Evaluation of the special conservation measures for Greater Snow Geese

REPORT OF THE GREATER SNOW GOOSE WORKING GROUP

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Joint Venture of the North American
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EXECUTIVE SUMMARY

In an effort to protect Arctic wetlands from overgrazing by the rapidly growing Greater Snow Goose population, goose harvest management was modified in 1998–1999 via the implementation of new regulatory measures. These involved more liberal bag and possession limits and hunting methods during existing harvest seasons and the implementation of a spring conservation harvest in Québec. These measures have been in place for more than five years and are evaluated in this report through an examination of their impacts on Greater Snow Goose demography and behaviour relative to long-term population trends. The data used in this report span the years 1965–2003, with an emphasis on the 1998–2003 period.

The growth in abundance of the Greater Snow Goose population was quickly stopped following the liberalization of the regular hunting season harvest in the United States and Canada and the implementation of special conservation measures in Canada. Spring survey data indicated a decline in population size between 1999 and 2003 (from 1 008 000 to 678 000 Greater Snow Geese). However, refinements to the survey methodology resulted in a 2004 estimate of 957 600 (an increase of 41% over 2003) and a 2005 estimate of 814 600, leading to uncertainty about the population response to the new measures. Although such a large increase in population size cannot be reconciled with available demographic data and is likely due to increased efficiency in the survey, it suggests that the population has been at least stable (and probably declining) since the implementation of new conservation measures in 1998–1999.

The distribution of geese staging in Québec in fall and spring continued to shift towards agricultural regions in the southwestern and north-central parts of the province, a trend that began in the 1980s. A northward shift in the winter distribution occurred in the mid-1980s, but there were no changes associated with the recent liberalization of harvest regulations in the United States; geese remained concentrated in mid-Atlantic Flyway states.

Productivity in Greater Snow Geese is highly variable among years as a result of several environmental and biological factors. Several indices of productivity suggest that the new measures and in particular the spring conservation harvest reduced reproductive output. There is evidence of increased disturbance on both fall and spring staging grounds since the regulatory changes. In spring, this appears to have implied additional energetic costs to females just prior to the breeding season, with negative consequences for body condition, breeding effort, and nesting success.

Estimated total harvest and harvest rate increased with the new measures, particularly for adult geese, the principal target of these regulatory changes. The increased harvest was due not only to the spring conservation harvest but also to the more liberal regulations and special conservation measures implemented during existing regular hunting seasons, especially in winter. The new regulatory measures led to an increase in hunting mortality rates and a corresponding decrease in survival for adult Greater Snow Geese, from an average of 83.0% before the changes to 72.5% following their implementation.

Productivity of Arctic vegetation has been relatively high in recent years, but it is as yet unclear whether this is related to favourable weather conditions or to the impact of the new measures on the breeding population. Marshes continue to be heavily used by geese during staging and wintering; increased use of agricultural fields for feeding may have allowed geese to surpass the limits of their natural habitats, but may also be preventing severe damage to natural vegetation in wintering and staging areas.

A matrix population model accurately projected population growth rate before and after the implementation of special conservation measures (up to 2003). Without conservation measures, the model predicted that the population would have grown at an annual rate of 7.8%. With conservation measures in place, it predicted an annual decline of 8.0%. Spring conservation harvest had the greatest influence on the reduction of the growth rate, through increased mortality of adults and an unexpected reduction in fecundity (breeding propensity and clutch size). Several harvest scenarios were examined, and all those that included a spring harvest resulted in a projected reduction of the population growth rate, even if the spring harvest were to occur only in alternating years. Significant increases in current adult harvest rates during fall and winter would be required to maintain a stable population in the absence of a spring conservation harvest.

This report outlines the success of the special conservation measures (Canada) and liberalization of regular hunting season regulations (Canada and the United States) in halting the growth of the Greater Snow Goose population. Results presented in the first section of this report greatly expand our understanding of factors affecting the population dynamics of geese in general and Greater Snow Geese in particular. Of particular interest is the detailed review of the impacts of harvest and associated disturbances on demographic parameters and growth rate of the Greater Snow Goose population. The second section of the report uses the most up-to-date scientific information to project potential growth of the population under a number of harvest scenarios. It is hoped that this exercise will lead to improved management strategies for this population and play an important role in the development of management plans that take into account the long-term sustainability of the Greater Snow Goose harvest, as well as the needs and concerns of all stakeholders.

This work would not have been possible without the efforts and involvement of researchers and managers from Université Laval, Université du Québec à Montréal (UQÀM), the Canadian Wildlife Service, and the U.S. Fish and Wildlife Service. We would also like to thank Ray T. Alisauskas, Michael J. Conroy, and the Atlantic Flyway Snow Goose, Brant and Swans committee members for very useful comments and additions to this report. The Arctic Goose Joint Venture of the North American Management Waterfowl Plan and the Canadian Wildlife Service provided financial support for this work.

INTRODUCTION

A critical challenge for North American wildlife managers in recent years has been the explosion of several Arctic-nesting goose populations. Their rapid growth in abundance has been attributed in part to anthropogenic actions such as the creation of hunting-free refuges, declining hunting pressure, climate change, and the availability of agricultural crops as alternative food sources (Ankney 1996; Batt 1997, 1998; Gauthier *et al*. 2005). “Light geese” in particular, including Lesser Snow Geese (*Chen caerulescens caerulescens*), Greater Snow Geese (*Chen c. atlantica*), and Ross’s Geese (*Chen rossii*), have shown unprecedented population increases over the past few decades, bringing potential negative consequences for the geese themselves and for other cohabiting plants and animals (Abraham and Jefferies 1997). Severe destruction of salt marsh vegetation on midcontinental Lesser Snow Goose breeding grounds and resulting declines in body condition and reproductive success (Cooch *et al*. 1991; Williams *et al*. 1993) raised concern for the health of the Arctic ecosystems faced with these growing numbers of geese (Abraham and Jefferies 1997). However, despite these signs of possible density-dependent regulation in some populations, light geese continued to show exponential growth, prompting the publication of two reports by the Arctic Goose Habitat Working Group to address these issues (Batt 1997, 1998).

The second of those reports (Batt 1998) specifically addressed the case of the Greater Snow Goose, a population that breeds in the eastern Canadian Arctic and winters on the east coast of the United States, migrating through Québec where it stages in spring and fall. This population’s growth rate reached an average of 9.7% annually between 1983 and 1997 (Reed *et al*. 1998), and the Arctic Goose Habitat Working Group worried that, while not yet the case, breeding grounds might suffer the same consequences as were observed for Lesser Snow Geese (Giroux *et al*. 1998b). Consequently, through an analysis of the demographic parameters to which population growth is most sensitive (Gauthier and Brault 1998), a series of measures were proposed to stop population growth and stabilize abundance (Giroux *et al*. 1998a). In particular, these recommendations included an increase in harvest, because hunting mortality reduces survival in this species (Gauthier *et al*. 2001) and growth in abundance is highly sensitive to changes in survival (Gauthier and Brault 1998). More extreme measures, such as culling or commercial hunting, were also presented as options for the Lesser Snow Goose population (Johnson and Ankney 2003); however, these alternatives were to be considered only if hunting manipulations did not achieve the stated goal of protecting natural habitats.

In 1998–1999, new regulations based on the management recommendations of Giroux *et al*. (1998a) were implemented with the goal of stabilizing the growth of the Greater Snow Goose population. The Migratory Birds Convention, signed in 1916, allowed for a maximum hunting season length of 107 days that had to occur between 1 September and 10 March. It also included provisions for conservation harvest to occur outside of this framework. In keeping with the guidelines of the Migratory Birds Convention, regulatory changes to Greater Snow Goose harvest included liberalization of regulations during the existing hunting season in Québec starting in fall 1999 and implementation of special conservation measures in Canada. The special conservation measures included the use of previously banned methods, such as baiting and electronic calls, as well as allowing a conservation harvest to occur outside of regular hunting seasons (CWS Waterfowl Committee 2001a, 2001b). In the U.S. portion of the Atlantic Flyway, bag and possession limits were liberalized in the winter of 1998–1999 (J. Kelley, U.S. Fish and Wildlife Service, pers. comm.). The initiation of a spring conservation harvest in Québec during April and May was seen as the most significant measure of all.

These special conservation measures were initiated in 1998–1999 and have been in place since. Now, more than five years after these changes were made, it appeared timely to reevaluate the present status of the population and the impact of the various management approaches on population growth rates and vital rates in order to improve management of Greater Snow Geese in accordance with the principles of adaptive management

(Walters 1986; Lancia *et al*. 1996). We chose to evaluate the impacts of the special conservation measures over the 1998–2003 period because these measures were put in place in the 1998–1999 hunting season and there are comparable monitoring data for all these years. Updated information about the size of the population (2004–2005) is also reported but is not included in the analyses. The present report had the main goals of 1) updating current knowledge of Greater Snow Goose population trends, 2) reviewing impacts that special conservation measures have had on the behaviour and demography of the population, and 3) evaluating the success of the conservation measures in achieving the originally stated goals, in order to develop effective future management plans. It is organized into two major sections, the first considering past and present trends in the population and the second projecting possible future dynamics and evaluating management alternatives.

While the main purpose of the regulatory changes initiated in 1999 was to stabilize abundance through decreased adult survival (Gauthier and Brault 1998; Giroux *et al*. 1998a), the measures that were implemented may have also brought other consequences for Greater Snow Geese. Section I of this report therefore examines characteristics of the demography, behaviour, and harvest of this population since the initiation of the special conservation measures, relative to historic patterns. Data were obtained from a variety of published and unpublished sources and include information from long-term ongoing studies as well as the results of analyses specifically aimed at understanding the effects of the new measures. In this section, the changes in hunting regulations for Greater Snow Geese and the evolution of the total Greater Snow Goose kill are discussed first, followed by a review of the population growth and the changes in staging and wintering distributions associated with the population expansion. Next, reproductive data are presented: the high interannual variability in productivity in relation to environmental factors and hunting, as well as the specific impacts of the spring harvest on reproduction. Many aspects of hunting are then considered, including characteristics of the harvest, harvest rates, and the demographic impacts of the changes in regulations on the survival and hunting mortality rates of this population. Finally, this section also addresses the concern that initially motivated the development of these special measures: the impacts of geese on their natural habitats over the long term and in relation to the regulatory changes. The effects of Greater Snow Geese on crop depredation in southern Québec are also discussed.

Based on the insight into the Greater Snow Goose population provided by the synthesis of information in Section I, the next part of this report (Section II) considers the effectiveness of the new conservation measures in achieving the stated goals of the 1998 Arctic Goose Habitat Working Group report (Batt 1998) and evaluates alternative future management actions. Population projection models are used to forecast the potential consequences of alternative harvesting regimes that could be used to attain these goals in the future. Finally, Section III concludes with a discussion of the observed changes in the demography and behaviour of the Greater Snow Goose population in light of the recommendations that were proposed by the 1998 Arctic Goose Habitat Working Group. The implications of our current understanding of the status of the Greater Snow Goose and its natural habitats as well as recent information on the management of this population not included in previous sections are also reviewed. Furthermore, the anticipated impacts of various environmental factors and uncertainties over the next few years are considered in order to contribute to the implementation of a sustainable management plan for this light goose population.

SECTION I: PRESENT STATUS OF THE POPULATION AND EVALUATION OF THE EFFECTS OF THE SPECIAL CONSERVATION MEASURES

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TEMPORAL CHANGES IN HARVEST

Harvest regulations

Greater Snow Geese are subject to hunting on breeding, 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 (Reed *et al*. 1998). Harvest on staging grounds in southern Québec and on wintering grounds on the east coast of the United States, in contrast, results in large numbers of geese being taken each year and is well documented.

Information on hunting regulations in Canada for the period 1971–2002 is shown in Table 1-1. Daily bag limits were moderately low for the first 20 years, increasing from five to six in 1989. During this period, season length varied somewhat from year to year, and sneaking (stalking) was allowed as a hunting technique. The daily bag limit increased fairly rapidly between 1992 and 1998 (from 8 to 12; Table 1-1) in response to the rapid growth of the population, but sneaking became prohibited. Major changes in regulations occurred in 1998 and 1999, following the recommendations made by the Arctic Goose Habitat Working Group to halt the growth of the population (Batt 1998) and the designation of this subspecies as overabundant. In 1999, the daily bag limit increased to 20 (possession limit increased to 60), sneaking was allowed again, and the seasons were extended by advancing the opening date to the first Saturday of September. However, the most drastic regulatory change occurred through the implementation of special conservation measures concerning overabundant species: a spring conservation harvest was allowed from 15 April to 31 May in Québec during the 1998–1999 season (extended to 1 April to 31 May in the 2001–2002 season), electronic Snow Goose calls were allowed as long as the decoys used represented white-phased Snow Geese, and baiting or hunting over bait crop were permitted under specific permits issued by the Canadian Wildlife Service (CWS) Regional Director. Daily bag limits during the special conservation harvest periods were the same as those for the regular season, and sneaking was allowed. This special conservation harvest was limited to farmlands. Special conservation measures were intended to be temporary and to apply only to populations designated as overabundant.

Hunting seasons for Greater Snow Geese were closed in the Atlantic Flyway from 1931 until 1975. Seasons were resumed following the completion of an environmental assessment ("Proposed Open Season on Greater Snow Geese") by the U.S. Fish and Wildlife Service (USFWS) in 1975. From 1975 to 1995, daily bag limits remained relatively low (from two to five; Table 1-1). After that, they steadily increased, reaching 15 in 1998. In that year, the Greater Snow Goose possession limit was eliminated. Season length in the U.S. Atlantic Flyway has been at the maximum allowed by the Migratory Birds Convention (107 days) since 1990. Recently, hunting has also been allowed on several wildlife refuges, including the following important refuges for Greater Snow Geese: Edwin B. Forsyth, New Jersey; Back Bay, Virginia; Chincoteague, Virginia; Bombay Hook, Delaware; and Prime Hook, Delaware. In contrast to Canada, no special conservation measures have yet been implemented in the U.S. Atlantic Flyway.

Total harvest

The continental harvest of Greater Snow Geese increased on average by 2793 geese per year during the 1967–1997 period ($P < 0.001$, $R^2 = 0.54$) (see Appendix A for number of birds harvested annually). Most of the increase resulted from increased harvest in Québec (1967–1997: 1823 geese per year, $P < 0.001$, $R^2 = 0.49$), while harvest remained relatively stable in the United States following the reopening of the hunt in 1975 (1975–1997: slope = 304 geese per year, $P = 0.295$, $R^2 = 0.05$). Total harvest of adults, but not of juveniles, increased following the implementation of special conservation measures relative to previous years (one-tailed t-test comparing residuals of the 1967–2002 relationship between 1967–1997 and 1998–2002; adults $t = 6.14$, df = 33, $P < 0.001$; juveniles $t = 0.80$, df = 33, $P = 0.215$).

Summary: Temporal changes in harvest

- Greater Snow Goose harvest regulations have been liberalized over the past few decades in response to the rapid growth of the population. The implementation of special conservation measures in Canada during the 1998–1999 season was the most drastic of these changes. These new regulations included increased bag and possession limits, permission to use previously prohibited hunting methods, and a spring conservation harvest in Québec.

- During the period of rapid population growth before the implementation of special measures, the Canadian harvest showed an increase over time, but the U.S. harvest remained stable.

- The continental harvest of Greater Snow Goose adults increased following the implementation of special conservation measures, but the harvest of juveniles was relatively unaffected.

Table 1-1. Summary of Greater Snow Goose harvest regulations for 1971–2002 for regular fall and winter seasons and for the spring harvest since the end of the 1998 season (i.e. spring 1999). Note that regulations for the Québec fall hunting season are shown only for the south-central area of the province (i.e. along the St. Lawrence River) and that other regions were subject to slightly different regulations; in the Atlantic Flyway states, these regulations are the U.S. Fish and Wildlife Service recommendations, but individual states could set more restrictive limits.

	Québec fall (South central area)				Atlantic flyway states winter			Québec spring			
Year[a]	Season length[b, c]	Daily bag	Possession [d]	Methods [e, f]	Season length	Daily bag	Possession	Season length	Daily bag	Possession	Methods [f]
1971	86	5			Closed	-					
1972	86 (41)	5			Closed	-					
1973	109 (41)	5			Closed	-					
1974	100 (34)	5			Closed	-					
1975	100 (33)	5			30	2	4				
1976	102 (27)	5			30	2	4				
1977	102 (30)	5			60	2	4				
1978	101 (30)	5			70	2	4				
1979	96 (30)	5			70	4	8				
1980	98	5	10		70	4	8				
1981	99	5	10		90	4	8				
1982	100	5	10		90	4	8				
1983	101	5	10		90	4	8				
1984	103	5	10		90	4	8				
1985	97	5	10		90	4	8				
1986	98	5	10		90	4	8				
1987	99	5	10		90	4	8				
1988	101	5	10		90	4	8				
1989	93	5	10		90	5	10				
1990	93	6	12		107	5	10				
1991	93	6	12		107	5	10				
1992	93	8	16		107	5	10				
1993	93	8	16	Sneaking prohibited	107	5	10				
1994	94	8	16	Sneaking prohibited	107	5	10				
1995	93	8	16	Sneaking prohibited	107	5	10				
1996	93	8	16	Sneaking prohibited	107	8	24				
1997	93	12	36	Sneaking prohibited	107	10	30				
1998	105	12	36	Sneaking prohibited	107	15	No limit	47	12	36	Calls, bait
1999	117	20	60	Calls, bait	107	15	No limit	47	20	60	Calls, bait
2000	117	20	60	Calls, bait	107	15	No limit	61	20	60	Calls, bait
2001	117	20	60	Calls, bait	107	15	No limit	61	20	60	Calls, bait
2002	117	20	60	Calls, bait	107	15	No limit	61	20	60	Calls, bait

[a] These years refer to the 12 months beginning during the reproductive season, i.e. "1980" is the period from summer 1980 to summer 1981.

[b] Season length from 1971 to 1979 refers to Québec's Central District and Cap Tourmente (in parentheses).

[c] Seasons over 107 days (i.e. 1999–2002) were possible under special conservation measures only.

[d] Prior to 1992, total possession of Snow and Canada geese combined was also limited, at limits higher than the numbers shown.

[e] Sneaking was prohibited in Québec from 1993 to 1998, forcing hunters to use blinds and decoys when hunting in fields.

[f] Baiting was allowed only under permit from the CWS Regional Director. In fall, this involved hunting in a bait crop field, and in spring, laying out bait.

ABUNDANCE AND DISTRIBUTION

Total abundance

In contrast to most waterfowl species, which are surveyed either during winter or on their breeding grounds, the annual estimate of Greater Snow Goose abundance is based on an aerial photographic survey performed on spring staging grounds (Reed *et al*. 1998). This spring survey is conducted during the months of April and May, when the entire Greater Snow Goose population is present on the staging area and when geese are concentrated in marshes and farm fields in southern Québec. From the 1960s to the end of the 1980s, all flocks of geese were photographed and the total number of birds in each photo was counted to determine the total abundance; however, with the rapid population growth, this method became increasingly expensive and time-consuming. Survey methods were consequently modified in 1991 to improve accuracy, to minimize the time required for counting such large numbers of birds, and to account for the possibility that some birds were missed during the flights, given the expanding staging distribution. The new procedure involved counting only samples of the photos based on a fixed sampling design. Three surveys (1991–1995), then two (1996–2003), and finally only one (2004–2005) were conducted each spring. In years with repeated surveys, the one yielding the largest estimate was used (for more detailed explanations of survey methods, see Reed *et al*. 1998; Béchet *et al*. 2004b). As goose numbers continued to increase and their range expanded into agricultural lands farther inland from the St. Lawrence River, it became important to assess the accuracy of the spring survey. As such, radio-marked geese were used to estimate the proportion of flocks missed by the photographic survey in 1998–2000 (Béchet *et al*. 2004b). This telemetry study showed that the spring surveys underestimated population size by 11% in 1998 and 29% in 2000, likely due to further redistribution of geese on their staging grounds. Precision of these estimates (coefficient of variation) was established at 5.9% and 11.2%, respectively. To avoid this problem in the future, the survey methods were again revised in 2001. Since then, all known staging areas of southern Québec and southeastern Ontario are covered by four aircraft in a single day, thus reducing biases caused by movements of geese during the survey (Cotter 2002). The surveys are also conducted early in the season before substantial fragmentation of the flock occurs and synchronized at each site to coincide with the daily return of the birds to their main roosts. The survey method was further modified in 2004 as a result of additional changes in staging distribution. Based on the recommendations of a group of experts, five aircraft were used to cover the entire staging area. The higher number of aircraft reduced the size of territory that each had to cover, so that flights over important goose areas could be timed to occur when geese were still concentrated at the roosts and these areas could be searched more intensively.

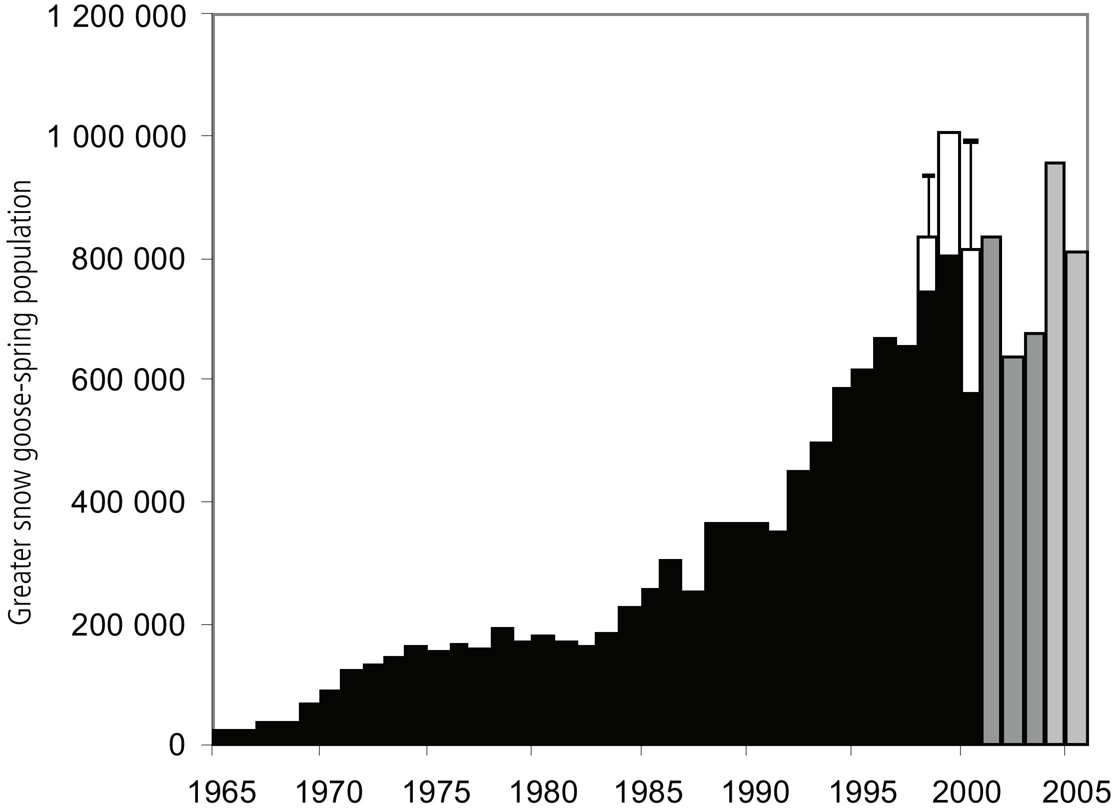

Figure 1-1. Greater Snow Goose abundance for 1965–2005 based on spring aerial surveys; black and grey bars represent different survey methodology, and white bars indicate the correction made by telemetry (see text for details). Standard errors could be calculated for 1998 and 2000.

Estimated population sizes for spring 1965–2005 are plotted in Figure 1-1. Population growth was rapid in the late 1960s, followed by a period of relative stability from 1974 to 1982; after this, growth resumed, reaching an average annual rate of increase of 9.9% (λ = 1.099; 95% confidence interval [CI]: 1.089–1.108) between 1982 and 1999 (Gauthier and Brault 1998; Menu *et al*. 2002). Population growth was quickly halted and reversed following implementation of the special conservation measures. The population, as measured by the spring aerial survey, declined at an average annual rate of 9.4% between 1999 and 2003 (λ = 0.906; 95% CI: 0.824–0.987, exponential growth model). When 2004–2005 population estimates are included, they clearly indicate that the population has been at least stable since implementation of special conservation measures (λ = 0.990). However, 2004 and 2005 estimates complicate interpretation of the recent population trend. For instance, the 2004 population estimate shows a 41% increase over 2003, a number that is impossible to reconcile with demographic data, considering the level of harvest in the population in 2003–2004 and the production of young in 2003. Without additional information (e.g. other surveys using the 2001–2003 method), we cannot resolve this paradox. Hence, at the moment, we believe that 2004–2005 survey data should not be used in the evaluation of the population *trend* due to the change in survey methodology in 2004.

Breeding population on Bylot Island, Nunavut

Greater Snow Geese breed throughout the eastern Canadian Arctic, with highest concentrations (10–15% of the world population) nesting on Bylot Island, Nunavut (73°N, 80°W; Reed *et al*. 1992, 2002). Aerial photographic surveys of the 1600-km^2 southern plain of the island have been conducted every five years since 1983 during brood rearing (mid-July and early August). These surveys provide an estimate of population size on Bylot Island according to breeding status, as well as an index of the abundance of broods in habitats of varying quality (for methodological details, see Reed and Chagnon 1987; Reed *et al*. 1992, 1998, 2002). Estimates of the number of juveniles, breeding adults, and non-breeding (mainly failed breeders) adults are shown in Figure 1-2. Numbers of breeders and juveniles peaked in 1993, whereas non-breeder numbers were greatest in 1998; overall, numbers on Bylot Island demonstrated an increase through 1993 followed by a decline from 1993 to 1998 and relative stability since then (1998–2003). These estimates fit relatively well with trends in abundance on the island. The apparent peak in 1993 can be considered an exception, given extremely favourable conditions for reproduction that year (when reproductive success is high, fewer birds leave the island to moult elsewhere, which increases the local summer population; Reed *et al*. 2003a). When taking reproductive success into consideration, the survey on Bylot Island suggests relatively stable breeding numbers in recent years, possibly since 1993 (Reed *et al*. 2002). Considering the increase in total population size after 1993 (Fig. 1-1) and relative stability at Bylot Island, either other existing colonies must have grown or new colonies must have appeared. However, no extensive surveys have been conducted over the entire breeding range of Greater Snow Geese in recent years.

Distribution

We examined long-term distributional trends and potential impacts of special conservation measures during each of the three main hunting seasons. In addition to distributional data obtained from annual surveys and intensive field studies of individually marked birds, harvest distribution can be a valuable tool for examining changes in spatial distribution of the population, even though the latter may sometimes be confounded with changes in the distribution of hunter activity. Two main indices of harvest distribution used in this report are returns of goose tails from hunter surveys conducted by CWS (see description in harvest section below) and band recoveries. Greater Snow Geese have been marked with metal leg bands in several locations and at varying intensities since 1970 (n = 56 942; there were very few bandings before 1970). Most banding occurred from 1970 to 1974 and from 1990 to the present; geese were banded mainly during the summer in Nunavut and to a lesser extent during staging in southern Québec and during winter in Atlantic Flyway states. Bands were engraved with the address and the toll-free phone number (since 1996) of the Bird Banding Laboratory (USFWS), where a database of all band recoveries was compiled. Banding and recovery records provided an indication of the age and sex of each bird reported, as well as harvest location and date. Since 1970, 7222 birds have been recovered; during the intensive banding period from August 1990 to July 2003, of 44 874 birds banded, 4830 were recovered.

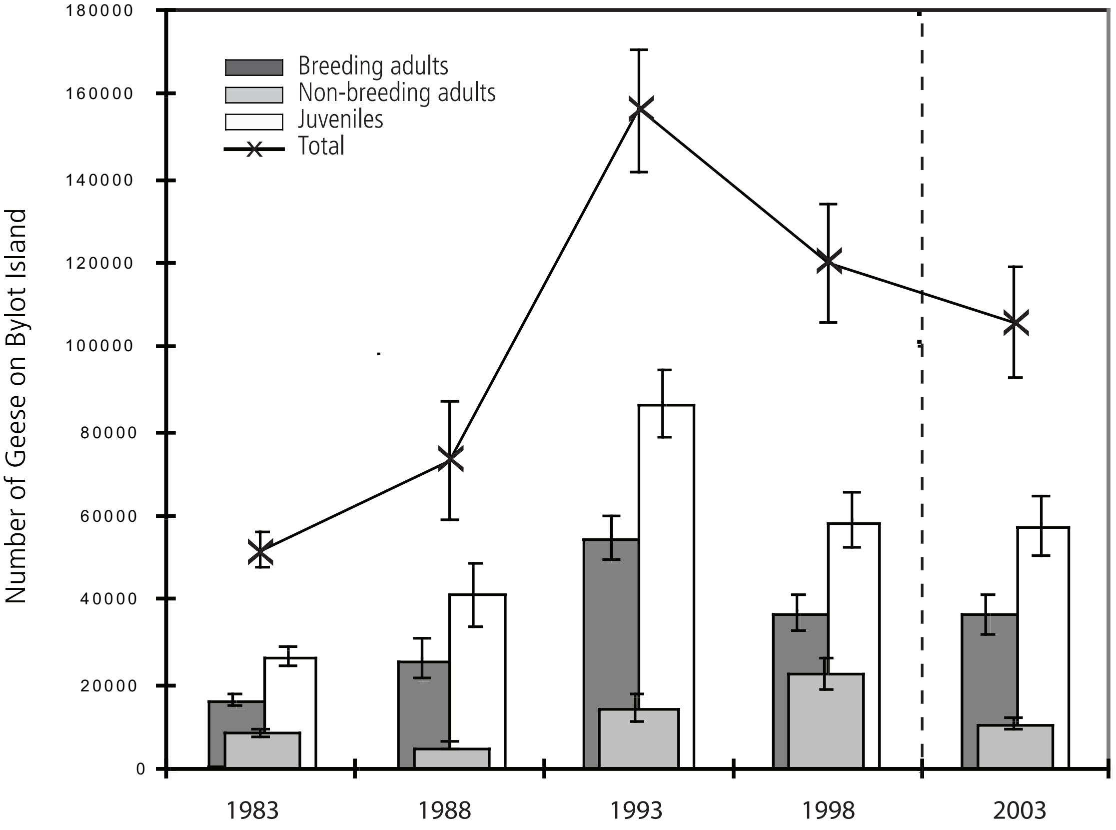

Figure 1-2. Population estimates (± SE) for Greater Snow Geese on breeding grounds from 1983 to 2003, including numbers of breeders, non-breeding adults, and juveniles. The dashed line indicates the start of special conservation measures. Data are from Reed *et al.* (2002) and A. Reed (unpubl.)

Fall distribution

The bulrush (*Scirpus pungens*) marshes of the St. Lawrence River estuary have historically provided an important food source during spring and fall, resulting in high goose densities in the upper estuary just east of Québec city. Beginning several decades ago, however, staging geese increasingly began to feed in farmlands (initially in spring only, then also in fall) and considerably expanded their range into southwestern Québec, away from natural marshes (Reed *et al.* 1998; Olson 2001; Gauthier *et al.* 2005). Figure 1-3 shows historical trends in the distribution of harvested birds on staging grounds as determined from recoveries of banded geese. In the last three decades, the relative proportion of fall harvest in the St. Lawrence estuary area has declined, from over 90% in the early 1970s to just over 50% in the 1990s. At the same time, the proportion of geese harvested in areas southwest of the estuary, near Lac Saint-Pierre and the Québec-U.S. border, has increased from very few to close to 40% in the 1990s. These patterns closely parallel those observed in staging distributions of geese during fall (Reed *et al.* 1998; Olson 2001) and likely reflect an increased use of cornfields in southwestern Québec as an additional food resource (Gauthier *et al.* 2005). The same trend in spatial distribution of harvest is evident when based on tails returned through the CWS National Harvest Survey (Fig. 1-4).

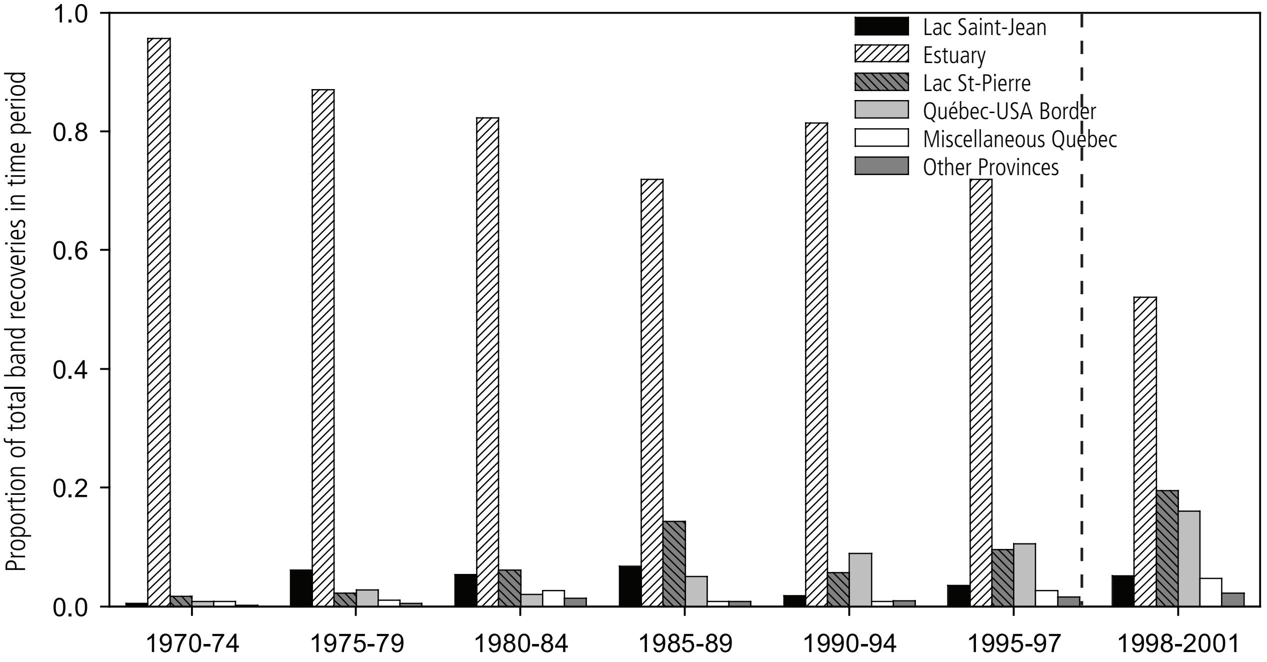

Figure 1-3. Distribution of hunter-shot banded Greater Snow Geese recovered during fall in Canada (n = 3779). The dashed line indicates the liberalization of regulations (United States) and the start of special conservation measures (Canada). Data from Calvert *et al.* (2005).

When compared with the four preceding years (1995–1998), the first four years of special measures (1999–2002) showed a fall harvest much less concentrated in the estuary and a spreading towards the southwest of the province near Lac Saint-Pierre and the U.S. border and towards Lac Saint-Jean (band recoveries: Fig. 1-3; tail returns: Fig. 1-4). Although hunting disturbance experienced by Greater Snow Geese may have increased with liberalization of regular hunting season regulations (see below), it is difficult to isolate any potential distributional effects of new regulations from long-term trends without additional information.

Olson (2001) recorded more disturbances following the 1999 regulatory changes, but did not find a shorter fall staging period in the estuary for radio-marked geese that year compared with 1996–1998 (Fig. 1-5). However, he observed an increasing length of stay by individual geese in southwestern Québec between 1996 and 1998, which resulted in an overall longer staging period in Québec. A separate estimate of fall stopover time in the estuary, based on neck collar observations, detected interannual variability in staging duration, but no mean change between the 1980s and 1990s; staging times were shorter in 1999–2000 than in the two previous years, but were very similar to those of the early 1990s (Bourguelat 2003; Fig. 1-6). This evidence further suggested no major change in fall staging duration in the estuary despite the growing use of southwestern Québec during the period of rapid population growth, but no noticeable effects of new conservation measures on fall behaviour of geese (Olson 2001; Bourguelat 2003).

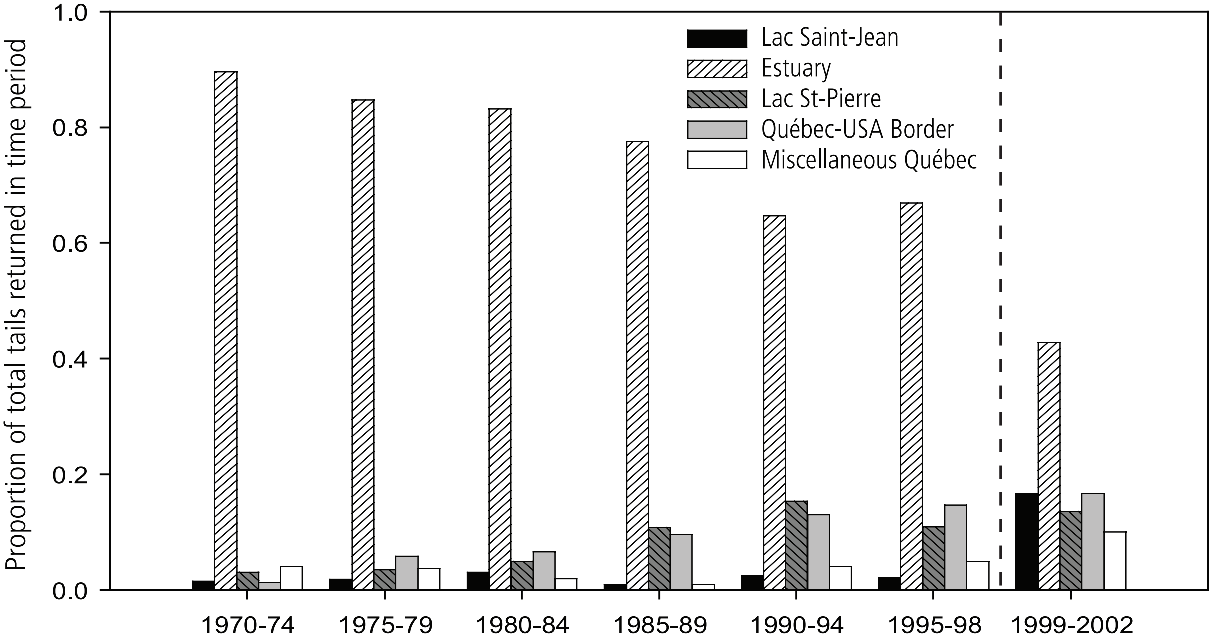

Figure 1-4. Distribution of goose tails returned by hunters during fall in Québec; (n = 7568). The dashed line indicates liberalization of regulations (United States) and the start of special conservation measures (Canada). Data from Calvert *et al.* (2005).

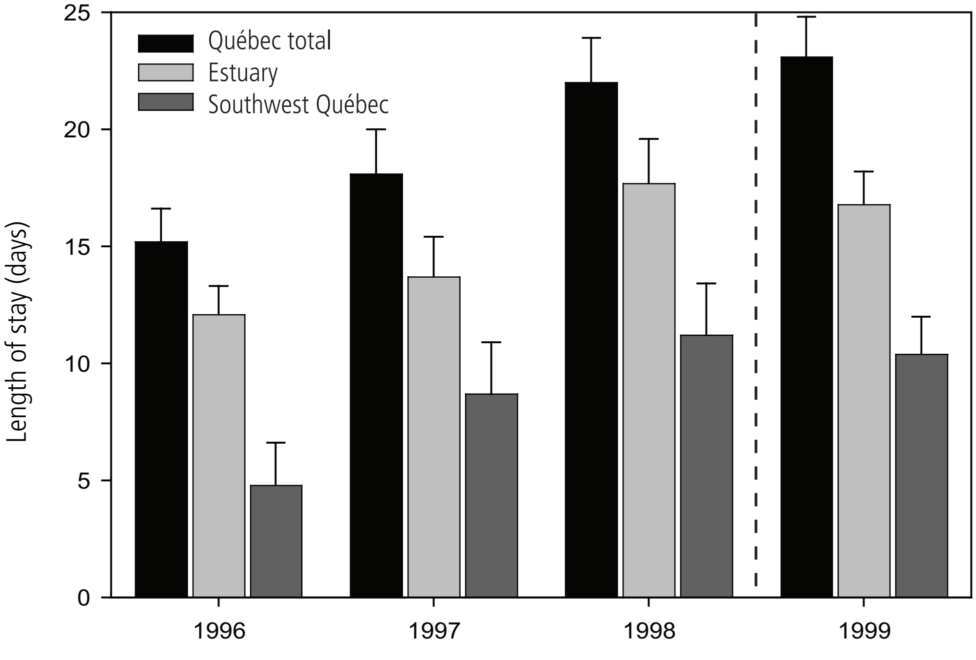

Figure 1-5. Fall staging duration (mean + SE) of radio-marked Greater Snow Geese in all of southern Québec, as well as in the estuary and southwestern regions of the province, from 1996 to 1999 (mean annual sample size = 49; range 13–76). The dashed line indicates the start of the special conservation measures. Data are from Olson (2001).

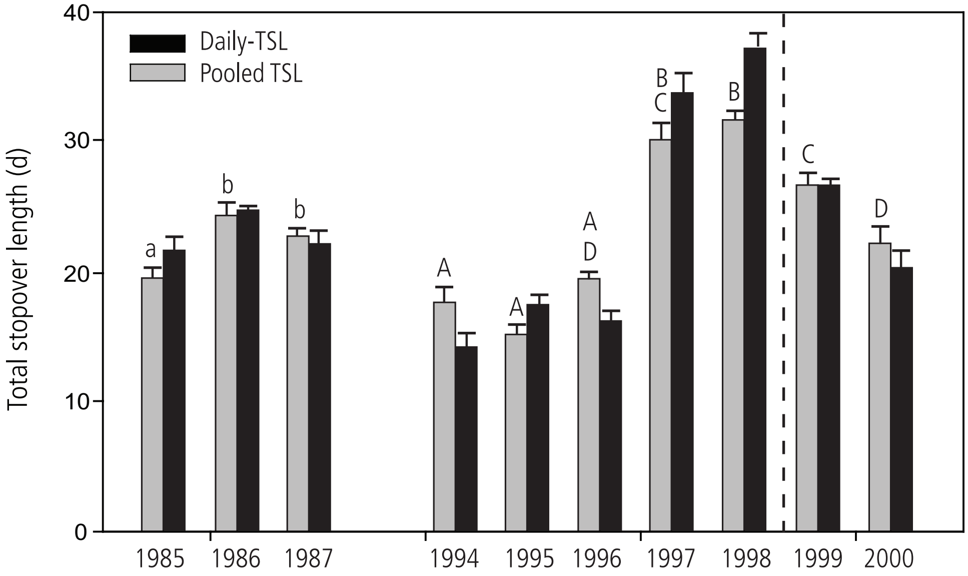

Figure 1-6. Staging duration (mean + SE) of neck-collared Greater Snow Geese in the St. Lawrence estuary during fall from 1985 to 1987 and from 1994 to 2000, based on two different estimation methods (daily estimates and five-day pooled estimates). For daily estimates, means with different letters differ significantly ($P > 0.05$) within each time period. The dashed line indicates the start of the special conservation measures. TSL = total stopover length in days (from Bourguelat 2003).

Winter distribution

Winter distribution of Greater Snow Geese has also changed over time. Wildlife refuges in the south-central Atlantic Flyway (Virginia, North Carolina) were traditionally areas of highest densities of wintering geese; since the mid-1980s, however, this distribution has shown a shift towards much larger concentrations in more northerly states, with particular increases in Maryland and Delaware and, to a lesser extent, New Jersey (Reed *et al*. 1998). These distributional shifts may have been due in part to the greater availability of cornfields in mid-Atlantic Flyway states than farther south in recent decades and to increasing temperatures throughout the wintering grounds (Gauthier *et al*. 2005). Figure 1-7 illustrates this change based on midwinter inventories conducted each January in the Atlantic Flyway; these data are indices only and not true abundances, but they are nonetheless useful to show general temporal patterns of wintering distribution (Serie and Raftovitch 2003).

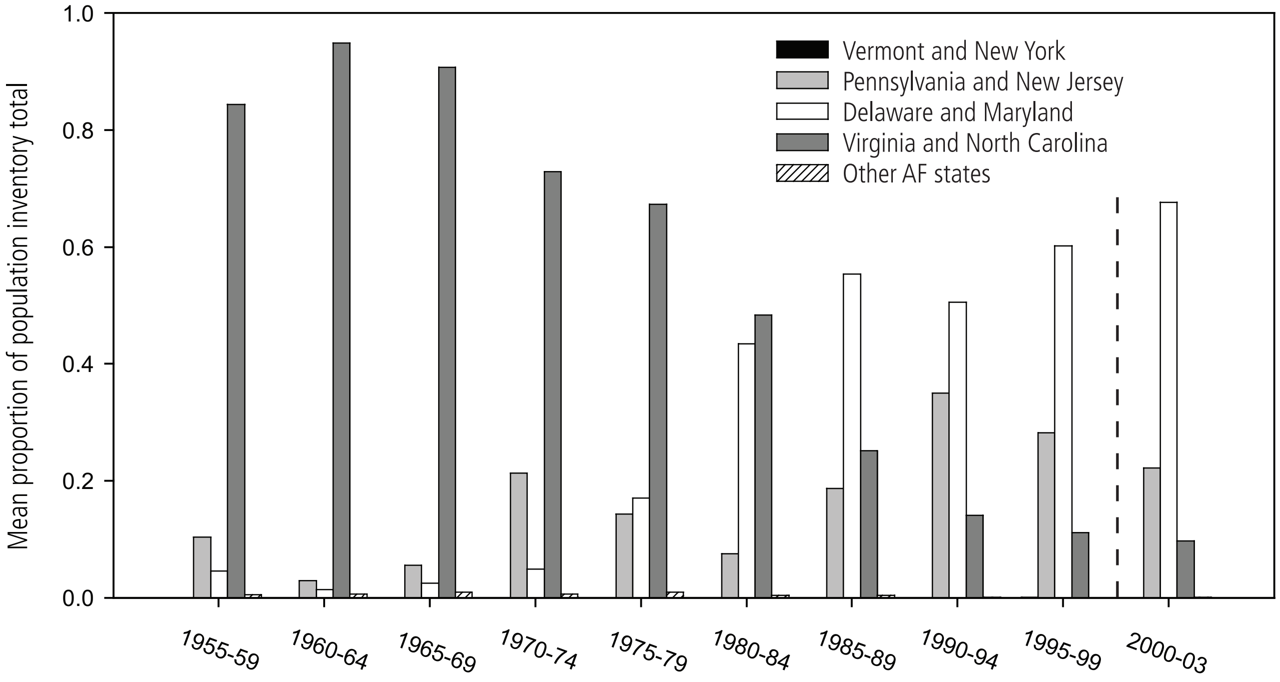

Figure 1-7. Winter distribution of Greater Snow Geese based on the midwinter inventories of the Atlantic Flyway, by pairs of states and five-year periods from 1955 to 2003. The dashed line indicates liberalization of harvest in the United States. Data are from USFWS (unpubl.).

Distribution of winter harvest also showed a temporal change characterized by a general northward trend, very similar to distributional patterns observed in the midwinter inventory. When the U.S. hunting season reopened in 1975, the most southerly Atlantic Flyway states (Virginia and North Carolina) represented over 60% of winter harvest; by the late 1990s, however, this proportion had dropped below 10% (Fig. 1-8). In the 1990s, most harvest instead occurred in mid-Atlantic Flyway states — namely, Pennsylvania, New Jersey, Delaware, and Maryland; the proportion also increased somewhat farther north, in Vermont and New York. Geese wintering in northern states may have been subject to lower hunting pressure, which could have contributed to the growth in abundance there since the mid-1980s (see harvest section below, Calvert *et al.* 2005).

No specific studies have been done to assess the consequences of regulatory changes on the migratory behaviour or distribution of Greater Snow Geese during winter. However, as with the fall, harvest distribution in winter may provide clues about the effects of these modifications. For example, a comparison of the geographic locations of winter band recoveries after liberalization of regulations (1999–2002) relative to 1995–1998 showed little distributional change, although geese were concentrated much farther north during both periods than in the 1970s. These long-term data indicate a major northerly shift in the mid-1980s, with relative stability in distribution since then (Calvert *et al.* 2005), and suggest that no major changes in winter distribution have been associated with the liberalization of regulations since 1999.

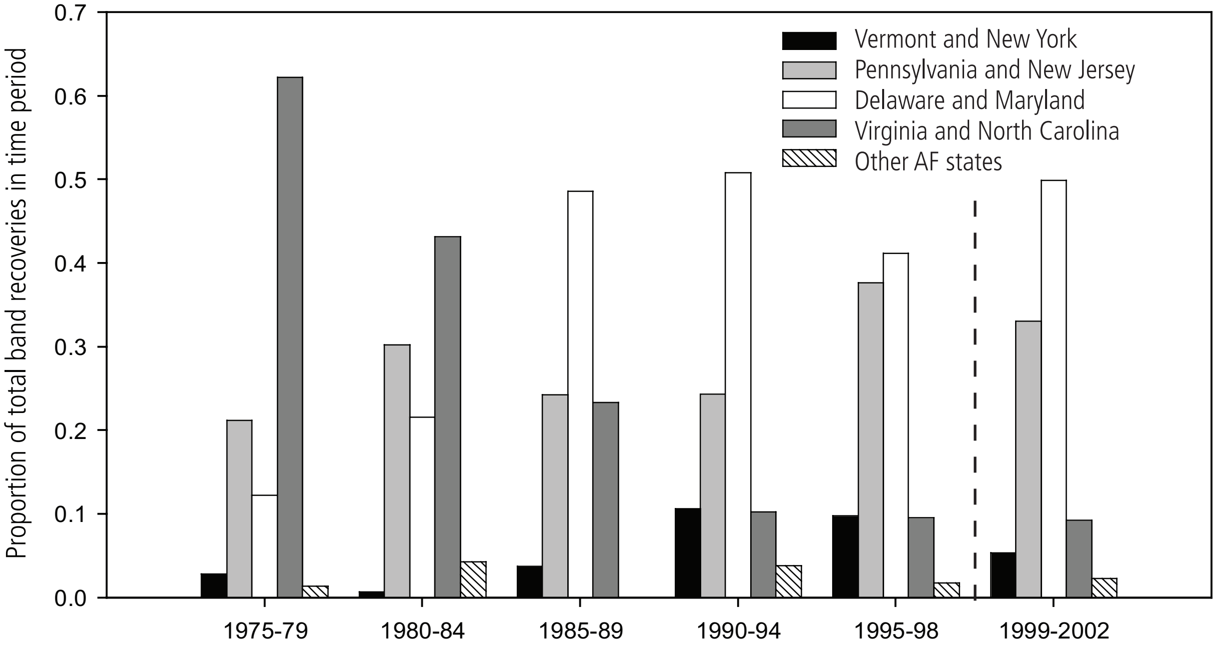

Figure 1-8. Distribution of hunter-shot banded geese recovered on wintering grounds in Atlantic Flyway states (n = 2542). Harvesting began in the United States only in 1975, and the period 1999–2002 includes liberalized regulations. The dashed line indicates liberalization of harvest in the United States (from Calvert *et al.* 2005).

Spring migration movements

Geese were radio-tracked during the springs of 1997–2000 to assess whether disturbance levels increased with implementation of the spring conservation harvest and how this might have impacted the migratory movements of geese heading north (Béchet *et al.* 2003, 2004a). There was evidence that spring harvest in 1999 and 2000 greatly increased disturbance levels in all regions of Québec relative to the two previous years without the harvest (Béchet *et al.* 2003, 2004a; Fig. 1-9). Scaring activities to chase geese from farmlands probably also contributed to increased disturbance as these activities became more organized and systematic around 1999. Disturbance was particularly severe in the estuarine region of Québec (the last major spring staging area for Greater Snow Geese before their departure for breeding grounds), and hunting triggered a stronger response than other disturbances, such as scaring or accidental human disturbances (Béchet *et al.* 2004a).

Migratory movements were also affected by the new spring harvest. In years without harvest, spring migratory movements were predominantly northeastward, from southwestern Québec towards the estuary, with very few movements in the other direction (Béchet *et al.* 2003). In contrast, during years with harvest, the probability of returning southwestward was more than four times greater than in previous years (Béchet *et al.* 2003; Fig. 1-10). This reverse movement was particularly strong immediately following the opening of the harvest season, suggesting that geese may have returned to previously occupied areas where they had not experienced the same hunting disturbance (Béchet *et al.* 2003).

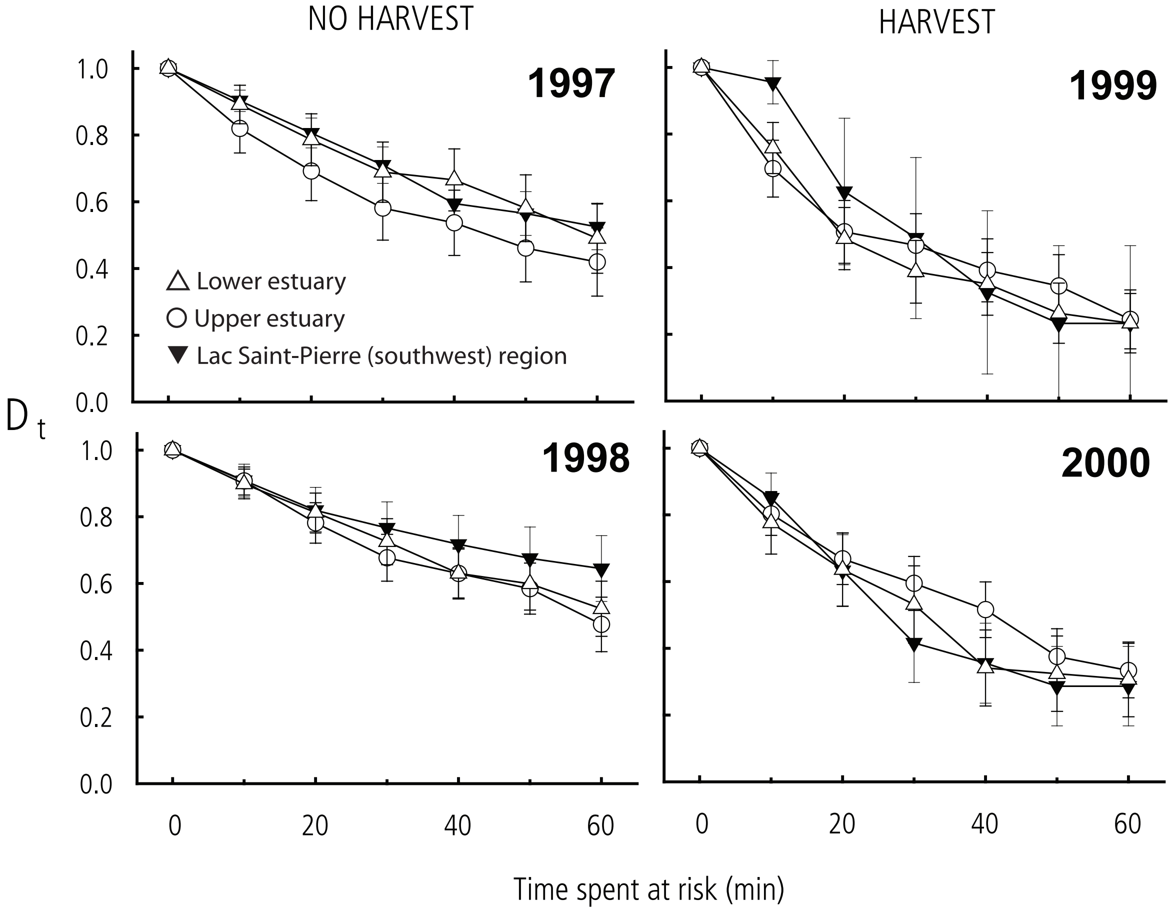

Figure 1-9. Probability of completing a foraging bout without being disturbed (D_t; mean ± 95% CI) relative to time spent at risk of disturbance for Greater Snow Geese in southern Québec in two years without a spring conservation harvest (1997 and 1998) and two years with a harvest (1999 and 2000) (from Béchet *et al.* 2003).

The distribution of spring recoveries of banded birds from 1999 to 2003 is shown in Figure 1-11. This distribution was similar to fall recoveries of banded birds for the same time period (Fig. 1-3), with some differences. Although the spring and fall ranges had the same extent, spring recoveries tended to be more spread out than fall recoveries, especially throughout southwestern Québec and the lower estuary. We also note a lower proportion of the harvest in the Lac Saint-Jean region in spring than in fall. The spreading out of the spring harvest is consistent with findings mentioned above that suggest higher rates of movement by geese in years with a spring harvest, including reverse movements, presumably in response to increased hunting disturbance.

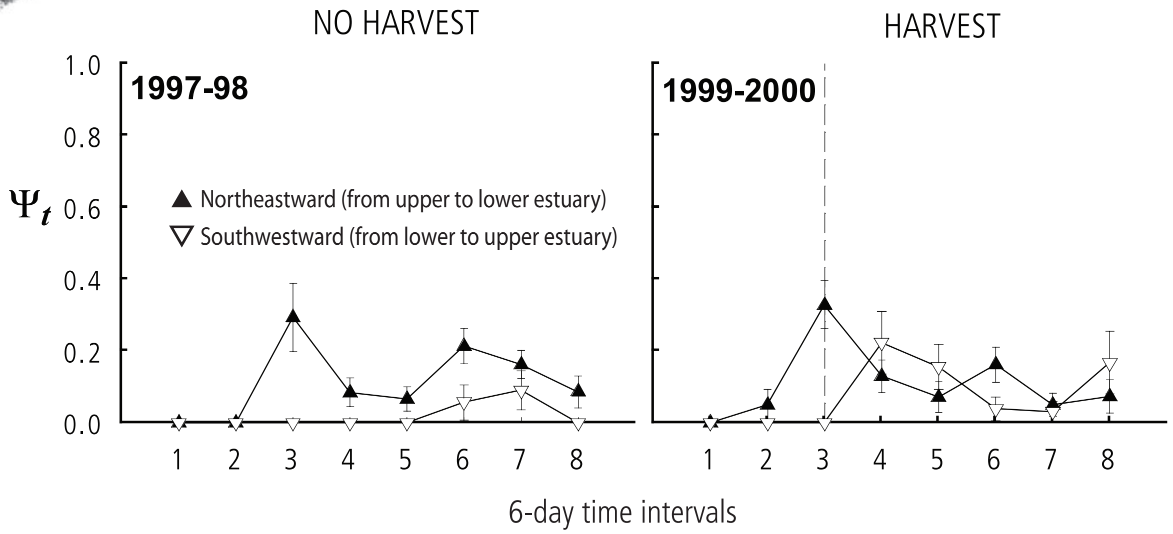

Figure 1-10. Movement probabilities (ψ_t; mean ± SE) of Greater Snow Geese northeastward from the upper to lower St. Lawrence estuary (black) and southwestward from the lower to upper estuary (white) over six-day periods in 1997–1998 (no spring harvest) and 1999–2000 (spring harvest) from 28 March to 21 May. The dashed line indicates the start of the spring conservation harvest (from Béchet *et al.* 2003).

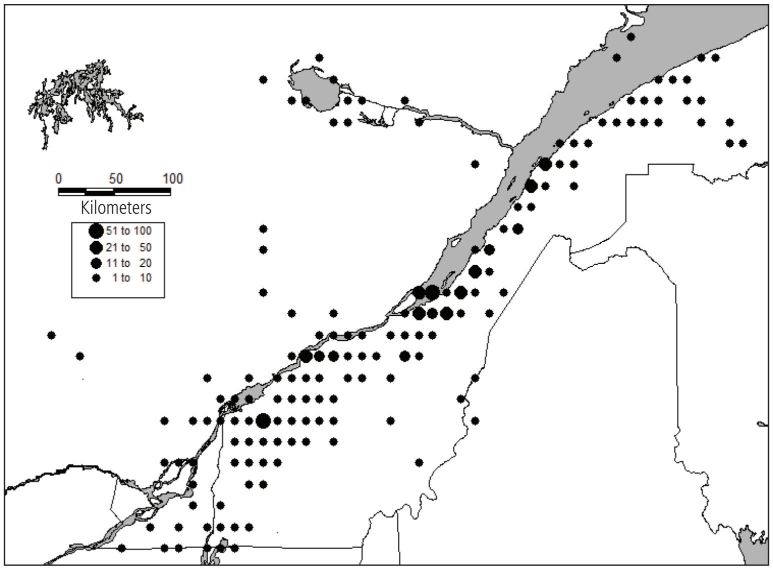

Figure 1-11. The distribution of Québec spring band recoveries in 1999–2003 (n = 837), precise to 10 minutes.

Summary: Abundance and distribution

- Spring survey estimates indicate that population growth observed until the late 1990s was stopped and that the population at least stabilized following the implementation of the new measures in 1999. Although the most recent surveys (2004 and 2005) suggest that the population may still be relatively high (although stable since 1999), recent changes in survey methodology prevent a direct comparison of these values with previous estimates.
- Breeding ground surveys on Bylot Island indicate that the population at this important colony has been relatively stable since 1993. Considering the overall increase in population size that occurred after 1993, it is likely that other existing breeding colonies have grown or that new colonies have appeared. Lack of a comprehensive breeding ground survey for Greater Snow Geese prevents us from confirming such local abundance and distribution changes on the Arctic breeding grounds.
- Long-term changes in staging distribution observed during the period of rapid population growth have persisted since implementation of special measures in 1999, with continued expansion by geese into southwestern and north-central Québec. Increasing use of farmlands in a changing landscape may be the main reason for these historical changes, but new conservation measures probably also contributed in recent years. Winter distribution showed a northward shift in the mid-1980s, also likely linked to increased use of farmlands and changes in agricultural practices, but appears to have changed little since then.
- Liberalization of regular hunting season regulations likely increased disturbance to geese, but consequences for fall and winter distribution are unknown. There is, however, evidence that spring conservation harvest increased disturbance levels of geese and modified spring movements, most notably by increasing southwestward migratory (i.e. reverse migration) movements and possibly also by further dispersing geese throughout southern Québec.

BREEDING AND PRODUCTIVITY

An important potential effect of conservation measures is on reproduction. Hunting disturbance, for example, through effects on the movements and distribution of waterfowl, can increase energetic costs and decrease time available for feeding (Bélanger and Bédard 1990; Riddington *et al*. 1996). It is well known that conditions on spring staging grounds can affect subsequent reproductive season in Arctic-nesting geese (Davies and Cooke 1983; Alisauskas 2002), because nutrients acquired during this period are invested in migration to the breeding grounds and in reproduction (Choinière and Gauthier 1995; Gauthier *et al*. 2003a). We therefore examined possible effects of special conservation measures on Greater Snow Goose reproduction through analyses of long-term trends in productivity, in addition to some recent in-depth studies of various aspects of goose reproduction.

Nesting parameters: Long-term trends

Several measures of Greater Snow Goose productivity are evaluated each year, beginning on the breeding grounds at Bylot Island (for methodological details, see Lepage *et al*. 1999, 2000; Bêty *et al*. 2001). On average, more than 300 nests (annual range 86–846) have been monitored each year since 1989. Determined for each nest are 1) egg-laying date (the date on which a first egg is laid in a nest), 2) clutch size (the total number of eggs found in the nest), and 3) nesting success (the proportion of all nests in which at least one egg hatches, calculated by the Mayfield [1975] method). Breeding propensity (i.e. probability that a mature female attempts to breed) is another important variable, but is difficult to determine; however, using radio-marked birds, Mainguy *et al*. (2002) and Reed *et al*. (2004a) were able to estimate it for a subset of years. Finally, during the banding drives in early August, at a time when moulting adults are flightless and young have not yet fledged, the ratio of juveniles per adult is determined from the sample of geese captured in banding nets, as an index of productivity for the summer.

Productivity data collected on Bylot Island during 1989–2003 are shown in Table 1-2. Most of these indices are highly variable from year to year, a well-known phenomenon in species nesting in the Arctic, where breeding success is strongly influenced by stochastic environmental conditions (Lepage *et al*. 1996; Skinner *et al*. 1998; Bêty *et al*. 2003; Reed *et al*. 2003b, 2004a). Despite this high annual variability, these data suggest that some reproductive parameters were negatively affected by spring conservation harvest. Statistical analyses based on individual nests revealed that, during years with spring harvest, lay date was significantly later and clutch size was significantly reduced compared with previous years (one-tailed, one-factor analyses of variance [ANOVA], contrasting all nests in regular and special regulations years: lay date $F_{1.5301} = 760.8$, $P < 0.001$; clutch size $F_{1.4911} = 40.56$, $P < 0.001$). In contrast, analysis of nesting success revealed no change with the new measures (one-tailed, one-factor ANOVA using annual mean nesting success as individual values, $F_{1.13} = 0.38$, $P = 0.273$); however, this test lacks statistical power because it ignores the fact that each annual value is based on several hundred individual nests. Finally, the proportion of geese captured at the end of the reproductive season that were juveniles tended to be lower in years with a spring harvest, but this effect was weak (loglinear analyses in PROC CATMOD comparing models with and without an age*harvest interaction [age = juvenile vs. adults]; sum of AIC model weights with interaction age*harvest = 0.13).

Effect of spring harvest on reproductive parameters

In recent years, several studies (e.g. Mainguy *et al*. 2002; Bêty *et al*. 2003; Reed *et al*. 2004a) tested the hypothesis that the spring conservation harvest negatively affected reproductive parameters of Greater Snow Geese when other confounding factors (e.g. climatic variables) were controlled for. One of the most important factors influencing the annual reproductive output is breeding propensity (i.e. the proportion of sexually mature birds that attempt to breed). Intensive tracking of radio-marked geese from 1997 to 2002 allowed researchers to shed light on this question. The proportion of radio-marked birds that completed spring migration to Bylot Island (i.e. proportion of individuals detected on the breeding grounds among those detected and known to be alive in spring in Québec) was drastically reduced in years with a spring conservation harvest compared with previous years (Table 1-3; $\chi^2 = 24.92$, df = 1, $P < 0.001$). This is not due to the death of birds in spring, because most of the birds that did not complete the migration were subsequently resighted during either fall or spring in Québec (Mainguy *et al*. 2002).

Among radio-marked birds that reached Bylot Island in that study, the proportion of birds that attempted to breed (i.e. for which we found a nest) was also drastically reduced in years with a spring conservation harvest compared with previous years (Table 1-4; $\chi^2 = 13.31$, df = 1, $P = 0.003$). This analysis did not control statistically for climatic conditions in the Arctic, but Mainguy *et al*. (2002) examined environmental conditions in those years (snow and spring temperature) and found little difference between years with and years without a spring harvest. Although the previous comparison was made among females marked with radio-collars, these marked females may have been disproportionately affected by the spring conservation harvest compared with unmarked birds; for example, Reed *et al*. (2004b) and Demers *et al*. (2003) showed that collars had a negative effect on the reproduction of Snow Geese. However, Reed *et al*. (2004a) provided even stronger evidence that the breeding propensity of Greater Snow Geese was reduced in years with a spring harvest (Fig. 1-12). Their analysis used only females marked with a metal leg band, thus eliminating any potential confounding effect due to the presence of a radio-collar, and they statistically controlled for environmental conditions at the onset of breeding in the Arctic (i.e. snow cover on the ground). Therefore, these data suggest that the breeding propensity of females was reduced in years with a spring conservation harvest.

Table 1-2. Productivity data for Greater Snow Goose nesting on Bylot Island, Nunavut, before (1989–1998) and after (1999–2003) implementation of the spring conservation harvest, indicating median date of egg laying, mean clutch size, nesting success (proportion of nests in which at least one egg hatched; Mayfield 1975), and ratio of juveniles to adults at time of banding in early August. Data are from Gauthier *et al*. (2003b).

	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	**Mean (SE) 1989–1998**	1999	2000	2001	2002	2003	**Mean (SE) 1999-2003**
Median date of egg laying (June)	11	13	11	20	6	11	10	14	10	7	**11.3 (1.23)**	17	16	13	16	9	**14.2 (1.46)**
Mean clutch size	3.82	3.52	3.59	3.21	4.41	3.55	3.64	3.99	4.27	4.06	**3.81 (0.12)**	3.12	3.65	3.43	3.43	3.90	**3.51 (0.13)**
Nesting success (%)	70	79	72	70	89	40	14	65	83	79	**66 (7.2)**	14	83	57	53	82	**58 (12.6)**
Juveniles:adults at banding	--	1.15	1.46	0.81	1.55	0.79	1.10	0.83	1.06	1.09	**1.09 (0.09)**	0.54	1.08	1.03	0,81	1.31	**0.95 (0.13)**

Table 1-3. Number of radio-marked Greater Snow Geese detected at departure from spring staging areas in southern Québec and during summer on Bylot Island. Data are from Mainguy *et al.* (2002) and G. Gauthier and J.-F. Giroux (unpubl.).

Year	Number leaving southern Québec	Number detected on Bylot Island	%
1997	37	35	95 %
1998	70	54	77 %
Total 1997-1998	**107**	**89**	**83 %**
1999	57	11	19 %
2000	67	23	34 %
2001	19	9	47 %
2002	(20-30)*	3	(10-15 %)
Total 1999-2001	**143**	**43**	**31 %**

* Exact number of radio-marked geese leaving southern Québec is unknown in 2002 because no intensive tracking was conducted that spring. Maximum potential number is 30, but number is probably lower due to mortality.

Table 1-4. Number of radio-marked Greater Snow Geese present on Bylot Island and known to have nested. Data are from Mainguy *et al.* (2002) and G. Gauthier and J.-F. Giroux (unpubl.).

Year	Number detected on Bylot Island	Number of nests found	%
1997	35	20	57 %
1998	54	29	54 %
Total	**89**	**49**	**55 %**
1999	11	0	0 %
2000	23	2	9 %
2001	9	2	22 %
2002	3	0	0 %
Total	**46**	**4**	**9 %**

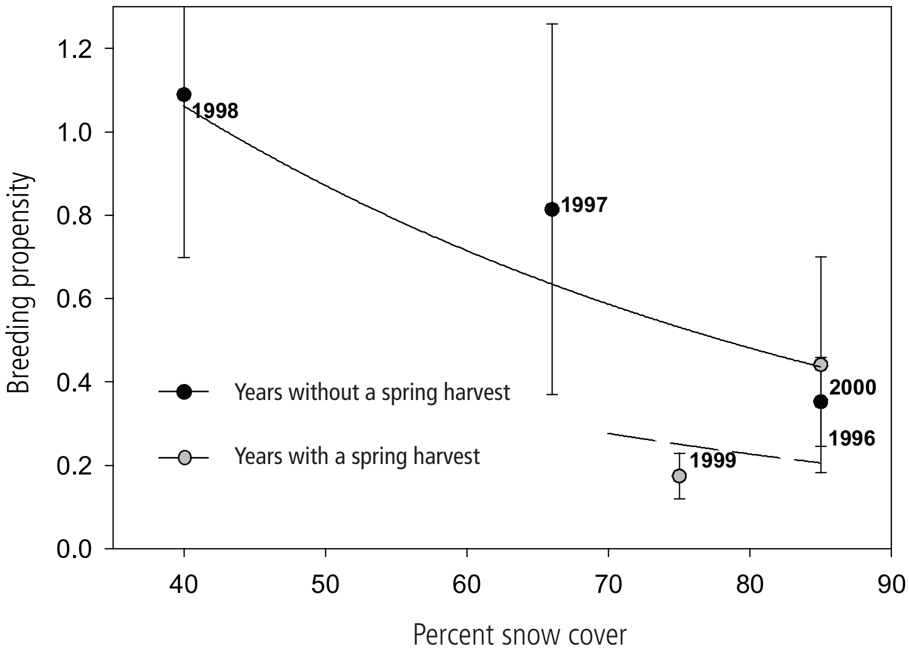

Figure 1-12. Relationship between snow cover on 5 June on Bylot Island and estimated breeding propensity (± SE) of female Greater Snow Geese. Lines are predicted values of breeding propensity from model: logit (breeding propensity) = 0.79 [± 0.67] – 2.05 [± 0.96] * snow cover – 0.78 [± 0.35] * (0: no spring harvest; 1: spring harvest) (from Reed *et al.* 2004a).

In a similar analysis, Bêty *et al.* (2003) showed that, after controlling for environmental conditions, Snow Geese laid eggs four days later on average in years with a spring harvest than in years without (Fig. 1-13). This is a very large difference, considering that survival probability to the first winter declines rapidly in goslings hatched after peak laying date compared with goslings hatched at peak laying date (Lepage *et al.* 2000). As a result, fewer late-hatched individuals eventually recruit in the breeding population because their survival probabilities are reduced (Reed *et al.* 2003b). In the first two years of the spring harvest, birds also laid a reduced clutch size (Mainguy *et al.* 2002).

By what mechanisms did the spring conservation harvest negatively impact many components of Snow Goose reproduction? As discussed above, disturbance events affected migratory behaviour of geese during spring staging, and this resulted in a reduction of energy gains, particularly in years with the spring harvest (Béchet *et al.* 2004a). Nutrient reserves at the beginning and the end of spring staging were analyzed by Féret *et al.* (2003). They found that, while energetic reserves at the time of arrival in early spring did not differ between years with and without the spring harvest, fat and protein reserves at the time of departure were clearly reduced in springs with harvest (Féret *et al.* 2003; Fig. 1-14). In addition, they detected a change in carbon stable isotope signature, suggesting that hunting disturbance may also have resulted in a reduced intake of corn (Féret *et al.* 2003), a food source that has become important to staging and wintering geese in recent years (Alisauskas *et al.* 1988; Giroux and Bergeron 1996). Another study examined the fat and protein reserves and body mass of laying females on the breeding grounds and compared these values between years before and after spring harvest (Mainguy *et al.* 2002). They also found evidence for a decreased body condition in years with a spring harvest (Mainguy *et al.* 2002; Fig. 1-15a,b,c). Therefore, reduced nutrient accumulation along the St. Lawrence River in spring due to increased disturbance was still evident among birds breeding in the Arctic; this was likely the cause for the reduced breeding performance of geese in years with a spring harvest.

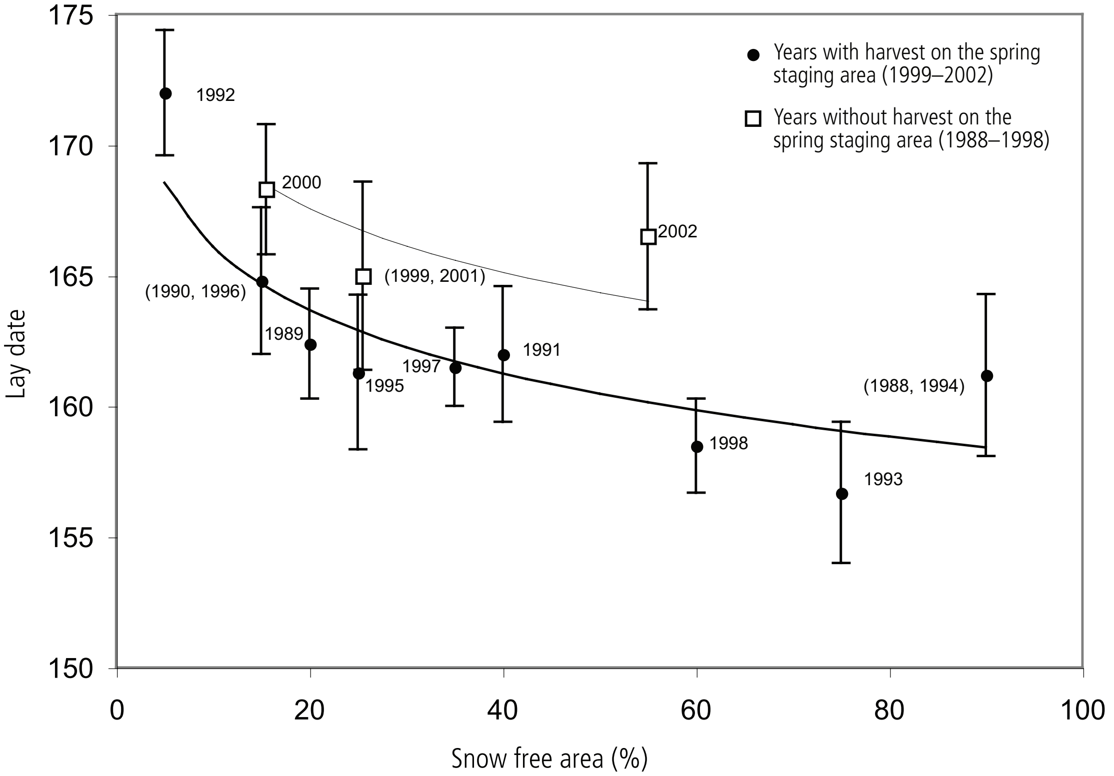

Figure 1-13. Relationship between lay date of Greater Snow Geese and climatic conditions (% snow-free area on 5 June) in years with (1999–2002) and without (1988–1998) harvest on the spring staging area. Corresponding years are near each data point. Values are standard deviations (each dot represents 52–522 nests). Lay dates are expressed in Julian date, where 1 January = 1. Multiple linear model: climatic condition (log-transformed), $F_{1,3674} = 2220$, $P < 0.001$; hunting (on staging area: yes = 1, no = 0), $F_{1,3674} = 1086$, $P < 0.001$; lay date = 174.2 − 3.5 × climatic condition + 3.9 × hunting. The use of log-transformed snow-free area improved the fit of the model (untransformed, $R^2 = 0.40$; transformed, $R^2 = 0.51$) (from Bêty *et al*. 2003).

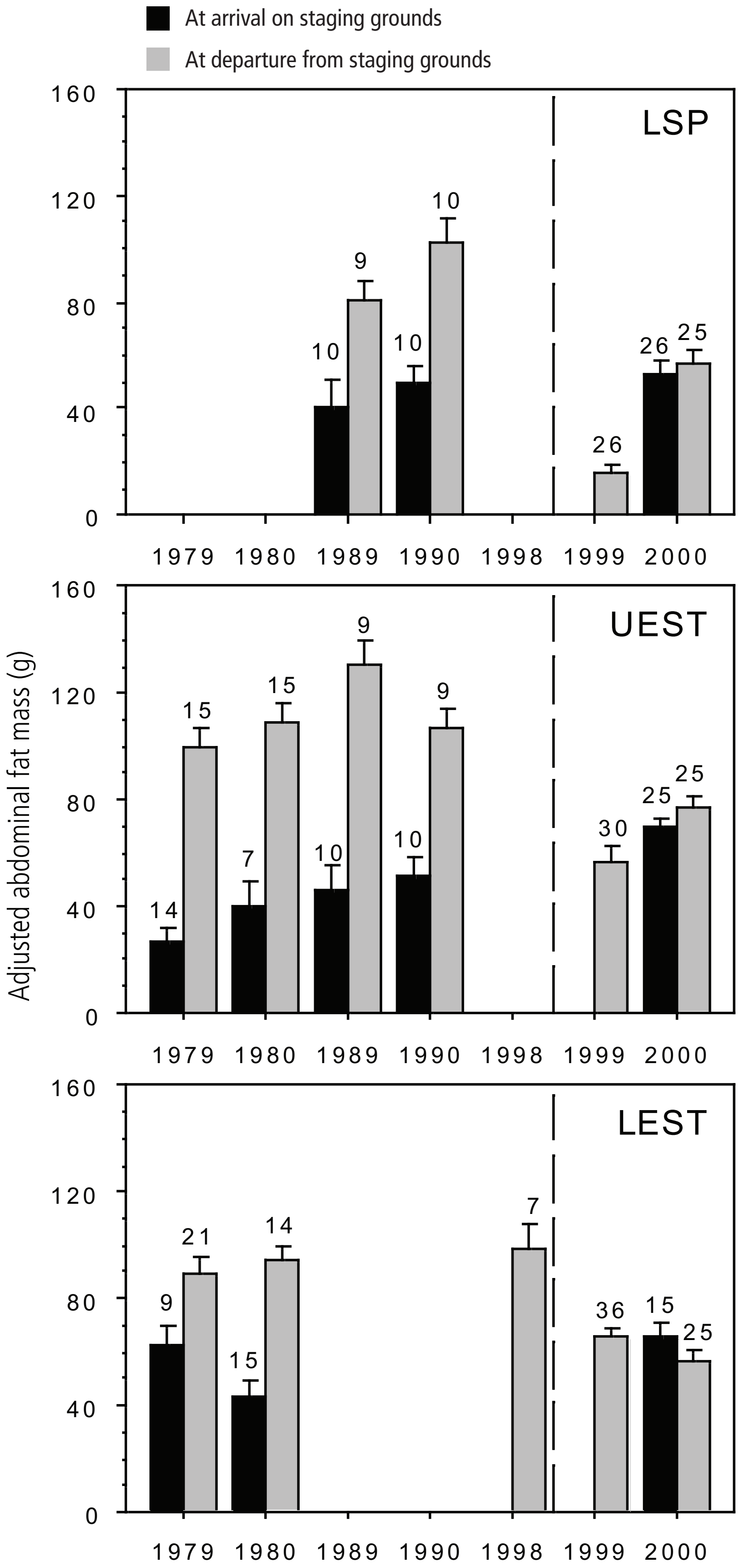

Figure 1-14. Mean (±SE) abdominal fat mass, adjusted for body size, of adult Greater Snow Geese collected in the Lac Saint-Pierre (LSP), upper estuary (UEST), and lower estuary (LEST) regions of the St. Lawrence River, Québec during the springs of 1979–2000. Numbers above bars represent sample sizes, and the dashed line indicates the start of the spring conservation harvest (from Féret *et al*. 2003).

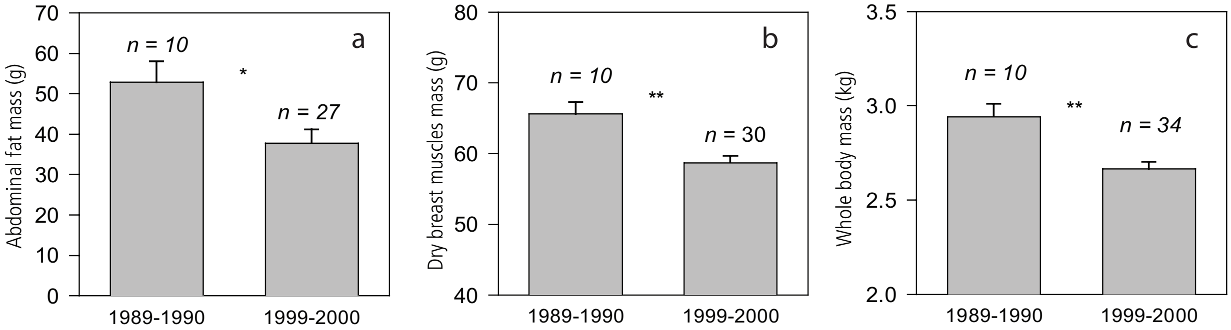

Figure 1-15. Indices of female Greater Snow Goose body condition during the egg-laying period (a: abdominal fat mass, b: dry breast muscle mass, c: whole body mass; all body condition indices were adjusted for body size) in years without (1989–1990) and with (1999–2000) a spring conservation harvest. Bars represent mean (±SE); sample sizes are indicated above bars; statistical significance (tested with one-way ANOVA) represented by * ($P < 0.05$) and ** ($P < 0.01$). Data are from Mainguy *et al.* (2002).

Proportion of young in the fall population

Annual Snow Goose productivity can also be measured by the proportion of juveniles observed in fall or winter (Appendix B). Among these estimates, likely the best indicator of annual productivity is the fall age ratio survey, which has been conducted on staging grounds in Québec annually since 1967 (Fig. 1-16). Although a small amount of hunting occurs before field observations (Reed *et al.* 1998), this index is less biased by harvest mortality than are surveys done in winter. The fall age ratio surveys take place towards the end of fall migration, and therefore this parameter integrates mortality incurred during migration from breeding to staging grounds. This post-fledging mortality can be very high and variable from year to year and may be related to climatic conditions, body mass, and fledging date (Owen and Black 1989; Sedinger *et al.* 1995; van der Jeugd and Larsson 1998; Reed *et al.* 2003a; Menu *et al.* 2005). Changes in staging distribution discussed above could have potentially biased this productivity index in recent years (up to 2003), as it was estimated only in the area of the upper estuary, whereas an increasing number of geese are now staging elsewhere. The 2004 productivity index included counts from all major fall staging areas of southern Québec. The fall age ratio remains an important indicator of productivity and may have an important bearing on fall harvest (see below).

The mean proportion of juveniles in fall was lower in years with special conservation measures (1999–2003 average: 17.1% ± 5.4%) than in years without (1973–1998 average: 26.3% ± 2.5%; one-tailed $t = 1.51$, df = 29, $P = 0.071$). A loglinear analysis comparing numbers of adults and juveniles observed in fall in years with and without a spring harvest provided strong support for that observation (n = 466 427 adults and 155 012 juveniles surveyed from 1973 to 2003; PROC CATMOD in SAS comparing models with and without age [juveniles vs. adults]*harvest [spring harvest present or absent] interaction; sum of AIC model weights with interaction age*harvest > 0.99). Fall brood size has also been measured at the same time as fall age ratios, providing additional metrics of productivity (Appendix B). Mean brood size (SE) following the special conservation measures was 2.25 (0.11) for 1999–2003, compared with 2.52 (0.05) for 1973–1998, also showing an important decline with implementation of the spring harvest (one-tailed test, $t = 2.23$, df = 29, $P = 0.017$). Overall, these analyses suggest that the spring conservation harvest reduced Greater Snow Goose productivity.

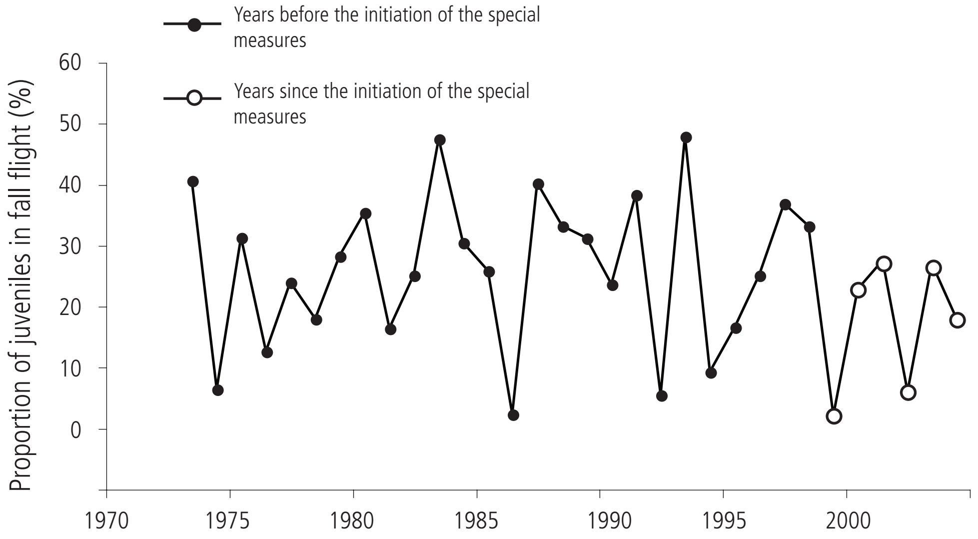

Figure 1-16. Proportional representation of juvenile Greater Snow Geese during fall staging in Québec from 1973 to 2004, as determined from visual estimates. Data are from Reed *et al*. (1998) and A. Reed (unpubl.).

Reproductive data and fall age ratios presented thus far are both useful indices of breeding success, but they do not measure exactly the same thing: reproductive parameters are estimated only for the portion of the population breeding at Bylot Island, whereas fall age ratios on staging grounds are estimated from a sample of the entire population and are affected by migration mortality. Nevertheless, end-of-summer age ratios at Bylot Island and those measured in fall were closely correlated ($r = 0.86$, df = 12, $P < 0.001$), suggesting that the continental population is well represented by observations made on Bylot Island breeders.

Summary: Breeding and productivity

- Productivity indices for the total population and for the breeding colony at Bylot Island show high interannual variation as a result of environmental fluctuations. Since implementation of special measures, most breeding parameters have been negatively affected: breeding propensity has been reduced, egg laying has been delayed, and clutch size has been reduced, although nesting success and the age ratio at banding showed no change. The result of these negative impacts was that fall age ratio and brood size were lower in years with a spring conservation harvest.
- Spring conservation harvest caused increased disturbance to staging Greater Snow Geese, reducing their ability to store nutrients for migration to nesting grounds and for reproduction. This extra energetic cost and corresponding decline in body condition appear to be the main reasons for the observed reduction in productivity since implementation of the special conservation measures.

GENERAL HARVEST CHARACTERISTICS

Hunter and harvest survey data

Two main sources of data provide information about size and age composition of harvest: 1) recoveries of geese that were banded on breeding grounds (see above), and 2) hunter surveys conducted during fall and spring in Canada and during winter in the United States. Fall hunter surveys are conducted as part of the CWS National Harvest Surveys program. Two surveys are sent annually to different samples of purchasers of Migratory Game Bird Hunting Permits: the Species Composition Survey (SCS), sent early in the hunting season, and the Harvest Questionnaire Survey (HQS), sent at the end of the season. The HQS, introduced in 1967, is a country-wide mail questionnaire sent at the beginning of December (a reminder mailing is sent in February), whose main purpose is to provide estimates of the size, distribution, and timing of the harvest of ducks and geese in Canada. The survey has been refined over the years since its introduction (for details of early survey design, see Smith 1975; Cooch *et al*. 1978). The HQS also provides various other statistics, such as the number of active and successful hunters and their harvest, the average season bag, the average daily bag, and the average number of days spent hunting. However, the HQS does not provide species-specific data.

In the SCS, sampled hunters are requested to mail in one wing from each duck and tail feathers from each goose they kill and retrieve. The results of the survey are used to partition harvest estimates obtained from the HQS among species, age (young-of-the-year vs. adults), and sex (although sexes are not distinguishable from goose tail feathers). The survey also uses tail length to distinguish between the two subspecies of Snow Geese (Lesser and Greater), but there is evidence that this method is unreliable. For instance, the annual proportion of Lesser Snow Geese reported in the Québec harvest during 1976–2002 based on the SCS index (mean 0.06; annual range 0.00–0.19) is high relative to the annual proportion of blue-phase geese in the harvest (mean 0.01; annual range 0–0.03). The presence of blue geese is a useful marker to distinguish these two subspecies because blues are very rare in Greater Snow Geese (<1%; A. Reed and G. Gauthier, unpubl. data), whereas eastern Lesser Snow Goose populations contain a very large proportion of blues (>70%; Cooke *et al*. 1995). Consequently, for analyses based on HQS data in this report, all Snow Geese in Québec were considered to be Greater, as the proportion of Lesser was assumed to be negligible.

A special harvest survey has also been conducted in spring following the introduction of the spring conservation harvest in Québec. In 1999, hunters were required to register to participate in the spring harvest and were sent a diary to record hunting activities; this was followed by a telephone survey. From 2000 onward, a mail questionnaire was sent at the end of spring, along with a reminder mailing to hunters not responding initially. The survey was divided into two strata: 1) permit holders who were residents of Québec and who had already purchased a permit in the previous fall and 2) permit holders who purchased a permit during the spring only. It was anticipated that spring permit purchasers would be more likely to participate in the spring harvest than fall permit purchasers. With the exception of 1999, 3000 hunters have been sampled annually. Spring surveys provide estimates of the number of active and successful hunters, the number of hunting days, and the total harvest per hunting district (for hunting districts, see Appendix C). Spring surveys also provide estimates of the number of hunters using particular methods of hunting, as well as the temporal and spatial distributions of the Snow Goose harvest. Age ratios in the spring kill have been estimated from tail feathers sent in on an opportunistic basis by outfitters, hunting guides, and hunters; annual sample size was between 265 and 3508 tails (P. Brousseau, unpubl. data).

Since the 1950s, the USFWS has estimated hunter activity and harvest through surveys of samples of federal duck stamp purchasers; surveys of total harvest and hunter activity were conducted in a manner similar to those in Canada. The duck stamp surveys were phased out in 2002 and have been replaced with the Harvest Information Program (HIP), in operation since 1999 (USFWS 2003). This new survey program is based on purchasers of state-issued hunting licences instead of federal duck stamps, from which the USFWS stratifies samples according to species hunted and success rate. Sampled hunters are given hunting diaries to avoid problems of memory bias, and reminders to complete survey forms are sent throughout the hunting season. The Waterfowl Parts Collection Survey is the U.S. equivalent to the Canadian SCS and has been relatively unchanged since the 1950s. The U.S. surveys separate blue-phase geese from white-phase geese, assuming that blue geese represent Lesser Snow Geese; however, in Atlantic Flyway states, the proportion of blue geese in the harvest was minimal (mean 0.02; annual range 0–0.04), and, as with the Canadian harvest, we assumed that all blue and white Snow Geese were Greater Snow Geese. For more details on the U.S. surveys, see USFWS (2003).

Harvest estimates presented in this report were obtained from the National Harvest Survey database for Québec and from the equivalent U.S. surveys for the Atlantic Flyway states (Serie 1996; Martin and Padding 1997, 1998, 1999, 2000, 2001, 2002; USFWS 2003). Greater Snow Goose harvest estimates from the new HIP monitoring system in the United States were on average 37% higher than estimates using the old method for the same years (USFWS 2003; see Table 1-5 for a comparison of these figures). However, the estimates using this new method are only preliminary and may actually overestimate the true harvest, as no consideration of response bias (e.g. incorrect memory of harvest or exaggeration of number killed) was made (P.I. Padding, USFWS, pers. comm.). Therefore, harvest data in this report for 1999–2001 are from the original duck stamp harvest surveys to facilitate comparison with previous years. In 2002, HIP data were used, as the original duck stamp harvest survey was discontinued in that year.

Table 1-5. Comparison of Snow Goose annual harvest estimates for the Atlantic Flyway states from duck stamp sales methods (until 2001, now out of use) and the Harvest Information Program (ongoing since 1999; preliminary figures only), and the difference in new estimate relative to the original survey (mean: 37%). Data are from P. Padding (unpubl.).

Year	Duck stamp harvest survey	Harvest Information Program	Relative difference (%)
1999	40 100	54 800	36 %
2000	47 000	71 900	53 %
2001	64 300	77 800	21 %
2002	---	39 300	---

Annual harvest rate was calculated as the total annual harvest (Canada + United States) divided by fall population size (determined as spring population size multiplied by spring to fall adult survival, adjusted to include the current year's production of young as estimated from the fall productivity surveys), following the procedure of Menu *et al*. (2002); spring harvest was included with the previous fall/winter harvest (e.g. the 2003 spring harvest was part of the 2002–2003 hunting season). Seasonal harvest rates (fall, winter, and spring) were estimated in the same way; that is, each season's harvest was calculated relative to the total population estimate from the previous fall (i.e. at the start of the hunting season). This approach was used because band recovery data were not available in most years and because there is no accurate estimate of reporting rate available for this population. Also, significant variation in post-fledging survival during fall migration (i.e. after banding but prior to harvest) has been documented in juvenile Greater Snow Geese (Menu *et al*. 2005), limiting the usefulness of banding data to estimate harvest rates in juveniles. Adult harvest rates estimated with harvest survey and population survey data were highly correlated with recovery rates from band recovery models for years in which band recoveries were available (1990–2002), but, as expected, the correlation was not as strong with juveniles (Calvert and Gauthier 2005).

Hunter activity

The total number of regular season (i.e. fall and winter) hunters as measured by the sales of waterfowl hunting permits and the number of active waterfowl hunters is shown in Figure 1-17. Permit sales have generally declined in both countries over the long term; however, while permit sales in the U.S. portion of the Atlantic Flyway have remained fairly stable since the early 1990s, Québec sales have continued to drop (although much more slowly since 1997). The number of active waterfowl hunters generally showed declines similar to those of permit sales, with the exception that the number of active hunters has grown in the Atlantic Flyway over the last decade. Neither region's hunting activity appears to have changed since initiation of the special conservation measures. It should be noted that these data include all types of waterfowl hunters, not just Greater Snow Goose hunters. For the spring conservation harvest in Québec, the surveys suggest that the number of active spring hunters (±SE) declined over the seven years that these measures have been in place, from 9643 (±346) in 1999 to 3921 (±259) in 2005 (Table 1-6).

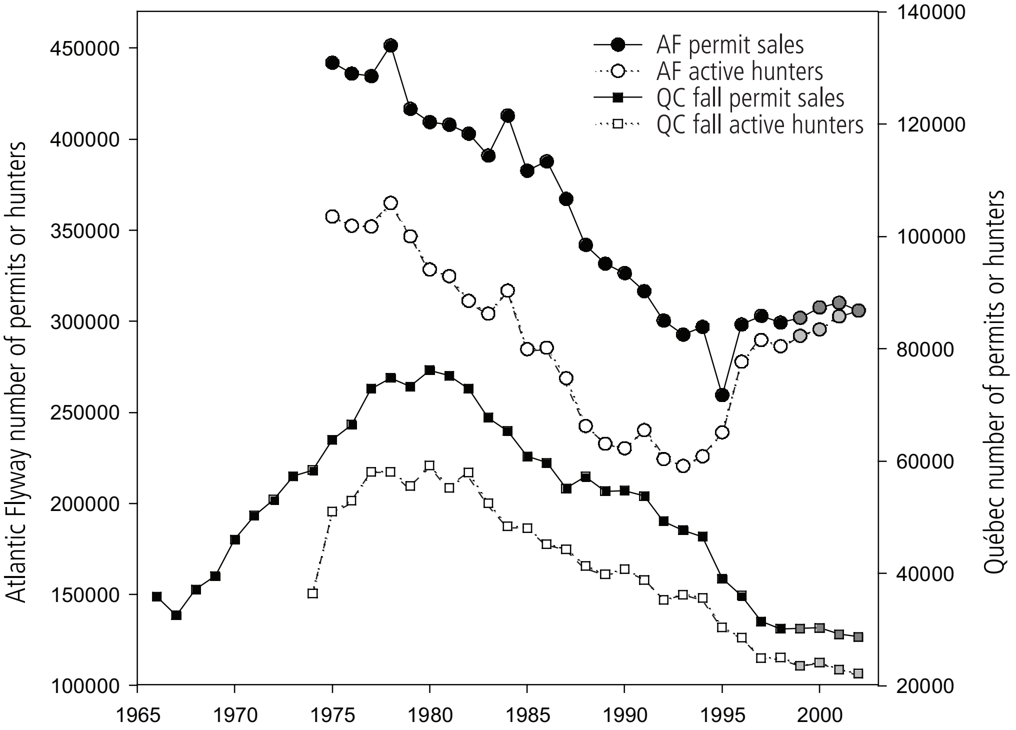

Figure 1-17. Total annual sales of waterfowl hunting permits and number of active waterfowl hunters in Québec and the Atlantic Flyway states; data for the Atlantic Flyway are shown only since 1975, when Snow Goose hunting reopened, whereas Québec hunting permit sales data start in 1967 and Québec active hunters data in 1974 (data for 1999 onwards include spring). Grey markers indicate years since the start of the special conservation measures.

Tableau 1-6. Spring conservation harvest in Québec 1999–2005

Year	1999	2000	2001	2002	2003	2004	2005
Number of active hunters	9 643	9 171	6 574	6 772	4 039	3 842	3 921
Number of successful hunters	4 824	5 773	4 639	3 639	2 772	2 667	2 799
Number of hunting days		48 043	31 912	32 008	15 913	17 780	15 766

Harvest methods and success

The number of Greater Snow Geese killed per successful hunter during fall in Québec is shown in Figure 1-18 as an index of annual hunter success rate. Before implementation of special measures, mean harvest per hunter increased over time (linear regression 1974–1998: slope = 0.187 geese per year, $R^2 = 0.502$, $P < 0.001$). This trend continued when special measures were included (linear regression 1974–2002: slope = 0.184 geese per year, $R^2 = 0.532$, $P < 0.001$), and there was no evidence of an effect of the new measures (one-tailed t-test comparing residuals of the 1974–2002 relationship between 1974–1998 and 1999–2002, $t = -0.03$, df = 27, $P = 0.49$).

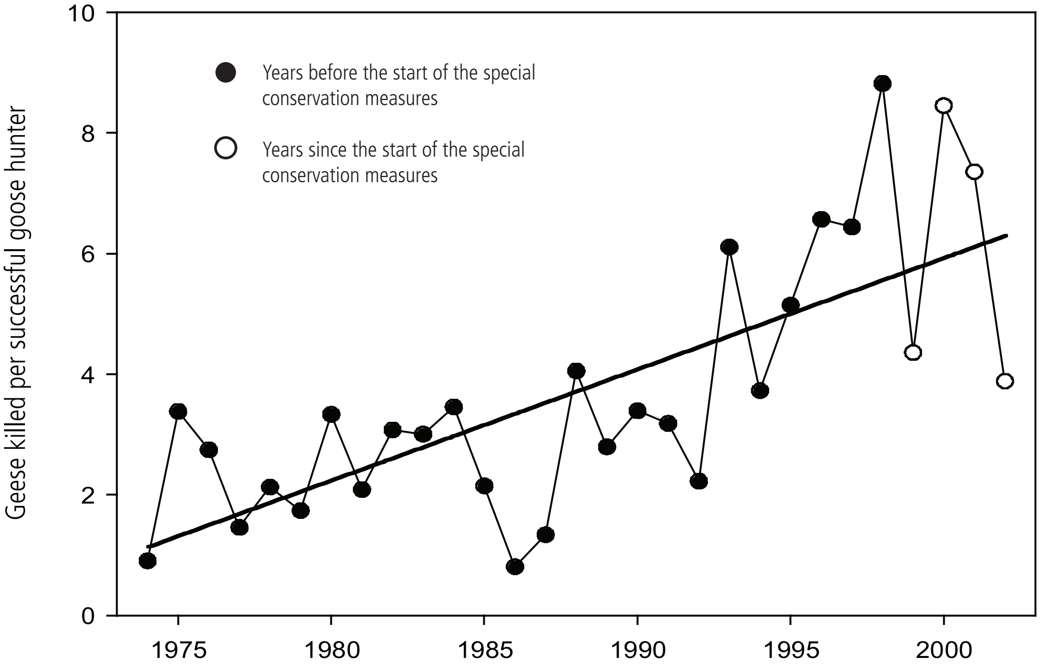

Figure 1-18. Average fall harvest per hunter in Québec, measured as number of Greater Snow Geese harvested per successful goose hunter each year; over time, success rate showed a linear increase, and virtually identical slopes with or without conservation measure years (R^2=0.532, P<0.001).

The relative success of each hunting method permitted during the spring conservation harvest was assessed with specific surveys and questionnaires (Lemoine 2003). These data suggested that in the first year that the spring harvest was implemented (1999), stalking was the most effective technique, but the success of this technique decreased over time, possibly because the geese became more wary of hunters (Fig. 1-19). In contrast, the success of hunters using a blind and decoys increased over time, becoming the most effective method by the third year of the spring harvest (2001) (Lemoine 2003). The latter result was due in large part to an increased use of electronic calls in blind and decoy setups.

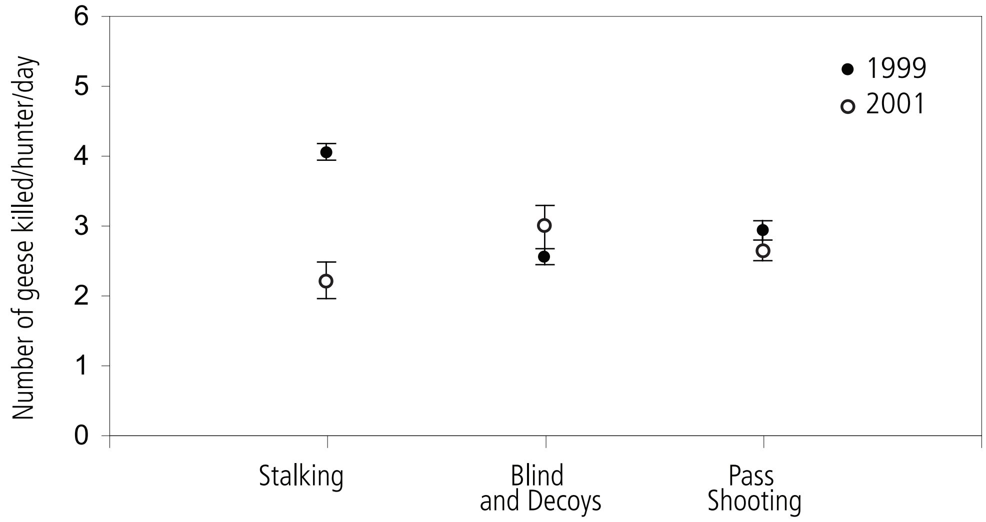

Figure 1-19. Mean (± SE) number of Greater Snow Geese killed per successful hunter per day using stalking, blinds and decoys, and pass shooting during the 1999 and 2001 spring conservation harvests, based on hunters' diaries and the CWS postal survey.

Regional spring harvest success (defined as the probability of killing and retrieving at least one goose and calculated as the proportion of active hunters that were successful) can also be estimated with data from the special spring surveys conducted by CWS since 1999. The annual proportion of successful hunters separated by hunting district in Québec (see Appendix C for hunting districts) is shown in Figure 1-20. Success showed a general increase in the Upper Estuary (district F) and Lac Saint-Pierre (district G), but was relatively stable elsewhere and was generally lowest around Montréal–Outaouais (district H) and the Eastern Townships (district I).

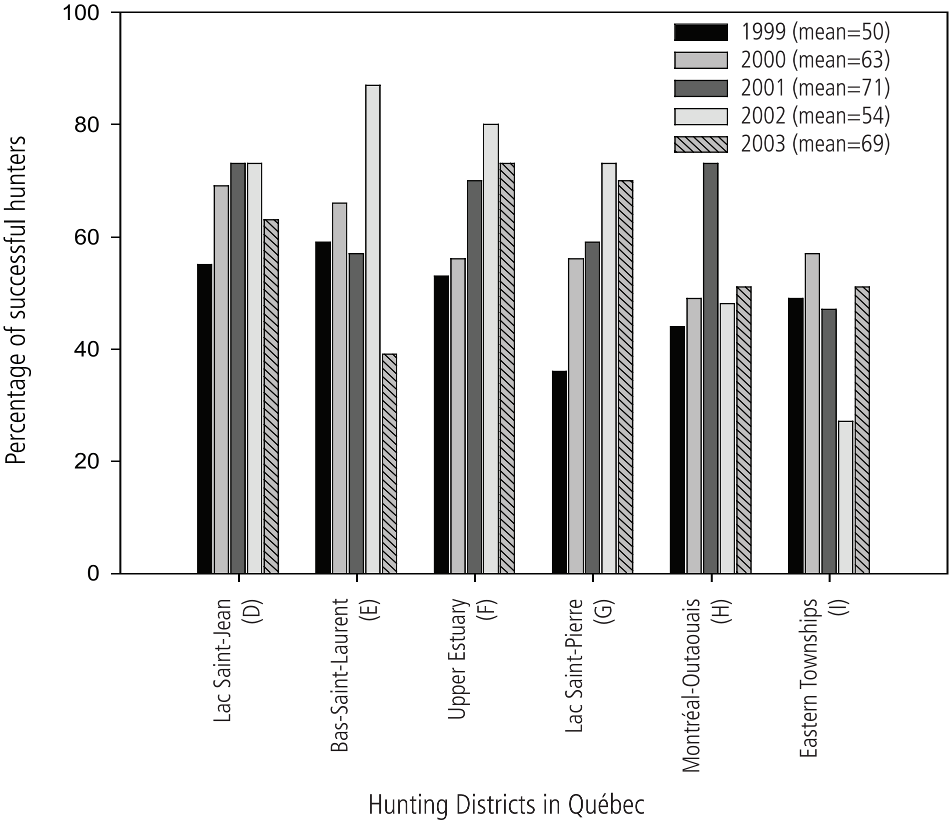

Figure 1-20. Estimated percentage of hunters who killed at least one goose during the spring Greater Snow Goose conservation harvest, by Québec hunting district. See Appendix C for illustration of districts. Note that the 2003 values for Montréal–Outaouais (district H) and Eastern Townships (district I) are shown equal, but only their sum was estimated. Annual means for all regions combined are shown with each year in the legend.

Harvest rates

Although total harvest increased during the period of population growth, it did not grow at the same rate as abundance, resulting in an overall decline in harvest rate over time. Season-specific harvest rates are shown in Figures 1-21 (adults) and 1-22 (juveniles). These data suggest that variation in harvest rate can be divided into four distinct periods: before 1975 (reopening of the hunting season in the United States), 1975–1984, 1985–1997, and since 1998 (i.e. introduction of special measures; see also Menu *et al*. 2002). Harvest rate increased with the opening of the Atlantic Flyway harvest in 1975 and was relatively stable until 1984 (24.4% ± 2.4%), but dropped off again in the mid-1980s and remained low (12.2% ± 0.1% for the period 1985–1997) until the initiation of the new measures in the 1998–1999 hunting season. However, the impact of the latter differed between adults and juveniles (ANOVA, interaction age*period, $F_{3.62} = 3.42$, $P = 0.022$). The reduction in harvest that occurred in the mid-1980s was significant in both adults and juveniles (Table 1-7); however, with the introduction of the new measures in 1998, harvest rate more than doubled in adults, whereas it showed only a slight, non-significant increase in juveniles (Table 1-7; harvest rate for that period: 19.1% ± 1.3%).

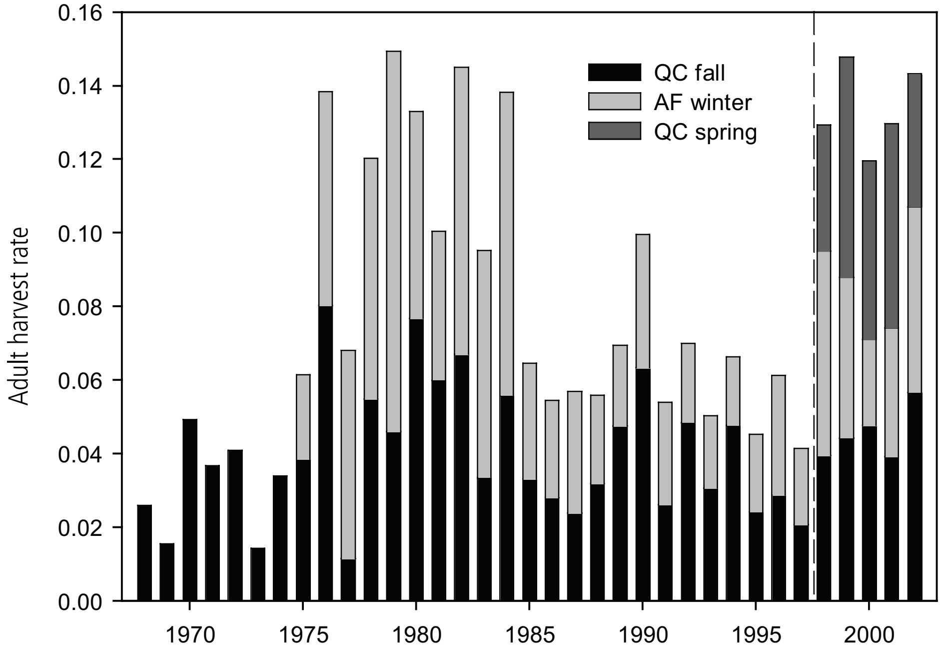

Figure 1-21. Adult Greater Snow Goose annual harvest rate partitioned by season for 1968–2002, calculated as proportion of fall population harvested during each season. The dashed line indicates the start of the special conservation measures.

Examination of these patterns by season/region (Québec fall and U.S. winter) and time period also revealed different temporal changes between seasons (Table 1-7). Again, variations in annual harvest rate were not consistent between age groups (ANOVA with interaction age*time period, fall in Québec: $F_{3.62} = 2.64$, $P = 0.057$; winter in Atlantic Flyway states: $F_{3.50} = 4.76$, $P = 0.013$). Adult harvest rates during fall in Québec declined significantly by 32% after 1984 and showed a slight, non-significant increase with the new measures in 1998 (Table 1-7). In the Atlantic Flyway states, adult harvest rates showed a stronger significant decline than in Québec after 1984 (59%) and a non-significant increase with the new measures in 1998 (Table 1-7). For juveniles, harvest rates also dropped in the mid-1980s during both fall and winter. With the new measures in 1998, juvenile harvest rates remained unchanged in Québec, but showed a non-significant increase in the Atlantic Flyway states (Table 1-7).

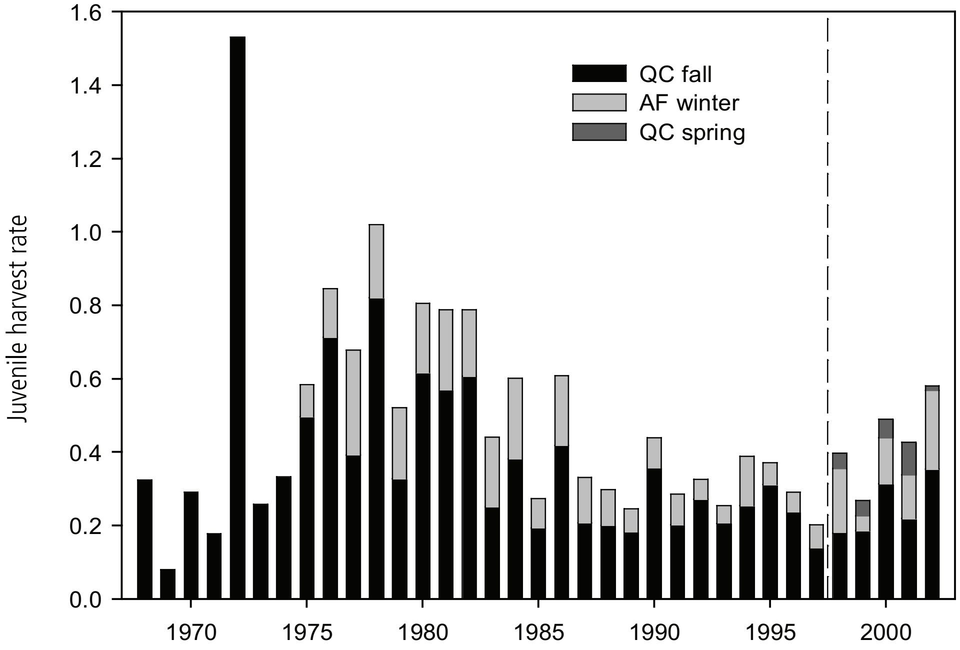

Figure 1-22. Annual harvest rate of juvenile Greater Snow Geese partitioned by season for 1968–2002, calculated as proportion of fall population harvested during each season; note that some estimates of juvenile harvest rate are >1, likely due to poor harvest data in some early years. The dashed line indicates the start of the special conservation measures.

Table 1-7. Mean Greater Snow Goose harvest rate (95% CI), by age (adults >1 year and juveniles), region, and time. The times shown represent periods of relative stability in harvest rates. Periods without harvest in a particular season are indicated no harvest (N/H). Different superscript letters within a row indicate a significant difference between means (Tukey a posteriori test, $P < 0.05$).

		Harvest rate (95% CI)			
		1968 - 1974	**1975 - 1984**	**1985 - 1997**	**1998 - 2002**
Total annual	**Adults**	0.031 (0.015-0.047)^{a}	0.115 (0.101-0.128)^{b}	0.061 (0.049-0.073)^{c}	0.134 (0.115-0.153)^{b}
	Juveniles	0.428 (0.236-0.620)^{ab}	0.708 (0.548-0.869)^{a}	0.332 (0.191-0.473)^{b}	0.433 (0.206-0.660)^{ab}
Québec (fall)	**Adults**	0.031 (0.019-0.043)^{a}	0.052 (0.043-0.062)^{b}	0.035 (0.026-0.044)^{a}	0.046 (0.032-0.059)^{ab}
	Juveniles	0.428 (0.239-0.617)^{a}	0.518 (0.360-0.676)^{a}	0.245 (0.106-0.283)^{a}	0.251 (0.027-474)^{a}
AF states (winter)	**Adults**	N/H	0.063 (0.052-0.072)^{a}	0.026 (0.017-0.035)^{b}	0.042 (0.028-0.056)^{ab}
	Juveniles	N/H	0.190 (0.158-0.223)^{a}	0.087 (0.059-0.115)^{b}	0.135 (0.089-0.180)^{ab}
Québec (spring)	**Adults**	N/H	N/H	N/H	0.047 (0.037-0.057)
	Juveniles	N/H	N/H	N/H	0.047 (0.023-0.072)

Age ratio in the harvest

The age ratio in the harvest changed over the course of a year, with a much greater proportion of juveniles killed in fall than in winter (Fig. 1-23). The greater vulnerability of young compared with adults explains their high representation in the fall harvest. Reduction of the proportion of juveniles in the harvest in winter is due in part to a decrease in their vulnerability over time, as well as a reduction in their availability. The spring conservation harvest was implemented with the goal of increasing adult harvest, and this was apparently successful, as the spring harvest showed a higher proportion of adults compared with the other seasons. The proportion of adults in the fall harvest also increased with the regulatory changes in 1999, but the proportion in winter remained stable. Harvest age ratios varied not only on a large regional scale (i.e. fall harvest in Québec vs. winter harvest in the Atlantic Flyway vs. spring harvest in Québec), but also within Québec. Following the same pattern of decreasing juvenile availability and vulnerability with time during their first year, the harvest included a higher proportion of juveniles in the areas reached early during fall migration (e.g. Lac Saint-Jean, the St. Lawrence estuary) than in regions in which they arrived later (Fig. 1-24).

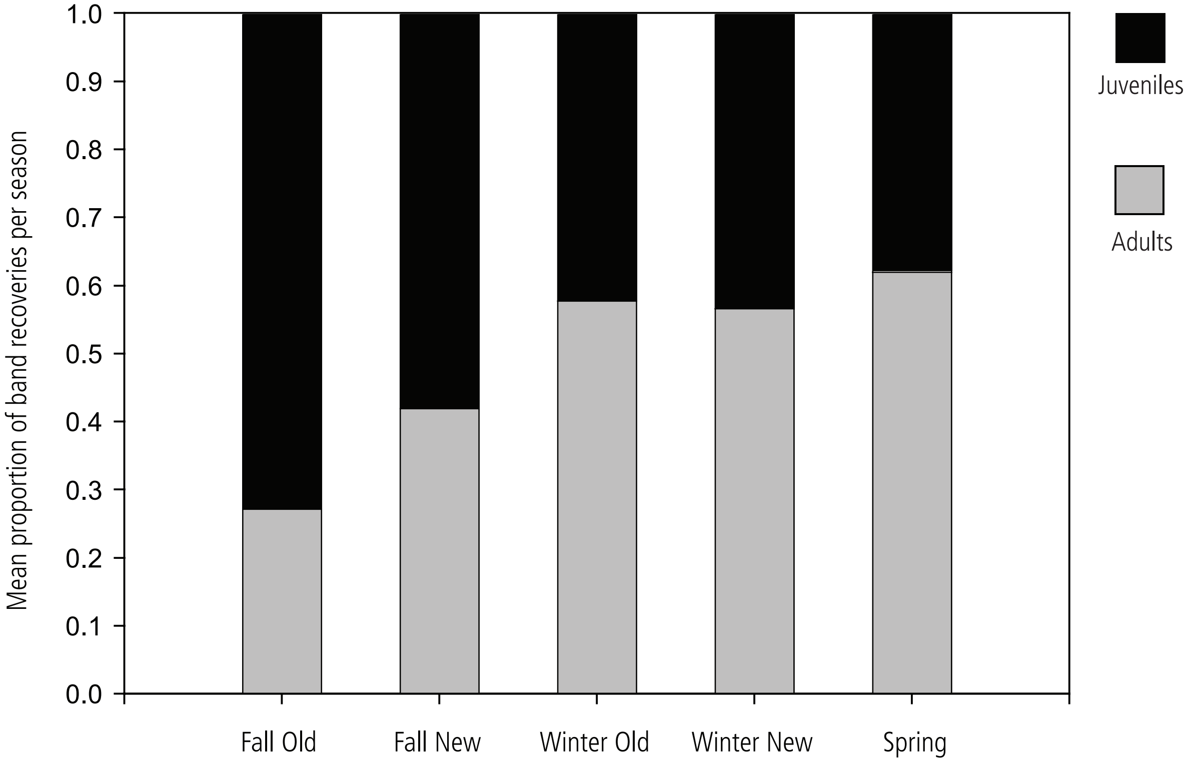

Figure 1-23. Mean proportion of adult and juvenile Greater Snow Geese among recoveries of banded birds by hunters during the period of old (1990–1997) and new (1998–2002) harvest regulations. Data from Calvert *et al.* (2005).

The age representation in the harvest also varied over the years. Tail returns in fall showed a gradual increase in the proportion of adults in Québec, although this was most noticeable during the last time period, when the conservation measures were in place (Fig. 1-25). For these comparisons, the use of tail returns was preferred over band recoveries, as the age ratios of the banded sample varied over time (especially in the 1970s and 1980s), leading to biased recovery age ratios.

The vulnerability of juveniles to harvest during their first year likely translates into a strong increase in harvest in years when juvenile availability is high. Data specific to the Cap Tourmente National Wildlife Area (A. Reed and S. Turgeon, CWS, pers. comm.) indicated that the proportion of juveniles in the kill increased with juvenile representation in the early-fall flight when this fall representation was below approximately 25%, but stabilized after this point ($P < 0.0001$, $R^2 = 0.826$; Fig. 1-26).

Spatio-temporal variation in harvest

Changes in harvest distribution over time were previously described and used to infer changes in the distribution of geese. However, it is worthwhile to point out that the abrupt decline in winter harvest rate noted in the mid-1980s coincided with the northward shift in goose distribution, as inferred from winter surveys and the distribution of band recoveries (see above). Calvert *et al*. (2005) argued that this northward shift in distribution was a leading cause of the abrupt decline in winter harvest at that time.

The geographic distribution of spring conservation harvest in Québec was also monitored as part of the special surveys since 1999, providing information in addition to that gained from banded birds harvested during spring. Most spring harvest occurred in the upper St. Lawrence estuary (region F), although this proportion has declined since 2001, the year that the opening date of the spring conservation harvest was changed from 15 April to 1 April. The proportion of harvest in the lower St. Lawrence estuary (region E) has also been declining, but in this case the decline has been considerable and constant since the spring harvest began. In contrast, the proportion of spring harvest in the Lac Saint-Jean area (region D), and especially around Montréal (region H), has increased, while remaining stable near Lac Saint-Pierre (region G; Fig. 1-27). The increase in region H could be related to earlier opening dates (1 April instead of 15 April) of spring conservation seasons since 2001, providing Québec hunters first access to geese in the areas reached earliest during northward migration (typically southwestern Québec).

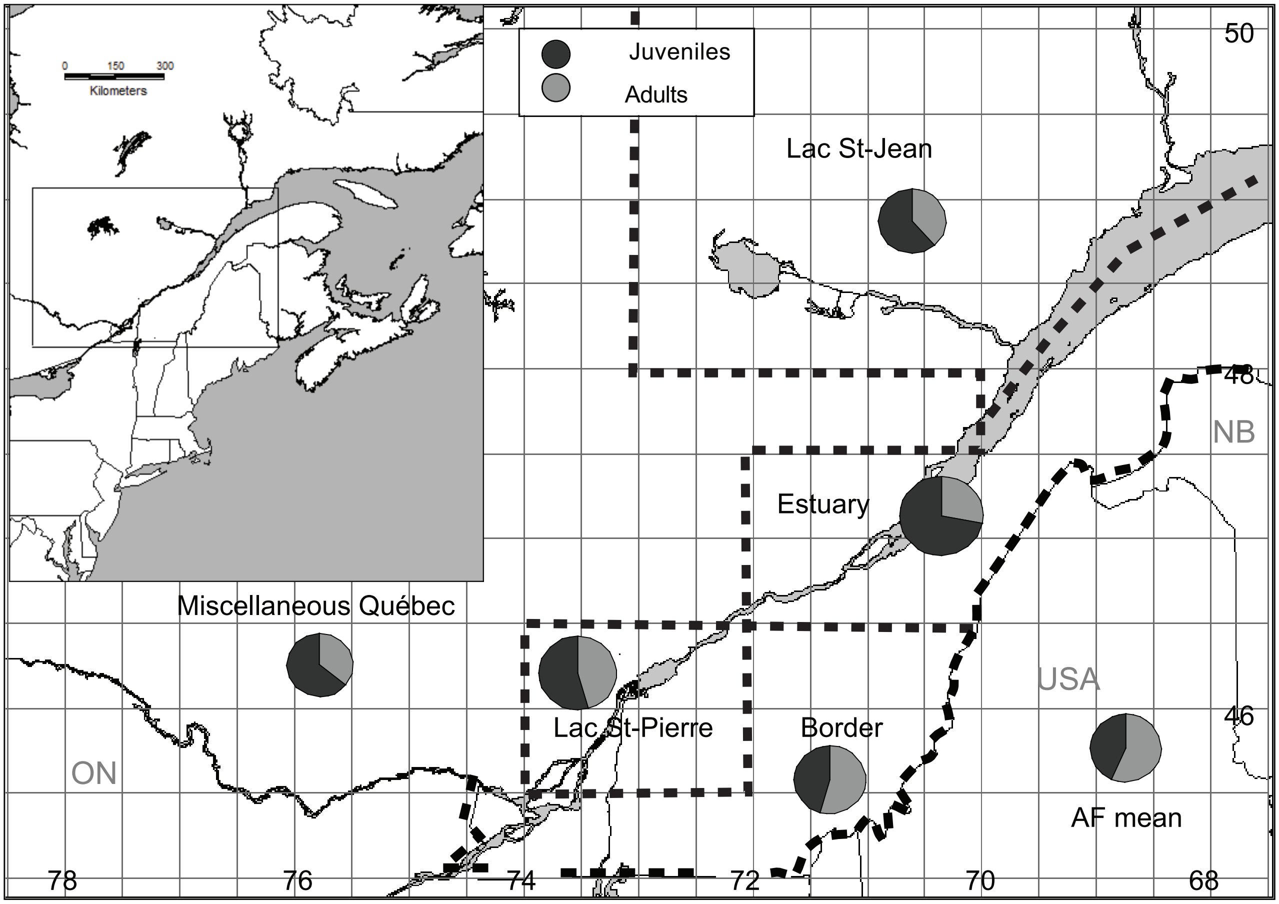

Figure 1-24. Mean proportion of adult and juvenile Greater Snow Geese among recoveries of banded birds by hunters according to region in Québec and for the whole Atlantic Flyway, 1970–2002. Circle size is proportional to sample size on a logarithmic scale (Lac Saint-Jean: 626; Estuary: 6758; Border: 1269; Lac Saint-Pierre: 1122; Miscellaneous Québec: 470; Atlantic Flyway: 845). Data to 2001 are from Calvert *et al.* (2005).

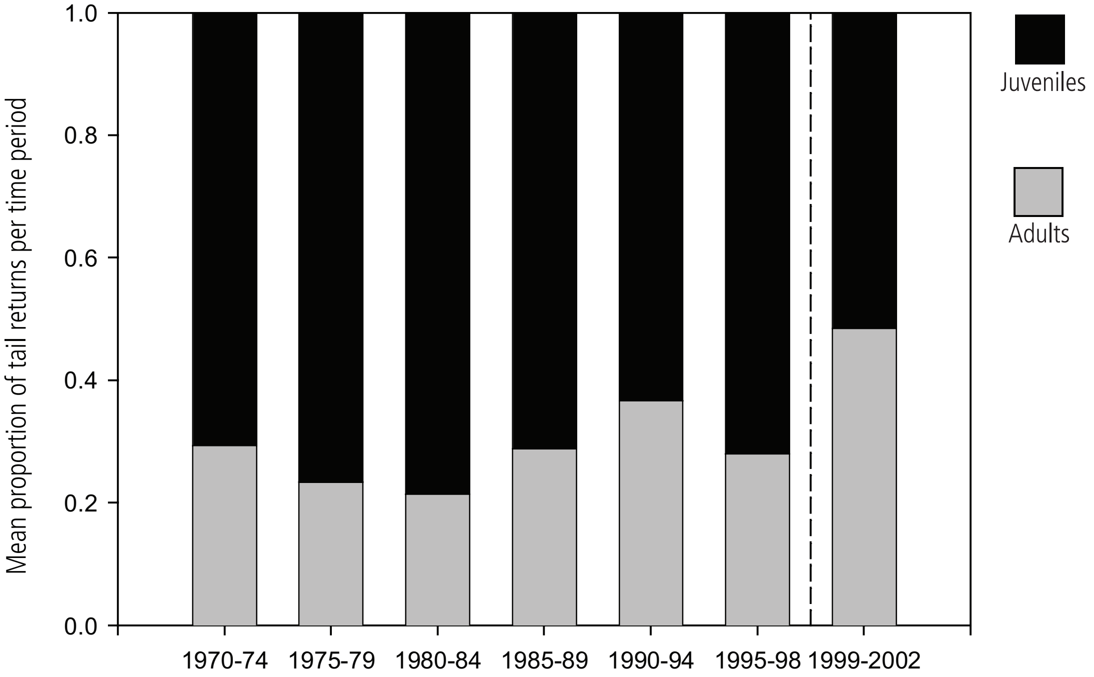

Figure 1-25. Mean proportion of adult and juvenile Greater Snow Geese in the Québec fall harvest over time based on tail returns as a part of the Species Composition Survey. The dashed line indicates the start of the special conservation measures. Data from Calvert *et al.* (2005).

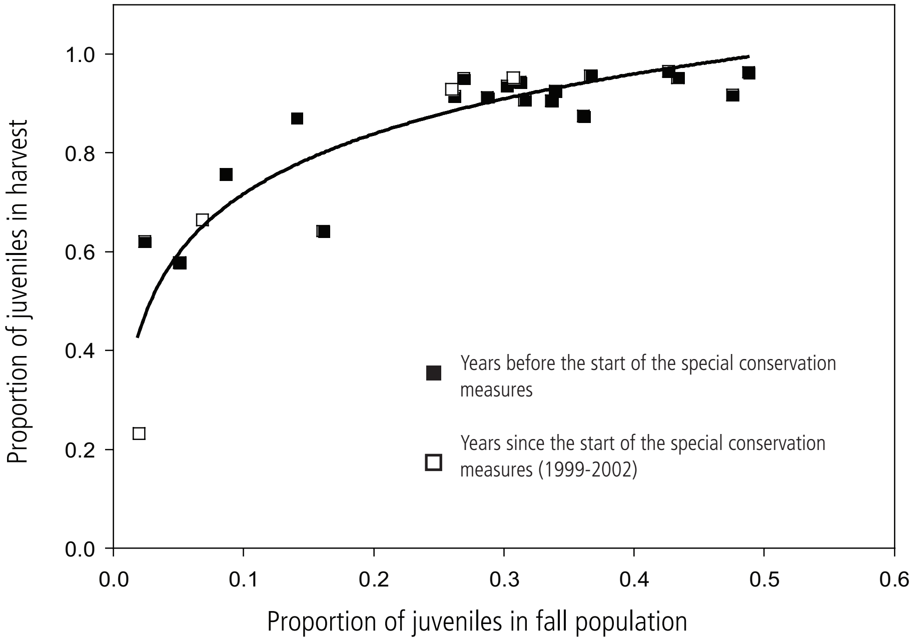

Figure 1-26. Proportion of juvenile (<1 year) Greater Snow Geese in the fall harvest of the Cap Tourmente National Wildlife Area, Québec, relative to the proportion of juveniles observed in the fall population on an annual basis for 1980–2002. A logarithmic curve (black line) fits the data (R^2 = 0.826). Data are from A. Reed and S. Turgeon (unpubl.).

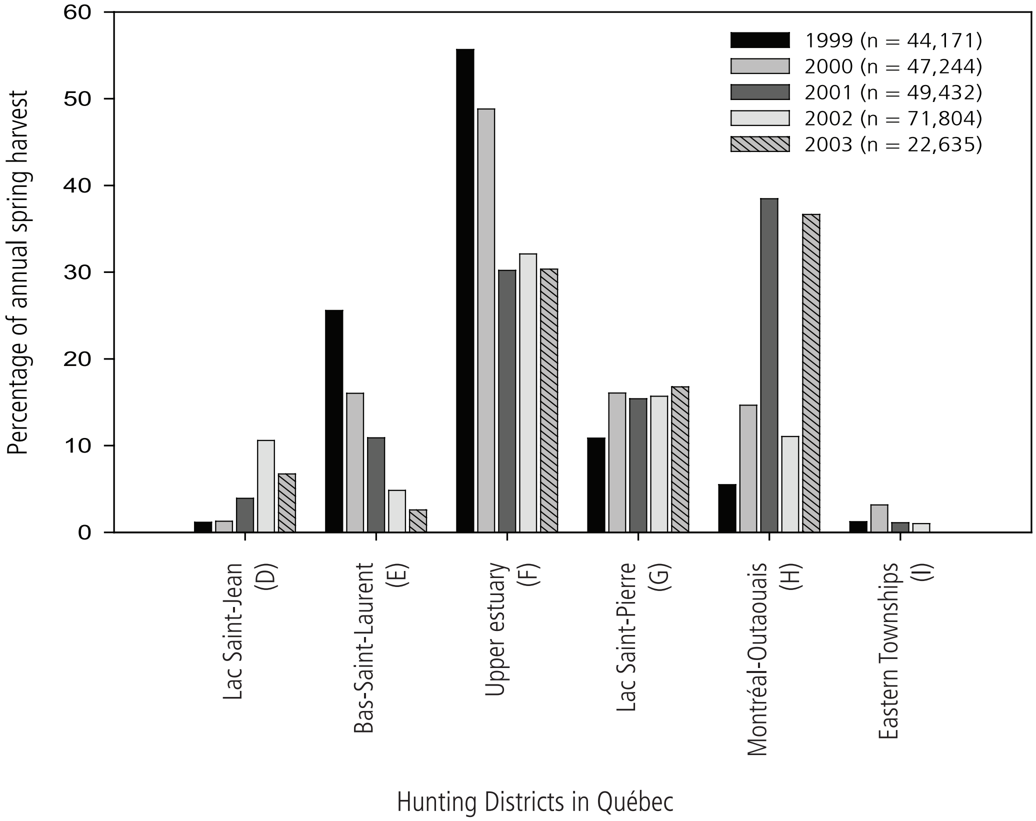

Figure 1-27. Regional distribution of Greater Snow Geese harvested during the spring conservation seasons, by district (see Appendix C) in Québec; number of geese harvested is indicated in the legend. Note that only the sum of the 2003 harvest in regions H and I was estimated and is indicated entirely as district H.

Summary: General harvest characteristics

- Sales of waterfowl hunting permits in both Québec and the Atlantic Flyway states declined until the mid-1990s but have remained relatively stable since then. The number of active hunters followed the same trend in Québec but has increased since the mid-1990s in the Atlantic Flyway states following an initial decline. It is assumed that these trends reflect similar changes in the number of hunters who hunted Greater Snow Geese.
- Harvest rates remained low from the mid-1980s until the initiation of the new hunting regulations in 1998–1999; harvest rates have increased since then, especially for adult geese, and the increase was stronger in the Atlantic Flyway winter harvest than during fall in Québec. When taking into account spring harvest, total annual harvest rates of adults, but not juveniles, now exceed the high values encountered during the late 1970s to early 1980s.
- An earlier opening date for the spring conservation harvest since 2001 may have resulted in a greater proportion of the harvest occurring in southwestern Québec than in 1999–2000, as this area is the first reached by geese during northward migration.

IMPACTS OF HARVEST ON MORTALITY AND SURVIVAL

Geese generally experience harvest mortality that is additive to natural mortality (Hestbeck and Malecki 1989; Francis *et al*. 1992; Hestbeck 1994; Gauthier *et al*. 2001). As a result, changes in harvest should directly affect mortality (and its complement, survival) of these species. Population growth is highly sensitive to changes in adult survival in Greater Snow Geese (Gauthier and Brault 1998), such that changes in adult harvest would be expected to have a strong effect on population growth rate. For these reasons, the implementation of special conservation measures for Greater Snow Geese targeted a reduction in adult survival through greater hunting mortality (Gauthier and Brault 1998). Harvest survey data presented in the previous section demonstrated an increase in harvest (see Appendix A) and harvest rate (see Figs. 1-21 and 1-22). Thus, it was expected that the increase in hunting mortality rate observed since 1999 would result in a corresponding decrease in survival. In this section, we estimate the strength of this predicted relationship.

Estimation of annual and seasonal survival and recovery probabilities

As described above, Greater Snow Geese on Bylot Island, Nunavut, have been marked with metal leg bands since the 1990 breeding season. Models based on band recoveries can provide estimates of survival and recovery probabilities. The latter parameter is the probability that a banded bird is shot and retrieved and its band reported during the next hunting season (Brownie *et al*. 1985). Hereafter, each "year" indicates the 12-month period beginning at the time of banding that year and ending just before banding the following year (e.g. "1996" refers to the period from August 1996 to July 1997). Between 1990 and 2002, 44 874 geese were banded at Bylot Island, Nunavut. All birds were sexed, aged (juveniles and adults), and marked with USFWS metal bands, and some adults (mainly females) were fitted with plastic neck collars (for details, see Menu *et al*. 2000). Recovery records ($n = 4830$) were obtained from the Bird Banding Laboratory in the United States, and only hunter-shot wild birds were used in the analysis. Estimates of annual harvest rates were taken as the ratio of the total number of Greater Snow Geese reported in the harvest surveys to the fall population size (as described previously). Band recovery models were constructed in program MARK (White and Burnham 1999) to estimate annual survival and recovery rates for 1990–2002 (unless otherwise stated, all survival, recovery, and mortality analyses are from Calvert and Gauthier 2005; see that paper for additional details).

We also examined the relative contribution of each season (fall regular hunting season in Québec, winter regular hunting season in the United States, and spring conservation hunting season in Québec) to the overall mortality rate following implementation of special conservation measures. Development of a more flexible model in program SURVIV (White 1983) allowed separation of recovery rates for each of these seasons. Band recoveries from each year were divided into two (fall in Québec and winter in the United States, 1990–1997) or three (fall in Québec, winter in the United States, and spring in Québec 1998–2002) seasons. The model structure was based on the notion that the number of banded geese recovered in a particular season depended not only on survival since banding and the year- and season-specific recovery rate, as with the annual models, but also on the probability of *not* being shot in a previous season the same year (for details of model structure, see Calvert and Gauthier 2005).

Effects of conservation measures on annual and seasonal recovery rates

There was important variation in annual recovery rate according to age, sex of adults, and presence of a plastic neck collar. In particular, adult recovery rates showed a larger increase after the implementation of conservation measures than in previous seasons (Fig. 1-28). Juvenile recovery rates were much more variable than adult rates but were also generally higher after the implementation of conservation measures (Fig. 1-28). A model contrasting annual adult recovery rates before and after the initiation of the special measures was highly ranked when combined with an effect of band solicitation (which would affect reporting rate) during fall from 1990 to 1993.

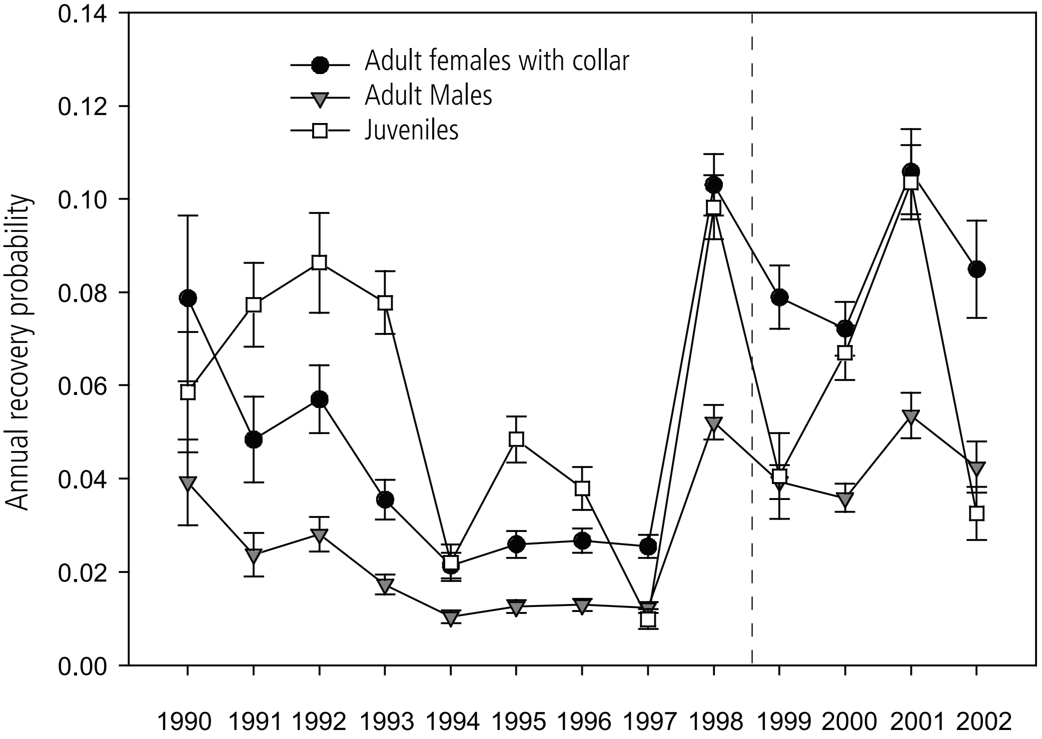

Figure 1-28. Annual recovery probabilities (mean ± SE) for Greater Snow Geese from 1990 to 2002, estimated from the best model in program MARK. The dashed line indicates the start of the special conservation measures (from Calvert and Gauthier 2005).

Estimates of seasonal recovery rates are shown in Figure 1-29. Overall, there was a tendency for high band recovery rates in the early 1990s, probably due to some band solicitation by G. Gauthier and his Université Laval team to increase the probability of recovering hard-to-detect markers (i.e. webtags). Recovery rates during fall and winter were relatively low from 1994 to 1997, indicating that the potential impact of toll-free band inscriptions, introduced in 1996, on reporting rates did not result in an immediate significant increase in band recovery rates. Band recovery rates increased concomitantly with the implementation of special conservation measures in 1998, especially in adults, and remained high thereafter. However, this increase was much more important in winter than in fall. Spring recovery rate tended to decline from 1998 to 2002, except for 2001, when it was relatively high. Juveniles again showed large annual fluctuations in recovery rate. It should be noted that the increase in fall recovery rates in 1998 occurred before liberalization of fall regulations in Canada (1999) and after the introduction of 1-800-327 BAND (1996) (Calvert and Gauthier 2005).

Effects of conservation measures on hunting mortality rates

Some of the temporal variation observed in recovery rates could be due to reporting rate differences (e.g. the effect of band solicitation in 1990–1993 and the introduction of 1-800 bands on Greater Snow Geese in 1996), and such biases had to be accounted for in order to examine changes in hunting mortality rate. Hunting mortality rate was calculated by dividing recovery rate by the product of retrieval rate (the probability that a shot bird is retrieved by the hunter) and band reporting rate (Brownie *et al*. 1985). A retrieval rate value of 80% obtained from another study was used (Anderson and Burnham 1976); analyses by Lemoine (2003) suggest this to be a reasonable estimate for this population. Reporting rate was estimated as the slope of the relationship between recovery rates of adult males (i.e. birds without collars) and the adult annual harvest rate calculated from the National Harvest Survey (for more details, see Figs. 1-21 and 1-22 and Calvert and Gauthier 2005; Table 1-8). Because the recovery rate of adults wearing collars was twice that of those without collars, we assumed that this was entirely due to reporting rate, because previous studies showed no difference in survival between birds with and without collars (Menu *et al*. 2000; Reed *et al*. 2004b). Therefore, we doubled the reporting rate value of birds wearing neck collars relative to those without collars; other studies also concluded that collars likely increase reporting rates by hunters (Samuel *et al*. 1990; Castelli and Trost 1996).

Table 1-8. Band reporting rate for hunter-shot adult Greater Snow Geese estimated from the relationship between annual band recovery rates and annual harvest rates for different time periods (from Calvert and Gauthier 2005).

	Band reporting rate		
	1990-1993	**1994-1995**	**1996-2002**
Geese without neck collars	0.40	0.25	0.36
Geese with neck collars	0.80	0.50	0.72

Adults showed a large increase in annual hunting mortality after the implementation of the special conservation measures, but the effect in juveniles was not as clear (Fig. 1-30). Juvenile mortality was highly variable from year to year, although we note that mortality rates were the highest ever reported for two of the five years with special conservation measures. On a seasonal basis, the increase in adult hunting mortality appears to have been caused not solely by the implementation of the spring harvesting season, but also by the liberalization of regular hunting season regulations. In particular, adult winter hunting mortality showed a large increase after 1998, while there was little evidence for a similar increase in adult fall hunting mortality, despite the implementation of special hunting measures (electronic calls, baiting) and liberalization of regulations (increased bag and possession limits, sneaking). Juvenile hunting mortality rate also appeared to increase in winter following liberalization, although not in fall. Hunting on some U.S. refuges may have contributed to increased harvest.

While these analyses provide evidence for a large increase in hunting mortality rates in winter but not in fall, they should be interpreted cautiously. Reporting rates used to calculate seasonal mortality rates were based on harvest rate estimates from national harvest surveys and spring population surveys and recovery rates from our annual models, data for which the magnitude of error and bias is unknown. In particular, we used the same band reporting rates for Québec and the United States, but if these rates differ (e.g. lower reporting rates in Québec than in the United States due to language differences), this would tend to underestimate hunting mortality in Québec and overestimate it in the United States (see Calvert and Gauthier 2005). However, an analysis of the sensitivity of our kill rate estimates to variations in band reporting rate suggested that bias in estimates of kill rate was relatively small, particularly before implementation of special measures, and that the direction of the bias was the same in both time periods (Calvert and Gauthier 2005). Therefore, if patterns found are genuine, they suggest that the Canadian harvest was perhaps already close to its limit, which would explain why liberalizations during the regular fall season had little effect, whereas the U.S. harvest could still grow.

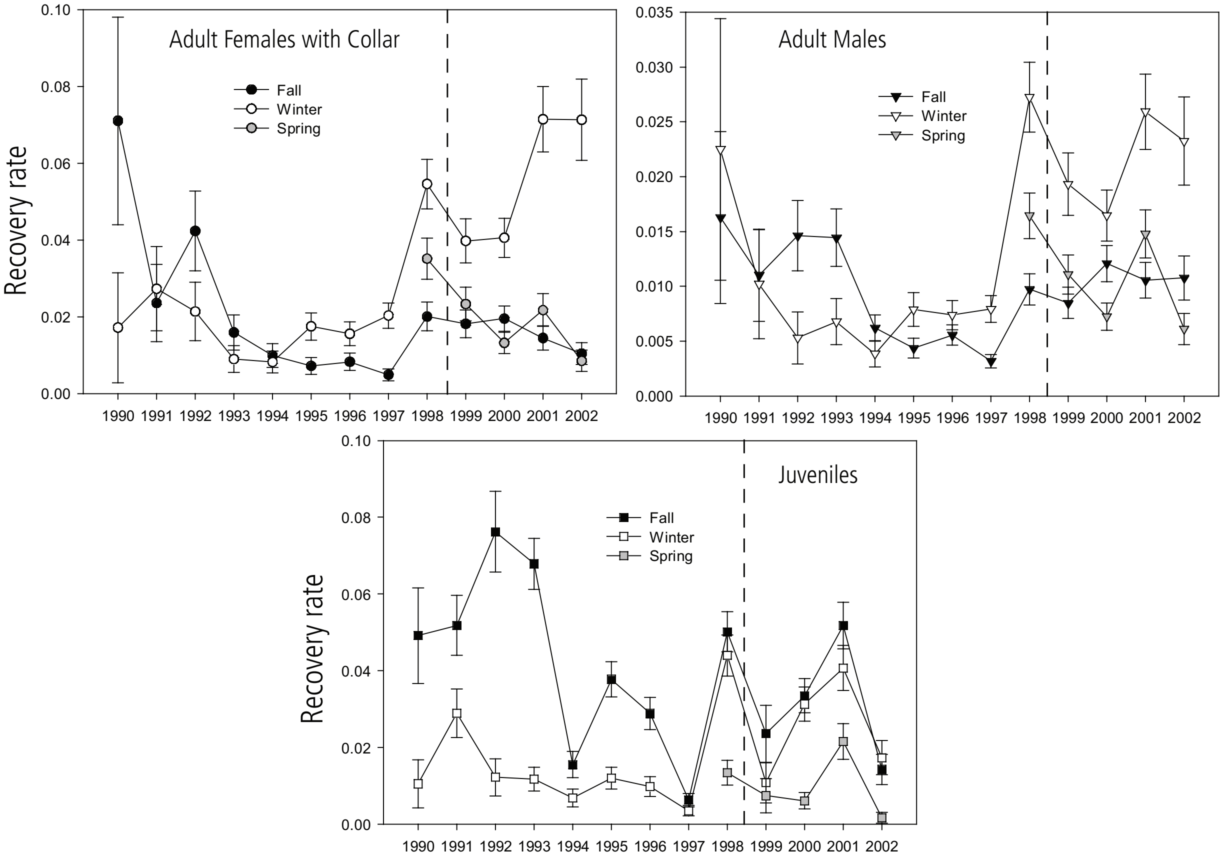

Figure 1-29. Seasonal recovery rates (mean ± SE) for Greater Snow Geese from 1990 to 2002, as calculated in the program SURVIV. Fall recoveries come from harvest in Québec, winter recoveries from harvest in Atlantic Flyway states, and spring recoveries from the spring conservation harvest in Québec. The vertical dashed lines indicate the start of the special conservation measures in Canada (spring: 1998 season; fall: 1999 season) and liberalization of regulations in the United States (winter 1998–1999) (from Calvert and Gauthier 2005).

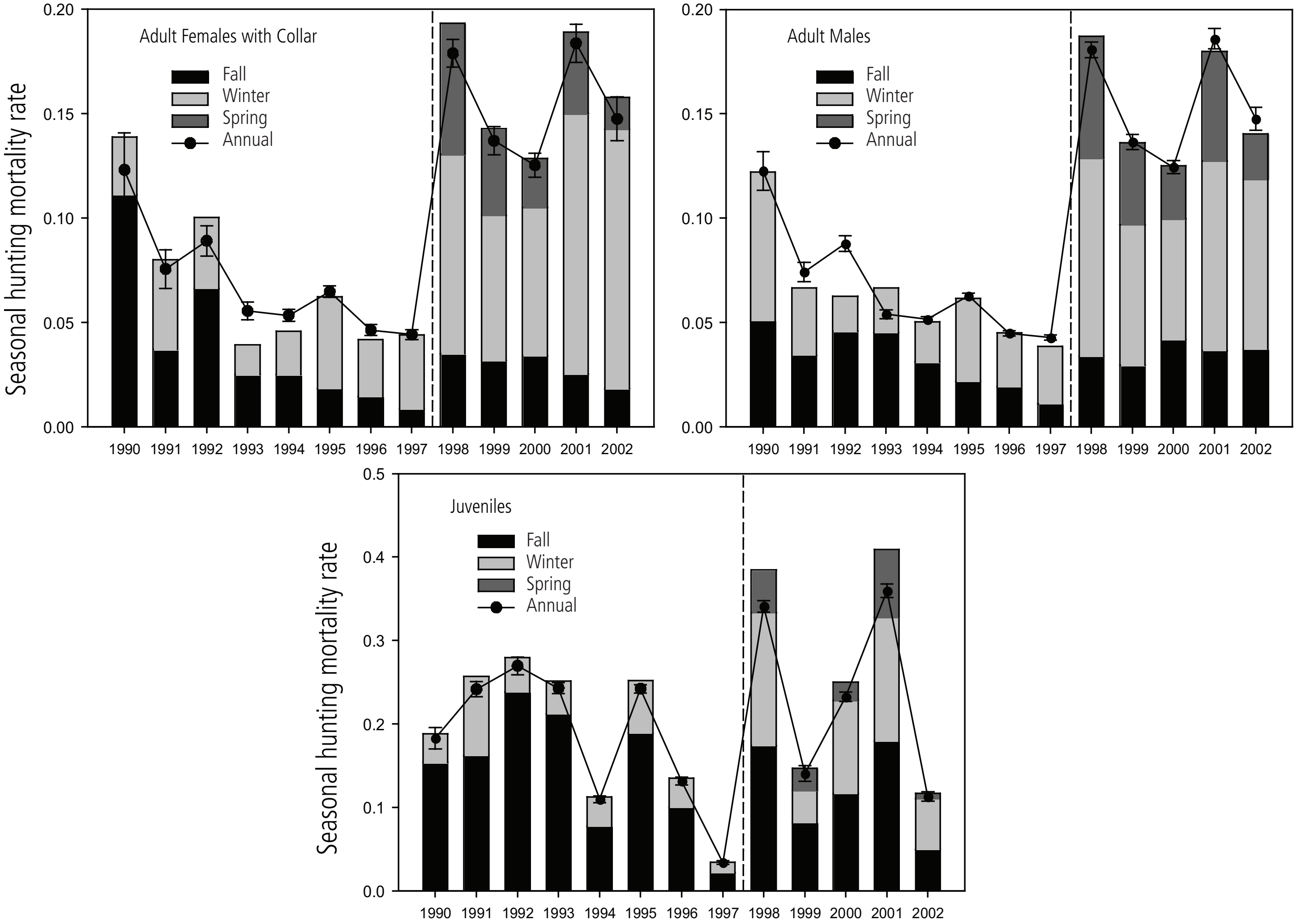

Figure 1-30. Annual (line; mean ± SE) and seasonal (bars) hunting mortality rate estimates for Greater Snow Geese from 1990 to 2002, before and after the implementation of conservation measures. Fall recoveries come from Québec, winter recoveries from Atlantic Flyway states, and spring recoveries from Québec. Seasonal rates do not sum exactly to annual estimates due to the calculation of each rate relative to the size of the population at the start of the interval. The dashed lines indicate the implementation of special conservation measures in Canada and the liberalization of regulations in the United States (from Calvert and Gauthier 2005).

Effects of conservation measures on survival rates

Survival estimates from band recovery analyses suggested large annual variation for both age groups (Fig. 1-31). However, a model that constrained temporal variation in adult survival to only two periods, essentially comparing means of survival before and after implementation of special conservation measures, suggested an important effect of such measures. Mean adult survival was 83.0% (95% CI: 80.9–85.0%) from 1990 to 1998 and 72.5% (68.6–76.0%) from 1998 to 2002, showing a significant decline in survival following implementation of the special conservation measures. It should be noted that the pre-measures adult survival estimate obtained in this analysis fits well with those from previous studies (83.0% ± 5% for 1990–1998, Gauthier *et al*. 2001; 80.0% ± 4% for 1990–1996, Menu *et al*. 2002). There was no evidence that juvenile survival rates (46.1% [41.0–51.2%] and 50.0% [41.8–58.3%] for 1990–1998 and 1998–2002, respectively) were affected by conservation measures. Band recovery data therefore suggested that adult survival decreased by about 13% with the initiation of the special conservation measures, although this effect did not explain all temporal variation observed, and that no parallel effect on survival was detected for juveniles, despite a slight increase in harvest (Calvert and Gauthier 2005).

In an independent study, analyses of the fates of radio-collared adult females from 1996 to 1999 also suggested a decline in survival following the implementation of the special conservation measures. Lemoine (2003) observed a large decrease in survival from August to June (11 months), from 0.90 (±0.04 SE) before implementation to 0.66 (±0.07) after implementation. In particular, he noted that survival was reduced during hunting seasons (Lemoine 2003; Fig. 1-32).

Relationships between harvest rate and survival

While band recovery models can be powerful tools for estimating demographic rates of harvested populations, small sample sizes due to low recovery rates often result in poor precision of estimates. For example, survival probabilities presented above include a few years when confidence intervals include the boundary value of 1 and two years (1990 and 1997) when adult survival estimates were unrealistically low. (note that Menu *et al*. [2005] related low 1997 juvenile survival to very cold weather at the end of the summer that year.)

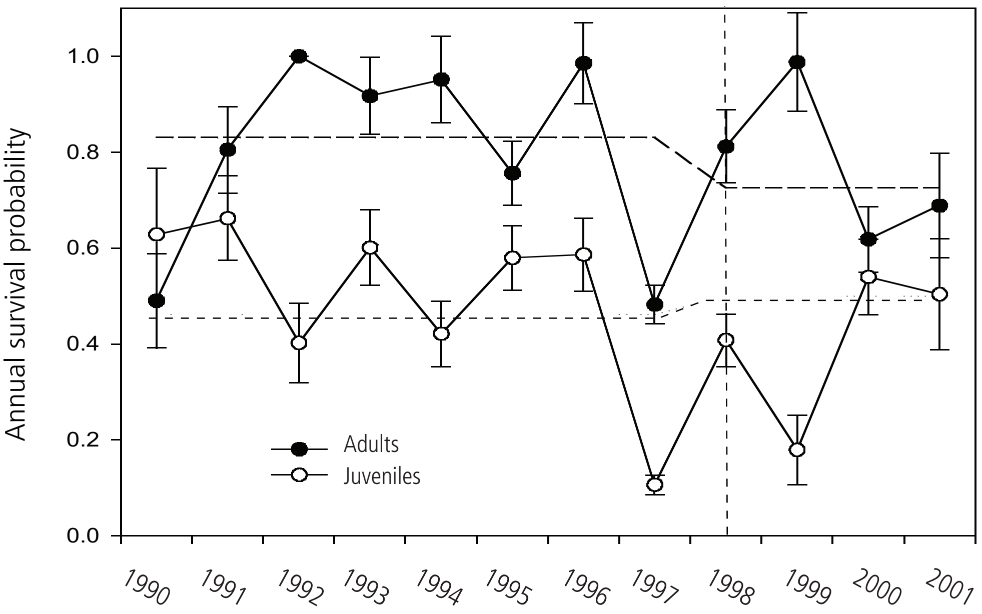

Figure 1-31. Annual survival probabilities (mean ± SE) for adult and juvenile Greater Snow Geese from 1990–1991 to 2001–2002, estimated from band recoveries. The vertical dashed line indicates the start of the special conservation measures; horizontal lines indicate the mean survival probabilities for 1990–1991 to 1997–1998 and for 1998–1999 to 2001–2002 for adults (dashed) and juveniles (dotted) based on a model constraining survival to differ only before versus after the special conservation measures (from Calvert and Gauthier 2005).

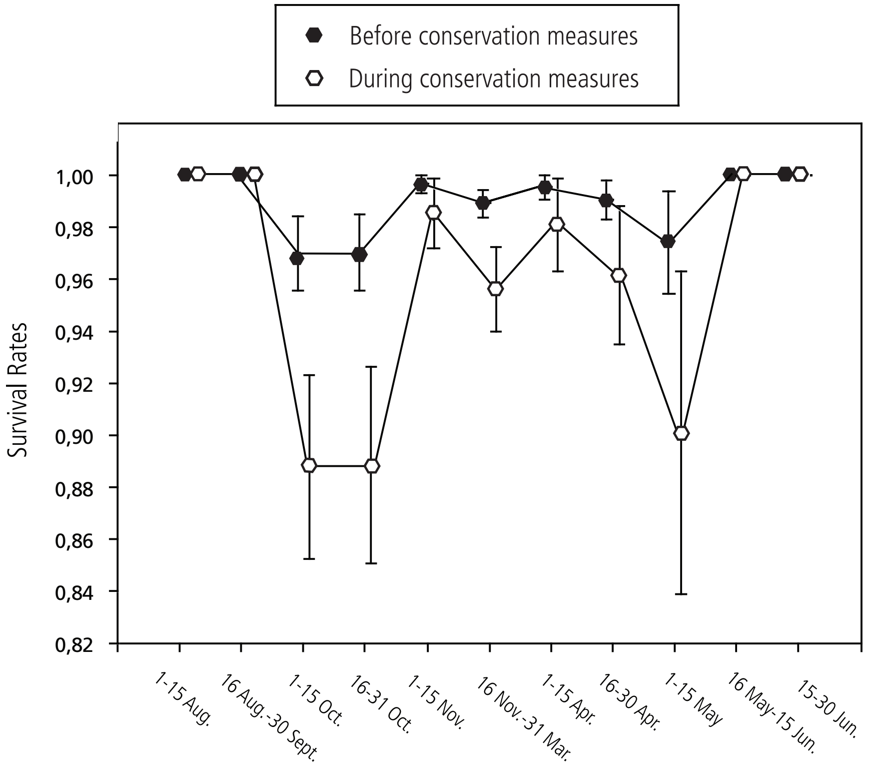

Figure 1-32. Survival estimates (mean ± SE) for adult female Greater Snow Geese marked with radio-collars over two-week periods (except in winter and during spring migration to the Arctic) in 1996–1997 (before the special conservation measures) and 1998–1999 (during the special conservation measures) (from Lemoine 2003).

In their analysis, Calvert and Gauthier (2005) found that annual variation in survival rate was due to several factors, not simply variation in harvest rates. Imprecision in harvest rate and demographic estimates likely contributed to this situation, given that previous evidence for additive mortality for this population is strong (Gauthier *et al*. 2001). Despite large confidence intervals, Calvert and Gauthier (2005) found an inverse relationship between harvest rate *(H)* and adult survival rate *(S)* (β= –7.00, 95% CI: –10.80 to –3.19), with the complete relationship being:

$$[\mathit{logit}\ S_i^{AD} = 1.95 - 7.00 * H_i]$$

A negative slope is consistent with the hypothesis of additive hunting mortality, and the intercept (i.e. when harvest rate = 0), which provides an estimate of survival in the absence of hunting (i.e. a "natural" survival rate), was 87.6%. This value corresponds fairly well with an estimate of 91.3% for survival in the absence of hunting derived from independent data of sightings of collared females (Gauthier *et al*. 2001). No similar relationship was found in juveniles (Calvert and Gauthier 2005). Analysis of the relationship between harvest rate and survival in juveniles is complicated by several factors, including the large annual variation in production of young and in survival during the fall migration that precedes the hunting season (Menu *et al*. 2005).

Summary: Impacts of harvest on mortality and survival

- For adult Greater Snow Geese, the increase in total harvest that accompanied special conservation measures brought an increase in hunting mortality rates and a corresponding decline in survival from an average of 83.0% during 1990–1997 to 72.5% during 1998–2002. A negative relationship between harvest rate and adult survival was detected as expected, but harvest did not fully explain the strong temporal variation in survival that was observed.
- Spring harvest was the most drastic regulation change implemented, and it contributed to the increase in annual hunting mortality of adults. However, hunting mortality also increased during winter in the United States, although apparently not in fall in Québec, as a result of changes in regulations.
- Although juvenile harvest increased following regulatory changes, their hunting mortality increased only slightly and their survival rate did not change. However, analysis of the impact of hunting on juveniles is complicated by the large annual variation in both production of young and fall migration survival.

These results are consistent with the original management goals established for the population, which were to stabilize the population at a level of one million or less by the year 2002. This goal was to be reached by reducing adult survival through the doubling of hunting mortality (i.e. increasing harvest rate from 12% to 24%).

IMPACTS OF SNOW GEESE ON NATURAL HABITATS AND FARMLANDS

Snow Geese use a variety of feeding methods, such as grazing on aboveground leaves and shoots, grubbing of belowground roots, and gleaning waste cereal grains, which allow them to readily exploit a wide variety of natural habitats and also to benefit from agricultural foods in recent decades (for details of feeding methods in different habitats, see Bélanger and Bédard 1994a, 1994b; Abraham and Jefferies 1997; Hill and Frederick 1997; Giroux *et al*. 1998b). Their efficiency in exploiting vegetation, however, may imply severe consequences for the regenerative capacities of their forage plants and the surrounding ecosystems. In particular, the rapid population growth of Lesser Snow Geese and consequent expansion of breeding range in the central and eastern Arctic have resulted in extreme degradation and destruction of plant communities in coastal salt marshes, which are not expected to recover quickly (reviewed in Abraham and Jefferies 1997; Jefferies *et al*. 2004).

Greater Snow Geese are not yet at the same critical level of abundance as their sister subspecies and depend on freshwater wetland habitats for breeding, instead of the coastal salt marshes used by Lesser Snow Geese in the Hudson Bay area. Nonetheless, growing populations of light geese can have a significant impact on Arctic freshwater wetlands (Alisauskas *et al*. 2006), and there remains the potential for Greater Snow Geese to have parallel impacts on their Arctic habitats and the surrounding environment, a concern that largely contributed to the recommendation for special conservation measures (Giroux *et al*. 1998a, 1998b). Furthermore, they have increased their dependence on additional food available in agricultural fields over the past few decades (Gauthier *et al*. 2005), resulting in crop damage in some areas (Filion *et al*. 1998), a pattern that became an additional motivation for the regulatory changes implemented in 1998–1999 (Giroux *et al*. 1998a). This switch to a diet dominated by agricultural foods may have been a major factor that allowed the rapid growth in abundance since the 1980s, by permitting geese to exceed the previous carrying capacity of natural habitats in winter and spring (Gauthier *et al*. 2005). Such evidence underlines the importance of feeding ecology for population dynamics of Greater Snow Geese and for their management.

Long-term impacts on Arctic breeding grounds

Among the diverse plants that the geese consume in the Arctic (reviewed in Giroux *et al*. 1998b), wetland graminoids are the most important component of the diet, and impacts of geese on graminoids have therefore been carefully quantified. Since 1990, plant biomass has been measured at the end of each summer both inside and outside exclosures on one important brood-rearing area on the south plain of Bylot Island. Since 1998, two other sites have been added, one at the main nesting colony on Bylot Island and one at another brood-rearing area, and thus three sites have been sampled annually. This monitoring has allowed estimation of plant production and biomass removed by geese annually. Intensity of use by geese has been simultaneously measured by counts of feces in transects adjacent to exclosures (G. Gauthier, ongoing study; for general methodology, see Gauthier *et al*. 1995).

Goose grazing removes a significant amount of the graminoid biomass produced each year on Bylot Island, as shown by the difference in biomass between grazed and ungrazed plots in most years (Figs. 1-33, 1-34, and 1-35). Although the impact of goose grazing is quite variable among years, there is no evidence for directional changes in grazing impact, despite the increase in the goose population during the 1990s (Gauthier *et al*. 2004a). Instead, annual grazing impact appears to be closely related to local goose density on the breeding grounds, which is driven by highly variable production of juvenile geese; years of elevated reproductive success, and consequently years with a large number of young geese, are those that bring the strongest impact on vegetation (Gauthier *et al*. 2004a).

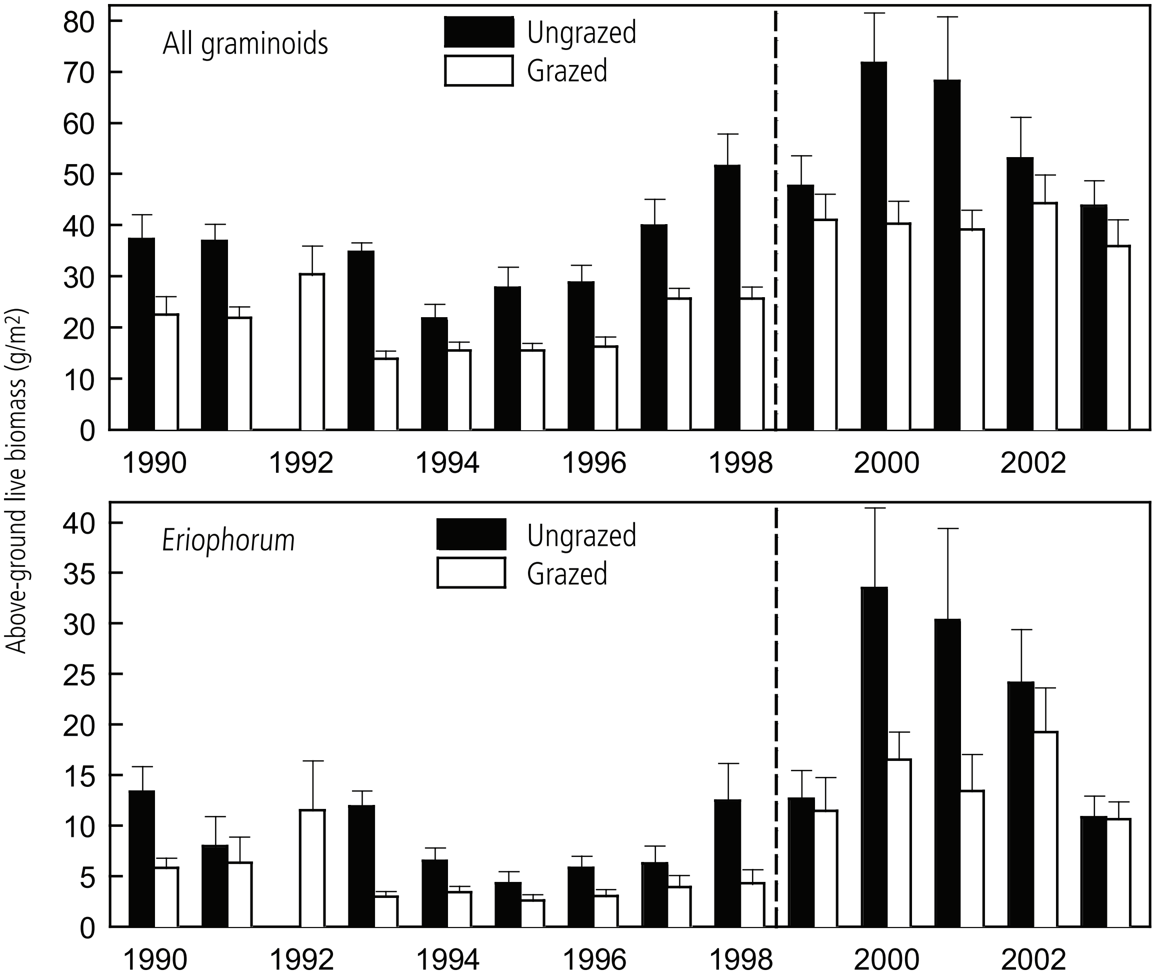

Figure 1-33. Biomass (mean ± SE) of graminoids and of *Eriophorum scheuchzeri* only in mid-August 1990–2003 (1992 not available for ungrazed) in grazed and ungrazed (exclosure) sites (n = 12 each year) of the Base-camp Valley (main brood-rearing area) on Bylot Island, Nunavut. The dashed line indicates the start of the special conservation measures (from Gauthier *et al.* 2003b).

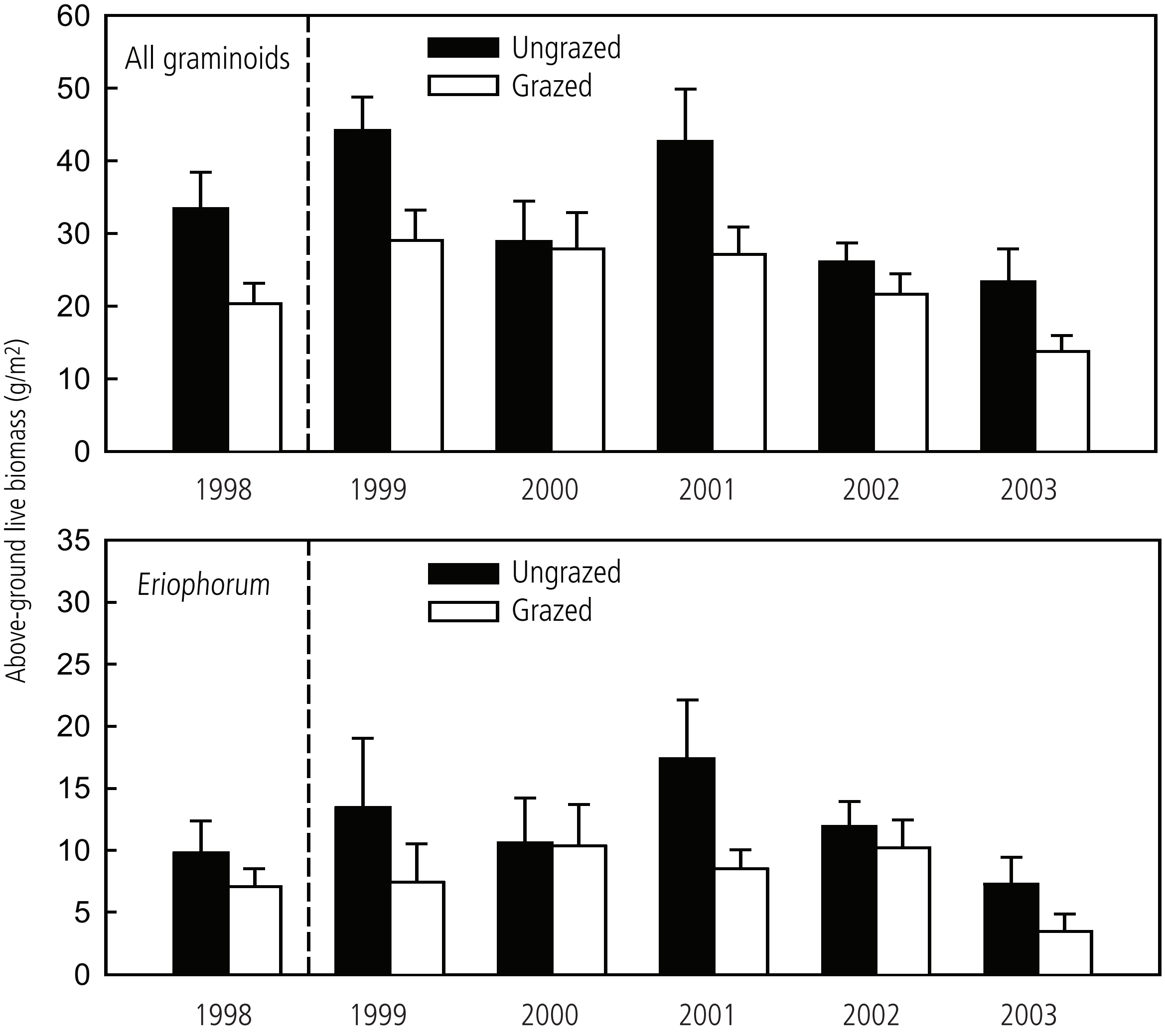

Figure 1-34. Biomass (mean ± SE) of total graminoids and of *Eriophorum scheuchzeri* only in mid-August 1998–2003 in grazed and ungrazed (exclosure) sites (n = 12 each year) of the Camp-2 area (main nesting colony) on Bylot Island, Nunavut. The dashed line indicates the start of the special conservation measures.

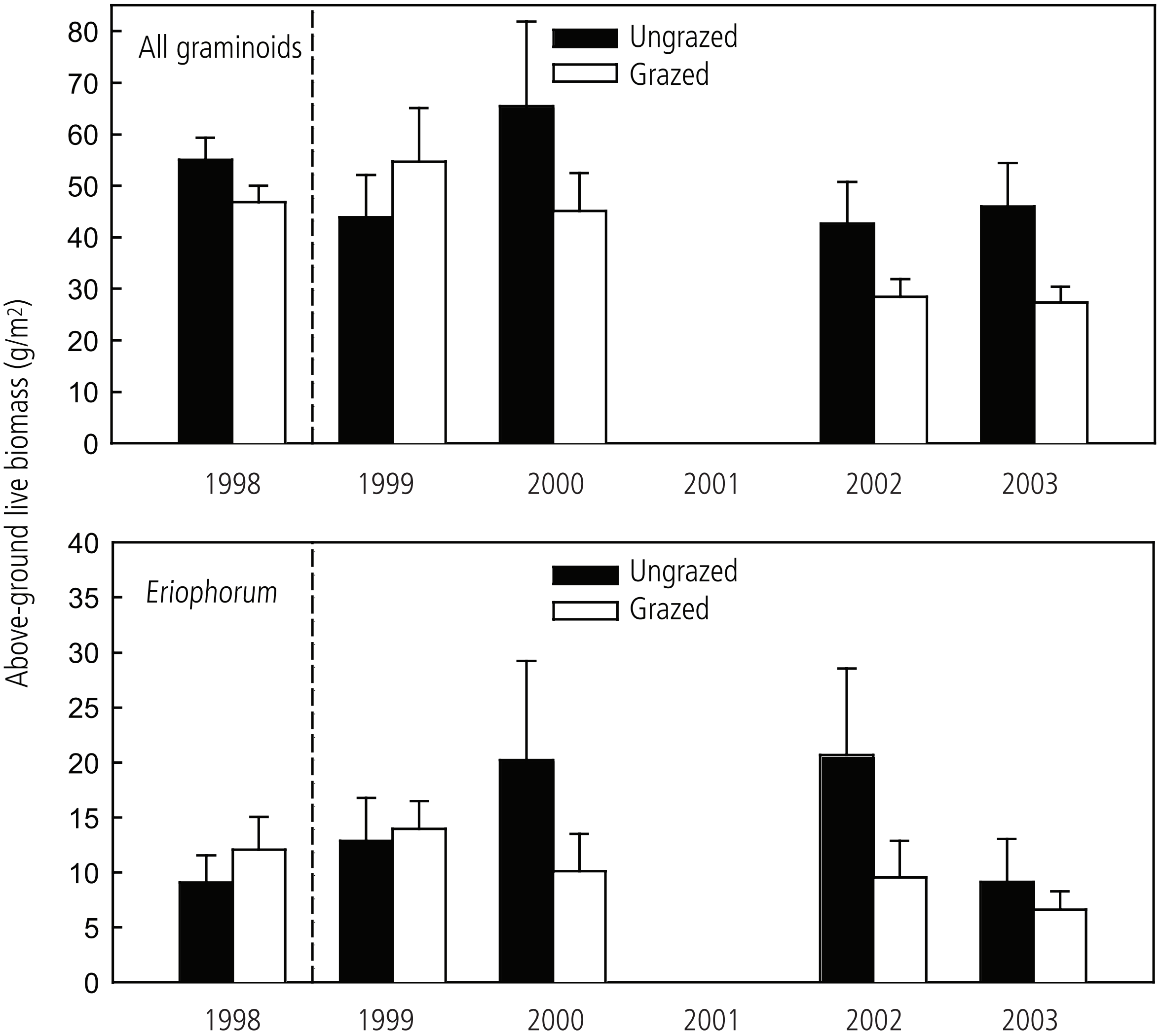

Figure 1-35. Biomass (mean ± SE) of graminoids and of *Eriophorum scheuchzeri* only in mid-August 1998–2003 in grazed and ungrazed (exclosure) sites (n = 12 each year) of Dufour Point area (brood-rearing area) on Bylot Island, Nunavut. The dashed line indicates the start of the special conservation measures. Data are from G. Gauthier (unpubl.).

Herbivores may positively impact the plants they eat under some conditions (e.g. through nutrient additions from their feces; Hik and Jefferies 1990), but there is no such evidence for Greater Snow Geese on Bylot Island (Gauthier *et al.* 1995). Experiments based on long-term exclosures suggest instead that chronic grazing by geese has a persistent effect on vegetation, reducing plant production and altering composition through selective grazing on one particular species, *Eriophorum scheuchzeri* (Gauthier *et al.* 2004a, 2004b). Despite these impacts, Greater Snow Geese have apparently not yet reached densities at which permanent damage to the vegetation can be detected. A study of freshwater wetlands on Bylot Island suggested that the theoretical carrying capacity of 341 000 geese for this habitat had not yet been attained (Massé *et al.* 2001). Instead, these data indicated that the 1997 goose population, which was close to the historical maximum, was at roughly half of the short-term capacity of the wetlands (46% ± 10%; Massé *et al.* 2001). These authors nonetheless warned that the long-term sustainable capacity of this habitat would possibly be lower if high grazing led to a further decline in plant production. However, there is no evidence for such a decline, as plant production measured within exclosures indicated an increasing trend in total plant biomass since 1990 (Fig. 1-33; Gauthier *et al.* 2004a), suggesting that

so far the plants are able to recover from chronic grazing. Therefore, unlike Lesser Snow Geese from the Hudson Bay area, which have impacted vegetation on their breeding grounds past the point of its potential for rapid recovery (Abraham and Jefferies 1997), Greater Snow Goose abundance appears not yet to have reached such a critical level in the Arctic.

Effects of the special conservation measures on Arctic vegetation

Special conservation measures were introduced principally to reduce the likelihood of damage to Greater Snow Goose natural habitats. Accordingly, we examined whether impact by grazing on breeding ground vegetation has changed since implementation of the special conservation measures, using measurements of graminoid and *Eriophorum* biomass. We conducted this analysis on the data set with the longest record (Fig. 1-33), using a factorial ANOVA with 10–12 exclosures per year, where the dependent variable was biomass per square metre inside or outside each exclosure at the end of the summer; conservation measures (pre: 1990–1998 vs. post: 1999–2003) and grazing (presence or absence) were both categorical independent variables. The interaction measures*grazing was tested in the model to verify whether the difference between grazed and ungrazed biomass differed between the years before and after the implementation of conservation hunting regulations. In both cases, there was no evidence for this effect ($F_{1.306} = 0.12$, $P = 0.73$ for all graminoids; $F_{1.306} = 1.49$, $P = 0.22$ for *Eriophorum* only), suggesting that special conservation measures had no influence on grazing impact by geese in the Arctic. An index of goose use adjacent to the exclosure areas, as measured by feces counts (Fig. 1-36), was also analyzed using a factorial ANOVA with 9–12 exclosures per year, where the dependent variable was droppings per square metre at the end of the summer for each exclosure and the categorical independent variable was the existence of conservation measures (pre: 1990–1998 vs. post: 1999–2003). This analysis also indicated no change in intensity of use after the new measures were initiated ($F_{1.149} = 0.03$, $P = 0.87$).

Inspection of Figure 1-33 suggests that graminoid biomass on Bylot Island was higher in years following implementation of the special conservation measures (particularly 2000–2002) than in previous years. A statistical analysis confirmed that biomass estimates inside the goose-free exclosures were indeed higher on average both for total graminoids (mean ± SE pre-measures = 34.9 ± 1.7 g/m^2, post-measures = 56.9 ± 4.1 g/m^2, $F_{1.153} = 32.5$, $P < 0.001$) and for *Eriophorum* only (pre-measures = 8.6 ± 0.8 g/m^2, post-measures = 22.3 ± 2.9 g/m^2, $F_{1.153} = 29.5$, $P < 0.001$). However, climatic factors also had a strong impact on plant production in the Arctic, as a recent analysis showed a significant relationship between temperature in July and plant production in wetlands (Gagnon *et al.* 2004). As the latter study also found that 2000 and 2001 were the warmest summers on Bylot Island since 1990, higher average plant production after implementation of the conservation measures may thus be explained equally well by climatic factors. Therefore, both effects are confounded, and it is not possible to conclude whether the special measures had an effect on plant production in wetland habitats used by geese in the Arctic.

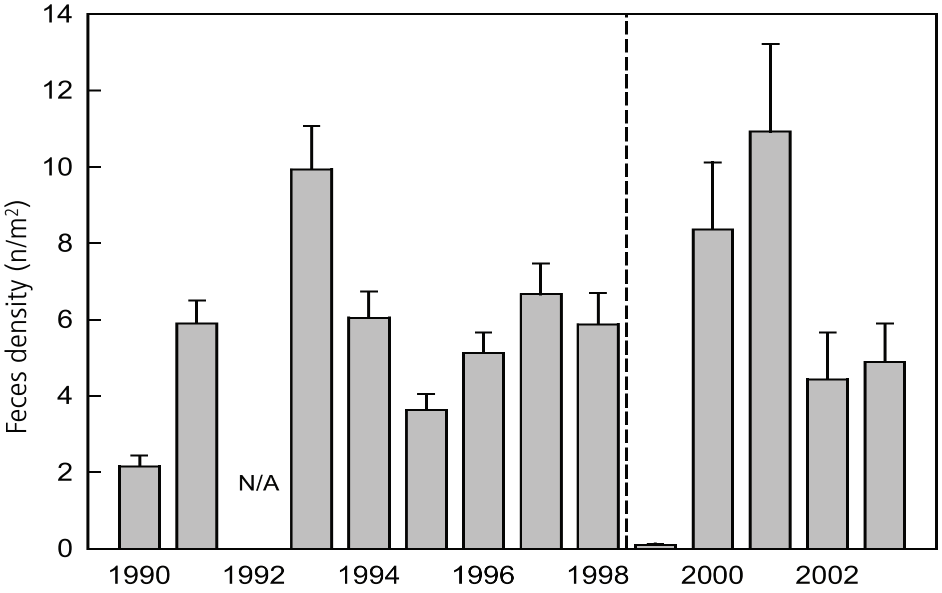

Figure 1-36. Goose feces density (mean ± SE) in mid-August 1990–2003 (1992 data not available), from transects on Bylot Island, Nunavut, as a measure of goose use near exclosures (n = 12 each year). The dashed line indicates the start of the special conservation measures (from Gauthier *et al*. 2003b).

Impacts on natural habitats during staging in Québec

During spring and fall staging along the St. Lawrence River in Québec, Greater Snow Geese rely primarily on tidal marshes as their natural feeding habitats (Giroux *et al*. 1998b). These marshes are located on both the north and south shores of the river in the upper estuary and provide a major staple food for staging geese in the form of *Scirpus pungens* rhizomes (Giroux and Bédard 1988; Bédard and Gauthier 1989). The geese are adaptable in their marsh foraging methods, primarily grubbing underground plant parts but also grazing new shoots in spring, allowing flexible exploitation of available vegetation (Bélanger and Bédard 1992). Foraging activities, in combination with environmental factors such as ice scouring of the marshes, can reduce *Scirpus* biomass and alter composition of the marsh plant community (Bélanger and Bédard 1994b).

Given the potential for severe impacts of geese on coastal marshes (e.g. Lesser Snow Geese; Abraham and Jefferies 1997), effects of Greater Snow Geese on staging ground marshes have been estimated through vegetation sampling in and around hunting-free refuges. Vegetation sampling on the north shore of the estuary has been conducted at the Cap Tourmente National Wildlife Area, a major staging area for geese in both spring and fall. *Scirpus* stem density was sampled annually from 1971 to 1984 and biennially since then (Fig. 1-37; for methodological details, see Lefebvre *et al*. 2001; Lefebvre and Cotter 2002). Density of *Scirpus* in a portion of the Cap Tourmente National Wildlife Area intensively used by geese (non-hunting sites) showed an average decline of 45% since 1971, or 1.3% per year (linear regression 1971–2004: $R^2 = 0.36$, df = 1, 22, $P = 0.002$). However, stem density appears to have been relatively stable since the early 1990s, including the three years after implementation of the conservation measures (2000, 2002, and 2004). The most obvious factor that could explain the long-term decline is the repeated presence of geese feeding in the marsh, although the number of goose-days has also been declining in recent years, possibly as a response to lowered food resources. On the south shore of the estuary, the biomass of several forage plants has been measured sporadically since 1983 at migratory bird sanctuaries that are heavily used during fall staging (for methodological details, see Lefebvre *et al*. 2000). At Montmagny, biomass was much reduced in the sanctuary relative to adjacent hunted areas in all years sampled, but no overall temporal trend has been detected since the mid-1980s (Lefebvre *et al*. 2000; Fig. 1-38). In contrast, similar *Scirpus pungens* biomass was measured inside and outside the sanctuary at Cap-Saint-Ignace, although again there was no evidence of temporal change (Lefebvre *et al*. 2000; J.-F. Giroux, unpubl. data; Fig. 1-39). These data suggest that while feeding by geese may reduce bulrush biomass in the areas most heavily used (i.e. hunting-free zones), no long-term effects on vegetation growth have been detected on the south shore of the St. Lawrence estuary over the past 20 years.

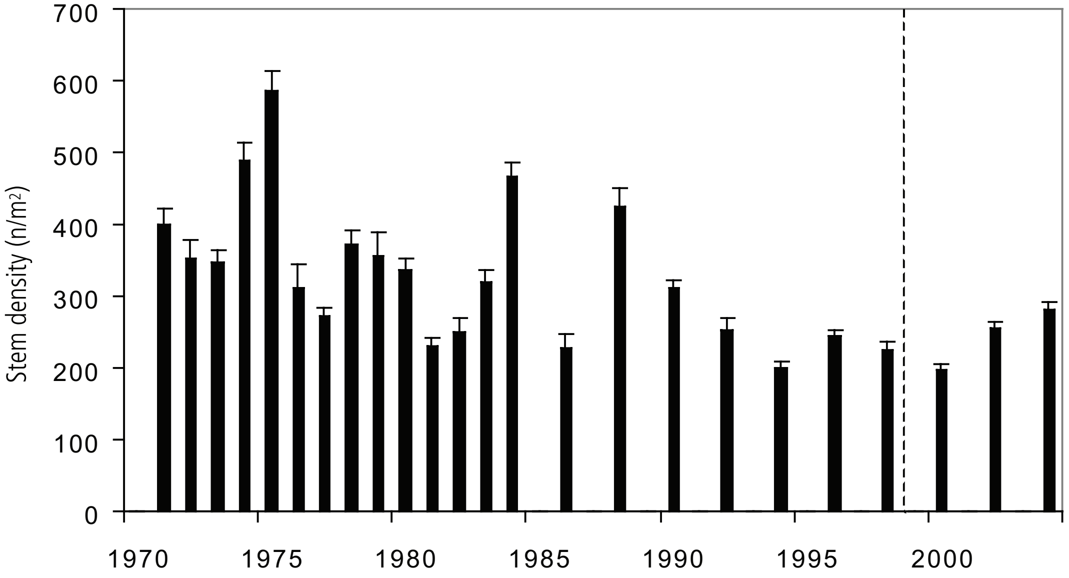

Figure 1-37. Density of *Scirpus pungens* stems (mean ± SE) at the Cap Tourmente National Wildlife Area in late summer from 1971 to 2004. The dashed line indicates the start of the special conservation measures. Data are from Lefebvre *et al*. (2001), Lefebvre and Cotter (2002), and J. Lefebvre (unpubl.).

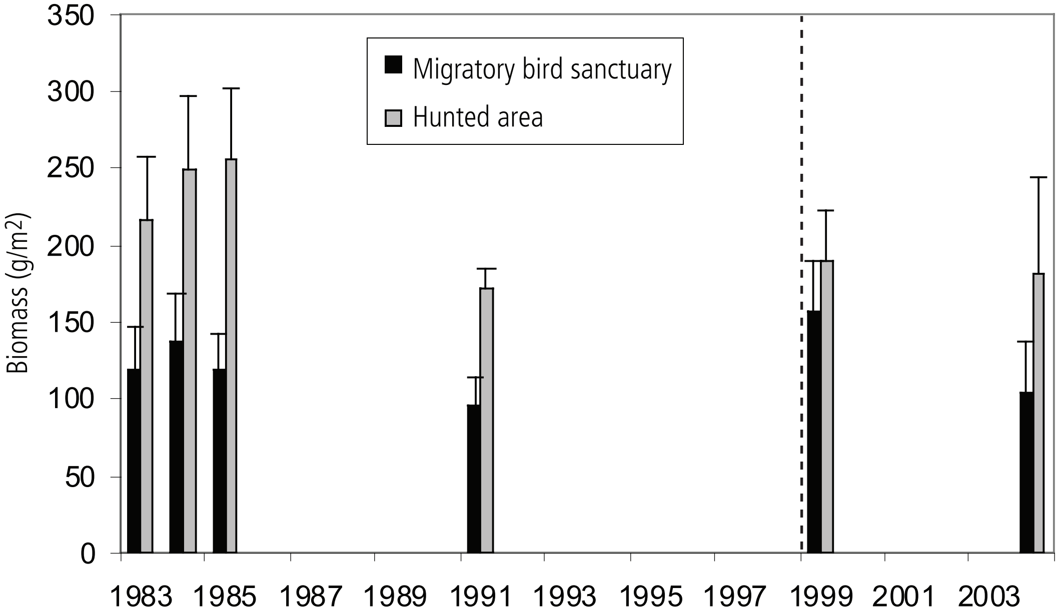

Figure 1-38. Density of *Scirpus pungens* biomass at Montmagny Migratory Bird Sanctuary, within and just outside areas protected from sport hunting, in late summer from 1983 to 2004, representing heavily grazed and less heavily grazed areas, respectively. Data from Lefebvre *et al.* (2000), Lefebvre and Cotter (2002), and J. Lefebvre (unpubl.). The dashed line indicate the conservation measure.

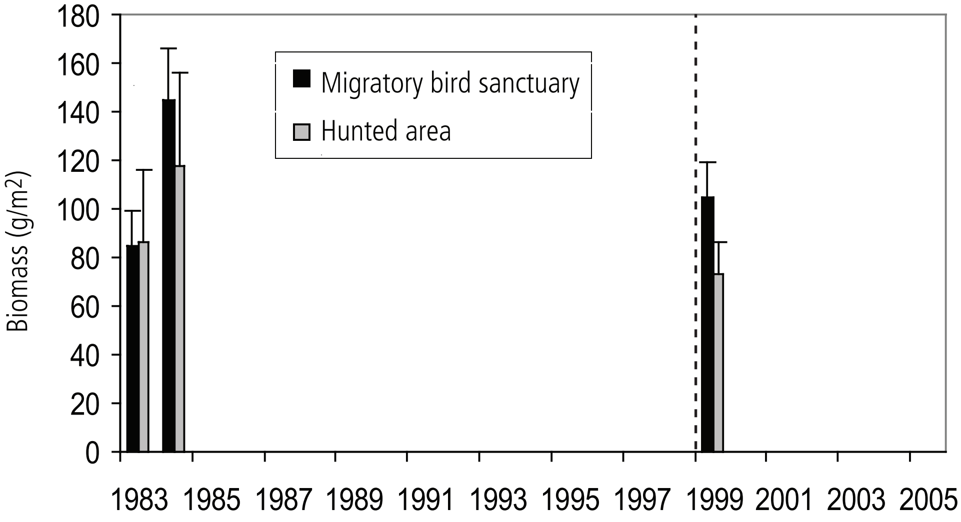

Figure 1-39. Density of *Scirpus pungens* biomass at Cap-Saint-Ignace Migratory Bird Sanctuary, within and just outside areas protected from sport hunting, in late summer from 1983 to 1999, representing heavily grazed and less heavily grazed areas, respectively. The dashed line indicates the start of the special conservation measures. Data are from Lefebvre *et al.* (2000) and J. Lefebvre (unpubl.).

However, in the absence of experiments using exclosures to remove the effects of geese, it is impossible to conclusively attribute the decline of *Scirpus* production to goose usage. Other factors such as nutrient availability, sediment accumulation, and hydrology could also affect *Scirpus* productivity in these marshes. Investigations are under way to assess the impact of geese relative to other environmental factors.

Impacts on Québec farmlands during staging

Beginning in the early 1970s, Greater Snow Geese expanded their staging area to include farm fields along the south shore of the St. Lawrence River and in regions adjacent to refuges (Filion *et al*. 1998; Gauthier *et al*. 2005). Grazing in hayfields became particularly common during spring (Gauthier *et al*. 1988; Bédard and Gauthier 1989), in addition to feeding on waste grain and corn (Filion *et al*. 1998). The importance of agricultural foods increased during the period of rapid population growth, possibly due to a reduction in the per capita availability of marsh vegetation caused by the increase in goose abundance (Bélanger and Bédard 1994a; Filion *et al*. 1998; Gauthier *et al*. 2005). Changes in distribution observed in recent years, away from the estuary and towards southwestern Québec where feeding occurs solely in farmlands (mostly cornfields), showed that dependence of geese on agricultural foods has continued to increase (Gauthier *et al*. 2005). Feeding in farm fields is more prevalent in spring than during fall staging. Several factors may contribute to this, such as fall hunting pressure that concentrates geese in refuges and sanctuaries in the marsh, a higher abundance of *Scirpus* rhizomes in natural marshes in fall following the summer growth season, and onset of spring growth in hayfields that provide highly nutritious young shoots of grass to geese (Filion *et al*. 1998; Giroux *et al*. 1998b). Consequently, it is in spring that damage to crops and resulting costs to farmers have been greatest (Filion *et al*. 1998). An experiment conducted in the St. Lawrence estuary indicated that goose grazing may delay plant maturity and significantly reduce yield for a variety of crops (Filion 1998). In recent years, however, some fall damage has also been reported in the Lac Saint-Jean region, where geese feed on small cereal grains that have not yet been harvested. This problem is more serious when weather conditions during the growing and/or harvest season delay harvest operations.

Managers were interested in the possible effects of the special conservation measures on crop depredation, as potential disturbance associated with hunting activities could reduce field use by geese. Disturbance related to spring harvest and, to some extent, scaring likely reduced energy gained from feeding in fields (Féret *et al*. 2003; Béchet *et al*. 2004a), which may reduce impacts of goose grazing on farm crops. The total surface area of crops damaged by waterfowl (mostly Greater Snow Geese) was highly variable between 1992 and 2004 in Québec (Fig. 1-40), and a simple comparison of means shows no difference in total area affected before (1992–1998) or during (1999–2003) conservation harvests ($F_{1.10} = 0.48$, $P = 0.51$). The amount of crop damage by geese in spring is influenced by many factors besides the size of the population, including spring weather, agricultural practices (e.g. phenology of plowing/sowing), bird behaviour and movement, intensity and type of hunting activity, and intensity of scaring activity by farmers or specialized personnel. Without spring harvest, more damage could have been recorded, but this was impossible to test with controls, because the spring harvest occurred in all regions of southern Québec. One noticeable effect of spring harvest, however, was the greater proportion of damage in the lower class (10–74.9% grazing damage class) following the start of the hunt (72% vs. 57%; $F_{1.10} = 28.45$, $P < 0.001$), which was also associated with a greater number of damage reports. This indicates that damage was spread among a larger number of farms but at a lower average intensity. This was corroborated by a decrease in flock size during years with spring harvest compared with earlier years (A. Béchet and J.-F. Giroux, unpubl. data).

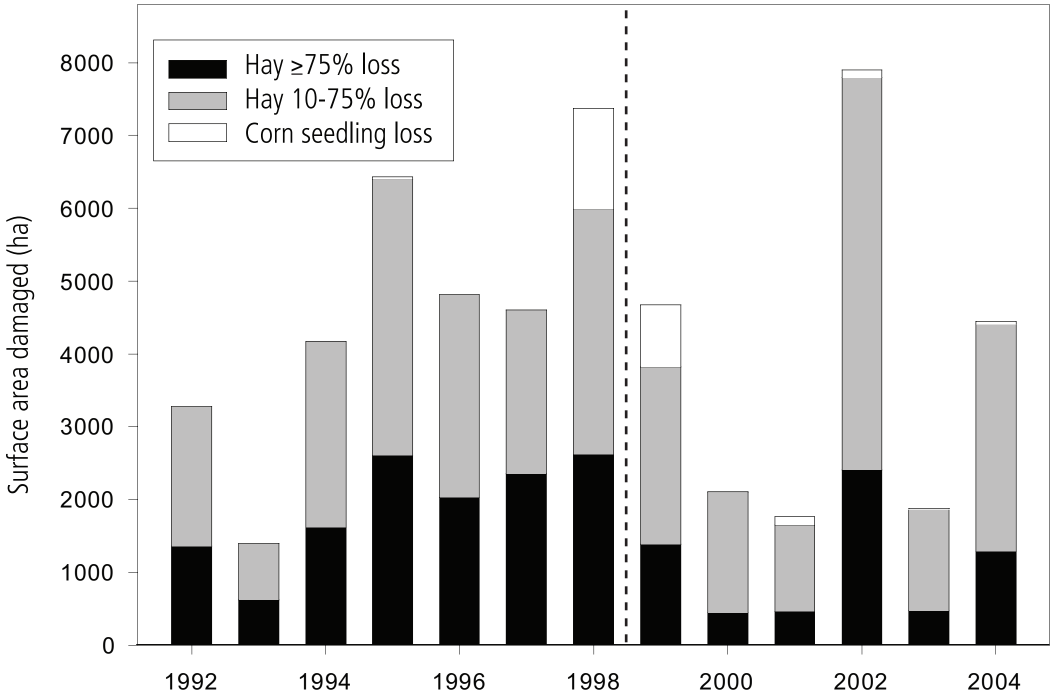

Figure 1-40. Total surface area of crops damaged by waterfowl (mostly Greater Snow Geese) in Québec from 1992 to 2004. The dashed line indicates the start of the special conservation measures. Data are from La Financière Agricole du Québec (unpubl.)

Impacts on natural wintering and staging ground habitats in the Atlantic Flyway states

The ability of Greater Snow Geese to benefit from several types of foods and to easily move among feeding sites has allowed them to exploit a wide variety of areas on the Atlantic coast (Hill and Frederick 1997), but specific impacts on vegetation are poorly understood. Severe "eat-outs" of salt marsh vegetation occurred in several Atlantic Flyway refuges where Snow Geese were present during the 1970s and 1980s (Smith and Odum 1981; Giroux *et al*. 1998b). As on staging grounds, *Scirpus* biomass and growth were negatively impacted by goose grazing (A. Froelich and D. Lodge, unpubl. data, presentation at the 2000 INTECOL Millennium Wetland Event in Québec). However, during the 1990s, this damage did not increase at the same rate as goose population growth in regions where nearby agricultural fields provided an alternative food source (mainly waste corn and winter cereals), although eat-outs did persist in traditional wintering areas without farm foods available (Giroux *et al*. 1998b). Generally, natural habitats affected by Snow Geese along the Atlantic coast have been limited to small areas (in proportion to the area covered by salt marshes) where damage is intense but localized, mostly in wildlife refuges (Giroux *et al*. 1998b).

From the mid-1970s to the late 1990s, the number of Snow Geese using the salt marshes near Forsythe National Wildlife Refuge increased (Batt 1998). Concurrently, the amount of salt marsh vegetation severely damaged by Snow Geese increased. In an attempt to alleviate this damage, Forsythe National Wildlife Refuge instituted, in 1998, special hunts for Snow Geese within its impoundments during October. Special Snow Goose hunts were held from 1998 to 2002 and then again in 2004. No special hunts were held in 2003 owing to the decline in the

number of Snow Geese using the refuge that year. When comparing pre-hunt years (1993–1997) with years when hunting occurred (1998–2003), the peak and average numbers of Snow Geese using Forsythe National Wildlife Refuge during the fall declined by about 50%. Despite this decline, significant damage remains.

Negatively impacted salt marsh acreage at Forsythe National Wildlife Refuge has remained relatively stable since about 1998. The minimum area damaged is currently estimated to be 270 ha adjacent to refuge impoundments. Additional areas have also been impacted, but there is no estimate of area. In addition to salt marsh degradation, eat-outs have affected refuge infrastructure, with occasional storms damaging the dyke system. Batt (1998) indicated that about 2% of *Spartina* marshes along the Delaware Bay shore of New Jersey were impacted from 1970 to the mid-1990s. No surveys are in place to measure Snow Goose damage to these marshes, but casual observation suggests that the present level of damage is minor and similar to that observed over the previous decades. In addition, damaged areas are not consistent from year to year, thereby allowing regeneration of previously damaged marshes.

Prime Hook National Wildlife Refuge in Delaware, which winters 100 000–150 000 Greater Snow Geese, has shown increased annual seed production on moist soil impoundments (A. Larson, pers. comm.). Presumably this increased production is due to the high influx of nutrients (feces) and annual soil disturbance from feeding bouts. *Spartina* marshes at Prime Hook have experienced severe damage, but tend to recover the following year. The situation is much different at Bombay Hook National Wildlife Refuge, where estimates of annual damage to salt marsh habitats are about 400 ha (R. Brown, pers comm.).

Extensive eat-outs on *Spartina alterniflora* have occurred in wetlands along Newport Bay, Maryland. The source of these problem birds is a private sanctuary adjacent to the Newport Bay marshes that was once used by large numbers of Canada Geese (*Branta canadensis*). The sanctuary is now dominated by about 30 000–50 000 Greater Snow Geese, which appear to have displaced Canada Geese that were former winter residents. Other extensive eat-outs by Greater Snow Geese exist on small islands in Chincoteague Bay and along Assateague Island National Seashore, from birds that winter at Chincoteague National Wildlife Refuge and move north from the refuge to feed.

The number of Snow Geese reported on the midwinter inventory in Virginia has not changed much in the last 10 years. However, larger numbers of Snow Geese often stage in Virginia earlier in the year (November) before heading farther south. A redistribution of some birds in the state has led to Snow Geese using new areas of coastal marsh. Although Snow Goose impacts on coastal marsh habitats are not widespread in Virginia, damage can be significant in specific localized areas. Damage to coastal marshes and eat-out areas still exists in the Chincoteague area, where the damage has been observed for a long time. Probably 20–30 ha of eat-outs by Snow Geese exist in this area. Additional damage has been noted farther south along the coast, where a flock of 8000–10 000 Snow Geese has wintered for the past 4-5 years. An area of about 20 ha of *Spartina alterniflora* marsh has been denuded and is now generally devoid of any vegetation. Other marsh areas in this vicinity where Snow Geese have been feeding show sparser vegetation but have been impacted to a lesser degree.

Numbers of Snow Geese wintering in coastal habitats in North Carolina have generally declined over the long term. The core wintering areas in coastal habitats, Pea Island National Wildlife Refuge and Mackay Island National Wildlife Refuge, winter approximately 6000–10 000 Snow Geese. Reports of damage to native vegetation have likewise declined over the long term. Snow Geese occasionally denude very small patches of *Spartina alterniflora* at Pea Island National Wildlife Refuge, but these appear to recover quickly.

Impacts on farmlands in the Atlantic Flyway states during staging and wintering

The northward redistribution of geese on their wintering grounds may in part be a consequence of their growing dependence on agricultural foods, as corn growing decreased in southern states but not in mid-Atlantic states (Gauthier *et al*. 2005). Moreover, an informal survey suggested a decline in the number of complaints about crop damage by farmers in Virginia and North Carolina, with an increase in Delaware, Maryland, and Pennsylvania in the late 1990s (Filion *et al*. 1998), consistent with this distributional shift.

Delaware is the only Atlantic Flyway state with wintering or staging Greater Snow Geese that has conducted an annual survey of Snow Goose damage in recent years. Damage to agricultural crops in 1998, the first year of the survey and the year before liberalization of hunting regulations (i.e. allowing staggered hunting days after 4 January), was 8130 ha, with an estimated value of $515 091. Damage to agricultural crops was greatly reduced following the change in hunting regulations, but has been variable across years. For 2001–2002, Snow Goose damage amounted to 2827 ha, with a landowner-assessed value of $235 078. This is substantially below that reported in 2000 (4159 ha, $394 440) and slightly below that reported in 1999 (2849 ha, $235 252). Damage was primarily to wheat, barley, and rye crops and was most prevalent in January and February. Damage was most frequent in Sussex County adjacent to Prime Hook National Wildlife Refuge (T. Whittendale, Delaware Department of Natural Resources, pers. comm.). Maryland also reported important damage to agricultural crops, but this was not quantified. Maryland's approach to alleviating problems of crop damage has been to tell farmers how to apply for federal depredation permits (L. Hindman, Maryland Department of Natural Resources, pers. comm.). Damage to agricultural crops, generally winter wheat, in Virginia still occurs on a localized basis. However, little quantitative information is available, because farmers receive no payments for damage caused by wildlife and seldom report acreage figures (G. Costanzo, Virginia Department of Game & Inland Fisheries, pers. comm.). Damage to winter wheat likely occurs on a localized basis in North Carolina, but few, if any, reports are received by the state wildlife agency or U.S. Department of Agriculture – Wildlife Services (J. Fuller, North Carolina Wildlife Resources Commission, pers. comm.).

Summary: Impacts of Snow Geese on natural habitats and farmlands

- Greater Snow Goose grazing on Arctic graminoids during the breeding season is high and reduces the plant production in wetlands, although vegetation has not been damaged past the point of recovery, as has been observed with Lesser Snow Goose populations. Goose abundance on Bylot Island, one of the largest breeding colonies, was still at only half the estimated carrying capacity of the island's wetlands in 1997. Plant production has been especially high in recent years, but we cannot determine if this was a consequence of the special conservation measures.
- There is evidence for a gradual long-term decline in marsh vegetation in some wildlife refuges in the St. Lawrence estuary, although not in others, and there is no evidence that the special conservation measures have affected these trends yet.
- A continued shift towards feeding in agricultural fields is incurring sustained damage to crops in southern Québec, and this has apparently not declined since the implementation of the special conservation measures. However, there is at present no direct relationship between the number of geese in the population and the amount of crop damage in Québec.

- Destruction of coastal salt marsh vegetation in winter has been reported in some U.S. coastal refuges. However, these areas are small and apparently have not changed in recent years, presumably due to the exploitation of agricultural crops for feeding and the introduction of hunting in some refuges.
- Crop damage due to Snow Goose grazing also occurs in some Atlantic Flyway states. It appears that the liberalization of hunting regulations and changes to framework dates have helped attenuate this problem in some states.

SECTION II: PROJECTED GROWTH RATE OF THE GREATER SNOW GOOSE POPULATION UNDER ALTERNATIVE HARVEST SCENARIOS

Gilles Gauthier and Eric T. Reed

INTRODUCTION

The previous section of the report illustrates the wealth of scientific knowledge on Greater Snow Geese that has been accumulated over the years. The size of the population is well monitored by the spring aerial survey, although there has been some uncertainty in the accuracy of the survey in recent years, and intensive studies occur on the breeding and staging grounds. These studies have important applied aspects, many of them revolving around the role of climate, habitat, and harvest on the dynamics of the population. The long-term nature of the scientific study of Greater Snow Geese has proven invaluable for our present evaluation of the effects of special conservation measures on the population, allowing comparisons between periods with and without these measures.

Waterfowl harvest management is hampered by several sources of uncertainty. These include stochastic temporal and spatial variation in environmental factors such as climate, annual variation in harvest realized under a given set of regulations, and an incomplete understanding of how populations are affected by harvest and other biological factors. It is through evaluation of past data, the comparison of predictions based on these data and observed results, and frequent updating of models that uncertainty can be reduced. The information presented in the first section of this report provides the scientific basis for reducing key sources of uncertainty, which in turn will allow more refined harvest strategies to be developed.

In this section, we explore and evaluate the projected impacts of a range of harvest scenarios on the growth rate of the population with the use of population projection matrix models (Caswell 2001). An initial matrix model for this population was first developed by Gauthier and Brault (1998). Since then, however, our knowledge of the impact of harvest on various demographic parameters has improved considerably (e.g. Gauthier *et al*. 2001; Mainguy *et al*. 2002; Menu *et al*. 2002; Reed *et al*. 2003b, 2004a), and new theoretical developments now allow more refined models (Gauthier and Lebreton 2004). We used the most recent information available to develop an updated population model, and we evaluated the impact of eight different harvest scenarios on population growth with this model. Harvest scenarios were chosen for their likelihood of application and simplicity. We also compared the model's predictions with the observed growth rate of the population for the periods with (1999–2003) and without (1985–1998) special conservation measures in order to evaluate its performance.

We separated the annual cycle of the bird into four components: 1) summer in the Arctic, 2) fall in Québec, 3) winter in the United States, and 4) spring in Québec. This allowed us to estimate the effect of change in harvest in each hunting season (fall in Québec and winter in the United States) or during the special spring conservation harvest in Québec, on population response of Greater Snow Geese. For instance, we predicted the effect of spring conservation harvests on population growth through reductions in both survival and fecundity. We considered a scenario in which the spring harvest effects on fecundity diminish over time, as geese likely learn to avoid disturbance due to spring harvest. We also examined the impact of changes to the special conservation measures designed to reduce harvest level by, for example, having a spring harvest once every second year instead of annually, assuming that fecundity would still be reduced in years with a spring harvest. Finally, we considered a situation where existing regulations and conservation measures applied to fall hunting would be maintained (electronic calls, hunting over bait, sneaking, etc.), but there would be no spring harvest.

Special conservation measures, such as a spring harvest, are temporary measures, as they were designed to be applied only to a population that is overabundant (Government of Canada 2006). Should a sustainable population level be attained, a long-term management goal will be to maintain the population at or near this level, without the use of special conservation measures. Thus, we evaluated what level of harvest (during regular hunting seasons) would be required to maintain a stable population and how it could be partitioned between Canada (mainly Québec) and the United States. In so doing, we examined three scenarios of harvest allocation: 1) equal increase in Canadian and U.S. harvest, 2) increase in Canadian harvest only, and 3) increase in U.S. harvest only.

METHODS

General model

Our model is a time-dependent deterministic model based on birth-pulse matrix projection (Caswell 2001). We used a prebreeding formulation with four stages because recruitment to the breeding cohort of adults is completed only at age four in Greater Snow Geese (Reed *et al*. 2003b). Our model therefore considers a population vector (N) with four age-classes made up of individuals respectively ages 1, 2, 3, and 4 or more (i.e. N_1, N_2, N_3, and N_{4+}) at the time of the census. The time interval in our model thus extends from the onset of breeding in year t to t+1. The demographic parameters are included in matrix A, where the first row contains the net fecundity terms (fecundity F_i multiplied by first-year survival, S_J) for each stage i, and subsequent rows contain the transition probabilities (S_i), i.e. the probability of passing from one stage to the other (= survival). For a four-stage model, the matrix is:

$$\mathbf{A} = \begin{bmatrix} 0 & F_2 \bullet S_J & F_3 \bullet S_J & F_4 \bullet S_J \\ S_1 & 0 & 0 & 0 \\ 0 & S_2 & 0 & 0 \\ 0 & 0 & S_3 & S_4 \end{bmatrix} \qquad \mathbf{N} = \begin{bmatrix} N_1 \\ N_2 \\ N_3 \\ N_4 \end{bmatrix}$$

The fecundity estimates, expressed as females surviving to fledging per adult female, are obtained as a product of several individual components, as follows:

$$F_i = BP_i \bullet (TCL_i / 2) \bullet NS_i \bullet P1_i \bullet P2_i \bullet P3_i$$

where i = age, BP = breeding propensity, TCL = clutch size, NS = nesting success, $P1$ = egg survival in successful nests, $P2$ = hatching success, and $P3$ = gosling survival from leaving the nest until banding. A full definition of these variables can be found in Table 2-1. We divided clutch size by two because we modelled only the female component and assumed a 1:1 sex ratio at hatching. Other non-zero terms in the matrix correspond to adult survival probability (i.e. survival after one year), which is considered the same for all age-classes.

Table 2-1. Definition of reproductive and survival parameters.

Parameter	Definition
Breeding propensity (*BP*)	Probability that a female alive at time t will attempt to breed (i.e. will lay at least one egg).
Total clutch laid (*TCL*)	Total number of eggs laid by a nesting female (clutch size).
Nesting success (*NS*)	Probability that a nest will be successful, i.e. that at least one egg will hatch.
Egg survival (*P1*)	Probability that an egg will survive to hatching in successful nests.
Hatching success (*P2*)	Probability that an egg that reached hatching stage in successful nests will produce a gosling leaving the nest.
Gosling survival (*P3*)	Probability that a gosling leaving the nest survives until banding, which occurs just before fledging.
First-year survival (S_J)	Probability that a fledged gosling, i.e. juvenile bird, will survive from banding (i.e. near fledging) until the start of breeding in the following year (note that this corresponds to a 10-month period).
Annual adult survival (S_A)	Probability that an adult bird (>1 year old) will survive from the start of a breeding period in year t to year t+1.

Fecundity

Fecundity data are from the long-term study of Greater Snow Goose reproduction on Bylot Island (Lepage *et al*. 2000; Reed *et al*. 2003b, 2004a; G. Gauthier, unpubl. data). For most parameters, we used data from 1991 to 1998. The reproductive success of Greater Snow Geese in the High Arctic is highly variable, and fecundity between good and poor years may vary by more than one order of magnitude (Reed *et al*. 1998; Menu *et al*. 2002). In order to account for this high variability, we classified reproduction as good (1), average (2), or poor (3) based on the proportion of young in the fall counts conducted annually by CWS (see Gauthier and Brault 1998). Good reproduction resulted in fall age ratios >30%, average between 10 and 30%, and poor <10%. Our analyses suggest that most fecundity parameters as well as juvenile survival, but not adult survival, will be enhanced or reduced in a good or a poor year, respectively.

Average reproductive parameters for good, average, and poor years are presented in Table 2-2. Values of *TCL*, *P1*, *NS,* and *P2* came from Lepage *et al*. (2000). Values for *P3* are based on information on change in brood size between hatch and banding, corrected for total brood loss (for details, see Gauthier and Brault 1998). Although some of these breeding parameters improve slightly with age in Snow Geese (Cooke *et al*. 1995), our data are from birds of unknown age, and thus age effects on these parameters were ignored. Accession of females to the breeding cohort is a gradual process starting at age two and completed at age four in Greater Snow Geese (Reed *et al*. 2003b). We calculated age-specific breeding proportion (*BP*, Table 2-1) from the recruitment rate values (a_i, probability that an individual starts breeding) of Reed *et al*. (2003b) following Pradel and Lebreton (1999). Reed *et al*. (2004a) also showed that the breeding propensity of adults is variable among years.

From their analysis, we estimated that breeding propensity was ~1 in a good year, 0.8 in an average year, and 0.5 in a poor year. We applied these coefficients to the breeding propensity values to estimate *BP* in good, average, and poor years.

In order to obtain an average measure of fecundity, we first determined the quality of reproduction for each year between 1985 and 1998 using data on fall age ratios. We then filled a vector of annual fecundity using values in Table 2-2 based on the quality of reproduction for that year. Depending on the quality of reproduction, overall fecundity could take one of the values shown in Table 2-2 for each age-class. Finally, we calculated the average observed fecundities for the period 1985–1998 (i.e. average of our age-specific fecundity vector) and used them in the model. These values were $F_2 = 0.173$, $F_3 = 0.471$, and $F_4 = 0.692$.

Table 2-2. Components of fecundity (mean ± SE). Data are from the long-term study at Bylot Island.

Component	Age	Fecundity (mean ±SE)		
		Good years	Average years	Poor years
BP	2	0.25 ± 0.09	0.21 ± 0.07	0.13 ± 0.05
	3	0.68 ± 0.16	0.58 ± 0.13	0.34 ± 0.08
	4+	1.0	0.80	0.50
TCL	2-4+	4.145 ± 0.066	3.853 ± 0.071	3.526 ± 0.051
P1	2-4+	0.9395 ± 0.0117	0.9071 ± 0.0126	0.9107 ± 0.0154
NS	2-4+	0.8412 ± 0.0420	0.6021 ± 0.0229	0.5638 ± 0.0516
P2	2-4+	0.9370 ± 0.0046	0.9370 ± 0.0046	0.9370 ± 0.0046
P3	2-4+	0.650 ± 0.082	0.610 ± 0.108	0.543 ± 0.010
Overall fecundity (in female/female)	2	0.2494	0.1263	0.0599
	3	0.6783	0.3488	0.1566
	4+	0.9976	0.4811	0.2303

Results presented in previous sections of this report showed that fecundity of Greater Snow Geese has been reduced during years with a spring conservation harvest (see also Mainguy *et al*. 2002; Bêty *et al*. 2003). However, data are insufficient to determine the precise effect on each fecundity component. As an index of the effect of the spring harvest on fecundity, we compared the mean fall age ratio in the population between years without a spring harvest (1985–1998) and those with a spring harvest (1999–2003). This comparison showed a 35% reduction, on average, in fall age ratio in years with a spring harvest. Thus, to model this reduction in fecundity, we multiplied the fecundity of all age class by 0.65 in years with a spring harvest.

Adult survival and harvest rate

In order to examine the impact of harvest on the population in various hunting seasons, we divided both adult and juvenile survival into seasonal components. Within each season, we expressed survival as a function of harvest rate, that is, the probability for a bird alive at the beginning of the season to be killed and retrieved (i.e. harvested) by hunters. We assumed in all cases that hunting mortality was fully additive to natural mortality, as this was shown to be true in many goose populations, and in Greater Snow Geese in particular, at least for adults (Francis *et al*. 1992; Rexstad 1992; Gauthier *et al*. 2001; Calvert and Gauthier 2005). Adult survival was thus expressed as:

$$S_A = S_A^S \, S_A^F \, S_A^W \, S_A^P$$

where the superscript refers to the individual seasons (S = summer, F = fall, W = winter, P = spring). For adults, we assumed that summer was the period spent in the Arctic and during the first leg of the fall migration (i.e. from June to September; four months). Fall was the period spent in southern Québec during staging (i.e. fall hunting season during October and November; two months). Winter was the period spent on the U.S. wintering grounds (i.e. winter hunting season from December to March; four months). Finally, spring was the period spent in southern Québec during staging and the subsequent migration (i.e. the period of conservation harvest from April to May; two months).

Gauthier *et al*. (2001) modelled the relationship between harvest rate and adult survival of Greater Snow Geese during the full hunting season (i.e. from fall to spring, but during a period where no spring conservation harvest took place) using an extensive capture–recapture data set. The analysis was based on adult females neck-collared on Bylot Island from 1990 to 1998. Gauthier *et al*. (2001) defined this period as the "winter," which, in their analysis, extended over a 6.5-month period.[1] The relationship modelled by Gauthier et al. (2001) was:

$$S_A^w = a - bHR$$

where a = winter survival in the absence of harvest and b = the slope of the relationship between harvest rate (HR) and survival. Under the assumption of additivity of hunting and natural mortalities, the parameters in the relationship above are such that $a = b$ (Burnham and Anderson 1984), and Gauthier *et al*. (2001) indeed found that the estimate of b did not differ significantly from the intercept a. They further found that monthly survival in the absence of harvest appeared constant throughout the year. They thus expressed annual survival as:

$$S_A = \left(a^{5.5/6.5}\left(a - bHR\right)\right)/r$$

where the exponent 5.5/6.5 takes into account the difference in length between the "summer" (5.5 months) and "winter" (6.5 months) periods. The additional parameter, r, was the probability for retention of neckbands estimated from an independent data set. The latter parameter was necessary because the analysis of Gauthier *et al*. (2001) was based on the resighting of neck-collared birds, which have a retention rate of less than 1.

In order to partition harvest rate into the three hunting seasons, we had to assume that the previous relationship was true in each of the three seasons as well. Taking into account the relative length of each of the four seasons as defined above in our model, we expressed adult survival in each season as follows:

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[1] Note that the "winter" period of Gauthier *et al*. (2001) differs in length from the winter period defined in the current model. To avoid confusion, we used the lowercase subscript w to distinguish their winter period from the one defined here.

$$S_A^S = a^{4/6.5} / r^{4/12}$$
$$S_A^F = \left(a^{2/6.5} - bHR_A^F\right) / r^{2/12}$$
$$S_A^W = \left(a^{4/6.5} - b\left(HR_A^W / S_A^F\right)\right) / r^{4/12}$$
$$S_A^P = \left(a^{2/6.5} - b\left(HR_A^W / \left(S_A^F S_A^W\right)\right)\right) / r^{2/12}$$

Note that since harvest rate is always calculated on the fall population size (i.e. the population at the start of the hunting season in fall), the winter and spring harvest rates had to be corrected for the number of geese still alive at the beginning of these intervals (this was obtained by dividing the harvest rates by the survival rate of individuals during the previous hunting season). Parameters estimated by Gauthier *et al.* (2001) were $a = 0.926$, $b = 1.207$, and $r = 0.95$. However, a recent modelling exercise using the Kalman Filter (Gauthier and Lebreton 2004) showed that the impact of harvest on survival may have been slightly overestimated by Gauthier *et al.* (2001). When information from population size was brought into a likelihood function combining census and demographic information, the best fit was obtained with the following parameter values: $a = 0.935$, $b = 1.100$, $r = 0.943$. The latter parameter values were thus used in the current model.

Juvenile survival and harvest rate

Similarly to adults, we partitioned the 10-month survival rate of juveniles into seasonal components as follows:

$$S_J = S_J^M \; S_J^F \; S_J^W \; S_J^P$$

Because juveniles are banded in early August, their "summer" period was reduced to two months (August and September), which corresponds to the fledging period in the Arctic and the first leg of the fall migration. We thus used the superscript M to refer to this period in juveniles. The three other seasonal periods were identical to those for adults. For juveniles, we also assumed that hunting was additive to natural mortality, but we had no estimates of the parameters relating harvest to annual or winter survival as in adults. However, if we assume that $a = b$ in the relationship between survival and harvest under a scenario of complete additivity (Burnham and Anderson 1984), then we have:

$$S_J = a_J (1 - HR_J) \qquad \text{and} \qquad a_J = S_J \big/ (1 - HR_J)$$

We estimated a_J from the previous equation for a number of years for which an estimate of juvenile survival (S_J), starting at fledging, was available from band recovery analyses (1990–1996, from Menu *et al.* 2002), in combination with independent estimates of juvenile harvest rate in those years. Because the first-year survival of Menu *et al.* (2002) covered a full year whereas juvenile survival in our model covered only 10 months (see above), we estimated S_J as $S^{10/12}$. The parameter a_J, which represents juvenile survival in the absence of harvest, is likely to vary between years due to high and variable fall migration mortality (Menu *et al.* 2005). Natural mortality of juveniles is generally high in years of poor breeding (due to late hatching and poor gosling growth) and low in good breeding years (due to early hatching and good gosling growth). We thus estimated three values of a_J, each corresponding to three contrasting conditions of quality of reproduction described above. In order to do so, we calculated average survival and harvest observed in good, average, and poor years of reproduction and estimated a_J for these three contrasting situations. Estimates of a_J were 0.755 (good), 0.740 (average), and 0.468 (poor). For reasons of parsimony, we used the mean from these values in our model ($a_J = 0.654$).

A further complication with juvenile survival is that natural mortality cannot be assumed to be constant over their first year, as in adults. On the contrary, natural mortality is much higher shortly after fledging and

during the early fall migration period than during the rest of the winter (Francis *et al*. 1992; Menu *et al*. 2005). In the absence of precise partitioning of the natural mortality between these periods, we assumed that 80% of the natural mortality of juveniles is concentrated during the fall migration and the rest equally spread over the rest of the year based on the migration mortality estimates of Menu *et al*. (2005). We thus estimated juvenile survival during fall migration as:

$$S_J^M = a_J^{4/5} = 0.738$$

and the parameter a_J used in modelling the relationship between harvest and juvenile survival in the other seasons became a_{J*}:

$$a_{J*} = a_{J*}^{1/5} = 0.927$$

We thus expressed juvenile survival in each hunting season as follows:

$$\begin{aligned} S_J^F &= a_{J*}^{2/8}\left(1 - HR_J^F\right) \\ S_J^W &= a_{J*}^{4/8}\left(1 - HR_J^W / S_J^F\right) \\ S_J^P &= a_{J*}^{2/8}\left(1 - HR_J^W / \left(S_J^F S_J^W\right)\right) \end{aligned}$$

Harvest rate

Harvest for this population was obtained from the National Harvest Survey conducted annually by CWS and the USFWS (Appendix A). Age-specific harvest rate was estimated by calculating the ratio of the number of adults (or juveniles) harvested to the fall population size of adults (or juveniles) (for details, see Gauthier *et al*. 2001; Menu *et al*. 2002). The size of the adult population in fall is calculated by multiplying the population from the previous spring survey by spring to fall survival (0.96). The size of the juvenile population in fall was estimated by multiplying the adult population by $p/(1-p)$, where p is the proportion of young in the fall flock. We made these calculations separately for fall harvest in Québec, winter harvest in the United States, and spring harvest in Québec.

Menu *et al*. (2002) showed that, although the harvest rate of Greater Snow Geese fluctuated annually, it did not show any long-term trend for the period 1985–1997. We thus used the average fall and winter harvest rates over these years as our "reference" seasonal harvest value (i.e. harvest rate before the implementation of special conservation measures). Similarly, we used the average fall, winter, and spring harvest rates over the period 1998–2002 as our seasonal harvest values after the implementation of special conservation measures. The harvest rate values used are presented in Table 2-3

Table 2-3. Average harvest rates used in the model.

		Québec (Fall)	U.S.A. (Winter)	Québec (Spring)
Adults	**1985-1997**	0.0350	0.0258	0
	1998-2002	0.0455	0.0416	0.0469
Juveniles	**1985-1997**	0.2448	0.0872	0
	1998-2002	0.2507	0.1349	0.0472

Statistical analysis

Annual rate of population growth (λ) was calculated analytically as the largest positive eigenvalue of the transition matrix. When required, we used Monte Carlo simulations (1000 time steps repeated 10 000 times). All calculations and simulations were done with the software ULM 4.0 (Legendre and Clobert 1995). To compare the projected growth rate with the observed growth rate of the population, we used the stochastic growth rate estimator (Caswell 2001):

$$\ln(\lambda) = \frac{\ln(N_t) - \ln(N_0)}{t}$$

where N_t is population size at the end of the period, N_0 is population size at the start of the period, and t is the number of years included in the period.

RESULTS

Using average harvest rates observed during 1985–1997, the model predicted an annual growth rate λ of 1.078 from 1985 to 1998. The observed growth rate of the population during the same period was 1.094 (or 1.084 if we used the population estimate without the telemetry correction in 1998). In comparison, if we use the prevailing harvest rate during the period 1998–2002 (i.e. during the implementation of special conservation measures) and we include a negative impact of hunting on fecundity, the model predicts $\lambda = 0.920$ from 1999 to 2003. The observed growth rate during this period was 0.922. Therefore, this suggests that the model performed relatively well in predicting the growth rate of the population during these two contrasting periods, despite a slight underestimation of λduring the period of exponential growth of the population.

We then examined the contribution of the spring conservation harvest to the recent reduction in λ (Table 2-4). Without spring harvest, the growth rate of the population should have been 1.036 during the period 1999–2003. This suggests that the spring harvest contributed 73% of the observed reduction in growth rate. The spring harvest not only increased mortality but also reduced fecundity. The model suggests that 47% of the reduction in growth rate due to the spring harvest was actually an indirect consequence of the concomitant reduction in fecundity, the remainder being due to increased mortality. As geese become accustomed to the presence of hunters in spring, they may modify their behaviour, and thus the negative impact of disturbance due to the spring harvest on fecundity may diminish. However, even if this impact on fecundity were to disappear completely, the current harvest level observed in spring would be barely sufficient to maintain the population decline ($\lambda = 0.970$).

A long-term management goal will be to maintain the population at a fixed level, that is, to have a $\lambda = 1.0$, once a desirable population level is reached. All scenarios examined indicate that the presence of a spring harvest would lead to a negative growth rate, even if the harvest were present only in alternating years ($\lambda = 0.9779$; Table 2-4). In contrast, complete removal of the spring harvest, while U.S. regulations remain as they are, would result in population growth, albeit at a lower rate than before; this is because of the recent increase in harvest rates during the regular hunting seasons due to the implementation of special conservation measures in Canada (electronic calls, baiting, sneaking). We therefore examined how much harvest rate would have to increase during the regular hunting season to maintain a stable population in the absence of a spring harvest (Table 2-5). Analysis of the recent impact of special conservation measures on harvest rates during regular hunting

seasons showed that the impact of these measures was most pronounced on adults, with little or no impact on juveniles. Therefore, we considered increases in adult harvest rates only. If additional measures were implemented in Canada and the United States, the harvest during both regular hunting seasons would have to increase by about 33% to maintain a stable population (Table 2-5). If measures were implemented in Québec alone, a 69% increase in harvest would be required to stabilize the population. In contrast, if changes were to be made in the United States only, then the increase in the U.S. harvest alone would have to be 73%.

Table 2-4. Effect of various scenarios with and without special conservation measures on projected growth rate of the population.

Scenario	Growth rate (λ)	Characteristics
A	1.0779	No conservation measures (situation between 1985 and 1998)
B	0.9204	Situation between 1999 and 2003 with the implementation of special measures
C	0.9699	With a spring harvest but no reduction in fecundity
D	0.9779	With a spring harvest in alternating years and reduction in fecundity
E	1.0355	Without a spring harvest but with special measures maintained during the regular season

Table 2-5. Increase in adult harvest rate above the level observed during the regular hunting seasons in Québec and the United States (1998–2002) that would be required to maintain a stable population ($\lambda = 1.0$).

Scenario	Québec (Fall)		U.S.A. (Winter)		Characteristics
	Harvest rate	% change	Harvest rate	% change	
F	0.077	69 %	0.042	0	Increase in harvest in Québec only
G	0.046	0	0.072	73 %	Increase in harvest in United States only
H	0.062	36 %	0.056	35 %	Similar increase in harvest in Québec and the United States

Conclusion

These population projections, when used properly, can help in developing future management strategies and improve conservation of the species. Interpretation and use of the results from such models need to consider the fact that they are projections as opposed to predictions. Most importantly, population projections from these models assume that future conditions will be similar to those in the past for a given scenario because parameter estimates used in the model remain the same. In the particular case of this analysis, we must therefore assume at the minimum that 1) behaviour of geese does not change over time, 2) hunting pressure (e.g. number of active hunters) remains stable for a given set of regulations, and 3) hunter success rate is maintained. However, it is obvious that we cannot predict with certainty how goose behaviour will evolve in the future because, in the past, geese have proven to be very adaptable to changing conditions. Two striking examples are their adaptation to feeding in farmland following large-scale agricultural changes and, more recently, a trend towards reduced impacts of spring harvest on fecundity, possibly a result of changes in goose behaviour during spring staging. Regarding the second assumption, the number of waterfowl hunters in Québec appears to have stabilized in recent years after being in decline for several decades. However, hunter participation in the spring harvest has declined, and there is concern that spring harvest rates may not be sustained in the future at the level they were during the 1998–2003 period. The general uncertainty regarding population processes and harvest clearly shows the importance of long-term monitoring and frequent updating of models used to inform management strategies.

Results from these models are also sensitive to the accuracy of parameters that are used in the models. The model assumes no density-dependent effects on demographic parameters, an assumption that is valid at current population levels but may not be valid at higher population sizes. Also, the only available demographic data for Greater Snow Geese come from the ongoing population study at the Bylot Island colony. Because this colony represents 15% of the total breeding population, it is possible that parameters estimated from this site may not apply throughout the breeding range of the species. However, the projected population growth rate from the model tracked growth rate of the population, as measured by the spring inventory, very well both for the period preceding the implementation of special conservation measures and for the period in which these were applied up to 2003. Assuming that population growth was accurately measured with the spring aerial survey, this suggests that the structure of the model and the parameters used were representative of the entire population.

Finally, an important limitation with our study is the fact that several regulatory changes often occurred simultaneously. Because we measure harvest only on a seasonal basis (total harvest or harvest rate), it is impossible to separate the effects of individual changes in regulations acting simultaneously. An example of this is the situation that has been in place since 1998–1999, when special conservation measures were put in place. Although it is possible to quantify the effects of the conservation measures in spring as a whole, it is not possible to disentangle the effects of individual measures such as the use of electronic calls or baiting. The situation during the fall hunting season is even more problematic, because we were unable to separate the contribution of special conservation measures (electronic calls, baiting, and extension of fall season over the 107-day limit) from that of changes to the normal regulations (bag limit, sneaking). This limits our ability to accurately project population growth in the absence of special conservation measures, as we cannot estimate what fall harvest would be in their absence.

Despite these limitations, population projection matrix models can be powerful management tools. The first version of the model presented here (Gauthier and Brault 1998) and a similar one developed for midcontinent Lesser Snow Geese (Rockwell *et al*. 1997) were instrumental in directing conservation actions that would have the greatest impact on population growth rate. The original Greater Snow Goose model indicated that a doubling of adult harvest would result in a stabilization of the population and that this effect would be greatest if adult harvest in particular were increased. The implementation of special conservation measures achieved a doubling of the harvest for adults, and, as projected by the model, the growth of the Greater Snow Goose population has been stopped.

Summary: Projected growth rate of the Greater Snow Goose population under alternative harvest scenarios

- The population model accurately predicted population growth rate before and after the implementation of special conservation measures. Without conservation measures, the model predicted that the population would have grown at a rate of 7.8% annually. With conservation measures in place, it predicted an annual decline of 8.0%.

- The spring harvest had the greatest influence on the reduction of the growth rate, mainly through mortality of adults and a reduction in fecundity.

- All scenarios that included a spring harvest resulted in a projected reduction of the population growth rate, even if the spring harvest were to occur only in alternating years.

- Significant increases in present-day adult harvest rates during fall and winter would be required to maintain a stable population in the absence of a spring conservation harvest.

CONCLUSION

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Recommendations of the 1998 Arctic Goose Joint Venture Greater Snow Goose Habitat Working Group (Batt 1998) resulted primarily in the establishment of special conservation measures in Canada, which included a spring harvest in Québec. This latter represents a landmark change in game bird regulations by allowing, for the first time since the signing of the *Migratory Birds Convention Act* in 1916, harvest of migratory game birds in spring. Additional special measures included the use of electronic calls, the use of baiting, and a 10-day extension to the fall hunting season in Canada. Furthermore, sport harvest was liberalized in fall in Québec and in winter in the United States (i.e. during the normal 107-day regulatory period), by increasing bag limits and allowing stalking as an additional hunting technique.

Most recommendations dealing with population and habitat monitoring in the 1998 report were maintained or implemented. For example, a study carried out by Béchet *et al*. (2004a) allowed refinements to the spring population survey by developing a method for reducing detection bias inherent in the population size estimate through the use of telemetry data. This was needed because disturbance caused by the spring harvest and the scaring campaign in agricultural fields increased bird dispersion in southern Québec. However, considering the recent eastward and northward changes in the distribution of geese staging in southern Québec, a new research project that will monitor the distribution and movements of geese fitted with satellite telemetry transmitters will be initiated in 2006. Results from this study should allow more accurate annual estimates of the spring population size by assessing the proportion of geese that are missed during fixed-wing surveys. This project will also lead to a better understanding of current migratory routes and distribution of Greater Snow Geese on their Arctic breeding grounds since the recent population increase. A method for counting the number of geese in flocks using digital imagery analyzed with specialized software is also under development and will contribute to reduced observer bias during spring surveys.

Trends in the spring population size over the last few years indicate that the conservation actions implemented in 1998–1999 have been successful in halting the growth of the population, which now numbers between 800 000 and one million individuals. It is also likely that the population has started to decline from the peak values recorded at the start of the management actions in 1998–1999, but uncertainty related to changes in the survey methodology in recent years prevents making a definite statement about such a decline. Stabilization of the population at this level was one of the main suggestions of the previous working group (Batt 1998). In spite of this stabilization of population growth rate since 1998–1999, it appears that the environmental conditions that have led to the overabundance of geese are still present and may even be increasing in eastern North America. These environmental conditions include global warming (milder summers on the Arctic breeding grounds) and increasing acreages of cornfields near staging and wintering grounds. These conditions are likely to result in better individual body condition of geese and a concomitant reduction in natural mortality rates (Gauthier *et al*. 2005). All of these changes suggest that a cautious approach is always justified in the management of this population. Batt (1998) warned that a population size greater than one million individuals could cause serious ecological damage to habitats used by Greater Snow Geese and that it would be increasingly difficult to manage such a large population. This conclusion leads directly to the recommendation of implementing measures to stop the growth of the population. Despite the success of the special conservation measures in achieving this goal thus far, it appears that many of the conditions that led to the conclusion of the working group in 1998 still prevail today.

It was also recommended that a target population size be established once the population had been stabilized (Batt 1998). It was suggested that a scientific evaluation of the carrying capacity of all natural habitats used by geese be carried out to guide the determination of this target population size. Unfortunately, carrying

capacity has not yet been determined for staging and wintering habitats, and this lack of information limits the possibility of including this important aspect of Greater Snow Goose biology in its actual management. Only the carrying capacity of Arctic breeding habitats has been estimated so far (Massé *et al.* 2001). However, a five-year study endorsed and funded by the Arctic Goose Joint Venture was initiated in 2004 to continue and improve past studies on the condition of bulrush marshes used by geese during migratory stopovers. The study aims at evaluating possible effects of a reduction in plant primary productivity (e.g. >60% over the past 25 years at Cap Tourmente National Wildlife Area) and changes in the composition of plant communities on the ecological integrity of bulrush marshes. Impacts of marsh degradation on other wildlife species and the marshes' lower overall contribution to the primary productivity of the St. Lawrence estuary's food chain still need to be determined.

As recommended in the previous scientific evaluation report (Batt 1998), an improved understanding of social and economic benefits derived from the presence of geese on their staging and wintering grounds has been gained in recent years. The demographic explosion of the Greater Snow Goose over the past decades has resulted in a dramatic increase in hunting, bird-watching, and ecotourism opportunities (festivals, interpretation centres, etc.). A recent study of the socioeconomic impacts of the presence of staging Canada Geese and Greater Snow Geese over the last five years in Québec has shown that direct and indirect economic benefits represent approximately $31 million. On the other hand, estimated costs of activities related to Greater Snow Goose management represent approximately $1.6 million. These costs are incurred by wildlife agencies and university researchers who conduct surveys and related ecological studies and by agricultural partners that implement the crop damage prevention program and compensate farmers for their losses (Groupe conseil Genivar inc. 2005).

The local economic benefits associated with the presence of geese on their staging and wintering grounds are thus significant and must be taken into account in the development of a sustainable resource development framework. A study was initiated in the spring of 2005 with the aim of determining a suitable target population size for Greater Snow Geese in North America based on ecological and social considerations (Bélanger *et al.*, in prep.). To achieve this objective, a cost–benefit approach was used to compare different management scenarios based on continental population size during the last four decades. The analysis included available data on current knowledge of the carrying capacity of the natural habitats, on the potential of hunting regulations as a management tool, and on social benefits stemming from the presence of geese on their staging and wintering grounds. Preliminary results show that a population ranging from 500 000 to 750 000 brought optimal benefits to the society. However, a more thorough analysis that will also consider new data, particularly for wintering grounds, is necessary before final conclusions can be drawn.

Of all the special conservation measures implemented in 1998–1999, the spring conservation harvest in Québec, which was intended to be temporary until the population was once again under control, was the most effective at reducing population growth through its direct (survival) and indirect (fecundity) effects on adult breeders (Calvert and Gauthier 2005). Under the current hunting regulations in Québec and the United States, harvest models developed in this report indicated that the 2004 North American Waterfowl Management Plan (NAWMP) goal of 500 000 birds would not be reached by 2010 (Fig. 3-1). This will be particularly true if the expected decline in the spring harvest in Québec and the attenuation of the indirect effects of disturbance are confirmed. Recent statistics for both the number of hunters and the total number of geese harvested in spring in Québec during the conservation harvest tend to show a decline in the effectiveness of this measure as a tool to control population size (P. Brousseau, CWS, unpubl. data). Moreover, attenuation of the indirect effects of disturbance (from both the spring harvest and scaring activities) on the fecundity of geese is now becoming evident (G. Gauthier, Université Laval, unpubl. data).

The population model presented in this report suggests that following the complete closure of the spring conservation harvest, a stabilization of the population would require an increase in total harvest of 33% during all regular hunting seasons or an increase in the Québec or the U.S. harvest alone by as much as 66%. However,

data reviewed in this report and those recently available tend to indicate that the total Canadian harvest (spring conservation and fall sport harvests combined) cannot be increased considerably in Québec over the next few years (Calvert and Gauthier 2005). Therefore, the only sustainable management solution to control the size of this population in North America in the medium and long terms would be to substantially increase harvest in the United States. However, the regular season in the United States is already very liberal and extends for the entire 107 days allowed by the *Migratory Birds Treaty Act*. Implementation of special conservation measures in the United States, particularly as a late winter/spring conservation harvest, would thus be required to increase the overall harvest of Greater Snow Geese. If conservation measures were put in place in the United States, the major Greater Snow Goose harvest states in the Atlantic Flyway (Delaware, Maryland, New Jersey, New York, Pennsylvania, Virginia, Vermont) have all expressed interest in participating in a conservation order on Snow Geese, and all states feel that they could have a significant effect on Snow Geese in years with good production. There are some caveats to participation, largely how the harvest would be monitored and assessed. If it can be assessed through existing surveys (HIP), most of the concerns with administration would be alleviated. North Carolina would not participate in a conservation order, nor would it likely participate with increased regular hunting season measures. With regards to increased regular hunting season measures, all the states except for New York and Vermont feel that significant increases in harvest could occur.

In light of the results presented in this evaluation of special conservation measures for Greater Snow Geese, and considering the projections of population growth derived from the population models developed in section II of this report, as well as the anticipated impacts of the various environmental factors mentioned above, the working group suggests that:

1. methods to obtain unbiased continental population size estimates be developed using annual correction factors. This could be accomplished through the use of satellite telemetry technology;

2. the existing long-term habitat and population monitoring be maintained or enhanced, and, notably, that the ecological carrying capacities of staging and wintering natural habitats used by geese be assessed and the ecological integrity of other Arctic nesting colonies and densely used moulting sites be investigated;

3. the expected impacts of environmental factors, such as the impact of climate change on goose mortality, be investigated and their role in the overall goose population dynamics be better understood and predicted over the long term;

4. that a harvest management strategy for the Atlantic Flyway consider a substantial increase in U.S. harvest, as this appears to be the only sustainable management solution to control the size of this population at or around the current NAWMP goal of 500 000 birds;

5. a cost–benefit study to determine a suitable target population size for Greater Snow Geese in North America based on ecological and social considerations be conducted during this transition phase towards reaching the NAWMP goal. The analysis should integrate data, yet to be collected, on the carrying capacity of natural habitats;

6. the scientifically based management approach successfully used over the last decades for the Greater Snow Goose be pursued (i.e. with a periodic scientific evaluation scheduled at 5- to 10-year intervals) within an adaptive management framework considering the rapid and often unpredictable behavioural responses of geese to changing environmental and harvest management conditions in place.

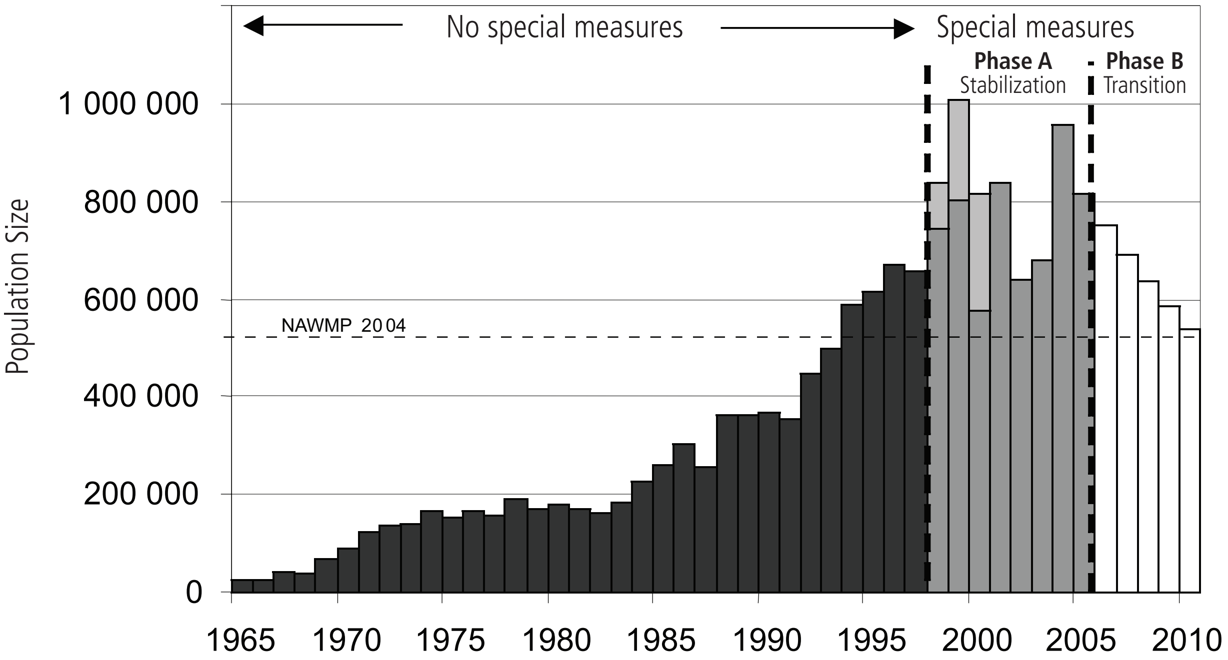

Figure 3-1. Population size of the Greater Snow Goose in North America as determined from spring aerial surveys from 1965 to 2005 and as predicted by the harvest model from 2006 to 2010 including present U.S. and Canadian hunting regulations (e.g. liberalized bag and possession limits, spring conservation harvest in Québec). The horizontal dashed line indicates the 2004 NAWMP goal of 500 000 birds.

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APPENDICES

Appendix A. Total number of adult and juvenile Greater Snow Geese harvested, by hunting season, from 1968 to 2002; note that the Atlantic Flyway winter hunt opened only in 1975, and the Québec spring harvest in 1999 (at the end of the 1998 season). Data are from the CWS and the USFWS (unpubl.). U.S. numbers are from the duck stamp survey except for 2002, when they were estimated from the Harvest Information Program (HIP).

	QUÉBEC (FALL)		ATLANTIC FLYWAY (WINTER)[1]		QUÉBEC (SPRING)		TOTAL ANNUAL	
Year	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles	Adults	Juveniles
1967[2]		16 800						16 800
1968	975	1 725					975	1 725
1969	1 028	2 272					1 028	2 272
1970	4 252	21 048					4 252	21 048
1971	4 361	8 939					4 361	8 939
1972	5 304	796					5 304	796
1973	1 965	24 235					1 965	24 235
1974	5 389	3 611					5 389	3 611
1975	5 690	33 289					5 690	33 289
1976	12 763	16 336	9 098	3 002			21 860	19 339
1977	1 779	18 914	8 571	13 629			10 351	32 542
1978	10 160	33 121	12 108	7 992			22 268	41 113
1979	7 517	20 971	16 092	11 908			23 609	32 879
1980	13 273	58 138	9 647	17 653			22 920	75 791
1981	9 848	18 218	6 585	6 915			16 433	25 133
1982	10 503	31 825	12 191	9 509			22 694	41 334
1983	5 960	40 227	10 745	29 655			16 704	69 883
1984	12 089	36 024	17 327	20 273			29 416	56 297
1985	8 267	16 781	7 872	6 928			16 139	23 709
1986	8 204	2 872	7 607	1 293			15 811	4 165
1987	5 871	34 055	8 074	20 426			13 945	54 481
1988	11 165	34 611	7 867	15 733			19 032	50 344
1989	16 617	28 748	7 435	9 665			24 052	38 413
1990	22 427	39 022	12 647	8 853			35 074	47 875
1991	8 871	42 406	9 231	17 169			18 102	59 575
1992	20 890	6 685	9 123	1 277			30 013	7 962
1993	14 732	90 455	9 325	21 075			24 057	111 530
1994	27 114	14 641	10 173	7 427			37 287	22 068
1995	14 360	36 761	11 090	6 210			25 450	42 971
1996	18 510	51 086	20 194	11 106			38 703	62 193
1997	13 096	50 811	12 626	22 474			25 722	73 285
1998	31 754	71 763	43 320	67 580	27 607	16 564	102 681	155 907
1999	39 967	3 597	38 431	769	53 769	807	132 168	5 172
2000	37 303	71 996	17 636	27 864	37 976	11 794	92 915	111 654
2001	31 549	66 885	28 684	36 716	44 599	27 205	104 832	130 806
2002	34 829	13 758	30 941	8 354	22 169	466	87 940	22 577

1. There was a harvest of 9200 birds in the United States in 1975, but the age ratio was unknown. These data are therefore not shown.
2. There is no age-specific information available for 1967. The number thus represents the total number of Greater Snow Geese harvested.

Appendix B. Productivity indices for Greater Snow Geese, based on visual estimates of flocks. The proportion of juveniles in the flight (with sample size) and brood size (number of broods) are shown as estimated from fall surveys in the St. Lawrence estuary of Québec from 1973 to 2004 and winter surveys in the Atlantic Flyway from 1956 to 2002. Data are from Reed et al. (1998 and references therein), A. Reed (unpubl.), and U.S. Department of the Interior (2004).

Year	Québec visual survey				Atlantic Flyway visual survey	
	Proportion of juveniles		Brood size		Proportion of juveniles	
1956					33.8	
1957					34.4	
1958					3.1	
1959					42.7	
1960					34.1	
1961					1.2	
1962					28.4	
1963					33.9	(2 728)
1964					20.5	(8 179)
1965					2.8	(2 524)
1966					37.0	(5 516)
1967					12.4	(5 236)
1968					12.5	(3 613)
1969					24.3	(5 004)
1970					46.8	(6 930)
1971					11.3	(8 334)
1972					0.4	(3 214)
1973	40.6	(800)	2.94	(49)	41.1	(4 900)
1974	6.4	(7 282)	2.19	(119)	2.0	(6 148)
1975	31.2	(17 579)	2.71	(1 294)	37.3	(11 460)
1976	12.6	(20 847)	2.46	(419)	9.8	(34 892)
1977	23.9	(10 297)	2.28	(396)	23.8	(7 531)
1978	17.9	(9 679)	2.34	(309)	14.7	(16 159)
1979	28.2	(20 849)	2.65	(1 226)	23.2	(8 041)
1980	35.3	(12 120)	2.76	(651)	36.3	(12 140)
1981	16.3	(10 683)	2.30	(229)	17.0	(17 229)
1982	25.1	(9 577)	2.48	(661)	23.8	(12 773)
1983	47.4	(12 353)	2.86	(1 246)	48.9	(19 206)
1984	30.4	(39 781)	2.63	(2 434)	27.4	(11 133)
1985	25.8	(33 700)	2.49	(1 682)	31.0	(14 972)
1986	2.3	(22 998)	1.89	(74)	2.3	(13 109)
1987	40.2	(33 278)	2.77	(1 882)	37.9	(17 467)
1988	33.1	(40 246)	2.76	(2 444)	31.2	(14 467)
1989	31.1	(29 191)	2.59	(2 014)	30.1	(17 735)
1990	23.6	(20 313)	2.54	(830)	17.2	(24 439)
1991	38.3	(15 102)	2.69	(1 247)	26.2	(27 805)
1992	5.4	(32 252)	2.06	(404)	4.5	(10 501)
1993	47.8	(24 136)	2.75	(2 743)	44.6	(23 082)
1994	9.2	(16 444)	2.44	(242)	13.4	(19 726)
1995	16.6	(19 519)	2.47	(665)	13.3	(13 221)
1996	25.1	(22 595)	2.34	(1 247)	30.5	(23 728)
1997	36.8	(17 586)	2.69	(1 222)	28.7	(30 905)
1998	33.1	(17 982)	2.52	(1 440)	26.5	(43 321)
1999	2.1	(20 822)	2.09	(91)	2.8	(21 619)
2000	22.7	(26 492)	2.54	(1 302)	34.6	(25 022)
2001	27.5	(22 106)	2.36	(1 072)	21.2	(12 646)
2002	6.0	(18 930)	1.91	(274)	2.8	(20 444)
2003	27.0	(15 900)	2.36	(1 092)	15.8	(9 201)
2004	17.8	(26 206)	2.44	(1 031)	12.1	(33 748)

Appendix C. Hunting districts for migratory birds in Québec (from CWS Waterfowl Committee 2001a).