by R. H. Kerbes

Lesser Snow Geese in the eastern Canadian Arctic

Canadian Wildlife Service Report Series Number 35

Errata: **The nesting population of Lesser Snow Geese in the eastern Canadian Arctic: A photographic inventory of June 1973**

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Page 45, Appendix 2, last line in the right column:

For $\frac{1}{2}\hat{T} \pm \frac{1}{2}s\,(\hat{T})$

Read $\frac{1}{2}\hat{T} \pm s\,(\hat{T})$

Page 45, Appendix 2, middle column:

For $s_{yx}^2 = \frac{n-1}{n-2}\, s_y^2\,(1-\rho^2)$

Read $s_{y.x}^2 = \frac{n-1}{n-2}\, s_y^2\,(1-\rho^2)$

For $n = N/(\Sigma A_i/n)$

Read $n^1 = N/(\Sigma A_i/n)$

Environment Canada Wildlife Service

Environnement Canada Service de la Faune

The nesting population of Lesser Snow Geese in the eastern Canadian Arctic: A photographic inventory of June 1973

by R. H. Kerbes

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Cover: A mixed pair of Lesser Snow Geese on the nesting colony at McConnell River, NWT. The dark bird is a blue phase female; she is sitting on the nest. Her mate, in the foreground, is a white phase male. Both birds show a reddish-yellow discolouration of their normally white heads. This is a natural iron oxide stain occasionally seen in Snow Geese.
Photo by B. C. Lieff

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The author

Richard H. Kerbes has been a wildlife biologist with the Canadian Wildlife Service in Ottawa since 1965. He is primarily concerned with research and surveys on geese in the eastern Canadian Arctic. His studies have ranged from southern James Bay to northern Ellesmere Island. In 1969–70 he conducted exchange-duty studies of geese in Scotland and Iceland. He holds an Honors B.Sc. in Zoology from the University of Alberta and an M.Sc. in Zoology from the University of Western Ontario.

Acknowledgements

N. G. Perret first suggested in 1965 that I might use aerial photography to count nesting Lesser Snow Geese. Later discussions I had with C. Thompson and J. D. Heyland led to the initiation of the project.

I am grateful to R. Norton, T. Colley, and K. Connor for their enthusiastic co-operation while carrying out the 1972 and 1973 photographic missions; to R. N. Jones, L. S. Maltby (Prevett), S. E. Dodd, and T. Clerment for persevering with me through various phases of analysing the photographs; to G. E. J. Smith, R. K. Ross, S. G. Curtis, and A. R. Sen for developing the statistical analysis of the results; to H. Blokpoel and F. G. Cooch for commenting on the manuscript; and to P. A. M. Angehrn for assisting me in organizing and analysing the data and for drafting the figures.

I extend special thanks to my supervisor, Hugh Boyd, for his whole-hearted support of the project through all its stages.

Perspective

In the last twenty years or so changes in land use have led to massive changes in the distribution of Snow Geese on their wintering and staging areas. As a result, controversy has arisen about the scale of hunting permitted and its impact on the Snow Goose population. In Canada it has become particularly urgent to find out to what extent Indians and Inuit in the north still depend on hunting geese for food, so as to be able to balance their needs against the demands of sport hunting elsewhere in Canada and in the USA.

Now that biologists can measure hunting kill with greater accuracy, it is more than ever necessary to have reliable measurements of population size against which to judge the impact of hunting and other causes of loss. The midwinter aerial surveys that were used as an index of population for many years have become more difficult to carry out, as well as less complete and reliable, as the wintering range has enlarged. The two best opportunities each year to estimate population size are when the geese are nesting and when, a few weeks earlier, they are concentrated in a narrow strip along the coast of southern Hudson Bay and James Bay.

The work reported here represents the most comprehensive attempt yet to furnish a quantitative base-line against which to measure changes in the population of Lesser Snow Geese nesting in eastern Arctic Canada. The establishment of a permanent photographic record of nesting distribution in June 1973 not only permits an estimate of population size but also helps greatly in understanding how the geese distribute themselves within colonies, where they choose to set up colonies and to site individual nests, and what food is available to the geese while nesting and raising their families. This report forms a substantial contribution to a major study of the population dynamics of Snow Geese being conducted by the Canadian Wildlife Service and by groups of biologists from universities.

Abstract

I surveyed the population of Lesser Snow Geese (*Anser caerulescens caerulescens*) nesting in the eastern Canadian Arctic by means of large-format vertical photography in June 1973. Subsequent analyses of the photographs gave a total estimate of 528,700 (±43,600) *nesting pairs* in the population. Of those, 42% were in the colonies of southwest Baffin Island, 15% on south Southampton Island, 37% on west Hudson Bay, and 6% at Cape Henrietta Maria. I also determined the total nesting area, nest distribution pattern, and colour ratio for each colony.

I developed the methods for obtaining and analysing the photographs during experimental surveys of the nesting colonies in 1971 and 1972. Optimum results were obtained with standard mapping survey techniques and equipment using *Kodak Aerocolor Negative* film and a 12 in. focal length lens. The films were analysed on a light table with a binocular microscope.

The photographic survey of 1973 has provided the first accurate assessment of this population. Although earlier records are much less precise it is apparent that the colour ratio has changed slightly in favour of the blue phase or has remained nearly static at all colonies for the past decade: a majority of blue phase at Cape Henrietta Maria and on Baffin Island, and a majority of white phase on west Hudson Bay and Southampton Island. For the past 30 to 40 years the size of colonies has probably not changed on Baffin Island, has perhaps increased on Southampton Island, has definitely increased at Cape Henrietta Maria, and has shown a phenomenal increase on west Hudson Bay. That area now appears to be much closer to its carrying capacity than are the Southampton or Baffin island areas. Potential climatic deterioration on Southampton and Baffin islands and potential over-grazing of west Hudson Bay are major future threats to the population.

Résumé

En juin 1973, à l'aide de photographies verticales prises sur pellicules de grand format, j'ai étudié la population de Petites Oies Blanches (*Anser Caerulescens caerulescens*) nichant dans l'est de l'Arctique canadien. Des analyses subséquentes des photographies ont permis d'estimer à 528,700 (±43,600) le nombre de *couples nicheurs* au sein de la population. De ces derniers, 42% se trouvaient parmi les colonies du sud-ouest de l'île Baffin, 15% dans le sud de l'île Southampton, 37% dans la partie ouest de la baie d'Hudson et 6% au cap Henriette-Marie. J'ai aussi déterminé toute l'aire de nidification, le mode de distribution des nids et un rapport des couleurs pour chaque colonie.

C'est au cours de dénombrements expérimentaux des colonies d'oiseaux nicheurs, en 1971 et 1972, que j'ai mis au point les méthodes d'obtention et d'analyse des photographies. Les procédés et appareils normaux de cartographie, avec films *Kodak Aerocolor Negative* et lentille de 12 pouces de distance focale, ont donné les meilleurs résultats. Un microscope binoculaire a servi à l'analyse des films, posés sur une table lumineuse.

Le dénombrement photographique de 1973 a permis la première évaluation précise de la population. Malgré une plus grande indétermination des dossiers précédents, il appert que le rapport des couleurs ait quelque peu changé en faveur de l'oie bleue ou soit demeuré presque le même dans toutes les colonies au cours des dix dernières années: l'oie bleue prédomine au cap Henriette-Marie et sur l'île Baffin tandis qu'une majorité d'oies blanches habite l'ouest de la baie d'Hudson et l'île Southampton. Au cours des 30 à 40 dernières années, les colonies n'ont probablement pas changé en importance dans l'île Baffin, ont peut-être augmenté dans l'île Southampton, se sont sans aucun doute accrues au cap Henriette-Marie et ont subi un accroissement phénoménal dans l'ouest de la baie d'Hudson. Cette région semble maintenant beaucoup plus près de sa capacité de charge que ne le sont les îles Baffin et Southampton. La détérioration possible du climat de ces dernières et l'éventuelle utilisation à outrance de la végétation dans la partie occidentale de la baie d'Hudson constituent les principales menaces futures à la population.

Резюме

В июне 1973 г. я занимался обследованиями породы гуся голубого северного (Anser Caerulescens), гнездящегося в восточной части канадской Арктики; для этого я применял крупно-форматное вертикальное фотографирование. В соответствии с последующим анализом фотоснимков общая оценка популяции гусей составила 528 700 (+/— 43 600), *гнездящихся пар*, 42% из них находились в колониях юго-западной части Баффиновой земли, 15% — на юге- о-ва Саутгемптон, 37% — на западе Гудзонова залива и 6% на Кейп Генриетта Мария. Мне удалось также определить общую площадь гнездования, месторасспределение гнезд и цветовое соотношение для каждой колонии.

Я разработал методы съемок и их анализа во время опытных обследований гнездящихся колоний в 1971 и в 1972 г.г. Оптимальные результаты были получены при помощи стандартной картографической техники и оборудования: я использовал пленку *Кодак Аэроколор Негатив* и линзы с 12-дюймовым фокусным расстоянием. Пленки были подвержены анализу на освещенном столе с бинокулярным микроскопом.

Фотографическое обследование в 1973 г. позволило сделать первую точную оценку популяции. Несмотря на то, что более ранние данные менее точны, все же очевидно что за последнее десятилетие цветовое соотношение слегка изменилось в сторону голубой окраски или же осталось почти без изменения во всех колониях. Преобладающая часть гусей с голубой окраской находилась на Кейп Генриетта Мария и на Баффиновой земле, а основная часть гусей с белой окраской — на западе Гудзонова залива и о-ва Саутгемптон. Кажется, что за последние 30-40 лет размер колоний почти не изменился на Баффиновой земле и увеличился незначительно на о-ве Саутгемптон и существенно увеличился на Кейп Генриетта Мария; на западе Гудзонова залива размер колоний увеличился феноменально. Можно сказать, что популяция этой области больше приближается к своему оптимальному значению, чем области о-ва Саутгемптон и Баффиновой земли. Потенциальное ухудшение климатических условий на Саутгемптоне и Баффиновой земле и потенциальное оскудение питательных ресурсов западной части Гудзонова залива представляет в будущем угрозу росту популяции.

Aerial view of the Lesser Snow Goose colony in late June at East Bay, N.W.T.
Photo by H. C. Hanson.

Introduction

Lesser Snow Geese are possibly the most numerous geese in the world. The larger of their two main populations nests in the eastern Canadian Arctic (hereafter referred to as the eastern Arctic). The numbers, distribution, and colour phase ratios of the nesting colonies of that population are the subject of the following report.

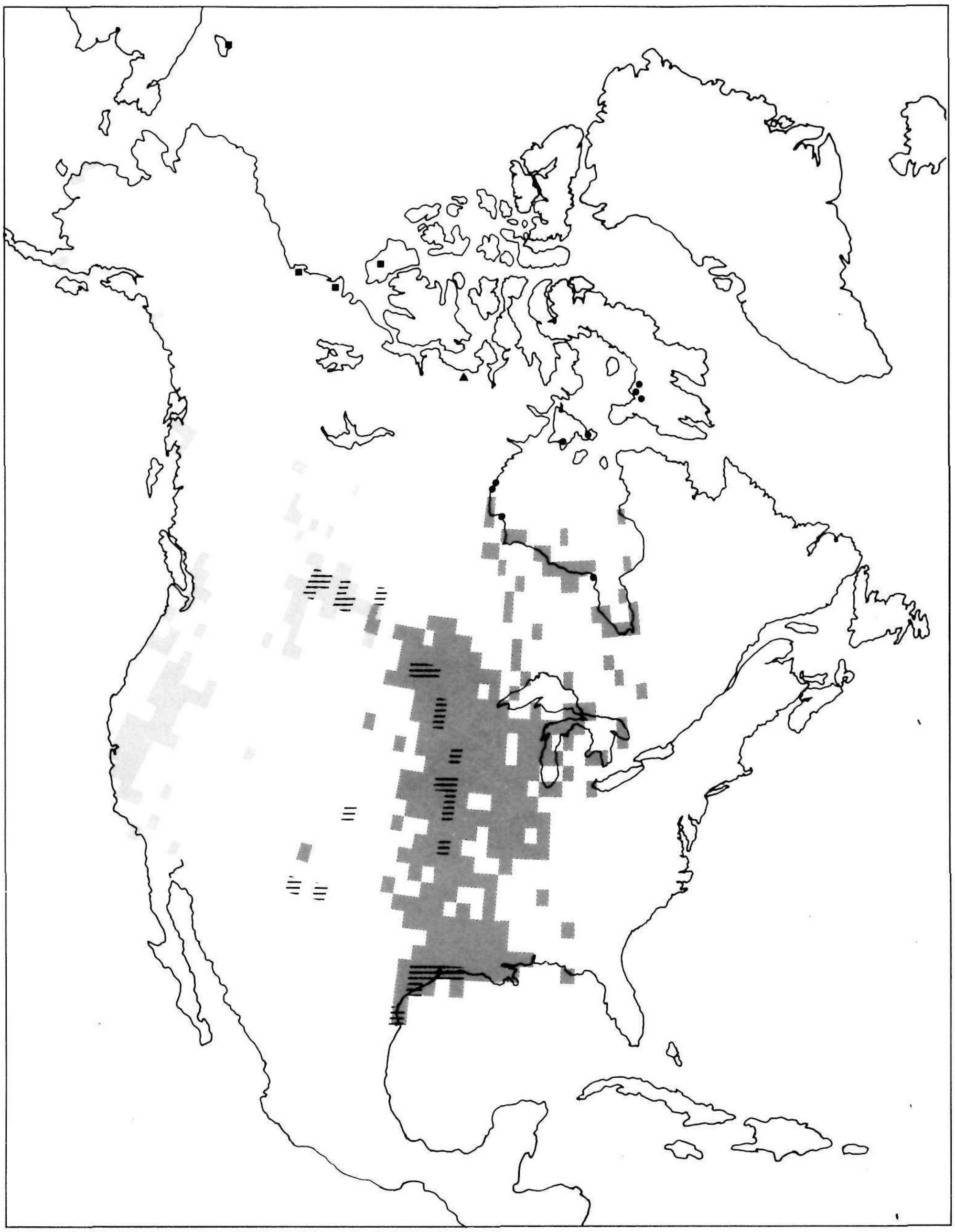
The eastern Arctic population consists of at least two million birds nesting near Hudson Bay and its northern extension, Foxe Basin; wintering near the Gulf of Mexico (Dzubin, Boyd, and Stephen, 1973; this report). The second main population, that of the western Canadian Arctic, contains about 600,000 birds nesting on Banks Island, Wrangel Island, and the deltas of the Mackenzie River and Anderson River; wintering in California (Uspenski, 1967; Lynch and Voelzer, 1974; Barry, pers. comm.). Between those two, the small central Canadian Arctic population of about 25,000 birds nests in association with Ross Geese in the Queen Maud Gulf region; wintering in Mexico and Texas (Barry, 1960; Ryder, pers. comm.). Ranges of the three populations are shown in Figure 1.

The eastern Arctic population is clearly important to the economy of North America in the form of sport hunting. Sport hunters in the USA harvested an estimated average of 326,000 birds from this population each year from 1962 to 1971 (Dzubin et al., 1973). Although the annual harvest in Canada is much smaller, about one-third that of the USA (Cooch and Curtis, pers. comm.), it has special importance to the native people of the James Bay area. Geese are still essential as both a food resource and a component of the culture of the people (Hanson and Currie, 1957; Aitken, 1975).

By 1970 new developments had extended interest in the conservation of eastern Arctic Lesser Snow Geese beyond those traditional concerns. In the USA the harvest was steadily increasing, and controversy over *short-stopping* and an alleged redistribution of the harvest had arisen between the southern and northern states

Figure 1
Distribution of the populations of Lesser Snow Geese showing their main nesting areas and their migration and wintering areas as shown by direct band recoveries (from Dzubin, 1974)

Figure 1



Recovery Areas	Nesting Areas	Population
(dark shading)	●	Eastern Canadian Arctic
(horizontal lines)	▲	Central Canadian Arctic
(light shading)	■	Western Canadian Arctic

Miles 0 500 1000
Kilometers 0 800 1600

of the Central and Mississippi flyways (Dzubin et al., 1973). In Canada the migration staging areas on James Bay faced increasing pressure from sport hunting and the threat of environmental damage from hydro-electric developments (Glooschenko, 1972). In the Arctic the acceleration of activities related to exploitation of petroleum and mineral resources threatened to harm the nesting geese and their habitat (McLaren, 1971). An accurate base-line assessment of the population had to be obtained if future changes were to be measurable and if critical habitats were to be identified and protected.

Past surveys of the geese on the wintering grounds (Lynch, 1973 and earlier; Lynch and Voelzer, 1974), the staging areas of James and Hudson bays (Hanson, Lumsden, Lynch, and Norton, 1972), and the nesting grounds (Cooch, 1955; Kerbes, 1967, 1969) monitored changes in numbers, productivity, and colour ratios, but they failed to provide data with reliable confidence limits. Apparently the population was too large and its distribution too complex for traditional counting techniques to work anywhere. (Recent improved counts of migrant Snow Geese on Hudson and James bays by Curtis and Lumsden will be noted later in this report.)

The Canadian Wildlife Service mounted an attack at a new technical level and a substantially higher financial level in 1971. As Heyland (1972) had already done in 1970 with samples of nesting Greater Snow Geese, I adapted and applied the professional skills and equipment of large-format vertical photography (a technology at least 30 years old) to obtain a photographic inventory of the eastern Arctic colonies of Lesser Snow Geese. All the colonies were successfully photographed in June 1973. The results of analysing those photographs are central to the following presentation. They give the location, total nesting pairs, total nesting area, nest distribution pattern, and colour ratio of nesting birds for each of the colonies. The biological significance of the June 1973 inventory in relation to past records and future possibilities and the application of aerial photography (in Appendix 1) are discussed at length.

The photographs of the colonies contain much more than the basic results presented here. Further analysis can provide a wealth of new information on the distribution and behaviour of the geese, on the details of nesting habitat, and on the relationships between the two both within and among colonies.

Methods

1. Definitions

The *Lesser Snow Goose* is the polymorphic subspecies *Anser caerulescens caerulescens* which includes two colour phases, white and blue (Delacour and Mayr, 1945; American Ornithologists' Union, 1973).

Adult-plumaged *white phase* birds have white plumage except for varying amounts of dark colouring on the wing (Cooke and Cooch, 1968).

Adult-plumaged *blue phase* birds have grey plumage with a white head (usually) and varying amounts of white on the ventral surface (Cooke and Cooch, 1968).

A *nest* is here defined as a nesting pair of adult birds with an active nest, unless specified otherwise.

To analyse, as used here, is to count geese systematically from photographic film as described.

To scan, as used here, it to examine photographic film to determine the absence or presence of geese.

Visual observations are not based on photographs, but were recorded "live" from the aircraft during the photographic missions.

Scale is the ratio of a distance on a photograph or map to its corresponding distance on the ground. The scale of an aerial photograph equals the height of the aircraft above the ground divided by the focal length of the lens (Thompson, 1966). For example, at 1,500 m (5,000 ft) with a 6 in. lens the scale is 5,000 ÷ 0.5 or 1:10,000. Hence, as used here, *high-level* photography had a smaller scale (i.e. given images were smaller) than *low-level* photography.

2. Narrative review of photography and analyses

On July 1, 1971 we obtained the first large-format vertical photographs of nesting Lesser Snow Geese on Baffin Island. On April 21, 1972 I did experimental vertical photography of flocks of captive Lesser Snows and Canada Geese at Kortright Waterfowl Park, Guelph, Ontario. We examined and analysed those films (*Plus-X* black-and-white from Baffin Island and *Double-X* black-and-white and *Color Negative* from Guelph) in May 1972. I concluded that *Color Negative* film at scales of 1:10,000 (for white phase geese) and 1:4,000 (for blue phase) was optimal for counting purposes.

Accordingly, I used *Color Negative* film at those scales on my first photographic survey of the eastern Arctic colonies from June 10 to July 10, 1972. Due to an extremely late spring on the more northern colonies, where prolonged snow cover prevented nesting, only the La Pérouse Bay and McConnell River colonies were successfully photographed. We analysed the McConnell River photographs (scale 1:10,000) in October and November 1972, and the La Pérouse Bay, McConnell River (scale 1:4,000) and Baffin Island 1971 photographs from December 1972 to April 1973. After the 1971 and 1972 films had been analysed, I concluded that *Plus-X* film at 1:10,000 and 1:3,000 was optimal for counting geese (Kerbes and Prevett, 1973).

Therefore, I used *Plus-X* at those scales for the next photographic survey of the eastern Arctic colonies from June 4 to 29, 1973. Because the 1973 nesting season was very good in all colonies and the weather during the survey was almost perfect, I was able to photograph almost all the colonies successfully. We made the basic analyses of the photographs from September 1973 to March 1974, and the comparisons of counts and other tests on counting accuracy in April 1974. We also made a series of special counts (to be described later) for calculating correction factors and confidence limits of the basic counts in May and June, 1974. We carried out statistical calculations and organization of data for the final estimates of colony size and colour ratio in July and August 1974.

3. Obtaining photographs

Table 1 gives details of the equipment and films used to obtain photographs from 1971 to 1973. Basic procedures were similar to those used in mapping photography as reviewed by Thompson (1966).

An aerial survey firm, under contract, provided a small twin-engined aircraft equipped for photography and manned by a pilot and a cameraman–navigator on a stand-by basis for the nesting season. I accompanied the crew to tell them when and where to take photographs. In addition, I made a visual reconnaissance from the aircraft.

The camera had large-format film (producing a 9 in. x 9 in. negative) and a lens of 6 in. or 12 in. focal length. It was mounted so that the lens viewed the ground vertically through a hole in the belly of the aircraft.

To achieve total photo coverage of a given nesting colony, we flew a pattern of predetermined parallel lines over the area at the desired height above ground, and exposed a series of photographs. Forward overlap between frames gave continuous coverage of the ground passing beneath the aircraft along the flight line. Lateral overlap between adjacent lines gave continuity between lines. We did not require more than a single flight line if the nesting area was narrow enough to be covered by the width of a frame, or if only sample coverage was needed.

4. Analysing photographs

4.1. Equipment

The equipment used in the analysis of photographs included:

1) Survair light box which was a plywood box, 106 cm x 78 cm x 14 cm, containing a standard (4,500°K) fluorescent light fixture, topped with a 6 mm layer of translucent glass, with commercially made roller brackets attached to each end of the box to hold and transport rolls of film;

2) Spencer binocular microscope on a stand with a flexible arm, placed on a board mounted on castors to give mobility;

3) Wild M7 binocular microscope, with a stand, placed on a table polished with graphite to give mobility;

Table 1
Specifications of photographic surveys of eastern Arctic Lesser Snow Geese, 1971–73

Survey	Aircraft type	Camera Type	Camera Max. shutter speed (sec.)	Lens Focal lgth. (in.)	Lens Filter	Film type	Scales (approx.)	Photo coverage Line mi.	Photo coverage Area (km²)
Baffin Island 1971	Piper Aztec	Zeiss RMK/23	1/500	6	B	*Plus-X*†	1:2,100	7	5
							1:11,000	97	392
Guelph* 1972	Cessna 320	Zeiss RMK30/23	1/1,000	12	none	*Double-X*‡ *Col. Neg*§	‖	‖	‖
Eastern Arctic 1972	Aero Commander	Zeiss RMK30/23	1/1,000	12	none	*Col. Neg*§	1:4,000	63	93
							1:10,000	69	253
Eastern Arctic 1973	Aero Commander	Wild RC8	1/500	6	500 Pan X	*Plus-X*†	1:3,000	622	686
							1:10,000	1,043	3,836

* Experimental work on captive birds.
† *Kodak Plus-X Aerographic* Film 2402 (*Estar* Base).
‡ *Kodak Double-X Aerographic* Film 2505 (*Estar* Base).
§ *Kodak Aerocolor Negative* Film 2445 (*Estar* Base).
‖ Approximately three frames obtained for each of the films and scales used (1:2,000; 1:4,000; 1:6,000; 1:8,000; 1:10,000, and 1:12,000).

4) Richards M1M-231100 light table with a mounted Bausch and Lomb *Stereo-Zoom 7* binocular microscope with 0.5X adapter;

5) nylon grids (invented by R. N. Jones) made by stringing fine nylon fishing line across a wooden frame to form two grids of about 20 cm x 20 cm, one with 1 cm x 1 cm squares and the other with 2 cm x 2 cm squares;

6) acetate grids made by plotting lines with a precision drafting machine on clear acetate sheets to form two grids of 26 cm x 26 cm, one with 1 cm x 1 cm squares and the other with 2 cm x 2 cm squares;

7) data sheets of standard metric graph paper, 25 cm x 18 cm, marked to correspond with the nylon grids; or paper photo-copies of the acetate grids.

4.2. Basic procedure and image identification

As in standard Canadian government aerial photography, each roll and frame of the exposed film from 1972 and 1973 was given an identification number by the Interdepartmental Committee on Air Surveys, and the flight lines of photography were plotted on an index map. After analysis, we deposited the original films and their indexes in the National Air Photo Library.

We analysed the original negative of each film by mounting it in roll form on the Survair light box or the Richards light table and examining it through a binocular microscope. We placed the film emulsion side down and applied the analysis work and marking on the *Estar* base or back of the film, while taking care to keep the film clean and to prevent it from being scratched.

The geese appeared on the photographs as oval images if they were on the ground, or as spread-eagle images if they were flying. The white phase birds appeared as distinct dense black images on the negative film. The blue phase birds presented a faint grey image. Often the white head of the blue phase (a tiny black dot image) or the bird's shadow (a white image) aided in identifying the blue phase.

We recorded geese as breeding birds (distributed in pairs on the ground) or as non-breeding birds (distributed in flocks on the ground or in flight). Only white phase geese were counted on the high-level photographs by using the 1 cm x 1 cm grid and magnification to fill the microscope's field of view with one grid square. We counted both white and blue phases on the low-level photographs by using the 2 cm x 2 cm grid with appropriate microscopic magnification.

4.3. Detailed procedure for counting white phase geese

We made positive contact prints or half-size black-and-white positive prints of every frame of the high-level negatives to be analysed for nesting white phase geese. We analysed the original negatives by flight lines, first placing the grid on or under a frame and marking the corners of its position with a fine nylon-tipped pen on the film. If we saw geese, we recorded the numbers in the corresponding grid square of the data sheet for that frame. We moved the microscope slowly down the first column until it reached the bottom row, and then repeated the procedure by going up the next column. The corners of the area examined and marked on the first frame were also marked on the second frame to account for forward overlap in moving the grid to examine a new ground area on the second frame. In effect we searched the ground area frame-by-frame. If there was sufficient forward overlap (60% or more) we had to examine only every alternate frame. The grid position indicating the actual area examined on each frame was also marked on the corresponding print. We accounted for lateral overlap as follows. Beginning at one edge of an area photographed, we designated the first flight line and every alternate one after it as primary lines, and those between them as secondary lines. We analysed the primary lines first, so that lateral overlap had to be considered only when analysing the secondary lines. Each secondary frame was first compared to the prints of the primary frames which it bordered. The area already examined and marked on the print was located and marked on the secondary frame. That portion already examined on the primary frame we blocked off from the secondary frame so as to examine only the ground area between primary lines. The corresponding data sheets of the secondary frames were also blocked off and filled in accordingly.

After all frames had been analysed, the data sheets provided a grid count of white birds on the colony. We tallied the total numbers of nesting and non-breeding birds and measured the total nesting area for each frame.

4.4. Calculations

To calculate the total number of white phase plus blue phase nests in the analysed area of a given colony, we multiplied the number of white phase nesting geese counted by the reciprocal of the percentage white phase for the colony, and divided by two, it being assumed that one male and one female would be associated with almost all active nests at the time of photography. We calculated the colour ratio, or percentage of white, from sample counts of white and blue phase nesting geese on low-level photographs. For this we obtained minimum sample sizes of 1,600 whites plus blues for each colony.

We plotted the boundary of the area occupied by nesting birds at each colony on standard National Air Photo Library scale 1:60,000 vertical photographs with reference to the data sheets of the analysed area. We supplemented this by scanning the photographic coverage of areas not analysed in detail, and with visual observations made during the photographic flights. We also plotted the area and position of each photograph analysed on the 1:60,000 photographs. Sizes of the total nesting area and the total photographic coverage were measured by planimeter. In some cases we measured the area of coverage from the analysed film (using a scale factor corrected by comparison to the standard 1:60,000 photographs and 1:250,000 maps).

At some colonies the high-level coverage of the nesting area was not quite complete and, due to limited time, we did not analyse all available film. We expanded the mean density of nests on the analysed sample by the total nesting area to estimate total nests in the colony.

At some colonies both the extensive sample counts of white phase birds as well as the colour-ratio sample counts of white and blue phases were taken from the low-level photographs.

We calculated the 95% confidence intervals of the estimated colony size, based on high-level coverage, by comparing counts of white birds made on high and low-level photographs of the same sample areas. For colony size estimates based on low-level photographs we used only the variance of the sample to estimate the 95% confidence interval of the total estimate of colony size.

For further description and discussion of methods and statistical procedures see Appendices 1 and 2.

The colonies

Table 2 gives the key results for each colony from the June 1973 survey, including total size and area, colour ratio, mean density, proportion analysed, and 95% confidence intervals of the total number of nests and colour ratio of nesting birds. This section elaborates on those results and discusses earlier records for each colony proceeding from south to north. I have grouped the 16 nesting colonies into four geographic regions:

1) south Hudson Bay — the coast of Hudson and James bays, from La Pérouse Bay to Attawapiskat, and the north coast of Akimiski Island;

2) west Hudson Bay — the coast of Hudson Bay from Thlewiaza River to Maguse River;

3) Southampton Island — the southern lowlands of the island;

4) Baffin Island — the coastal plain from Garnet Bay to Taverner Bay.

Figure 2 shows the locations of the regions and colonies, and subsequent figures show more details for each colony. Note that most of the major colonies (Cape Henrietta Maria, McConnell River, Wolf Creek, Boas River, East Bay, and Bowman Bay) are shown at the same scale to facilitate comparisons.

Previous workers have not standardized colony names, as will be noted when former names differ from the ones I have assigned. I hope that future workers will adopt the names given here.

Table 2
Summary of results of a photographic survey of the nesting colonies of Lesser Snow Geese in the eastern Canadian Arctic, June 1973

Colony	Total no. nests (±2s.e.)	Total nesting area km² (% anal. on photos)	Mean density (nests/km²)	% blue phase (±2s.e.)
Cape Henrietta Maria	29,600 (± 7,800)	69.1 (37)	428	72.7 (±3.3)
La Pérouse Bay	2,800	6.8 (83)	412	26.0
Subtotal — S. Hudson Bay	32,400	75.9	427	
Tha-anne River	3,200	1.1 (22)	2,909	20.8 (±2.2)
S. McConnell River	5,900	90.0 (67)	66	24.0
McConnell River	163,000 (±29,100)	249.4 (72)	654	24.2 (±4.8)
Wolf Creek	22,500 (± 3,600)	60.1 (62)	374	25.0 (±4.9)
Maguse River	500	10.6 (49)	47	25.0
Subtotal — W. Hudson Bay	195,100	411.2	474	
Ell Bay	200	37.5 (94)	5	23.0
W. Boas River	4,000	80.0 (10)	50	23.0
Boas River	64,800 (±12,000)	384.0 (40)	169	23.1 (±2.6)
Bear Cove	400	1.6 (37)	250	35.0
SW. East Bay	1,000	150.0 (0)	7	35.0
East Bay	7,500 (± 1,800)	97.3 (32)	77	34.7 (±6.3)
Subtotal — Southampton Is.	77,900	750.4	104	
Bowman Bay	91,900 (±23,500)	193.7 (67)	474	80.9 (±2.8)
Cape Dominion	36,400 (±10,100)	1,210.0 (3)	30	60.6 (±4.6)
Koukdjuak River	95,000 (±13,400)	1,533.0 (5)	62	41.4 (±3.2)
Subtotal — Baffin Is.	223,300	2,936.7	76	
Total	528,700 (±43,600)	4,174.2	127	43

1. South Hudson Bay

Hanson and Lumsden have checked the productivity of the colonies of this region with aerial surveys almost annually since 1957. Hanson et al. (1972) summarized their results up to 1970 and reviewed the history and development of the colonies.

Most of the nesting geese are in the colonies at Cape Henrietta Maria, Ontario and La Pérouse Bay, Manitoba, with perhaps fewer than 100 pairs in any given year found intermittently along the coast from La Pérouse Bay southeast for about 1,100 km (700 mi) to Akimiski Island (Hanson et al., 1972). That string of records thus connects the two colonies, which are considered to have different origins (to be noted later), and makes it logical to consider south Hudson Bay as a region.

1.1. Cape Henrietta Maria

1973 — 29,600 nests, 73% blue (Fig. 3). This was the only colony where adverse weather prevented adequate photography during my survey. I obtained low-level sample coverage on June 11, but clouds made high-level photography impossible. Due to an obvious difference in nest densities between the western and eastern parts of the colony, I divided it into two strata for calculating the mean densities and total nests (Table 3).

Table 3
Calculation by strata of the size of the Cape Henrietta Maria Lesser Snow Goose colony, June 11, 1973

Stratum	Total no. nests (2±s.e.)	Total nesting area km² (% anal. on photos)	Mean density (nests/km²)
Western	27,000 (±7,700)	36.7 (32)	736
Eastern	2,600 (± 800)	32.4 (43)	80
Total	29,600 (±7,800)	69.1 (37)	428

Earlier records — After visiting the Cape in late August, 1944 and talking with Indians who knew the area, Smith (1944) surmised that there was a colony of about 100 nesting pairs, 75% blue phase. He also noted reports of Snow Geese nesting on Akimiski Island. Lumsden (1957) made the first detailed studies of the Cape colony in 1957, including the banding of 50 goslings. Since then aerial productivity appraisals

Figure 2
Breeding range of the eastern Arctic population of Lesser Snow Geese showing colonies, regions, air bases, and localities mentioned in the text.

Figure 2

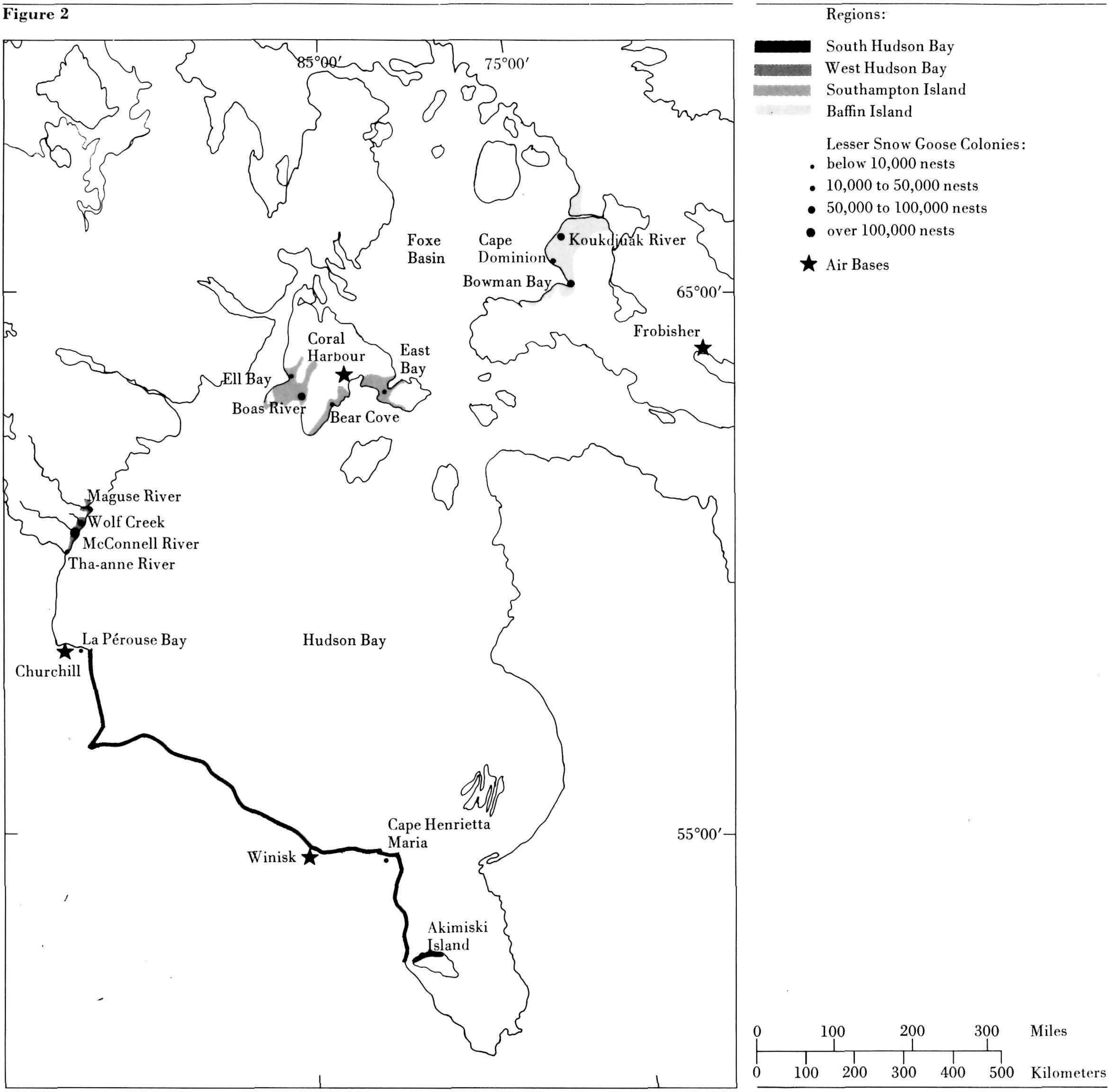
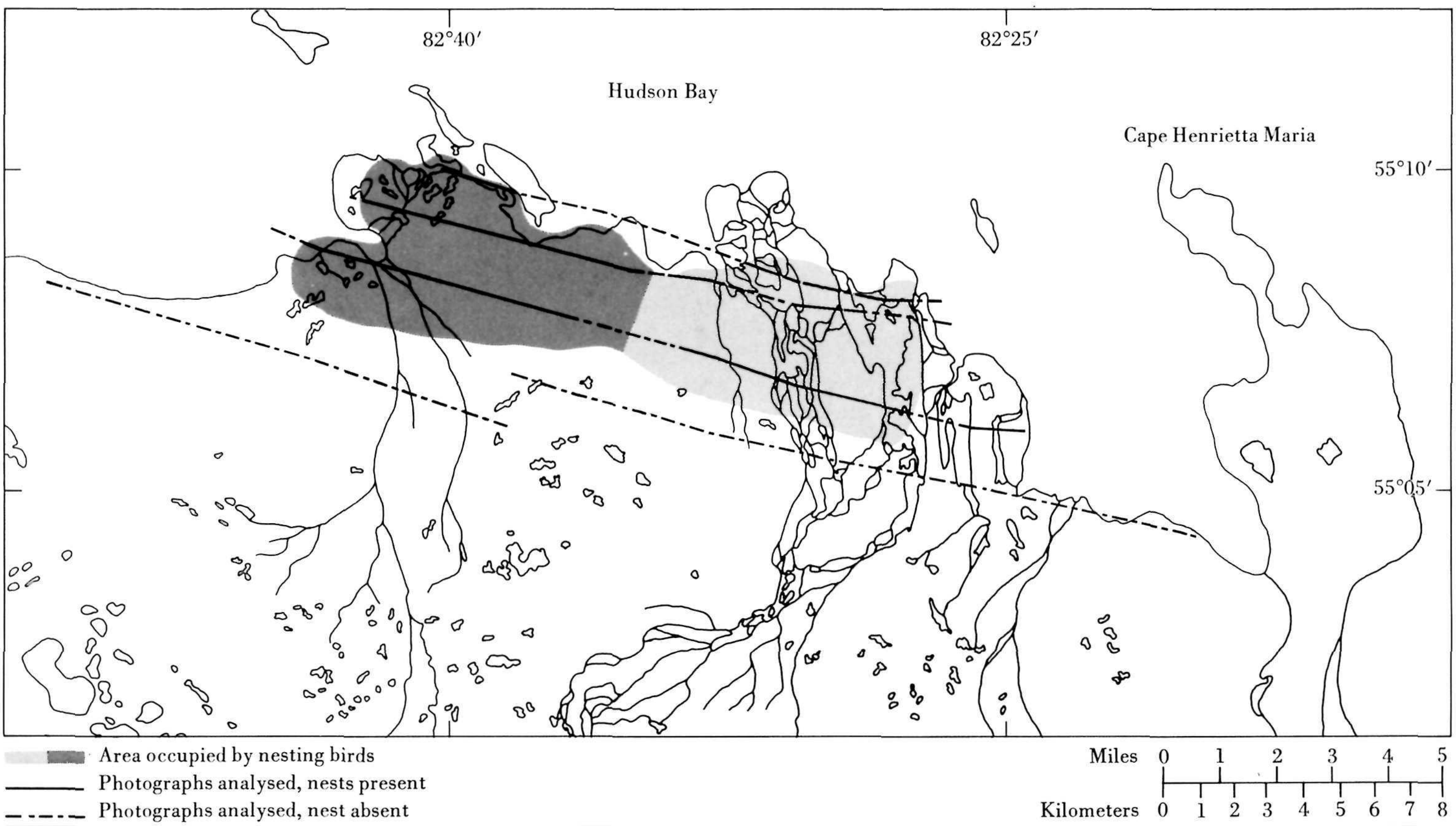


Figure 3
Lesser Snow Goose colony at Cape Henrietta Maria, Ontario, showing the area occupied by nests, June 11, 1973, and the analysed photographic coverage. Shading indicates strata of nesting densities.

Figure 3



have been made annually (Hanson et al., 1972) and an annual banding program has been underway since 1969 (Lumsden, pers. comm.).

In 1972 and 1973 Lumsden (pers. comm.) censused the nesting birds by means of small-format (35 mm) vertical aerial photography. He found that the nesting area was about the same in both years. His estimates of the total nesting population — 22,300 nests (1972) and 25,300 nests (1973) — were probably more accurate than my estimate in 1973. Our results indicate that the colony has tripled since 1957, when Lumsden estimated a total of 17,000 birds, including non-breeders (Hanson et al., 1972). The colour ratios estimated by Lumsden of 71.5% blue (1972) and 71.9% blue (1973) were very close to the one I estimated in 1973.

Hanson et al., (1972) calculated that the percentage of blue in the adult component of the colony had increased steadily at the rate of 0.622 per year. They suggested, as did Cooch (1964), that this colony was founded by birds from Baffin Island.

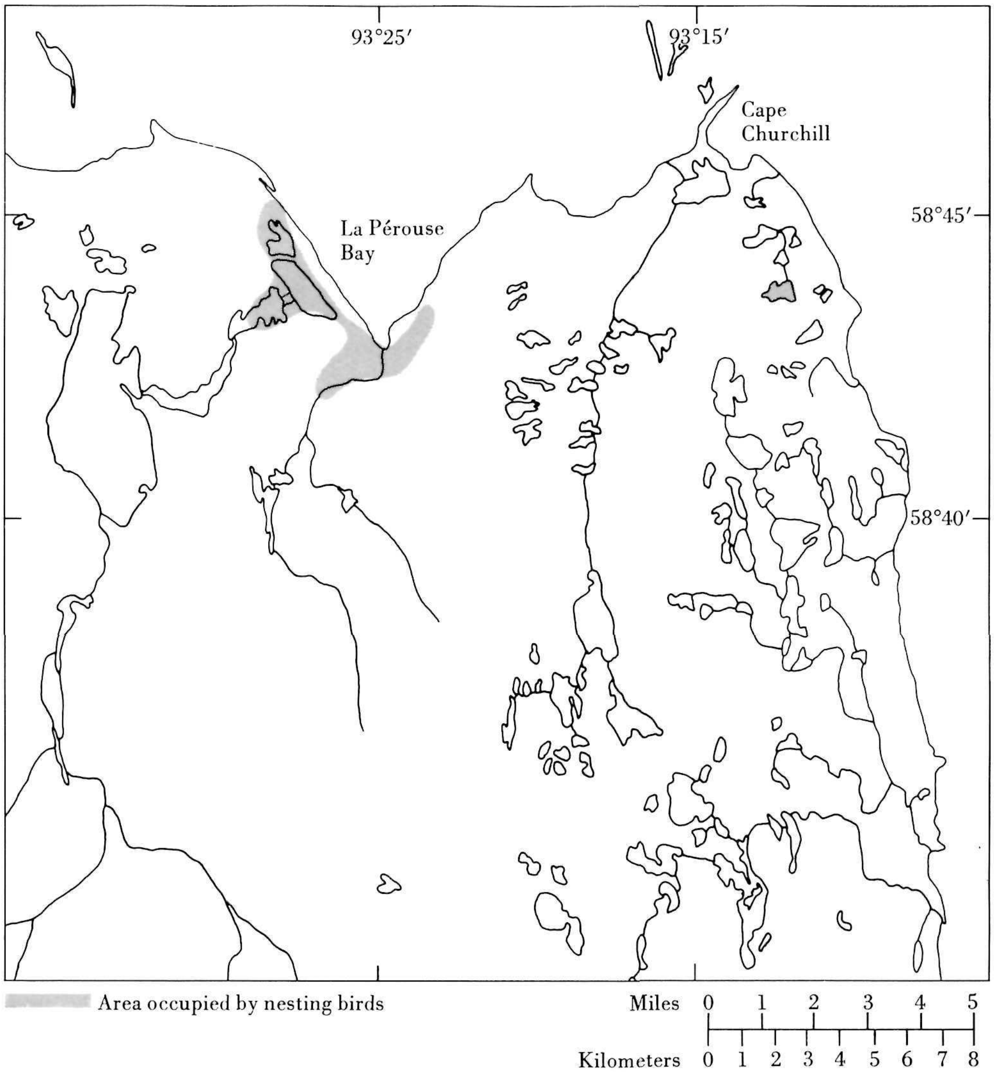
1.2. La Pérouse Bay

1973 — 2,800 nests, 26% blue (Fig. 4). We obtained total high-level photo coverage and extensive low-level coverage at La Pérouse Bay on June 13 and 15, but the resolution of the photographs was too poor to permit accurate goose counting, apparently because of heavy humidity haze. However, researchers censused the colony on the ground and advised (Cooke and Finney, pers. comm.) that the ground area, total nests, and colour ratio were similar to those of 1972. My successful photographic survey of the colony in 1972 (Kerbes and Prevett, 1973) agreed closely with ground counts. Therefore, the 1972 results have been entered in Table 2 and Figure 4.

Earlier records — In 1953 Wellein and Newcomb (1954) saw 23 nests and 3 broods between Norton Lake and La Pérouse Bay, and in 1956 Foster (1957) found 15 nests at La Pérouse Bay. Aerial surveys of the colony at La Pérouse Bay have been undertaken since 1962 by Hanson et al. (1972), who have called it the "Cape Churchill Colony." A team led by F. Cooke of Queen's University has studied the colony since

Figure 4
Lesser Snow Goose colony at La Pérouse Bay, Manitoba, showing the area occupied by nests, June 1972 and 1973.

Figure 4



1968. Nesting biology, distribution, behaviour, genetics, and population turnover in relation to colour phase are being followed through nest history studies and a banding and colour marking scheme (Cooke, 1975; Cooke and Finney, pers. comm.).

The colony seems to have changed little since 1963, when Hanson et al. (1972) estimated a total of 5,600 birds, 24% blue. Estimates made from the ground by Cooke and Finney (pers. comm.) indicated that the population remained stable at about 3,000 nesting pairs in 1972, 1973, and 1974, and that the colour ratio was 26% blue in 1972 and 1973, and 28% blue in 1974. Since its colour ratio and migration pattern are similar to those of west Hudson Bay and Southampton Island, the colony was probably founded by birds from those regions (Hanson et al., 1972; Dzubin et al., 1973).

In addition to the geese nesting in the colony, Cooke and Finney (pers. comm.) reported a few nests, perhaps up to 200, scattered along the coast from La Pérouse Bay to Cape Churchill, and in 1968, 1969, and 1970 Pakulak observed about 200 nests (50% to 75% blue) at a small lake about 6.5 km (4 mi) south of Cape Churchill. I observed that small colony in 1972 and 1973, but my photographs did not permit accurate analysis to confirm that the unexpectedly high blue percentage still existed.

2. West Hudson Bay

Hanson and Lumsden have included west Hudson Bay in their surveys since 1964. They have summarized their results up to 1970 and reviewed the history and growth of the colonies (Hanson et al., 1972). They reported that during flights (all done post-hatch) they usually were not out of sight of flocks with young for some 113 km (70 mi) of coast from Thlewiaza River to Maguse River, and they called that sector the "McConnell River Colony."

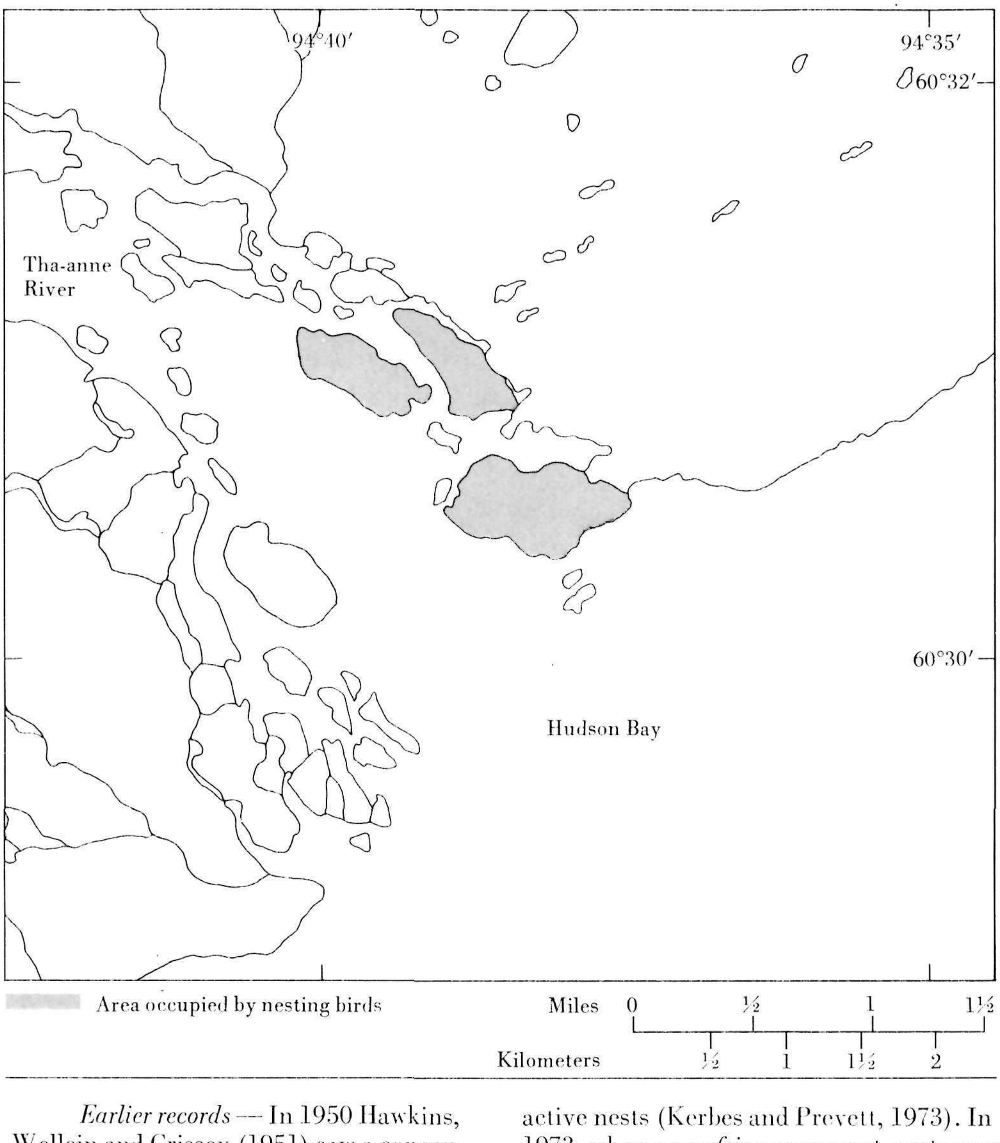
West Hudson Bay contains the huge colony at McConnell River, the new colony at Wolf Creek, the small colonies at Tha-anne River and Maguse River, and an area of scattered nests between Tha-anne and McConnell, which I have designated "South McConnell River." Except for 100 adults with young reported at Seal River, Manitoba in 1968 (Hanson et al., 1972), there are no records of breeding birds between the south and west Hudson Bay regions.

2.1. Tha-anne River

1973 — 3,200 nests, 21% blue (Fig. 5). We obtained complete high- and low-level photographic coverage for this colony and its environs on June 18 and 19. Analysis and scanning of the film revealed a very dense concentration of nests on three small islands, totalling about 1 km², in the north-east corner of the joint mouth of the Tha-anne and Thlewiaza rivers. The colour ratio, which was calculated from a large sample of birds in low-level photographs, was not significantly different from that at McConnell River. This is the densest colony and the only one limited to deltaic islands.

Figure 5
Lesser Snow Goose colony at Tha-anne River, N.W.T., showing the area occupied by nests, June 18 and 19, 1973.

Figure 5



Earlier records — In 1950 Hawkins, Wellein and Crissey (1951) saw a concentration of nests that was probably on the same islands as those occupied in 1973.

Hanson et al. (1972) suggested that in some years *aufeis*, or ice accumulating on the delta over winter, prevented nesting on the islands when it covered them and did not melt soon enough. I found *aufeis* in my survey of 1972, but not on the three nesting islands, which were covered with active nests (Kerbes and Prevett, 1973). In 1973, when no *aufeis* was present, nests were again only on those three islands. MacInnes (pers. comm.) observed similar numbers on the three islands in June, 1969.

2.2. South McConnell River

1973 — 5,900 nests, 24% blue. From analysis of a continuous strip of photographs and from visual observations taken on June 18 along the coast, I estimated that nests were scattered within 8 km (5 mi) of the high-tide line from the north shore of Tha-anne River to the south border of the McConnell River colony. About 80% of those nests were in the northern 25% of that area. The area apparently provides feeding grounds for many non-breeders, as well as local breeders and others from Tha-anne and McConnell after hatch. Colour ratio was similar to McConnell River.

Earlier records — The unnamed river north of the Tha-anne mentioned by Hanson et al. (1972) as a potential nesting area did not have any nests nor did it appear to be suitable nesting habitat in 1972 or 1973.

2.3. McConnell River

1973 — 163,000 nests, 24% blue (Fig. 6). We photographed the McConnell River colony on June 18 and 19. Subsequent analysis showed it to be the largest single colony in the eastern Arctic. The density of nests was greatest along the north branch of the McConnell River and on the large island between the north and south branches.

Earlier records — In 1941 Angus Gavin observed nesting birds in small areas at each of the north and south branch mouths of the McConnell River; he estimated a total of 14,000 birds (Cooch, 1963, and pers. comm.). Cooch (1958, 1961, 1963) called this the "Eskimo Point Colony," where he undertook banding and other studies in 1954, 1959, and 1961. After studying Canada Geese there in 1959 and 1960, C. D. MacInnes led a many-faceted study of geese with a team of graduate students from the University of Western Ontario from 1964 to 1971. In 1972 and 1973 Harwood and Ankney, respectively, continued the studies. No investigators were present in 1974 — for the first time in 15 years.

McConnell River has the best historical record of all colonies, and it shows the most phenomenal growth. In the 32 years since 1941 it has increased almost 30-fold (assuming that Gavin's 14,000 were adult-plumaged birds and that the 326,000

Figure 6
Lesser Snow Goose colony at McConnell River, N.W.T., showing the area occupied by nests, June 18 and 19, 1973, and the analysed photographic coverage. The numbers represent average densities in nests/km² for the nesting areas within photo frames.

Figure 6

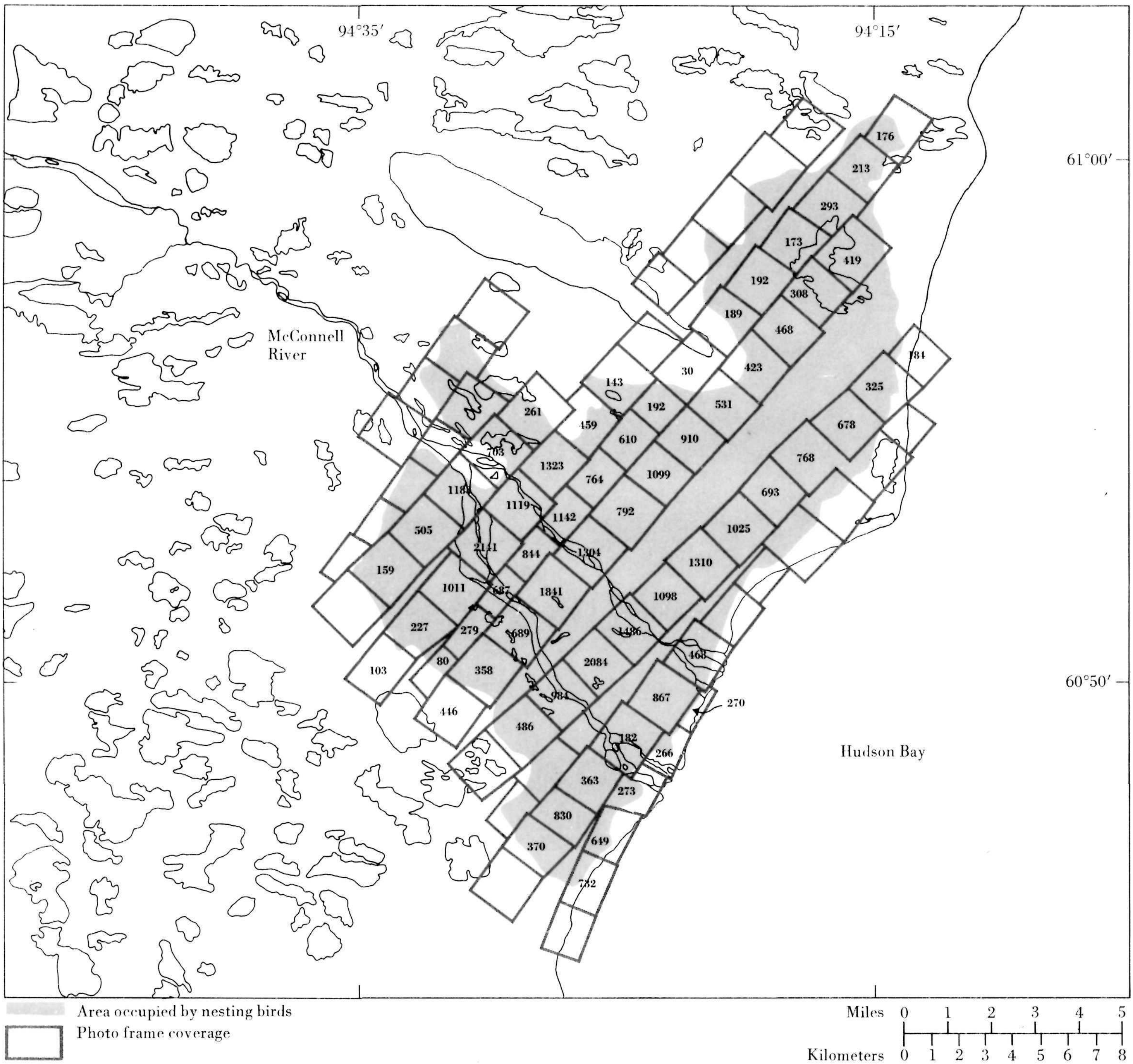
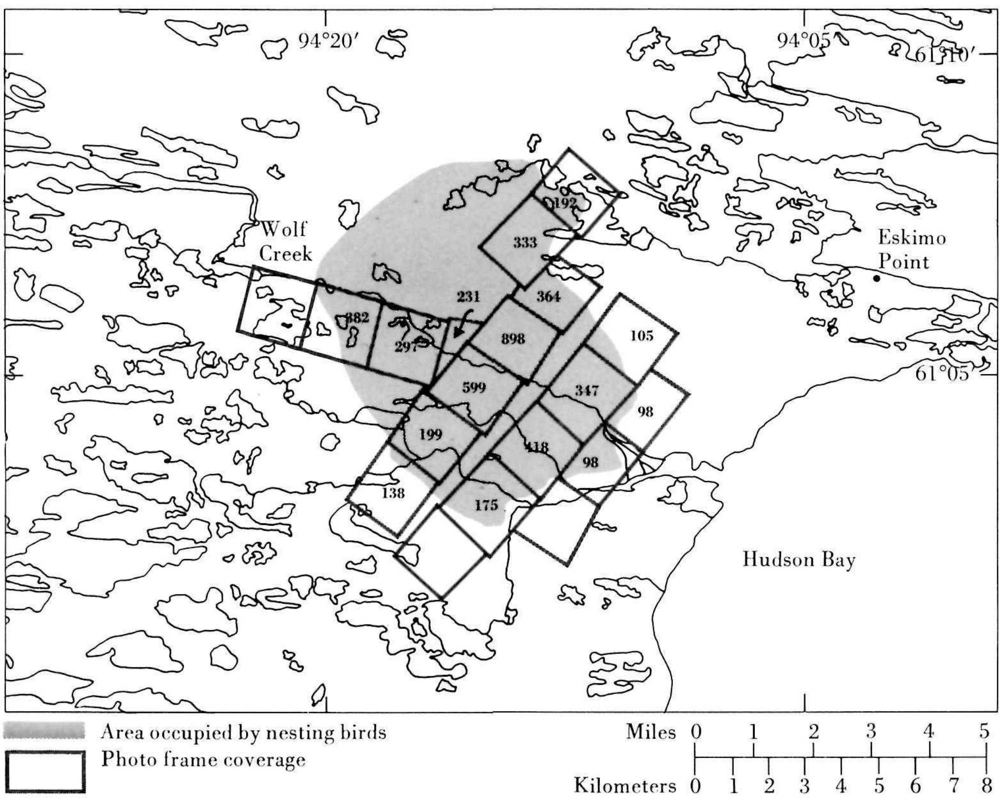


Figure 7
Lesser Snow Goose colony at Wolf Creek, N.W.T., showing the area occupied by nests, June 18, 1973, and the analysed photographic coverage. The numbers represent average densities in nests/km²
for the nesting areas within photo frames.

Figure 7



nesting birds in 1973 were accompanied by 90,000 non-breeders). The lack of accurate population counts prior to the 1972 and 1973 surveys prevents reconstruction of the yearly rate of growth.

In 1971 C. Von Barloewen (pers. comm.) used a ground sampling technique to estimate 45,000 nests in the colony. My photo surveys tallied 117,000 nests in 1972 (Kerbes and Prevett, 1973). It is unlikely that the total nests more than doubled, as it would seem, between 1971 and 1972. MacInnes and Harwood (pers. comm.) reported that the nesting phenology was later and more restrictive in 1972 than it was in 1971. Therefore, Von Barloewen's estimate probably was low because it underestimated the mean density of the colony and the size of its northern area. The difference between 1972 and 1973 arose because 1972 was a late season and the size of the nesting area was restricted by late snow cover (Harwood pers. comm.), while 1973 was one of the earliest and best on record (Ankney, pers. comm.).

Hanson et al. (1972) pointed to the apparent steady increase in the frequency of blue genes in the colony from only a trace percentage of blue in 1941 to 17% blue in 1961 (Cooch, 1963), followed by an apparently stable period from 1964 (24.5% blue) to 1969 (25.5% blue). The ratio remained at that level in each year from 1970 to 1973 (Prevett and MacInnes, pers. comm.; this report).

2.4. Wolf Creek

1973 — 22,500 nests, 25% blue (Fig. 7). Wolf Creek is the unofficial name (English translation of the Inuit name "Amaurokilik") of the small river which enters Hudson Bay about 6.5 km (4 mi) south of Eskimo Point. The colony, crossed at its centre by Wolf Creek, was photographed on June 18. Blokpoel (1974) referred to it as the "Eskimo Point Colony."

Earlier records — On June 27, 1967 J. P. Prevett (pers. comm.) saw a small nesting colony of about 1,500 pairs along the shores of Wolf Creek about 3.2 km (2 mi) inland from Hudson Bay. It has grown rapidly since then. During the survey in 1972 I estimated visually that there were 30,000 nests. The higher total for 1972 than for 1973 may have been due to an immigration of geese from Southampton Island, where nesting was prevented by an exceptionally late spring (Kerbes and Prevett, 1973), or it may have been due to overestimation in 1972.

The Wolf Creek colony is closer to a human settlement than any other: flightless geese have been seen at midsummer on the streets of Eskimo Point.

2.5. Maguse River

1973 — 500 nests, 25% blue (Fig. 8). This area was thoroughly reconnoitred and extensive sample areas were photographed on June 18. Analysis of photographs and notes taken during the flight indicated about 100 nests on Austin Island and about 400 nests along a tributary of the north branch of Maguse River. Colour ratio was similar to Wolf Creek.

Earlier records — Acting on a tip from Cooch about an Inuit report, Lumsden found about 4,000 geese with young on the southern half of Austin Island on August 15, 1964 (Hanson et al., 1972). MacInnes (pers. comm.) reported about 50 nests on Austin Island and about 250 on a tributary of the north branch of the Maguse River in 1969. As we recorded nests at both in 1973, the colony seems to have changed little.

In both 1972 and 1973 many thousands of non-breeding geese were in the area (apparently more were concentrated there than at any other site in the west Hudson Bay region).

Figure 8
Lesser Snow Goose colony at Maguse River, N.W.T., showing the areas occupied by nests, June 18, 1973.

Figure 8

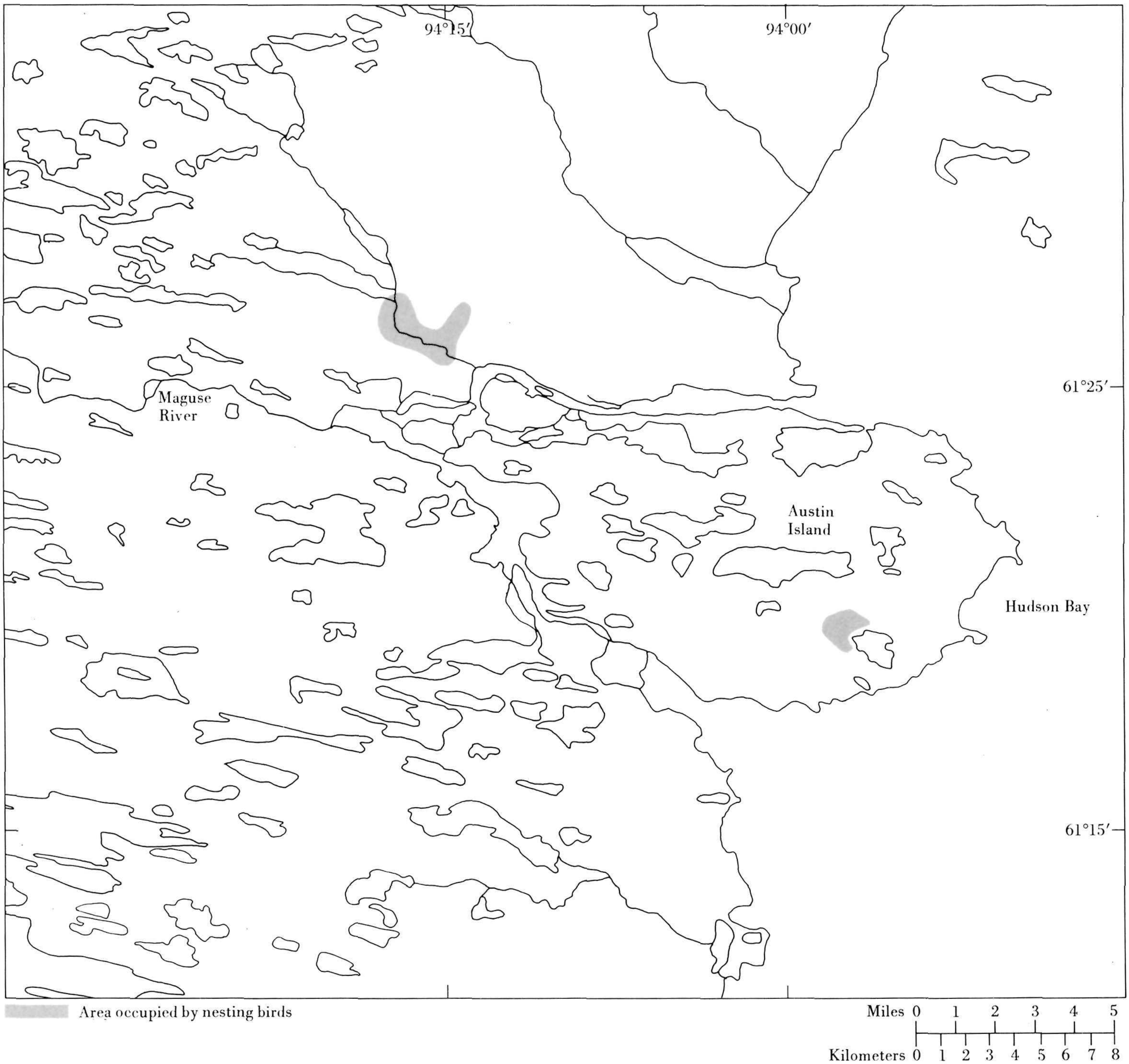
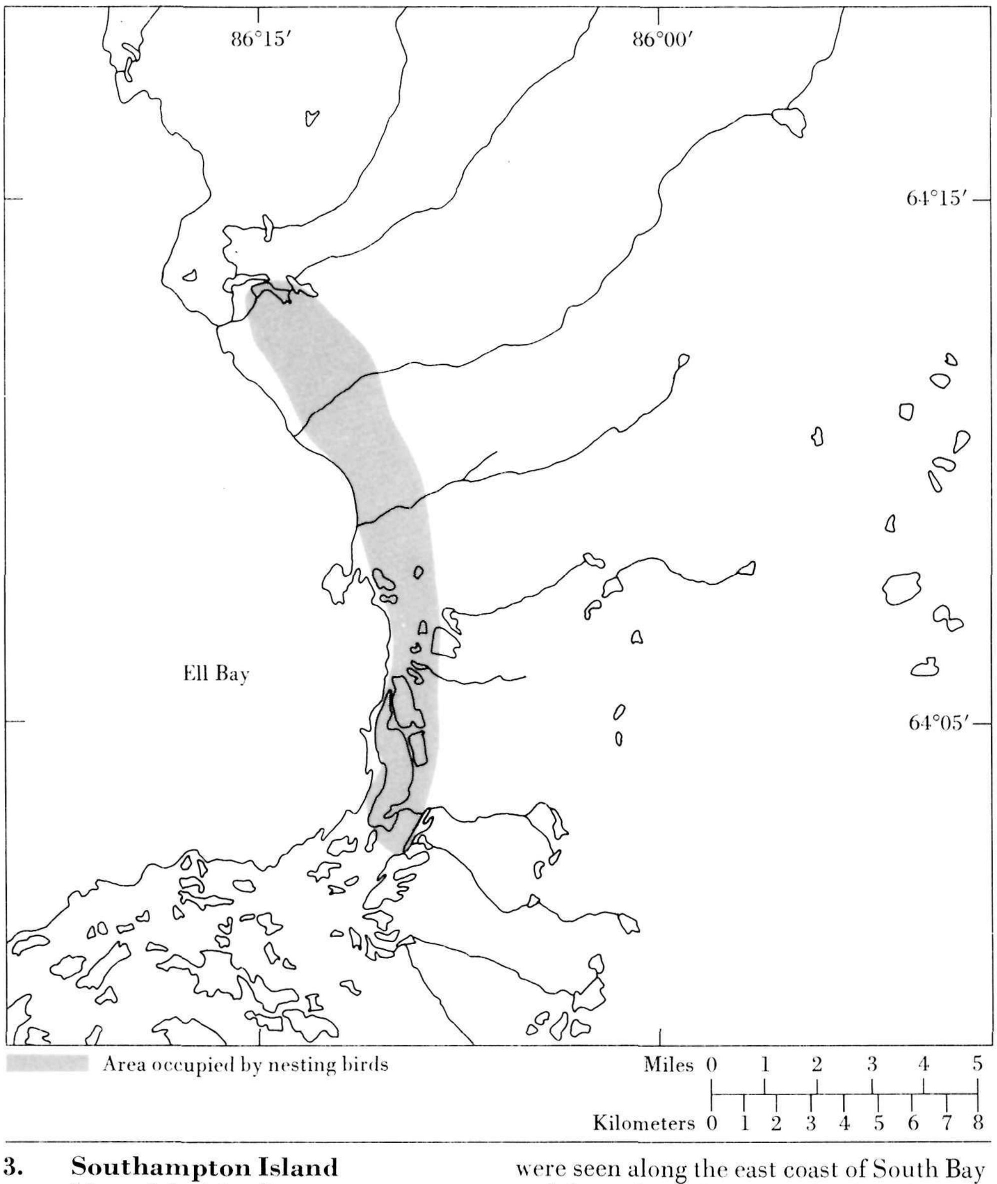


Figure 9
Lesser Snow Goose colony at Ell Bay, N.W.T., showing the area occupied by nests, June 23, 1973.

Figure 9



3. Southampton Island

Most of the island's geese nest at Boas River, with smaller numbers at East Bay and Bear Cove. Some also nest in diffuse colonies at Ell Bay and in two areas adjacent to large colonies — west of Boas River and southeast of East Bay. Parker and Ross (1973) reported that during aerial surveys in August 1971 flocks of geese were seen along the east coast of South Bay and throughout the lowlands of southwest Southampton Island.

Extensive aerial surveys of the Southampton colonies were made by Cooch in 1955 (Cooch, 1955) and by me in 1966 (Kerbes, 1967).

Inventory of the colonies during the 1972 survey was thwarted by the exceptionally late spring, which prevented nesting on Southampton and Baffin islands. Flocks of geese were seen on or near the Southampton colony sites and a few (total 2,000 birds) on the east end of Coats Island (Kerbes and Prevett, 1973), where there may be a small colony. We surveyed most of the sedge lowlands of Southampton Island, i.e., the existing and potential colony sites, in 1973, but did not visit Coats Island.

3.1. Ell Bay

1973 — 200 nests, 23% blue (Fig. 9). Visual observations and analysis of photographs taken on June 23 revealed a large area of diffuse nesting near Ell Bay. Colour ratio was approximately the same as that of Boas River.

Earlier records — MacInnes (pers. comm.) found old nests and other signs of a colony when he visited Ell Bay in 1961.

3.2. West Boas River

1973 — 4,000 nests, 23% blue. Notes and photographs taken on June 23 showed scattered nests in an area averaging 4 km in width extending for 20 km along the coast west of the western boundary of the Boas River colony. Density within the area varied greatly and the colour ratio was similar to that of Boas River.

Earlier records — Sutton (1932) relayed Inuit reports of nests occurring along the north shore of the Bay of God's Mercy as far as Cape Kendall. However, Manning (1942), Cooch (1958), and Kerbes (1967) reported no such westward extension.

3.3. Boas River

1973 — 64,800 nests, 23% blue (Fig. 10). This colony, which was photographed on June 21 and 23, proved to be the most difficult for navigation. The low relief, extensive melt-water flooding, and bewildering maze of water courses were aptly described by Cooch (1958). Analysis of sample photo strips has shown that, although nest densities were low, the total nesting area was much bigger than that of McConnell River.

Figure 10
Lesser Snow Goose colony at Boas River, N.W.T., showing the area occupied by nests, June 21 and 23, 1973, and the analysed photographic coverage. The numbers represent average densities in nests/km² for the nesting areas within photo frames.

Figure 10

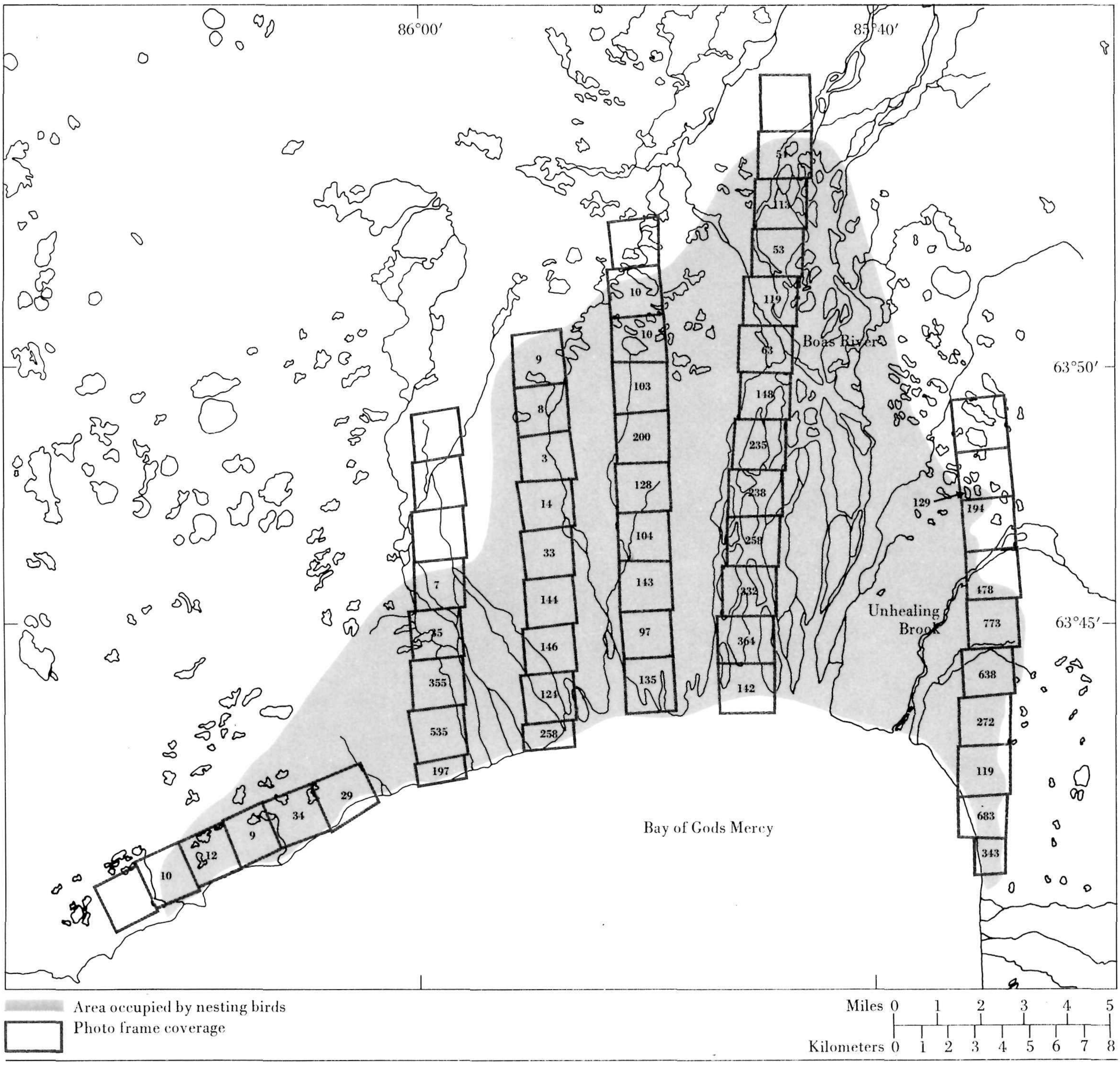
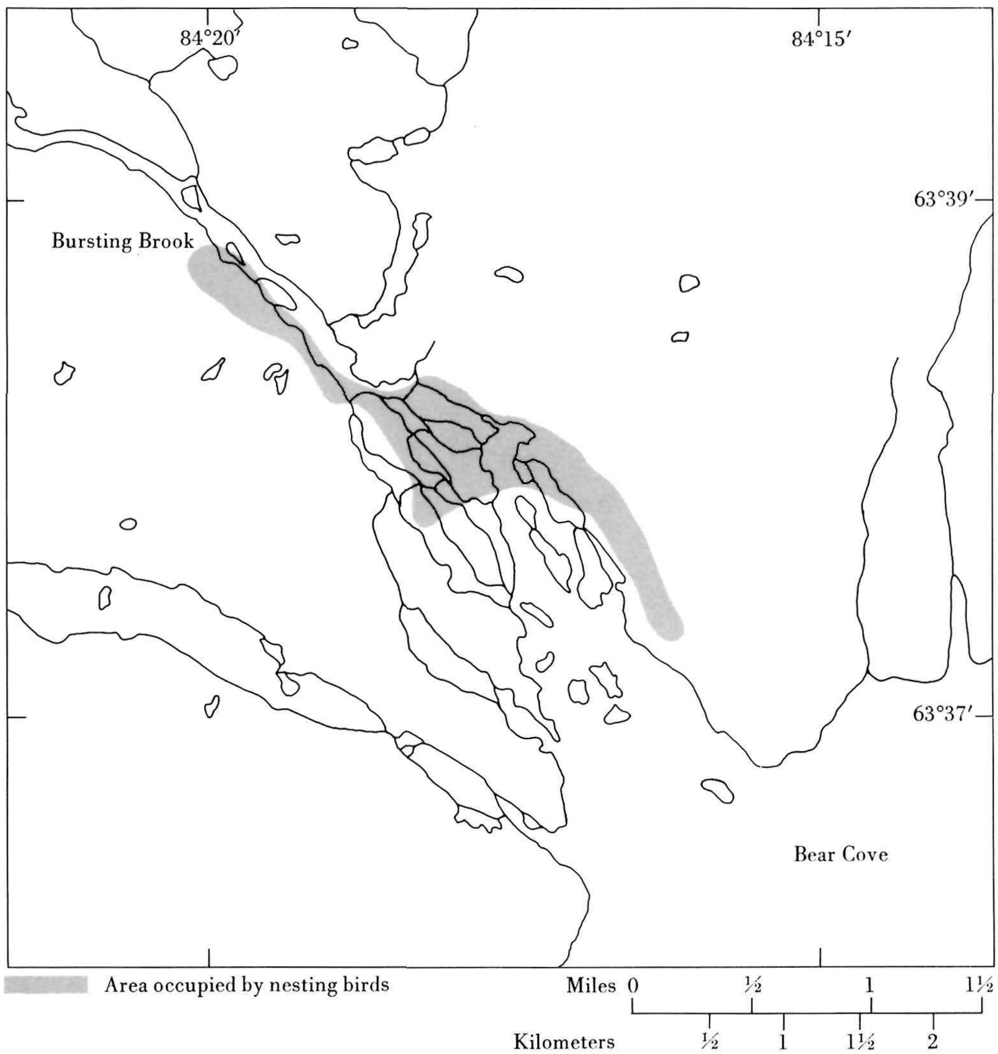


Figure 11
Lesser Snow Goose colony at Bear Cove, N.W.T., showing the area occupied by nests, June 21, 1973.

Figure 11



Earlier records — In 1929 local Inuit advised Sutton (1932) of this colony. It was investigated by Manning (1942) in 1934 and by Bray (1943) and Manning in 1936. Cooch (1958) did his classic Blue Goose nesting studies in 1952 and 1953. In 1953, 1956, and 1957 Barry (1956, 1962) studied Brant there and in 1961 MacInnes (pers. comm.) studied Canada Geese. Banding was undertaken in 1934, 1952 to 1961, 1965 and 1966; in the later years by Tooma Netser of Coral Harbour.

The colony has increased more than four-fold in total number of nests, from 15,000 estimated in 1934 (Manning, 1942) to 65,000 in 1973. Apparently most of that increase has been since 1961 (Cooch, 1963). The nesting area used from 1952 to 1961 (Cooch 1958, 1963), in 1966 (Kerbes, 1967) and 1973 did not alter significantly. Manning (1942) estimated the nesting area to be much smaller in 1934 (about 35 km^2) than the area used from 1952 to 1973 (about 400 km^2) yet Cooch (1963) implied that there had been no increase in numbers up to 1961. Either Manning's estimate of numbers was too high or his estimate of area too low, or, more likely, Cooch's estimate of total numbers was too low. It is most unlikely that the density of nests would have been much greater in 1934 than it was from 1952 to 1961.

The proportion of blue phase increased dramatically from 5% blue in 1934 (Manning, 1942) to 33% in 1961 (Cooch, 1963). Since then it has stabilized or perhaps has decreased to 23% blue phase in 1973.

3.4. Bear Cove

1973 — 400 nests, 35% blue (Fig. 11). We thoroughly searched and photographed this area from the air on June 21. Analysis of photographs showed a small colony on the banks of Bursting Brook with a colour ratio close to that of East Bay.

Earlier records — Southampton Island Inuit reported a small nesting colony at the mouth of Bursting Brook in 1942 (Manning, 1944). Cooch (1963) cited a report that there were 2,000 birds, 33% blue, in 1960. Apparently the colony has changed little since.

3.5. Southwest East Bay

1973 — 1,000 nests, 35% blue. We saw scattered solitary nests and pockets of a few nests each in a broad zone of very low and waterlogged tundra extending from the southwest boundary of the East Bay colony across the narrow base of Bell Peninsula to the east shore of Native Bay on June 21 and 23. Parts of the area were photographed, but they have not been analysed. I visually estimated the total nests and colour ratio.

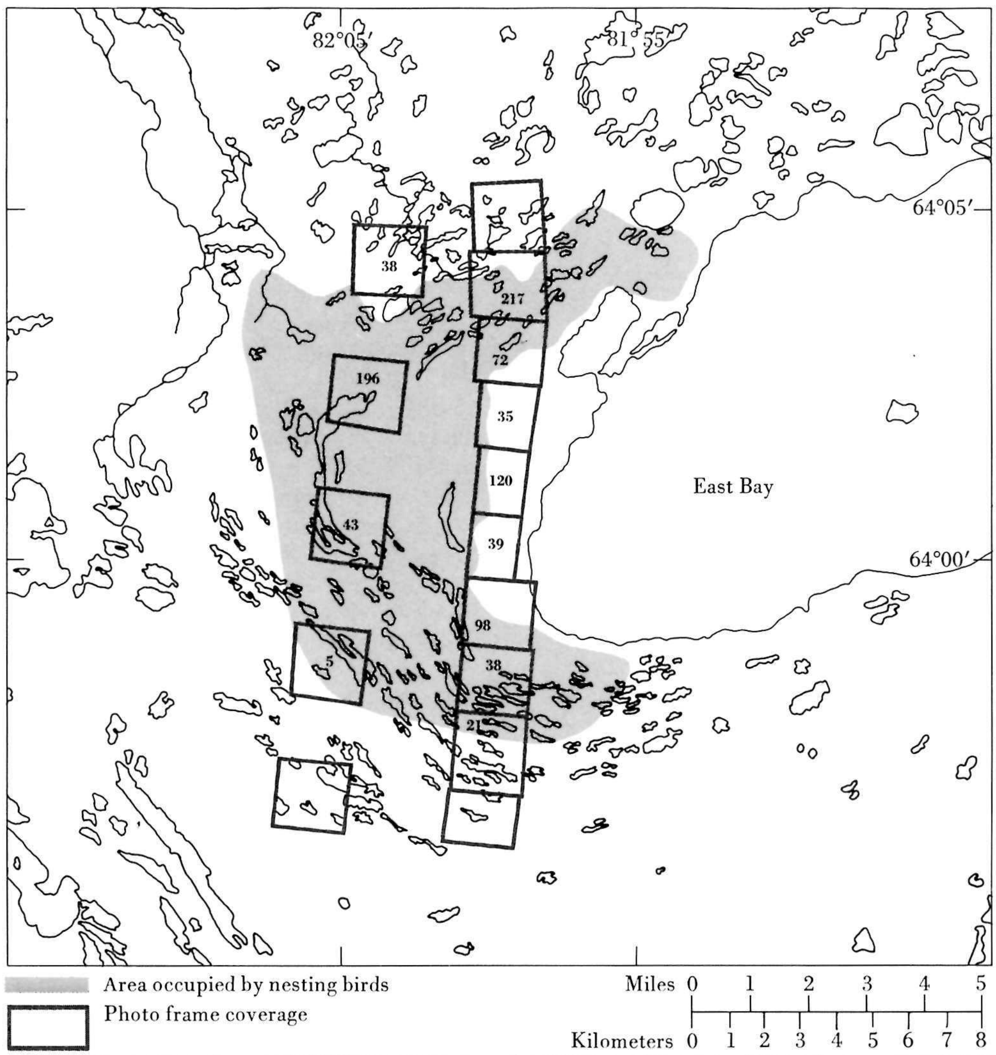
Earlier records — See East Bay.

3.6. East Bay

1973 — 7,500 nests, 35% blue (Fig. 12). This colony was completely photographed on June 21 and 23. Analysis of sample photographs showed that its colour

Figure 12
Lesser Snow Goose colony at East Bay, N.W.T., showing the area occupied by nests, June 21 and 23, 1973, and the analysed photographic coverage. The numbers represent average densities in nests/km² for the nesting areas within photo frames.

Figure 12



ratio was significantly different from that of Boas River.

Earlier records — Probably on the basis of information received from Inuit in 1934 and 1936, Manning (1942) indicated that geese nested at least occasionally in the general area where the East Bay and southwest East Bay colonies were delineated in 1973. The Inuit reported the East Bay colony to Loughrey in 1952 (Arctic Circular, 1959). Barry (1962) studied Brant at East Bay in 1957.

In 1955 Cooch (1963) estimated there were 25,000 birds, 33% blue, in almost exactly the same area delineated as the East Bay colony in 1973. I found geese nesting in the same area in 1966 (Kerbes, 1967). Since the 1955 estimate included non-breeders and had no statistical confidence limits, it may not mean that the colony was larger than in 1973.

4. Baffin Island

The breeding grounds of the Great Plain of the Koukdjuak extend along the west coast of Baffin Island for 257 km (160 mi) from Bowman Bay to Taverner Bay. Following the early work of Soper (1930) and Manning (1942), aerial surveys of the geese were flown by Loughrey (1952) and Cooch (1955). In 1961 Lemieux led a banding expedition along the Koukdjuak River (Lemieux and Heyland, 1967). I conducted an aerial survey in 1966, and in 1967 and 1968 I carried out aerial surveys, breeding biology studies, and banding operations (Kerbes, 1967, 1969). I also undertook aerial photographic surveys in 1971, 1972 and 1973.

The Great Plain of the Koukdjuak includes over 11,000 km² of sedge lowland adjacent to Foxe Basin and Koukdjuak River. The geese use that area for feeding, but they nest almost exclusively in some 3,000 km² of the plain along the coast from Bowman Bay almost to the mouth of Koukdjuak River. Cooch (1961) arbitrarily divided the nesting grounds into three colonies: Bowman Bay, Cape Dominion, and Koukdjuak River.

In some years a few geese nest north of Koukdjuak River, and there have been reports of small colonies southwest of Bowman Bay at Garnet Bay, Cory Bay, and Aukpar River (Cooch 1955, 1963). Prince Charles and Air Force islands, which are northern extensions of the Great Plain of the Koukdjuak, provide summer range for small numbers of non-breeding geese from the colonies of the plain (Elliott, Manning, pers. comm.). During the aerial surveys of 1966 to 1968 and 1971 to 1973 I saw no nests outside the three main colonies.

A review of the *1973* results for each of the Baffin colonies follows. *Earlier records* are discussed for all three together because of their close relationship.

4.1. Bowman Bay

1973 — 91,900 nests, 81% blue (Fig. 13). On June 26 to 28 we found nests on a strip averaging 3 to 4 km wide above the high-tide line along the east shore of Bowman Bay, in what Putnam (1928) called the "Blue Goose Prairie." It has since been misspelled "Bluegoose Prairie" on official maps, and Kerbes (1969) referred to this colony as "Bluegoose Prairie." Due to obvious differences in nest densities among the northern, central, and southern parts of the colony, we based our calculations on stratification (Table 4).

Table 4
Calculation by strata of the size of the Bowman Bay Lesser Snow Goose colony, June 26 to 28, 1973

Stratum	Total no. nests (2 ± s.e.)	Total nesting area km² (% anal. on photos)	Mean density (nests/km²)
Northern	8,900 (± 5,700)	28.3 (57)	314
Central	60,300 (± 13,100)	79.0 (91)	763
Southern	22,700 (± 18,600)	86.4 (48)	263
Total	91,900 (± 23,500)	193.7 (67)	474

4.2. Cape Dominion

1973 — 36,400 nests, 61% blue (Fig. 14). The photographic coverage analysed (taken June 26 to 28) and estimated nesting areas for Cape Dominion and Koukdjuak River and their relationship to Bowman Bay are shown in Figure 14. The border between Cape Dominion and Bowman Bay was based on a definite geographic feature (the unnamed river) and on an apparent change in the colour ratio, which we estimated from small photographic samples at many points in the Baffin colonies. The percentage of blue tended to decrease proceeding north from Bowman Bay. We selected the most obvious point of change in ratio as the border between Dominion and Koukdjuak, and arbitrarily drew that border perpendicular to the coast.

For Dominion and Koukdjuak, I used counts of white phase nesting birds from only the low-level photos to compute the mean density. Much of the high-level photo coverage was analysed, but only to define the edge of the nesting area. The high-level counts could not be used to compute densities because not enough high- and low-level coverage overlapped to permit calculation of the correction factors and confidence limits. Accordingly, I based the confidence limits for Dominion and Koukdjuak (as for Cape Henrietta Maria) on the variance within the low-level samples (Appendices 1 and 2).

4.3. Koukdjuak River

1973 — 95,000 nests, 41% blue (Fig. 14). I have covered special aspects of the photographic survey of this colony under Cape Dominion (above). Koukdjuak River was 21% larger than Cape Dominion, but it contained 61% more nests, mainly because of better drained habitat with higher and more numerous nest sites. In both Koukdjuak and Dominion nest densities varied greatly over short distances. Areas within about 2 km of the high-tide line and within about 0.5 km of stream banks had fairly uniform densities, but other areas showed extreme clumping of nests.

4.4. Bowman Bay, Cape Dominion, and Koukdjuak River

Earlier records — Historical data on the distribution, numbers, and colour phase ratios of the Baffin colonies are sketchy. Although Soper (1930) saw only a relatively small number of nests near Bowman Bay in 1929, he suggested that the nesting grounds extended at least as far as Koukdjuak River. In 1938 Manning (1942) confirmed that geese were found almost continuously along the coast from Bowman Bay to Taverner Bay, but nests did not occur in significant numbers north of the Koukdjuak River. The same pattern has been reported in subsequent surveys in 1952 (Loughrey, 1952), 1955 (Cooch, 1955), 1966 to 1968 (Kerbes, 1969), 1971 (Kerbes and Prevett, 1973), and 1973 (this report).

The estimates of population made prior to 1973 should be considered only as indicators of order of magnitude. The Baffin nesting grounds are too widespread and contain too many geese to be measured

Figure 13

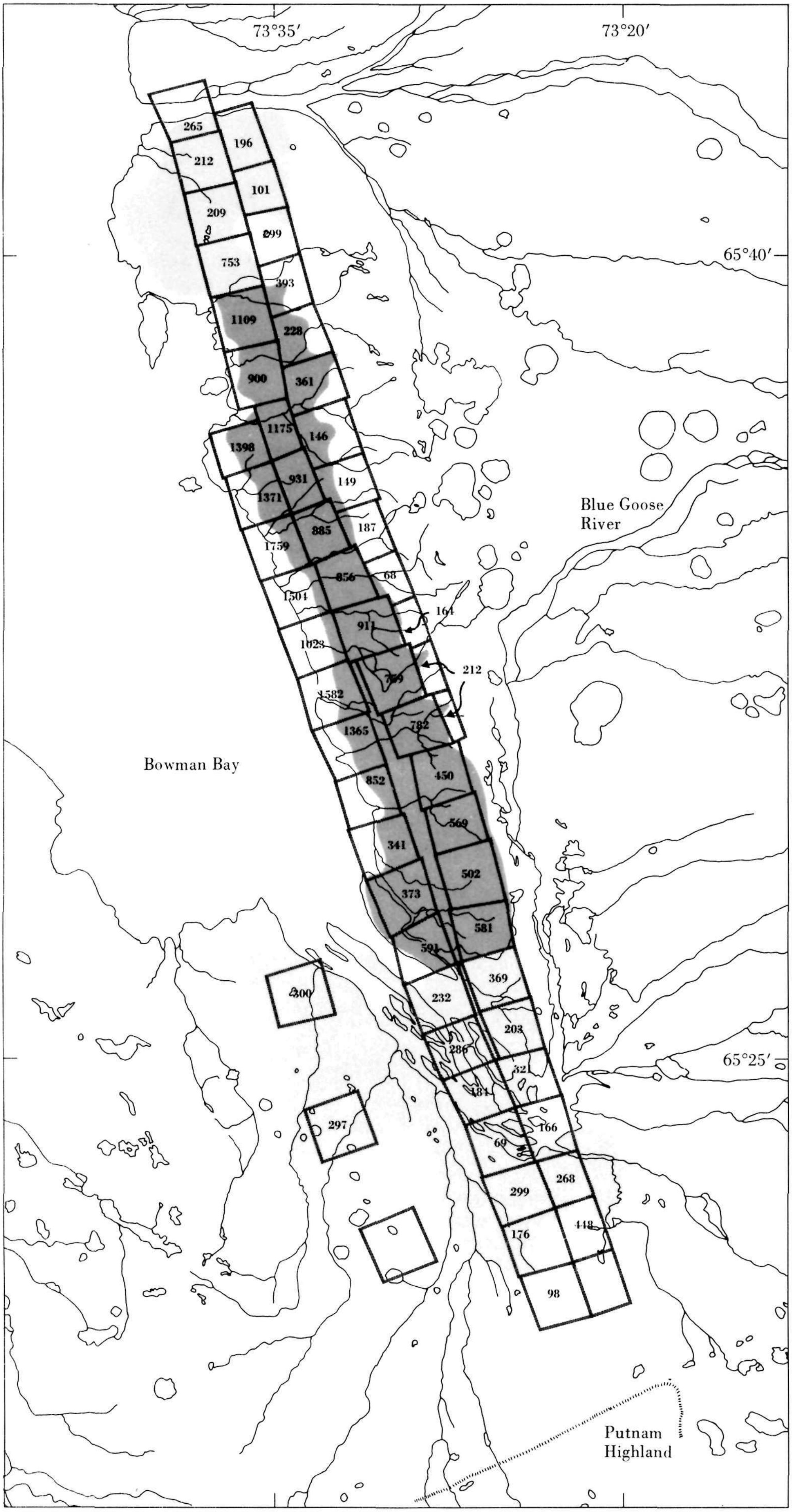


Figure 13
Lesser Snow Goose colony at Bowman Bay, N.W.T., showing the area occupied by nests, June 26 to 28, 1973, and the analysed photographic coverage. The numbers represent average densities in nests/km² for the nesting areas within photo frames. Shading indicates strata of nesting densities.

Area occupied by nesting birds
Photo frame coverage

0 1 2 3 4 5 Miles
0 1 2 3 4 5 6 7 8 Kilometers

Figure 14

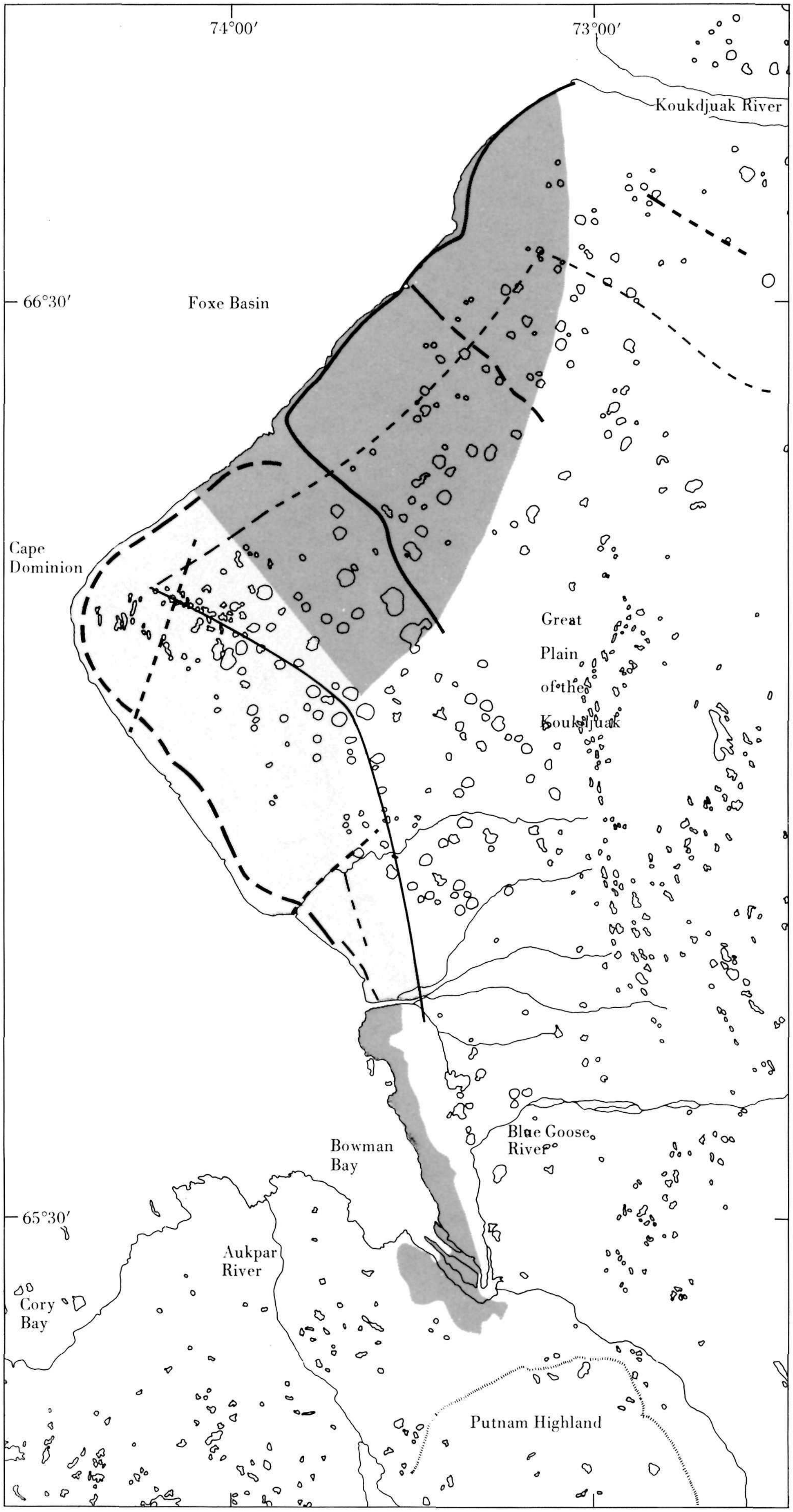


Figure 14
Lesser Snow Goose colonies at Cape Dominion and Koukdjuak River, N.W.T., showing the area occupied by nests, June 26 to 28, 1973, and the photographic coverage. The Bowman Bay colony is included to show its relative position and size.

Area occupied by nesting birds

Position of aerial photos analysed

Low level
Every frame
Every second frame
Every fifth frame

High level
Every frame
Every second frame
Every fifth frame

0 5 10 15 20 Miles

0 5 10 15 20 25 30 Kilometers

Table 5
Percentage blue phase of Lesser Snow Geese in the Baffin Island colonies, 1929 to 1973

Year	Bowman Bay	Cape Dominion	Koukdjuak River	Authority
1929	96	—	—	Soper (1930)
1938	—	14	10	Manning (1942)
1955	97	80	45	Cooch (1963)
1961	—	—	51	Lemieux and Heyland (1967)
1967	88	—	—	Kerbes (1969)
1968	85	76	57	Kerbes (1969)
1971	80	—	—	Kerbes and Prevett (1973)
1973	81	61	41	This report

during a coastal boat trip (Manning) or a single flight (Cooch) with visual observations only. Nevertheless, the previous estimates of total adult-plumaged birds on the Baffin Island nesting grounds — a *minimum* of 200,000 in 1938 (Manning, 1942) and a total of 405,000 in 1955 (Cooch, 1963) — suggest that the total number may not have changed significantly compared to the total of 446,600 nesting birds counted in 1973. Comparison of Cooch's estimate with mine for Bowman Bay shows close agreement between 185,000 adult-plumaged birds in 1955 (Cooch, 1963) and 183,800 nesting birds in 1973. Both are much lower than my estimate of 282,000 nesting birds in 1967 (Kerbes, 1969). Probably the number of nests was greatly overestimated in 1967, since it was based on a very small sample of visual transect counts.

Estimates based on field observations of the colour phase ratios of the colonies are given in Table 5. Those were probably much more accurate than the early estimates of population size. Since 1955 the percentage of blue phase has decreased at Bowman Bay and Cape Dominion, and it seems to have increased and then decreased at Koukdjuak River. The differences in ratios among the three colonies in 1973 are statistically significant (Table 2).

Nesting success and production of the Baffin colonies go through drastic fluctuations, as was aptly illustrated in the studies by Kerbes (1969) at Bowman Bay. Snow cleared from the nesting grounds in 1967 early enough to allow the geese to nest over most of the potential area. In 1968, however, snow cover was much deeper and harder and the nesting grounds melted clear some two weeks later than in 1967. Consequently, geese were able to nest only on the southern part of the Bowman Bay colony. The area on Baffin occupied by nests in 1968 was a mere 5% of what it had been in 1967. Lower nest densities and higher predation rates in 1968 served further to reduce production. Hanson (pers. comm.) suggested that the northern limit of nesting on Baffin depends on the phenology of the spring season. That may not be quite true, however, for the habitat of Koukdjuak River is not as low and wet as that of Cape Dominion, and therefore may not take as long to clear even if its phenology is slightly later.

Occasional failure of breeding seasons, such as 1968 on Baffin, are a part of the expected history of an arctic goose colony (Cooch, 1958; Barry, 1962). The retarded season reduces or prevents nesting, but does not prevent the geese from spending the spring and summer on the colony. However, on Baffin Island in 1972 the snow cover cleared three to four weeks later than normal. In attempting the photographic survey I found only about 5% of the surface of the nesting grounds free of snow or melted water on July 9, and about one-tenth of the expected number of geese. The season was so late that it not only prevented the geese from nesting, but apparently forced them to spend the summer elsewhere (Kerbes and Prevett, 1973). The retarded season was caused by heavier than usual winter snowfall accompanied by colder than usual spring temperatures.

It has been suggested that the Baffin Island region has begun a trend towards more accumulation of snow and ice on the land (Bradley and Miller, 1972; Bradley, 1973a, 1973b; Kukla and Kukla, 1974). Obviously, such a trend would not be conducive to continued nesting there, especially since the colonies on Baffin already have the shortest season of all (Cooch, 1958; Kerbes, 1969).

Colour phase ratios

Cooch (1963) described an increase in the percentage of blue phase in Lesser Snow Goose colonies over the period 1929 to 1961, and on the basis of estimating the rate of increase over those years he predicted future colour ratios at major colonies. Table 6 shows his estimates of the ratios in 1955 and his predictions for 1970 for the major eastern Arctic colonies compared to what they were in 1973.

Only at McConnell River was the ratio predicted for 1970 close to the ratio observed in 1973, the other values predicted for 1970 being higher than those of 1973. The 1973 ratios were the same as the 1955 ratios at Boas River and Koukdjuak River, but were lower than the 1955 ratios at Bowman Bay and Cape Dominion. Ryder (1971) and Hanson et al. (1972) also have described departures from Cooch's predictions.

A decrease in the mean percentage of blue for the whole eastern Arctic population is also evident. From Cooch's estimate of 62% blue in 1955 it has declined to about 50% blue in 1973–74. It was estimated to be 43% blue in June 1973, 49% in December 1973 (Lynch and Voelzer, 1974), and 52% blue in May 1974 (Curtis, pers. comm.).

Cooch (1961, 1963) attributed the increase of blue phase geese primarily to a recent warming in the eastern Arctic. He drew supporting evidence from records of climate and climate-dependent phenomena, and from his observations of the comparative nesting biology of blue and white phase geese. He considered the increasing abundance of blue phase to be an example of adaptive polymorphism, which, under the warming climate, favoured the blue phase.

The departure of present blue phase frequencies from what Cooch predicted may be due to a reversal of the climatic warming trend which he documented. Mitchell (1961, 1972) and Lamb (1966) showed that mean annual world temperature increased from about 1900 to 1950, but has since decreased. The responsibility of man's industrial and agricultural activities for

Table 6
Estimated percentage of blue phase at selected Lesser Snow Goose colonies in the eastern Arctic, 1955-73

Colony	Cooch (1963) Estimated for 1955	Cooch (1963) Predicted for 1970	Estimated from photos for 1973
McConnell River	8	27	24
Boas River	25	52	23
Bowman Bay	97	99	81
Cape Dominion	80	91	61
Koukdjuak River	45	73	41

inducing or reversing the trend to lower temperatures is debatable [see, for example, Bryson (1967) and Mitchell (1972)]. However, Bradley and Miller (1972), Bradley (1973a, 1973b) and Kukla and Kukla (1974) documented recent evidence of deteriorating climate in the eastern Arctic, shown especially by a decreasing snow-free period and a trend towards accumulation of snow and ice on the land.

Climate and other factors which may influence changes in colour ratios have been discussed by Hanson et al. (1972) and by Cooke, MacInnes, and Prevett (1975).

Total size of population

The population can be grouped into three categories: the breeders, the non-breeders, and the young of the year. Total population reaches its annual minimum just prior to hatch and its annual maximum at hatch. I have estimated the total number of breeders in June 1973, but it takes considerable speculation to account for the number of non-breeders present in June and the number of young hatched in July. According to Cooch (1958), Prevett (1972), and Cooke (pers. comm.) non-breeders (which, like nesting birds, are adult-plumaged) are composed of (1) all yearlings (birds hatched the previous summer), and (2) a variable proportion of two-year-olds and some older birds that are not in breeding condition or have failed in nesting. The proportion of failed breeders in the non-breeding category mainly depends on the phenology of the nesting season — fewer birds are able to nest as the season becomes critically delayed.

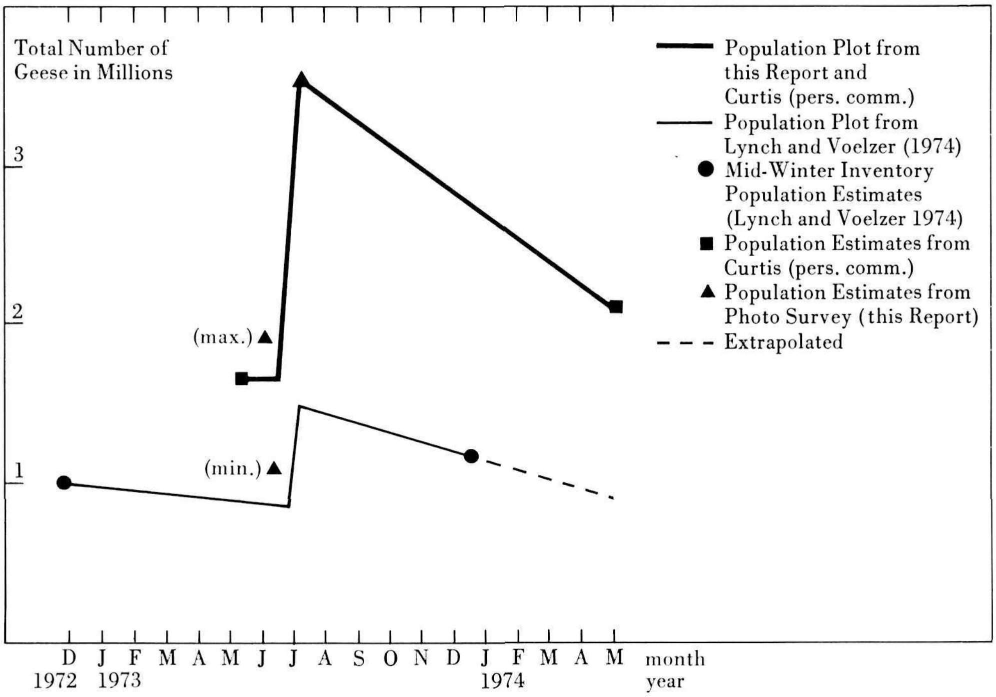
During incubation non-breeders are found in low-density pockets within, on the fringes of, or beyond the limits of the nesting area. I did not account for all the non-breeders with the photographic surveys, since it was logistically possible to sample or cover only the nesting areas and their immediate environs. Table 7 gives the percentage of non-breeders in the total white phase birds counted on the 1973 photographs of nesting areas. The percentage was low at all colonies, particularly on Southampton Island and Bowman Bay, where it was less than 5%. That was expected, since in 1972 virtually no young were hatched on Southampton or Baffin, while the Hudson Bay mainland colonies had average production (Kerbes and Prevett, 1973; Lynch, 1973). Cape Dominion and Koukdjuak River showed a relatively high proportion of non-breeders because their mean nest densities were very low, allowing non-breeders to use large areas within the colony where there were few or no nests. Hence, most non-breeders were probably on those colonies and the estimate of about 10% non-breeders at Cape Domin-

Figure 15
Comparison of estimates of the eastern Arctic population of Lesser Snow Geese, December 1972 to May 1974.

Table 7
Estimated percentage of non-breeders among white phase Lesser Snow Geese counted from photographs within nesting area of colonies, eastern Arctic, June 1973

Colony	Total white phase counted	Non-breeders (% of total)
Cape Henrietta Maria	5,599	5.3
McConnell River	138,579	4.4
Wolf Creek	24,643	7.5
Boas River	47,142	3.8
East Bay	4,440	2.4
Bowman Bay	21,242	3.2
Cape Dominion	4,263	11.2
Koukdjuak River	10,287	8.2
Total	256,195	4.6

Figure 15



ion and Koukdjuak River was probably valid. However, the percentage estimate at the other colonies is low, since an unknown and probably variable proportion of non-breeders were not on the nesting areas sampled by the photographic counts.

During their productivity appraisals of the population on the wintering grounds in December 1973, Lynch and Voelzer (1974) estimated that 45.6% of the adult-plumaged birds were non-breeders. That proportion seems inordinately high, even if allowance is made for the skewing effects of greater mortality of young birds between June and December. Hanson et al. (1972) estimated a five-year average of 25% non-breeders among the adult-plumaged birds which were included in their photographic samples of combined family flocks at McConnell River. The actual mean value was higher than 25%, since their samples did not include flocks made up entirely of non-breeders.

In place of attempting to guess what the actual proportions of non-breeders and young birds were, we can calculate the theoretical minimum and maximum numbers as follows. In June 1973 a minimum of 4.6% of the population were non-breeders (Table 7); therefore, the total minimum population was 1,108,000 birds. Alternatively, we can use the percentage from Lynch and Voelzer (1974) — a maximum of 45.6% non-breeders — which gives a maximum population of 1,944,000 birds in June 1973.

To calculate the theoretical maximum population at hatch we can assume that the mean brood size at hatch was at least 3.5 in 1973, which was an early nesting season. Cooch (1958) found the mean brood at hatch was 4.12 at Boas River in 1952, also an early nesting season, and Kerbes (1969) found a mean of 3.3 at Bowman Bay in 1967, which was an average season.

Cooch (1961) estimated hatching success at 81% in an early season, 63.5% in an average season, and 51% in a late season. Cooch (1958) and Kerbes (1969) found that most egg-loss occurred early in or prior to incubation, but Harvey (1971) found that most egg-loss was late in incubation. Since the photographic survey was done approximately half-way through incubation, we can assume that 15% of the eggs in the nests counted in June 1973 did not survive to hatch.

Using the above factors and assuming that there was no significant loss of birds between June and July, I put the theoretical maximum total population in July 1973 at 3,517,000 birds: 30% breeders, 25% non-breeders, and 45% young.

Figure 15 shows the theoretical June and July 1973 populations compared to other estimates made by Lynch and Voelzer (1974) and Curtis (pers. comm.) between December 1972 and May 1974. It is immediately apparent that the estimates for May 1973 and May 1974 (obtained by Curtis and Lumsden from aerial surveys along the coast of Hudson and James bays using visual estimation of total numbers of white phase birds expanded by colour ratio estimates made from small-format oblique photographs) fit much better with the June 1973 estimate than do the estimates from Lynch and Voelzer.

Lynch and Voelzer (1974) used productivity appraisals taken on the wintering

Distribution of nesting and feeding habitat

grounds (Lynch and Singleton, 1964) applied to base-line population counts from the *Mid-winter Inventory* to draw up the population plot shown in Figure 15. The *Mid-winter Inventory* is an annual count of the population on its wintering grounds near the Gulf of Mexico taken by visual estimates from aerial surveys co-ordinated among federal and state wildlife agencies. The inventory has long been criticized for its incompleteness, lack of reliability and gross underestimation. Lynch (1973) showed that an apparent doubling of the inventory count, from 631,000 in 1967 to 1,340,800 in 1971, had happened while the population had actually *declined* over the same period, according to his appraisals of productivity. Lynch's continued concern about the inaccuracy of the *Mid-winter Inventory* (Lynch and Voelzer, 1974) has been amply substantiated by the photographic survey of June 1973 and the surveys of May 1973 and May 1974. The *Mid-winter Inventory* accounted for only about one-half of the population in December 1973.

With the problems of improving the *Mid-winter Inventory* virtually insurmountable (Lynch and Voelzer, 1974; Lynch, 1973; A. Brazda, pers. comm.), the eastern Arctic population is obviously best censused on its nesting grounds or during its spring migration along Hudson and James bays.

The basic requirements of a nesting colony are nest sites and food. Geese arrive on the nesting grounds in spring usually so early that their food is still covered by snow or melt water. At that time food is not critical, for they arrive with energy reserves capable of sustaining them for almost a month; enough time to allow for nest-building, egg-laying, incubation, and hatch of their young. The availability of nest sites at that early stage is critical to their reproductive success. However, the availability of food at hatch becomes critical to the recovery of the parents and the growth of the young within the limits of the short arctic summer (Soper, 1930; Cooch, 1958; Lieff, 1973; Ankney, 1974).

1. Nesting habitat

Lesser Snow Geese nest on low tundra hummocks or ridges on coastal plains, and on small islands in braided river channels and deltas, which provide relatively dry and open sites in early to mid June, when much of the surrounding area is still covered by snow, ice or water.

Soper (1930) and Cooch (1958) have more fully described the typical nesting habitat. Cooch (1958) showed that the availability of nest sites varied over very short periods and with localized topography and run-off. Additional sites became available quickly as snow and melt water disappeared. He also believed that the nesting behaviour of the geese was flexible enough to permit crowding when habitat was limited, but that geese tended to spread out if sites were available.

The figures for the main colonies in 1973 show the nest density patterns in terms of photo frames analysed. Since the total nesting area and the photo-frame areas include both land and water surfaces, the density figures represent the total spacing of nests, not of the territories defended by nesting pairs. Maximum density, therefore, depends on habitat characteristics and on minimum size of territory.

Cooch (1958) observed territories as small as one nest per 7 m², and he pointed out that the minimum territory tolerated was unknown. At McConnell River in 1966, Harvey (1971) found an average of one nest per 278 m² in his study area, while in 1971 Von Barloewen (Ankney, 1974) found densities as high as one nest per 100 m². Among the highest densities recorded from my 1973 photo analysis was one nest per 27.3 m² in 900 m² at Tha-anne River.

It seems (Cooch, 1958) that the contagious distribution (clumping) of nests is not caused by the sociability of the geese, but by topographical features of the habitat and the timing of the melt. Therefore, it is difficult, if not impossible, to estimate potential maximum densities of nests. Probably most colonies could support much higher densities than they did in 1973, if the nest sites were exposed in time, if birds were available to take them, and if food was present after hatch.

2. Feeding habitat

Studies by Lieff (1967, 1973) at McConnell River showed that geese feed selectively on above-ground parts of sedges and grasses, which are the dominant plants of their habitat. That habitat, which I call sedge lowlands, provides both nest sites and food. If food resources are depleted in the vicinity of the nest site, the parents will lead their young to feeding areas up to 50 km distant (Cooch, 1958).

By referring to aerial photographs (from both my goose surveys and the standard scale 1:60,000), to ERTS-1 satellite imagery, and to my own experience, I have mapped the sedge lowlands for west Hudson Bay, Southampton Island, and Baffin Island in Figures 16, 17, and 18 respectively. South Hudson Bay has not been mapped, since it differs markedly from the other regions in shape (extremely long and narrow) and in flora (less arctic than the others).

3. South Hudson Bay

Figures 3 and 4 show the nesting areas in 1973 at Cape Henrietta Maria and La Pérouse Bay. Hanson et al. (1972) recorded

Figure 16
West Hudson Bay, N.W.T., showing the nesting and feeding habitat (sedge lowland) of Lesser Snow Geese.

Figure 16

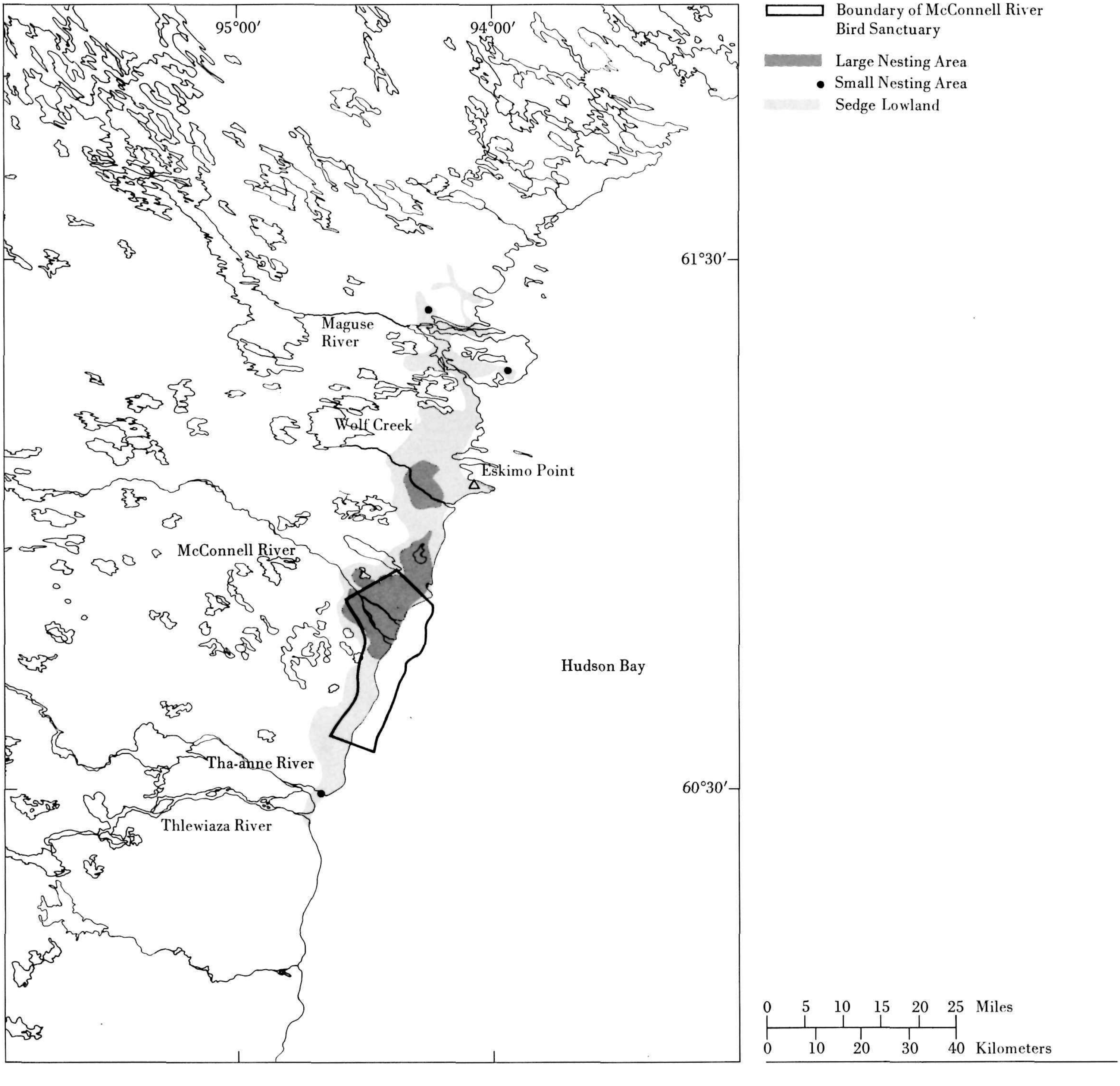
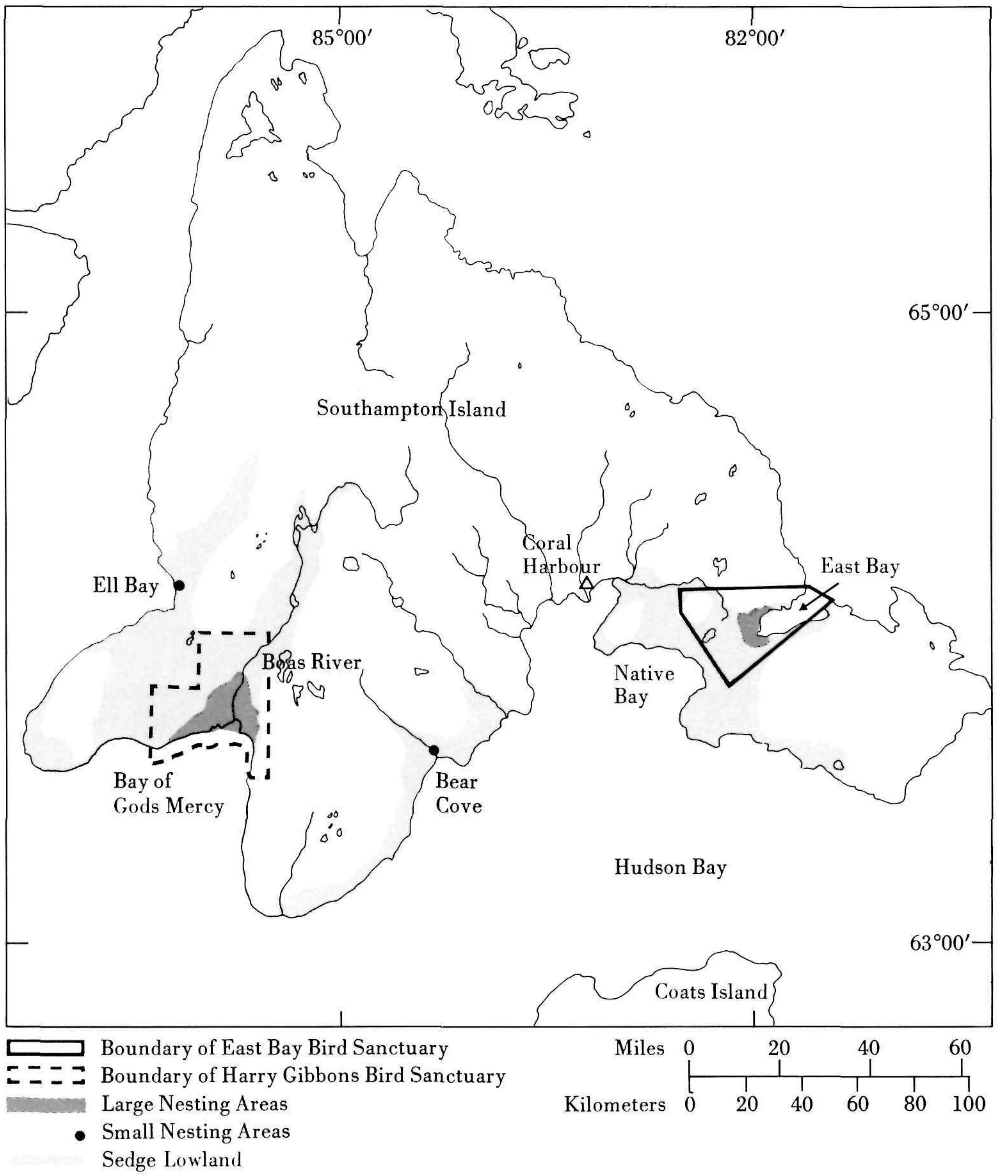


Figure 17
Southampton Island, N.W.T., showing the nesting and feeding habitat (sedge lowland) of Lesser Snow Geese.

Figure 17



small numbers of broods at points scattered throughout this region from La Pérouse Bay to Akimiski Island, which they termed vagrant nestings. They noted that vagrant nestings were concentrated in four areas, and believed that the area near the Manitoba-Ontario border and the north coast of Akimiski Island were most likely to be colonized in future. As noted above, the goose habitat zone of this region is not readily mapped or comparable to that of the more northern regions.

4. West Hudson Bay

The nesting areas in 1973 and the sedge lowlands are mapped in Figure 16. Records by Macpherson and Manning (1959); Dzubin, Dauphiné, and Parker (pers. comm.); and Miller (1972) of small numbers of birds nesting inland — west of this area but east of the Ross Goose colonies in the Queen Maud Gulf region — represent at most a few hundred pairs. They are probably related more closely to the central Arctic population than to the eastern Arctic population.

5. Southampton Island

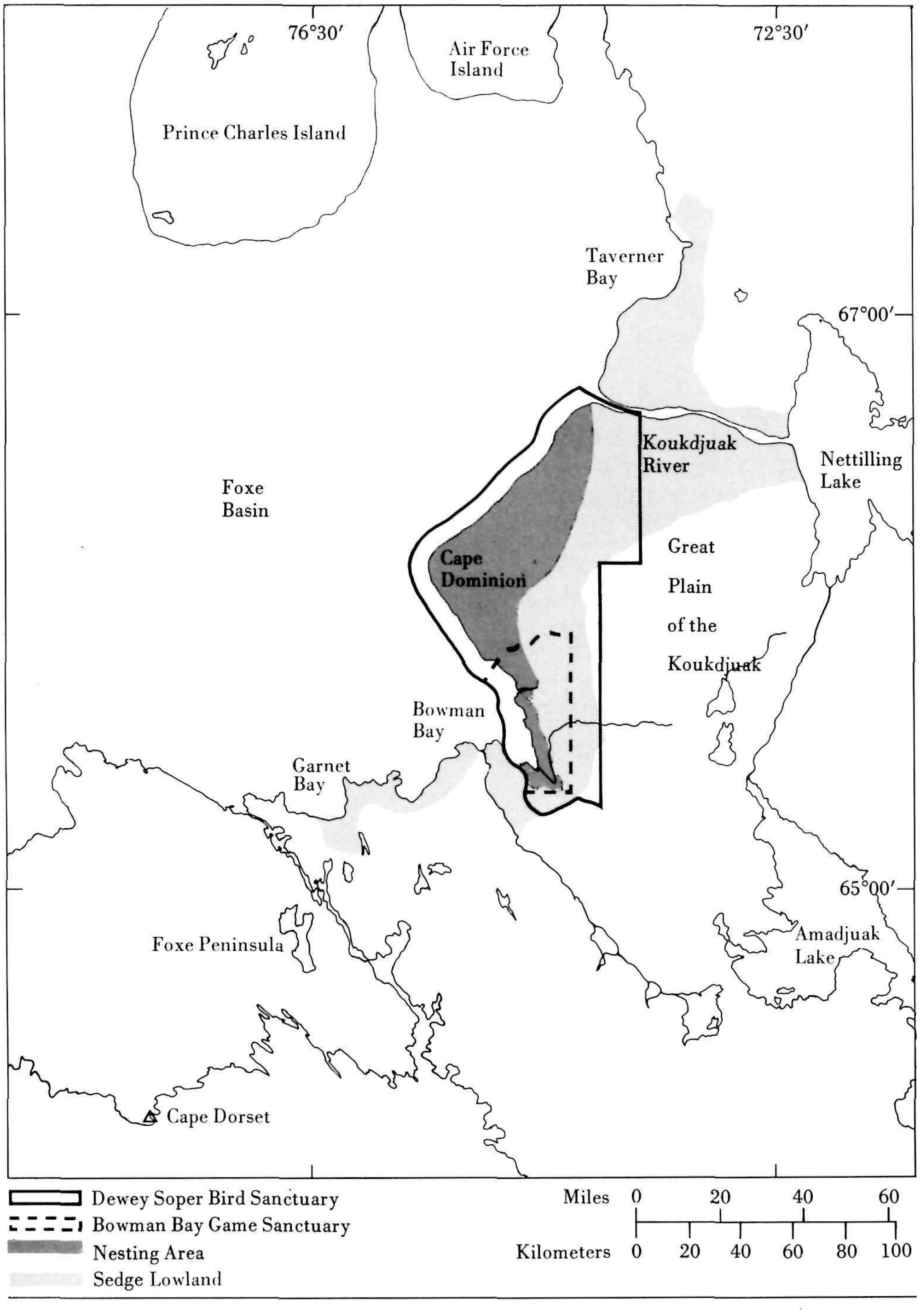
In addition to the sources mentioned, I referred to Bird (1953) and Parker (1975) in mapping the sedge lowlands in Figure 17. The goose habitat of Southampton Island is not as easily defined as that of west Hudson Bay or Baffin Island. In the latter two regions the sedge lowland zone is virtually continuous and its border with rock outcrops, old beaches, or dry uplands is well defined. On Southampton much of the sedge lowland zone has an ill-defined border as it gives way from continuous cover to smaller and smaller pockets of sedge. Each of the three main continuous areas (Figure 17) supports at least one colony.

6. Baffin Island

The nesting areas in 1973 and the sedge lowlands are mapped in Figure 18. The sedge lowlands are essentially the coastal flatlands of the Great Plain of the Koukdjuak, with an extention to Cory and Garnets bays on northern Foxe Peninsula. On Baffin Island the northern edge of Lesser Snow Goose range borders the southern edge of Greater Snow Goose range. A few nesting white geese have been reported from about 160 km (100 mi) northwest of Taverner Bay (Elliott, and Pimlott, pers. comm.). Although no specimens have been collected, those birds are believed to be Greater Snows because they had no blue phase among them. Their nesting pattern also is typical of Greater Snows, which nest in small scattered groups throughout much of northern Baffin and islands north of it.

Figure 18
Southwest Baffin Island, N.W.T., showing the nesting and feeding habitat (sedge lowland) of Lesser Snow Geese.

Figure 18



7. Protection of habitat

By 1961 all major colonies had been given legal protection through the establishment of federal migratory bird sanctuaries. Their boundaries are outlined in Figures 16, 17 and 18. Cape Henrietta Maria and much of the south Hudson Bay coast are afforded some protection by Polar Bear Provincial Park, established by the Province of Ontario in 1969.

Although the colonies remain remote and basically untouched by detrimental human activities, the inexorable push for resources, particularly petroleum, poses a considerable threat. Several offshore exploratory oil and gas wells have been drilled in Hudson Bay, and the proposed eastern Arctic pipeline may affect the west Hudson Bay colonies or, possibly, the Southampton colonies. Although less likely than Hudson Bay, Foxe Basin has also been mentioned as a potential petroleum-bearing area (Trettin, 1969).

Habitat in the west Hudson Bay area needs further protection, since it is supporting an increasing proportion of the Lesser Snow Goose population (see next section) and is the most threatened by increasing industrial activities. It has been proposed that the whole sedge lowland area of west Hudson Bay be established as a national wildlife area, and within that the McConnell River Bird Sanctuary should be expanded to include all of the nesting areas of the Tha-anne River, South McConnell River, McConnell River and Wolf Creek colonies.

The sanctuaries on Southampton and Baffin islands appear to be adequate, although large areas of important feeding habitat remain outside their boundaries.

Estimated maximum food resources and population

Table 8 shows the food resources and the theoretical maximum populations they could sustain in the main nesting regions compared to the existing populations. (Actual nesting areas are from Table 2 and areas of sedge lowlands are calculated from Figures 16, 17, and 18.) Air Force and Prince Charles islands, which total about 11,000 km^2 of sedge lowlands (perhaps of marginal quality) have not been included in the Baffin figure. Lieff (1973) estimated the annual rate of production of food (sedge and grass in dry weight) for McConnell River, and Parker (1975) did the same for Southampton Island. Since no value was available for Baffin Island, I have used the Southampton value because of the similar latitude and terrain. At McConnell River, Harwood (1974) estimated that the mean daily intake of (undried) vegetation was 1.5 kg per adult goose per day. Assuming that the vegetation was 70% water (Harwood, 1974) and that the mean annual length of feeding period on the breeding grounds was 55 days (Lieff, 1973), I estimated the mean annual intake in dry weight at 24.75 kg per goose. I divided that factor into the estimated total annual production to estimate the potential goose population. The actual goose population in July 1973 was considered to be the maximum population for each region, which expanded the respective totals of nesting birds from Table 2 by the factors calculated previously to account for the numbers of non-breeding and young birds.

Table 8 is based on several unproven assumptions and does not account for all variables. Other herbivores compete with Lesser Snow Geese for sedge and grass as food. Canada Geese and a few White-fronted Geese occur at McConnell, while Canadas and Brant are on Southampton and Baffin. Caribou are virtually absent from Southampton (Parker, 1975) and are rare on west Hudson Bay (Lieff, 1973) and on Baffin (Kerbes, 1969). Lemmings are not common in any of the nesting colonies, except in the high years of their population cycles. The estimate of daily food intake used in calculating potential goose population was for adults (birds at least in their second summer), but I have applied it to the yearlings and the young geese as well, since the figures are for the maximum number of birds sustained. In my estimate of actual population only the basic number of nesting pairs is accurate. The number of non-breeders and young are based on assumed proportional estimates.

Table 8
Estimated food resources and potential population levels of eastern Arctic Lesser Snow Geese, excepting south Hudson Bay

	West Hudson Bay	Southampton Island	Baffin Island	Total
1973 nesting area (km^2)	410	750	2,940	4,100
Sedge lowland (km^2)	1,100	7,400	12,200	20,700
Productivity (kg/ha/yr.)	633*	400†	400†	—
Production (kg x 1,000/yr.)	70,000	296,000	488,000	854,000
Potential goose pop.‡	2,828,000	11,960,000	19,717,000	34,505,000
Actual goose pop. July 1973‡	1,298,000	518,000	1,485,000	3,301,000
Actual pop. as % of potential pop.	45.9	4.3	7.5	9.6

*Lieff (1973).
†Parker (1975).
‡See text.

In spite of the above variables, the data of Table 8 show differences so great that they must mean that west Hudson Bay is much closer to its carrying capacity than is Southampton or Baffin, and it may be in danger of over-population.

Cooch (1958) showed that geese from Southampton Island and west Hudson Bay sustained increased hunting mortality when they occasionally interrupted their southward migration to the Gulf Coast wintering grounds by stopping in the north central states (an area centered on eastern South Dakota). He suggested that such stopovers were due to delayed breeding seasons which led to the decreased weight of migrants and the necessity for the geese, particularly the young, to make the additional refueling stop on their way south. Cooch's hypothesis was further developed by MacInnes (1971), who showed that the frequency of stopovers of geese from McConnell River had increased during the 1960's. MacInnes suggested that heavy stopovers occurred in years when the growth of vegetation at McConnell River had been retarded by prolonged cold and cloudy weather in June. He proposed that food (either its quality or quantity or both) was a limiting resource at McConnell River, since poor summer diet could indirectly increase the death rate of geese during migration. After pointing to the growth of the McConnell colony from 1960 to 1970, he further suggested that "Possibly the increasing regularity of mid-continent stopover is a reflection of the increased numbers having a severe effect on summer feeding range."

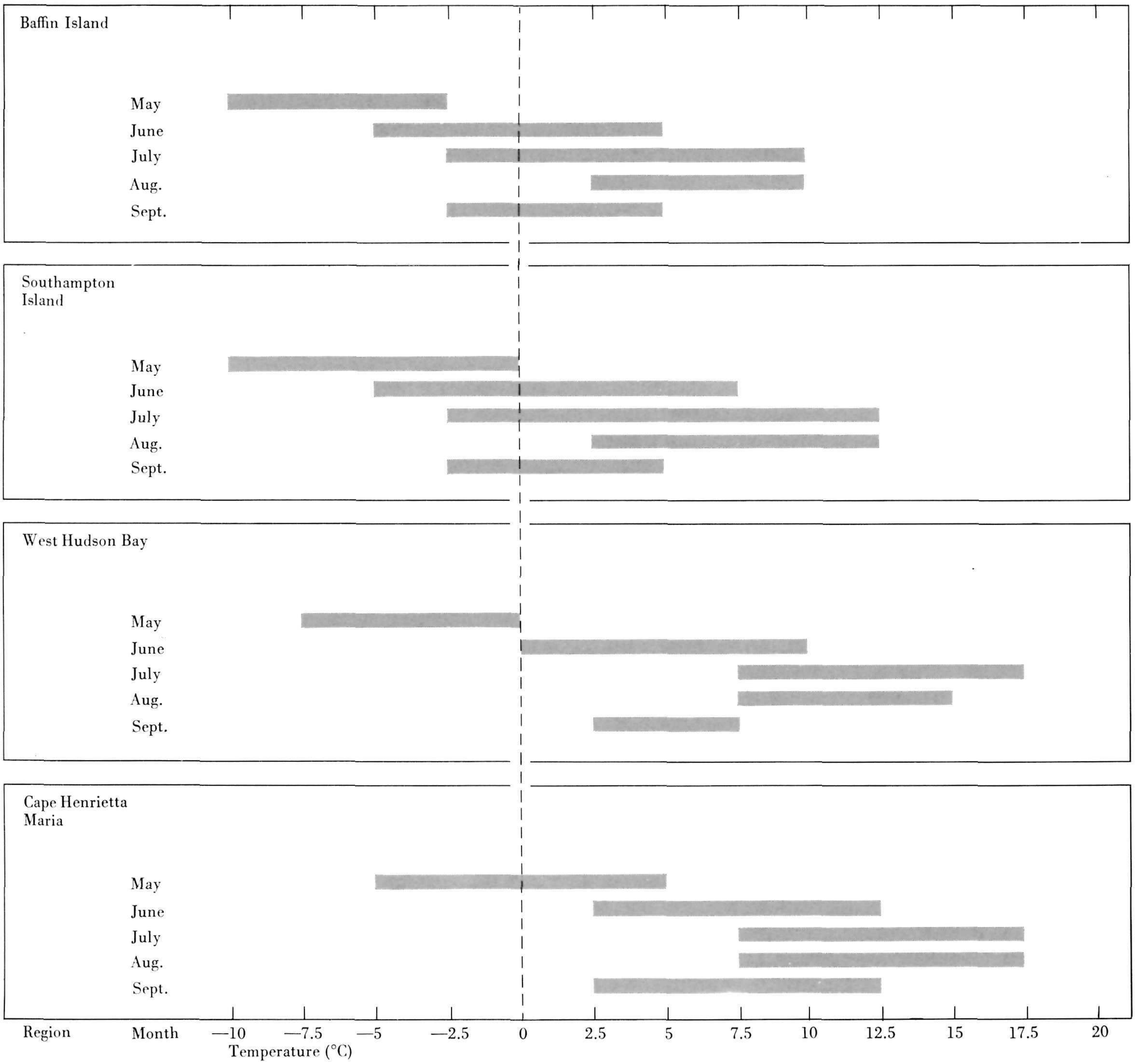
Lieff (1973) provided experimental evidence that feeding conditions at McConnell River, especially in Canada Goose brood rearing areas, were apparently deteriorating as a result of the rapidly increasing numbers of Lesser Snow Geese. Dzubin et al. (1973) confirmed that the harvest had increased significantly in the northern and central states from 1962 to 1971, and they showed that a disproportionately large part of that harvest came from McConnell River, according to direct band recoveries.

McConnell River is a paradox among the colonies; while showing the fastest growth, it also shows the highest rate of harvest and the most obvious signs of over-grazing.

The potential food resources and population of the south Hudson Bay region

Figure 19
Mean monthly temperature ranges for the eastern Arctic Lesser Snow Goose nesting regions, May to September (derived from the National Atlas of Canada, 1974).

Figure 19



have not been calculated for lack of suitable parameters, but would certainly present at least as low a ratio of potential to actual population as Southampton and Baffin Islands. We do not know the exact factors needed for a colony to become established and grow successfully, but they appear to be habitat and climatic factors tied to the traditions of the geese.

Present climatic conditions offer a simple explanation for west Hudson Bay being more productive than the more northern areas. All of the eastern Arctic colonies fall within the Arctic climatic zone (Kimble and Good, 1955). However, as might be expected of areas spread over such wide latitudes, there is a marked cooling and shortening of the summer proceeding north from Cape Henrietta Maria to Baffin Island (Fig. 19). To the geese, so dependent on finding a season long enough for successful reproduction, small differences in the date of habitat clearance can be critical. They need a minimum of 90 days — 10 for nest construction, 12 for egg-laying, 23 for incubation, and 45 for the young to reach flying stage — (Cooch, 1958). The mean date of habitat clearance at the southernmost colony, Cape Henrietta Maria, is at least 15 days earlier than it is at the northernmost colony, Koukdjuak River (Cooch and Lumsden, pers. comm.; Soper, 1930; Kerbes, 1969).

As noted previously, the recent apparent increase in glacierization of Baffin Island (Bradley and Miller, 1972) has sounded an ominous note for the future of the colonies on Baffin and Southampton islands. Presumably, it would take much longer for a deteriorating climate to affect the colonies of west or south Hudson Bay. Bradley (1973b) has also said "However, in view of the variability of the climate of Baffin Island over the past several decades, caution should be exercised in extrapolating any current trends very far into the future."

The danger of premature conclusions on weather trends has been made evident recently. In 1972, with the news of the drastically late season in the Arctic, many people spoke of the decline of the Baffin and Southampton colonies, but then 1973 was a record early year with record production. Talk subsided about the decline of Baffin, only to rise again in 1974 with the record late summer in the High Arctic.

Recent evolutionary and geological history

Johansen (1956) suggested that the late Tertiary ancestors of the Snow Geese were dark and that the white phase arose as late as the period of Pleistocene glaciations. Cooke and Ryder (1971) pointed out that among the Lesser Snow, Greater Snow, and Ross geese only the Lesser Snow had retained the dark or blue phase in adult plumage. Ploeger (1968) suggested that white and blue phase Lesser Snows were geographically separated only during the maximum of the last glacial period, with the white phase surviving in refugia in the Bering Strait region and the blue in the Canadian arctic archipelago.

Today the eastern Arctic colonies are located on plains adjacent to, and only recently emerged from, the sea. Hence they are covered with marine clays, silts, and sands. All except those of west Hudson Bay, which are Precambrian, are in Paleozoic sediment basins (Bird, 1967). Have the geese established their present colonies because of special mineral and nutrient requirements or simply because geological history has led them there?

The last ice sheet retreated from the areas now occupied by the goose colonies about 7,500 to 7,000 years ago (Bryson, Wendland, Ives, and Andrews, 1969). Those areas were invaded by the sea when the ice left, and since then, through isostatic rebound, they have slowly emerged. Using data on post-glacial emergence, Hanson et al. (1972) estimated that the present Cape Henrietta Maria colony may have become available to geese only within the last 250 years. Andrews (1970) estimated that the rate of isostatic rebound has been about 10% to 40% slower for the nesting area on Baffin Island than for those on Hudson Bay or Southampton Island. Cape Dominion and Koukdjuak River colonies have the widest and flattest zone of coastal sedge lowlands, extending some 57.5 km from the present coast inland to the 35 m contour above sea level. The next widest zones (except for Cape Henrietta Maria) are for McConnell River and Boas River — 22.5 km to the 35 m contour. Therefore, Lesser Snow Goose habitat must have been available on Baffin long before it was available on the other present main colonies.

Traditions established when only the Baffin nesting grounds were available may account for almost half the population still nesting in the coldest part of its breeding range.

Conclusion

The large-format vertical photography that we obtained in June 1973 has provided the first precise and unbiased base-line data on the distribution, numbers, and colour ratios of the nesting Lesser Snow Geese in the eastern Arctic.

Although the low precision of earlier surveys has ruled out detailed comparisons, the 1973 assessment suggests that the percentage of blue phase geese in the population is no longer increasing. The 1973 results also confirm that the *Mid-winter Inventory* counts have grossly underestimated the population, and give warning that the west Hudson Bay area is much closer to its carrying capacity than are Southampton or Baffin islands.

Through the 1973 photographic inventory a proven, though expensive, technique has been applied at last on a large scale in a field traditionally restricted to modest budgets and "eyeball" techniques. The results show that this method has probably provided the most precise census to date of a wildlife population as large as that of the eastern Arctic Lesser Snow Geese. As such, it has clearly demonstrated the present value and future potentialities of large-format vertical photography.

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Appendices

Appendix 1
Discussion and evaluation of methods and materials used in the photographic surveys of eastern Arctic Lesser Snow Geese, 1971 to 1973.

1. Basic principles and assumptions

In discussing the field of photo interpretation, Colwell (1960) said "...the amount and reliability of the information obtained depends on the training and aptitude of the observer and on the nature of the scene observed." Further, he pointed out that photo interpretation comprises at least three mental acts: 1) measurement (usually visually or mentally) of photographic images, 2) identification of the objects imaged and, 3) appropriate use of this information in the solution of the problem at hand; and that those acts are stimulated especially by the following characteristics of photographic images: size, shape, shadow, tone and colour, texture, and pattern.

Those points were readily applicable to the counting of geese. The individuals who analysed film were well aware of what a goose colony looked like and each underwent a familiarization and training period with the film before counts began. The nesting colonies were a good subject for aerial photography, providing images, particularly of white phase geese, which contrasted with the background of flat even terrain covered by vegetation shorter than the geese. The low relief of the colonies also provided a nearly uniform scale across each photo, making for consistent *size* of goose images, as well as facilitating plotting of position and calculation of the sizes of areas examined.

Following the recognition of images of goose size, we used other clues, especially shape, tone or colour (and shadow, for locating blue phase) to confirm a goose image. The pattern of images of geese on the ground was essential to separating the nesting birds (grouped in pairs on their nest territories) from the non-breeding birds (defined as groups or flocks of three or more individuals). Flying birds were easily recognized and were classed as non-breeders.

The assumption that breeding and non-breeding geese could be separated by their distribution patterns and by whether or not they were flying was supported by Heyland's (1972) results with Greater Snow Geese and by ground truth from La Pérouse Bay. In 1972 at La Pérouse Bay, Cooke and his research group were on the colony when our survey aircraft carried out photography from an altitude of 1,200 m (4,000 ft). They reported that only the non-breeders flew in response to the aircraft passing overhead. Of many thousands of geese counted on low-level photographs from 1971, 1972, and 1973, only a small percentage were in flight.

We assumed that both white and blue phase birds could be accurately counted from low-level photographs, and that the photographic sample provided a representative measure of the mean colour ratio of a given colony. The accuracy of our method was supported by researchers working on the ground at McConnell River in 1972 (Ankney, pers. comm.) and 1973 (Harwood, pers. comm.). The colour ratios which they estimated were within the 95% confidence limits of our estimates. In order to ensure that our count of blues and whites provided a representative colour ratio, we selected the photographic sample from all parts of a given colony, since Cooke and Finney (pers. comm.) have shown that colour phase distribution is probably contagious.

A final assumption was that the number of nests was equal to one-half of the estimated total of nesting birds. Ground studies by Cooch (1958) and Prevett (1972) found almost all active nests attended by one female and one male parent goose, and that any yearling birds still with their parents at the egg-laying stage departed once incubation was under way.

Table 9
High- and low-level white phase count comparisons in the eastern Arctic Lesser Snow Geese photographic surveys, 1971–73

Year	Colony	No. white phase counted: High-level	No. white phase counted: Low-level	% diff. high from low	Corr.§ coeff.	Slope§	Sample areas: No.	Sample areas: Size (km^2)
1971*	Bowman Bay	261	264	− 1.1	—	—	7	0.35
1971†	Bowman Bay	256	237	+ 8.0	0.850	1.010	9	0.91
1973†	Bowman Bay	1,474	1,928	−23.5	0.839	1.233	17	6.15
1972‡	McConnell River	1,926	1,913	+ 0.7	—	—	4	1.03
1972†	McConnell River	3,075	3,155	− 2.5	0.983	0.977	10	3.52
1973†	McConnell River	2,169	2,831	−23.4	0.878	1.089	10	2.46
1973†	Wolf Creek	3,057	2,862	+ 6.8	0.975	0.972	15	3.23
1973†	Boas River	2,875	2,698	+ 6.6	0.954	1.015	18	3.66
1973†	East Bay	596	417	+42.9	0.656	0.700	14	3.95

*Comparison analysis in 1973.
†Comparison analysis in 1974.
‡Comparison analysis in 1972.
§See Appendix 2 for derivation.

2. Suitability of aircraft and analysis equipment

The Aero Commander was well suited to the photo survey. A valuable feature was its high-wing configuration, which afforded good visibility of the ground, facilitating visual observations of the geese before and during the taking of photographs. The Commander provided adequate load capacity and a minimum range of 1,600 km (1,000 mi), which was needed on ferry flights between bases and to ensure that the colonies could be photographed with a minimum of trips back to base for refueling. Like most conventional photo survey aircraft, it was limited to operating only from bases with prepared runways.

In 1973 we greatly improved the equipment used in analysing the film by acquiring the Wild M7 binocular microscope and the Richards light table with Bausch and Lomb optics. Dodd found that the Wild M7 was essential to the ease and accuracy of her counts, and was much superior to the Bausch and Lomb optics, apparently due to the former's colour-aberration correction. The acetate grids and their data sheets were also a considerable improvement over the nylon grid and graph-paper data sheets for ease of operation and for record keeping.

3. What is the best camera system?

Replication of high-level counts, air–ground comparisons, and high and low-level comparisons produced consistent results in the counts derived from the 1971 and 1972 films (Kerbes and Prevett, 1973). However, we did not find such consistency when checking the much more complete and operational films of 1973. Replicate counts and comparisons between high and low (control) counts showed that counts from the 1973 high-level film were subject to intermittent and changeable biases.

We derived a correction factor for a given colony size estimate by comparing sample high- and low-level counts from that colony, and incorporating the variances into a single expression in order to compute confidence limits for the estimate of colony size. The detailed method and formulae are given in Appendix 2 and the results of the comparisons in Table 9.

In Table 9 the low-level count was assumed to be the correct count, hence the *percent difference* value gives a rough but simple evaluation of the high-level count, while the correlation coefficient and slope give measures of the agreement between high and low. For perfect agreement both those values would be equal to 1. The accuracy of the counts from the 1972 film was considerably higher than that from the 1971 and 1973 film. Also, the two comparison analyses of the 1972 film showed closer agreement than those of the 1971 film. Hence we concluded that the 1972 film provided the most accurate counts.

The quality of the photographs and the accuracy of counts depended on: 1) the camera system (camera, lens, filter and film); 2) exposure and development of film; 3) sun angle and atmospheric condition at the time of photography; 4) analysis procedure.

The last three factors remained essentially constant in all years: No. 2 was determined by standard air photo procedures, No. 3 by natural phenomena (sunlight during the middle four hours of the day in arctic air free of dust or smoke though subject to variable humidity haze), and No. 4 was more efficient, but its basic method or accuracy did not change.

Therefore, the superiority of the 1972 film, as illustrated in Table 9, must have been due to differences in camera systems. The camera system was essentially the same in 1971 and 1973. Its basic differences from the 1972 system were: 1) slower shutter speed; 2) use of a filter; 3) 6 in. focal-length lens vs. the 12 in. of 1972; 4) *Plus-X* black-and-white film vs. the *Color Negative* of 1972 (Table 1).

The first two features caused insignificant differences in quality. Image motion was not a problem on any film (i.e., the faster shutter speed was not necessary even at low-level) and the *minus blue* filter used in 1971 and 1973 was standard procedure for *Plus-X* film, as was no filter used in 1972 with *Color Negative*. The critical parts of the camera system must have been the lens and the film type. The two lenses and two films are compared below.

3.1. Comparison between 12 in. and 6 in. lens

1) Image Resolution: A 12 in. lens is subject to less fall-off in illumination and image quality towards the edges of the field of view than is a 6 in. lens (Howard, 1970).

2) Disturbance to the geese: A 12 in. lens permits flying at twice the height possible when using a 6 in. lens to get the same scale; hence the 12 in. lens causes less disturbance to geese on a colony, and fewer nesting birds are apt to fly and be counted as non-breeders or be missed by the photograph.

3) Operational: Unlike a 6 in. lens, a 12 in. lens does not permit good visual observation of geese from the aircraft while flying low-level (scale 1:3,000) photography because of the altitude, although geese can be seen through the viewing screen on the camera, which looks vertically at the ground through the lens.

4) Navigational: Navigation during photography with a 12 in. lens is easier than with a 6 in. lens because the higher altitude allows more ground features to be used as position fixes for keeping on the desired photo line.

5) Photogrammetry: The equipment and skills of topographic mapping are geared to photography with a 6 in. and not to a 12 in. lens. However, goose counting does not require photogrammetric specifications.

6) Cost: Mainly for the above reason, 6 in. lenses are more readily available and cost less to use than a 12 in. lens, although the difference is only 1% or less of a major survey operation.

3.2. Comparison between *Color Negative* and *Plus-X* film

1) Image identification: Colour photography, especially from altitudes of up to 3,000 m (10,000 ft), permits the interpreter to recognize and understand information more rapidly and with greater confidence than with black-and-white photography (Slaney, 1972). This is due to the enormous increase in combinations of hue, value (brightness or dullness), and chroma or intensity, as compared with tonal differences only in black-and-white photographs (Howard, 1970).

2) Image resolution: The resolving power of *Color Negative* is slightly less than *Plus-X*. Eastman Kodak Company (1971) rated them 40 and 50 lines per mm, respectively, for a Test-Object Contrast of 1.6:1.

3) Image granularity: Grain size of *Color Negative* is considerably smaller than it is for *Plus-X*. Eastman Kodak Company (1971) rated their RMS granularity values at 13 and 30, respectively, at a net density of 1.0.

4) Sensitivity to exposure and development: Black-and-white films have a wider tolerance to over- and under-exposure than colour films. In black-and-white photography it is necessary only to adjust the exposure to the quantity of available light; but with colour the adjustment also has to be made according to the quality of available light. The development of colour film is also more complicated and critical than with black-and-white (Howard, 1970).

5) Cost: The purchase and development costs of *Color Negative* are about three times those of *Plus-X*.

6) Eyestrain during analysis: Some observers find that *Color Negative* can induce eyestrain and headaches more readily than does *Plus-X*. Of four people who analysed the goose survey films, only one found eyestrain to be a significant deterrent to *Color Negative*.

On all important points concerning image quality the 12 in. lens and *Color Negative* have the advantage over the 6 in. lens and *Plus-X*. Although costs are higher for *Color Negative*, they are not exorbitant when considered as part of a major operation, such as a survey of goose colonies. From two-thirds to three-quarters of the expense of such a survey is for the stand-by charter of aircraft and crew, which decreases the extra proportion needed for *Color Negative*. Slaney (1972) argued that large-format vertical colour photography was the cheapest and most effective remote sensing system available. He also calculated that the cost of photography for a geological survey (on the same scale as the goose survey) was 34% higher with colour film than with black-and-white.

We were able to make detailed comparisons between lenses and film types only for the McConnell River colony. Perhaps other colonies would not have given results so favourable to the 12 in. lens and *Color Negative* film, but on the strength of the results summarized in Table 9, and with the basic characteristics of lenses and film types, we concluded that the 12 in. lens with *Color Negative* produces better quality photographs and consequently more accurate counts of geese.

4. Large-format vertical photography as an aid to studying Lesser Snow Geese

My photographic surveys strongly support Heyland's (1972) assertion that large-format vertical photography is superior to visual methods or small-format oblique photography in a census of wildlife populations. MacDowall (1972) described such photography as "Probably the oldest, most widely used, and most highly developed method of remote sensing of earth resources. It allows extremely high resolution imagery to be collected and, with well trained interpreters, vast amounts of information are available from this imagery. Photographic film is one of the most compact information storage methods available and as such the camera can collect large amounts of data easily and concisely."

The first and most critical phase of a photographic inventory of nesting geese is the acquisition of photographs providing adequate quantity (coverage of all colonies) and quality (accurate readability and precise measurement). By contracting specialists with professional training and equipment you greatly increase the likelihood of obtaining such photographs. Less expensive photographic survey methods can be used, but their results are more likely to be of only local or experimental use.

To undertake photography of all the eastern Arctic Lesser Snow Goose colonies in one nesting season is to gamble that bad weather or mechanical breakdowns will not thwart completion of the job during the incubation period. That period begins with the completion of egg laying on south Hudson Bay in early June and ends with the hatch of eggs on Baffin Island in mid-July. Incubation takes only 23 days (Cooch, 1958) in any one colony, but the south to north delay of nest initiation gives a potential survey period of six weeks.

My experience has shown that readability of photographs is more important than extensive coverage in determining the confidence limits of population and colour ratio estimates. The tests of accuracy and the process of obtaining correction factors for the 1973 photography caused at least six months' delay and almost doubled the cost of analysing the film. Analysis of the 1973 photographs of Cape Dominion and Koukdjuak River colonies showed that small, and accurate, low-level sample counts could give population estimates with confidence limits almost as narrow as for colonies with extensive, but less accurate, high-level sample counts.

Ideally, the objective is to obtain total photographic coverage from which a relatively small number of representative sample areas can be counted accurately. A procedure such as stratified random sampling is probably desirable because of the contagious distribution (clumping) of birds on a colony. The existing near-total coverage of the McConnell River colony for 1972 and 1973 provides a universe on which to test various amounts and types of sampling. For logistical reasons it is often not possible to obtain total photographic coverage of a colony, although adequate samples can be obtained. A problem may arise if there is too little coverage to identify accurately (by analysis and scanning of the film) the boundaries of the nesting areas.

The amount of tedious photo analysis can be reduced through sampling and perhaps, eventually, through the use of automatic scanning devices (Heyland, 1972).

Although the methods used by Hanson et al. (1972) to appraise productivity on the Hudson Bay mainland colonies in July, and by Curtis (pers. comm.) and Lumsden to count spring migrant geese on the Hudson – James Bay coast in May are much cheaper than my method of photographically counting the nesting birds, each of the two former methods has serious disadvantages.

Unlike the nesting census, the July survey methods cause the breeding geese to move away from the approaching aircraft, since it must fly as low as 60 m above ground, with almost continual bankingmaneuvers (Hanson et al., 1972). By disturbing the birds, surveys flown over nesting colonies in July may cause significant losses of the young when they are only one or two weeks old. Observers at McConnell River (J. P. Prevett, L. S. Maltby, and B. C. Lieff, pers. comm.) reported that goslings were often separated from their parents, and were thus put at risk to predators such as gulls, when the geese fled from low-flying aircraft.

The May survey provides estimates of total numbers, but no measure or prediction of nesting success. The July survey does not give total population estimates and the productivity appraisals it provides are available too late (late July or early August) to be incorporated into the governmental process of setting hunting regulations for that year. A photo inventory of nesting birds in June provides both a reliable total count and a good prediction of nesting success (based on immediate appraisal by the biologist in charge) early enough to effect hunting regulations, if necessary. Although determination of final estimates of total nests took a long time after the 1972 and 1973 photographs had been taken, in both years I was able to predict immediately what the productivity of the birds was going to be on the basis of what I saw from the photographic survey in June (Lynch, 1973; Lynch and Voelzer, 1974). With the experience now gained, analysis of future survey photographs will be much faster and more efficient.

The major disadvantage of my method of photographing the colonies is cost. For example, the June 1973 inventory cost approximately $30,000 to obtain the photographs plus almost that much again to purchase equipment and to hire assistants to analyse them. In contrast, the May 1973 coastal survey cost about $12,000 plus $3,000 for analysis (Curtis, pers. comm.). Nevertheless, for reasons given above, an accurate photographic count is probably worth much more than four times the value of a spring coastal count or a midsummer productivity appraisal.

Although Lumsden (pers. comm.) succeeded in using small-format (35mm) vertical photography to obtain an accurate count of the nests at Cape Henrietta Maria in 1972 and 1973, it is doubtful that all the colonies could be censused in one season by this means. A 35 mm photo frame is about 35 mm x 25 mm, which is only 1.7% of the frame area of 9 in. x 9 in. format. Therefore, in order to obtain the same amount of coverage at the same scale, at least 7 times as many photo lines would have to be flown with 35 mm format, and there would be at least 60 times as many individual photographs to be analysed, with consequent multiplication of overlap between frames to be accounted for.

Although small format is not suitable for photographing widespread nesting geese, it can be used successfully with individual flocks of nonbreeding geese or breeding geese after hatch, as Boag and Cooke (pers. comm.) have demonstrated at La Pérouse Bay. They used 70 mm format vertical photography, which has a frame area 9.4% that of 9 in. format. Leonard and Fish (1970) used 35 mm format to census Sandhill Crane flocks in Texas.

A photographic census can probably be reduced in cost and increased in efficiency with new or better equipment, such as the continuous strip camera (Howard, 1970). Lavigne and Øritsland (1974) used ultra-violet photography to identify white mammals against a white background of snow and ice. Lavigne (pers. comm.) has suggested that although ultra-violet probably will not identify dark birds such as blue phase geese against a dark background, there are probably photographic films and methods available which can give better images of blue phase geese than did the conventional films and methods used in our surveys.

For use as base-line modelling data, the photographic census probably does not need to be repeated more than once every five years. In intervening years a relatively low-cost visual survey could be made from a short-term chartered aircraft. The biologist conducting that survey could monitor the size and productivity of the colonies by comparing what he sees to the base-line data from the photographic surveys. Such a survey can be supplemented, or perhaps replaced, by following the course of snow clearance on the colonies with satellite imagery and by establishing liaison with agencies such as the N.W.T. Fish and Wildlife Division and the Arctic weather stations of the Atmospheric Environment Service.

Heyland (1972) discussed the history and future possibilities of large-format vertical photography in the study of wildlife populations. Large white colonial nesting birds provide the easiest targets, as Heyland (1972) demonstrated with Greater Snow Geese, Boeker (1972) with White Pelicans, and I with Lesser Snow Geese in the eastern Arctic. The next logical subjects are Lesser Snow Geese in the western Arctic. They are particularly well suited to photography, since they contain only a trace of blue phase (Barry, pers. comm.), which would not have to be identified on the photographs. The Ross and Lesser Snow geese of the central Arctic are also good candidates for photography. However, since both nest in the same colonies (Ryder, 1971) and since the Ross and the white phase Snow geese would probably present the same image, we would need to have ground information on their relative proportions and on the colour ratio of the Lesser Snows.

Good photographs are a bank of information; they provide an accurate and permanent record which can be re-evaluated as new information needs and new analysis techniques arise. Probably only the most basic and important data have so far been extracted from our photographs of Lesser Snow Geese. Much remains to be discovered. An immediate practical need is for study of the distribution of white and blue phase and of breeding and non-breeding birds, in order to refine the sampling methods of future surveys. Possibilities for research on aspects such as behaviour and habitat, both within and among colonies, are virtually endless.

Appendix 2
Statistical procedures used in estimating the population sizes and colour ratios of eastern Arctic Lesser Snow Goose colonies from the 1973 photographic survey (by G. E. J. Smith).

1. Introduction

For most colonies studied, aerial photography was done at two scales: a) 1:10,000 (high-level) where there was estensive coverage, and b) 1:3,000 (low-level) where coverage consisted of a sample of those areas photographed at high level.

Since counts of white phase geese from high-level photography are biased whereas those based on low-level photographs are relatively unbiased, we used a double-sampling regression estimator adapted from Cochran (1963, 334–339). This procedure corrects the bias in the high-level count by means of a comparison with the low-level count on areas of duplicate coverage.

In other colonies, only low-level photographs were available. In these the standard ratio estimator is appropriate.

2. Estimation procedure for colonies where both high- and low-level photographic coverage is available (double-sampling regression estimator)

2.1. Estimating numbers of white phase geese

Let i refer to the i^{th} sampling unit which has been analyzed from both high- and low-level photography. It consists of an area defined by recognizable natural boundaries such as stream banks or tundra patterns. Further,

Let n = number of sampling units

A_i = area of the i^{th} sampling unit

Y_i = number of white phase nesting geese counted on the i^{th} sampling unit from low-level photography

X_i = number of white phase nesting geese counted on the i^{th} sampling unit from high-level photography

We will assume the linear model

$$Y_i = bX_i + aA_i + e_i A_i \qquad (1)$$

where the e_i are independently and identically distributed random variables.

Thus the low-level (or true) count varies linearly with the high-level count and area. The variation with area is reasonable since the number of rocks and other objects available to be mistaken for geese or the number of geese likely to be missed in the analysis of high-level photography is proportional to area. Similar reasoning leads to the assumption of error e_iA_i, being proportional to A_i.

Let $x_i = X_i/A_i$ = density of white phase nesting geese on the i^{th} sampling unit as determined from high-level photography

$y_i = Y_i/A_i$ = density of white phase nesting geese on the i^{th} sampling unit as determined from low-level photography, i.e. the true density.

Division of equation (1) by A_i yields

$$y_i = bx_i + a + e_i \qquad (2)$$

which is equivalent to equation 12.17 of Cochran (1963, 334,) when a and b are the regression parameters of the model.

Let $\bar{x} = \Sigma x_i/n$

$\bar{y} = \Sigma y_i/n$

$s_x^2 = (\Sigma x_i^2 - n\bar{x}^2)/(n-1)$

$s_y^2 = (\Sigma y_i^2 - n\bar{y}^2)/(n-1)$

$s_{xy} = (\Sigma x_i y_i - n\bar{x}\bar{y})/(n-1)$

$\rho = s_{xy}/s_x s_y$ = correlation between the x's and y's

$b = s_{xy}/s_x^2$

$s_{yx}^2 = \dfrac{n-1}{n-2} s_y^2 (1-\rho^2)$

$\hat{X}$ = number of white phase nesting geese counted from high-level photography

N = total nesting area of the colony analyzed from high-level photography

$n = N/(\Sigma A_i/n)$ = the approximate number of sampling units needed to cover the area analyzed from high-level photography

F = fraction of total nesting area of the colony analyzed from high-level photography.

Then the estimator of the total white phase nesting geese in the colony and its variance are, respectively,

$$\hat{Y} = [N\bar{y} + b(\hat{X} - N\bar{x})]/F \quad \text{and}$$

$$\text{var } \hat{Y} = \left(\frac{N}{F}\right)^2 \left\{ s_{y\cdot x}^2 \left[\frac{1}{n} + \frac{(\hat{X}/N - \bar{x})^2}{(n-1)s_x^2}\right] + \frac{(1-F)}{n^1}(s_y^2 - s_{y\cdot x}^2) \right\}$$

These formulas correspond to the equations following (12.17) and (12.29) of Cochran, 1963. The above refer to estimated totals rather than means. In the colonies analyzed, n^1 was very large and F usually close to 1, making the last term very small, hence it was omitted in the calculations.

One statistical assumption which is violated in the above procedure is the fact that the high-level photography is not a random selection of areas from the colony. However in view of the fact that it represents a high proportion of the area, and is *typical* of the colony, this violation will not be serious.

2.2. Estimating colour phase ratio

The final step in the estimation of total geese is the estimation of the colour phase ratio from an independent sample from low-level photography. Using the standard ratio estimator, the colour phase ratio and its variance are respectively

$$\hat{p} = \Sigma w_i/\Sigma t_i \quad \text{and}$$

$$\text{var } \hat{p} = \frac{m}{m-1}(\Sigma w_i^2 + \hat{p}^2\Sigma t_i^2 - 2\hat{p}\Sigma w_i t_i)/\Sigma t_i^2$$

where

w_i = number of white phase nesting geese counted from the i^{th} sampling unit

t_i = number of white and blue phase nesting geese counted from the i^{th} sampling unit

m = number of sampling units

Thus the estimator and variance of total white and blue phase geese are

$$\hat{T} = \hat{Y}/\hat{p} \quad \text{and}$$

$$\text{var } \hat{T} = \hat{T}^2 \left(\frac{\text{var } Y}{\hat{Y}^2} + \frac{\text{var } \hat{p}}{\hat{p}^2}\right)$$

Assuming normality, 95% confidence limits for $\hat{T}$ are approximately $\hat{T} \pm 2s(\hat{T})$, where $s(\hat{T}) = \sqrt{\text{var } \hat{T}}$; 95% confidence limits for the number of nests are $\frac{1}{2}\hat{T} \pm \frac{1}{2}s(\hat{T})$.

3. Estimation procedure for colonies where only low-level photographic coverage is available

In these colonies we used the standard ratio estimator for the white phase geese, i.e.,

$$\hat{Y} = N\,\Sigma\hat{Y}_i/\Sigma A_i$$

$$\text{var } \hat{Y} = \frac{n\,(1-f)}{(n-1)\,(\Sigma A_i)^2}\,(N^2\Sigma\hat{Y}_i^2 + \hat{Y}^2\Sigma A_i^2 - 2N\hat{Y}\Sigma A_i\hat{Y}_i)$$

where $\hat{Y}_i$, A_i, $\hat{Y}$ and n have the same definitions as in section 2, N is total area of colony and f is the portion of the colony which was analyzed from low-level photography.

The same procedure as before may be used to estimate the colour phase ratio. Thus the estimate and variance of the total number of geese in the colony are respectively

$$\hat{T} = \hat{Y}/\hat{p} \quad \text{and}$$

$$\text{var } \hat{T} = \hat{T}^2\left(\frac{\text{var } \hat{Y}}{\hat{Y}^2} + \frac{\text{var } \hat{p}}{\hat{p}^2}\right)$$

95% confidence limits for $\hat{T}$ and the number of nests, $\hat{T}/2$, have the same expressions as in section 2.

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