ARCTIC
VOL. 62, NO. 1 (MARCH 2009) P. 65–74

Distribution and Diet of Ivory Gulls (*Pagophila eburnea*) in the North Water Polynya

NINA J. KARNOVSKY,[1,2] KEITH A. HOBSON,[3] ZACHARY W. BROWN[1] and GEORGE L. HUNT, Jr.[4]

(*Received 4 February 2008; accepted in revised form 21 May 2008*)

ABSTRACT. Ivory gulls (*Pagophila eburnea*, Phipps, 1774), one of the world's least-known species, have declined throughout their range in recent years. This study describes the patterns of ivory gull use of the North Water polynya, a large polynya that occurs every year near ivory gull breeding sites on Ellesmere Island, Nunavut, Canada. We conducted at-sea surveys from Canadian icebreakers during the summers of 1997–99. In 1998, stomach contents of five ivory gulls were analyzed. We measured stable isotope ratios ($\delta^{13}C$, $\delta^{15}N$) of liver, muscle, feather and bone to determine how ivory gull diets vary during the year. We observed a total of 275 individuals, most of which were seen on the western side of the polynya. Flying was the predominant behavior (76% of individuals); other behaviors included sitting on ice, sitting on water, and feeding. Four juveniles were seen in August and September. Birds collected had arctic cod (*Boreogadus saida*) in their stomachs. Other food items included an otolith from an unidentified species of Liparid fish and two bones from a mole, presumed to be a star-nosed mole (*Condylura cristata*). Stable isotope results indicated that ivory gull trophic levels (TLs) were high (around TL 4 based on $\delta^{15}N$) but varied over the season. From the three individuals whose feathers were analyzed, we conclude that differences among individuals in their winter diets or foraging locations are possible.

Key words: ivory gull, *Pagophila eburnea*, arctic cod, *Boreogadus saida*, North Water polynya, star-nosed mole, *Condylura cristata*, stable isotope analysis, carbon-13, nitrogen-15.

RÉSUMÉ. Les mouettes blanches (*Pagophila eburnea*), soit l'une des espèces les moins connues dans le monde, ont enregistré un déclin à travers l'ensemble de leurs habitats ces dernières années. Cette étude décrit les habitudes des mouettes blanches dans la polynie des eaux du Nord, une grande polynie qui se développe chaque année près des sites de reproduction de mouettes blanches sur l'île Ellesmere, au Nunavut, Canada. Nous avons effectué des relevés depuis des brise-glace canadiens au cours des étés 1997 à 1999. En 1998, le contenu des estomacs de cinq mouettes blanches a été analysé. Nous avons également mesuré les ratios d'isotopes stables ($\delta^{13}C$, $\delta^{15}N$) dans les foies, les muscles, les plumages et les os afin de déterminer comment le régime alimentaire des mouettes blanches variait au cours de l'année. Nous avons observé 275 individus, provenant principalement du côté ouest de la Polynie. La majorité (76 %) étaient en vol. Parmi les autres comportements observés, notons la présence d'oiseaux sur la glace, d'oiseaux sur l'eau et d'oiseaux en train de se nourrir. Quatre oiseaux juvéniles ont été repérés en août et en septembre. Les oiseaux capturés avaient de la morue polaire (*Boreogadus saida*) dans l'estomac. Les autres aliments trouvés comprenaient un otolithe provenant d'une espèce non identifiée de poisson Liparidé, et deux os de taupe, probablement un condylure étoilé (*Condylura cristata*). L'analyse des isotopes stables indique que les niveaux trophiques (NT) des mouettes blanches étaient élevés (NT 4 environ en fonction de $\delta^{15}N$), mais variaient au cours de la saison. À partir des trois individus dont les plumes ont été analysées, nous en avons conclu qu'il est possible qu'il existe des différences entre les régimes d'hiver ou les lieux de nourriture des individus.

Mots clés : mouette blanche, *Pagophila eburnea*, morue polaire, *Boreogadus saida*, polynie des eaux du Nord, condylure étoilé, *Condylura cristata*, analyse des isotopes stables, carbone 13, azote 15

[1] Pomona College, Department of Biology, 175 West 6th Street, Claremont, California 91711
[2] Corresponding author: Nina.Karnovsky@pomona.edu
[3] Environment Canada, 11 Innovation Boulevard, Saskatoon, Saskatchewan S7N 3H5, Canada
[4] Department of Ecology and Evolutionary Biology, University of California, Irvine, Irvine, California 92697, USA; current address: School of Aquatic and Fishery Sciences, Box 355020, University of Washington, Seattle, Washington 98195, USA

Реферат: Популяция белых чаек (*Pagophila eburnea*), одного из наименее изученных в мире видов птиц, значительно уменьшилась за последние годы. Эта работа описывает кормовое поведение белых чаек размножающихся в районе “Северной полыньи ”, которая ежегодно формируется в районе мест размножения белых чаек на острове Элсмир, Нунавут, Канада. В течение летних сезонов 1997-99, мы вели наблюдение в общей сложности за 275 особями, которые в основном концентрировались в западной части полыньи. Во время наблюдений, большинство (76%) особей было отмечено в полёте, другие виды поведения включали отдых на льду или воде, и кормёжку. Содержание желудков пяти особей было исследовано в 1998 году. Основу диеты составляла арктическая треска (*Boreogadus saida*). Также мы нашли отолиты рыб *Liparid* spp. и фрагменты скелетов насекомоядных, возможно кротов (*Condylura cristata*). Для того, чтобы установить, что составляет основу питания белых чаек в течение года мы измерили изотопный состав ($\delta^{13}C$, $\delta^{15}N$) печени, мускулов, перьев, и костей. Результаты изотопных анализов показали, что трофический уровень (ТУ) белых чаек был довольно высоким (ТУ около 4 судя по $\delta^{15}N$ анализам), но варьировал в течение летнего сезона. Основываясь на результатах анализов перьевого покрова трёх исследованных особей, мы пришли к заключению что зимний состав корма или места зимовки возможно варьируют между отдельными особями.

Ключевые слова: белая чайка, *Pagophila eburnea*, арктическая треска, *Boreogadus saida*, полынья «Северная вода», звездонос, *Condylura cristata*, изотопный анализ, углерод-13, азот-15.

INTRODUCTION

Recent at-sea surveys suggest that Canadian ivory gull (*Pagophila eburnea*, Phipps, 1774) populations are declining (Chardine et al., 2004). Local residents in Arctic Canada have also observed declines in this species (Mallory et al., 2003). Gilchrist and Mallory (2005) conducted aerial surveys of colony sites and reported an 80% decline in numbers since the 1980s. Since 2006, ivory gulls have been classified as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2006). Mechanisms driving the decline of this species are unknown; hypotheses include contamination from anthropogenic sources (e.g., Braune et al., 2006, 2007), hunting (Stenhouse et al., 2004; Gilchrist and Mallory, 2005), relocation to new breeding sites (deemed unlikely because of the large extent of aerial surveys; Gilchrist and Mallory, 2005), increased predation with the loss of protective ice around nunatak nesting sites, and reduction of ice edges associated with feeding during winter (Krajick, 2003). As the ivory gull is associated with ice for much of its life history, climate change and sea ice declines (e.g., Comiso, 2002) may be major threats.

The North Water polynya in northern Baffin Bay attracts millions of seabirds every year (Fig. 1; Karnovsky and Hunt, 2002). The North Water is the largest (~ 80 000 km^2) recurrent polynya in the Arctic and one of the most important for seabirds and other upper–trophic level predators (Fig. 1; Stirling, 1980). As the most northerly polynya of its size, the North Water may be a crucial feeding ground for ivory gulls during their breeding season, when they are at the northernmost extent of their range. Breeding colonies have been reported in southeastern Ellesmere Island—the western edge of the North Water (Robertson et al., 2007). This study documents the distribution, abundance, and foraging ecology of ivory gulls in the North Water. We determined the at-sea distribution of ivory gulls in the North Water throughout their breeding season (over three years) and assessed the diets of five individuals using both stomach-content analysis and stable isotope analysis of different tissues. Stomach-content analysis provides an indication of the taxa and size of recently consumed prey. By measuring $\delta^{13}C$ values in different tissues, we determined the relative use of coastal (more enriched) or pelagic (more depleted) prey (Hobson et al., 1995). Stable nitrogen isotope values ($\delta^{15}N$) show stepwise enrichment with trophic level and so reflect trophic position (Hobson and Welch, 1992; Michener and Schell, 1994). The period of temporal integration of diets using stable isotope tracers depends on the metabolic rate of tissues; the rate is high for tissues like liver and low for tissues like bone collagen (Hobson and Clark, 1992). Feathers provide dietary information for the period of feather growth (Cherel et al., 2000). Thus, we measured $\delta^{13}C$ and $\delta^{15}N$ values in several tissues in order to create a time-dependent model of diet and habitat use.

METHODS

At-Sea Surveys

Surveys were conducted in the North Water in August 1997, April to July 1998, and August and September 1999. We combined observations made during all survey months in 1997 to 1999 to describe the seasonal changes in ivory gull distributions through the breeding season. Surveys were conducted from a Canadian Coast Guard icebreaker, the *Louis St. Laurent* in 1997 and the *Pierre Radisson* in 1998 and 1999. As the ship traveled between stations where oceanographic and ice measurements were made, we conducted surveys from inside the bridge, using the strip transect methodology (Tasker et al., 1984), throughout the day and night whenever the ship was underway. Birds were observed from one side of the ship (where lowest glare gave best visibility). All birds seen within a 300 m arc (determined from the 300 m distance, the eye height of the observer, and the distance to the horizon using right triangle geometry; Heineman, 1981)

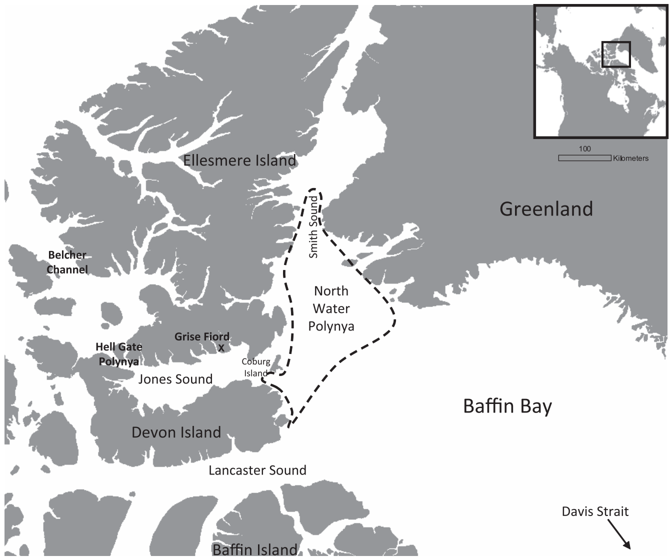

FIG. 1. The North Water polynya and surrounding area. The dashed line indicates the average May extent of the polynya (Dunbar, 1969).

were identified and counted. We also noted their behavior (flying, feeding, sitting on water, sitting on ice) and entered all observations into a notebook computer. We recorded ice conditions during our surveys and classified both the percent and the type of ice cover in the area. Types of ice cover included icebergs, pancake ice, brash ice/packed slush, floes of small, medium, large and vast sizes, new ice, and fast ice (attached to land). Ice classifications were similar to those used by Ainley et al. (1994). To evaluate the east-west gradients in ivory gull distributions, we divided the survey area into western (Canadian) and eastern (Greenland) sides as follows: from 72˚30′ N to 77˚30′ N, the polynya was split in two by the meridian 75˚ W. North of 77˚30′, our division angled northeast, bisecting Smith Sound (see April, Fig. 2).

Stomach Contents

Five ivory gulls were collected at sea on three separate days between 29 May and 9 June, 1998 (Fig. 2). We removed their stomachs and proventriculi and examined them for contents. We calculated the frequency of occurrence of prey (the percentage of birds in which the prey item was found, not including those with empty stomachs). We defined the numerical abundance of each prey species as its percentage of the total count of prey items. We identified otoliths and bones to the lowest possible taxon. When possible, otolith lengths and widths were measured to the nearest 0.1 mm using a dissecting microscope. As each fish has two (sagittal) otoliths, otoliths were paired on the basis of morphology and right- or left-handedness to determine the total number of fish represented. We used the regression presented by Frost and Lowry (1981), where fish length in cm = 2.198x + 1.588 (x being the otolith length in mm), to estimate the lengths of the arctic cod (*Boreogadus saida*) consumed. Lengths of paired otoliths were averaged for this analysis.

Stable Isotope Analysis

We collected small subsamples (approx. 1 g) of muscle and liver tissue, three to five grams of bone (humerus), and the outer primary from each of the birds and kept these samples frozen. In the laboratory, muscle and liver samples were thawed, washed, dried, powered, and treated with a 2:1 chloroform:methanol solution to remove lipids. Feathers were cleaned with the same solvent solution. After drying, small portions of a distal vane were removed for analysis. Bone was cleaned of attached muscle and marrow was removed. After the cleaned bone was rinsed in the solvent solution and dried, we extracted collagen using the same methods as Hobson and Montevecchi (1991). Stable-carbon and nitrogen isotope assays were performed using the same methods as Hobson et al. (2002). Trophic level (TL) was estimated based on known $\delta^{15}N$ values of *Calanus* copepods and an assumed diet-tissue isotopic discrimination factor for an Arctic marine food web (Hobson, 1993; Hobson et al., 1994). Tissue-specific discrimination values were based on those in Mizutani et al. (1990, 1991). We assumed the average trophic enrichment for Arctic food webs to be 3.8‰ (Hobson and Welch, 1992). We used ANOVA to compare trophic levels and $\delta^{13}C$ values amongst tissues. Because of the small number of individuals collected, these results should be interpreted with caution.

RESULTS

At-Sea Surveys

We surveyed 4512 km^2 over 157 days, and we observed 275 ivory gulls in the North Water. The majority of the birds (169) were seen in August and September (Tables 1 and 2). Additionally, during the transit to the North Water in April 1998, 94 ivory gulls were seen approximately 1700 km to the south of the polynya, between the southern tips of Baffin Island and Greenland, at approximately 62–63˚ N and 56–58˚ W. Two of those ivory gulls were seen near the carcass of a hooded seal (*Cystophora cristata*) that had been killed by a polar bear (*Ursus maritimus*). Two birds seen in April were in first winter plumage (dark face). We did not observe any ivory gulls in the North Water in April, and no ivory gulls were seen during the transit south along the western edge of Davis Strait in early October 1999. During the rest of the months, ivory gulls were sighted most often on the western (Canadian) side of the North Water polynya (Fig. 2, Table 2).

At-Sea Behavior

Of the 275 gulls observed in the North Water, 208 (75.6%) were flying, 19 (6.9%) were sitting on ice, 43 (15.6%) were attracted (flying) to the observation vessel, three (1.1%) were feeding (seen capturing prey), and two (0.7%) were sitting on the water (Table 1). We found ivory gulls more often in

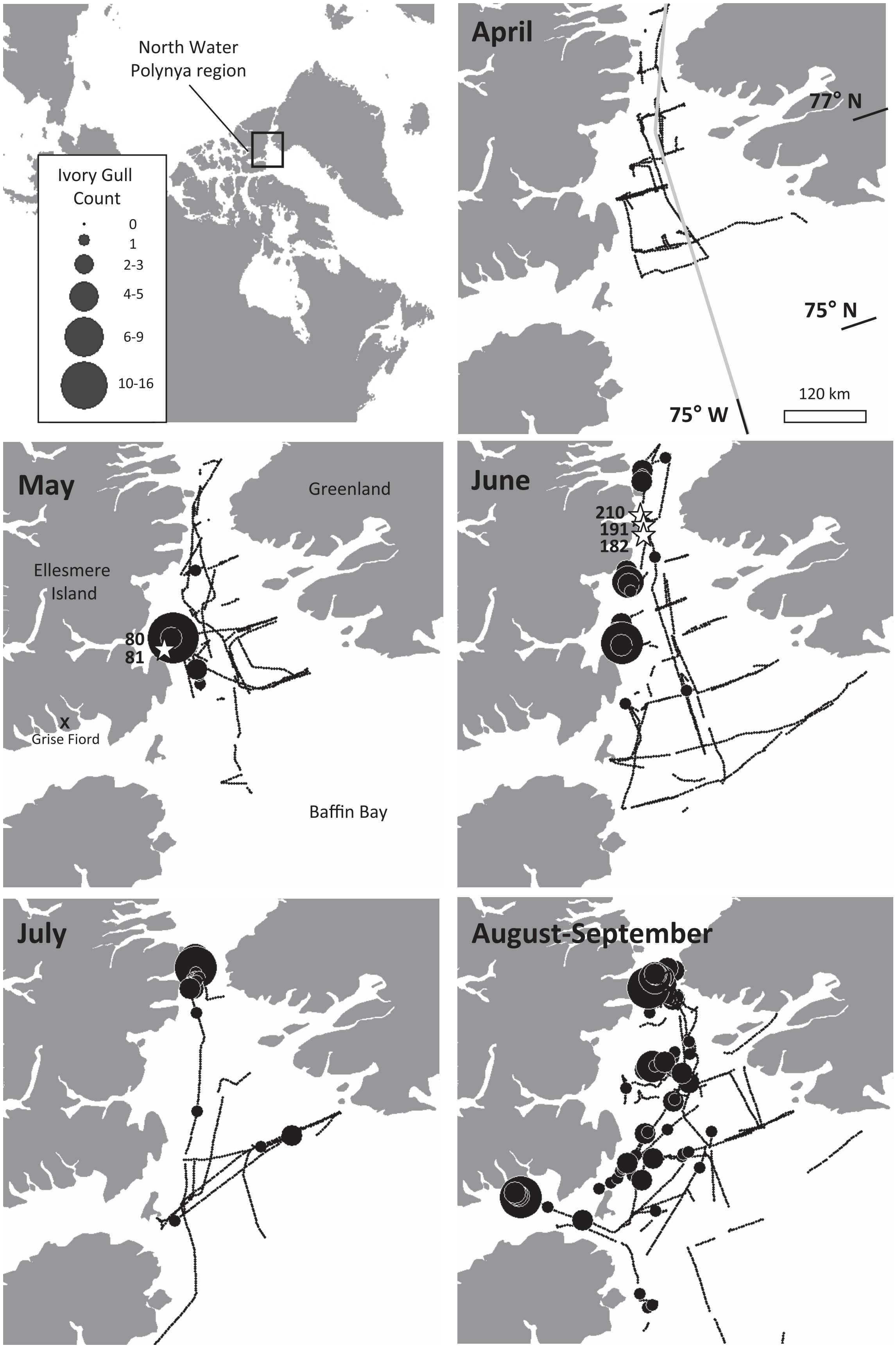

FIG. 2. Ivory gull distributions in the North Water polynya. The April–July maps are from observations in 1998; the August–September map is a combination of observations made in 1997–99. The grey line in April represents our division of the polynya into eastern and western halves. The stars indicate the locations of birds collected in May and June, 1998.

TABLE 1. At-sea behavior of ivory gulls surveyed in the North Water polynya, 1997–99.

	April 1998	May 1998	June 1998	July 1998	August 1997	August–September 1999
Flying		28	26	36	68	50 (1 juv)
Sitting on ice		3	7		1	8 (1 juv)
Ship attracted			3	2	12 (+ 1 juv[1])	26
Feeding				1		2
Sitting on water						2 (1 juv)
Total ivory gull count	0	31	36	39	81	88

[1] Landed on ship; not within observation arc and not included in counts data.

TABLE 2. The densities of ivory gulls surveyed on the western (Canadian) and eastern (Greenland) sides of the North Water polynya. The Aug–Sept measurements combine those from August 1997 and August–September 1999; all others are from 1998.

	West			East		
	Survey area (km^2)	IVGU Count	IVGU/km^2	Survey area (km^2)	IVGU Count	IVGU/km^2
April	346	0	0	714	0	0
May	400	31	0.078	243	0	0
June	503	35	0.070	339	1	0.003
July	432	36	0.083	171	3	0.018
Aug–Sept	825	117	0.142	539	52	0.096

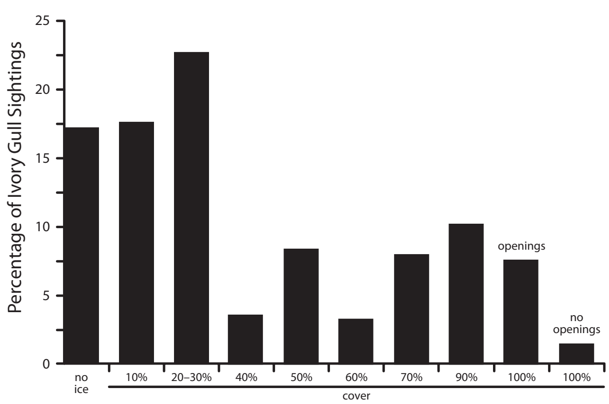

FIG. 3. Percentage of ivory gulls observed in association with various levels of ice cover in the North Water polynya.

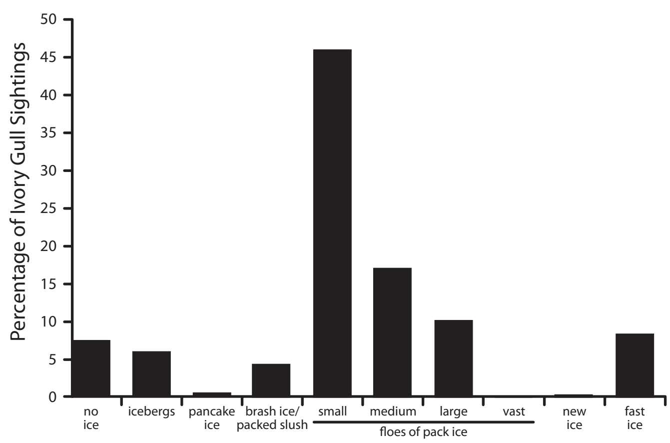

FIG. 4. Percentage of ivory gulls observed in association with different ice forms in the North Water polynya.

areas of low ice cover: 157 gulls (57%) were seen in areas of 30% ice cover or less (Fig. 3). Almost half (126, 46%) of the ivory gulls we saw were in areas characterized by small floes of pack ice (Fig. 4).

Feeding birds were seen aerial dipping (Ashmole and Ashmole, 1967) from a height of about 50 m. Gulls were described as "milling over a lead" or "flying along ice edge" or "dipping into leads in the ice." A total of four juveniles were seen during this study. Three of the juveniles were seen on 4 September 1999 (Table 1) in association with adults and had characteristic black spots on their wings; one was seen begging from an adult. On 25 August 1997, one juvenile landed on the ship.

Stomach Contents

All birds collected were adults, three females and two males. The four stomachs that contained food items all had arctic cod otoliths (Table 3). These otoliths represented a total of 16 fish taken by the four birds, with a maximum of six fish taken by one individual. Arctic cod made up 85.7% of all prey items found in stomach samples. Otolith measurements indicate that the average length of the arctic cod consumed was 179 ± 22 mm. An entire arctic cod was dropped by one of the birds. The length of the fish (235 mm) was slightly longer than the length calculated from its otoliths (213 mm). In the stomachs we also found a piece of quartz, an unidentified species of Liparid fish, and a humerus and ulna from the forearm of a mole (based on information in Feldhamer et al., 2004), which we presumed (on the basis of known ranges of moles; Petersen and Yates, 1980) to be a star-nosed mole (*Condylura cristata*).

Stable Isotope Analysis

Ivory gulls occupied a trophic level (TL) close to 4. Trophic level estimates based on different tissues varied

TABLE 3. Characteristics and diets of five ivory gulls collected in 1998.[1] F = female, M = male.

Bird	Sex; wt. (g)	Date Location	Behavior	Prey	Number	Mean Fish Length (mm ± SD)[2]	Frequency of occurrence (%)	Numerical abundance (%)
080	F; 480	29 May 1998 76°57.45′ N 77°32.00′ W	Feeding with 081	*B. saida*	6	174 ± 7.6	100	85.7
081	F; 490	29 May 1998 76°57.45′ N 77°32.00′ W	Feeding with 080	*B. saida*	4	189 ± 17.6		
				Liparid sp.	1	NA	25	3.6
182	M; 623	7 June 1998 78°21.76′ N 74°59.92′ W	Sitting on ice	*B. saida*	4	166 ± 31.3		
				Piece of quartz	1		25	3.6
191	F; 551	7 June 1998 78°24.26′ N 74°55.73′ W	Sitting on ice	*B. saida*	2	198 ± 21.7		
				C. cristata[3] humerus and ulna	1		25	3.6
210	M; 540	9 June 1998 78°27.5′ N 74°54.0′ W	Flying	None				

[1] See Figure 2.
[2] Fork lengths calculated from otoliths based on regression in Frost and Lowry (1981).
[3] Identified to family; species based on known mole distributions (Petersen and Yates, 1980).

slightly. Mean trophic levels of bone and liver were highest and those for feather and muscle were lowest (Table 4). The TL estimates based on feathers from the three birds sampled ranged from 3.7 to 4.9. Because of this variability, the assumption of equal variances was violated (Levene's test of Equality of Error Variances $p = 0.00$), so TL based on feather samples could not be included in a test of differences among all tissues. Trophic level estimates from liver, muscle, and bone differed from each other ($F_{2,6} = 36.34$, $p < 0.0001$). In Tukey's post-hoc tests, mean trophic level from muscle differed from levels from liver and bone ($p = 0.001$), but liver and bone were not significantly different from each other ($p = 0.91$). Because of small sample sizes (only one male was sampled for liver, muscle, and bone), we could not test for effects of sex.

Estimates of $\delta^{13}C$ values from different tissues indicated that liver and muscle were the most depleted, and feather and bone were the most enriched (Table 4). There were significant differences in mean $\delta^{13}C$ values of prey ($F_{3,12} = 35.6$, $p < 0.001$). All $\delta^{13}C$ values estimated from liver, muscle, and feather differed from each other ($p \leq 0.003$). Bone $\delta^{13}C$ values only differed from those from feathers ($p < 0.001$).

DISCUSSION

Spatial and Temporal Distribution

There were strong temporal and spatial trends in ivory gull use of the North Water. No ivory gulls were seen in the polynya in April; however, some were found farther south, in the same location (~ 62–63° N and 56–58° W) where Renaud and McLaren (1982) found high concentrations during their aerial surveys in March. These birds were likely transiting north to their breeding grounds or were non-breeding birds (two had immature plumage). Ivory gulls arrived in the North Water in May, which coincides with the early spring phytoplankton bloom (Klein et al., 2002). Sightings of ivory gulls increased from May until August and September. The high numbers of sightings in August and September may have been due to an influx of post-breeding birds and fledglings. It was during this time that we observed juveniles (n = 4) as well as adults in the North Water. The North Water begins to close again at the end of September. In their aerial surveys of the polynya and Baffin Bay in the mid 1970s, Brown et al. (1975) found ivory gulls in the southern portion of the North Water in September and then in eastern Baffin Bay in October, so this period is likely when they begin to migrate out of the polynya. During our transit south in October, we did not find any birds along western Baffin Bay.

Initially (May and June) ivory gulls focused their foraging activity along the western side of the polynya (Table 2, Fig. 2). This pattern is in stark contrast to the one observed for zooplanktivorous dovekies, which foraged on the eastern side of the polynya, along the west Greenland coast, after their arrival in May (Karnovsky and Hunt, 2002). The eastern side of the polynya was the first area to open in 1998 (Melling et al., 2001), and in May *Calanus* spp. copepods were found there in high abundance (Ringuette et al., 2002). Piscivores like ivory gulls may avoid foraging in the open water along the eastern side of the polynya; the western side had more pack ice (Mundy and Barber, 2001; Ingram et al., 2002), and there may have been more adult-size arctic cod in leads there, as adult arctic cod are often associated with ice (Gradinger and Bluhm, 2004). In July, most of the ivory gull sightings were in the north of the polynya, close to the ice bridge that develops each year in northern Smith Sound (Ingram et al., 2002). In August and

TABLE 4. Estimated trophic level (using tissue-dependent model in Hobson et al., 2002) and $\delta^{13}C$ values of prey consumed (using tissue-dependent isotope discrimination factors) by ivory gulls collected in the North Water in May and June 1998 in days, weeks, months, and years prior to collection.

Tissue	n	Estimated Trophic Level	Prey $\delta^{13}C$ values
Liver (days)	4	4.8 ± 0.23	-21.80 ± 0.12
Muscle (weeks)[1]	5	4.0 ± 0.17	-21.42 ± 0.29
Feather (months)	3	4.1 ± 0.72	-20.90 ± 0.26
Bone (years)	4	4.8 ± 0.08	-20.02 ± 0.65

[1] Muscle values are from Hobson et al. (2002).

September, ivory gulls were found in both the north and south of the polynya, but they maintained a more westerly distribution (Fig. 2, Table 2).

Our at-sea surveys were made during three years, but data were combined to provide insight into the seasonal dynamics of ivory gulls' usage of the polynya. Spring and summer measurements were made in 1998, and fall measurements (August and September) were made in 1997 and 1999. It is possible that the seasonal patterns were due in part to inter-annual differences in foraging conditions. However, measurements of biogenic flux made throughout the study period indicate strong seasonal changes and no major differences among years (e.g., Miller et al., 2002). For these reasons, we feel that our measurements are typical of a single season. We have combined our data in the same way that others have in describing the seasonal progression of the polynya's physical and biological characteristics (e.g., Klein et al., 2002; Miller et al., 2002).

Our survey results are difficult to compare to other studies, since these were the first at-sea surveys of the entire North Water to be conducted during the entire breeding season (albeit over three years). We found many fewer birds in the North Water than Renaud and McLaren (1982) found in southwestern Baffin Bay and eastern Lancaster Sound during aerial surveys in 1976 and 1978–79. In several instances, they saw a greater number of birds on a single date and in one location than we did over our entire study period (e.g., 640 individuals in Grise Fiord on 14 September 1979). Renaud and McLaren (1982) conducted surveys in August to October, later in the season than the majority of our records, and were approximately 200 km to the southwest of the North Water. However, there was some spatial and seasonal overlap between the two studies, and the differences in numbers of sightings may reflect recent population declines in this species.

Chardine et al. (2004) conducted at-sea surveys in 1992 and 2002 in Jones and Lancaster sounds and along the western edge of Ellesmere Island. During their earlier surveys, they found ivory gulls in Jones Sound and in the southwest corner of the polynya (near Coburg Island). In the later survey, the only ivory gulls that they found were along the western edge of Ellesmere Island and near Belcher Channel. In their aerial and ground surveys of Hell Gate polynya, Mallory and Gilchrist (2005) counted five ivory gulls in 2003 but none in 2004. To understand whether ivory gull usage of the North Water has fundamentally changed in recent years, we need to repeat surveys within the polynya and compare those results to the ones described here. Additional surveys throughout the Canadian Arctic are needed to assess whether the birds have shifted their migration patterns, their breeding locations, or both.

Diets

The importance of arctic cod to the ivory gull diet is clear: this food item has been documented in the Chukchi Sea (Divoky, 1976), the Barents Sea (Mehlum, 1990), the Svalbard region (Mehlum and Gabrielsen, 1993), near Wrangel Island (Stishov et al., 1991), and now in northern Baffin Bay (this study). We calculated an average arctic cod fork length of 179 mm, which is larger than those collected by Divoky (1976) from ivory gull stomachs in the Chukchi Sea (140 mm maximum total length).

Arctic cod were important to ivory gulls during the breeding season in the North Water polynya. However, in nearby Lancaster Sound, Renaud and McLaren (1982) observed high numbers of ivory gulls feeding on whale and seal kills near settlements and scavenging the offal of beluga whales (*Delphinapterus leucas*). In Davis Strait, just to the southeast, Orr and Parsons (1982) found that the gulls took several lanternfish (Myctophidae) species in April–May, but not arctic cod.

To our knowledge, this is the first recorded instance of ivory gulls preying on moles. The bones found are likely from the star-nosed mole (*Condylura cristata*) because its range extends to the Labrador Peninsula (Petersen and Yates, 1980), which overlaps the wintering distribution of Canadian ivory gulls (Haney and MacDonald, 1995). It is possible that the mole bones were scavenged from an arctic fox (*Alopex lagopus*) scat, but it is also possible that the mole was captured by the ivory gull since these birds are known to prey on lemmings (Bent, 1921).

Our stable isotope results were in general agreement with a piscivorous diet. Hobson et al. (2002), who compared the TL of these same five birds on the basis of $\delta^{15}N$ measurements of muscle only, found that they occupied the same TL (i.e., TL 4) as thick-billed murres (*Uria lomvia*) and northern fulmars (*Fulmarus glacialis*) and were exceeded only by glaucous gulls (*Larus hyperboreus*), with TL of 4.6.

Because of the variation in elemental turnover rates of the tissues we examined isotopically, we were able to extend dietary estimates integrated over several time periods. Evidence from liver suggests that in the days just before collection, the birds' diets were the most depleted in ^{13}C. During this time, they were feeding at a high trophic level (TL 4.8 based on $\delta^{15}N$), which suggests that scavenging on pelagic marine mammal carcasses may have been important at that time. Over the several weeks before collection (based on measurements of isotope ratios in muscle tissue), diets were similarly depleted in ^{13}C, but the gulls fed at a lower trophic level (had lower $\delta^{15}N$ values). These results would be consistent with a diet composed primarily of arctic cod (Hobson et al., 2002). Interestingly, the measurements of trophic level based on feathers were highly variable. This variability could indicate individual differences in trophic level of prey during the post-breeding period. Since carbon and nitrogen in bone collagen have an extremely low turnover rate, isotope values reflect diets integrated over years. Average trophic level based on bone measurements was high and similar to liver, again suggesting that scavenging on marine mammal carcasses is important on an annual basis. The more enriched $\delta^{13}C$ values of post-breeding (feather) and longer-term dietary estimates (bone) support relatively more inshore and higher trophic positions, respectively, for those periods. While the isotope data showed strong patterns, caution should be used when interpreting our results because of the small number of individuals used in this study. Given the rarity of this species, we do not recommend collecting more individuals; whenever possible, stable isotope levels and stomach contents should be analyzed in salvaged individuals.

Contaminant levels were measured in these same ivory gulls by others (Moisey et al., 2001; Fisk et al., 2001a, b; Buckman et al., 2004; Campbell et al., 2005). Mercury levels (Hg) and $\delta^{15}N$ values were determined in ivory gull eggs collected from Seymour Island, Nunavut, Canada by Braune et al. (2007). In a trophic level comparison of ivory gull eggs to those from other seabirds, only glaucous gull eggs from Prince Leopold Island exceeded ivory gulls, which is the same pattern reported in Hobson et al. (2002) for the seabirds in the North Water. The mean $\delta^{15}N$ (± SD) determined from the analysis of ivory gull eggs by Braune et al. (2007) was similar to our finding for liver (eggs 17.3 ± 0.6‰ n = 6; liver 16.9 ± 0.9‰ n = 4). Because diet-tissue $\delta^{15}N$ discrimination factors are similar between liver and eggs (Hobson, 1995), these $\delta^{15}N$ values are comparable. Our TL modeling suggests that ivory gulls maintain a relatively similar trophic position throughout the year, and this finding will assist in future interpretations of the role of contaminants in the decline of this species.

Our results highlight the importance of the North Water polynya to the ivory gull. In their recent aerial colony surveys in the Canadian Arctic, Robertson et al. (2007) found that many previously occupied colonies are no longer occupied, and in others, the numbers of gulls present have declined. Ellesmere Island is the only place where new colonies have been discovered, which indicates the critical importance of the North Water for ivory gulls. The species depends on ice edges to access sympagic prey, and the North Water appears to provide a dependable source. The ivory gull may be particularly vulnerable to changes in climate that cause reduction in summer ice cover in the Canadian Arctic Archipelago.

ACKNOWLEDGEMENTS

We thank the captains and crew and officers of the CCGS *Louis St. Laurent* and *Pierre Radisson* for their assistance. Thanks to the Iviq Hunters & Trappers Organization of Grise Fiord, Nunavut, for permission for the project to collect birds in the region. Collections were made under a permit from the Canadian Wildlife Service. P. Akeeagok, D. Andriashek, W. Calvert, J. Carlson, A. Fisk, M. Holst, N. Lunn, I. Stirling, and J. Zamon provided assistance in the field. We also thank M. Fortier and C. Michel for help with logistics. Thanks to chief scientists L. Fortier, M. Gosselin, and B. Hargrave for their support throughout the project. P. Healy performed stable isotope sample preparation. Stable isotope measurements were conducted at the Department of Soil Science, University of Saskatchewan. Special thanks to G. Fowler for identifying the mole bones. Thanks to J. Kang Lee for getting the at-sea distribution data into ArcGis. L.K. Yamasaki worked on an earlier version of this paper. D. Thomson gave advice on statistics. Special thanks to Olivier Pauluis for translating the abstract into French and to Stephanie Harves, Maria Prokopenko, and Alexander Kitaysky for translating it into Russian. Z. Brown was supported by a post-baccalaureate grant from the Mellon Foundation. This work was supported by National Science Foundation Office of Polar Programs grant number OPP 9725071. This paper is a contribution to the International North Water Polynya Project initiated under the Arctic Ocean Sciences Board.

REFERENCES

Ainley, D.G., Ribic, C.A., and Fraser, W.R. 1994. Ecological structure among migrant and resident seabirds of the Scotia–Weddell confluence region. The Journal of Animal Ecology 63:347–364.

Ashmole, N.P., and Ashmole, M.J. 1967. Comparative feeding ecology of sea birds of a tropical oceanic island. Peabody Museum of Natural History, Yale University Bulletin 24: 1–131.

Bent, A.C. 1921. Life histories of North American gulls and terns. New York: Dodd, Mead & Company.

Braune, B.M., Mallory, M.L., and Gilchrist, H.G. 2006. Elevated mercury levels in a declining population of ivory gulls in the Canadian Arctic. Marine Pollution Bulletin 52:969–987.

Braune, B.M., Mallory, M.L., Gilchrist, H.G., Letcher, R.J., and Drouillard, K.G. 2007. Levels and trends of organochlorines and brominated flame retardants in ivory gull eggs from the Canadian Arctic, 1976–2004. Science of the Total Environment 378:403–417.

Brown, R.G.B., Nettleship, D.N., Germain, P., Tull, C.E., and Davis, T. 1975. Atlas of Eastern Canadian Seabirds. Ottawa: Canadian Wildlife Service.

Buckman, A.H., Norstrom, R.J., Hobson, K.A., Karnovsky, N.J., Duffe, J., and Fisk, A.T. 2004. Organochlorine contaminants in seven species of Arctic seabirds from northern Baffin Bay. Environmental Pollution 128:327–338.

Campbell, L.M., Norstrom, R.J., Hobson, K.A., Muir, D.C.G., Backus, S., and Fisk, A.T. 2005. Mercury and other trace elements in a pelagic Arctic marine food web (Northwater polynya, Baffin Bay). Science of the Total Environment 351-352:247–263.

Chardine, J.W., Fontaine, A.J., Blokpoel, H., Mallory, M., and Hofmann, T. 2004. At-sea observations of ivory gulls (*Pagophila eburnea*) in the eastern Canadian High Arctic in 1993 and 2002 indicate a population decline. Polar Record 40:355–359.

Cherel, Y., Hobson, K.A., and Weimerskirch, H. 2000. Using stable-isotope analysis of feathers to distinguish moulting and breeding origins of seabirds. Oecologia 122:155–162.

Comiso, J.C. 2002. A rapidly declining perennial sea ice cover in the Arctic. Geophysical Research Letters 29(20), 1956, doi:10.1029/2002GL015650.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006. COSEWIC assessment and update status report on the ivory gull *Pagophila eburnea* in Canada. Ottawa: COSEWIC. http://www.sararegistry.gc.ca/status/status_e.cfm.

Divoky, G.J. 1976. The pelagic feeding habits of ivory and Ross' gulls. The Condor 78:85–90.

Dunbar, M. 1969. The geographical position of the North Water. Arctic 22:438–441.

Feldhamer, G.A., Drickamer, L.C., Vessey, S.H., and Merritt, J.F. 2004. Mammalogy: Adaptation, diversity, and ecology, 2nd ed. New York: McGraw Hill. 190–191.

Fisk, A.T., Hobson, K.A., and Norstrom, R.J. 2001a. Influence of chemical and biological factors on trophic transfer of persistent organic pollutants in the Northwater polynya marine food web. Environmental Science and Technology 35:732–738.

Fisk, A.T., Moisey, J., Hobson, K.A., Karnovsky, N.J., and Norstrom, R.J. 2001b. Chlordane components and metabolites in seven species of Arctic seabirds from the Northwater polynya: Relationships with stable isotopes of nitrogen and enantiomeric fractions of chiral components. Environmental Pollution 113:225–238.

Frost, K.J., and Lowry, L.F. 1981. Trophic importance of some marine gadids in northern Alaska and their body-otolith size relationships. Fishery Bulletin 79:187–192.

Gilchrist, H.G., and Mallory, M.L. 2005. Declines in abundance and distribution of the ivory gull (*Pagophila eburnea*) in Arctic Canada. Biological Conservation 121:303–309.

Gradinger, R., and Bluhm, B. 2004. In situ observations on the distribution and behavior of amphipods and arctic cod (*Boreogadus saida*) under the sea ice of the High Arctic Canada Basin. Polar Biology 27:595–603.

Haney, J.C., and Macdonald, S.D. 1995. Ivory gull (*Pagophila eburnea*). In: Poole, A., and Gill, F., eds. The birds of North America, No. 175. Philadelphia: The Academy of Natural Sciences and Washington, D.C.: The American Ornithologists' Union.

Heineman, D. 1981. A range finder for pelagic bird censusing. Journal of Wildlife Management 45:489–493.

Hobson, K.A. 1993. Trophic relationships among High Arctic seabirds: Insights from tissue-dependent stable-isotope models. Marine Ecology Progress Series 95:7–18.

———. 1995. Reconstructing avian diets using stable-carbon and nitrogen isotope analysis of egg components: Patterns of isotopic fractionation and turnover. Condor 97:752–762.

Hobson, K.A., and Clark, R.G. 1992. Assessing avian diets using stable isotopes II: Factors influencing diet-tissue fractionation. Condor 94:189–197.

Hobson, K.A., and Montevecchi, W.A. 1991. Stable-isotopic determinations of trophic relationships of great auks. Oecologia 87:528–531.

Hobson, K.A., and Welch, H.E. 1992. Determination of trophic relationships within a High Arctic marine food web using stable-isotope analysis. Marine Ecology Progress Series 84: 9–18.

Hobson, K.A., Piatt, J.F., and Pitochelli, J. 1994. Using stable isotopes to determine seabird trophic relationships. Journal of Animal Ecology 63:786–798.

Hobson, K.A., Ambrose, W.G., and Renaud, P.E. 1995. Sources of primary production, benthic pelagic coupling, and trophic relationships within the Northeast Water polynya: Insights from $\delta^{13}C$ and $\delta^{15}N$ analysis. Marine Ecology Progress Series 128:1–10.

Hobson, K.A., Fisk, A., Karnovsky, N., Holst, M., Gagnon, J.M., and Fortier, M. 2002. A stable isotope ($\delta^{13}C$, $\delta^{15}N$) model for the North Water food web: Implications for evaluating trophodynamics and the flow of energy and contaminants. Deep-Sea Research II 49:5131–5150.

Ingram, R.G., Bacle, J., Barber, D.G., Gratton, Y., and Melling, H. 2002. An overview of physical processes in the the North Water. Deep Sea Research II 49:4893–4906.

Karnovsky, N.J., and Hunt, G.L., Jr. 2002. Estimation of carbon flux to dovekies (*Alle alle*) in the North Water. Deep-Sea Research II 49:5117–5130.

Klein, B., Leblanc, B., Mei, Z.-P., Béret, R., Michaud, J., Mundy, C.-J., Von Quillfeldt, C., et al. 2002. Phytoplankton biomass, production and potential export in the North Water. Deep-Sea Research II 49:4983–5002.

Krajick, K. 2003. In search of the ivory gull. Science 301: 1840–1841.

Mallory, M.L., and Gilchrist, H.G. 2005. Marine birds on the Hell Gate polynya, Nunavut, Canada. Polar Research 24:87–93.

Mallory, M.L., Gilchrist, H.G., Fontaine, A.J., and Akearok, J.A. 2003. Local ecological knowledge of ivory gulls in Nunavut, Canada. Arctic 56:293–298.

Mehlum, F. 1990. Seabird distribution in the northern Barents Sea marginal ice-zone during late summer. Polar Research:61–65.

Mehlum, F., and Gabrielsen, G.W. 1993. The diet of High-Arctic seabirds in coastal and ice-covered, pelagic areas near the Svalbard archipelago. Polar Research 12:1–20.

Melling, H., Gratton, Y., and Ingram, R.G. 2001. Ocean circulation within the North Water polynya of Baffin Bay. Atmosphere-Ocean 39:301–325.

Michener, R.H., and Schell, D.M. 1994. Stable isotope ratios as tracers in marine and aquatic food webs. In: Lajtha, K., and Michener, R.H., eds. Stable isotopes in ecology and environmental science. Oxford: Blackwell. 138–157.

Miller, L.A., Yager, P.L., Erickson, K.A., Amiel, D., Bâcle, J., Cochran, J.K., Garneau, M.-E., et al. 2002. Carbon distributions and fluxes in the North Water, 1998 and 1999. Deep-Sea Research II 49:5151–5170.

Mizutani, H., Fukuda, M., Kabaya, Y., and Wada, E. 1990. Carbon isotope ratio of feathers reveals feeding behavior of cormorants. Auk 107:400–403.

Mizutani, H., Kabaya, Y., and Wada, E. 1991. Nitrogen and carbon isotope compositions relate linearly in cormorant tissues and its diet. Isotopenpraxis 4:166–168.

Moisey, J., Fisk, A.T., Hobson, K.A., and Norstrom, R.J. 2001. Hexachlorocyclohexane (HCH) isomers and chiral signatures of α-HCH in the Arctic marine food web of the Northwater polynya. Environmental Science and Technology 35: 1920–1927.

Mundy, C.J., and Barber, D.G. 2001. On the relationship between the spatial patterns of sea ice type and the mechanisms which create and maintain the North Water (NOW) polynya. Atmosphere-Ocean 39:327–341.

Orr, C.D., and Parsons, J.L. 1982. Ivory gulls, *Pagophila eburnea*, and ice edges in Davis Strait and the Labrador Sea. Canadian Field-Naturalist 96:323–328.

Petersen, K.E., and Yates, T.L. 1980. *Condylura cristata*. Mammalian Species 129:1–4.

Renaud, W.E., and McLaren, P.L. 1982. Ivory gull (*Pagophila eburnea*) distribution in late summer and autumn in eastern Lancaster Sound and western Baffin Bay. Arctic 35:141–148.

Ringuette, M., Fortier, L., Fortier, M., Runge, J.A., Bélanger, S., Larouche, P., Węsławski, J.M., and Kwasniewski, S. 2002. Advanced recruitment and accelerated population development in Arctic calanoid copepods of the North Water. Deep-Sea Research II 49:5081–5099.

Robertson, G.J., Gilchrist, H.G., and Mallory, M.L. 2007. Colony dynamics and persistence of ivory gull breeding in Canada. Avian Conservation and Ecology 2:8. http://www.ace-eco.org/vol2/iss2/art8/.

Stenhouse, I.J., Robertson, G.J., and Gilchrist, H.G. 2004. Recoveries and survival rate of ivory gulls banded in Nunavut, Canada, 1971–1999. Waterbirds 27:486–492.

Stirling, I. 1980. The biological importance of polynyas in the Canadian Arctic. Arctic 33:303–315.

Stishov, M.S., Pridatko, V.I., and Baranyuk, V.V. 1991. Birds of Wrangel Island. Novosibirsk: Nauka, Siberian Division.

Tasker, M.L., Jones, P.H., Dixon, T., and Blake, B.F. 1984. Counting seabirds at sea from ships: A review of the methods employed and a suggestion for a standardized approach. Auk 101:567–577.