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Rapid Growth of a Nesting Colony of Lesser Snow Geese (*Chen caerulescens caerulescens*) on the Ikpikpuk River Delta, North Slope, Alaska, USA

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Abstract.—A small colony of nesting Lesser Snow Geese (*Chen caerulescens caerulescens*) was discovered on the Ikpikpuk River delta in 1992. The number of nesting pairs averaged 35 (Range = 0-60) from 1992 to 1998, then increased dramatically from 176 in 1999 to 12,373 in 2015, for a λ of 1.40 (SE = 0.138). Concomitant with this dramatic population increase, the geographic extent of the colony expanded annually from three small islands in the northwestern portion of the delta during 1992-1999 to all vegetated deltaic islands in 2001 and farther inland on the mainland from 2006 onward. When colony growth was most rapid (2001-2008), nesting success averaged 79% (Range = 48-97%). Low nesting success during 2009-2014 (< 50% in all years except one), primarily caused by brown bears (*Ursus arctos*), was followed in 2015 by 96.6% success. In 2015, ~22,000 adults (in both brood-rearing and adult-only flocks) were accompanied by more than 25,000 goslings in July and August. These numbers represent a remarkable increase in the abundance of Snow Geese west of the Colville River, where only 15 years previously fewer than 500 birds nested. Both immigration and high productivity probably have contributed to colony growth, although the relative importance of effects of the two factors in this growth has not been determined. Further analyses may provide insights into population relationships and the management implications of rapid local and regional growth of Snow Goose populations in northern Alaska. *Received 9 July 2015, accepted 30 July 2016.*

Key words.—Alaska, *Chen caerulescens caerulescens*, Ikpikpuk River, Lesser Snow Geese, nesting, Western Arctic Population.

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Early in the 20th century, Lesser Snow Geese (*Chen caerulescens caerulescens*; hereafter, Snow Geese) were reported to be "common breeders" along the northern coast of Alaska (Bailey 1948; Gabrielson and Lincoln 1959), and at least one reference suggested the existence of a colony of Snow Geese near Barrow (Bailey *et al.* 1933). By mid-century, however, Snow Geese were relatively uncommon on the coastal plain north of the Brooks Range in Alaska (hereafter, the North Slope) during the breeding season (King 1970; Ritchie *et al.* 2000), although large numbers (often hundreds of thousands of birds) staged annually in autumn on the North Slope in the eastern portion of the Arctic National Wildlife Refuge, just west of the USA-Canada border (Robertson *et al.* 1997; Hupp *et al.* 2002). In the mid-1980s, probably fewer than 300 pairs of Snow Geese nested annually across a broad area of Alaska's Beaufort Sea coast, most occupying a small colony that was discovered in 1971 on Howe Island in the Sagavanirktok River delta (Johnson and Herter 1989).

During various waterfowl survey efforts in the late 1980s and early 1990s, we observed that Snow Geese appeared to be increasing in abundance at several sites across the North Slope. In an effort to assess our belief that Snow Geese were increasing in abundance, we conducted aerial surveys in coastal areas across much of the western Beaufort and northern Chukchi Seas in 1992 and 1993. Although those surveys documented scattered nesting pairs and small clusters of Snow Geese in coastal areas, they appeared to verify earlier assessments that breeding Snow Geese were relatively uncommon on the North Slope of Alaska. During the initial survey in 1992, however, we located a small Snow Goose colony with about 60 nests on the Ikpikpuk River delta (Ritchie *et al.* 2000) and have continued to monitor increasing numbers of Snow Geese in that colony and in surrounding areas.

Here, we document changes in the abundance and distribution of breeding Snow Geese at the Ikpikpuk River delta colony and in adjacent coastal brood-rearing and molting habitats in Smith and Harrison Bays, including data on numbers and distribution of nests, hatching success and brood-rearing distribution.

METHODS

Study Area

The Ikpikpuk River empties into Smith Bay along the Beaufort Sea coast in northern Alaska (105 km southeast of Barrow), forming a delta composed of numerous low relief islands, thaw lakes, and mudflats (Fig. 1). With headwaters in foothills of the central Brooks Range, most of the Ikpikpuk River basin is part of the Arctic Coastal Plain Ecoregion (Gallant *et al* 1995; Nowacki *et al.* 2001), bounded on the north by the Beaufort Sea and on the south by the Arctic Foothills Ecoregion. The Ikpikpuk River delta is dominated by wet graminoid/herbaceous plant communities and unvegetated mudflats. Arctic coastal salt marsh vegetation is extensive on the outer delta. Snow Geese have been recorded nesting primarily on vegetated deltaic islands, many of which are dominated by ice-wedge polygons, which provide fairly consistent protection from flooding during spring breakup and micro relief for nesting sites. In recent years, nesting has also occurred on tundra habitats south of the delta, less often affected by flooding. Brood-rearing areas span about 145 linear km of Beaufort Sea coastal tundra habitats, from the colony northwest at least 40 km to Admiralty Bay and east as far as 100 km to the Kogru River in Harrison Bay.

Nesting Surveys

Aerial surveys were conducted annually during nesting at the Ikpikpuk colony from 1992 to 2015. All pairs of Snow Geese on the ground, either standing or with one bird incubating, were considered to represent nesting pairs (Kerbes 1982). Observations confirm that nesting male Snow Geese attend the incubating female, particularly during disturbances, and that aircraft flying above ~250 m rarely cause birds of either sex to flush from nest sites (Kerbes 1982). Single birds on the ground were uncommon, but were considered to represent nests if they occurred in habitats and landforms used for nesting, such as rims of low-centered polygons. Single birds were not considered to represent nests when they occurred on water or at sites not typically used for nesting, such as barren mudflats or wet riverbanks. Birds in flight and small flocks on the ground were considered to be non- or failed-breeders.

With few exceptions, all nesting surveys were flown by Cessna 185 aircraft during the third week of June. During 1992-2004, surveys were flown at 95-140 kmph

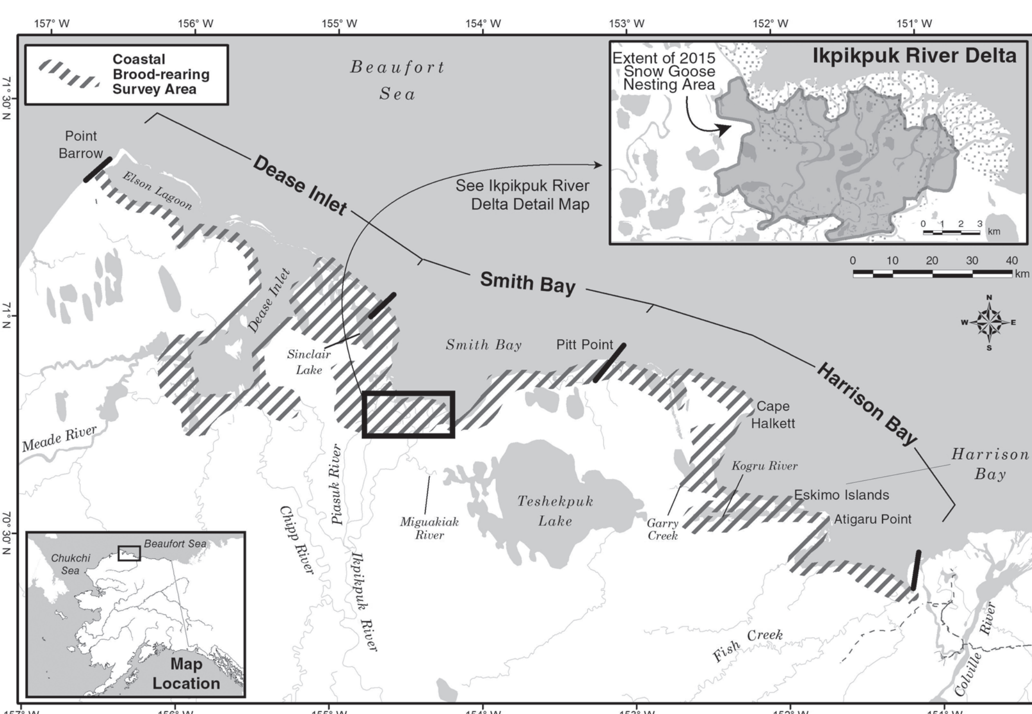

Figure 1. Survey areas for nesting and brood-rearing Lesser Snow Geese, Barrow to Fish Creek, 1992-2015.

and ~50-100 m above ground level (agl). Starting in 2005, higher altitudes (~300 m agl) were maintained during surveys as a precaution to prevent disturbance as the colony increased in size. During all surveys from 1992-2009, two observers positioned on opposite sides of the aircraft recorded counts of all adults and nests.

As the size of the Ikpikpuk colony increased, estimating nesting pairs from an aerial survey became increasingly difficult and, in 2009, we initiated an annual photographic census to count nests more accurately. Prior to photographic census each year, observers surveyed the extent of the colony and attempted to count the numbers of nests (i.e., pairs on the ground) and flying birds, as in previous years. In 2009, a single observer attempted to photograph all nests from an aircraft flying a systematic pattern of parallel transect lines ~400 m apart. The method was improved in 2010 and subsequent years by doubling the number of transect lines at ~200 m separation. Photographic censuses were conducted in a Cessna 185 aircraft with a belly mounted camera and aerial photography view port, flown at about 120-180 kmph ground speed and 305 m agl. The pilot used an onboard geographic positioning system (GPS) to follow predetermined flight track lines covering the entire breeding distribution of Snow Geese in the area. Flight tracks were recorded continuously (location intervals were 3 sec in 2015 and between 4 and 30 sec in previous years), both on the pilot's GPS and on a hand-held GPS operated by the observer. We used a Canon EOS 40D digital SLR camera (10.1 megapixel) controlled by a laptop operated from the front seat. We used a 17-85 mm image-stabilizing camera lens, which was set to a focal length of 24-28 mm. Photographs were taken at 3- to 4-sec intervals during 2009-2014 and at 1-sec intervals in 2015. In areas not adequately covered or where photograph quality was poor, particularly in early years as we experimented with the technique, visual estimates from the air were used to supplement photographic census estimates.

Prior to 2014, time signatures (to the nearest second) associated with each photograph were used to geolocate photographs with the GPS track record. Photographs were projected onto base imagery of the Ikpikpuk River delta in ArcMap GIS software (Environmental Systems Research Institute 2011) based on the GPS flight log and the time that each photograph was taken. Using this method, individual nests could be accurately assigned to nesting islands and, with some effort, duplicate nests from overlapping photographs could be removed from counts. In 2014 and 2015, we used a cloud-based imagery processing service that used a Structure From Motion analysis (Westoby *et al.* 2012) to match points across adjacent photographs and stitch them into a seamless mosaic. Since 2009, the best estimates of the number of nests typically were obtained from the photographic census, sometimes augmented by aerial counts in parts of the colony not adequately covered by photographs.

The long-term rate of increase of the nesting population (λ) was estimated by averaging the annual rate of change ($Nt/Nt - 1$) for each year from 1999 to 2015, the period over which there were no gaps in the survey record. The standard error also was computed for the estimate.

Nest Fate Surveys

We conducted ground searches of the Ikpikpuk Snow Goose colony after hatch during 1992-1993 and 2001-2015 to count (or sample) nests, estimate colony boundaries, and assess the fate (success or failure) of Snow Goose nests. Our methods changed during this period as the colony expanded. Prior to 2008, when nesting occurred on the most readily accessible nesting islands in the western Ikpikpuk River delta, we attempted to search all nesting islands as completely as possible to enumerate and assess the fates of all nests in the colony. During 2001-2003, the best estimate of the number of nests was obtained from the ground searches, and during 2004-2009, the best estimate of the number of nests was obtained from ground searches augmented by a subsequent helicopter survey of parts of the colony that ground searchers could not access (Table 1).

During 2010-2015, we employed a stratified random sampling design to obtain unbiased estimates of nest success for the entire colony. The sampling design also provided an independent statistical estimate of the number of nests, which would be superior to photographic census in years when large numbers of nest failures occurred prior to the census (e.g., 2014). To select a stratified random sample of nest plots, we used GIS to create a systematic grid of points at 100-m intervals across the Ikpikuk River delta encompassing all known nest locations. Each of these points was used as a center point to generate circular plots with a 50-m radius. Plots with > 50% water cover (e.g., river channels, lakes) or mudflats were removed. We randomly selected 160 (2010), 278 (2011) and 250 (2012-2015) circular plots from the nesting area and adjacent, suitable habitats. Plots were selected from among three (2010) or four (2011-2015) nest density strata. In 2010, strata were derived from the 2009 nest distribution (which proved to be a poor basis for stratification); subsequently, strata were derived each year from previous photographic surveys in June. Cutpoints for strata (none, low, medium and high) were chosen arbitrarily based on the histogram of observed numbers of nests in each plot. The distribution of sample plots among strata was based on an optimal allocation formula that takes the total number of plots available and the total number of plots selected for potential sampling (e.g., 250 plots during 2012-2015) and uses the variance for each strata (estimated from the photographs) to calculate the best allocation of plots among strata (Schaeffer *et al.* 1996). In the field, we surveyed as many of these randomly selected plots as logistically possible. Each plot was searched by walking a zigzag search pattern while using a hand-held GPS for navigation to ensure that the entire plot was searched. We counted and assessed the fates of all nests found in each plot.

In all years, ground searches were conducted by two to four people during mid-July, no more than 2 weeks after hatch. Nest locations were recorded using hand-

Table 1. Counts of nests and flying adults and apparent nesting success of Lesser Snow Geese at the Ikpikpuk River delta colony, 1992-2015. Number of nests determined from aerial surveys in 1992-2000, ground searches during 2001-2003, combined aerial and ground counts during 2004-2009, aerial photographic survey during 2010-2013 and 2015, and sampling in 2014. Number of flying birds estimated during aerial survey of the nesting colony assumed to be non-breeding adults or breeders whose nests failed prior to the survey. Nesting success estimated variously as described in text; nd = not determined.

Year	Nests	Flying (Non-breeding) Adults	Nesting Success (%)
1992	60	80	7
1993	42	56	21
1994	5	10	nd
1995	55	90	nd
1996	0	0	nd
1997	50	60	nd
1998	nd[1]	nd	nd
1999	176	200	nd
2000	250	1,000	nd
2001	335	560	48
2002	918	604	63
2003	1,149	934	97
2004	1,436	28	90
2005	1,116	158	70
2006	2,386	351	86
2007	2,505	4,290	85
2008	4,641	5,116	89
2009	4,479	416	1
2010	4,769	2,330	8.5
2011	8,886	1,250	65.5
2012	5,381	2,700	49.6
2013	9,051	2,500	41.5
2014	8,321	5,700	15.4
2015	12,373	850	96.6

[1]No nest survey was conducted in 1998, but 57 pairs with young were recorded in July, confirming successful nesting probably in numbers similar to previous years.

held GPS units and marked with a small piece of wood when double counting was a concern. Nests were classified as successful if at least one eggshell fragment in the nest bowl was largely separated from a thickened shell membrane (Downing 1980), unsuccessful if eggshell fragments were firmly attached to papery shell membrane or if shell fragments were totally missing (Downing 1980), or unknown when physical evidence was equivocal.

Prior to 2010, we assumed that apparent nest success based on nests we visited was representative of the entire colony. For stratified sampling conducted 2010-2015, we calculated the total number of nests and nest success by strata and then estimated the values for the entire area using the formulas for a stratified random sample (Schaeffer *et al.* 1996) after correcting for the unsurveyed area between circular plots. We have no means of assessing the comparability of earlier estimates, but we believe that the earliest estimates of nesting success were the most accurate because the colony was small and all or most nests were examined. The accuracy of estimates of nesting success may have decreased during 2001-2009, as smaller proportions of the colony were surveyed. While areas searched appeared to be representative, some types of nest loss (such as flooding or mammalian predation) may have affected some parts of a colony more than others. With stratified random sampling throughout the nesting areas since 2010, the accuracy of estimates of nest success (and of total number of nests) has increased and confidence intervals (not presented here) can be calculated.

Brood Surveys

Aerial brood-rearing surveys were conducted annually during 1994-2015 (excluding 1998) approximately 4 weeks post-hatching, when goslings were large and easily counted. The brood-rearing survey area was divided into three sections, west to east: Dease Inlet (Barrow to Sinclair Lake), Smith Bay (Smith Bay and inland areas from Sinclair Lake to Pitt Point), and Harrison Bay (Pitt Point to the western channel of the Colville River) (Fig. 1). The surveys were flown using a Piper Supercub or Bellanca Scout fixed-wing aircraft at approximately 75-150 m agl and 120 kmph with a pilot and one observer. Observers recorded the location of each group and the numbers of adults and young. Groups with and without goslings were summarized separately. Various numbers of adults (non-breeders and failed breeders) often were flight-capable at the time of the survey, and sometimes these birds reacted to our aircraft by taking flight. Numbers were estimated for such flocks and included in totals (i.e., groups without goslings). Locations of all Snow Geese were recorded on 1:250,000 U.S. Geological Survey maps and, since 1996, by onboard GPS. All data were entered into ArcMap GIS software (Environmental Systems Research Institute 2011). Starting in 2002, aerial counts were improved by photographing, at a minimum, all brood-rearing groups of > 50 birds. In practice, many smaller groups and some groups without broods also were photographed, particularly with the advent of digital photography in recent years. Following the survey, photographs were reviewed, either projected on a screen (slide film) or on a computer screen (digital photographs), to count the number of Snow Goose adults and goslings.

Matrix Model of Population Growth

To evaluate the roles of production and immigration on growth of the Snow Goose population in the Ikpikpuk colony, we used a simple matrix model of population growth. The matrix growth model started with the number of breeding females in 1999 (because a continuous annual record starts in that year) and used the annual production of females (estimated as half the number of goslings counted during brood surveys and assuming a 50/50 sex ratio) to compare population growth under different scenarios of survival, fidelity and breeding propensity. The model accommodated up to four age-specific values of survival (female survival fledging to 1 year, 1 to 2 years, 2 to 3 years, and 3 years and over), and two age-specific values of fidelity and of breeding propensity (2-year-old females and females older than 2 years).

RESULTS

Colony Size and Growth

When first observed in 1992, the Ikpikpuk colony had about 60 nests (Table 1). The number of nesting pairs averaged 35 (Range = 0-60) during 1992 to 1998. The number of nesting pairs increased from 176 in 1999 to 12,373 in 2015, a finite growth rate (λ) of 1.40 per year (SE = 0.138; Table 1). Annual estimates showed increases exceeding 1,000 nests in 2006, 2,000 nests in 2008, 3,000 nests in 2013, and 4,000 nests in 2011 and 2015. The rate of increase in the number of nests from one year to the next exceeded 20% in 10 of 16 years from 2000 onward (no estimates are available for 1998 and 1999).

Our estimates of colony growth are complicated by nest failures that may have occurred prior to our single annual aerial survey, particularly in years when nesting success was low. Although photographic counts are precise, they may be biased low, particularly during 2009-2014, when poor nesting success was attributed to the presence of predators, particularly brown bears (*Ursus arctos*). In 2014, this bias was particularly evident because widespread nesting failure occurred prior to the photographic census, as revealed by comparison of photographic census results with observations from nest fate surveys. We consider the estimate derived from stratified random sampling to be the most accurate number of nests in that year (Table 1).

In some years, spring flooding affected nest initiation and reduced the number of nesting pairs on the Ikpikpuk River delta. Islands used for nesting in 1992 were flooded in 1993 when all nests occurred on a single elevated ridge on an adjacent partially flooded island. In 1996, high water and ice associated with spring flooding covered most of the islands then used by nesting Snow Geese. It is unknown whether Snow Geese attempted to nest or if flooding prevented nest initiation, but we saw no nests during the nesting aerial survey and few brood-rearing Snow Geese during subsequent brood-rearing surveys in 1996.

Geographic Expansion

In 1992, the majority of Snow Geese nested on three small islands in the western Ikpikpuk River delta (Fig. 2). During the aerial survey in 1993, when the outer delta was flooded, all nests were located on a fourth adjacent island. These four islands comprised the nesting area until 1999, when the colony entered a period of expansion across the delta to the south and east. By 2001, all of the vegetated deltaic islands in the area had nests on them. After 2006, when the outer delta had become occupied, some Snow Geese began to nest farther inland, in polygonized moist sedge habitats on the mainland to the south. The geographic ex-

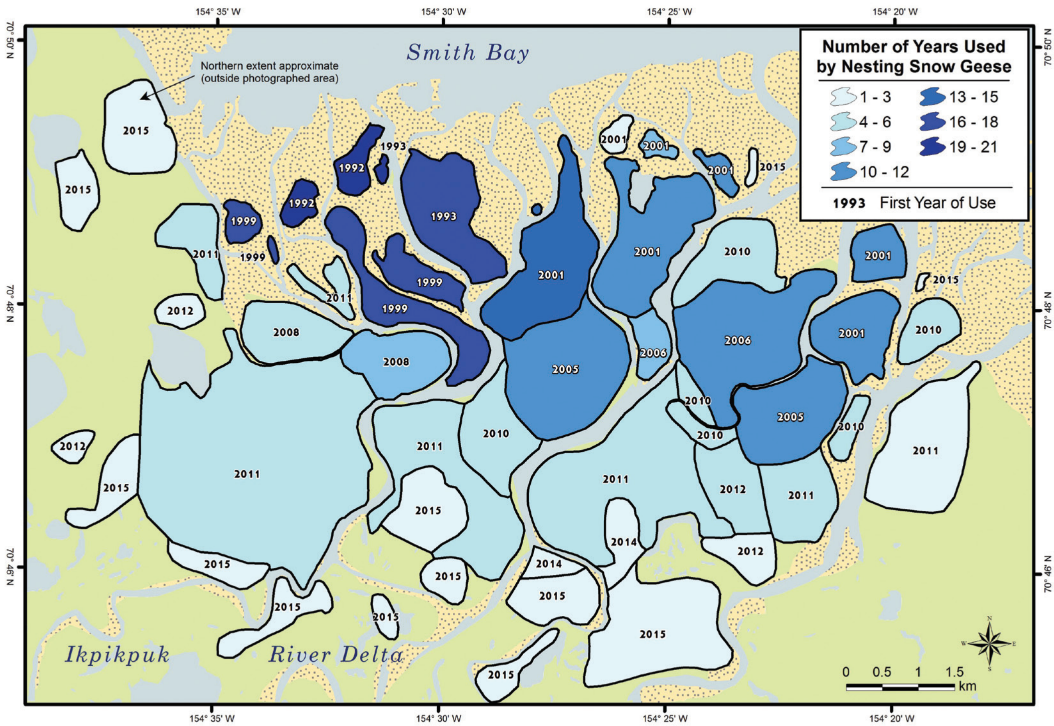

Figure 2. Nesting areas used by Lesser Snow Geese in the Ikpikpuk River delta, 1992-2015.

tent of the colony expanded annually from 1999 to 2011. In 2011, there was a further southward shift and broad expansion of the Ikpikpuk colony. Between 2011 and 2014, the outer boundaries of the colony shifted primarily within the bounds of the 2011 distribution, but another expansion of the nesting area occurred in 2015. Photographic census has documented substantial variability in the density of nests in different parts of the colony. While it is possible that inland nesting was under-reported in some years, extensive aerial reconnaissance suggested that survey coverage of the region was complete each year.

Nesting Success

Nesting success of Snow Geese at the Ikpikpuk colony was highly variable among years (Table 1). Low nesting success in 1992 and 1993 was attributed to a combination of predation and flooding. No estimates of nesting success were available for the next 7 years, during which colony growth was negligible. When colony growth was most rapid, between 2001 and 2008, apparent nesting success averaged 79% (Range = 48-97%). In 2009 and again in 2010, brown bears depredated nests in the colony, resulting in nest success of 1% and 8.5%, respectively. Brown bears also reduced nest survival in 2012 and 2013, when success was just over 40%. In 2014, nesting success continued to be low, but the causes were unknown. Since 2010, stratified random sampling has yielded estimates of nesting success ranging from 8.5% (2010) to 96.6% (2015).

Distribution and Numbers of Brood-rearing and Molting Birds

Snow Geese that nest on the Ikpikpuk River delta rear their broods in coastal habitats between eastern Dease Inlet and the mouth of the Kogru River (Fig. 3). The number of brood-rearing and molting Snow Geese in the Barrow-Kogru River region increased from around 500 adults and young during 1995-1997 to between 10,000 and

26,000 combined adults and young during 2006-2014, and a peak of 45,176 adults and young in 2015 (Table 2). Although brood-rearing groups occurred west as far as Dease Inlet and east as far as the Kogru River in Harrison Bay, nearly all goslings were located closer to the colony, in the Smith Bay survey section (Fig. 1), between Sinclair Lake and west of Pitt Point (Figs. 3 and 4). Small numbers of molting and brood-rearing Snow Geese located in the easternmost portion of the survey area (south and east of Atigaru Point) likely originated from nesting colonies in or adjacent to the Colville River delta, east of the survey area and were excluded from analysis.

Brood-rearing groups averaged 32% goslings over 20 years of surveys (no surveys in 1998). Years of particularly high productivity (> 40% goslings) occurred in 1995, 1999, 2000, 2002-2004, 2006 and 2015. Between 2007 and 2014, brood-rearing groups averaged only 18% goslings, and productivity was particularly poor (1-6% goslings) in 4 of 7 years during 2009-2015.

In photographs of brood-rearing and molting groups since 2002, between 1.2 and 4.2% of adults annually were blue-phase Snow Geese. Over all years (72,539 photographed birds), blue geese averaged 2.5% of total adult Snow Geese in photographed groups.

Matrix Model of Population Growth

The matrix growth model started with 176 breeding females in 1999 (Table 1). Published adult survival rates for Snow Geese in other colonies range between 0.827 and 0.968 for sexes combined (Rockwell *et al.* 1997; Dufour *et al.* 2012), and most recently survival was estimated as 0.88 for adult female Snow Geese at Karrak Lake (Wilson *et al.* 2016). Survival rates vary with age and, in several studies, first-year survival of Snow Geese was 10% to 70% that of adults (Baldassarre 2014). Although few age-specific estimates of survival have been published for Snow Geese, first-year survival of females at La Perouse Bay (1973-1991) was estimated as 0.20 to 0.68 (Cooke *et al.* 1995). Using values on the high end of the reported ranges (0.68 for female survival from fledging to 1 year and 0.968 for survival of adult female Snow Geese 1 year and older), there could have been a maximum of 12,656 breeding-age females (2 years

Table 2. Composition of Snow Goose groups during brood-rearing surveys, Barrow to Atigaru Point, Alaska, 1995-1997 and 1999-2015.

Year	Total Groups	Brood Groups	Adults without Broods	Adults with Broods	Total Adults	Goslings	Total Birds
1995	12	12	0	196	196	229	425
1996	6	3	107	43	150	67	217
1997	20	9	381	96	477	137	614
1999	30	22	278	509	787	621	1,408
2000	38	25	485	579	1,064	869	1,933
2001	28	16	422	331	753	213	966
2002	32	25	109	1,509	1,618	1,113	2,731
2003	44	42	27	1,913	1,940	2,165	4,105
2004	66	47	1,062	2,543	3,605	3,328	6,933
2005	73	42	2,995	1,500	4,495	1,312	5,807
2006	143	134	211	7,320	7,531	8,301	15,832
2007	113	81	2,066	4,033	6,099	3,387	9,486
2008	274	203	3,573	9,266	12,839	8,179	21,018
2009	156	18	14,493	550	15,043	113	15,156
2010	120	13	10,541	561	11,102	174	11,276
2011	291	231	5,846	10,095	15,941	9,924	25,865
2012	360	156	13,902	7,447	21,349	4,180	25,529
2013	288	69	18,303	4,049	22,352	1,231	23,583
2014	128	29	16,732	537	17,269	444	17,713
2015	481	461	1,265	18,771	20,036	25,123	45,159

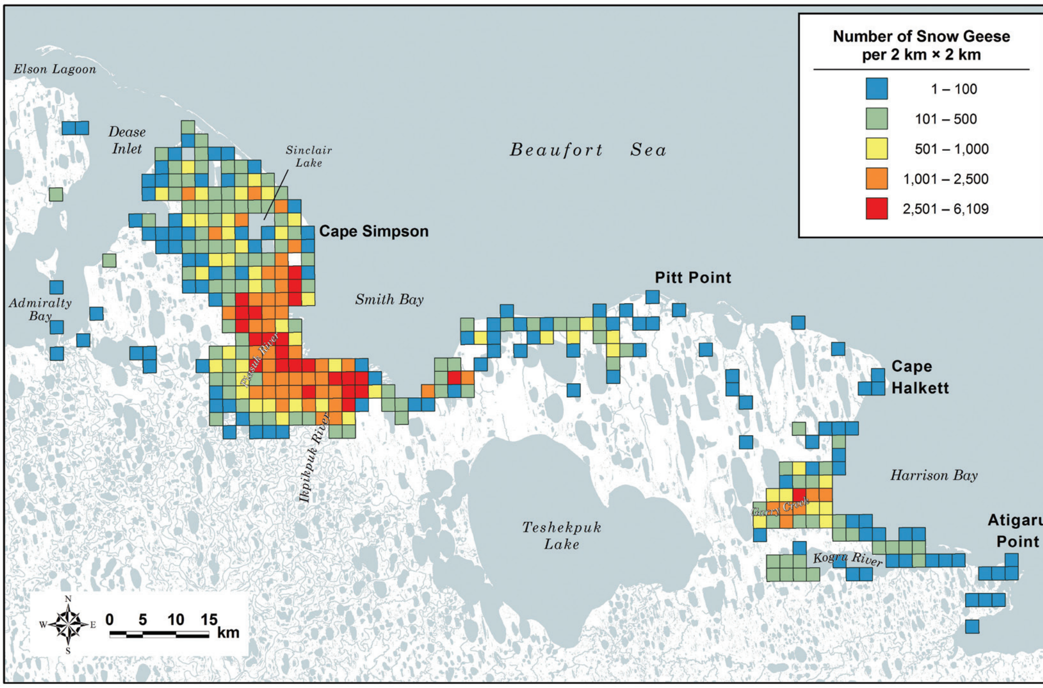

Figure 3. Brood-rearing locations of Lesser Snow Geese (adults and goslings combined) between Dease Inlet and Harrison Bay, 1995-2015 (intensity of use computed as cumulative numbers per each 4-km² grid block).

and older) in 2015. Although quite close to the observed 12,373 nests in 2015, this estimate assumes 100% fidelity of females to natal colony and 100% breeding propensity of females 2 years and older. Wilson *et al.* (2016) calculated that the mean adult female fidelity to natal colony was 0.90 at Karrak Lake. If we assume similar high fidelity (0.90) to the Ikpikpuk colony for females 2 years and older, then the estimated population of females 2 years and older is only 7,069, or only 57% of the number of females that were observed nesting in 2015. Clearly not all females 2 years and older breed annually; if less than

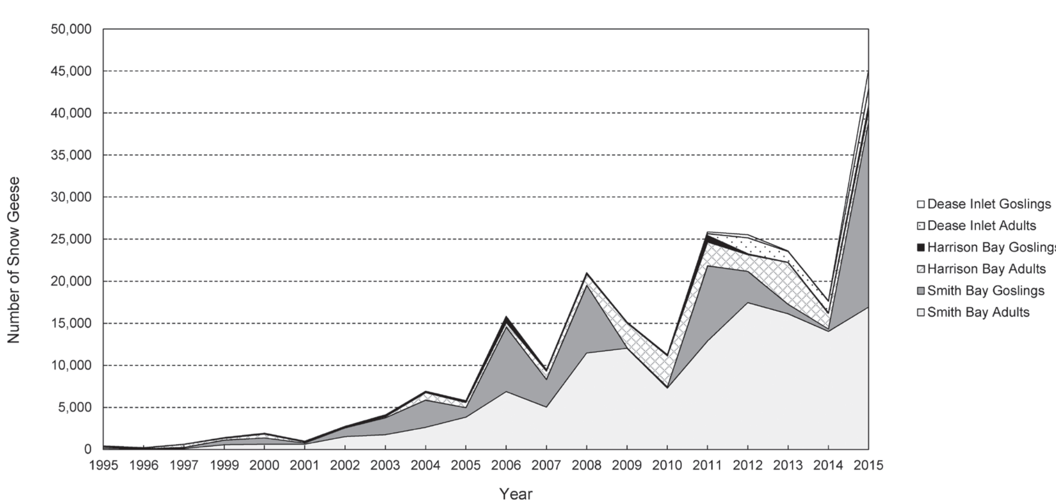

Figure 4. Numbers of adult and gosling Lesser Snow Geese in the Dease Inlet, Smith Bay, and Harrison Bay survey sections, late July 1995-2015.

100% of eligible females nest, the count falls even shorter of the observed number of nests in 2015. True values of survival, fidelity and breeding propensity are unknown for the Ikpikpuk colony, but under these assumptions of what appear to be relatively high survival, fidelity, and breeding propensity, fairly substantial immigration of breeding females is suggested.

Discussion

Snow Geese that breed on the Ikpikpuk River delta are part of the Western Arctic Population (WAP). The primary nesting area for the WAP is located on Banks Island, Northwest Territories, Canada, and that colony was estimated at approximately 500,000 nesting birds in recent years (Hines *et al.* 2010; Pacific Flyway Council 2013). Scattered smaller colonies of < 2,000 nesting adults occur in coastal areas along the Beaufort Sea coast west of Banks Island: in major river deltas in the Northwest Territories, Canada, including the Anderson River delta and Kendall Island in the Mackenzie Delta, and in Alaska on the Sagavanirktok, Colville and Kukpowruk River deltas (Pacific Flyway Council 2013). Surveys indicated that numbers of birds in these smaller colonies varied greatly among years, but none exceeded several thousand birds in recent decades (Wiebe Robertson and Hines 2006; Pacific Flyway Council 2013), and the Anderson River colony appeared to be shrinking substantially (Obst *et al.* 2013).

In contrast to the major Snow Goose colonies in northern Canada and Russia, which include tens or even hundreds of thousands of birds, colonies in Alaska until recently have numbered at most several thousand. With rapid growth, the largest colony in Alaska on the Ikpikpuk River delta now numbers 20,000-24,000 adults. In recent years of moderate to high productivity (2008, 2011 and 2015), these adults were accompanied by 8,000-25,000 goslings in July and August. These numbers represent a remarkable increase in the abundance of Snow Geese west of the Colville River, where only 15 years previously fewer than 500 birds nested (Table 1).

The average annual rate of growth in the breeding population on the Ikpikpuk River delta was 40.0% from 1999 to 2015, compared to annual growth of around 4% per year from 1976 to 2010 in the larger WAP. As in other colonies, low harvest rates and high adult survival of Snow Geese (Alisauskas *et al.* 2011; Pacific Flyway Council 2013) have likely contributed to the increase in numbers at the Ikpikpuk River delta, but we suspect that immigration likely also played a role in establishing the colony and contributing to its rapid increase.

Productivity in the Ikpikpuk colony has been highly variable but clearly contributed to population increase during the early years of rapid growth (2003-2008), when nesting success averaged 86% and the percent composition of brood groups averaged 42% goslings. The number of goslings per nesting female at late brood-rearing was as high as 3.53 (in 1999) and was greater than 2.0 in 4 years prior to 2009. In contrast, however, substantial nest loss (primarily due to brown bears) reduced productivity in each year during 2009-2014, nesting success averaged only 29% over that period, and goslings comprised less than 30% of brood groups in 3 of 6 years. Most recently, in 2015, brown bears were absent, nesting success was high, and production averaged 2.03 goslings per female late in brood-rearing.

Two observations suggest that immigration contributed to population growth of Snow Geese in the Ikpikpuk colony. The relatively high abundance of blue-phase Show Geese associated with the Ikpikpuk colony (2.5% of adults in brood-rearing photographs) compared with < 0.5% estimated at Banks Island, the primary colony of the WAP (Samelius *et al.* 2008), suggests past or ongoing immigration from the Midcontinent Population, which nests in the central and eastern Canadian Arctic, where blue-phase Snow Geese are more common. Additionally, simple matrix models of population growth suggest that only exceptionally high levels of survival, fidelity, and breeding propensity could result in the observed level of population growth in the absence of substantial immigration.

The large colony on the Ikpikpuk River delta, now with more than 12,000 nesting pairs, appears able to sustain multiple seasons of fairly severe predation, managing in 2011, 2012 and 2013 to hatch large numbers of eggs despite the presence of brown bears. This is in contrast to earlier years (2009 and 2010) when the population was smaller. Moreover, despite nearly complete destruction of the colony by brown bears in 2009 and 2010, and despite poor nesting success during 2011-2014, the number of nests increased substantially in 2011 and again in 2015, also suggesting that growth of the colony is in part from immigration.

Snow Goose breeding populations have been expanding in North America since at least the 1960s (Kerbes 1983; Kerbes *et al.* 1983; Alisauskas and Boyd 1994), probably in large part due to increased availability of agricultural resources and resulting increased survival in wintering areas (Davis *et al.* 1989; Abraham *et al.* 2005; Gauthier *et al.* 2005). Snow Geese often forage by grubbing for roots and rhizomes, particularly during spring prior to emergence of above-ground vegetation (Kerbes *et al.* 1990). This behavior, coupled with high fidelity to breeding areas (Ganter and Cooke 1998) and rapid population growth, has resulted in long-term alteration of habitat in some nesting areas and Arctic coastal salt marshes used for brood-rearing, primarily near very large colonies in the central and eastern Canadian Arctic (Ganter *et al.* 1995; Ankney 1996; Handa *et al.* 2002; Peterson *et al.* 2013). Increased numbers of Snow Geese have resulted in density dependent reductions in growth and survival of goslings (Cooch *et al.* 1991; Williams *et al.* 1993; Gadallah and Jefferies 1995) and dispersal of young breeders to higher quality breeding areas (Ganter and Cooke 1998).

In response to the overabundance of white geese (Greater Snow Geese [*C. caerulescens atlanticus*], Lesser Snow Geese, and Ross's Geese [*C. rossii*]), special conservation measures have been implemented to increase harvest of some populations. Efforts to reduce numbers of Greater Snow Geese have met with some success, and the population has been fairly stable since the implementation of special conservations measures in Canada and the United States (Reed and Calvert 2007). In the Midcontinent Population, however, managers are faced with Snow Goose numbers expanding well above population objectives, and management efforts to reduce the growth of this population thus far have failed (U.S. Fish and Wildlife Service 2007; Alisauskas *et al.* 2011).

Increasing numbers of Snow Geese in the WAP and across much of the North Slope are consistent with patterns of population growth and colony expansion throughout North America. The WAP, which includes the Ikpikpuk and other North Slope colonies, also has been designated as overabundant in Canada, and conservation measures to increase harvest are in place in Alberta and the Northwest Territories. The objective is to control the population through harvest before it grows to the point where breeding or staging habitats or other species in Canada are affected. However, the WAP mixes during migration and on the wintering grounds with the Wrangel Island Population (~200,000 nesting birds), which nests on Wrangel Island, Siberia, Russia, and the overabundant Midcontinent Population of Lesser Snow and Ross's geese, complicating management options for these populations in the continental United States (Pacific Flyway Council 2013; U.S. Fish and Wildlife Service 2015), and the WAP has not been designated as overabundant in the United States.

With the very rapid growth of the colony on the Ikpikpuk River delta, it is tempting to speculate on interrelationships between Snow Goose populations in northern Alaska and those in western and central Arctic Canada and Russia. High rates of immigration likely have contributed to the rapid increase in abundance of Snow Geese on the North Slope, and candidate sources are numerous in the Canadian Arctic. Factors like repeated disturbance by predators or locally depleted forage may have resulted in abandonment of some traditional breeding areas and immigration of breeding adults into the Ikpikpuk or other North Slope colonies. Given the large size of the Midcontinent Population and WAP, even low rates of dispersal estimated between 5% and 10% for female Snow Geese (Wilson *et al.* 2016) could result in hundreds of thousands of birds emigrating from Canadian colonies annually. In both Ross's Geese and Lesser Snow Geese in the Midcontinent, new nesting colonies seem to appear as pulsed events (Geramita and Cooke 1982; Alisauskas and Boyd 1994; Abraham *et al.* 1999; Alisauskas *et al.* 2012). Dispersal estimates suggest that large numbers of Ross's Geese are similarly dispersing to nest at unknown locations (Wilson *et al.* 2016). To date, no Ross's Geese have been observed in the Ikpikpuk colony or in brood groups.

Further management of the WAP through special conservation measures may slow the rapid increase in abundance of Snow Geese on the North Slope, assuming that immigrants to the North Slope are from the WAP. Some evidence suggests an affiliation with the Midcontinent Population, however, and it seems clear that control measures implemented in Alaska would be ineffective at reducing the number of immigrants in any case. Measures of survival and immigration rates should be calculated, and band encounter data should be used to determine affiliations. A better understanding of habitat availability and of biomass production and harvest rates should be used to inform decisions on the need for population control on the North Slope.

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