeding birds were flocks of adults only), and number of adult birds within 200m on each side of the aircraft. A navigator in the left front seat also recorded geese beneath the helicopter that were not visible to rear observers.

Transects were originally divided into 2 strata (Figure 8); Ross's geese were observed mostly in the stratum nearest the coast, while snow geese occurred over a much broader area. Ross's geese were difficult to differentiate from white phase lesser snow geese when they occurred in mixed flocks, so only pure flocks of Ross's geese were tallied separately in our observations, and likely represent only a minimum estimate for that species. The survey was originally designed to estimate numbers of cackling geese, and survey intensity was greatest in coastal areas. We estimated numbers of Ross's geese only in stratum A because few were tallied outside of that stratum, while snow goose numbers were estimated over the entire survey area (strata A and B).

Data from individual transects were first divided among strata, and average densities of adults (birds/km²) were calculated by species using program AERIAL, and methods outlined in Krebs (1989:149-151) for unequal sized transects. Transect densities were averaged over the entire stratum, and then multiplied by the area of the stratum to obtain estimates of total number of adults by stratum. Stratum estimates were then summed to obtain estimates of the total number of geese in the survey area.

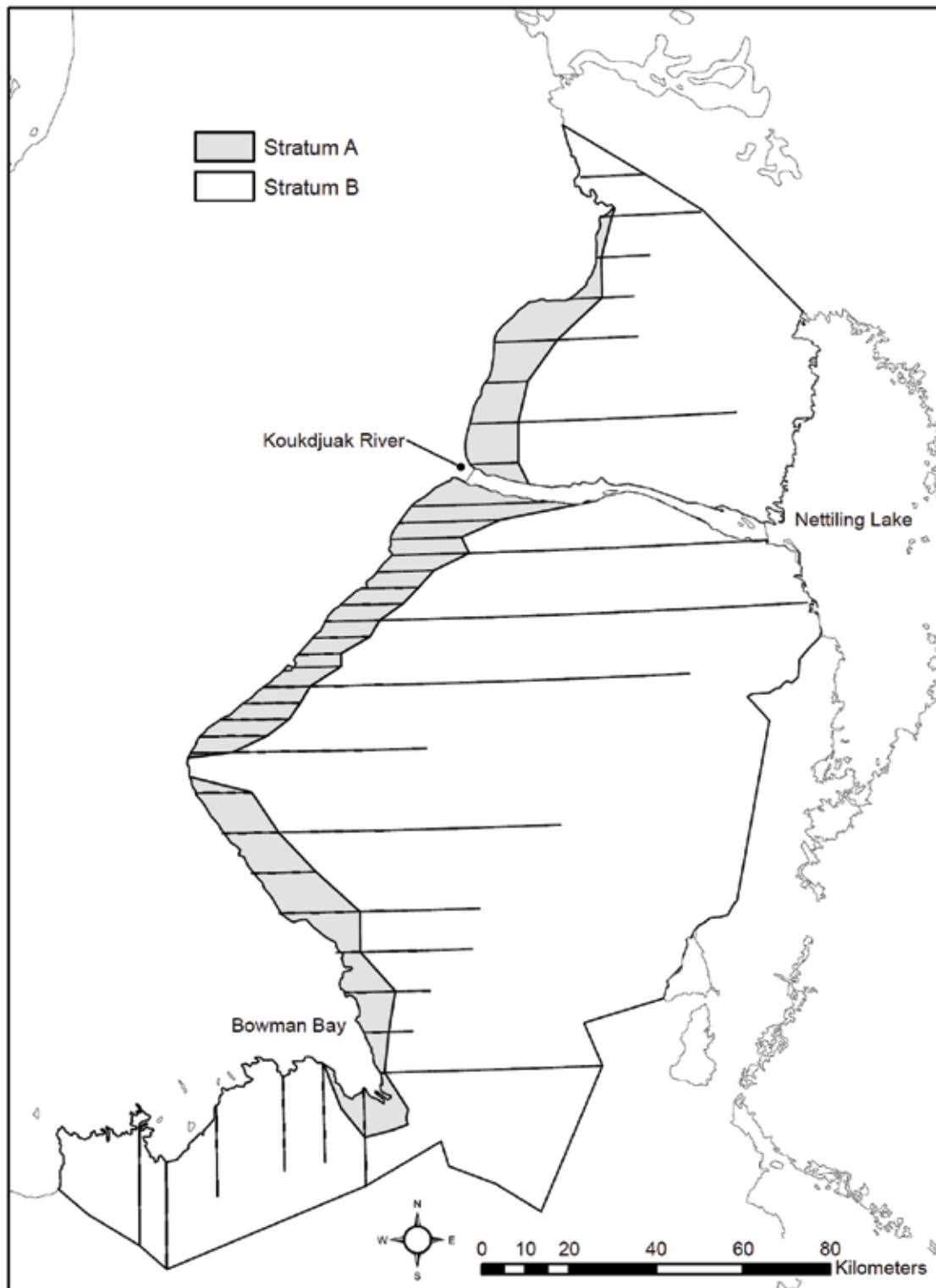


Figure 8. Survey area on the Great Plain of the Koukdjuak, Baffin Island.

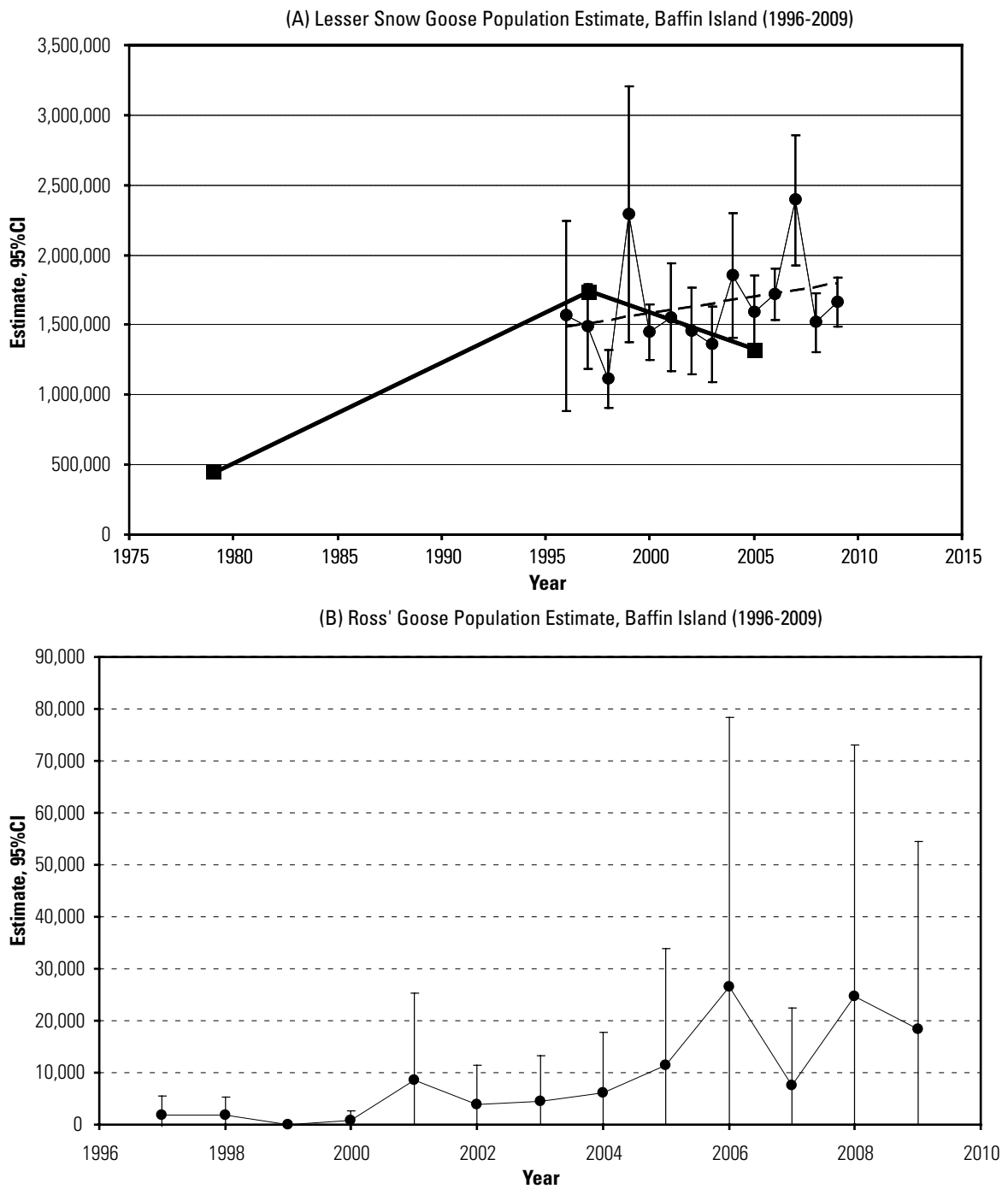


Figure 9. Numbers of (A) lesser snow geese and (B) Ross's geese estimated from post-breeding helicopter transect surveys on the Great Plain of the Koukdjuak, Baffin Island, 1996-2009. Also shown in (A) are estimates of nesting snow geese on Baffin Island from aerial photographs (Kerbes et al. 2006, in prep).

The number of lesser snow geese on the Great Plain of the Koukdjuak, Baffin Island, averaged 1,613,332 birds from 1996 - 1999, and 1,654,508 birds from 2000 - 2009. Log-linear regression over $n = 14$ years yielded an estimate of $\hat{\lambda} = 1.015$, (95%CI: 0.99,1.02). Overall, these data suggest no significant change in numbers of post-breeding lesser snow geese over the 14 year span of surveys (Figure 9A). For Ross's geese, annual estimates varied considerably, but variance was such that the 95% CI included zero in every year. Annual point estimates appeared to increase dramatically between 1997 and 2009 (Figure 9B), but these surveys, originally designed for other purposes, failed to capture any statistical change in Ross's goose numbers on Baffin Island.

Photo Survey of Brood-rearing Areas

Photographic surveys of post-breeding flocks have been used to estimate numbers of greater snow geese on Bylot Island (Reed and Chagnon 1987) and lesser snow geese on Banks Island (Samelius et al. 2008), but not with midcontinent lesser snow geese. Random samples of 2 km x 2 km area were drawn from a sampling frame geographically defined as the brood-rearing area known to contain all geese and accompanying goslings dispersing after hatch from a specific nesting colony. Samelius et al. (2008) stratified their sampling according to (i) river valleys, which tended to contain higher densities of geese, and (ii) uplands that had lower densities. Each 2 km x 2 km plot was visited by a helicopter from which all flocks in each sample were photographed. This procedure provided density and abundance estimates of adults and young during the brood-rearing period for specific nesting regions. Thus, in addition to adult population size, a measure of pre-fledging recruitment (ratio of goslings/adult) was available. As well, there is potential to separate flocks of productive adults from nonbreeders and failed breeders, thereby providing insight into nesting effort. This method has not been used for midcontinent snow goose or Ross's geese to date, but has the potential to provide at least the same information as photo estimates of nesting geese at colonies (Kerbes 1975), plus information about local productivity and abundance of nonbreeders in each year (Samelius et al. 2008). However, for estimates at the superpopulation level, this would need to be done at all known colonies. The cost and logistics of such an effort has precluded its use in a repeatable fashion in all areas that snow geese are known to nest.

Ground Estimates of Nesting Geese

Surveys of ground plots have been used to estimate numbers of nesting geese at Karrak Lake in the QMGBS annually from 1993 to 2009 (Kellett and Alisauskas 2010), nesting snow geese on Banks Island, NWT from 1995 to 1998 (Samelius et al. 2008), and nesting Ross's geese near McConnell River, Nunavut, from 2003 to 2006 (Caswell 2009). Sample plots (e.g., 30 meter radius at Karrak Lake in QMGBS) within a defined area (ideally, the perimeter of a contiguous nesting distribution of geese) are visited on foot by researchers, and all nests found on plots are counted. Thus there are no assumptions about breeding status of geese, because only nests are counted, and species composition (Ross's and lesser snow geese) can be estimated from egg measurements (Alisauskas et al. 1998). Further, detailed information about the local recruitment process until hatch can be collected, including nest initiation date, clutch size, nest survival, and egg survival in successful nests for each

of Ross's and lesser snow geese. Coupled with information about local environmental conditions, not only are patterns of change in number of breeding geese and components of gosling production quantified, but ecological processes driving such changes can also be inferred.

Locations of systematically-spaced nest plots are determined using Universal Transverse Mercator (UTM) grid system at 1 km easting and northing intervals within the sampling frame, as determined each year by the colony perimeter. At Karrak Lake, the perimeter of the colony is mapped annually using a helicopter (Figure 10A) and the objective is to visit sample plots positioned systematically every km in a grid within the nesting colony, where all nests within a plot are counted (Figure 10B); there is good correspondence between nesting activity mapped from the helicopter and nest density subsequently determined by visiting each nest plot (Figure 10C).

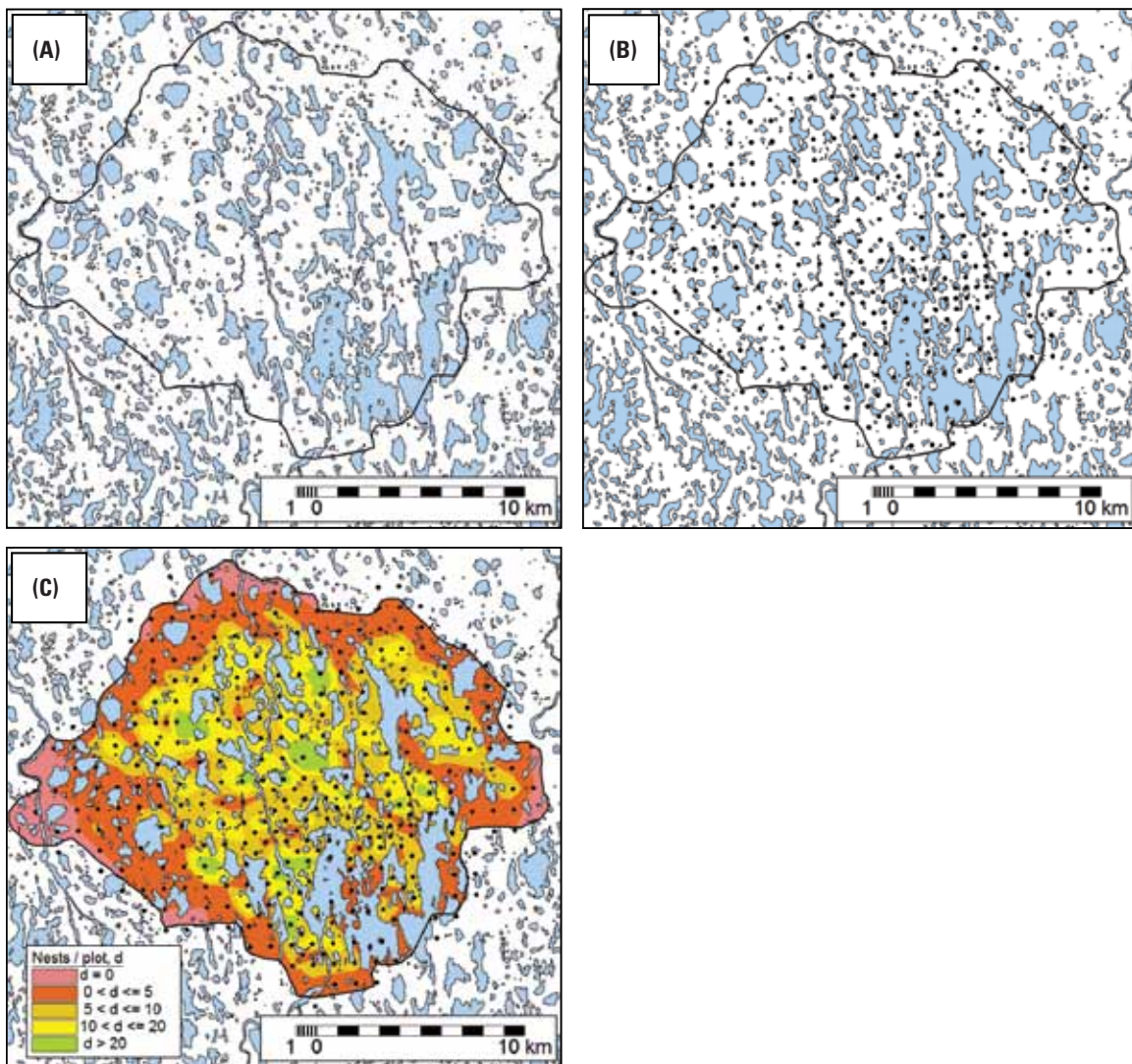


Figure 10. (A) Colony perimeter, (B) distribution of 30 meter radius nest plots, and (C) colony area post-stratified by number of nests/plot for estimation of abundance of nesting Ross's and lesser snow geese in June 2009 at Karrak Lake, Nunavut.

Two types of sample plots used are (i) initiation plots and (ii) incubation plots. Incubation plots are visited twice each summer: during incubation to estimate nest density, species composition (Alisauskas et al. 1998), clutch size, and nest initiation date by candling eggs (Weller 1956), and after hatch to determine nest fate by presence of egg caps from successfully hatched eggs (Klett et al. 1988). Occasionally, visits to all incubation plots are not achieved in some years due to inclement weather or manpower shortages and, as a result, a higher proportion of plots in high-density areas near the center of the colony and a lower proportion of plots in lower density areas on the colony periphery, may be visited (Figure 10B). If so, high density areas can become overrepresented in the sample resulting in mean nest densities that are biased high. Post-stratification (Anganuzzi and Buckland 1993, Thompson 1992) by nesting density using a Geographic Information System (GIS; Figure 10C) is necessary to reduce bias in the overall estimate.

Additionally, a small number ($n=36$) of initiation plots located in the center of 1 km intersections are visited every 4 days during nest initiation and every ~5 days during incubation to estimate the parameters mentioned above, but also laying rate, and partial clutch loss. These plots are also visited again after hatch to determine nest fate. Post-stratification is also necessary to appropriately weight areas that contain both initiation and incubation plots. Since sample plots and nests are found only on land, the area of the sampling frame should include only land, even though there is a large percentage of the earth's surface within the colony perimeter covered by water; this is accomplished using a GIS to calculate the area of terrestrial habitat within the perimeter of the colony (Figure 10C). Thereby, post-stratified estimation of density from both initiation and incubation plots is achieved, and abundance is calculated by taking the sum of products of stratum densities and respective areas of terrestrial habitat within the sampling frame.

Annual estimates of the abundance of Ross's and snow geese that attempted to nest at Karrak Lake, and Ross's geese from McConnell River (Caswell 2009) are shown in Figure 11. Unstratified estimates of nesting population size of both Ross's and snow geese at Karrak Lake were higher than post-stratified estimates there; however, in more recent years, unstratified and post-stratified estimates converged as sampling coverage by researchers approached spatial evenness. Ability to visit all sample plots, systematically spaced 1 km apart, within a large land area of over 250 km² since 2009 at Karrak Lake depends on number of personnel available. Regardless, post-stratified estimates provide a less biased estimate over the time series, and stratified samples were used to estimate density of nests for each species. Such stratification was not required at McConnell River because the much smaller size of the nesting colony there (14-18.8 km², Caswell 2009) allowed researchers to visit all sample plots systematically-spaced at 1 km intervals in all years.

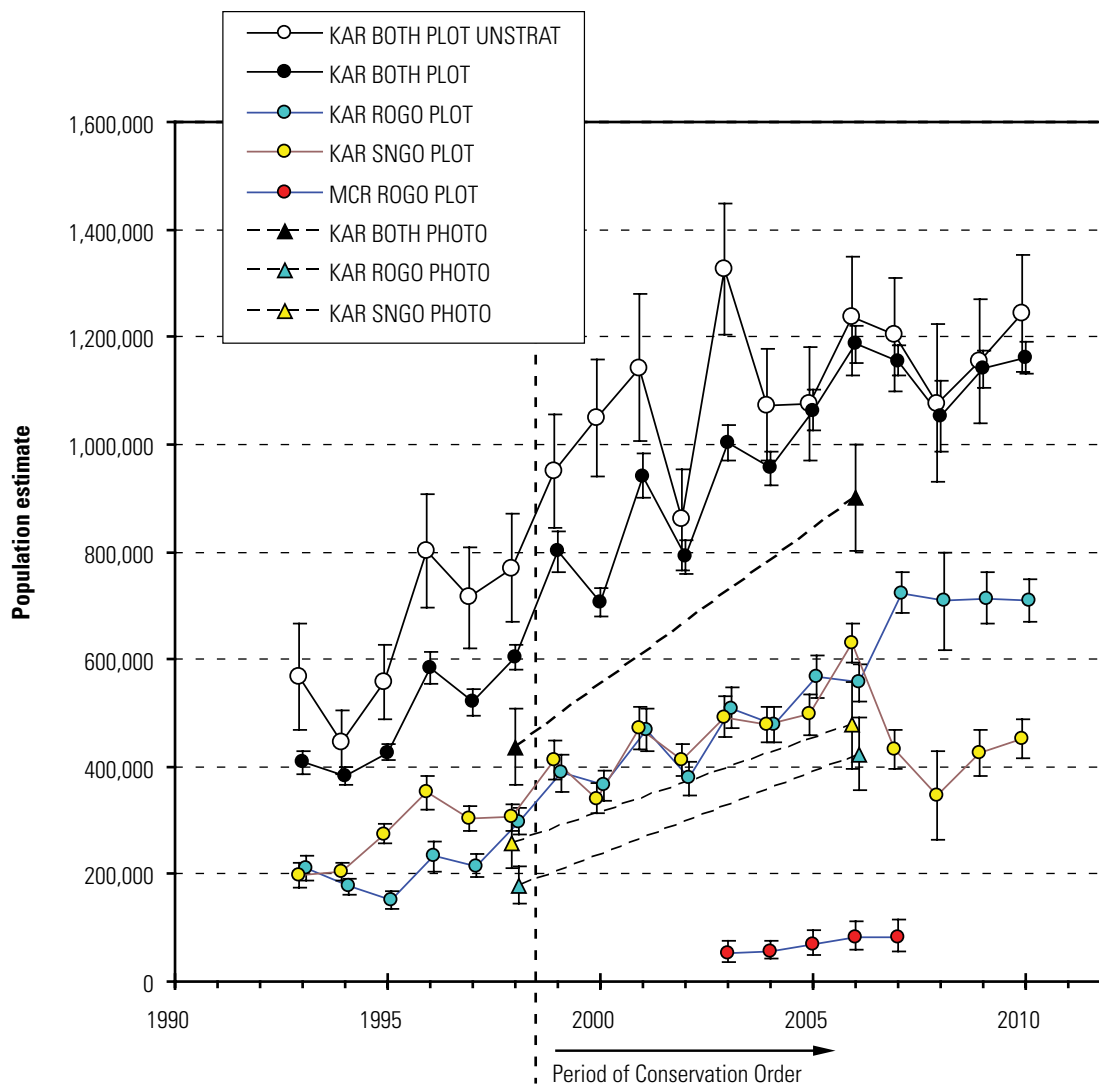


Figure 11. Estimated of number of nesting Ross's and lesser snow geese at Karrak Lake, Nunavut, 1993-2010, Ross's Geese at McConnell, Nunavut, 2003-2007. Shown also are number (triangles) of snow and Ross's geese estimated from aerial photographs (Kerbes et al. 2006).

Intrinsic rate of population change, \hat{r} , at Karrak Lake was estimated using log-linear regression (Eberhardt and Simmons 1992) separately for each species for the time series before (1993-1998) and during (1998-2010) the conservation order. Estimates of 95%CL (\hat{r}) were transformed to annual rate of population change, $\hat{\lambda} = e^{\hat{r}}$, shown in Figure 12. In all cases, point estimates of $\hat{\lambda}$ were > 1 suggesting continuing growth in population sizes for both Ross's and snow geese nesting at Karrak Lake before and during the conservation order and for the entire period. After 2006, number of nesting snow geese declined from 629,000 to between 362,000 and 452,000, while Ross's geese stabilized at about 715,000 between 2007 and 2010. However, this occurred 7 years after efforts to control snow geese began in 1999, and was most likely an outcome of 4 sequential nesting seasons with later-than-average dates of nesting at Karrak Lake. Snow geese appeared to be more sensitive to

delays in snowmelt at Karrak Lake than did Ross's geese, possibly because Ross's geese tend to arrive and nest a few days later than do snow geese, by which time more open ground is available.

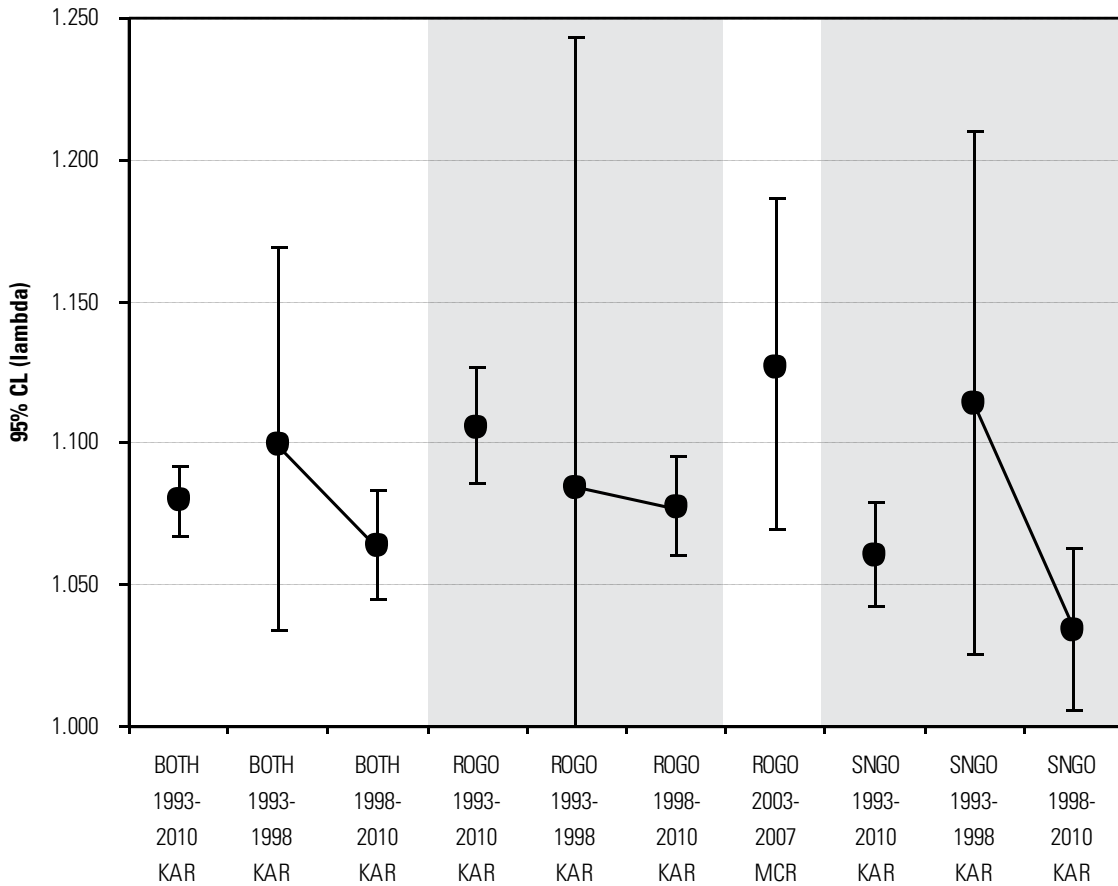


Figure 12. Estimates of annual rate of population change for Ross and lesser snow geese at Karrak Lake, Nunavut, and Ross's geese at McConnell River, Nunavut. Population growth was estimated with log-linear regressions over years (Eberhardt and Simmons 1992).

Population growth was evident also for Ross's geese at McConnell River, which was only determined during the conservation order. There was some evidence that population growth may have attenuated in Ross's geese at Karrak Lake, but confidence limits overlapped between periods before and during the conservation order (Table 3). Some of this overlap was due to imprecision of estimates made before the conservation order, when growth was more variable, and when fewer years of data were available for estimation. Nevertheless, both Ross's and snow geese nesting in these two Canadian arctic regions continued to show population increase during continental attempts at population reduction.

Table 3. Estimates of intrinsic rate of population increase, \hat{r} , for Ross's and snow geese nesting at Karrak Lake and Ross's geese nesting at McConnell River, Nunavut. Estimates were from log-linear regression of \hat{N} on year. Asterisks denote that $\hat{r} > 0$

Colony	Species	Time period		
		(1993-2009)	Before CO (1993-2009)	During CO (1998-2009)
Karrak Lake	Ross's	0.10±0.02*	0.08±0.13	0.08±0.02*
	Snow	0.07±0.02*	0.11±0.09*	0.04±0.03*
	Both	0.08±0.01*	0.10±0.06*	0.06±0.02*
McConnell River	Ross's	-	-	0.12±0.05*a

a Time series for McConnell River Ross's geese was 2003-2007.

Local Abundance Estimates from Mass Captures in August

Numbers of geese can be estimated using the Lincoln-Peterson approach with mark-recapture during regular banding operations. This has been applied to lesser snow geese captured annually during brood-rearing in the La Pérouse Bay region (Cooke et al. 1995), and has potential for use on different species or in other areas. Snow and Ross's goose goslings hatch and can disperse great distances from natal colonies to brood-rearing grounds with their parents. Ideally, geese dispersing from the same source colony should have the same probability of capture, as long as capture and banding operations occur throughout possible brood-rearing areas (see below). As well, if it can be assumed that possible brood rearing areas contain birds from only one source colony, then estimates during brood-rearing can be compared to those during nesting within years. The inference about the estimate applies to the area in which banding operations are done, perhaps defined as the minimum convex polygon determined from coordinates of all banding drives in the region (Figure 13). Banding operations usually are designed to sample geese once/year, so that estimates pertain to the time of banding for an open population allowing births, deaths, and movements into and out of the local population between years. A canonical estimator for the number of adults in the study area in year i is

$$\hat{N}_i^{AHY} = n_i^{AHY} / \hat{p}_i^{AHY} \quad \text{Eq.3}$$

where n_i^{AHY} is the number of adults captured in year i , and \hat{p}_i^{AHY} is an estimate of detection probability. Detection probability can be estimated (Lebreton et al. 1992) with capture-recapture software. An *ad hoc* estimator of variance for this quotient, derived with the delta method (Williams et al. 2001, Alisauskas et al. 2009), is

$$\text{vâr}(\hat{N}_i) = \frac{n_i^2(\text{vâr}(\hat{p}_i))}{\hat{p}_i^4} + \frac{\text{vâr}(n_i)}{\hat{p}_i^2} \quad \text{Eq. 4}$$

As an example, we used captures of Ross's geese from 1993 to 2008 in the brood rearing area surrounding the large nesting colony at Karrak Lake (Figure 13). Estimates of \hat{N}_i from 44,089 captures of adult Ross's geese during banding operations were compared to number of adult Ross's geese nesting in the Karrak Lake colony estimated from nest plots (Figure 14) for the corresponding

years. Detection probability was estimated from Pradel (1996) models for joint estimation of the annual rate of population change, $\hat{\lambda}_i$, and apparent survival, $\hat{\phi}_i$, in Program Mark (White and Burnham 1999). Abundance independently estimated from both nesting and banding data showed remarkably good agreement and parallelism over time, although there was considerably less precision from the banding data. Much of this imprecision was the result of low capture probabilities that ranged from 0.0017 to 0.0107, even though annual captures ranged from 285 to as high as 5,936. As can be seen from eq. 4, variance in \hat{N}_i is an inverse function of \hat{p}_i , so that there is potential to improve precision with increased banding effort. The population size of Ross's geese nesting at Karrak Lake was known to be in the hundreds of thousands, so low \hat{p}_i and high $\text{var}(\hat{N}_i)$ was expected. In other regions with lower numbers of geese, detection should increase if numbers of geese similar to this case study are captured, thus improving confidence in estimates of abundance. Point estimates of abundance from helicopter-assisted mark-recapture in August were higher than estimates of the number of nesting geese at Karrak Lake, the nesting colony assumed to contribute most if not all geese to the Karrak Lake brood-rearing area. However, the tendency for August estimates to be higher than June estimates made during nesting may stem from the inclusion of non-breeders and failed breeders in the sample of geese captured in August. Nevertheless, correlation between estimates using

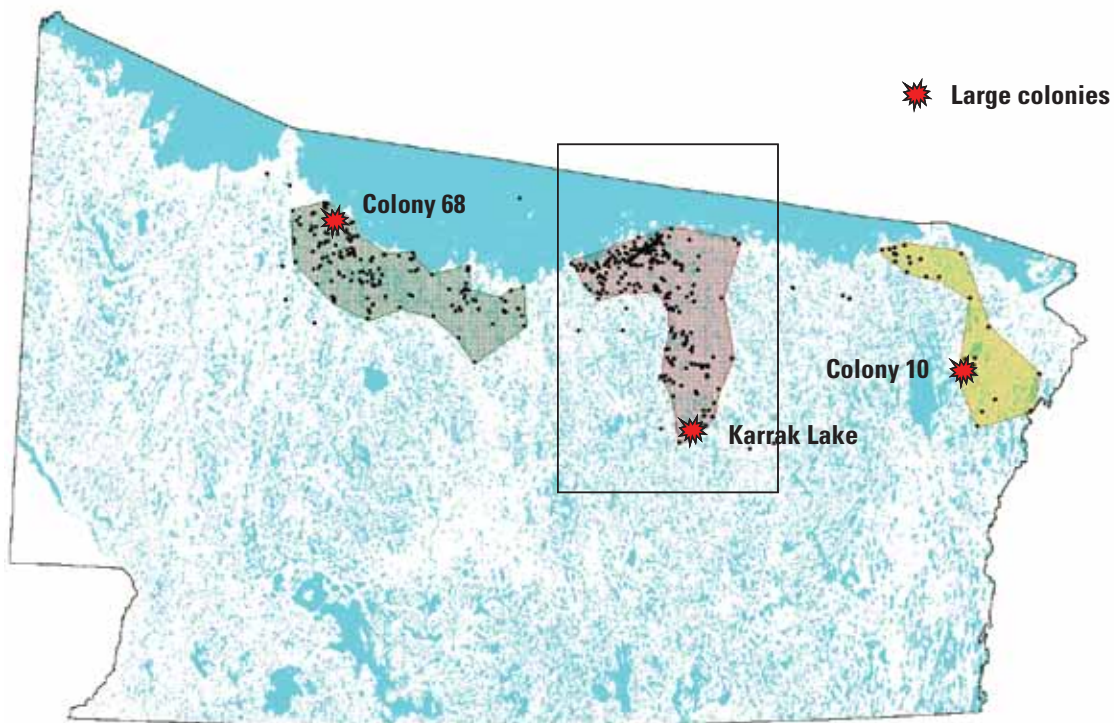


Figure 13. Location of banding sites (black dots) in 3 regions of the Queen Maud Gulf Migratory Bird Sanctuary, Nunavut, where Ross's geese have been captured with helicopter assistance (1993-2008). The Karrak Lake region (rectangle) includes the colony at Karrak Lake, and the center polygon which shows the area defined as brood areas in which Ross's geese have been sampled. Inferences about abundance of adult Ross's geese in Figure 14 pertain to this central minimum convex polygon (1886 km² composed of 1467 km² of land and 419 km² of water).

two independent approaches for Ross's geese from Karrak Lake indicated that this simple method has potential for estimation of regional abundance near arctic nesting areas, if the study area is carefully defined. It may be easiest to define the study area as being fixed across years, so that abundance becomes an expression of density within the fixed study area. Alternatively, it may be possible to map out changes in areas used during brood rearing, and as these expand, an expansion of banding effort to capture samples of birds even in outlying parts of the study area should provide an estimate of true local abundance. Thus, the inference about abundance depends on assumptions made about the sampling frame of geese as they occupy brood-rearing areas.

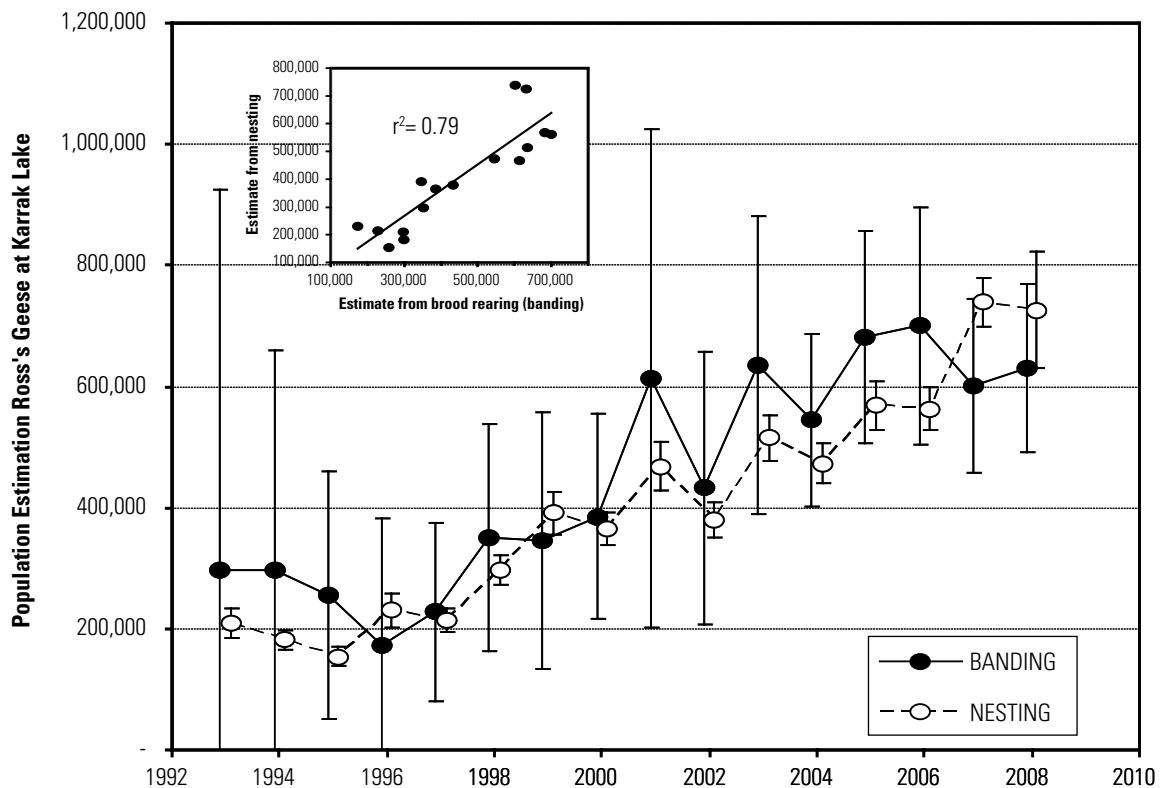


Figure 14. Abundance of adult Ross's geese estimated from helicopter-assisted August captures (filled circles) during the brood-rearing area of the Karrak Lake region (see Figure 13). Also shown are numbers of Ross's geese that attempted to nest at Karrak Lake in the same years, from Figure 11.

Lincoln's (1930) method

Lincoln's estimates for arctic-nesting geese pertain to the population size at the time of banding, which is usually August (see Boyd et al. 1982). Alisauskas et al. (2009) applied Lincoln's (1930) method for population estimation to 4 populations of geese nesting in arctic Canada, and suggested that it may provide a useful approach for drawing inference about abundance during the flightless period in the arctic and subarctic before fall migration. Briefly, Lincoln's (1930) estimator requires information about harvest rate, b_i , and the number of individuals harvested by hunters, H_i . Harvest rate for year i , b_i , is defined explicitly as the proportion of a population of size N_i that is harvested,

i.e., shot and retrieved by hunters, H_i , until the next banding effort in year $i + 1$. Thus, the relationship

$$b_i = \frac{H_i}{N_i} \quad \text{Eq. 6}$$

can be rearranged to provide an estimator for population size, as follows:

$$\hat{N}_i = \frac{\hat{H}_i}{\hat{b}_i} \quad \text{Eq. 7}$$

Harvest rate, \hat{b}_i , is estimated as the direct recovery rate, \hat{f}_i , of birds reported by hunters within a year of banding in the arctic, adjusted by band reporting rate, $\hat{\rho}_i$ (see Alisauskas et al. 2009 and references therein). Harvest, \hat{H}_i , is estimated annually with existing hunter surveys conducted by Canadian Wildlife Service and the U.S. Fish and Wildlife Service. Recently, Padding (*in press*) suggested that harvest estimates from the United States may be biased high, and Johnson et al. (2012) provided bias-corrected estimates of harvest for both Ross's and snow geese from the Central and Mississippi Flyways until the 2006 regular season. Estimates of \hat{b}_i and \hat{H}_i can be stratified by age, resulting in separate estimates of August population size for geese marked as either adults, i.e., marked after their hatch year, AHY, and goslings, i.e., marked in their year of hatch, HY.

Herein, we update the time series of \hat{N}_i for midcontinent snow geese, recently reported to 2006 by Alisauskas et al. (2011a), to 2009, and provide similar continental estimates of Ross's geese to 2009. We estimated direct recovery rates of Ross' and snow geese marked east of 110° W longitude and north of 53° N latitude (Canada's central and eastern arctic) with only regular legbands, and not reward bands or neckbands. Recoveries from only Canada and the United States were considered, to correspond with the geographic scope of harvest estimates available (Alisauskas et al. 2009). We used regular season harvest, \hat{R}_i and age ratios reported by CWS (Gendron and Collins 2007) and USFWS (Kruse et al. 2009) to estimate age-specific harvest for each flyway and Canada separately; then, age-specific harvest for each jurisdiction was summed to arrive at population level harvest. We used \hat{H}_i in the United States estimated from the Mail Questionnaire Survey (MQS) until 1998, and from the Harvest Information Program (HIP) from 1999 until the most recent year available. We estimated, for each age class j , i.e., HY and AHY, respective conservation order harvest, \hat{C}_{ij} , from \hat{R}_{ij} weighted by the quotient of bands recovered during the conservation order (or spring seasons in Canada), c_{ij} , and those recovered during the regular season, r_{ij} , using

$$\hat{C}_{ij} = \frac{c_{ij}}{r_{ij}} \hat{R}_{ij} \quad (3)$$

(Alisauskas et al. 2006, 2011a). Finally, age-specific total harvest was

$$\hat{H}_{ij} = \hat{R}_{ij} + \hat{C}_{ij} \quad (4)$$

and total annual harvest was the sum of age-specific total harvests in each year.

Harvest of Ross's and midcontinent snow geese.

Total adult harvest of midcontinent snow geese from 1989 to 2009 during regular seasons, $\hat{R}_{i,AHY}$, did not exceed 0.5 million, $\hat{H}_{i,AHY}$ never surpassed 0.8 million, and aggregate harvest of both age classes, \hat{H}_i , was estimated to have exceeded 1 million only in 1999 and 2001 (Figure 15A). The preceding estimates were based on U.S. harvest estimates reported by Kruse et al. (2009) from the MQS (1989-1998) and HIP (1999-2009). Use of Padding's U.S. harvest estimates corrected for bias (Johnson et al. 2012), available to 2006, but retaining estimates of Canadian harvest, as above, resulted in population-level harvest estimates of midcontinent snow geese that were substantially lower (Figure 15B): total adult harvest from 1989 to 2006 (the last year for which bias-corrected estimates were available) during regular seasons, $\hat{R}_{i,AHY}$, did not exceed 0.3 million, $\hat{H}_{i,AHY}$ never surpassed 0.5 million, and aggregate harvest of both age classes, \hat{H}_i , never exceeded 0.7 million. Positive bias in historical harvest estimated by Padding (*in press*) seems high, and remains to be verified.

Similarly for Ross's geese, North American harvest (excluding Mexico) of adults during regular seasons, $\hat{R}_{i,AHY}$, never exceeded 50,000, total harvest of adults, $\hat{H}_{i,AHY}$, peaked in 2004 with ~70,000 adults, and harvest of both age classes together, \hat{H}_i , peaked in 2001 at ~150,000 (Figure 16A). Annual harvest estimates of Ross's geese increased substantially before the conservation order, as reported by Alisauskas et al. (2006), but have declined steadily since 2001, the last year that they considered. This decline was largely the result of declining regular season harvest, while conservation order harvest remained relatively constant at ~30,000 adults and young each year since 2001. Estimates reported herein are based on HIP from 1999 onwards, and so are higher than those reported for 1999 to 2001 by Alisauskas et al. (2006) who relied on MQS estimates (Kruse et al. 2004) for those years. Use of bias-corrected estimates of U.S. harvest resulted in substantially lower estimates of Ross's goose harvest, as it did for midcontinent snow geese (Figure 16B). Alisauskas et al. (2011a), who reviewed historical estimates of U.S. harvest, noted that total harvest of midcontinent snow geese was substantially lower than initially thought achievable with liberalization of harvest regulations (Rockwell and Ankney 2000). Padding's estimates of harvest (Johnson et al. 2012) suggest that achievement of harvest goals met with even less success than concluded by Alisauskas et al. (2011a).

Clearly, our analyses were sensitive to variation in U.S. harvest estimates, depending on whether HIP or MQS was used, and also if Padding's bias-corrected estimates were used instead of those used historically without such adjustment. Otis (2006) noted that there has been some concern about bias in harvest estimates associated with the HIP sampling frame, but Padding's bias correction applies to historical estimates of all waterfowl harvest in the United States, and stems from unidentified sources. It is hoped that the discrepancy between unadjusted estimates (Kruse et al. 2009), and those corrected for bias by P.I. Padding (Johnson et al. 2012) for all U.S. waterfowl harvest estimates is resolved. We present population estimates from both sets of harvest levels for the reader to consider.

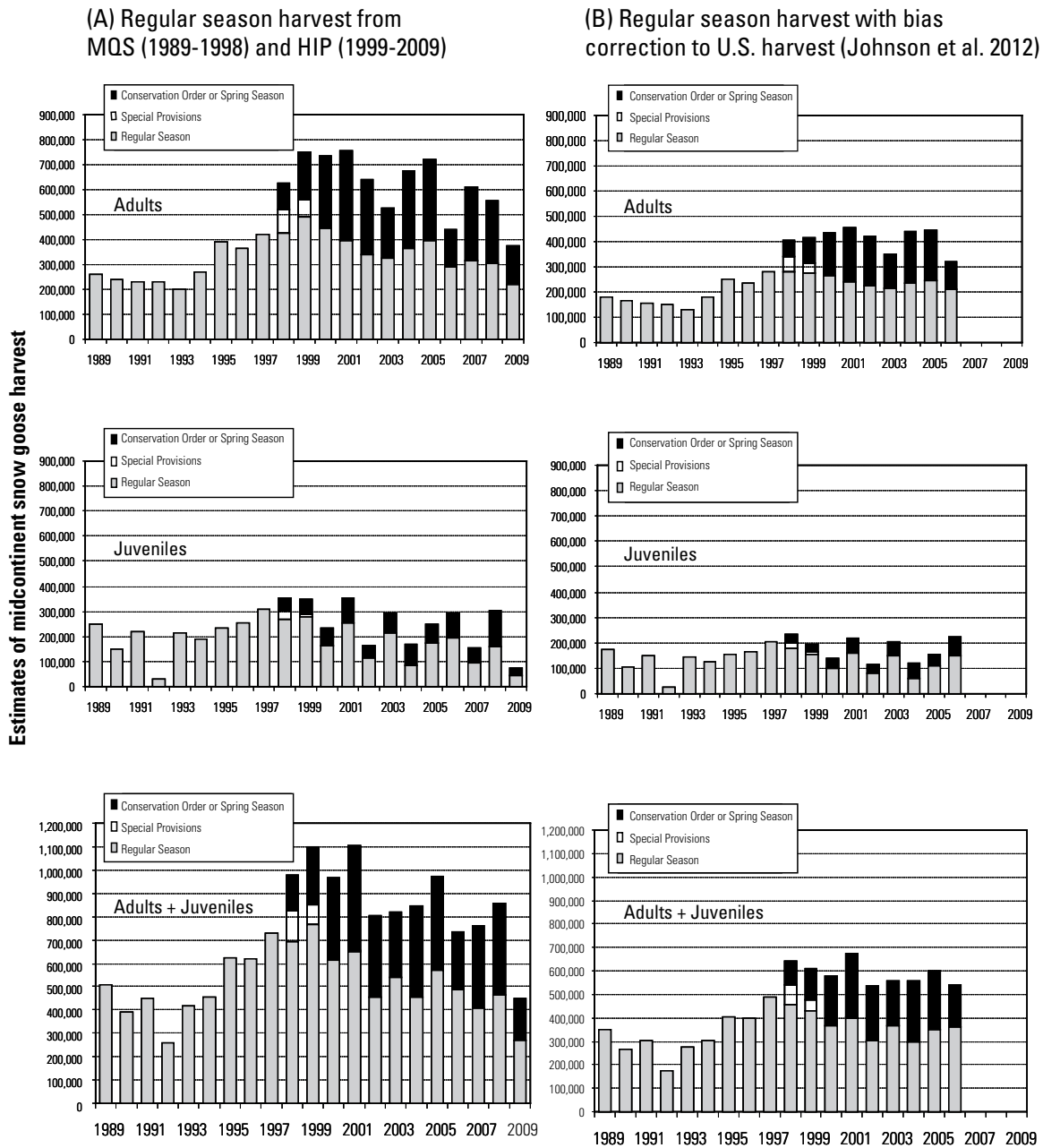


Figure 15. Harvest of lesser snow geese in Prairie Canada and the Central and Mississippi Flyway following methods of Alisauskas et al. (2011a). These largely represent midcontinent lesser snow geese that originate from Canada’s central and eastern arctic and subarctic regions, east of 110°W and north of 53° N.

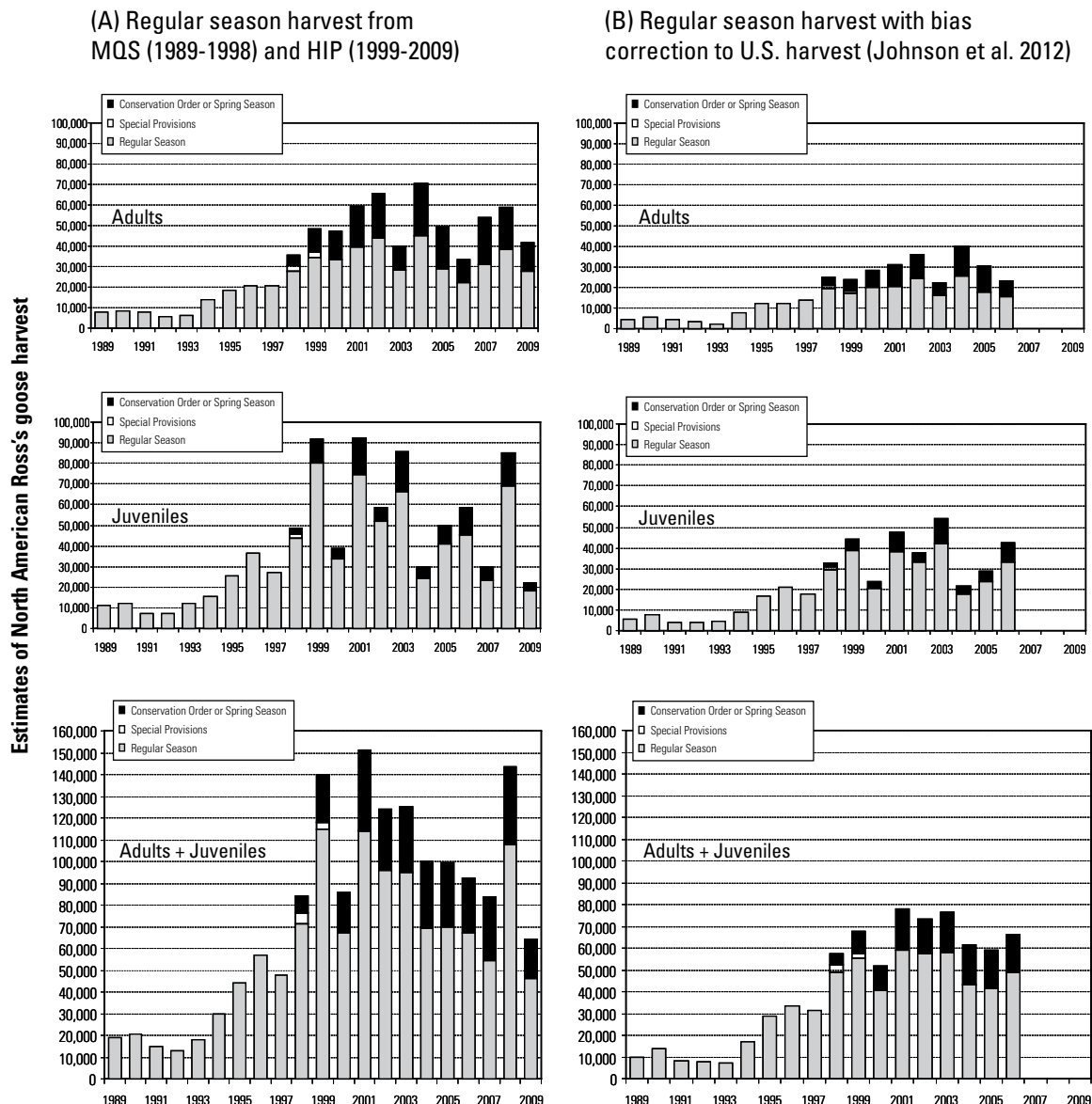


Figure 16. Harvest of Ross's geese in North America following methods of Alisauskas et al. (2011a). These largely represent Ross's geese that originate from Canada's central arctic regions, south of Queen Maud Gulf, Nunavut.

Harvest rate of Ross's and midcontinent snow geese.

Harvest rates, \hat{h}_{ij} , were estimated for each year i for age j (HY vs AHY) using respective direct recovery rates, \hat{f}_{ij} , and dividing by band reporting rate, ρ_i (see Alisauskas et al. 2009, 2011a for specific estimates used). Only birds marked with regular legbands or tarsal bands were used to calculate direct recovery rate because reward bands are designed to increase reporting rates (e.g. Zimmerman et al. 2009), and neckbands are known to be recovered at a higher rate than are regular legbands (Alisauskas and Lindberg 2002, Alisauskas et al. 2006, Caswell 2009). As well, only geese

reported by hunters were considered to correspond to the harvest process from which total harvest was estimated. Alisauskas et al. (2009) reported harvest estimates from 1989 to 2006 for 4 species of arctic-nesting geese, and Alisauskas et al. (2011a) estimated harvest probability for snow geese from 1971 to 2006 to provide historical context to more recent estimates during the conservation order. We update harvest rate for both age groups (HY vs AHY) of lesser snow geese harvested in the midcontinent and Ross's geese harvested in Canada and the United States.

As reported by Alisauskas et al. (2011a), harvest rate of midcontinent snow geese has declined substantially since 1970 in both juveniles (from about 0.30 in the 1970s to about 0.05 in the 2000s) and adults (from >0.10 in the 1970s to <0.05 in the 2000s, Figure 17A). Importantly, the most recent estimate for harvest rate of adult snow geese was 0.016 ± 0.005 (95%CL), suggesting very low harvest pressure. Although there was an increase in harvest rate of adults with the start of the conservation order, from 0.023 ± 0.001 in 1997 to 0.039 ± 0.007 in 1998, harvest rate has continued to decline during the conservation order (Alisauskas et al. 2011a). There was a much shorter time series available for harvest rates of Ross's geese because of little or no arctic banding using only leg bands before 1989 (Figure 17B). Nevertheless, there was sufficient information to examine change in harvest rate preceding the conservation order, which did not appear to have an influence. As for snow geese, harvest rate of both Ross's goose adults and juveniles continued to decline throughout the conservation order with the most recent estimates in 2009 of 0.021 ± 0.006 and 0.029 ± 0.012 , respectively. In fact, point estimates of harvest rate for adult Ross's geese were consistently lower than those of adult snow geese in 9 of 11 years from 1998 to 2009, meaning that vulnerability ($\hat{\psi} = \hat{h}_{Ross} / \hat{h}_{snow}$) of adult Ross's geese also tended to be lower. There did not appear to be any time trend in relative vulnerability for adults, but an increasing trend in vulnerability of juvenile Ross's geese relative to adults was very weak and accounted for only 5% of variation among years. The mean vulnerability of adult Ross's relative to snow geese from 1989 to 2009 was 1.00, whereas that of juvenile Ross's geese from 1990 to 2009 was 1.36. Thus juvenile Ross's geese, but not adult Ross's geese, were somewhat more susceptible to harvest than were juvenile snow geese, overall.

We estimated population abundance using historical estimates of U.S. harvest (Figure 18) and those corrected for bias by Padding (Figure 19) in the denominator of the estimator (Equation 2), although harvest rate was the same for corresponding years. After annual abundance was estimated for each age class, non-linear regression was used to determine if growth was either exponential (continuous rate of increasing \hat{N}_i over the full time series of available information) or logistic (increasing rate of growth in \hat{N}_i but attenuated rate of growth as with a change in the rate of growth over time). Alisauskas et al. (2011a) also fit up to 4th order polynomial equations, but we restricted our decision set for this exercise to either logistic or exponential population growth. We used the information-theoretic approach (Burnham and Anderson 2002) for model selection (Table 4).

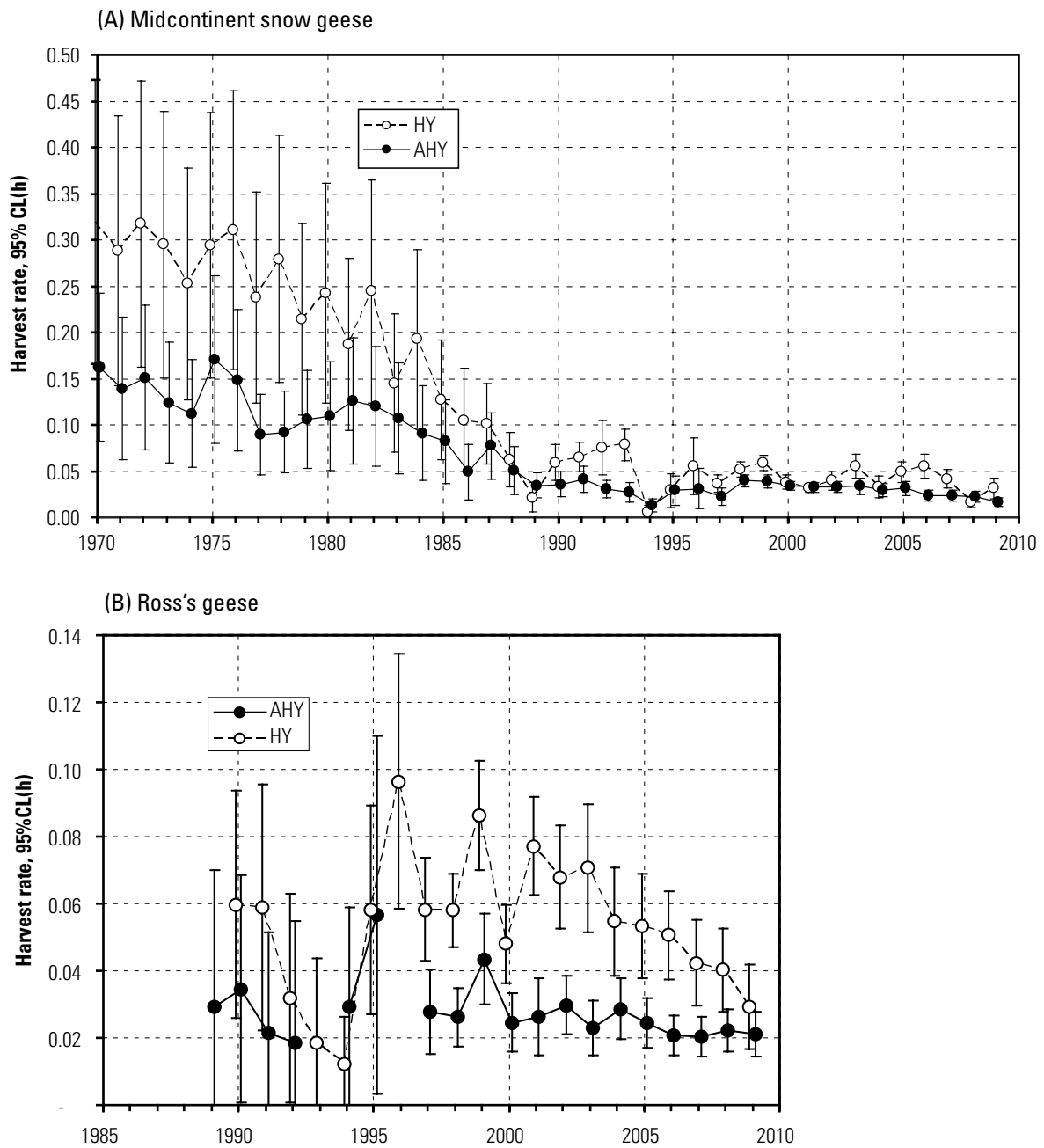


Figure 17. Harvest rate of (A) midcontinent lesser snow geese and (B) Ross's geese marked in Canada's central and eastern arctic and subarctic regions, east of 110°W and north of 53° N.

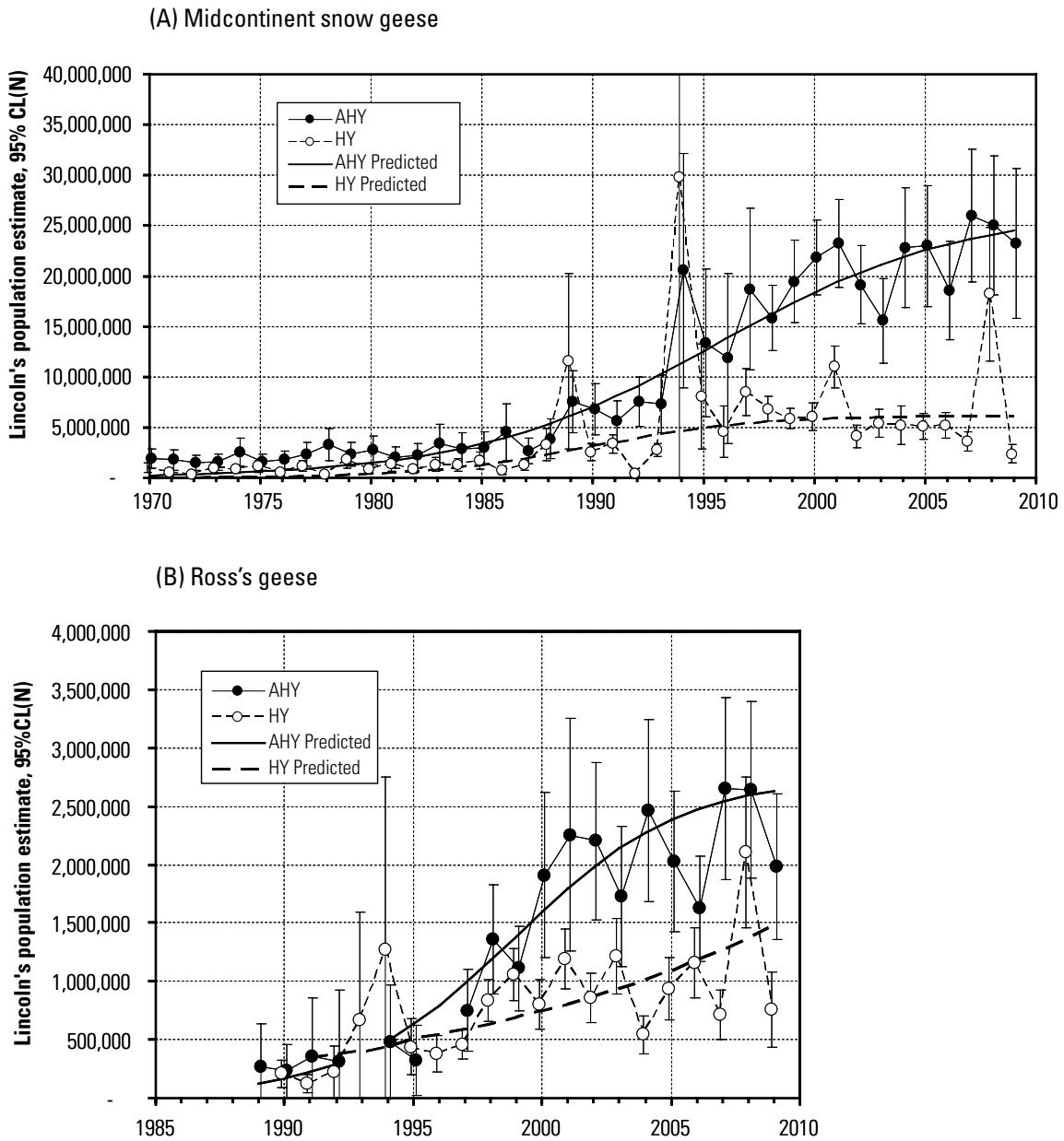


Figure 18. Lincoln estimates of (A) midcontinent lesser snow geese and (B) Ross's geese marked in Canada's central and eastern arctic and subarctic regions, east of 110°W and north of 53°N . Estimates pertain to abundance in August when most helicopter-assisted captures are made, following Alisauskas et al. (2009, 2011a).

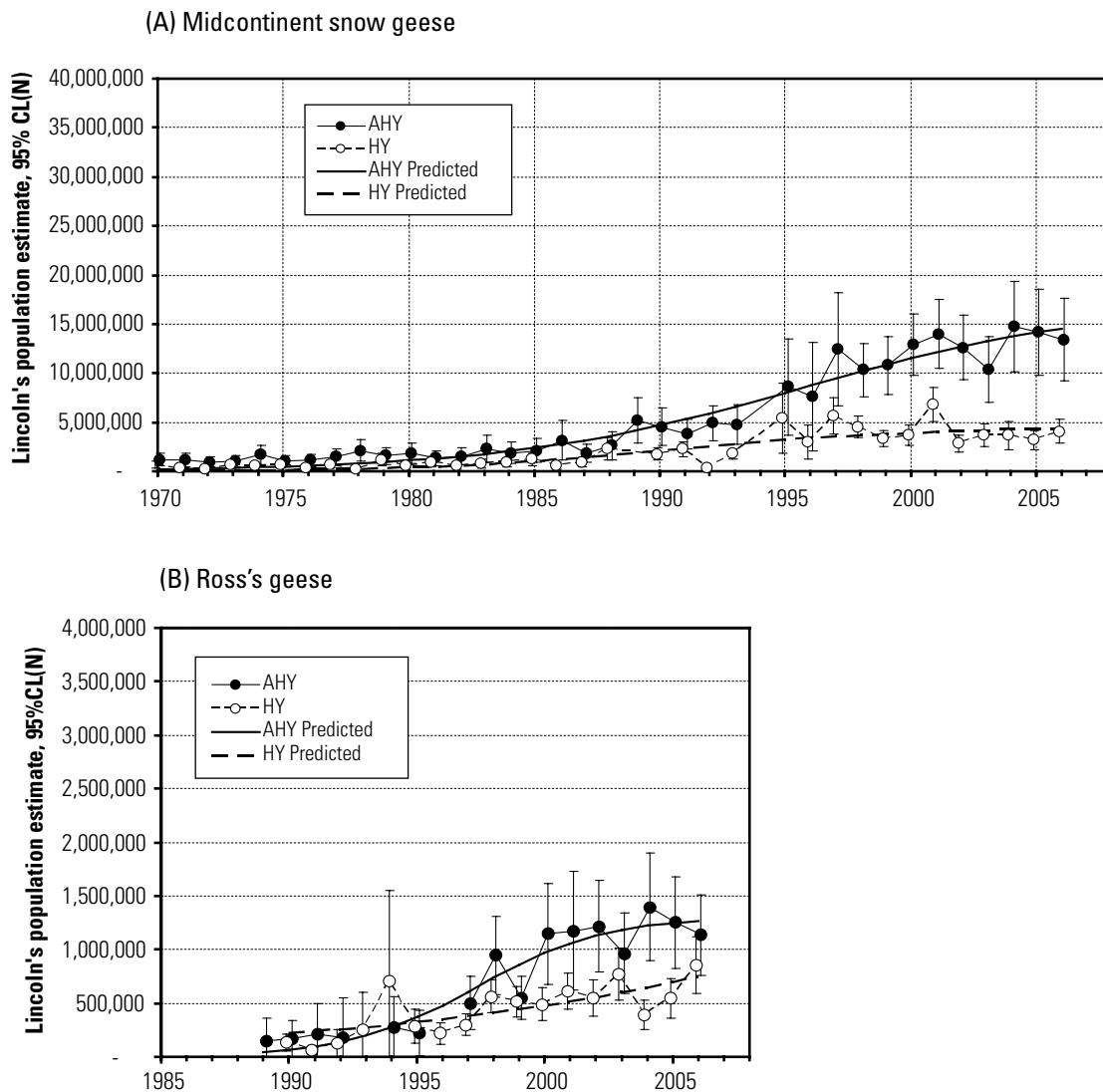


Figure 19. Lincoln estimates of (A) midcontinent lesser snow geese and (B) Ross's geese marked in Canada's central and eastern arctic and subarctic regions, east of 110°W and north of 53°N . Estimates pertain to abundance in August when most helicopter-assisted captures are made, following Alisauskas et al. (2009, 2011a), except that harvest estimates adjusted for bias (available only until 2006, Johnson et al. 2012) were used in Lincoln's estimator.

Table 4. Model selection between linear, exponential, logistic or cubic descriptors of population growth from 1970 to 2009 for midcontinent snow geese and continental Ross's geese by age class (AHY vs HY). Based on estimation of population size with Lincoln's method (Figure 18) using historic estimates of harvest (Figure 15) and harvest rate (Figure 17) in Canada and the United States

Species	Age	Model	n	ΔAIC	K	Weight
Snow	AHY	<i>Logistic</i>	40	0.00	4	0.94
		<i>Cubic</i>	40	5.53	5	0.06
		<i>Exponential</i>	40	19.76	3	0.00
		<i>Linear</i>	40	25.39	3	0.00
	HY	<i>Logistic</i>	40	0.00	4	0.31
		<i>Linear</i>	40	0.82	3	0.20
		<i>Exponential</i>	40	2.61	3	0.08
		<i>Cubic</i>	40	3.68	5	0.05
Ross's	AHY	<i>Logistic</i>	19	0.00	4	0.83
		<i>Cubic</i>	19	4.42	5	0.09
		<i>Linear</i>	19	4.80	3	0.08
		<i>Exponential</i>	19	12.39	3	0.00
	HY	<i>Linear</i>	20	0.00	3	0.52
		<i>Exponential</i>	20	0.84	3	0.34
		<i>Logistic</i>	20	2.94	4	0.12
		<i>Cubic</i>	20	6.01	5	0.03

There has been a tremendous increase in the number of midcontinent snow geese estimated each August since 1970, regardless of the U.S. harvest estimates used to estimate population size (Figures 18, 19). Padding's bias-corrected estimates were available only until 2006, so the time series of population size in Figures 19A, and 19B is shorter by one year compared to those estimated using historical estimates of U.S. harvest (Figure 18A and 18B). Population estimates made with Padding's bias-corrected U.S. harvest estimates were about 75% of the population estimates made with historical harvest data. Nevertheless, the general shape and growth rate were the same over the full time series available for each species. Specifically, logistic models fit annual abundance of both AHY and HY snow geese, and AHY Ross's geese better than exponential models, regardless of harvest estimates used. Exponential models fit HY Ross's goose abundance better than logistic, but examination of model weights suggested that model selection was somewhat more equivocal (Table 4). In summary, the data suggested that populations of both snow and Ross's geese continued to grow during the conservation order, but at an attenuated rate compared to the period before the conservation order. There did not appear to be any population decline during that time, in accordance with overall conclusions about continued growth from midwinter counts, nesting studies at Karrak Lake or McConnell River, or the periodic estimates from the aerial photographic method.

Comparison of Techniques Used to Determine Population Status of Lesser Snow Geese and Ross's Geese

Midwinter Surveys

Is the midwinter index (MWI) sufficiently accurate to be used in an evaluation of population reduction efforts? Rusch and Caswell (1997:114) acknowledged that “Midwinter indices suffer because 1) counts are imprecise due to difficulty counting large numbers and in achieving complete coverage of all areas; and 2) geese counted in winter are aggregations of birds from many colonies, populations and flyways.” Abraham and Jefferies (1997) suggested “The probability of midwinter index counts under-estimating the real population size has likely increased as the population has grown, due to the daunting task of monitoring the expanding wintering area used by geese, and the limitations of survey techniques for large clustered populations.” Bechet et al. (2004:639) had this to say about the ability of midwinter counts to reflect annual variation in greater snow goose abundance in the Atlantic Flyway: “Traditionally, population management of North American snow geese has been based on trends in numbers of geese detected from midwinter surveys (Eggeman and Johnson 1989, Heusmann 1999). These surveys do not provide estimates of total numbers. The winter range is sampled by flying transects and using experienced observers to estimate visually the size of the flocks encountered. No attempt is made to adjust for visibility bias or to extrapolate to areas outside the transects. Researchers assume that an equal portion of the population is encountered each year, the visibility bias is constant each year, and the trends detected reflect those occurring in the overall population. Wintering snow geese range widely over large expanses of coastal marshes and agricultural fields (Hill and Frederick 1997), and midwinter surveys are unlikely to encounter the same proportion of the population each year.” The same issues likely apply to counting midcontinent lesser snow geese, and because they now occupy a much larger winter range, the problems of representativeness are likely greater.

Kerbes (1975) suggested that the MWI could account for only half of breeding birds inferred from a photographic survey of light geese (mostly snow geese) in Canada's eastern arctic. Boyd et al. (1982) compared the MWI of light geese (thought at the time to be virtually completely composed of snow geese) with estimates of the abundance of midcontinent snow geese alive in August using Lincoln's (1930) method, and found that the former could account for only about 63% of the latter. Boyd (2000) found that the ratio of visual estimates to photo counts for flocks <2000 was about 1; 0.7 for flocks of 2000-4000; and 0.6 for flocks of >4000. The degree of underestimation that occurs when flock size can exceed 100,000 individuals is unknown, but we expect that it could be substantial. A more recent comparison of Lincoln-Peterson estimates with winter counts suggests that the proportion of the midcontinent population accounted for in winter surveys has declined to as little as 10% (Alisauskas et al. 2011a). A comparison of methods for enumerating the Svalbard population of pink-footed geese, *Anser brachyrhynchos*, concluded that counts were generally smaller than mark-resight estimates of abundance (Ganter and Madsen 2001); moreover, the discrepancy between

metrics of abundance varied among years. In that assessment of methods, counts were of <40,000 pink-footed geese made in a comparatively small area, The Netherlands; we expect discrepancies to be proportionally greater when dealing with populations that are much more numerous, i.e., in the tens of millions, with a much larger winter range, and so much more difficult to count reliably.

Midwinter counts have existed for more than 50 years, and trends in the index reflect the trajectory of the midcontinent population of lesser snow geese on a coarse scale. The limitations of this survey are well known, including the fact that an unknown proportion of the population is counted each year, survey coverage is inconsistent and mostly undocumented, it does not discriminate between Ross's geese and snow geese, nor does it discriminate between adults and juveniles being counted, and it is not based on a statistical sampling framework, so counts cannot be legitimately extrapolated to areas outside the survey. In short, it is probably the least rigorous of the surveys for snow geese, despite its widespread geographic coverage, yet it still reflects the overall population trend seen in other surveys of the midcontinent population.

Photo Surveys of Nesting Geese

Photographic surveys of nesting geese have been one of the primary tools for monitoring lesser snow geese and Ross's geese since the early 1970s (e.g., Kerbes 1975, Kerbes et al. 1983, Kerbes et al. 2006, Kerbes et al., in prep). This technique is based on a sound sampling framework that allows calculation of nest density estimates that can be extrapolated to the entire survey area. Data collection is fairly straightforward, and involves systematically photographing known colonies from a fixed wing aircraft. Photographs are then sampled to derive nest density estimates (Kerbes 1975). Costs of data collection are relatively low, but there is a high cost to data analysis, because it can be very time consuming to manually count large numbers of geese from photographs. If automated counting techniques could be perfected, this would greatly improve the usefulness of photographic surveys.

Despite some of their advantages, photographic surveys of nesting areas must be regarded as minimum estimates, because they do not include non-breeding geese, which may represent a high proportion of the population in some years (Kerbes et al. 2006, Reed et al. 2004). Likewise, the survey accounts for an unknown proportion of the overall population, because only known colonies are surveyed, and new colonies continue to be found in new areas as snow goose populations expand (e.g., Kerbes et al. 2006). The number of geese nesting annually is likely highly sensitive to variation in snowmelt which, if delayed, is known to reduce the number of geese attempting to nest in a given year. As well, estimates are sensitive to seasonal decline in numbers of nests due to abandonment or depredation. For example, if nest success is 80%, then the estimate of nesting geese from photos taken during late incubation may be only 80% of the number attempting to nest. Thus, use of photographic surveys of nesting geese as an index to population size must be treated cautiously, because estimates are subject to many sources of variation that are unrelated to population size.

Changes in the size of nesting colonies are inferred from only two points in time, often separated by several years between photography, instead of during an uninterrupted series of several years. Thus, it is conceivable that if a second estimate is made during a late nesting year with poor breeding effort, then the inference could be one of population decline, compared to a year with good breeding effort which might result in a conclusion of population increase. In either case, the number of geese alive in the region could be the same, except that the number not sampled, because they are nonbreeders and absent from the breeding colony, can be vastly different. For example, although the La Pérouse Bay colony was estimated from photography to be 58,700 in 1997 and 83,600 in 2006, extremely deep and persistent snow cover there in 2009 apparently prevented any nesting by snow geese (R.F. Rockwell, personal communication; see also results from helicopter transect surveys at Cape Henrietta Maria, below). Also, Ross's geese cannot reliably be distinguished from snow geese in photographs, so without supporting ground estimation of species ratios, all light geese on images are assumed to be snow geese. Though species ratios have been estimated at some of the major colonies in the central arctic during photographic surveys, they have not been done elsewhere, and considerable evidence exists to suggest that Ross's geese have increased in number and expanded their range eastward over the past few decades (Alisauskas et al. 2006).

Estimates from photographic counts of light geese nesting at Karrak Lake (Kerbes et al. 2006) were 72.5% of those made from visits to plots of nesting geese in 1998, and 76.0% in 2006. Reasons behind the consistent discrepancy in these two years are not clear, but may be related to (i) exclusion of flying geese during photo interpretation, (ii) exclusion of groups of >4 standing within the colony boundary, (iii) differences between the two methods in mapping colony boundaries, (iv) inability to distinguish nesting geese from unmelted snow, (v) inability to detect blue geese on photos taken from lower altitudes, (vi) abandonment of nesting by geese during incubation prior to photographic sampling, and (vii) incomplete detection of goose images on photographs. Note that estimates from nest plots are for numbers of nests initiated and thus numbers of geese that attempted to nest, regardless of ultimate success at doing so.

Despite some of these weaknesses, photographic surveys have provided useful snapshots of colony dynamics over time, as well as information about large-scale changes in nesting distribution as snow goose populations have continued to expand. After the most recent round of photographic surveys, it appears that not only has the midcontinent population of snow geese continued to grow, but nesting distributions appear to have shifted westward. Such information is useful to ensure that banding efforts continue to coincide with the geographic distribution of the population (Alisauskas et al. 2011a), and to inform future habitat monitoring activities.

Aerial Transect Surveys During Nesting

Ross et al. (2004) pointed out some advantages of helicopter transect sampling over the photo method, including quick implementation, less susceptibility to inclement weather, lower cost of sampling, no need for specialized crews, and no labor-intensive photo-interpretation thus leading

to timeliness of results. Moreover, stationary nests rather than geese that can fly out of the sample area are counted from the helicopter. Finally, helicopter transect sampling can be adjusted to accommodate changes in the distribution of the colony, or detection of new colonies. Ross et al. (2004) mentioned the potential to misidentify nests of other goose species as those of snow geese, but did not report or discuss probability of detecting nests during the survey. This technique allows density estimates to be applied over an entire survey area, and has the potential to provide even more accurate estimates if detection probabilities are estimated during the survey. Though it has been used successfully at Cape Henrietta Maria in Ontario, its application on much larger remote colonies, where nest densities may be 10 times higher, has not been attempted.

Helicopter Transects and Photo Surveys During Brood Rearing

Surveys of post-breeding flocks can provide useful information about trends in population size, as well as information about annual productivity in the form of juvenile:adult ratios (F. D. Caswell, personal communication). While this survey technique is based on a statistical sampling framework that can provide estimates of numbers of birds in a given area, it is not usually possible to know what proportion of a population occupies that area (e.g., many non-breeding birds may depart from nesting areas). There are also difficulties associated with estimating numbers of birds that are often in mixed species flocks that contain varying proportions of juvenile birds. Counts of such flocks are assumed to be accurate in terms of species identification (e.g., in mixed flocks of Ross's geese and snow geese) and numbers of adults and juveniles of each species, but studies have shown increasing biases as flock sizes increase (e.g., Boyd 2000), and the degree to which this bias might be exacerbated by mixtures of species and age groups is unknown. Photographic surveys of post-breeding flocks can overcome some of the difficulties associated with estimating flock sizes and species composition, but may have some of the same limitations in terms of the unknown proportion of the population that is sampled. However, the large and remote areas occupied by some post-breeding geese could make it difficult to survey an adequate portion of the post-breeding range.

Ground Estimates of Nesting Geese

Abundance estimation of nesting geese from the ground is best suited to largely insular colonies with reasonably well-defined perimeters, as was the case in the examples mentioned above. The method is more difficult to apply to larger continuous distributions of nesting geese; for example, the largest known nesting ground of light geese is on SW Baffin Island, where nests are distributed more or less continuously along 300 km of coastline, covering 4,600 km² (Kerbes et al. 2006). While the technique is based on a statistical sampling framework, and can provide accurate estimates, its application on a large scale would be time consuming, and would require considerable infrastructure and support to transport and house ground crews in remote locations. For these reasons, ground surveys of nesting lesser snow geese are not considered to be feasible at a large scale.

Local Abundance During Banding Drives

Although not widely employed, this method could provide another regional estimate of both AHY and HY geese with no additional cost if done properly during banding operations. This also has potential to estimate abundance retrospectively if banding operations were conducted in a consistent manner with a core study area common to all years at the very least. Although precision was low, point estimates were remarkably well correlated with an independently derived estimate of the number of nesting geese at the source colony. Since captured Ross's and snow geese are readily distinguishable in the hand, this method may have an advantage over the aerial photo method in mixed colonies. Thus, in addition to estimation of parameters associated with band recovery models, banding operations can provide useful estimates of abundance and other derived estimates such as the rate of population growth, which can also be acquired directly following Pradel (1996). In addition to regional abundance, mark-recapture at multiple sites representing the most populous arctic breeding regions used by light geese can be used to estimate exchanges between different breeding strata (Alisauskas et al. 2011b). Thus the role of immigration and emigration between different arctic breeding strata on metapopulation dynamics could also be evaluated (e.g., Rockwell et al. 2012).

Lincoln's (1930) Method

Of all methods discussed in this report, Lincoln's (1930) method is the only one that can provide an unbiased estimate of population size for midcontinent lesser snow geese or Ross's geese. The estimates based on this technique are considerably higher than all previous estimates, and if correct, suggest that most other techniques have underestimated population sizes, or at least have provided a false sense of abundance in these populations. Even if harvest estimates and/or reporting rate estimates prove to be biased, it might be more tractable to correct such biases (Johnson et al. 2012) than to obtain population estimates through traditional survey methods.

The midcontinent population of lesser snow geese is very large, and nests in remote locations in many individual colonies, often at very high densities, making it difficult to monitor this population using conventional survey techniques. The increasingly high costs of aircraft and fuel positioning in the arctic make population monitoring an expensive proposition during the nesting season, and the population may be spread over an even larger geographic area during the post-breeding, migration, and wintering periods of the annual cycle. Most of the survey techniques that have been used to monitor this population are capable of providing estimates for some portion of the population, but only Lincoln's method provides overall population estimates.

There are several assumptions inherent in the use of banding data and harvest estimates to estimate population size, including that harvest estimates are accurate (or at least consistently biased, so that the trends are accurate, if not the estimates themselves), that band reporting rates are known, and that banded samples of lesser snow geese are representative of the midcontinent population as a whole (Alisauskas et al. 2009). This requires maintenance of a representative banding program on nesting areas, as well as national harvest surveys to estimate harvests by species.

Some readers may find it difficult to accept that abundance estimated with Lincoln's (1930) method could be possible, after having grown accustomed to the lower numbers counted during midwinter, or estimated from photographs during nesting at some colonies. A simple thought experiment may convince some that these estimates could be close to reality. Imagine a large flock of geese in a field feeding at a density of 1 goose/m². Such densities, although difficult to estimate, seem possible to those who have frequently observed such large groups of snow geese during migration or winter. Often such flocks can cover fields that are 0.25 miles² (0.64 km²) or more in size. If such a density of geese were to settle on and fill 1 section of land (i.e., 2.56 km²), then that area would contain 2.56 million geese. Conversely, a population of 25 million geese at a density of 1/m² could be contained inside ~9.7 sections of land (or ~25 km²). In other words, the entire midcontinent population of lesser snow geese could occupy a square area with sides that are just over 5 km long. Anyone who has driven across the Canadian prairies or similar areas during peak migration periods for lesser snow geese, and witnessed multiple large aggregations of staging birds along the road, should have no difficulty in accepting that such numbers are possible.

We suggest that Lincoln's (1930) estimates are credible, and depend on capture and marking of geese, which has the added benefit of providing additional population information (e.g., Alisauskas et al. 2011a, Dufour et al. 2012). The method does not provide direct information about the distribution of the population during the nesting season, although it is possible to do so with mark-recapture estimation methods from data acquired during regular banding. There is value in maintaining photographic and other enumeration methods on nesting areas as independent means to monitor changes in distribution of the population as it continues to expand (e.g., Rockwell et al. 2012). However, we recommend that annual pre-season (July or August) capture and marking of geese with legbands in the arctic provides the greatest amount of information about arctic-nesting geese from a single field program. This includes estimates of (1) survival (regional and continental), (2) harvest rate (regional and continental), (3) harvest distribution (regional and continental), (4) production of young and recruitment until August (regional and continental), (5) population size (regional with mark-recapture, continental with Lincoln's method), (6) rate of population growth (direct regional estimation from mark recapture, ad hoc estimation from Lincoln's estimates of abundance). Pre-season banding of geese provides not just the pattern of population change at multiple scales, but has great potential to address the processes (survival, recruitment, and associated ecological covariates) underlying such change. Thus, with adequate attention to numbers of geese marked at several areas, banding may be the most multifaceted and scientifically rigorous single endeavour for assessing status of arctic goose populations at several spatial scales.

Summary

Collectively, survey results convey a consistent picture of growth by the midcontinent population of lesser snow geese and Ross's geese since 1997. Midwinter counts, photographic surveys of nesting

colonies, and Lincoln estimates based on banding and harvest data all indicate that these populations are larger now than they were when conservation harvests were initiated in 1999. Surveys on nesting areas show that population growth has not been consistent across the arctic, and there are indications of slowed growth and even declines at some colonies. For example, photographic survey estimates of nesting snow geese declined between 1997 and 2003-2005 at 3 of 4 nesting areas in the eastern arctic and subarctic (Table 2). On the other hand, independent transect surveys also showed virtually no changes in numbers of post-breeding snow geese from 1996 to 2009 on Baffin Island (Figure 9A), though it appeared that Ross's geese were increasing, albeit at a statistically undetectable rate (9B). We cannot rule out the possibility that nesting snow geese have increased outside of surveyed areas in the eastern arctic, and that those increases have not been detected using the methods employed. Results of transect surveys of snow goose nests at Cape Henrietta Maria, Ontario were consistent with declines indicated by the photographic survey, and dramatic increases in numbers of nesting snow geese and Ross's geese were evident in the central arctic based on photographic surveys of nesting geese, ground estimates of numbers of nests, and regional mark-recapture population estimates during banding. Overall, it appears that numbers of both midcontinent lesser snow geese and Ross's geese have continued to grow, and that this growth is largely being driven by increasing numbers of birds of both species in the central arctic region of Canada.

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MODELING THE MIDCONTINENT POPULATION OF LESSER SNOW GEESE

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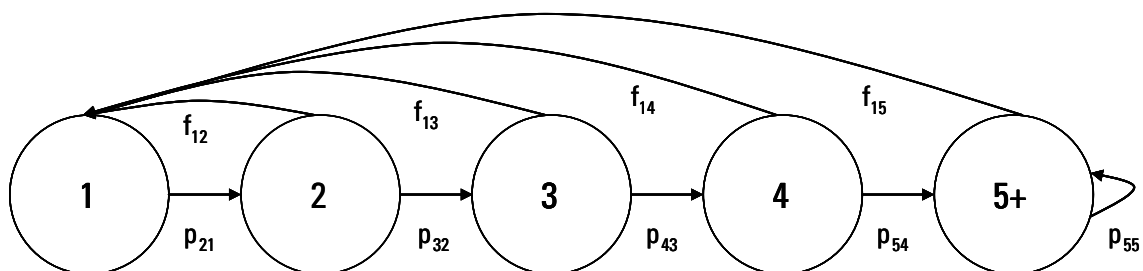
Introduction

The modeling portion of *Arctic Ecosystems in Peril* (Rockwell et al. 1997) depicted how a reduction in the size of the midcontinent population of lesser snow geese requires that the population growth rate be reduced to $\lambda < 1.0$ for some period of time. We also used the model to explore how various combinations of reductions in reproductive success and age-specific survival might achieve this goal. Consistent with the results of an elasticity analysis, it was argued that reductions in adult survival would be a more efficient means of reducing the growth rate to a point where the population should decline. This was particularly appealing because reductions in adult survival could be obtained by increasing hunting mortality through changes in harvest regulations, thus using North American hunters as the main management tool. Although there was subsequent debate over the level of harvest required to achieve management goals (Cooke et al. 2000, Rockwell and Ankney 2000), there was no disagreement over the fact that an increase in harvest would begin shifting the population's dynamics in the right direction.

In this chapter, we use the same basic modeling approach to examine several issues that have emerged since the publication of *Arctic Ecosystems in Peril*. First, we examine the population's projected growth in light of our best estimates of current adult survival. We present this against a backdrop of the possible combinations of survival and reproductive success that control the population's dynamics. We also examine the potential impact of stochastic variation on these projections. Recent research on transient dynamics has shown that rapid shifts in demographic variables, such as the anticipated shift in adult survival, can lead to unanticipated changes in population size related to transient dynamics and momentum (Koons et al. 2005, 2006). We examine the potential impact of momentum on this system. Finally, it appears that different segments of the midcontinent population of lesser snow geese may be subject to different levels of adult mortality. If so, a metapopulation model may be a closer approximation to reality and we explore the ramifications of such a model on both regional and global dynamics as well as elasticity. Finally, we highlight data needs for continued monitoring of the midcontinent population of lesser snow geese.

Projection Model

We used a 5 age class, birth pulse, Lefkovich model to project the midcontinent population of lesser snow geese that corresponds to the following life cycle diagram:



where 1,2,...5+ represent individuals that are produced but not yet 1-year-old, 1 but not yet 2-years-old, through individuals that are at least 5 years old, respectively. The transitions $f_{1,j}$ and $p_{i,j}$ correspond to reproductive input to age class 1 from classes j and the survival of individuals age j to age i over the interval t to $t+1$, respectively. The life cycle diagram is cast as a projection matrix A of the form:

$$A = \begin{matrix} & 0 & f_{1,2} & f_{1,3} & f_{1,4} & f_{1,5+} \\ p_{2,1} & 0 & 0 & 0 & 0 & 0 \\ 0 & p_{3,2} & 0 & 0 & 0 & 0 \\ 0 & 0 & p_{4,3} & 0 & 0 & 0 \\ 0 & 0 & 0 & p_{5+,4} & p_{5+,5+} & 0 \end{matrix} \quad (1)$$

Rockwell et al. (1997) used the same life cycle diagram and matrix but used a post-breeding census approach to parameterize the matrix. Here, we have switched to a pre-breeding census projection since it better corresponds to the timing of breeding ground censuses, avoids any potential confounding of covariance in stochastic situations (Cooch et al. 2003) and allows simpler interpretation of elasticity analyses (Caswell 2001, Cooch et al. 2003). The last can be seen from the actual parameterization in which:

$$f_{1,j} = 0.5 \times BP_j \times TCL_j \times (1-TNF_j) \times P1_j \times P2_j \times (1-TBF_j) \times P3_j \times s_0 \quad (2)$$

$$p_{i,j} = s_a \quad (3)$$

where for age class j

BP is breeding propensity

TCL is the size of the total clutch laid

TNF is the probability of total nest failure

P1 is the probability of egg survival in nests that did not fail totally

P2 is the probability that an egg hatches

TBF is the probability of total brood failure

P3 is the probability that a gosling from a brood that did not totally fail fledges

and

s_0 is the survival probability from fledging to just before the next reproductive effort

s_a is the annual adult survival probability

All of the demographic variables contributing to recruitment are found only in the first row and only adult survival is found in the non-zero entries in the rest of the matrix. Since elasticity accrues for the matrix elements, the sum of the first row's elasticities will yield the overall elasticity for recruitment and the sum over the remaining elements yields the elasticity of adult survival. This contrasts with the situation for a post-breeding census where adult survival contributes to first row elasticities (Caswell 2001). Since the terms in the first-row elements are multiplied together, the lower level elasticity of each age-specific demographic variable is simply estimated as the elasticity of the appropriate matrix cell.

Basic Dynamics

Although substantial effort has gone into estimating the current level of adult survival and whether it has changed in response to the management actions initiated after the publication of *Arctic Ecosystems in Peril*, little effort (or funding) has been centered on monitoring or improving estimates of the demographic variables leading to recruitment. Because they have substantially lower elasticity values (and therefore less potential to change population growth rate), this is not necessarily an unwise decision given limited resources (Caswell 2001). Because of this, we are forced to use the recruitment estimates from the original report as our best baseline estimates for the purposes of this chapter. It is worth noting, however, that preliminary analyses of juvenile to adult ratios in the Canadian fall flight have not substantially changed over a period that begins before the onset of the harvest management actions and continues to the present (Dufour et al. 2012).

The underlying demographic variables vary with age (e.g. Rockwell et al. 1993, Cooch et al. 2001) and are summarized in Table 1. The recruitment estimates across the 5 age classes of our pre-breeding census projection matrix (the first row of A) are:

$$a_{1,j} = [0 \quad 0.08 \quad 0.20 \quad 0.22 \quad 0.24] \quad (4)$$

To provide a better view of the population's potential growth rate should these estimates be high or low, and to examine the population's growth potential over a wide range of combinations of recruitment and adult survival, we estimated growth rate λ over a large portion of the potential parameter space. In doing this, we examined the range of adult survival rates reported in the literature for migratory geese (0.65 to 0.97) and combined those with a scalar change from 0.2 to 3.5 times the recruitment vector given in (4) to obtain representative growth rates. We have summarized these trials in Figure 1 by depicting isobars for all those combinations of recruitment and adult survival leading to population growth rates of $\lambda = 1$, $\lambda = 1.05$ and $\lambda = 0.95$. All combinations of recruitment and adult survival "northeast" of the $\lambda = 1.0$ isobar lead to population growth while all combinations to its "southwest" lead to declines. The large difference in scales of the X and Y axes highlights the fact that it takes greater changes in recruitment than adult survival to change the population's growth rate. This reflects the different elasticities of adult survival versus recruitment (0.87 versus 0.13).

Variable	age class				
	1	2	3	4	5+
BP	0	0.3500	0.7700	0.8300	0.8500
TCL	0	3.3995	3.9500	4.2545	4.4179
TNF	0	0.2550	0.2550	0.2550	0.2550
p1	0	0.9719	0.9677	0.9787	0.9840
p2	0	0.9340	0.9340	0.9340	0.9340
TBF	0	0.0735	0.0735	0.0735	0.0735
p3	0	0.7053	0.7053	0.6659	0.6659
s ₀	0	0.3000	0.3000	0.3000	0.3000

Table 1. Age class specific demographic variables contributing to recruitment of the midcontinent population of lesser snow geese. BP=breeding propensity; TCL=total clutch laid; TNF=total nesting failure; p1=egg survival; p2=hatchability; TBF=total brood failure; p3=fledging probability; s₀=survival from fledging to the next reproductive event. See text for more details and Rockwell et al. (1997) for citation information.

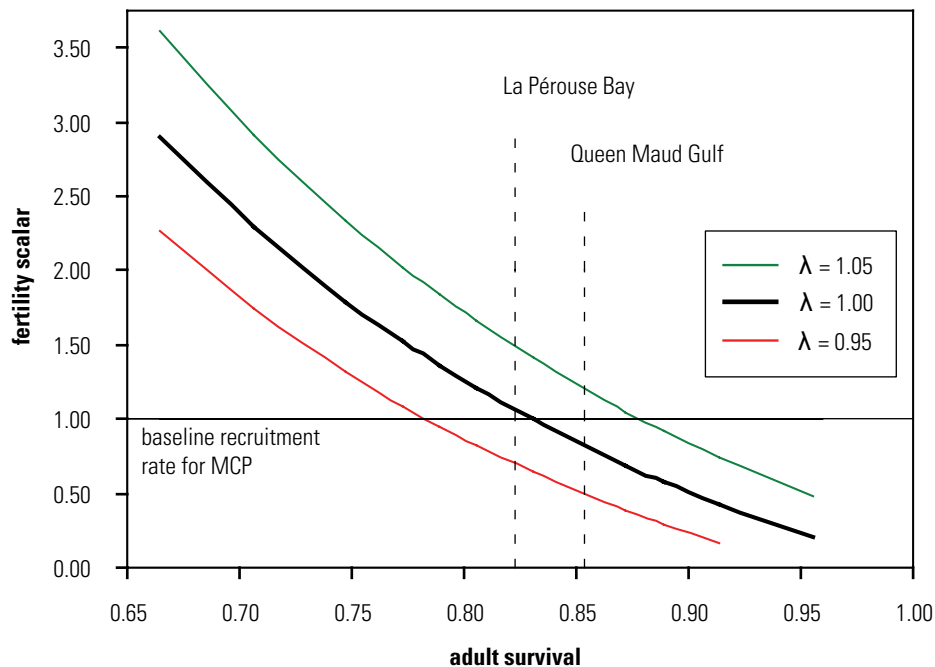


Figure 1. Growth rate potential of the midcontinent population of lesser snow geese. The baseline recruitment rate is the best estimate for the midcontinent population and is the age-specific vector [0, 0.08, 0.20, 0.22, 0.24] (see text). It corresponds to the fertility scalar value of 1 in the Figure. The corresponding values for fertility scalar 2 are [0, 0.16, 0.40, 0.44, 0.48], etc. The current mean estimates of adult survival for Queen Maud Gulf (0.8536) and La Pérouse Bay (0.8227) are indicated by verticals.

As part of their evaluation of the potential impact of altered hunting regulations associated with management of the midcontinent population of lesser snow geese, Alisauskas et al. (2011) estimated

annual adult survival rates for birds leg banded at Queen Maud Gulf, La Pérouse Bay, and other colonies. Here, we computed means for the longest-studied colonies, Queen Maud Gulf and La Pérouse Bay, for the period 1998 to 2003 (beginning in the first year after the management program went into effect) by weighting their annual adult survival estimates by the inverses of their respective standard errors. The mean adult survival rates are 0.8536 for Queen Maud Gulf and 0.8227 for La Pérouse Bay and are indicated in Figure 1 (note that these estimates do not include birds banded at other colonies as in other chapters of this document). While the projected growth rate for populations with a La Pérouse Bay adult survival rate is slightly below $\lambda=1.0$, populations with an adult survival rate like that from Queen Maud Gulf are projected to continue growing. We reexamine this issue in the section titled Metapopulation Dynamics.

Stochastic Population Growth

The modeling presented in *Arctic Ecosystems in Peril* (Rockwell et al. 1997) was based on deterministic projections in which the demographic variables did not change over the time intervals modeled. Although this approach simplified computations and allowed precise analytical estimates of elasticity and the like, it was chosen primarily because data were inadequate to provide robust estimates of overall variances for the variables, and were certainly not sufficient for isolating the process variance (that due exclusively to environmental fluctuations rather than sampling) that is truly meaningful in the real world. Although we still believe that models should be no more complex than available data (cf. Williams et al. 2001), we also realize that there are differences between deterministic and stochastic growth that should at least be examined. For example, it is well established that the relationship between deterministic (λ_1) and stochastic (λ_s) growth rates is $\lambda_1 \geq \lambda_s$, and that the extent of the inequality increases with variance in the demographic variables (assuming no covariance, and no positive relationships between mean and variance) (Caswell 2001). As such, it seems reasonable to examine the potential extent of stochastic effects on the projected growth rate of the midcontinent population of lesser snow geese. Because there is substantially more evidence for variation in demographic variables contributing to reproductive output than to adult survival, we have concentrated our examination to the former (Cooke et al. 1995; Cooch et al. 2001).

To examine the potential difference between estimates of growth rate for deterministically and stochastically projected populations, we used a pre-breeding census version of the projection matrix employed by Rockwell et al. (1997) that had an asymptotic deterministic growth rate of $\lambda_1 = 1.0517$. As explained earlier, the elements in the first row of the pre-breeding census matrix are the age-class-specific products of all contributors to the reproductive output of each age class, beginning with courtship at time = t (breeding propensity) through the production of a clutch, its survival, hatching of eggs, fledging and survival of the offspring to just before the next reproductive effort begins at time = $t+1$. As such, the first-row elements can be viewed as the annual recruitment rates for each age class. Although we do not have precise or robust estimates of variance for the components or their product,

we can examine the potential impact of their variation on population growth by incorporating different levels of variance of recruitment rate into sets of model projections. We accomplished this by sampling independent year-specific values for each first-row element from beta distributions defined by our best mean estimates of age-class-specific recruitment and a range in coefficient of variation ($CV = \sigma / \bar{X}$) for that mean. An example of the sampling distribution for recruitment for age-class 4 adults with a 20% coefficient of variation is depicted in Figure 2.

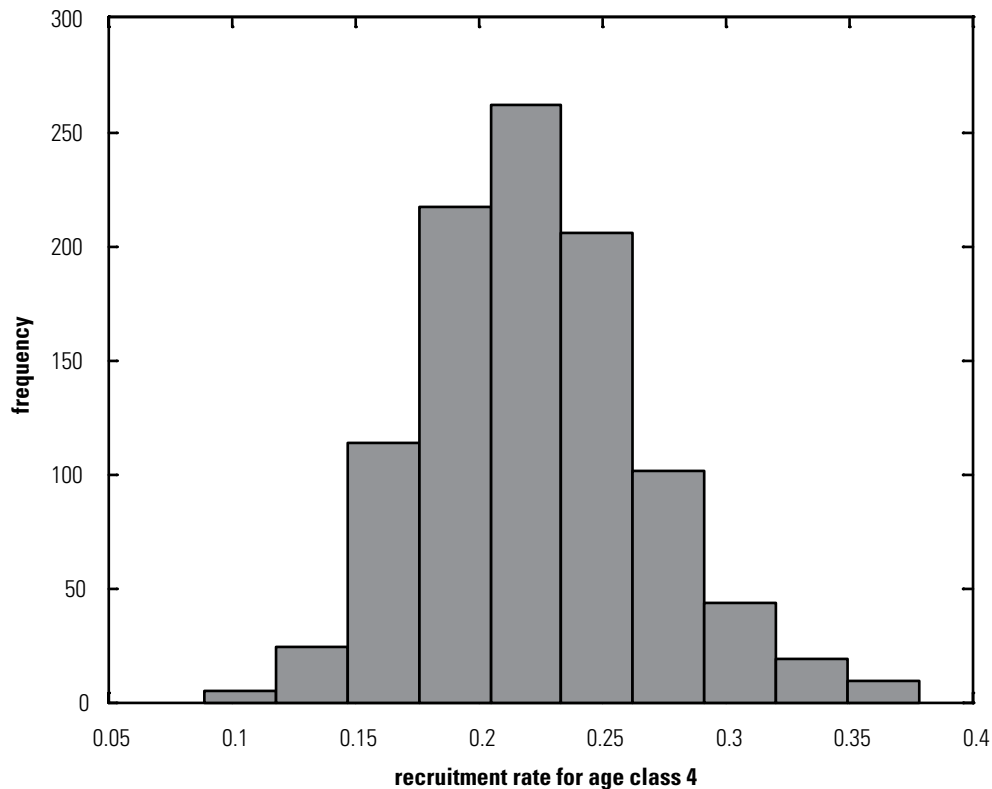


Figure 2. Frequencies of possible recruitment rates for 4-year-old lesser snow geese based on a mean of 0.2225 and a coefficient of variation of 0.2. The values are produced from a beta distribution with the shaping parameters $a = 19.2150$ and $b = 67.1446$ computed from the given mean and coefficient of variance.

Each model projection was initialized with the asymptotic stable age distribution and tracked for 100 years. The stochastic population growth rate (λ_s) was estimated using the Heyde-Cohen equation and verified for conformity with its expected asymptotic stability (Caswell 2001). The projection was repeated using the same parameterized beta distributions 1000 times and the mean and both upper and lower 2.5 percentiles of the λ_s values were recorded as the estimate and precision of stochastic population growth for a given coefficient of variation. We examined the effect of the extent of variation on stochastic growth rate for coefficients of variation ranging from 0.1 to 0.5. This spans ranges of total relative variance reported for many bird species (Clutton-Brock 1988; Newton 1989). It is worth noting that coefficients of process variation only would be lower (e.g. Hitchcock and Gratto-Trevor 1997).

The simulation results are depicted in Figure 3 where the deterministic expectation for the mean projection matrix is included for reference. While it is clear that the relation $\lambda_1 \geq \lambda_s$ holds and that the inequality increases with variation, the actual difference is vanishingly small, being only 0.1% for the projection set with the highest variance (CV=0.5). Further, the deterministic expectation is well within the 95% confidence limits of the stochastic growth rate estimates in all cases. Since the Heyde-Cohen estimator is asymptotically stable, the values of the confidence limits are specific to the 100 year projections, although they are indistinguishable from those based on projections as short as 10 years.

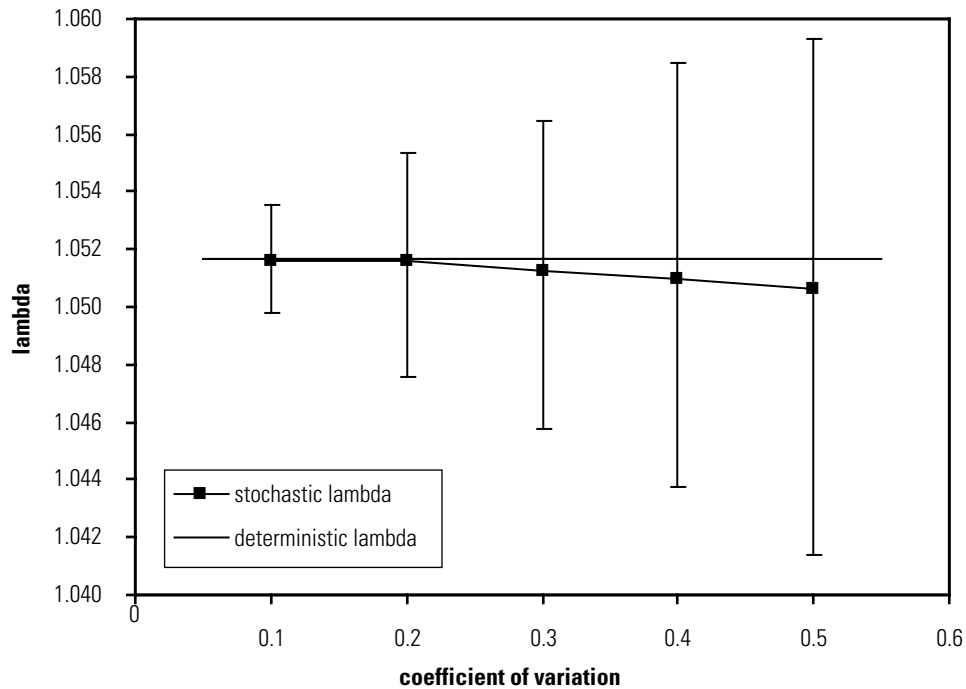


Figure 3. The effect of increasing variance on the stochastic growth rate of a population of lesser snow geese.

Although there is no information on the level of stochastic variation in adult survival, we can gain some insight on its potential impact using an approximation from Tuljapurkar recast in terms of elasticities (eqn. 14.77 in Caswell 2001). Focusing on a single demographic variable the relationship between the natural logs of stochastic and deterministic growth can be approximated as: $\ln(\lambda_s) \approx \ln(\lambda_d) - e_v \times V_v$ where e_v and V_v are the elasticity and variance of the variable of interest. If we assume, as a “worst case” scenario that the variance in adult survival is the same as that in recruitment and focus on the highest level we examined (CV=0.5), then we can simply rescale the difference in the natural logs of deterministic and stochastically projected growth rates by 0.87/0.13, the ratio of elasticities of adult survival and recruitment. Doing this we find a stochastic growth rate of $\lambda_s = 1.0445$ as opposed to $\lambda_s = 1.0506$ for stochastic variance in recruitment. This represents a reduction in the projected growth rate of 0.6% (as opposed to 0.1%) due to stochasticity. As indicated above, this would be a worst case approximation so the anticipated effect of stochastic variation in adult survival on population growth is less.

Given these minor effects of stochasticity in recruitment or adult survival on λ , we feel that the deterministic approximations of population growth and its response to various management options presented in Rockwell et al. (1997) are more than adequate. Because the effects of stochastic variation in recruitment are so small and since real data on actual process variance are so scant, we will use deterministic projections throughout this chapter (cf. Williams et al. 2001).

Transient Dynamics and Momentum

When an age-structured population is initialized with an arbitrary proportion of individuals in each age class, it will grow (or decline) at a variable rate until the proportion of individuals in each age class reaches its “stable age distribution”. At that point, the population as a whole will grow (or decline) at a single rate (or remain stationary at $\lambda=1.0$). The stable age distribution (SAD) and the single, long-term growth rate (λ_1) are formally known as the dominant eigenvector and dominant eigenvalue. Both are properties of the matrix controlling the population’s projection. Until a population reaches its SAD, it displays transient dynamics that are controlled by other properties of the matrix. Transient dynamics are also displayed when a population has reached its SAD but is suddenly subjected to an instantaneous change in one or more of its demographic variables. For example, if a population growing according to its SAD is suddenly subjected to a reduction in adult survival, such as that anticipated from substantial changes in hunting regulations, a period of transient dynamics will ensue.

Under such a pulse perturbation, the projection matrix is instantaneously altered and the corresponding SAD and long-term growth rate are also changed. Assuming no subsequent changes in underlying demographic variables, the new SAD and growth rate will be attained after the transient period. The situation is somewhat more complex, however, if one were to examine the actual population size rather than the age distribution or long term growth rate. In the case of a reduction in adult survival, the SAD anticipated after the perturbation will be shifted to a higher proportion of individuals in the younger age classes. However, the age distribution immediately after the perturbation will reflect the previous SAD and have disproportionately more individuals in older age classes. The mismatch, in this case a surplus of older, highly reproductive individuals (recall the recruitment rate vector) will continue producing during the transient period and the population size will be higher than expected had the population instantly shifted to its new (lower) growth rate. The surplus of individuals is referred to as population momentum (see Caswell 2001 for an overview). The analogy for this example would be a large ship that attempted to turn east at a fixed point from a northerly course. By the time the ship achieved a perfect easterly bearing, it would have drifted north of the point of the turn, a displacement resulting from the ship’s momentum.

In demographic situations, momentum results from a mismatch between the age distribution at the point of the perturbation and the SAD corresponding to the new projection matrix. In the previous example, the shift was to a younger distribution and the temporary surplus of older, and in this case

more productive, adults (Koons et al. 2005). Until that mismatch is resolved by passage through the transient period, the population grows at a higher than anticipated rate. Negative momentum can be generated if the pulse perturbation reduces the reproductive output such that the post-perturbation matrix is older than that existing before the shift. Detailed explanations and examples of both situations are given in Koons et al. (2006).

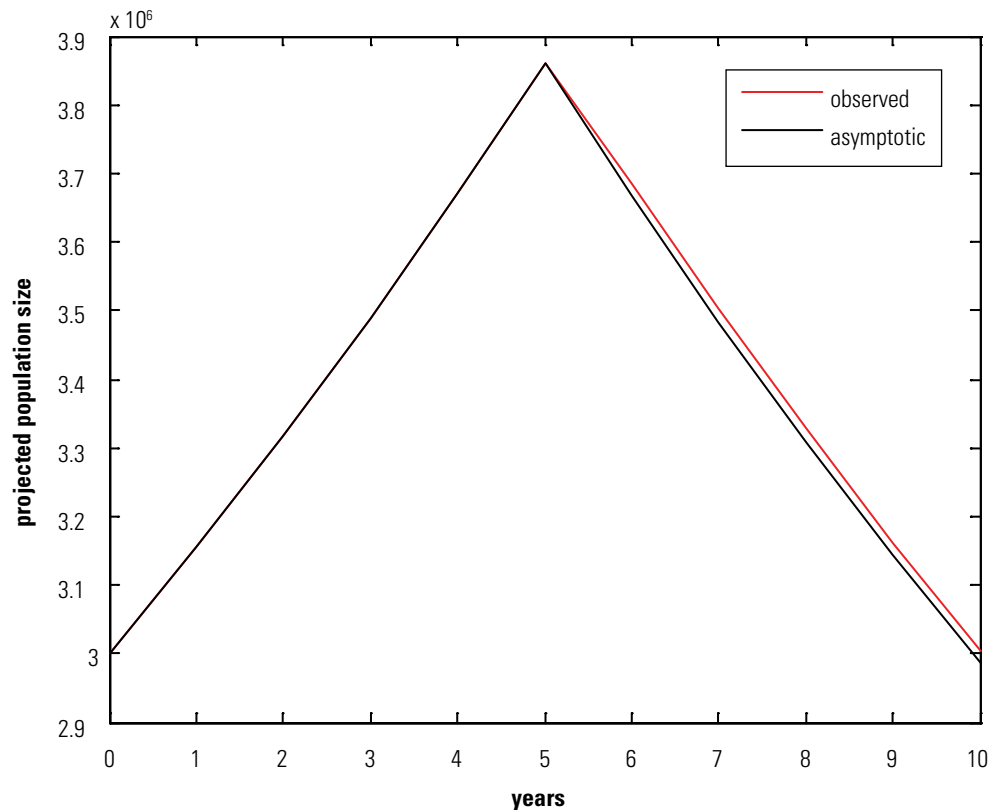


Figure 4. Effect of a shift from $\lambda = 1.0517$ to $\lambda = 0.95$ by reducing adult survival to $0.8897 \times s_a$. The “observed” projection made use of the post-perturbation matrix ($n_{t+1} = A \times n_t$) for $t \geq 5$ while the “asymptotic” projection was based on the asymptotic growth rate of the post-perturbation matrix ($n_{t+1} = \lambda_1 \times n_t$) for $t \geq 5$. See text for further details.

The shift in hunting regulations associated with attempts to control the midcontinent population of lesser snow geese represents a pulse perturbation and in light of the recent work on momentum, it is appropriate to examine the potential effects of the resulting transient dynamics and associated momentum on the population. To examine this, we used a pre-breeding census version of the projection matrix employed by Rockwell et al. (1997) that resulted in growth of $\lambda = 1.0517$ and initialized a population with the SAD of that matrix. After 5 years of projection, we changed the adult survival elements of the matrix to $0.8897 \times s_a$ so that the resulting post-perturbation matrix had $\lambda_1 = 0.95$, one of the desired goals of the management program. We continued projecting the population for 5 years. As a point of reference, we also projected the population from year 5 to 10 by scalar $\lambda_1 = 0.95$, the rate anticipated were there an instant change and no period of transient

dynamics. The results are depicted in Figure 4. As anticipated, the population projected with the post-perturbation matrix and experiencing transients is larger at year 10 although the magnitude of the effect is not terribly large: $N_{\text{observed}}=3,003,341$ while $N_{\text{asymptotic}}=2,986,141$ (a 0.58% surplus in the observed projection).

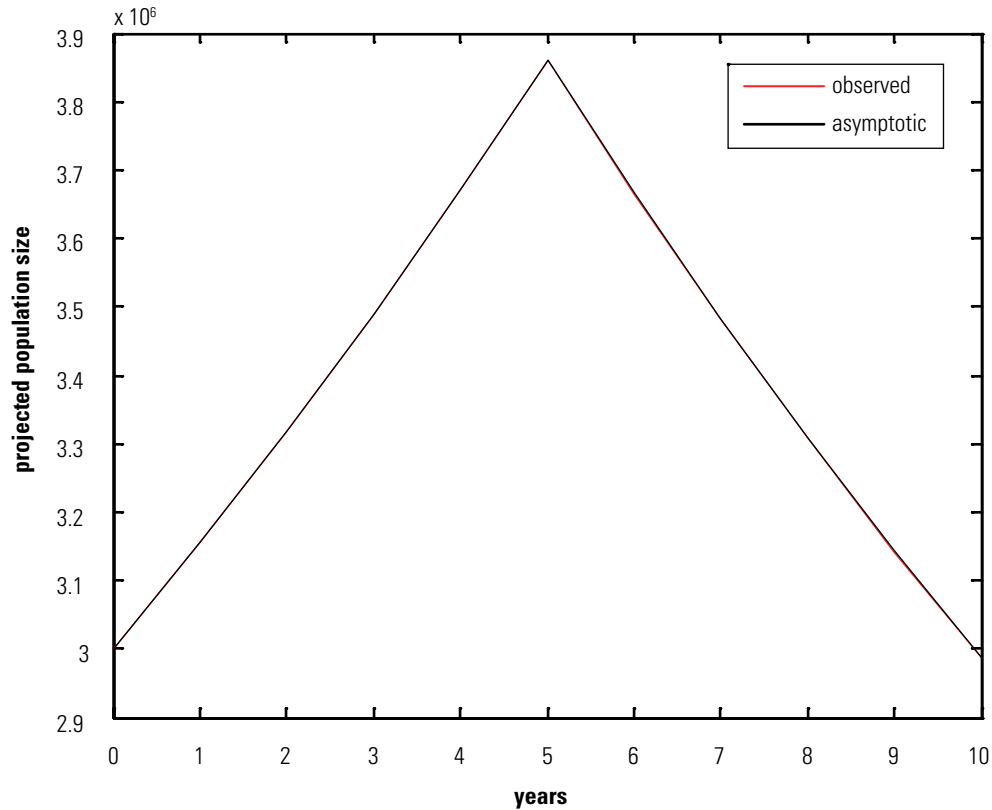


Figure 5. Effect of a shift from $\lambda = 1.0517$ to $\lambda = 0.95$ by reducing adult survival and juvenile survival to $0.90329 \times s_a$ and $0.90329 \times s_0$, respectively. The “observed” projection made use of the post-perturbation matrix ($\mathbf{n}_{t+1} = \mathbf{A} \times \mathbf{n}_t$) for $t \geq 5$ while the “asymptotic” projection was based on the asymptotic growth rate of the post-perturbation matrix ($\mathbf{n}_{t+1} = \lambda_1 \times \mathbf{n}_t$) for $t \geq 5$. See text for further details.

Under the new management regulations, however, hunters have not just increased the harvest of adults but have also increased the harvest of young of the year. As such, they have potentially reduced juvenile survival (s_0) as well as adult survival (s_a). Recall that in a pre-breeding census projection s_0 is included in the first-row matrix elements as part of fertility. We examined the potential effect of this complexity by again initializing a projection with the SAD from baseline matrix but at year 5 we changed adult survival to $0.90329 \times s_a$ and juvenile survival to $0.90329 \times s_0$, a combination resulting in a post-perturbation matrix with $\lambda_1 = 0.95$. (We assumed for simplicity that increased harvest affected adults and juveniles equally.) We again used a scalar projection with $\lambda_1 = 0.95$ as a point of reference. The results are depicted in Figure 5, where it appears that the “positive momentum” of the s_a shift is slightly outdone by a “negative momentum” expected from just an s_0 shift. The actual difference does

not show in the graph. At $t = 10$, $N_{\text{observed}} = 2,985,364$ while $N_{\text{asymptotic}} = 2,986,141$ (a 0.026% deficit in the observed projection).

The negative momentum generated by reducing only s_0 (to $0.3395 \times s_0$) is depicted in Figure 6 for reference. The more extreme momentum response relates in part to the higher proportionate change required in s_0 (a lower elasticity variable) to reduce λ_1 to 0.95. At $t = 10$, $N_{\text{observed}} = 2,934,263$ while $N_{\text{asymptotic}} = 2,986,141$ (a 1.73% deficit in the observed projection).

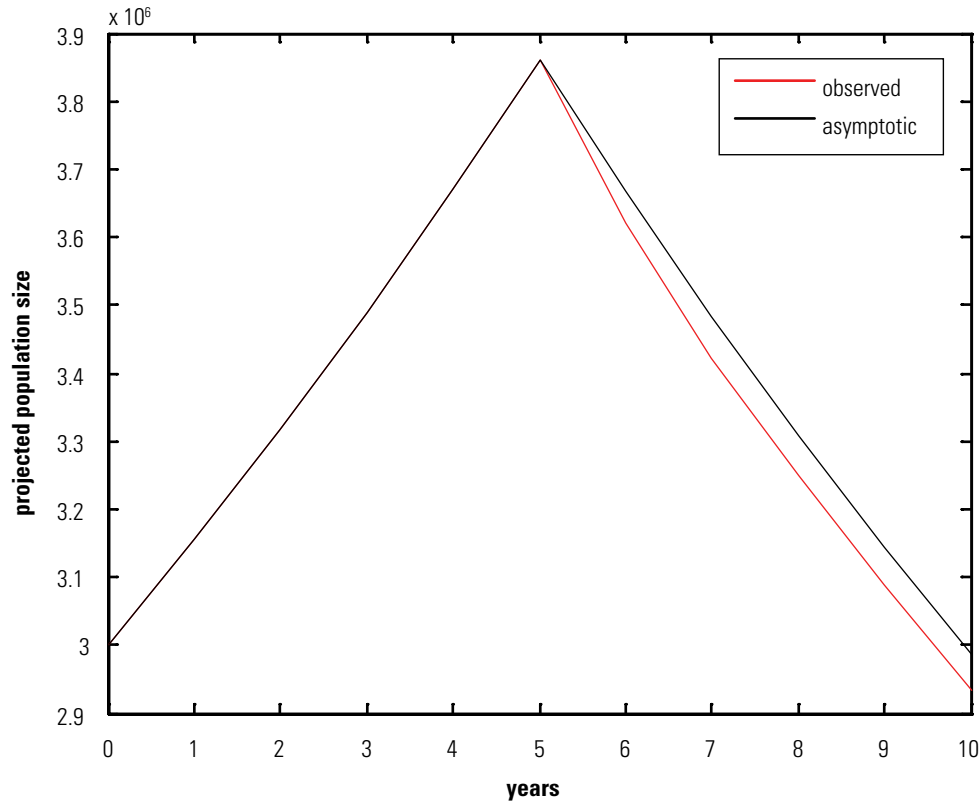


Figure 6. Effect of a shift from $\lambda = 1.0517$ to $\lambda = 0.95$ by reducing juvenile survival to $0.3395 \times s_0$. The “observed” projection made use of the post-perturbation matrix ($n_{t+1} = A \times n_t$) for $t \geq 5$ while the “asymptotic” projection was based on the asymptotic growth rate of the post-perturbation matrix ($n_{t+1} = \lambda_1 \times n_t$) for $t \geq 5$. See text for further details.

While we can show that transient dynamics and momentum may operate as a result of the pulse perturbation nature of the management action, it is not likely to have much of an effect on the dynamics of a closed lesser snow goose population (i.e., with no dispersal). This is in great part the result of the increased harvest altering both adult and juvenile survival leading to positive and negative momentum mitigating each other.

Metapopulation Dynamics

A recent analysis of banding and recovery data (Alisauskas et al. 2011) indicates that adult survival differs between the nesting colonies at Queen Maud Gulf and La Pérouse Bay, the only sites with large-scale, long-term banding data. In the absence of any compensation in recruitment rates, these findings imply that there are localized differences in population growth rates. If the adult survival estimates from these two colonies are representative at some more regional level, then modeling the midcontinent lesser snow geese as a single population could lead to erroneous or at least imprecise estimates of projected population growth. It would be more appropriate to model the system as a metapopulation structure composed of several segments that may be connected through immigration and emigration (henceforth dispersal). It should be noted that we are using the term metapopulation in its broadest, perhaps population genetics, context (see Esler 2000) and not in the restrictive sense of Hanski and Gilpin (1991) that examines only the extirpation and colonization of satellite segments without regard to their population size. It is our intent in this section to examine potential dynamics of a metapopulation approach to modeling the midcontinent population of lesser snow geese and to see how important realistic estimates of key parameters might be. Although our assumptions are simple and in places arbitrary, we feel the results are general and may be quite useful for future management.

Consistent with admonitions that models should not be more complex than available data or biological knowledge will support (Williams et al. 2001), we constructed a basic two segment metapopulation model for which the segments differ only in adult survival. Since our purpose is to examine the potential impact of a metapopulation structure on both local and global dynamics of the midcontinent population, we parameterized this model under two contrasting scenarios. In one, the more proximate basis for the difference in adult survival estimates is related to “East” versus “West” geography (perhaps related to Central versus Mississippi Flyway harvest differences or habitat differences along spring migration corridors) while the other assumes a “North” versus “South” bias possibly related to habitat quality at the nesting colonies or timing of migration. Under the North versus South scenario, much of the midcontinent population migrates through the range of southern nesting colonies and the habitat there appears more impacted which could contribute to an annual survival difference for residents. If geese from more southern colonies began fall migration earlier, they may be subjected to heavier harvest by simply being the first to arrive at hunting grounds (e.g. Alisauskas et al. 2011).

We parameterized the two metapopulation structures using data from Kerbes et al.’s (2006) estimates of nesting colony sizes for the midcontinent population. Our East West Structure assigns all geese from the West Hudson Bay complex and colonies east of there to the East segment and all geese west of there to the West segment. This leads to an initial split of the midcontinent population of 0.81 in the Eastern segment and 0.19 in the Western. Our North South Structure assigns all the geese from the West Hudson Bay complex and colonies south of there to the South segment and all

geese north of there to the North segment. This leads to an initial split of 0.84 to 0.16 (North to South). Although the relative splits for the two structures are about the same, they differ in whether the larger segment is projected to be growing or declining. The most recent evaluation of adult survival (Alisauskas et al. 2011) is more consistent with the North South Structure, although some of the banding data samples are rather small. As will be seen, however, the projected dynamics under the two structures question the veracity of that consistency and the contrast in dynamic structures highlight the data needed to realistically model the midcontinent population in light of survival variation among colonies or broader regions.

A metapopulation model requires some level of dispersal among its segments. There is limited evidence on the mixing of geese from the nesting colonies across broad geographic ranges. We arbitrarily chose a dispersal probability of 0.20 per individual and allowed only age class 1 birds (the most likely dispersers) to move between the segments. Although the dispersal rate is symmetrical between the segments, the numbers of immigrants and emigrants are not since there are initial differences in the sizes of the segments. We assume that adult survival is segment-of-residence specific so that immigrants take on the adult survival value of their “new” segment.

We used a 5-stage, pre-breeding census matrix to project the segments and lacking adequate data on stochastic variation, we used deterministic projections. There is wide overlap in growth rates under deterministic and stochastic projections, as shown above. The matrices for the two segments (W and E or N and S) are:

$$\begin{array}{cc}
 \begin{array}{ccccc}
 & 0 & 0.08 & 0.20 & 0.22 & 0.24 \\
 & 0.85 & 0 & 0 & 0 & 0 \\
 \mathbf{W=N=} & 0 & 0.85 & 0 & 0 & 0 \\
 & 0 & 0 & 0.85 & 0 & 0 \\
 & 0 & 0 & 0 & 0.85 & 0.85
 \end{array}
 &
 \begin{array}{ccccc}
 & 0 & 0.08 & 0.20 & 0.22 & 0.24 \\
 & 0.82 & 0 & 0 & 0 & 0 \\
 \mathbf{E=S=} & 0 & 0.82 & 0 & 0 & 0 \\
 & 0 & 0 & 0.82 & 0 & 0 \\
 & 0 & 0 & 0 & 0.82 & 0.82
 \end{array}
 \end{array}
 \quad (5)$$

with asymptotic growth rates of $\lambda_{\mathbf{W=N}} = 1.0241$ and $\lambda_{\mathbf{E=S}} = 0.9917$ respectively.

The two segments of a given structure were projected simultaneously and we assumed that dispersal between the segments was associated with spring migration such that immigration and emigration occurred immediately before reproduction. Immigration and emigration were implemented using an age-specific dispersal matrix (Gilliland et al. 2009). We present the model projections for the first 10 years since such near-term dynamics are often more instructive and potentially more useful in management situations than are equilibrium or asymptotic solutions (Koons et al. 2006). For completeness, however, we do discuss more long-term and equilibrium dynamics. In monitoring the dynamics of a metapopulation structure, it is necessary to examine growth of both segments as well as the overall metapopulation. Growth of a segment (local growth) in the presence of dispersal is a combination of “intrinsic growth” (that expected from fertilities and survival, e.g. $\lambda_{\mathbf{W=N}} = 1.0241$) and the difference between emigration and immigration. The latter are the product of the dispersal rate

(0.2 in this exercise) and the size of the relevant segment. We use the term “population growth” in its population dynamics sense of lambda which indicates a population is increasing when $\lambda > 1$, declining when $\lambda < 1$ and stable when $\lambda = 1$.

In the absence of dispersal (and as a point of reference), each segment of the East West Structure changes according to its intrinsic growth rate – the East segment declines ($\lambda = 0.992$) and the West segment increases ($\lambda = 1.024$) (Figure 7 solid lines). The dynamics of the metapopulation (Figure 7 solid line) are primarily controlled by the growth rate of the larger segment (East) in the beginning and the metapopulation declines until the two segments are of equal size (approximately 45 years). At that point, the growth rate of the metapopulation increases and is ultimately equal to the intrinsic rate of the West segment. At that point, the East segment would no longer exist.

Under 20% dispersal (Figure 7 dashed lines), the West segment initially grows faster ($\lambda = 1.074$) than expected from its intrinsic growth rate ($\lambda = 1.024$) since the number of immigrants from the substantially larger East segment is greater than the number of emigrants from the West. (Recall that the number of immigrants or emigrants is the dispersal rate times the abundance of the relevant segment.). Similarly, the East segment declines faster ($\lambda = 0.975$) than expected from its intrinsic rate ($\lambda = 0.992$). The dynamics of the metapopulation reflect the combined effects of segment-specific intrinsic rates and the dispersal between the different-sized segments and the metapopulation begins to grow slowly ($\lambda = 1.001$). As population sizes in the 2 segments equalize (about 23 years), the growth rate of the West segment begins to slow and that of the East segment begins to increase as immigration from the growing West segment overcompensates for losses from emigration and its intrinsic declining growth rate. Ultimately, the growth rates of both segments and the metapopulation approach an equilibrium that balances intrinsic rates with immigration and emigration gains and losses at $\lambda = 1.012$. Unlike the situation with no dispersal, both segments are maintained in standard source/sink fashion. The only odd twist is that initially, the East segment, which at $\lambda = 0.992$ would traditionally be called a “sink”, is behaving like a “source” owing to the high relative number of emigrants it provides.

In the absence of dispersal (again simply as a point of reference), each segment of the North South Structure changes according to its intrinsic growth rate – the South segment declines ($\lambda = 0.992$) and the North segment increases ($\lambda = 1.024$) (Figure 8 solid lines). The dynamics of the metapopulation (Figure 8 solid line) are primarily controlled by the growth rate of the larger segment (North) and the metapopulation increases. As the South segment continues to decline (and ultimately disappear), the growth rate of the metapopulation approaches the intrinsic rate of the North segment.

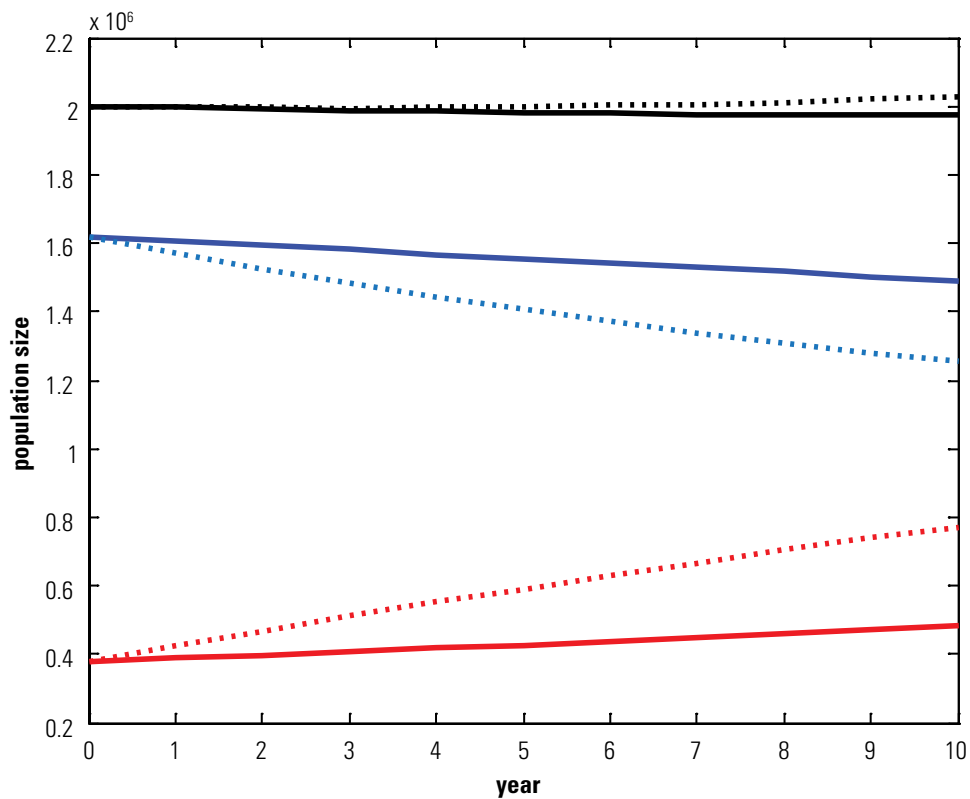


Figure 7. Projections of the midcontinent Metapopulation and its East and West segments assuming an 0.81 (East) to 0.19 (West) initial split of the nesting geese both without (solid) and with (dashed) 20% dispersal of first-year birds. Midcontinent Population (MCP) —; East Segment (East) —; West Segment (West) —. The 10-year realized growth rates based on the Heyde-Cohen equation (Caswell 2001) are: with no dispersal MCP $\lambda = 0.9986$; East $\lambda = 0.9917$; West $\lambda = 1.0241$; with dispersal MCP $\lambda = 1.0013$; East $\lambda = 0.9747$; West $\lambda = 1.0736$. (See text for more details.)

Under 20% dispersal (Figure 8 dashed lines), the South segment increases ($\lambda = 1.068$) since immigration from the larger, growing North segment overcompensates for its intrinsic growth rate ($\lambda = 0.992$) and its emigration. Growth of the North segment is less than expected ($\lambda = 1.004$) from its intrinsic rate ($\lambda = 1.024$) since the number of emigrants is far greater than the number of immigrants. The initial growth of the metapopulation ($\lambda = 1.017$) reflects the combined effects of segment-specific intrinsic rates and the dispersal between the different-sized segments. Since growth of the South segment reflects overcompensation of its intrinsic decline overbalanced by immigration from the North segment, it remains smaller and the two segments eventually reach an equilibrium where intrinsic growth (and decline) are balanced by immigration and emigration from appropriately-sized segments. At that point, both segments and the metapopulation grow at the same rate of $\lambda = 1.0121$. Again, both segments are sustained in a source/sink fashion.

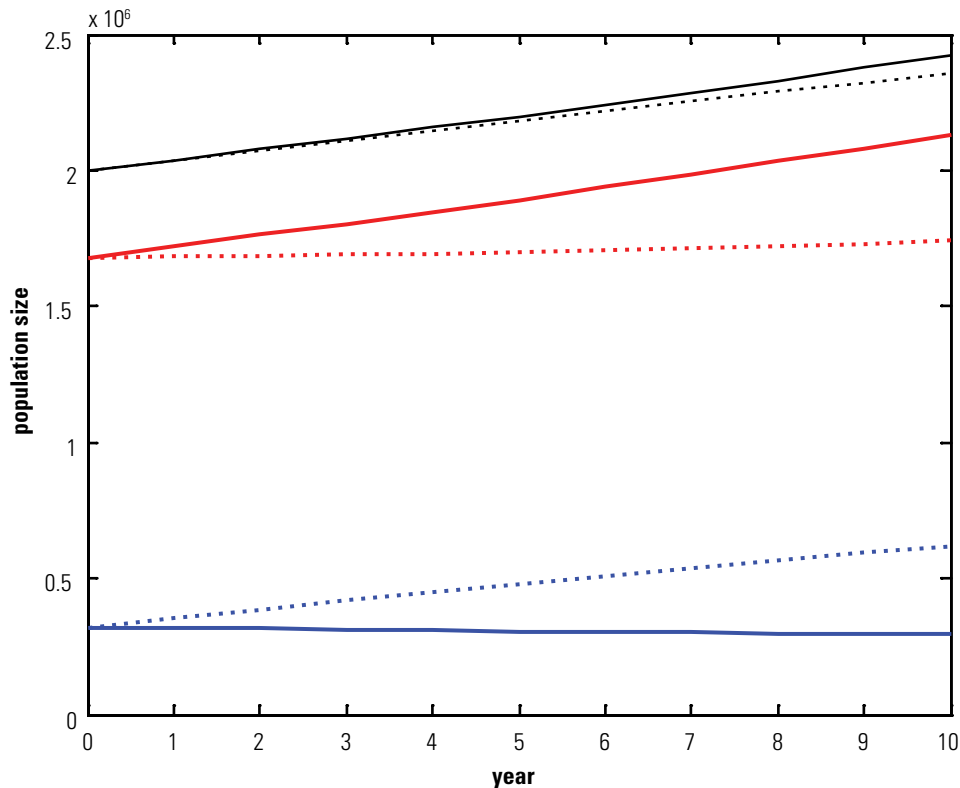


Figure 8. Projections of the midcontinent Metapopulation and its South and North segments assuming a 0.84 (North) to 0.16 (South) initial split of the nesting geese both without (solid) and with (dashed) 20% dispersal of first-year birds. Midcontinent Population (MCP) —; South Segment (South) —; North Segment (North) —. The 10-year realized growth rates based on Heyde-Cohen equation (Caswell 2001) are: with no dispersal MCP $\lambda = 1.0195$; South $\lambda = 0.9917$; North $\lambda = 1.0241$; with dispersal MCP $\lambda = 1.0167$; South $\lambda = 1.0681$; North $\lambda = 1.0036$. (See text for additional details.)

Although a complete analysis of the dependency of these dynamics on dispersal probability is beyond the scope of this chapter, we did examine the dynamics over a set of dispersal probabilities ranging from 0.1 to 0.4 to gain some insight of the robustness of the pattern and extent of shifts in local growth rates related to our arbitrary dispersal probability of 0.2. For the East West Structure, growth of the West segment increased over a range from $\lambda = 1.05$ to $\lambda = 1.09$ while that of the East Segment decreased over a range from $\lambda = 0.98$ to $\lambda = 0.96$ (for dispersal ranging from 0.1 to 0.4). For the North South Structure, growth of the South segment increased over a range from $\lambda = 1.03$ to $\lambda = 1.10$ while that of the North segment decreased over a range from $\lambda = 1.01$ to $\lambda = 0.99$. For both structures, the pattern of the shifts in local growth rate related to dispersal is the same over a four-fold range of dispersal values. While there are some differences in the extent of shifts as a function of the dispersal probability, it is clear that in both cases, the near-term growth rates of the initially smaller segment are substantially higher than their intrinsic potential. The source/sink dynamics of the metapopulation structures described above thus seem to be reasonably robust to differences in actual dispersal probability, at least over the range examined.

Although the two metapopulation structures we examined were somewhat hypothetical and the levels of dispersal were arbitrary, the dynamics of the systems are instructive and highlight the interplay between intrinsic growth rates, apportionment of the midcontinent population and dispersal. It is clear that local dynamics are not a simple function of local intrinsic growth characteristics nor are local dynamics necessarily predictive of more global metapopulation dynamics. Over the long-term (>50 years) and under a given level of dispersal, both structures ultimately reach the same asymptotic growth rate. Since that rate is a composite of intrinsic rates of the segments balanced by equilibrium levels of immigration and emigration between them, the overall asymptotic growth rate is lower than that projected for the more rapidly growing segment. This is typical of source/sink systems.

The near-term dynamics are more interesting and are more likely something managers can measure and respond to. For example, under the East West Structure, the West segment is projected to grow at a rate far in excess of its intrinsic expectation, owing to the disproportionate input of immigrants from the slowly declining East segment. This result is consistent with recent observations at the Queen Maud Gulf colony whose apparent growth rate has been $\lambda = 1.08$ (R.T. Alisauskas, personal communication), a value far greater than its projected intrinsic rate $\lambda = 1.02$ but similar to the projections here for the West segment under dispersal ranging from 10% to 40%. By contrast, under our North South Structure, the smaller (and intrinsically declining) South segment is projected to grow rapidly while the larger segment is projected to be nearly stable. This is inconsistent with estimates at both La Pérouse Bay and the southern Hudson and James Bay colonies which are stable or declining (K.F. Abraham, personal communication) and at Queen Maud Gulf. One could argue that from a metapopulation view, apportioning the midcontinent population into segments for which the larger one has an intrinsic growth rate less than 1 is more consistent with available data, at least for near-term dynamics over this range of dispersal values.

While such speculation is interesting and even testable, the real point of this section is to highlight that metapopulation dynamics are not necessarily indicative of local intrinsic growth rates or local dynamics. Rather, they are a composite of local intrinsic growth rates and the relative impacts of immigration and emigration. The latter, in turn, are a function of individual dispersal probabilities and the relative sizes of donor and recipient segments. Given there are differences in adult survival among the northern breeding colonies of the midcontinent population of lesser snow geese, it is crucial that we obtain estimates of the relative size of each segment with a different survival rate and estimates of dispersal among them. It seems clear that any further attempt to model or project the midcontinent population of lesser snow geese must rely on a metapopulation approach with robust estimates of these parameters.

Elasticity Analyses

Elasticity analysis is a prospective tool that allows one to examine how equal proportionate changes in demographic characters alter a population's future growth rate. The technique is not intended to

provide insights as to how the population came to possess a particular set of demographic character values nor their associated growth rates. Rather, elasticities of the demographic characters should be viewed as measures of the relative change in the population growth rate that can be achieved by manipulating those characters. As such, they offer managers a tool with which to weigh the outcomes of various possible actions and choose accordingly. The final choices, however, must be tempered by biological and social realities since some scenarios may be intractable while others are financially not feasible (cf. Rockwell et al. 1997; Schmutz et al. 1997).

Using the best available demographic data for the midcontinent population of lesser snow geese, Rockwell et al. (1997) showed that the elasticity of adult survival was substantially higher than that of any other demographic character. Because elasticity estimates can be sensitive to precise combinations of values of demographic variables and emergent growth rates, they showed further that the result was robust over a wide range of demographic characters that led to growth rates ranging from $\lambda=1.008$ to $\lambda=1.107$. Those evaluations used analytical solutions that relied on asymptotic (equilibrium) conditions. Subsequent perturbation analyses incorporating stochastic variation and near-term (5 to 10 year) simulations revealed the same pattern of relative effects for the demographic variables (Rockwell, unpublished). So too did models incorporating density-dependent effects, although in those scenarios one must examine the relative effects of equal proportionate changes of the demographic variables on the reactivity of growing or declining populations to the perturbation or the displacement of a perturbed equilibrium ($\lambda=1.0$) population and its return to equilibrium (Rockwell, unpublished).

Mills and Lindberg (2002) imply that failure to include immigration and emigration in the lesser snow goose model used by Rockwell et al. (1997) calls into question the veracity of the analyses and conclusions reached. In their reevaluation, they used a more retrospective approach (Life-stage Simulation Analysis) and concluded that including immigration and emigration (set to be equal) can change the relative reactions of the La Pérouse Bay population to changes in other demographic variables. They argued: "...this example demonstrates that connectivity, or movement, is nontrivial in terms of its impact on λ for this population" (p. 354). While this could be true locally, it ignores the fact that the original analysis was for the entire midcontinent population. However, their point raises an interesting issue, especially in light of current survival data that indicate the midcontinent population may actually be a metapopulation structure whose segments are controlled by different levels of at least some of the demographic variables.

To examine this further, we used a perturbation approach to evaluate the relative effects on metapopulation growth of equal proportionate changes in demographic variables including recruitment and adult survival within segments as well as dispersal among segments. We used the two metapopulation structures described in the previous section that apportion the midcontinent population into an East West Structure and a North South Structure. Intrinsic projected growth rates of the segments within the two structures are based on the estimates of recruitment and survival

described above, and are: $\lambda_{W,N} = 1.0241$ and $\lambda_{E,S} = 0.9917$. Recall from the previous section that for the East West Structure, the larger (East) segment (0.81 of the total initially) has the lower growth rate while for the North South Structure the larger (North) segment (0.84 of the total initially) has the higher growth rate. Consistent with Mills and Lindberg (2002), we assumed immigration and emigration for each segment (henceforth dispersal) involved a constant proportion of individuals and in the absence of real data allowed the proportion of individuals moving from one segment to the other to be one of several values (0.05, 0.10, 0.20, and 0.30).

As in the previous section, the model followed a time line that began with dispersal followed by birth-pulse reproduction and survival. The latter two were subsumed in a 5 stage class, Lefkovitch, pre-breeding census projection matrix. Each segment was initialized with its asymptotic stable age distribution and the metapopulation structure was projected for 10 years. The growth rates of both segments and the overall metapopulation were estimated using the Heyde-Cohen equation (Caswell 2001). We perturbed dispersal, adult survival of each segment and first-year (juvenile) survival (s_0) of each segment in turn by 1% from their baseline values (recall we used 4 “baseline” values of dispersal). We used juvenile survival as a way of perturbing recruitment in each segment since it is a multiplicative component of the pre-breeding census matrix’s first row and is not itself dependent on stage class. The relative effects of each perturbation on the metapopulation growth rate were evaluated as:

$$re = (\lambda_{\text{baseline}} - \lambda_{\text{perturbed}}) / \lambda_{\text{baseline}} / 0.01$$

following Schmutz et al. 1997, who explained that these are equivalent to lower level elasticities of the demographic variables being perturbed. It is important to note that these are near-term relative effects (see Koons et al. 2005) in that they are based on growth projected for just 10 years rather than at the systems equilibrium (asymptotic relative effects). We chose this time frame since it provides a better overview of the responsiveness of the system changes imposed by the management plan under review.

The results of the perturbation trials are summarized in Figure 9 where several trends are clear. First, the relative effect of dispersal is near zero and lower than the relative effects of any other demographic variables. Second, the relative effect of adult survival of the “source” segment is highest for both the East West and North South structures and is higher than the relative effect of the smaller segments’ adult survival. Recall that the source segment is the larger of the two in both structures and is thus initially providing the bulk of the dispersers. As such, its highest elasticity parameter tends to control overall dynamics at least in the near term. This difference in the relative effect of adult survival of the 2 segments declines as dispersal increases for both structures. This reflects the more rapid approach to equilibrium conditions of relative size, immigration, emigration and intrinsic growth expected with faster mixing of the two segments. Finally, the relative effects of recruitment are less than that of adult survival in all situations.

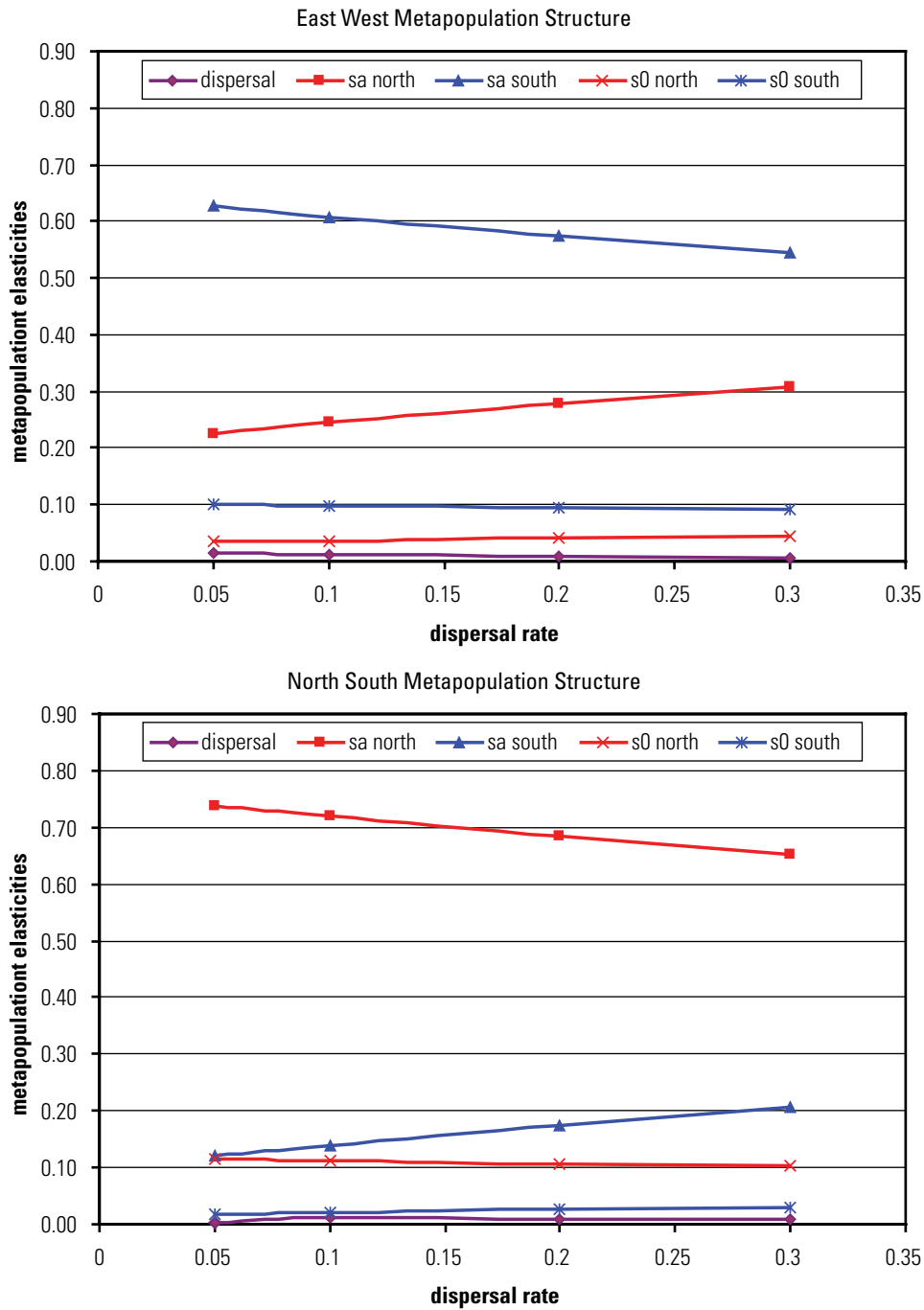


Figure 9. Relative effects of equal proportionate changes in the recruitment (s_0) and adult survival (sa) of the segments of the metapopulation structures and dispersal between them for both the East West and North South metapopulation structures.

The conclusion that adult survival has the greatest proportionate effect on the growth of lesser snow geese (Rockwell et al 1997) is valid whether the midcontinent population is treated as a single population or a metapopulation structure. Dispersal within the metapopulation has no effect on this conclusion.

Conclusions and Data Needs

Although we agree with Williams et al. (2001) that models should not be more complex than the available data, we are also believers in the famous admonition by Box (1979) that “all models are wrong, some models are useful”. Thus, in a spirit of realistic pragmatism, we have endeavored to examine the dynamics of the midcontinent population of lesser snow geese with a series of models that are simplistically consistent with available data while being mindful of potentially more complex biological underpinnings and the overall concerns of managers. Where actual data were not available, we explored the effects of a realistic range of possibilities. Several generalities emerged from these explorations and a few key data needs became apparent.

Regardless of which demographic variables changed historically and led us to a population that is numerically outstripping its resources, adult survival emerges as the vital rate that holds the most potential for changing the growth rate of the midcontinent population of lesser snow geese. If it is reduced through increased hunter harvest, then juvenile survival, a component of recruitment, will also be reduced since juveniles are a part of the overall hunter harvest. Given the current estimates of adult survival and recruitment, the projected growth rate of the midcontinent population of lesser snow geese is still positive with $\lambda > 1.0$. If a reduction in the midcontinent population is to be achieved using hunter harvest, that harvest will have to be increased. Since reduction of juvenile survival has a smaller effect on reducing the population growth rate, every attempt must be made to maintain a high proportionate harvest of adults. It is also important to stress that the observed population growth rate is a consequence of the current values of survival and recruitment. If the size of the midcontinent population is reduced through means other than a reduction in survival and/or recruitment (e.g. a one-time removal of a large portion of the population), the surviving population will still have the same positive growth rate ($\lambda > 1.0$) unless survival and/or recruitment are also reduced.

Although analysts and modelers prefer to have precise estimates of all variables that enter their projections, certain variables become the driving forces by their disproportionate effects on overall dynamics. Those are the variables for which robust estimates with high precision are necessary. From our current work, three variables emerge as critical for accurate monitoring and modeling of this system. The first is adult survival which, as shown, has a profound impact on dynamics of a single population or of a metapopulation structure and its segments. The second is the relative proportion of the midcontinent population belonging to metapopulation segments that have different adult survival rates. Without knowing these relative proportions, it is not possible to accurately project the overall growth rate of the entire metapopulation for even a single year. The third is the dispersal rates of individuals between the segments. These rates are required for multi-year projections and may also serve as a character that could be manipulated in aid of management. For example, in the absence of any dispersal, the fastest growing segment of a metapopulation structure becomes disproportionately larger. If dispersal from that segment to a slower growing segment could be achieved, the growth rate of

the overall metapopulation would be lowered. If dispersal was to a declining segment, then the overall metapopulation could actually be reduced. In that vein it is also critical to see if dispersal is primarily limited to young birds, as assumed here, or if all age classes do or could be enticed to disperse.

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Photo credit: Andrew Dierks

CONCLUSIONS

Unprecedented management actions were initiated in 1999 to reduce damage caused to arctic and subarctic ecosystems by the foraging activities of increasing numbers of midcontinent lesser snow geese and Ross's geese (Batt 1997, Moser 2001). Most of these actions were aimed at reducing survival of adult geese through increased harvest by hunters throughout the range of the midcontinent population, which was thought to be the most efficient means of reducing population size (Rockwell et al. 1997). Hunting regulations were liberalized during regular seasons, traditional hunting restrictions (e.g., prohibition on use of electronic calls, requirement for plugged shotguns, bag and possession limits) were relaxed or removed to promote increased harvest, and habitat management regimes on some refuges were altered to increase exposure of the birds to hunting outside of refuge areas. Additional amendments to the Migratory Birds regulations in Canada and the United States were made to allow conservation harvests of such overabundant species outside of hunting seasons. Conservation harvests aimed at controlling overabundant species are distinguished from hunting seasons and are authorized under regulations permitting take of migratory birds causing damage. Coincident with these management actions, monitoring programs were established or expanded to

evaluate changes in habitat, harvest, survival and productivity of the geese, as well as potential changes in their abundance and distribution in response to management actions. This report summarizes our analysis of available data to determine the effects of management actions on population status of midcontinent lesser snow geese and Ross's geese and their staging and nesting habitats in Canada.

Harvest of lesser snow geese and Ross's geese increased substantially before and during the period of conservation actions, but after initial increases in the early years, the kill by hunters has declined (Alisauskas et al. 2006a, 2011, 2012; Dufour et al. 2012, Johnson et al. 2012). Reasons for this decline are unclear, but similar patterns have been observed following the introduction of new hunting opportunities for other game birds as hunter interest waned because they reached a point of satiation, or birds began to respond behaviorally to increased harvest pressure (e.g., Sharp 1993, Vaa et al. 1999, Calvert et al. 2007). Similarly, harvest rates (i.e., the proportions of each population that are harvested annually) have continued to decline since implementation (Alisauskas et al. 2011, 2012), as the kill by hunters has not kept pace with increases in population size that have occurred. Regardless of specific harvest objectives, increased harvest opportunities did not result in attainment of even the more conservative goals that were originally proposed by Rockwell et al. (1997). Failure to meet harvest objectives likely resulted in part from an underappreciation of population size in the past (Alisauskas et al. 2011, 2012), leading to an underestimate of the harvest level necessary to meet management goals.

We found evidence of declining survival of adult lesser snow geese from the southern-most nesting colonies, and this was associated with earlier migration timing that led to higher harvest rates of the southern cohort, possibly in combination with density-dependent effects on survival that were a result of degraded habitat on southern nesting areas. Survival of arctic-nesting snow geese, constituting 90% of the midcontinent population, remained high and overall survival rates remained above the level required to induce a population decline. Survival of adult lesser snow geese from subarctic colonies averaged ~5% lower than that of birds from nesting colonies in the arctic (Dufour et al. 2012), and this may have been partly responsible for the reduced growth rate of the population since the start of conservation actions (Alisauskas et al. 2011). Increased harvest has not resulted in reduced survival of Ross's geese, whose numbers have continued to increase at a higher rate than have lesser snow geese since the start of conservation actions in 1999 (Alisauskas et al. 2006a, Alisauskas et al. 2012, Dufour et al. 2012). Unlike in greater snow geese (Reed and Calvert 2007), there was no indication that increased spring conservation harvest reduced productivity of midcontinent lesser snow geese based on age ratios in the fall harvest (Dufour et al. 2012). Continued expansion and productivity of agro-ecosystems, and the nutritional subsidy that they provide, may further increase survival and productivity of these geese.

Indices of abundance and estimates of population size suggest that growth of midcontinent lesser snow goose and Ross's goose populations has continued, though perhaps at a reduced rate. Use of banding and harvest data to estimate population size of midcontinent lesser snow geese and Ross's

geese shows promise for use as a monitoring tool. Our use of the Lincoln-Peterson estimator, first applied to lesser snow geese by Boyd (1976), suggested that population size of midcontinent light geese may be much higher than previously thought (Alisauskas et al. 2009; 2011; 2012), and this likely explains why increased harvest has not led to expected declines in population size. Population trajectories vary from colony to colony, and suggest that growth within nesting regions of the midcontinent population has been uneven, but that most recent growth for both species appears to be occurring in the central arctic where there may be room for considerably more expansion inland into freshwater wetland habitats. Information from photographic and other surveys on nesting areas were generally consistent with observed patterns of survival, indicating reduced growth or declines in some southern colonies of lesser snow geese, and considerable growth in some arctic colonies of both lesser snow geese and Ross's geese. Modeling of population trajectories under different metapopulation structures and assumptions about dispersal confirmed that adult survival remains key to regulating population size, and that knowledge of population structure, dispersal, and survival may be important to understanding observed variation in growth of different sub-units of populations (Rockwell et al. 2012). We predict continued growth of lesser snow goose and Ross's goose populations where favorable habitat conditions still exist, particularly in the central and western arctic portions of their present breeding range.

Evidence suggests that damage to staging and nesting habitats in coastal areas along James Bay and Hudson Bay has continued, and that the area affected by the foraging activities of the geese continues to expand (Abraham et al. 2012). Much of the salt marsh habitat along this coast has been severely degraded over time, and impacts to adjacent freshwater marshes are continuing as birds move inland to feed, away from the most severely degraded areas along the coast. Our knowledge of habitat conditions farther north, where most of the midcontinent populations of lesser snow geese and Ross's geese nest, remains inadequate. However, observations suggest that many light geese that nest north of 60° N latitude do so at inland locations, and rely much more on freshwater marshes than salt marshes (e.g., Slattery and Alisauskas 2007), compared to those in the southern subarctic stratum. There is evidence from at least some northern nesting areas, such as those on Southampton Island and near large colonies in the Queen Maud Gulf region, that habitat damage has occurred there also, and that Ross's geese contribute to the degradation where they exist in large numbers (e.g., Alisauskas et al. 2006b, Abraham et al. 2012). However, there remain vast expanses of apparently suitable brood-rearing habitat, particularly in the central arctic, that are largely unoccupied by light geese, so far. We have limited knowledge of the use of staging habitats north of agricultural regions in prairie Canada, and this limits our ability to document and/or predict habitat degradation caused by lesser snow geese and Ross's geese as their distribution expands and abundance increases over time.

Research and Management Considerations

To date, management actions have not been successful in reducing populations of midcontinent lesser snow geese and Ross's geese, though there is some evidence that growth rates may have slowed over the past decade. Several research and management issues emerged as a result of this review:

- Habitat monitoring programs have not been adequate to estimate carrying capacity of arctic habitats used by geese. Evaluation of available habitat, the extent of habitat damage caused by lesser snow geese and Ross's geese in arctic (i.e., north of 60°N latitude) staging and nesting areas, and recovery potential of degraded habitat is recommended. Additional investigation of impacts on other species inhabiting these ecosystems is also warranted.
- Our knowledge of habitat use by lesser snow geese and Ross's geese north of agricultural staging areas in prairie Canada is limited, and so it is not possible to know the extent of habitat damage that may be occurring outside of coastal salt marsh habitats along the coasts of James Bay and Hudson Bay, which are comparatively well monitored. Detailed studies of goose distribution and habitat use during northward migration in late spring and during southward migration in fall would be beneficial.
- Harvest surveys for light geese should be maintained and improved to better account for spring conservation harvests, and to better estimate species composition of harvest throughout the year. Pooling Conservation Order harvest estimates from individual state-conducted surveys provides a poor estimate of harvest. Alisauskas et al. (2006a, 2009, 2011) derived a method for estimating Conservation Order harvest of both Ross's and lesser snow geese by using the ratio of bands recovered during the Conservation Order harvest to bands recovered during regular seasons. However, a single nationwide harvest survey, including a parts collection survey that extends through the Conservation Order, should be implemented. Adjustments to estimation procedures may need to be pursued to account for any biases inherent in current survey protocols (e.g., Alisauskas 2012, Padding, *in press*). Improvements to harvest estimates are expected to improve the accuracy of population estimates that are based on banding data and harvest estimates.
- Ongoing banding of representative samples of lesser snow geese and Ross's geese on nesting areas should continue. Banding data, in conjunction with information from harvest surveys, can be used to estimate population size, while also providing information on harvest rates, migration chronology, survival, changes in distribution, and other parameters of interest to population managers (e.g., recruitment to fall flight).
- Regional changes in nesting distribution of midcontinent lesser snow geese and Ross's geese are apparent, and future changes are predicted, as some colonies expand, others are newly established or discovered, and others decline. Periodic photographic surveys of nesting colonies and ongoing documentation of new colonies should be continued to monitor future changes in nesting

distribution of both species, and to relate these changes to estimates of habitat quality and availability.

- Current efforts to increase harvests of midcontinent lesser snow geese and Ross's geese should be maintained, and expanded wherever possible. Consideration should be given to regulatory changes or other incentives that promote participation in light goose hunting, and offer hunters additional flexibility for transport, possession, gifting, and perhaps sale of legally harvested birds (e.g., Johnson 2003).
- Ross's geese have increased at a faster rate than have lesser snow geese since initiation of conservation actions in 1999 (Alisauskas et al. 2012), and appear to have increased even in areas where extensive damage caused by lesser snow geese was documented previously (e.g. west Hudson Bay; Kerbes et al. 1990, Caswell 2009). Ross's geese should be designated as an overabundant species in Canada, and spring conservation harvests should be expanded to allow take of both Ross's geese and lesser snow geese throughout the midcontinent range (Alisauskas et al. 2006a).
- It is clear that the goal of reducing midcontinent lesser snow goose and Ross's goose numbers is not likely to be achieved through increased harvest by hunters alone, at least with current hunter numbers, even if additional regulatory changes aimed at increasing harvest were implemented. Harvest rates would have to increase 3.6- to 4.8-fold to reduce current adult survival rates to levels below 80% such that the populations decline. Unfortunately, harvest rates are currently declining. Unless hunter numbers and harvest rates increase, reducing these populations to levels that could be controlled through hunting in the future will likely require implementation of a large scale direct control program (e.g., Johnson and Ankney 2003).
- The existence of agricultural subsidies in the form of waste grain is beyond the ability of wildlife management agencies to control, and many species benefit from those subsidies besides geese. Thus, the underlying conditions that have led to runaway growth of these populations are expected to remain in place well into the future. In the 1970s, much lower populations of both species underwent dramatic growth, so management policies allowing very liberal harvest would still be required to maintain population sizes at manageable levels even after any population control actions are successfully implemented. We recognize that there are considerable risks and uncertainties associated with implementation of direct control programs at such a large scale, not the least of which involve logistical considerations and cost (e.g., Alisauskas and Malecki 2003), as well as public acceptance.

In the absence of drastic population control measures, continued increases in population size of midcontinent lesser snow geese and Ross's geese are expected to lead to additional destruction of arctic and subarctic wetland habitats used by geese and other species. The difficulty of reducing migratory goose populations once they have reached such a large size points to the need for earlier,

more aggressive harvest management policies when goose populations exceed objectives and/or show signs of sustained increases over time. Our collective experience suggests that it is easier to recover goose populations that reach low levels than to reduce them after they experience runaway growth.

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APPENDICES

Assessment of Harvest from Conservation Actions for Reducing Midcontinent Light Geese and Recommendations for Future Monitoring Tables

Table 1. Regular hunting season light goose regulations in Manitoba and Saskatchewan, 1971 – 2007. Ranges of values reflect differences among zones within the provinces.

Year	Manitoba			Saskatchewan		
	Season length (days)	Daily bag limit	Possession limit	Season length (days)	Daily bag limit	Possession limit
1971	60-83	5	10	96-109	5	10
1972	58-83	5	10	95-111	5	10
1973	57-83	5	10	95-111	5	10
1974	62-83	5	10	83-111	5	10
1975	62-83	5	10	76-104	5	10
1976	62-83	5	10	74-102	5	10
1977	55-83	5	10	75-101	5	10
1978	65-83	8	16	81-100	5-8	10-16
1979	62-85	8	16	88-99	5-8	10-16
1980	62-92	8	16	88-97	5-8	10-16
1981	62-82	8	16	88-96	5-8	10-16
1982	61-81	8	16	81-95	5-8	10-16
1983	62-69	8	16	81-94	5-8	10-16
1984	62-76	8	16	88-99	5-8	10-16
1985	62-83	8	16	74-97	5-8	10-16
1986	62-83	8	16	88-104	5-8	10-16
1987	61-81	8	16	92-103	5-8	10-16
1988	59-83	8	16	81-101	5-8	10-16
1989	58-79	8	16	81-100	5-8	10-16
1990	55-76	5-8	15-16	81-106	5-8	10-16
1991	55-76	5-8	15-16	81-104	5-8	10-16
1992	61-83	5-8	15-16	81-103	5-8	10-16
1993	61-83	5-8	15-16	74-102	5-8	10-16
1994	59-80	5-8	15-16	76-101	8	16
1995	57-81	5-8	15-16	83-102	9	18
1996	55-83	8	32	90-104	10	20

Year	Manitoba			Saskatchewan		
	Season length (days)	Daily bag limit	Possession limit	Season length (days)	Daily bag limit	Possession limit
1997	55-83	10	40	90-104	10	20
1998	61-89	10	40	103	10	30
1999	60-88	10	40	102	20	60
2000	71-86	20	80	107	20	60
2001	61-84	20	80	107	20	60
2002	61-84	20	80	107	20	60
2003	61-84	20	80	107	20	60
2004	61-84	20	80	107	20	60
2005	61-84	20	80	107	20	60
2006	61-84	20	80	107	20	60
2007	61-84	20	80	107	20	60

Table 2. U.S. federal framework regulations (maximum season length and maximum daily bag and possession limits) for light goose hunting seasons in the Central and Mississippi Flyways, 1961 – 2008.

Year	Central Flyway ¹			Mississippi Flyway		
	Season length (days)	Daily bag limit	Possession limit	Season length (days)	Daily bag limit	Possession limit
1961	60	5	5	60	5	5
1962	75	5	5	60	5	5
1963	90, 75	5	5	70	5	5
1964	90, 75	5	5	70	5	5
1965	75	5	5	70	5	5
1966	75	5	5	70	5	5
1967	75	5	5	70	5	5
1968	75	2, 5	2, 5	70	5	5
1969	86	2, 5	4, 5	70	5	5
1970	90, 75	2, 5	4, 5	70	5	5
1971	90, 75	2, 5	4, 5	70	5	5
1972	93, 72	2, 4	4, 4	70	5	5
1973	93, 72	2, 5	4, 5	70	5	5
1974	93, 72	2, 5	4, 5	70	5	5
1975	93, 72	2, 5	4, 5	70	5	5
1976	93, 72	2, 5	4, 5	70	5	5
1977	93, 86	2, 5	4, 5	70	5	5
1978	93, 86	2, 5	4, 5	70	5	5
1979	93, 86	2, 5	4, 5	70	5	5
1980	93, 86	2, 5	4, 10	70	5	10
1981	93, 86	2, 5	4, 10	70	5	10
1982	93, 86	2, 5	4, 10	70	5	10
1983	93, 86	2, 5	4, 10	70	5	10
1984	93, 86	2, 5	4, 10	70	5	10
1985	93, 86	5	10	70	5	10
1986	93, 86	5	10	70	5	10
1987	93, 86	5	10	70	5	10
1988	95, 86	5	10	70	5	10
1989	95, 100	5	10	80	7	14
1990	100, 86-100	5, 5-7	10, 10-14	80	7	14
1991	107, 86-100	5, 5-7	10, 10-14	80	7	14
1992	107	5, 10	10, 20	80	7	14
1993	107	5, 10	10, 20	80	7	14
1994	107	5, 10	10, 20	107	7	14
1995	107	5, 10	10, 20	107	10	20

(continued next page)

Year	Central Flyway ¹			Mississippi Flyway		
	Season length (days)	Daily bag limit	Possession limit	Season length (days)	Daily bag limit	Possession limit
1996	107	10	40	107	10	30
1997	107	10	40	107	10	30
1998	107	20	no limit	107	20	no limit
1999	107	20	no limit	107	20	no limit
2000	107	20	no limit	107	20	no limit
2001	107	20	no limit	107	20	no limit
2002	107	20	no limit	107	20	no limit
2003	107	20	no limit	107	20	no limit
2004	107	20	no limit	107	20	no limit
2005	107	20	no limit	107	20	no limit
2006	107	20	no limit	107	20	no limit
2007	107	20	no limit	107	20	no limit
2008	107	20	no limit	107	20	no limit

¹ Where applicable, first entry applies to Montana, Wyoming, Colorado, New Mexico and west Texas; second entry applies to North Dakota, South Dakota, Nebraska, Kansas, Oklahoma and east Texas.

Table 3. Light Goose Conservation Order dates, days, bag and possession limits and special provisions in the Central and Mississippi Flyway states, 2006.

Flyway/State	Zone	Dates	Days	Bag	Possession	Electronic Calls	Unplugged Shotguns	1/2 Hour After Sunset
Central Flyway								
Colorado	Statewide	Feb. 24 - Apr. 30	66	no limit	no limit	Yes	No	Yes
Kansas	Statewide	Feb. 19 - Apr. 30	71	no limit	no limit	Yes	Yes	Yes
Nebraska	Statewide	Feb. 8 - Apr. 15	67	no limit	no limit	Yes	Yes	Yes
New Mexico	Statewide	Feb. 1 - Mar. 10	38	no limit	no limit	Yes	Yes	Yes
North Dakota	Statewide	Feb. 18 - May 7	79	no limit	no limit	Yes	Yes	Yes
Oklahoma	Statewide	Feb. 19 - Mar. 31	41	no limit	no limit	Yes	Yes	Yes
South Dakota	Statewide	Feb. 10 - May 8	88	20	no limit	Yes	Yes	Yes
Texas	East Zone	Jan. 29 - Mar. 25	57	no limit	no limit	Yes	Yes	Yes
	West Zone	Feb. 7 - Mar. 25	47	no limit	no limit	Yes	Yes	Yes
Wyoming	Statewide	Feb. 19 - Apr. 8	49	20	no limit	Yes	No	Yes
Mississippi Flyway								
Arkansas	Statewide	Feb. 5 - Apr. 29	85	no limit	no limit	Yes	Yes	Yes
Illinois	North Zone	Jan. 15 - Mar. 31	76	no limit	no limit	Yes	Yes	Yes
	Central Zone	Feb. 1 - Mar. 31	59	no limit	no limit	Yes	Yes	Yes
	South Zone	Feb. 1 - Mar. 31	59	no limit	no limit	Yes	Yes	Yes
Indiana	Statewide	Feb. 1 - Mar. 31	58	no limit	no limit	Yes	Yes	Yes
Iowa	Statewide	Jan. 16 - Apr. 15, 2007	91	20	no limit	Yes	Yes	Yes
Louisiana	East Zone	Dec. 4 - 15 & Jan. 29 - Mar. 11	54	no limit	no limit	Yes	Yes	Yes
	West Zone	Dec. 4 - 15 & Feb. 3 - Mar. 1	49	no limit	no limit	Yes	Yes	Yes
Minnesota	Statewide	Mar. 1 - Apr. 30	61	no limit	no limit	Yes	Yes	Yes
Mississippi	Statewide	Oct. 1 - Nov. 12; Jan. 29 - Feb. 2; Feb. 5 - Mar. 10	87	no limit	no limit	Yes	Yes	Yes
Missouri	Statewide	Feb. 1 - Apr. 30	89	no limit	no limit	Yes	Yes	Yes

Table 4. Light Goose Conservation Order mail questionnaire harvest survey characteristics, Central and Mississippi Flyway states, 2006.

Flyway / State	Sample Universe	No. in Sample Frame	No. Sampled	Follow-up	Memory/ Prestige Bias Correction	Non-response Bias Correction	Other / Comments
Central Flyway							
Kansas	Waterfowl hunters in small game harvest survey, HIP stamp buyers (after Jan 1)	1,652	1,652 (1,087 responses received)	Yes (one follow-up mailing)	No	No	
Nebraska	HIP database	40,000	4,000	No	No	Yes (not on 2006 - by phone)	Phone survey for non-response bias of mail survey
New Mexico	All license combinations permitting small game hunting	25,315	4,356	No	No	No	Geese are leaving the state by the time the LGCO begins so little hunter effort or effort to measure harvest
North Dakota	6,535 (All hunters HIP certified after Jan. 1)	2,629	1,588	Yes	Yes (Atwood Correction)	No	
South Dakota	All HIP	Resident - 33,914; Non-resident - 5,032	Resident - 2,889; Non-resident - 1,356	Yes (three follow-up mailings)	No	No	Hunters can report via the web
Texas	Super combo license and Migratory Game Bird Permits	548,081	10,000	Yes (two follow-up mailings)	Yes (regression correction)	Yes	
Wyoming	CO Permits	295	228	Yes	No	Yes	
Mississippi Flyway							
Arkansas	Snow goose registration database	800	800	Yes (reminder postcards followed by 2nd questionnaire mailing)	No	No	
Illinois	Illinois resident HIP registrants (2005-2006)	2,000	1,919	Yes (2 postcards, 1 additional survey)	No	Yes (0.478)	
Indiana	All registered CO permits	103	103	Yes (postcard)	No	No	Have very few hunters and very little harvest
Iowa	HIP registrants between Dec. 15 and April 15	8,578	2,942	Yes (one additional postcard)	Yes	Yes	New licenses go on sale Dec. 15 even though the old license is good through Jan. 10
Louisiana	Basic and Combination Licenses	11,119	294	Yes (3 mailing at 2.5 week intervals)	No	No	
Minnesota	All CO permit holders	1,363	1,363 (70% response rate)	Yes (2nd and 3rd mailings after 1 month)	No	Yes (1.43)	
Mississippi	All registered CO permits	100%	100% (336 for 05-06)	Yes	No	Yes	
Missouri	Migratory Bird Hunters	68,042	11,000	Yes (3 mailings)	No	No	

Table 5. Estimates of midcontinent light geese harvested in Canada during the regular season from 1975 to 2007

Year	Saskatchewan			Manitoba			N. Ontario (Zone 3)	Total MCLG in Canada		
	Snow Goose	Ross's Goose	Total	Snow Goose	Ross's Goose	Total	Snow Goose	Snow Goose	Ross's Goose	Total
1975	13,159	4,009	17,168	51,180	1,044	52,224	16,998	81,337	5,053	86,390
1976	21,269	3,178	24,447	31,604	99	31,703	11,313	64,186	3,277	67,463
1977	13,062	1,150	14,212	31,008	0	31,007	6,045	50,115	1,150	51,265
1978	11,582	3,706	15,288	39,766	660	40,426	6,455	57,803	4,366	62,169
1979	13,275	6,603	19,878	98,425	629	99,054	8,326	120,026	7,232	127,258
1980	16,240	3,017	19,258	90,882	789	91,671	7,460	114,582	3,806	118,388
1981	14,947	2,274	17,221	87,996	704	88,701	6,148	109,091	2,978	112,069
1982	22,229	3,309	25,538	81,900	658	82,558	3,027	107,156	3,967	111,123
1983	32,585	4,141	36,726	81,880	274	82,154	1,502	115,967	4,415	120,382
1984	32,340	3,471	35,811	76,630	297	76,928	771	109,741	3,768	113,509
1985	33,698	6,025	39,723	103,349	470	103,819	2,010	139,057	6,495	145,552
1986	31,325	506	31,831	48,949	592	49,542	1,951	82,225	1,098	83,323
1987	23,319	1,633	24,953	69,523	3,405	72,928	3,894	96,736	5,038	101,774
1988	24,204	1,321	25,525	71,323	1,143	72,466	1,963	97,490	2,464	99,954
1989	26,752	2,933	29,685	92,892	317	93,208	3,792	123,436	3,250	126,686
1990	31,818	5,899	37,716	53,754	111	53,865	2,105	87,677	6,010	93,687
1991	22,407	2,034	24,440	65,871	437	66,308	1,919	90,197	2,471	92,668
1992	21,241	1,329	22,570	26,786	1,645	28,431	669	48,696	2,974	51,670
1993	19,674	1,483	21,157	51,314	66	51,380	2,241	73,229	1,549	74,778
1994	30,257	6,374	36,631	56,221	1,119	57,340	480	86,958	7,493	94,451
1995	31,323	7,281	38,605	61,602	4,389	65,992	795	93,720	11,670	105,390
1996	34,547	15,598	50,144	46,163	2,066	48,230	260	80,970	17,664	98,634
1997	62,635	14,442	77,076	69,684	391	70,075	280	132,599	14,833	147,432
1998	68,985	23,085	92,070	52,121	3,833	55,954	609	121,715	26,918	148,633
1999	116,313	20,644	136,957	14,150	162	14,313	0	130,463	20,806	151,269
2000	68,377	14,332	82,710	31,699	1,724	33,423	679	100,755	16,056	116,811
2001	100,525	14,572	115,097	25,336	665	26,000	206	126,067	15,237	141,304
2002	85,932	27,842	113,775	24,252	1,987	26,239	250	110,434	29,829	140,263
2003	108,457	27,406	135,864	26,970	1,320	28,290	593	136,020	28,726	164,746
2004	76,710	19,174	95,883	23,159	1,794	24,953	492	100,361	20,968	121,329
2005	81,946	11,498	93,445	13,669	1,823	15,491	0	95,615	13,321	108,936
2006	116,278	22,975	139,253	31,937	2,503	34,440	378	148,593	25,478	174,071
2007	66,936	12,893	79,828	19,452	4,210	23,663	88	86,476	17,103	103,579

Table 6. Spring Conservation Harvest in Saskatchewan from 2001 to 2008

	Active Hunters			Successful Hunters			Hunting Days			Harvest		
	Saskatchewan Resident	Non Resident	Total	Saskatchewan Resident	Non Resident	Total	Saskatchewan Resident	Non Resident	Total	Saskatchewan Resident	Non Resident	Total
2001 ^a			860			551			2684			5233
2002 ^b	710	174	895	551	160	720	1847	610	2488	4565	2906	7718
2003	663	280	943	425	247	672	1989	1480	3469	5291	7648	12939
2004	599	209	808	487	186	672	2106	893	3000	10459	6422	16881
2005 ^c	572	173	771	462	144	608	1562	939	2552	4861	4766	9886
2006	399	249	648	283	249	532	1130	1246	2377	5203	7016	12219
2007	599	159	757	407	159	566	1748	924	2673	4240	5663	9904
2008	430	80	510	334	70	404	1336	510	1846	4200	2261	6460

a Saskatchewan residents and non-residents undifferentiated for analysis

b Totals includes data from hunters who purchased MGBHP after March 1 (i.e., spring)

c Total includes data from Alberta hunters

Table 7. Mail Questionnaire Survey estimates of midcontinent light geese harvested in the United States during regular hunting seasons, 1952-53 – 2001-02.

Year	Mississippi Flyway				Central Flyway				Total			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue		white	blue		white	blue	white	blue		
1952	22,040	83,778		138,380	71,576		209,955		160,419	155,354		315,773
1953	88,279	441,492		182,794	76,310		259,105		271,073	517,802		788,875
1954	18,379	69,117		46,169	15,613		61,781		64,548	84,730		149,278
1955	14,694	67,575		56,774	28,055		84,829		71,468	95,631		167,098
1956	32,225	49,539		81,285	25,545		106,830		113,510	75,084		188,594
1957	28,333	48,519		52,174	12,721		64,895		80,507	61,240		141,747
1958	41,329	47,745		58,933	25,635		84,567		100,262	73,380		173,641
1959	38,589	74,407		48,605	18,662		67,267		87,194	93,069		180,263
1960	20,089	43,939		45,689	19,367		65,056		65,778	63,306		129,083
1961	26,499	33,217		73,101	29,966		103,067		99,600	63,183		162,784
1962	9,715	29,867	0	61,724	25,680	0	87,404	0	71,439	55,547	0	126,986
1963	17,081	47,667	0	86,868	33,560	0	120,428	0	103,949	81,227	0	185,176
1964	24,454	70,762	0	82,927	28,771	0	111,698	0	107,381	99,533	0	206,915
1965	40,840	59,136	0	72,088	36,205	0	108,293	0	112,928	95,341	0	208,269
1966	58,444	103,850	0	137,154	56,580	0	193,734	0	195,598	160,430	0	356,028
1967	38,194	82,441	0	95,549	54,342	0	149,891	0	133,743	136,783	0	270,526
1968	27,869	42,061	0	64,219	26,638	0	90,857	0	92,088	68,699	0	160,787
1969	70,582	146,709	0	127,255	82,774	0	210,029	0	197,837	229,483	0	427,320
1970	94,961	178,991	0	201,596	112,706	0	314,302	0	296,557	291,697	0	588,255
1971	52,715	116,711	0	120,725	59,987	0	180,712	0	173,440	176,698	0	350,138
1972	51,055	64,484	0	109,993	41,069	0	151,062	0	161,048	105,553	0	266,601
1973	61,106	100,980	0	171,251	83,573	0	254,824	0	232,357	184,553	0	416,911
1974	69,581	113,943	0	169,577	71,744	195	241,516	195	239,158	185,687	195	425,040
1975	65,232	112,420	0	234,781	115,276	146	350,203	146	300,013	227,696	146	527,855

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Year	Mississippi Flyway				Central Flyway				Total			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1976	30,166	78,498	0	108,664	165,899	90,591	1,783	258,273	196,065	169,089	1,783	366,937
1977	46,777	87,638	0	134,415	192,315	113,987	300	306,602	239,092	201,625	300	441,017
1978	53,041	88,880	0	141,921	132,397	56,618	0	189,015	185,438	145,498	0	330,936
1979	58,667	116,942	0	175,609	232,059	106,332	1,598	339,989	290,726	223,274	1,598	515,598
1980	47,797	105,461	0	153,258	176,213	75,552	510	252,275	224,010	181,013	510	405,533
1981	45,234	72,109	0	117,343	192,423	97,446	2,706	292,575	237,657	169,555	2,706	409,918
1982	32,728	99,409	4,597	136,734	166,684	75,060	2,116	243,860	199,412	174,469	6,713	380,594
1983	79,631	118,574	295	198,500	160,613	85,135	1,675	247,423	240,244	203,709	1,970	445,923
1984	44,052	63,471	0	107,524	205,424	87,374	5,942	298,740	249,476	150,845	5,942	406,264
1985	44,143	60,627	116	104,886	147,669	69,199	3,833	220,701	191,812	129,826	3,949	325,587
1986	33,521	40,254	754	74,530	96,508	53,381	2,555	152,444	130,029	93,635	3,309	226,974
1987	21,935	37,908	166	60,008	109,061	73,524	404	182,989	130,996	111,432	570	242,997
1988	22,763	31,983	608	55,354	174,736	77,099	3,747	255,582	197,499	109,082	4,355	310,936
1989	42,519	60,479	0	102,998	192,498	93,773	8,416	294,687	235,017	154,252	8,416	397,685
1990	47,011	51,148	1,092	99,251	146,287	65,471	7,007	218,765	193,298	116,619	8,099	318,016
1991	51,308	65,886	353	117,547	169,609	78,457	7,178	255,244	220,917	144,343	7,531	372,791
1992	26,902	36,794	257	63,953	109,499	42,443	4,729	156,671	136,401	79,237	4,986	220,624
1993	32,644	43,397	614	76,655	180,442	89,842	7,417	277,701	213,086	133,239	8,031	354,356
1994	46,447	59,344	3,008	107,798	186,189	84,169	9,119	279,477	232,636	142,513	12,127	387,275
1995	94,052	108,412	3,888	206,352	219,357	116,949	19,700	356,006	313,409	225,361	23,588	562,358
1996	137,514	106,827	8,814	253,155	215,898	88,719	15,542	320,159	353,412	195,546	24,356	573,314
1997	141,943	110,345	8,701	260,989	228,134	130,732	12,435	371,301	370,077	241,077	21,136	632,290
1998	207,387	211,712	9,145	428,244	223,348	80,433	31,900	335,681	430,735	292,145	41,045	763,925
1999	210,975	114,009	13,020	338,004	237,903	78,354	48,303	364,560	448,878	192,363	61,323	702,564
2000	73,749	75,838	4,922	154,509	90,362	42,315	11,883	144,560	164,111	118,153	16,805	299,069
2001	85,554	80,370	13,292	179,216	147,094	64,595	33,074	244,763	232,648	144,965	46,366	423,979

Table 8. Harvest Information Program estimates of midcontinent light geese harvested in the United States during regular hunting seasons, 1999-00 – 2007-08.

Year	Mississippi Flyway			Central Flyway			Total			
	Snow goose		Ross's	Snow goose		Ross's	Snow goose		Ross's	
	White	blue	goose	white	blue	goose	white	blue	goose	
1999	170,607	94,123	9,632	247,335	84,423	50,127	417,942	178,546	59,759	656,247
2000	93,653	84,931	6,649	207,932	69,507	33,091	301,585	154,438	39,740	495,762
2001	118,377	116,667	17,675	177,141	61,629	47,856	295,518	178,296	65,531	539,345
2002	77,610	57,088	10,132	152,898	46,650	30,172	230,508	103,738	40,304	374,550
2003	121,649	80,818	19,478	144,303	49,132	28,634	265,952	129,950	48,112	444,014
2004	90,738	67,205	4,408	142,396	40,705	32,121	233,134	107,910	36,529	377,574
2005	93,479	107,368	4,948	171,557	71,151	41,087	265,036	178,519	46,035	489,590
2006	94,248	66,911	12,218	134,702	65,493	25,374	228,950	132,404	37,592	398,946
2007	70,128	52,901	6,638	160,052	43,748	21,093	230,180	96,649	27,731	354,561

Table 9. Estimated hunter numbers, Light Goose Conservation Order, Central and Mississippi flyway states, 1999-2008¹.

State	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Average ²
Colorado	1,638	3,276	2,495	1,323	2,162	1,877	1,281	2,704	2,367	2,555	2,168
Kansas	0	2,207	1,798	1,939	1,579	3,270	1,400	1,575	863	354	1,499
Nebraska	0	3,952	4,423	4,775	7,741	12,886	8,104	8,052	5,604	5,270	6,081
New Mexico	0	0	603	633	383	1,326	426	913	615	498	540
North Dakota	6,277	5,169	1,263	1,494	2,327	2,380	2,519	1,809	1,749	1,785	2,677
Oklahoma	597	494	222	249	269	150	89	106	112	122	241
South Dakota	8,630	6,067	5,383	8,316	8,982	6,466	6,753	6,914	5,288	6,601	6,940
Texas	11,170	27,882	18,441	21,735	10,594	7,215	8,531	6,665	2,585	2,473	11,729
Wyoming	0	0	248	191	204	221	228	254	165	186	170
Central Flyway	28,312	49,047	34,876	40,655	34,241	35,791	29,331	28,992	19,348	19,844	32,044
Arkansas	514	4,151	3,230	2,867	2,779	3,114	2,171	2,616	2,645	2,636	2,672
Illinois	1,227	865	4,665	5,107	3,111	5,976	5,689	5,543	5,962	6,409	4,455
Indiana	0	23	25	64	56	47	23	45	106	160	55
Iowa	1,414	2,134	2,429	3,095	2,125	2,584	1,886	2,457	2,229	2,116	2,247
Kentucky	0	137	148	148	159	144	98	94	217	210	136
Louisiana	8,700	10,200	8,600	7,500	6,000	5,900	5,000	5,900	4,400	4,500	6,670
Minnesota	0	1,461	393	1,209	553	690	618	516	514	775	673
Mississippi	0	22	144	183	236	390	155	233	643	559	257
Missouri	996	7,687	7,703	8,715	8,382	8,316	8,334	7,735	7,224	7,525	7,262
Mississippi Flyway	12,851	26,680	27,337	28,888	23,401	27,161	23,974	25,139	23,940	24,890	24,375
Total	41,163	75,727	62,213	69,543	57,642	62,952	53,305	54,131	43,288	44,734	56,470

1 State harvest-survey estimates

2 Average of years with Conservation Order

Table 10. Estimated light-geese (snow, blue, and Ross's) harvest, Light Goose Conservation Order, Central and Mississippi flyway states, 1999-2008¹.

State	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Total	Average
Colorado	13,417	31,783	22,457	7,594	27,395	24,497	16,135	18,535	23,375	13,745	198,933	19,893
Kansas	0	11,165	11,937	35,138	17,087	65,608	25,272	18,802	12,711	4,260	201,980	20,198
Nebraska	0	27,834	16,315	54,300	87,585	138,012	111,172	129,631	96,724	65,947	727,520	72,752
New Mexico	0	174	1,925	2,253	1,268	7,372	736	2,529	2,765	2,145	21,167	2,117
North Dakota	24,890	35,832	3,547	6,424	12,340	12,924	11,170	11,033	12,535	11,387	142,082	14,208
Oklahoma	6,650	2,668	1,603	3,548	1,991	1,575	490	615	1,198	842	21,180	2,118
South Dakota	95,113	68,917	54,375	91,162	70,072	96,767	116,397	99,547	96,555	107,137	896,042	89,604
Texas	53,451	102,225	77,322	87,794	35,625	34,827	37,354	28,905	17,817	22,831	498,151	49,815
Wyoming	0	0	875	1,216	1,772	1,364	1,070	2,622	928	1,019	10,866	1,087
Central Flyway	193,521	280,598	190,356	289,429	255,135	382,946	319,796	312,219	264,608	229,313	2,717,921	271,792
Arkansas	17,168	132,156	97,295	135,327	91,505	88,606	77,228	137,908	121,630	122,881	1,021,704	102,170
Illinois	2,504	7,612	36,830	17,875	30,564	37,189	43,839	74,268	44,514	97,021	392,216	39,222
Indiana	0	27	45	168	17	41	42	277	1,216	155	1,988	199
Iowa	12,043	20,681	13,851	29,249	17,006	32,181	12,771	21,263	17,525	15,198	191,768	19,177
Kentucky	0	952	1,170	1,235	1,288	1,168	450	731	3,657	2,547	13,198	1,320
Louisiana	155,900	110,300	101,700	102,800	98,600	105,500	66,800	96,300	80,500	58,900	977,300	97,730
Minnesota	0	6,290	316	3,516	2,005	2,735	1,395	1,360	1,786	2,412	21,815	2,182
Mississippi	0	333	379	1,554	3,600	7,955	3,223	6,108	11,776	8,965	43,893	4,389
Missouri	17,319	84,521	94,354	168,196	140,806	147,262	134,814	142,639	159,020	141,779	1,230,710	123,071
Mississippi Flyway	204,934	362,872	345,940	459,920	385,391	422,637	340,562	480,854	441,624	449,858	3,894,592	389,459
Total	398,455	643,470	536,296	749,349	640,526	805,583	660,358	793,073	706,232	679,171	6,612,513	661,251

¹ State harvest-survey estimates

Table 11. Hunter assistance and information programs for the Light Goose Conservation Order in Central and Mississippi Flyway states, 2006.

Flyway / State	Population /		Phone Hotline	News Releases	Website Info	Annual		Other / Comments
	Migration Surveys					Budget / Cost		
Central Flyway								
Colorado	No	No	No	Yes	Yes	\$0		
Kansas	No	No	No	No	Yes*	No		*Weekly waterfowl counts conducted through March
Nebraska	Yes	No	No	No	No	No		
New Mexico	No	No	No	No	No	Minimal		
North Dakota	No	Yes	No	No	Yes	Minimal		
Oklahoma	Yes	No	No	Yes	Yes	N/A		
South Dakota	Yes*	Yes	Yes	Yes	Yes	Unk		*GFP employees call into a hotline to report light goose movements in the spring
Texas	Unk	No	No	No	Yes*	not reported		*Weekly migratory bird updates
Wyoming	No	No	No	Yes*	No	not reported		*General information prior to conservation order
Mississippi Flyway								
Arkansas	Yes*	No	No	Yes*	Yes*	not reported		*Early Feb. aerial survey available to public
Illinois	Yes*	No	No	No	Yes	Unk		*Weekly and bi weekly aerial surveys thru Jan. 31
Indiana	No	No	No	Yes	No	No		Hopefully have more info available next year as website is re-vamped
Iowa	No	No	No	No	Yes*	No		*Website to explain why electronic calls, unplugged guns, and shooting 1/2 hour after sunset
Kentucky								
Louisiana	Yes*	No	No	Yes	Yes	No		*Normal winter surveys
Michigan								
Minnesota	No	No	No	Yes*	No	not reported		*Prior to season to inform hunters about need for permit and where to hunt
Mississippi	No	No	No	Yes	Yes	\$0		
Missouri	Yes*	No	No	Yes	Yes	No		CO info in Waterfowl Hunt Digest and website (*periodic counts on select state and federal areas)

Assessment of Harvest from Conservation Actions for Reducing Midcontinent Light Geese and Recommendations for Future Monitoring Appendices

Appendix 1. Canada's Harvest Questionnaire Survey form.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

2009 MIGRATORY GAME BIRD HARVEST SURVEY
RELEVÉ DE CHASSE AUX OISEAUX MIGRATEURS
CONSIDÉRÉS COMME GIBIER

INSTRUCTIONS

Please answer and return this short questionnaire as soon as you are done hunting for the season. Check and fill in shaded spaces.

If you did not hunt this season, complete questions 1 and 2 ONLY and return the questionnaire in the prepaid envelope.

Veillez répondre et retourner ce court questionnaire dès que votre chasse sera terminée pour cette saison. Cochez et remplissez les espaces ombragés.

Si vous n'avez pas chassé cette saison, répondez aux questions 1 et 2 SEULEMENT et retournez le questionnaire dans l'enveloppe pré-affranchie.

1 Did you buy a Canada Migratory Game Bird Hunting Permit for this season? / Aviez-vous obtenu un Permis de chasse aux oiseaux migrateurs considérés comme gibier cette saison-ci?

NO / NON YES / OUI → **2009 Permit No / N° de permis**

2 Did you hunt migratory game birds in Canada? / Aviez-vous chassé des oiseaux migrateurs considérés comme gibier au Canada?

THIS SEASON - CETTE SAISON (2009) YES / OUI NO / NON **2008** YES / OUI NO / NON **2007** YES / OUI NO / NON

3 In the box, print the name of the ONE town (and check the province) nearest to the place where you did MOST of your hunting this season. In the appropriate circle, give the number of kilometers between the hunting place and that town.

Dans la boîte, inscrivez le nom de la localité (et cochez la province) la plus proche de l'endroit où vous avez le plus chassé cette saison. Dans le cercle approprié, inscrivez la distance en kilomètres entre l'endroit de la chasse et la localité.

TOWN - LOCALITE

<input type="checkbox"/> N.L.T.N & Lab.	<input type="checkbox"/> Manitoba	
<input type="checkbox"/> P.E.I./P.É.	<input type="checkbox"/> SASK.	<input type="checkbox"/> 3 EAST / EST
<input type="checkbox"/> N.S.-N.E.	<input type="checkbox"/> Alta.-Ab.	<input type="checkbox"/> B.C.-C.B.
<input type="checkbox"/> N.B.-N.R.	<input type="checkbox"/> N.W.T.-T.N.O.	<input type="checkbox"/> Yukon
<input type="checkbox"/> Que.-Que.	<input type="checkbox"/> Ontario	

4 Indicate the number of DAYS on which you hunted DUCKS and/or GEESE this season. / Indiquez le nombre de JOURS où vous avez chassé le CANARD et/ou l'OIE et la BERNACHE cette saison. **DAYS / JOURS**

5 Indicate the total number of DAYS on which you hunted the following species of migratory game birds: Coots or Mudhens, Woodcock, Snipes, Rails, Doves, Band-Tailed Pigeons, Cranes, Murre. / Indiquez le nombre total de JOURS où vous avez chassé les espèces suivantes d'oiseaux migrateurs: Foulques, Bécasses, Bécassines, Râles, Tourterelles, Pigeons à queue banded, Grues, Guillemots. **DAYS / JOURS**

6 Indicate the number of BIRDS killed and retrieved. / Indiquez le nombre d'OISEAUX abattus et rapportés:

DUCKS / CANARDS <input style="width: 40px;" type="text"/>	WOODCOCK / BÉCASSES <input style="width: 40px;" type="text"/>	BAND-TAILED PIGEONS / PIGEONS À QUEUE BARRÉE <input style="width: 40px;" type="text"/>	MURRES / GUILLEMOTS <input style="width: 40px;" type="text"/>
GEESE / OIES ET BERNACHES <input style="width: 40px;" type="text"/>	SNIPES / BÉCASSINES <input style="width: 40px;" type="text"/>	SANDHILL CRANES / GRUES <input style="width: 40px;" type="text"/>	
COOTS / FOULQUES <input style="width: 40px;" type="text"/>	RAILS / RÂLES <input style="width: 40px;" type="text"/>	MOURNING DOVES / TOURTERELLES TRISTES <input style="width: 40px;" type="text"/>	

7 **DUCK CALENDAR** - Indicate on this calendar the NUMBER OF DUCKS you killed and retrieved on each day you hunted. MARK ZERO (0) for days when you hunted but retrieved no ducks. LEAVE BLANK all days not hunted. / **CALENDRIER DE LA CHASSE AU CANARD** - Indiquez sur le calendrier le NOMBRE DE CANARDS abattus et rapportés pour chaque jour où vous avez chassé. INSCRIVEZ ZÉRO (0) lorsque vous avez chassé sans rapporter de canards. LAISSEZ EN BLANC les dates où

<p>SEPTEMBER / SEPTEMBRE 2009</p> <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <tr><th>S/D</th><th>ML</th><th>T/M</th><th>WM</th><th>T/J</th><th>F/V</th><th>S/S</th></tr> <tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td></td><td></td></tr> <tr><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td></tr> <tr><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td></tr> <tr><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td></tr> <tr><td>27</td><td>28</td><td>29</td><td>30</td><td></td><td></td><td></td></tr> </table>	S/D	ML	T/M	WM	T/J	F/V	S/S	1	2	3	4	5			6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				<p>OCTOBER / OCTOBRE 2009</p> <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <tr><th>S/D</th><th>ML</th><th>T/M</th><th>WM</th><th>T/J</th><th>F/V</th><th>S/S</th></tr> <tr><td></td><td></td><td>1</td><td>2</td><td>3</td><td></td><td></td></tr> <tr><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td></tr> <tr><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td></tr> <tr><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td></tr> <tr><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td></tr> </table>	S/D	ML	T/M	WM	T/J	F/V	S/S			1	2	3			4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	<p>NOVEMBER / NOVEMBRE 2009</p> <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <tr><th>S/D</th><th>ML</th><th>T/M</th><th>WM</th><th>T/J</th><th>F/V</th><th>S/S</th></tr> <tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr> <tr><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td></tr> <tr><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td></tr> <tr><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td></tr> <tr><td>29</td><td>30</td><td></td><td></td><td></td><td></td><td></td></tr> </table>	S/D	ML	T/M	WM	T/J	F/V	S/S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30												
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Appendix 2. Canada's Species Composition Survey form.

ENVELOPPE PAPIER INTERIEURE ET EXTERIEURE
 INTERIOR PAPER ENVELOPE AND BULK ENVELOPE

ATTENTION HUNTERS !

- For each bird, insert ONE inner (paper) envelope in ONE plastic envelope and follow instructions below.
- Affix address label in the space provided below. If you don't have any, please fill in your name and address using a BALLPOINT PEN.
- Write your current permit number (# #) and fill in information in sections # 9 and # 10 using a BALLPOINT PEN.
- Return the envelope(s) as soon as possible. Thank you for your participation !

ATTENTION CHASSEURS !

- Pour chaque oiseau, insérer UNE enveloppe interne (papier) dans UNE enveloppe de plastique et suivre les instructions ci-bas.
- Placez une étiquette dans l'espace prévu. Si vous n'en avez pas, veuillez inscrire votre nom et adresse avec un STYLO À BILLE.
- Écrivez votre numéro de permis actuel (point #) et renseignez l'information sur vos prises aux points 9 et 10 en utilisant un STYLO À BILLE.
- Expédiez l'enveloppe(s) le plus tôt possible. Merci de votre participation !

CCARE 125030042 2007 AF 4A

Weight
Masse (see only)

9. Date Shot / Jour de la chasse

10. - In the box (TOWN), enter the county of the town (and check the province/territory in the space where you affix this tag).

- Dans la boîte (LOCALITÉ), indiquez le comté de la localité (et vérifiez la province/territoire où vous insérez ce libretto).

- Dans les cases (CANTONS), indiquez le comté ou les comtés qui entourent la localité.

171

Wing Length
Longueur de l'aile (see only)

30/09/07

Date received
Date reçue (see only)

PLACER IDENTIFICATION LABEL HERE
PLACER L'ÉTIQUETTE D'IDENTIFICATION ICI

1. NAME OF HUNTER / NOM DU CHASSEUR: M. Hunter

2. ADDRESS / ADDRESS: 1 Marked Lane

3. TOWN / VILLE: OTTAWA

4. PROVINCE / PROVINCE: ONTARIO

5. Your Canada Agency / Votre numéro de Permis Canadien: 210171001010

1. WEST / OUEST

2. NORTHWEST / N.-O.

3. NORTH / N.

4. EAST / EST

5. SOUTHWEST / S.-O.

6. SOUTH / S.

7. SOUTHEAST / S.-E.

TOWN - LOCALITÉ

OTTAWA


8. WEST / OUEST 9. NORTHWEST / N.-O. 10. NORTH / N. 11. EAST / EST

12. P.E.I. / P.E. 13. N.B. / N.B. 14. N.S. / N.S. 15. N.W.T. / N.W.T. 16. YUKON / YUKON

17. QUEBEC / QUÉBEC 18. ONTARIO / ONTARIO 19. MANITOBA / MANITOBA 20. ALBERTA / ALBERTA 21. BRITISH COLUMBIA / C.B. 22. SASKATCHEWAN / S.C. 23. ALBERTA / ALBERTA 24. BRITISH COLUMBIA / C.B.

905-976-1100 • 1-800-387-5633 • Environment Canada / Environnement Canada

Appendix 3. The U.S. Harvest Information Program survey form.



Waterfowl Hunting Record

1. IF YOU DID NOT HUNT DUCKS, GEESE, OR BRANT THIS SEASON, please check the box to the right and mail this form.
2. Please record your personal hunting activity for each day you hunted ducks, geese, or brant in the State specified in the attached letter. Record the number of birds you personally bagged; DO NOT include birds shot by other people. Please include ALL of your hunts for the birds listed; if you did not bag any birds during a hunt, record zero (0) for the birds you hunted that day.
3. IF YOU HUNTED DUCKS, GEESE, OR BRANT BUT DO NOT HAVE DETAILED RECORDS, check the box to the right and go to question number 6 to record your Season Totals.
4. Please include additional comments on a **SEPARATE SHEET** of paper. **2 2**

Please print all characters in **BLACK** ink using CAPITAL LETTERS ONLY as shown below.

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z 0 1 2 3 4 5 6 7 8 9

	Date of Hunt		County of Hunt	State of Hunt	Number of Birds Killed and Retrieved			
	Month	Day			Ducks	Sea Ducks	Geese	Brant
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								

5. IF YOU RUN OUT OF SPACE ON THIS FORM, please call 1-800-419-2965 from 7:30 am to 5:00 pm EST to receive an additional form. We will ask you for the serial number located at the bottom of this form.

6. SEASON TOTALS:

	Days Hunted	Birds Killed and Retrieved	Birds Downed but Lost
Ducks			
Sea Ducks			
Geese			
Brant			

Please call 1-800-327-BAND to report banded birds.


Appendix 4. The U.S. Parts Collection Survey envelope.

WATERFOWL HUNTERS

Form 3-165 (Revised February 2005) OMB No. 1018-0015
Approval Expires Feb. 29, 2008

DUCKS, BRANT & COOT


1. Cut the least damaged wing close to the body without including any flesh.
2. Make certain any **blood has drained and dried.**
3. Use one envelope (with inner envelope) for each wing.
4. Do not wrap wings in plastic because this speeds decay.




The wing should not contain any excess flesh or blood and therefore will remain dry and odor free in the mail.
 - MAIL AS SOON AS POSSIBLE (no postage required).
 - Mail the blue postcard to us if you need more envelopes. Do not put the postcard in this envelope.
 - Continue sending for the entire season.

FOR GEESE ONLY

1. Cut the outer 3 primary feathers of the wing about 6 inches from the tip and **send the wing tips.**
2. **Pull** out all the tail feathers. **Do not cut the rump of the goose.**
3. Use one envelope (with inner envelope) for each set of wing and tail feathers.



We only need the feathers that you cut from the wing and the feathers that you pull from the tail. This will ensure that the feathers do not contain flesh or oil glands and remain dry and odor free in the mail.

PLEASE COMPLETE				Please do not write in this block.			
Where Shot:				C O D E			
State _____							
County _____							
Town _____				A G E & S E X	AM	IM	UM
When Shot:					7	8	9
Date _____					4	5	6
Time _____					1	2	3
If the bird was banded, please write the band number below, AND report the band to the BIRD BANDING Laboratory by calling 1-800-327-BAND(2263).				M E A S			
Band Number _____							
Hunter's Name _____				TERTIAL COVERT			
				A-1	1-2	A&1-3	All Ad 5
				All Imm 4	AA1 7		S P
ENVELOPE CONTENTS Duck, Brant, or Coot Wing <input type="checkbox"/> Goose Tail and Wing Tip <input type="checkbox"/>				 A612770			

Appendix 5. The U.S. Mail Questionnaire Survey form.

ANNUAL SURVEY OF U.S. WATERFOWL HUNTERS					
A. WATERFOWL HUNTING (IN UNITED STATES ONLY)					
1. PLEASE REPORT ONLY YOUR OWN WATERFOWL HUNTING.					
		NUMBER YOU BAGGED (RETRIEVED KILL)			
PERIOD	NO. DAYS HUNTED	DUCKS AND MERGANSERS	GEESE AND BRANT	COOTS (MUD HENS)	SEA DUCKS (SEA COOTS)
SEPTEMBER TEAL SEASON			←	ONLY IN SOME CENTRAL AND MISSISSIPPI FLYWAY STATES	
OTHER SEPT. PLUS OCTOBER					
NOVEMBER					
DECEMBER					
JANUARY AND FEBRUARY					
TOTAL FOR ENTIRE SEASON					
2. NUMBER YOU KNOCKED DOWN <u>IN SIGHT</u> BUT COULD NOT RETRIEVE.					
_____ DUCKS AND MERGANSERS		_____ COOTS (MUD HENS)			
_____ GEESE AND BRANT		_____ SEA DUCKS (SEA COOTS)			
Please read letter on back of envelope					
3. WATERFOWL YOU BAGGED THIS SEASON THAT WORE METAL LEG BANDS.					
NUMBER OF DUCKS _____		NUMBER OF GEESE _____			
If known, please fill in the following (see instructions)					
BAND NUMBER	DATE SHOT	PLACE SHOT (NEAREST TOWN, ETC.)			
4. PLEASE COMPLETE FOR EACH STATE WHERE YOU HUNTED WATERFOWL					
		NUMBER YOU BAGGED (RETRIEVED KILL)			
STATES HUNTED	NO. DAYS HUNTED	DUCKS AND MERGANSERS	GEESE AND BRANT	COOTS (MUD HENS)	SEA DUCKS (SEA COOTS)
1.					
2.					
3.					
TOTALS					
B. HUNTING OF OTHER MIGRATORY BIRDS, (IN U.S. ONLY)					
1. DID YOU HUNT ANY OF THE BIRDS LISTED BELOW THIS SEASON?					
<input type="checkbox"/> YES <input type="checkbox"/> NO					
2. IF YES, PLEASE CIRCLE THE SPECIES YOU HUNTED AND FILL IN THE NUMBER YOU BAGGED (RETRIEVED KILL).					
MOURNING DOVE _____		OTHER RAILS (MARSH HENS) _____			
BARNYARD PIGEON _____		GALLINULES _____			
WOODCOCK _____		WHITE-WINGED DOVE _____			
SNIPE _____		BAND-TAILED PIGEON _____			
SORA RAIL _____		SANDHILL CRANE _____			
Form 3-2056G Rev. 1/89			OMB NO. 1018-0015 APPROVAL EXPIRES MAY 1994		

Appendix 6. Harvest of Midcontinent adult and immature snow geese, 1962-2007. No data available for MB and SK, 1962-1974. Totals include known-age birds only.

Year	Central and Mississippi Flyways			Manitoba, Saskatchewan and Northern Ontario			Total Midcontinent			Proportion Adults
	Adult	Immature	Total	Adult	Immature	Total	Adult	Immature	Total	
1962	69,968	53,438	123,406							
1963	93,811	86,256	180,067							
1964	103,142	97,797	200,938							
1965	102,116	98,924	201,040							
1966	151,274	191,684	342,958							
1967	149,455	113,768	263,223							
1968	115,299	40,121	155,420							
1969	167,575	239,587	407,162							
1970	272,464	295,410	567,874							
1971	216,007	121,469	337,476							
1972	195,630	62,999	258,628							
1973	152,673	253,394	406,067							
1974	242,020	167,898	409,917							
1975	226,335	291,327	517,662	24,327	39,123	63,450	250,662	330,450	581,112	0.43
1976	221,656	134,742	356,398	32,969	23,085	56,054	254,625	157,827	412,452	0.62
1977	183,390	247,065	430,455	22,031	23,218	45,249	205,421	270,283	475,704	0.43
1978	257,210	65,730	322,940	41,530	14,528	56,058	298,740	80,258	378,998	0.79
1979	190,328	308,271	498,599	43,217	64,140	107,357	233,545	372,411	605,956	0.39
1980	232,956	161,583	394,539	44,781	38,891	83,672	277,737	200,474	478,211	0.58
1981	204,879	195,232	400,111	41,835	50,610	92,445	246,714	245,842	492,556	0.50
1982	197,610	165,639	363,249	51,675	41,086	92,761	249,285	206,725	456,010	0.55
1983	270,641	161,929	432,570	62,170	44,984	107,154	332,811	206,913	539,724	0.62
1984	204,105	183,556	387,661	48,016	57,563	105,579	252,121	241,119	493,240	0.51
1985	169,510	143,624	313,134	71,478	66,652	138,130	240,988	210,276	451,264	0.53
1986	166,732	52,040	218,772	54,562	26,952	81,514	221,294	78,992	300,286	0.74
1987	145,105	93,224	238,329	55,996	38,667	94,663	201,101	131,891	332,992	0.60
1988	150,989	151,905	302,895	42,405	54,590	96,995	193,394	206,495	399,890	0.48
1989	194,168	186,919	381,087	61,405	59,734	121,139	255,573	246,653	502,226	0.51
1990	193,260	110,597	303,857	48,469	39,203	87,672	241,729	149,800	391,529	0.62
1991	185,932	171,467	357,399	44,727	45,132	89,859	230,659	216,599	447,258	0.52
1992	193,693	17,546	211,240	36,745	13,688	50,433	230,438	31,234	261,673	0.88
1993	169,210	172,281	341,490	30,960	44,580	75,540	200,170	216,861	417,030	0.48
1994	217,567	150,379	367,946	45,241	40,999	86,240	262,808	191,378	454,186	0.58
1995	338,324	187,938	526,262	45,254	46,654	91,908	383,578	234,592	618,170	0.62
1996	324,684	211,020	535,704	40,235	38,799	79,034	364,919	249,819	614,738	0.59
1997	339,500	254,672	594,172	71,937	55,324	127,261	411,437	309,996	721,433	0.57
1998	471,447	269,876	741,323	73,142	52,070	125,212	544,589	321,946	866,535	0.63

(continued next page)

Year	Central and Mississippi Flyways			Manitoba, Saskatchewan and Northern Ontario			Total Midcontinent			Proportion Adults
	Adult	Immature	Total	Adult	Immature	Total	Adult	Immature	Total	
1999	527,787	253,352	781,139	80,280	50,802	131,082	608,067	304,154	912,221	0.67
2000	446,328	164,433	610,761	64,513	34,520	99,033	510,841	198,953	709,794	0.72
2001	389,008	240,987	629,995	71,792	58,007	129,799	460,800	298,994	759,794	0.61
2002	362,612	110,248	472,860	73,336	38,180	111,516	435,948	148,428	584,376	0.75
2003	329,578	203,150	532,728	79,492	68,098	147,590	409,070	271,248	680,318	0.60
2004	338,966	69,194	408,161	71,308	31,048	102,356	410,274	100,242	510,517	0.80
2005	376,005	176,805	552,810	60,483	44,344	104,827	436,488	221,149	657,637	0.66
2006	294,338	172,658	466,996	75,195	78,435	153,630	369,533	251,093	620,626	0.60
2007	332,448	90,203	422,651	52,545	31,219	83,764	384,993	121,422	506,415	0.76

Appendix 7. Harvest of Midcontinent adult and immature Ross's, 1962-2007. No data available for MB and SK, 1962-1974. Totals include known-age birds only.

Year	Central and Mississippi Flyways			Manitoba, Saskatchewan and Northern Ontario			Total Midcontinent			Proportion Adults
	Adult	Immature	Total	Adult	Immature	Total	Adult	Immature	Total	
1962	0	0								
1963	0	0								
1964	0	0								
1965	0	0								
1966	0	0								
1967	0	0								
1968	0	0								
1969	0	0								
1970	0	0								
1971	0	0								
1972	0	0								
1973	0	0								
1974	195	0	195							
1975	0	146	146	634	3,892	4,526	634	4,038	4,672	0.14
1976	1,080	703	1,783	1,766	913	2,679	2,846	1,616	4,462	0.64
1977	230	70	299	709	490	1,199	939	560	1,498	0.63
1978	0	0	0	4,132	242	4,374	4,132	242	4,374	0.94
1979	334	1,263	1,598	2,925	3,915	6,840	3,259	5,178	8,438	0.39
1980	397	113	510	1,635	1,829	3,464	2,032	1,942	3,974	0.51
1981	1,202	1,503	2,705	1,378	933	2,311	2,580	2,436	5,016	0.51
1982	1,755	4,657	6,412	1,651	1,779	3,430	3,406	6,436	9,842	0.35
1983	68	1,882	1,950	2,027	2,584	4,611	2,095	4,466	6,561	0.32
1984	726	5,089	5,816	1,978	1,476	3,454	2,704	6,565	9,270	0.29
1985	1,762	2,178	3,940	1,660	4,582	6,242	3,422	6,760	10,182	0.34
1986	1,386	1,873	3,259	195	956	1,151	1,581	2,829	4,410	0.36
1987	80	478	558	1,360	3,379	4,739	1,440	3,857	5,297	0.27
1988	1,279	3,036	4,315	1,283	1,266	2,549	2,562	4,302	6,864	0.37
1989	2,462	5,953	8,415	1,704	1,505	3,209	4,166	7,458	11,624	0.36
1990	2,235	5,789	8,023	3,414	2,447	5,861	5,649	8,236	13,884	0.41
1991	2,491	4,696	7,187	1,655	971	2,626	4,146	5,667	9,813	0.42
1992	1,855	3,092	4,946	1,696	1,343	3,039	3,551	4,435	7,985	0.44
1993	1,493	6,433	7,926	944	891	1,835	2,437	7,324	9,761	0.25
1994	4,248	7,637	11,885	3,591	3,754	7,345	7,839	11,391	19,230	0.41
1995	8,817	14,381	23,198	6,200	5,238	11,438	15,017	19,619	34,636	0.43
1996	7,186	16,592	23,778	8,054	9,387	17,441	15,240	25,979	41,219	0.37
1997	7,692	12,876	20,568	5,188	8,814	14,002	12,880	21,690	34,570	0.37
1998	17,063	28,534	45,596	11,030	14,904	25,934	28,093	43,438	71,530	0.39

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Year	Central and Mississippi Flyways			Manitoba, Saskatchewan and Northern Ontario			Total Midcontinent			Proportion Adults
	Adult	Immature	Total	Adult	Immature	Total	Adult	Immature	Total	
1999	18,443	56,499	74,942	6,644	15,102	21,746	25,087	71,601	96,688	0.26
2000	25,505	27,132	52,638	7,513	8,912	16,425	33,018	36,044	69,063	0.48
2001	27,626	62,697	90,323	7,705	8,725	16,430	35,331	71,422	106,753	0.33
2002	34,839	35,221	70,060	9,711	20,381	30,092	44,550	55,602	100,152	0.44
2003	22,766	49,144	71,910	5,700	24,389	30,089	28,466	73,533	101,999	0.28
2004	36,341	13,867	50,208	10,757	10,970	21,727	47,098	24,837	71,935	0.65
2005	21,390	37,003	58,393	7,000	6,187	13,187	28,390	43,190	71,580	0.40
2006	15,675	31,047	46,722	7,089	19,467	26,556	22,764	50,514	73,278	0.31
2007	20,450	16,974	37,424	8,624	9,057	17,681	29,074	26,031	55,105	0.53

Appendix 8. State-specific Mail Questionnaire Survey estimates of snow and Ross's goose harvest in the U.S. portion of the Mississippi Flyway, 1952-53 – 2001-02.

Year	Minnesota				Wisconsin				Michigan			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue	white		blue	white	blue		white	blue		
1952	0	0	0	0	671	548	0	1,220	0	0	0	0
1953	2,994	1,126	0	4,120	822	1,080	0	1,902	272	926	0	1,198
1954	3,889	2,206	0	6,095	672	624	0	1,297	355	1,234	0	1,589
1955	851	1,448	0	2,299	333	1,021	0	1,354	905	770	0	1,674
1956	14,125	10,283	0	24,408	2,801	3,967	0	6,768	1,033	1,055	0	2,087
1957	3,091	935	0	4,026	1,773	724	0	2,496	308	839	0	1,147
1958	11,796	6,686	0	18,482	5,939	4,331	0	10,271	421	1,146	0	1,567
1959	7,739	4,346	0	12,085	2,603	3,359	0	5,963	570	2,121	0	2,691
1960	1,740	1,382	0	3,123	1,539	1,286	0	2,825	771	2,754	0	3,524
1961	10,748	6,889	0	17,637	1,295	2,805	0	4,100	291	773	0	1,064
1962	3,224	3,514	0	6,737	236	725	0	962	124	693	0	818
1963	4,451	6,817	0	11,268	649	1,633	0	2,281	0	0	0	0
1964	6,620	2,909	0	9,529	2,097	3,263	0	5,360	2,642	8,338	0	10,980
1965	10,959	3,847	0	14,806	1,139	1,109	0	2,248	0	1,803	0	1,803
1966	5,125	1,308	0	6,434	652	1,115	0	1,767	633	1,077	0	1,709
1967	11,329	9,972	0	21,301	212	1,445	0	1,657	680	994	0	1,674
1968	2,351	2,101	0	4,452	181	462	0	643	0	403	0	403
1969	12,653	14,815	0	27,469	6,782	14,390	0	21,172	1,928	16,535	0	18,463
1970	9,119	7,754	0	16,873	2,486	2,257	0	4,743	326	1,000	0	1,326
1971	9,674	14,465	0	24,139	559	8,432	0	8,990	357	2,911	0	3,268
1972	9,531	7,922	0	17,454	1,915	391	0	2,306	0	1,333	0	1,333
1973	3,780	4,824	0	8,604	2,015	4,104	0	6,119	151	2,617	0	2,767
1974	19,440	20,273	0	39,713	3,576	6,130	0	9,707	227	3,010	0	3,237

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Year	Minnesota			Wisconsin			Michigan		
	Snow goose		Ross's goose	Snow goose		Ross's goose	Snow goose		Ross's goose
	white	blue	Total	white	blue	Total	white	blue	Total
1975	9,556	5,924	0	2,288	3,795	0	144	147	292
1976	3,547	2,366	0	243	1,736	0	0	962	962
1977	2,245	5,602	0	0	1,843	0	0	1,147	1,147
1978	392	3,205	0	356	363	0	0	0	0
1979	16,799	25,285	0	767	3,449	0	579	1,925	2,504
1980	5,775	12,767	0	1,571	6,142	0	808	1,849	2,656
1981	2,794	8,151	0	0	2,751	0	187	1,525	1,712
1982	0	2,007	0	0	570	0	0	139	139
1983	787	535	0	0	0	0	0	0	0
1984	312	2,545	0	0	276	0	0	563	563
1985	2,198	3,740	0	156	159	0	0	595	595
1986	0	0	0	135	276	0	594	0	594
1987	1,183	7,245	0	0	180	0	0	145	145
1988	1,117	1,901	0	70	143	0	0	367	367
1989	2,981	5,710	0	1,204	1,473	0	93	668	761
1990	300	0	0	185	0	0	0	0	0
1991	1,589	4,543	0	396	0	0	221	452	672
1992	0	435	0	0	72	0	0	0	0
1993	1,611	4,569	0	428	1,667	0	0	459	459
1994	0	172	0	262	267	0	0	0	0
1995	229	234	234	107	109	0	0	356	356
1996	1,478	1,079	0	0	284	0	182	0	182
1997	0	1,466	0	0	687	0	537	0	537
1998	1,242	1,268	0	120	246	0	0	0	0
1999	757	1,160	0	153	780	0	0	0	0
2000	1,918	4,756	0	0	428	0	0	0	0
2001	367	2,251	0	0	265	0	266	0	266

Appendix 8. State-specific Mail Questionnaire Survey estimates of snow and Ross's goose harvest in the U.S. portion of the Mississippi Flyway, 1952-53 – 2001-02.

Year	Iowa				Illinois				Indiana			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1952	1,437	489		1,926	0	0		0	0		0	
1953	1,409	2,876		4,285	759	2,326		3,085	155	4,740		4,895
1954	991	1,517		2,508	1,245	1,187		2,432	0	878		878
1955	1,441	1,373		2,813	1,324	1,802		3,126	0	461		461
1956	5,445	7,818		13,264	943	1,604		2,547	238	122		360
1957	5,846	3,041		8,887	1,228	3,876		5,104	0	0		0
1958	5,387	4,845		10,232	1,219	2,334		3,553	0	1,095		1,095
1959	5,612	5,875		11,487	522	906		1,427	61	125		186
1960	4,001	3,611		7,612	789	1,853		2,642	852	2,490		3,341
1961	5,142	5,495		10,637	400	572		972	338	288		625
1962	4,998	7,975	0	12,973	0	1,245	0	1,245	109	222	0	331
1963	2,993	8,061	0	11,054	204	2,475	0	2,679	0	202	0	202
1964	4,128	4,839	0	8,967	293	2,392	0	2,685	0	1,551	0	1,551
1965	15,184	12,539	0	27,723	710	1,813	0	2,524	0	170	0	170
1966	10,935	7,940	0	18,874	1,474	3,609	0	5,083	87	443	0	530
1967	8,540	9,256	0	17,796	340	1,528	0	1,868	0	237	0	237
1968	4,365	7,047	0	11,412	347	1,575	0	1,923	0	466	0	466
1969	21,637	23,995	0	45,631	1,749	3,409	0	5,158	556	3,406	0	3,962
1970	25,425	25,591	0	51,017	889	3,161	0	4,050	113	461	0	574
1971	16,320	32,555	0	48,874	0	3,431	0	3,431	0	424	0	424
1972	21,775	19,795	0	41,570	0	1,777	0	1,777	0	312	0	312
1973	17,194	17,187	0	34,381	420	4,582	0	5,002	373	190	0	564
1974	24,234	23,448	0	47,682	893	5,267	0	6,161	0	0	0	0
1975	18,765	24,880	0	43,645	908	1,693	0	2,601	255	0	0	255
1976	8,627	9,328	0	17,955	325	1,993	0	2,318	0	0	0	0
1977	14,438	16,371	0	30,809	442	0	0	442	0	0	0	0
1978	11,262	14,031	0	25,294	599	1,225	0	1,824	0	0	0	0
1979	19,085	26,647	0	45,732	964	2,879	0	3,844	317	1,779	0	2,096
1980	12,863	11,924	0	24,787	1,062	4,335	0	5,397	0	824	0	824
1981	12,972	11,406	0	24,379	372	4,188	0	4,560	0	0	0	0
1982	5,884	8,955	0	14,839	1,078	2,414	0	3,492	0	0	0	0
1983	9,985	7,415	0	17,400	232	831	0	1,063	0	172	0	172
1984	14,817	8,381	0	23,197	174	1,640	0	1,814	0	180	0	180
1985	3,128	5,839	0	8,966	277	850	0	1,127	212	108	0	320
1986	7,577	4,899	0	12,476	281	179	0	461	0	0	0	0
1987	1,991	1,820	0	3,810	79	486	0	565	0	0	0	0
1988	5,750	5,009	0	10,759	0	0	0	0	0	73	0	73
1989	2,953	1,659	0	4,611	312	159	0	471	0	219	0	219
1990	1,629	1,656	0	3,285	519	901	0	1,420	69	0	0	69
1991	5,038	3,473	0	8,511	477	244	0	720	0	0	0	0
1992	2,105	2,281	0	4,386	0	439	0	439	0	0	0	0

1993	6,026	4,056	0	10,082	155	264	0	419	0	0	0	0
1994	1,331	1,163	0	2,494	136	418	139	693	0	0	0	0
1995	3,574	1,873	0	5,447	1,771	1,992	0	3,763	0	0	0	0
1996	3,608	2,390	204	6,202	1,660	3,347	0	5,007	0	0	0	0
1997	9,723	6,695	0	16,418	4,648	5,053	0	9,701	0	0	0	0
1998	10,673	6,208	260	17,142	1,723	1,055	0	2,778	0	0	0	0
1999	9,280	4,873	0	14,153	632	0	0	632	0	0	0	0
2000	299	305	0	605	315	643	322	1,280	0	0	0	0
2001	2,958	1,208	0	4,166	0	0	0	0	0	0	0	0

Year	Ohio				Missouri				Kentucky			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1952	0	481		481	0	0		0	0	0		0
1953	215	293		509	280	0		280	2,631	0		2,631
1954	216	0		216	804	2,736		3,540	80	0		80
1955	255	780		1,034	1,478	905		2,383	86	529		616
1956	291	594		885	2,161	2,574		4,735	0	106		106
1957	214	312		526	6,609	5,745		12,353	0	0		0
1958	150	0		150	2,625	1,563		4,188	85	0		85
1959	267	1,940		2,207	2,014	2,436		4,450	63	64		127
1960	211	3,059		3,270	3,863	2,781		6,644	104	354		458
1961	0	45		45	444	1,361		1,805	64	33		97
1962	0	687	0	687	561	946	0	1,507	0	0	0	0
1963	4,757	0	0	4,757	0	3,679	0	3,679	0	0	0	0
1964	0	177	0	177	5,449	2,271	0	7,719	0	0	0	0
1965	147	601	0	749	4,186	3,834	0	8,020	0	0	0	0
1966	0	292	0	292	12,119	12,003	0	24,122	0	132	0	132
1967	0	472	0	472	4,865	3,613	0	8,478	0	0	0	0
1968	0	110	0	110	8,414	5,774	0	14,188	0	91	0	91
1969	0	4,683	0	4,683	10,050	10,333	0	20,383	0	563	0	563
1970	79	81	0	161	16,203	9,935	0	26,137	0	0	0	0
1971	0	90	0	90	18,118	10,788	0	28,906	0	0	0	0
1972	0	0	0	0	8,788	4,959	0	13,747	94	0	0	94
1973	146	373	0	519	12,093	9,505	0	21,598	0	0	0	0
1974	111	340	0	451	16,207	10,723	0	26,929	0	807	0	807
1975	101	413	0	515	18,591	16,168	0	34,759	0	0	0	0
1976	145	148	0	294	6,596	4,780	0	11,376	0	127	0	127
1977	144	0	0	144	11,231	9,382	0	20,613	0	304	0	304
1978	0	0	0	0	6,045	5,864	0	11,909	0	0	0	0
1979	0	0	0	0	9,184	7,106	0	16,290	0	0	0	0
1980	0	0	0	0	2,628	3,460	0	6,088	331	0	0	331
1981	0	178	0	178	5,191	5,517	0	10,709	0	92	0	92
1982	0	244	0	244	4,196	6,044	183	10,422	0	0	0	0
1983	0	0	0	0	13,763	10,303	295	24,362	537	0	0	537
1984	163	0	0	163	7,841	7,694	0	15,535	0	201	0	201
1985	107	283	0	390	8,386	7,333	116	15,834	0	0	0	0

1986	0	0	0	0	14,220	12,064	754	27,039	0	0	0	0
1987	0	0	0	0	4,413	3,539	166	8,118	0	0	0	0
1988	0	0	0	0	3,754	2,677	0	6,432	0	171	0	171
1989	0	0	0	0	6,256	4,973	0	11,229	185	0	0	185
1990	0	279	0	279	7,031	4,185	47	11,264	0	0	0	0
1991	93	95	0	188	8,054	5,291	74	13,419	0	0	0	0
1992	74	0	0	74	3,092	2,368	0	5,460	212	96	0	308
1993	0	0	0	0	4,307	1,960	0	6,267	0	0	0	0
1994	0	0	0	0	10,120	8,322	0	18,442	0	0	0	0
1995	0	0	0	0	9,065	6,163	291	15,519	1,248	0	0	1,248
1996	0	0	0	0	26,721	12,572	494	39,788	744	1,138	0	1,882
1997	0	0	0	0	25,428	20,769	325	46,523	464	0	0	464
1998	0	0	0	0	47,839	38,851	2,112	88,802	0	0	0	0
1999	0	0	0	0	10,473	8,987	1,179	20,639	0	0	0	0
2000	0	0	0	0	8,542	8,384	380	17,305	0	0	0	0
2001	0	0	0	0	22,219	12,758	1,929	36,907	637	650	0	1,287
		Arkansas			Tennessee				Louisiana			
		Snow goose		Ross's	Snow goose		Ross's	Snow goose		Ross's		
Year	white	blue	goose	Total	white	blue	goose	Total	white	blue	goose	Total
1952	484	0		484	0	0		0	19,447	82,260		101,706
1953	1,034	2,111		3,144	0	0		0	77,708	426,014		503,721
1954	0	0		0	0	957		957	9,833	57,778		67,611
1955	0	3,392		3,392	126	0		126	7,745	54,787		62,532
1956	509	866		1,374	0	282		282	4,211	19,617		23,828
1957	920	939		1,860	0	238		238	8,214	31,870		40,084
1958	0	610		610	0	0		0	13,707	24,599		38,306
1959	692	777		1,469	239	699		938	16,735	48,109		64,844
1960	1,018	831		1,849	83	424		507	5,087	22,007		27,094
1961	931	279		1,210	0	75		75	6,767	14,409		21,176
1962	0	600	0	600	0	0	0	0	463	13,259	0	13,723
1963	0	1,404	0	1,404	0	0	0	0	3,985	23,396	0	27,381
1964	0	0	0	0	0	0	0	0	3,135	44,837	0	47,972
1965	0	757	0	757	0	0	0	0	8,148	31,688	0	39,836
1966	0	1,025	0	1,025	0	0	0	0	27,125	74,321	0	101,446
1967	0	1,552	0	1,552	0	528	0	528	11,926	51,612	0	63,539
1968	0	357	0	357	0	0	0	0	11,979	23,077	0	35,056
1969	0	572	0	572	0	0	0	0	14,422	50,720	0	65,143
1970	0	0	0	0	139	0	0	139	39,785	125,948	0	165,733
1971	0	2,419	0	2,419	0	0	0	0	7,565	41,196	0	48,761
1972	1,836	0	0	1,836	0	0	0	0	6,892	27,461	0	34,354
1973	0	720	0	720	0	947	0	947	23,870	55,931	0	79,801
1974	0	1,936	0	1,936	0	137	0	137	4,808	40,083	0	44,892
1975	1,402	2,289	0	3,690	0	710	0	710	12,587	54,276	0	66,862
1976	554	2,264	0	2,819	0	1,986	0	1,986	10,127	52,258	0	62,386
1977	2,402	1,581	0	3,982	0	0	0	0	15,502	50,894	0	66,396
1978	3,894	5,452	0	9,346	0	678	0	678	30,492	58,061	0	88,553

1979	1,389	4,254	0	5,643	0	0	0	0	9,582	41,206	0	50,788
1980	1,591	9,209	0	10,800	0	0	0	0	21,170	54,845	0	76,015
1981	3,512	6,276	0	9,788	0	0	0	0	17,562	32,025	0	49,587
1982	1,101	9,064	0	10,166	0	580	0	580	19,418	69,393	4,414	93,225
1983	2,947	2,749	0	5,696	0	0	0	0	50,384	95,605	0	145,989
1984	1,709	2,618	0	4,327	0	0	0	0	18,206	37,962	0	56,168
1985	8,097	8,267	0	16,364	0	0	0	0	21,583	33,453	0	55,036
1986	3,849	9,055	0	12,904	230	0	0	230	6,634	13,548	0	20,181
1987	4,876	4,263	0	9,140	0	682	0	682	9,392	19,545	0	28,938
1988	2,340	3,843	0	6,183	146	0	0	146	9,586	17,716	608	27,909
1989	7,809	7,352	0	15,162	191	0	0	191	20,165	38,268	0	58,432
1990	8,001	6,752	0	14,753	0	475	0	475	29,115	36,894	1,045	67,055
1991	17,644	19,406	279	37,329	320	0	0	320	17,176	32,178	0	49,354
1992	9,633	8,868	257	18,757	0	0	0	0	11,718	21,198	0	32,916
1993	6,619	8,127	109	14,856	0	0	0	0	13,332	21,283	505	35,120
1994	9,637	12,941	565	23,143	0	0	0	0	24,962	33,153	2,304	60,418
1995	50,561	52,762	1,379	104,702	232	237	0	469	23,071	41,006	1,984	66,060
1996	55,673	43,996	4,834	104,504	0	0	0	0	45,105	39,505	3,281	87,891
1997	36,398	18,652	0	55,049	305	0	0	305	57,462	54,822	8,376	120,659
1998	51,785	53,593	5,425	110,804	0	0	0	0	94,005	110,491	1,348	205,844
1999	83,026	56,291	6,883	146,201	517	351	0	868	99,845	36,977	4,038	140,860
2000	23,420	18,627	1,767	43,813	0	0	0	0	36,146	42,694	2,454	81,293
2001	29,708	21,665	8,352	59,726	0	0	0	0	26,882	40,764	1,617	69,263

Year	Mississippi				Alabama				Mississippi Flyway			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1952	0	0	0	0	0	0	0	0	22,040	83,778	0	105,818
1953	0	0	0	0	0	0	0	0	88,279	441,492	0	529,771
1954	0	0	0	0	294	0	0	294	18,379	69,117	0	87,496
1955	0	307	0	307	152	0	0	152	14,694	67,575	0	82,269
1956	384	392	0	776	84	259	0	343	32,225	49,539	0	81,764
1957	131	0	0	131	0	0	0	0	28,333	48,519	0	76,851
1958	0	300	0	300	0	235	0	235	41,329	47,745	0	89,074
1959	964	2,314	0	3,278	508	1,335	0	1,844	38,589	74,407	0	112,996
1960	32	517	0	549	0	590	0	590	20,089	43,939	0	64,028
1961	0	34	0	34	79	161	0	240	26,499	33,217	0	59,717
1962	0	0	0	0	0	0	0	0	9,715	29,867	0	39,582
1963	43	0	0	43	0	0	0	0	17,081	47,667	0	64,748
1964	91	186	0	277	0	0	0	0	24,454	70,762	0	95,217
1965	305	913	0	1,219	61	62	0	123	40,840	59,136	0	99,976
1966	295	453	0	748	0	132	0	132	58,444	103,850	0	162,294
1967	301	1,231	0	1,533	0	0	0	0	38,194	82,441	0	120,635
1968	161	383	0	544	70	216	0	286	27,869	42,061	0	69,930
1969	804	3,287	0	4,092	0	0	0	0	70,582	146,709	0	217,291
1970	0	2,141	0	2,141	396	662	0	1,059	94,961	178,991	0	273,953
1971	0	0	0	0	123	0	0	123	52,715	116,711	0	169,426

1972	224	533	0	757	0	0	0	0	51,055	64,484	0	115,539
1973	676	0	0	676	388	0	0	388	61,106	100,980	0	162,087
1974	0	1,616	0	1,616	85	173	0	258	69,581	113,943	0	183,524
1975	635	1,901	0	2,536	0	223	0	223	65,232	112,420	0	177,652
1976	0	179	0	179	0	370	0	370	30,166	78,498	0	108,664
1977	245	250	0	495	129	263	0	391	46,777	87,638	0	134,415
1978	0	0	0	0	0	0	0	0	53,041	88,880	0	141,921
1979	0	2,413	0	2,413	0	0	0	0	58,667	116,942	0	175,609
1980	0	0	0	0	0	105	0	105	47,797	105,461	0	153,258
1981	1,840	0	0	1,840	802	0	0	802	45,234	72,109	0	117,343
1982	1,051	0	0	1,051	0	0	0	0	32,728	99,409	4,597	136,734
1983	890	909	0	1,799	107	54	0	161	79,631	118,574	295	198,500
1984	280	286	0	567	551	1,126	0	1,677	44,052	63,471	0	107,524
1985	0	0	0	0	0	0	0	0	44,143	60,627	116	104,886
1986	0	0	0	0	0	234	0	234	33,521	40,254	754	74,530
1987	0	0	0	0	0	0	0	0	21,935	37,908	166	60,008
1988	0	0	0	0	0	83	0	83	22,763	31,983	608	55,354
1989	369	0	0	369	0	0	0	0	42,519	60,479	0	102,998
1990	162	4	0	166	0	0	0	0	47,011	51,148	1,092	99,251
1991	300	205	0	505	0	0	0	0	51,308	65,886	353	117,547
1992	68	1,038	0	1,106	0	0	0	0	26,902	36,794	257	63,953
1993	165	1,011	0	1,177	0	0	0	0	32,644	43,397	614	76,655
1994	0	1,909	0	1,909	0	0	0	0	46,447	58,344	3,008	107,798
1995	4,196	3,679	0	7,875	0	0	0	0	94,052	108,412	3,888	206,352
1996	1,478	2,514	0	3,992	866	0	0	866	137,514	106,827	8,814	253,155
1997	4,937	1,680	0	6,617	2,041	521	0	2,562	141,943	110,345	8,701	260,989
1998	0	0	0	0	0	0	0	0	207,387	211,712	9,145	428,244
1999	6,293	4,589	919	11,801	0	0	0	0	210,975	114,009	13,020	338,004
2000	3,110	0	0	3,110	0	0	0	0	73,749	75,838	4,922	154,509
2001	2,152	807	1,393	4,352	365	0	0	365	85,554	80,370	13,292	179,216

Appendix 9. State-specific Mail Questionnaire Survey estimates of snow and Ross's goose harvest in the U.S. portion of the Central Flyway, 1952-53 – 2001-02.

Year	Montana				North Dakota				South Dakota			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1952	429	0		429	822	0		822	3,503	334		3,837
1953	203	203		405	582	0		582	12,941	7,652		20,593
1954	239	0		239	5,687	1,152		6,839	12,656	4,611		17,266
1955	0	145		145	2,615	387		3,002	1,602	1,068		2,670
1956	408	0		408	6,930	1,788		8,718	11,621	7,032		18,652
1957	7,321	0		7,321	1,957	1,442		3,400	6,248	3,060		9,308
1958	2,388	0		2,388	3,631	1,614		5,244	10,205	5,245		15,450
1959	2,282	0		2,282	3,520	1,301		4,821	4,329	1,778		6,107
1960	2,446	0		2,446	1,388	747		2,135	2,879	823		3,701
1961	2,166	134		2,300	11,970	4,766		16,736	25,912	9,948		35,860
1962	1,920	0	0	1,920	7,311	2,399	0	9,710	20,995	12,122	0	33,117
1963	2,496	83	0	2,579	12,922	2,696	0	15,618	16,370	9,471	0	25,841
1964	790	0	0	790	15,111	2,909	0	18,020	14,614	5,635	0	20,249
1965	0	0	0	0	13,614	5,106	0	18,720	21,071	9,505	0	30,576
1966	0	0	0	0	21,794	6,020	0	27,814	13,683	6,187	0	19,870
1967	0	0	0	0	24,052	12,784	0	36,836	13,542	11,372	0	24,914
1968	0	0	0	0	12,323	5,283	0	17,606	9,125	3,721	0	12,846
1969	0	0	0	0	38,002	18,844	0	56,846	36,688	18,501	0	55,189
1970	0	0	0	0	40,430	16,354	0	56,784	31,767	12,549	0	44,316
1971	0	0	0	0	50,991	17,824	0	68,815	27,181	14,506	0	41,687
1972	0	0	0	0	29,788	10,832	0	40,620	20,590	7,956	0	28,546
1973	0	0	0	0	51,925	25,661	0	77,586	25,744	10,166	0	35,910
1974	0	0	0	0	74,155	26,577	195	100,927	17,238	10,253	0	27,491
1975	80	0	0	80	101,153	41,562	0	142,715	20,919	16,384	146	37,449
1976	0	0	0	0	64,604	28,747	0	93,351	6,422	4,685	0	11,107
1977	0	0	0	0	78,745	45,564	0	124,309	9,296	14,276	0	23,572
1978	0	0	0	0	63,911	27,738	0	91,649	8,302	5,304	0	13,606
1979	0	0	0	0	102,585	45,756	578	148,919	17,059	12,816	0	29,875
1980	87	0	0	87	53,070	30,478	0	83,548	5,724	6,702	0	12,426
1981	0	0	0	0	81,321	49,111	609	131,041	11,838	11,608	245	23,691
1982	0	341	0	341	53,268	32,722	577	86,567	5,546	6,042	0	11,588
1983	0	0	0	0	67,784	46,479	0	114,263	8,269	6,962	0	15,231
1984	125	0	0	125	45,793	31,647	388	77,828	16,274	9,119	183	25,576
1985	62	0	0	62	34,416	32,813	528	67,757	6,497	6,660	0	13,157
1986	110	0	0	110	36,472	31,440	500	68,412	3,735	2,861	133	6,729
1987	34	0	0	34	39,756	40,043	0	79,799	3,176	3,787	0	6,963
1988	122	0	0	122	65,608	41,436	564	107,608	11,369	9,518	88	20,975
1989	87	29	0	116	53,065	45,246	786	99,097	12,674	8,478	80	21,232
1990	202	0	0	202	24,617	23,516	542	48,675	17,395	11,816	341	29,552
1991	119	0	0	119	58,166	39,356	560	98,082	15,043	12,268	415	27,726
1992	0	0	0	0	24,073	19,201	1,062	44,336	4,875	3,688	254	8,817

1993	360	0	0	360	49,915	42,401	1,375	93,691	5,656	6,381	56	12,093
1994	339	339	174	852	67,155	51,379	1,030	119,564	7,370	5,023	101	12,494
1995	0	0	0	0	48,335	62,304	1,810	112,449	5,884	5,166	558	11,608
1996	0	0	0	0	64,354	40,164	2,572	107,090	20,267	12,917	1,222	34,406
1997	275	0	0	275	78,965	81,842	2,130	162,937	7,774	7,368	126	15,268
1998	1,061	212	212	1,485	38,841	39,011	1,260	79,112	11,686	5,251	508	17,445
1999	49	0	0	49	28,045	25,204	296	53,545	4,339	4,006	333	8,678
2000	0	0	96	96	18,126	23,304	516	41,946	1,267	1,528	0	2,795
2001	395	0	0	395	35,220	32,028	3,989	71,237	9,374	8,007	1,761	19,142
	Wyoming				Nebraska				Colorado			
	Snow goose		Ross's	Total	Snow goose		Ross's	Total	Snow goose		Ross's	Total
Year	white	blue	goose		white	blue	goose		white	blue	goose	
1952	0	0		0	1,416	0		1,416	0	0		0
1953	0	0		0	0	0		0	69	0		69
1954	0	0		0	4,057	1,427		5,484	0	0		0
1955	81	0		81	300	150		450	0	249		249
1956	0	0		0	1,782	1,262		3,044	0	0		0
1957	0	0		0	1,480	575		2,055	0	0		0
1958	0	0		0	6,743	4,065		10,808	344	0		344
1959	0	0		0	1,155	1,540		2,696	248	0		248
1960	0	0		0	1,464	976		2,440	246	0		246
1961	0	0		0	6,311	4,528		10,839	41	0		41
1962	0	0	0	0	1,205	1,422	0	2,627	0	0	0	0
1963	0	0	0	0	1,035	254	0	1,289	89	0	0	89
1964	0	0	0	0	914	1,026	0	1,940	98	0	0	98
1965	0	0	0	0	3,866	1,982	0	5,848	0	0	0	0
1966	0	0	0	0	2,854	1,365	0	4,219	0	0	0	0
1967	0	0	0	0	2,214	2,400	0	4,614	0	0	0	0
1968	0	0	0	0	1,219	2,651	0	3,870	0	0	0	0
1969	0	0	0	0	4,503	2,671	0	7,174	253	0	0	253
1970	0	0	0	0	5,754	1,623	0	7,377	251	0	0	251
1971	0	0	0	0	4,278	3,803	0	8,081	0	0	0	0
1972	0	0	0	0	2,372	1,423	0	3,795	0	0	0	0
1973	27	0	0	27	8,940	5,549	0	14,489	282	0	0	282
1974	0	0	0	0	5,214	5,175	0	10,389	0	0	0	0
1975	0	0	0	0	6,630	5,343	0	11,973	99	99	0	198
1976	0	0	0	0	1,785	1,461	0	3,246	409	0	0	409
1977	0	0	0	0	2,946	2,946	0	5,892	0	0	0	0
1978	0	0	0	0	3,623	2,264	0	5,887	525	0	0	525
1979	43	0	0	43	6,781	4,960	0	11,741	348	0	0	348
1980	61	0	0	61	678	1,357	0	2,035	405	0	0	405
1981	0	0	0	0	1,801	1,637	0	3,438	268	0	0	268
1982	0	0	0	0	1,908	2,768	0	4,676	815	0	0	815
1983	0	0	0	0	607	1,974	0	2,581	0	0	0	0
1984	0	0	0	0	2,887	2,130	284	5,301	1,294	0	388	1,682
1985	122	0	61	183	5,535	3,024	94	8,653	963	0	161	1,124

1986	120	60	0	180	4,163	2,955	125	7,243	3,069	0	309	3,378
1987	34	0	0	34	1,664	1,792	0	3,456	0	0	0	0
1988	0	0	0	0	2,027	1,533	0	3,560	253	0	0	253
1989	50	0	0	50	1,117	191	0	1,308	572	0	0	572
1990	0	0	4	4	5,619	3,042	212	8,873	1,226	0	0	1,226
1991	56	0	0	56	1,416	731	91	2,238	770	0	41	811
1992	0	0	0	0	4,899	1,930	0	6,829	689	0	137	826
1993	0	0	0	0	854	939	0	1,793	425	0	0	425
1994	133	0	0	133	4,312	1,929	340	6,581	113	0	0	113
1995	0	0	0	0	2,356	1,392	107	3,855	820	0	328	1,148
1996	299	0	0	299	3,960	2,174	356	6,490	2,044	0	388	2,432
1997	182	0	84	266	9,542	5,640	545	15,727	4,296	0	330	4,626
1998	1,811	0	0	1,811	14,381	6,608	1,525	22,514	15,443	231	2,996	18,670
1999	633	0	0	633	16,318	4,470	3,764	24,552	10,525	357	2,141	13,023
2000	119	0	0	119	1,955	977	782	3,714	8,048	0	898	8,946
2001	0	0	0	0	2,876	908	454	4,238	11,917	722	2,889	15,528
	Kansas				New Mexico				Oklahoma			
	Snow goose		Ross's	Total	Snow goose		Ross's	Total	Snow goose		Ross's	Total
Year	white	blue	goose		white	blue	goose		white	blue	goose	
1952	0	0		0	0		0	0	0		0	
1953	1,865	311		2,176	944	0	944	652	435		1,086	
1954	0	0		0	362	0	362	334	334		669	
1955	1,324	828		2,152	116	0	116	933	431		1,364	
1956	4,854	2,846		7,700	234	0	234	181	722		903	
1957	317	159		476	0	0	0	606	121		727	
1958	4,406	2,254		6,661	61	61	122	1,430	505		1,935	
1959	595	425		1,020	0	0	0	644	1,159		1,804	
1960	749	998		1,747	189	0	189	405	1,517		1,922	
1961	1,535	1,096		2,632	0	0	0	558	507		1,065	
1962	2,449	1,745	0	4,194	4	0	4	702	346	0	1,048	
1963	1,474	737	0	2,211	263	0	263	1,772	1,139	0	2,911	
1964	3,222	1,983	0	5,205	6	0	6	568	715	0	1,283	
1965	2,254	634	0	2,888	175	0	175	238	476	0	714	
1966	996	362	0	1,358	77	19	96	2,542	1,224	0	3,766	
1967	1,459	1,459	0	2,918	358	0	358	1,872	1,070	0	2,942	
1968	1,536	973	0	2,509	390	145	535	266	209	0	475	
1969	2,857	2,772	0	5,629	249	33	282	2,079	1,188	0	3,267	
1970	7,264	5,123	0	12,387	782	78	860	1,560	2,340	0	3,900	
1971	791	3,495	0	4,286	1,498	0	1,498	511	1,022	0	1,533	
1972	3,463	1,154	0	4,617	96	0	96	1,850	1,644	0	3,494	
1973	5,968	3,848	0	9,816	1,207	0	1,207	337	313	0	650	
1974	12,390	5,397	0	17,787	94	0	94	2,959	1,165	0	4,124	
1975	2,726	1,569	0	4,295	1,922	208	2,130	3,222	2,950	0	6,172	
1976	6,324	3,915	0	10,239	3,618	50	3,819	445	148	0	593	
1977	3,050	3,033	0	6,083	7,829	152	8,051	2,766	1,942	0	4,708	
1978	2,389	796	0	3,185	2,153	0	2,153	2,233	544	0	2,777	

1979	2,286	1,792	0	4,078	1,445	0	352	1,797	4,419	3,036	0	7,455
1980	448	390	0	838	2,613	0	113	2,726	1,729	1,092	0	2,821
1981	2,078	751	0	2,829	2,308	50	401	2,759	3,290	2,026	0	5,316
1982	787	664	123	1,574	2,104	70	226	2,400	831	312	0	1,143
1983	2,563	1,931	0	4,494	4,685	364	411	5,460	2,312	1,156	0	3,468
1984	2,032	1,129	0	3,161	4,255	145	1,267	5,667	3,445	2,211	67	5,723
1985	4,894	2,675	0	7,569	5,430	78	639	6,147	1,388	571	82	2,041
1986	5,116	3,528	0	8,644	2,555	50	249	2,854	993	306	0	1,299
1987	3,511	2,996	0	6,507	2,093	80	404	2,577	836	193	0	1,029
1988	1,045	663	0	1,708	2,810	0	64	2,874	559	407	0	966
1989	1,311	561	0	1,872	6,211	289	1,614	8,114	1,051	711	325	2,087
1990	3,513	1,518	132	5,163	4,660	117	832	5,609	1,278	802	0	2,080
1991	5,437	2,315	240	7,992	5,256	0	1,843	7,099	3,188	1,188	0	4,376
1992	2,733	1,429	0	4,162	220	0	73	293	379	253	0	632
1993	4,560	1,765	0	6,325	1,608	39	1,004	2,651	1,557	501	56	2,114
1994	9,564	4,060	451	14,075	7,989	0	1,839	9,828	1,073	143	72	1,288
1995	5,316	1,572	899	7,787	5,387	142	284	5,813	7,057	5,041	605	12,703
1996	6,160	3,721	513	10,394	4,385	263	1,008	5,656	4,767	1,634	136	6,537
1997	8,423	4,731	914	14,068	5,340	0	1,178	6,518	1,445	439	146	2,030
1998	8,805	4,002	2,803	15,610	7,408	215	2,041	9,664	2,963	1,852	370	5,185
1999	4,159	1,656	1,005	6,820	4,048	165	1,481	5,694	2,293	208	208	2,709
2000	6,150	1,814	0	7,964	4,132	136	987	5,255	5,928	2,292	955	9,175
2001	2,891	1,200	360	4,451	1,556	2	2,894	4,452	6,954	3,670	2,375	12,999

Year	Texas				Central Flyway			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue		
1952	132,209	71,242		203,451	138,380	71,576		209,955
1953	165,539	67,710		233,249	182,794	76,310		259,105
1954	22,833	8,089		30,922	46,169	15,613		61,781
1955	49,801	24,797		74,599	56,774	28,055		84,829
1956	55,276	11,895		67,171	81,285	25,545		106,830
1957	34,245	7,364		41,608	52,174	12,721		64,895
1958	29,725	11,890		41,616	58,933	25,635		84,567
1959	35,831	12,458		48,289	48,605	18,662		67,267
1960	35,924	14,305		50,229	45,689	19,367		65,056
1961	24,608	8,987		33,595	73,101	29,966		103,067
1962	27,138	7,646	0	34,784	61,724	25,680	0	87,404
1963	50,447	19,180	0	69,627	86,868	33,560	0	120,428
1964	47,604	16,503	0	64,107	82,927	28,771	0	111,698
1965	30,870	18,502	0	49,372	72,088	36,205	0	108,293
1966	95,208	41,403	0	136,611	137,154	56,580	0	193,734
1967	52,052	25,257	0	77,309	95,549	54,342	0	149,891
1968	39,360	13,656	0	53,016	64,219	26,638	0	90,857
1969	42,624	38,765	0	81,389	127,255	82,774	0	210,029
1970	113,788	74,639	0	188,427	201,596	112,706	0	314,302
1971	35,475	19,337	0	54,812	120,725	59,987	0	180,712

1972	51,834	18,060	0	69,894	109,993	41,069	0	151,062
1973	76,821	38,036	0	114,857	171,251	83,573	0	254,824
1974	57,527	23,177	0	80,704	169,577	71,744	195	241,516
1975	98,030	47,161	0	145,191	234,781	115,276	146	350,203
1976	82,292	51,585	1,632	135,509	165,899	90,591	1,783	258,273
1977	87,683	46,074	230	133,987	192,315	113,987	300	306,602
1978	49,261	19,972	0	69,233	132,397	56,618	0	189,015
1979	97,093	37,972	668	135,733	232,059	106,332	1,598	339,989
1980	111,398	35,533	397	147,328	176,213	75,552	510	252,275
1981	89,519	32,263	1,451	123,233	192,423	97,446	2,706	292,575
1982	101,425	32,141	1,190	134,756	166,684	75,060	2,116	243,860
1983	74,393	26,269	1,264	101,926	160,613	85,135	1,675	247,423
1984	129,319	40,993	3,365	173,677	205,424	87,374	5,942	298,740
1985	88,362	23,378	2,268	114,008	147,669	69,199	3,833	220,701
1986	40,175	12,181	1,239	53,595	96,508	53,381	2,555	152,444
1987	57,957	24,633	0	82,590	109,061	73,524	404	182,989
1988	90,943	23,542	3,031	117,516	174,736	77,099	3,747	255,582
1989	116,360	38,268	5,611	160,239	192,498	93,773	8,416	294,687
1990	87,777	24,660	4,944	117,381	146,287	65,471	7,007	218,765
1991	80,158	22,599	3,988	106,745	169,609	78,457	7,178	255,244
1992	71,631	15,942	3,203	90,776	109,499	42,443	4,729	156,671
1993	115,507	37,816	4,926	158,249	180,442	89,842	7,417	277,701
1994	88,141	21,296	5,112	114,549	186,189	84,169	9,119	279,477
1995	144,202	41,332	15,109	200,643	219,357	116,949	19,700	356,006
1996	109,662	27,846	9,347	146,855	215,898	88,719	15,542	320,159
1997	111,892	30,712	6,982	149,586	228,134	130,732	12,435	371,301
1998	120,949	23,051	20,185	164,185	223,348	80,433	31,900	335,681
1999	167,494	42,288	39,075	248,857	237,903	78,354	48,303	364,560
2000	44,637	12,264	7,649	64,550	90,362	42,315	11,883	144,560
2001	75,911	18,058	18,352	112,321	147,094	64,595	33,074	244,763

Appendix 10. State-specific Harvest Information Program survey estimates of snow and Ross's goose harvest in the U.S. portion of the Mississippi Flyway, 1999-00 – 2007-08.

Year	Minnesota				Wisconsin				Michigan			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1999	683	1,046	0	1,729	231	1,179	0	1,410	0	0	0	0
2000	2,440	6,052	0	8,493	0	552	0	552	0	0	0	0
2001	357	2,186	0	2,543	0	439	0	439	227	0	0	227
2002	0	4,261	0	4,261	320	0	0	320	0	0	0	0
2003	1,688	2,873	0	4,561	852	436	0	1,288	251	0	0	251
2004	377	1,152	0	1,529	0	0	0	0	0	0	0	0
2005	245	0	0	245	0	721	0	721	0	0	0	0
2006	1,058	1,801	0	2,858	266	271	0	537	0	222	0	222
2007	0	354	0	354	0	0	0	0	0	0	0	0

Year	Iowa				Illinois				Indiana			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1999	11,734	6,161	0	17,895	749	0	0	749	0	0	0	0
2000	325	332	0	657	336	687	343	1,366	0	0	0	0
2001	3,691	1,508	0	5,199	0	0	0	0	0	0	0	0
2002	1,129	0	0	1,129	0	435	0	435	0	0	0	0
2003	9,874	5,281	482	15,637	747	1,144	0	1,891	270	0	0	270
2004	324	662	0	986	802	491	0	1,294	0	0	0	0
2005	387	0	0	387	1,439	1,680	421	3,540	215	220	110	546
2006	242	0	0	242	1,927	1,574	1,577	5,078	0	0	0	0
2007	266	0	0	266	3,890	2,270	285	6,444	0	0	0	0

Year	Ohio				Missouri				Kentucky			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1999	0	0	0	0	15,432	10,153	1,403	26,988	0	0	0	0
2000	0	0	0	0	7,718	7,881	343	15,943	0	0	0	0
2001	0	0	0	0	23,506	13,777	2,227	39,510	718	733	0	1,450
2002	0	0	0	0	7,089	3,832	853	11,774	0	518	519	1,037
2003	0	0	272	272	24,537	14,239	3,251	42,026	0	0	0	0
2004	0	0	0	0	19,256	8,919	2,114	30,289	518	529	0	1,046
2005	0	0	0	0	15,144	8,836	983	24,963	905	0	0	905
2006	0	0	0	0	4,023	3,012	274	7,309	0	0	0	0
2007	0	328	0	328	2,388	898	128	3,415	0	834	0	834

Year	Arkansas				Tennessee				Louisiana			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1999	46,492	34,523	3,603	84,617	1,021	694	0	1,715	86,293	34,552	3,461	124,306
2000	52,877	41,080	3,528	97,485	0	0	0	0	25,383	28,347	2,434	56,164
2001	51,934	42,421	12,750	107,105	0	0	0	0	35,957	55,069	2,164	93,190
2002	55,439	24,260	4,726	84,425	1,619	0	0	1,619	11,279	23,031	3,846	38,156
2003	36,696	26,293	9,878	72,867	5,132	0	0	5,132	33,669	25,210	4,592	63,471
2004	38,248	26,248	641	65,137	0	0	0	0	27,995	25,260	666	53,921
2005	47,525	34,253	0	81,778	0	0	0	0	17,563	51,911	1,892	71,366
2006	57,049	31,365	8,978	97,392	1,072	0	0	1,072	25,801	27,731	1,389	54,920
2007	26,700	13,972	2,390	43,062	6,429	2,188	0	8,617	24,370	30,624	3,835	58,828

Year	Mississippi				Alabama				Mississippi Flyway			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1999	7,973	5,814	1,165	14,952	0	0	0	0	170,607	94,123	9,632	274,362
2000	4,572	0	0	4,572	0	0	0	0	93,653	84,931	6,649	185,232
2001	1,046	534	535	2,115	941	0	0	941	118,377	116,667	17,675	252,719
2002	735	751	188	1,674	0	0	0	0	77,610	57,088	10,132	144,830
2003	7,413	5,342	1,004	13,759	520	0	0	520	121,649	80,818	19,478	221,945
2004	3,219	3,943	988	8,149	0	0	0	0	90,738	67,205	4,408	162,352
2005	9,547	9,748	1,542	20,836	508	0	0	508	93,479	107,368	4,948	205,795
2006	1,833	936	0	2,768	979	0	0	979	94,248	66,911	12,218	173,377
2007	5,618	1,434	0	7,052	468	0	0	468	70,128	52,901	6,638	129,668

Appendix 11. State-specific Harvest Information Program survey estimates of snow and Ross's goose harvest in the U.S. portion of the Central Flyway, 1999-00 – 2007-08.

Year	Montana				North Dakota				South Dakota			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1999	63	0	0	63	33,074	28,940	360	62,374	4,797	4,428	369	9,594
2000	0	0	191	191	13,492	17,539	337	31,368	1,081	1,235	0	2,316
2001	106	0	0	106	21,699	19,275	2,885	43,859	8,666	7,536	1,696	17,898
2002	280	0	93	373	9,589	10,557	528	20,674	12,580	9,999	645	23,224
2003	259	65	129	453	10,009	14,529	108	24,646	17,734	10,278	605	28,617
2004	113	0	0	113	9,422	7,957	209	17,588	14,810	12,058	917	27,785
2005	54	0	0	54	6,317	12,633	902	19,852	11,425	8,988	305	20,718
2006	0	0	0	0	13,416	17,845	912	32,173	10,878	10,616	393	21,887
2007	83	0	0	83	13,599	14,523	528	28,650	5,834	4,001	0	9,835
Year	Wyoming				Nebraska				Colorado			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1999	242	60	0	302	18,341	4,938	3,997	27,276	7,154	243	1,455	8,852
2000	106	0	0	106	1,897	949	759	3,605	6,649	0	723	7,372
2001	0	0	0	0	3,553	1,122	561	5,236	7,358	446	1,784	9,588
2002	0	0	0	0	6,381	3,667	293	10,341	7,390	789	861	9,040
2003	325	0	0	325	3,680	950	712	5,342	12,548	1,686	2,060	16,294
2004	0	0	0	0	535	178	178	891	7,544	236	1,297	9,077
2005	0	0	0	0	2,407	1,032	344	3,783	5,380	229	458	6,067
2006	0	0	0	0	736	294	442	1,472	7,203	1,099	4,517	12,819
2007	0	0	43	43	613	306	153	1,072	2,529	0	474	3,003
Year	Kansas				New Mexico				Oklahoma			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue			white	blue		
1999	7,464	3,041	1,659	12,164	2,431	97	875	3,403	3,822	347	347	4,516
2000	5,050	1,515	0	6,565	3,505	238	1,723	5,466	5,647	2,196	941	8,784
2001	2,634	1,171	293	4,098	6,118	255	8,923	15,296	2,943	2,001	1,295	6,239
2002	13,341	2,122	3,639	19,102	4,588	0	2,000	6,588	2,499	595	1,547	4,641
2003	12,392	3,598	2,598	18,588	1,802	39	901	2,742	988	423	705	2,116
2004	9,949	3,011	1,833	14,793	1,027	0	2,311	3,338	2,123	386	1,158	3,667
2005	2,865	573	191	3,629	1,828	0	1,062	2,890	5,057	2,288	2,288	9,633
2006	7,710	5,140	1,542	14,392	1,675	84	775	2,534	6,665	889	3,110	10,664
2007	6,785	2,845	1,313	10,943	1,535	0	691	2,226	4,087	409	1,226	5,722

Year	Texas				Central Flyway			
	Snow goose		Ross's goose	Total	Snow goose		Ross's goose	Total
	white	blue			white	blue		
1999	169,947	42,329	41,065	253,341	247,335	84,423	50,127	381,885
2000	170,505	45,835	28,417	244,757	207,932	69,507	33,091	310,530
2001	124,064	29,823	30,419	184,306	177,141	61,629	47,856	286,626
2002	96,250	18,921	20,566	135,737	152,898	46,650	30,172	229,720
2003	84,566	17,564	20,816	122,946	144,303	49,132	28,634	222,069
2004	96,873	16,879	24,218	137,970	142,396	40,705	32,121	215,222
2005	136,224	45,408	35,537	217,169	171,557	71,151	41,087	283,795
2006	86,419	29,526	13,683	129,628	134,702	65,493	25,374	225,569
2007	124,987	21,664	16,665	163,316	160,052	43,748	21,093	224,893