

Breeding biology of Sabine's gull (*Xema sabini*) in the Canadian high Arctic

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Received: 12 April 2011 / Revised: 26 July 2011 / Accepted: 9 August 2011 / Published online: 23 August 2011
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Abstract The Sabine's gull (*Xema sabini*) is a small seabird that breeds in select locations across the circumpolar Arctic, but there have been few studies on its breeding biology, particularly from the high Arctic. We studied nesting phenology, breeding effort, and breeding success of Sabine's gulls over 5 years at a colony on a small island (Nasaruvaalik) in the Canadian high Arctic. Compared to studies in the low Arctic, nest initiation dates and adult body mass were more consistent across years, and reproductive success was typically higher at Nasaruvaalik Island. These differences may be related to the more predictable food sources available in the nearby polynya upon arrival from migration, as well as the lower predation pressure at our site.

Keywords Arctic · Breeding · Predation · Sabine's gull · *Xema sabini*

Introduction

The Arctic environment is undergoing rapid changes in response to a variety of anthropogenic stressors (e.g.,

climate change, contaminants, industrial development, and increased shipping), and this has prompted concerns for the health and status of certain wildlife populations inhabiting these regions (e.g., ACIA 2004; Arctic Council 2009). Marine birds have been key components of research on Arctic environmental change, as biomonitors of the levels of human-induced alterations to the Arctic (contaminants; Braune 2007), as sentinels of the pathways of deleterious effects of different stressors (Gaston et al. 2003, 2005), and in some cases, as examples of declines in wildlife populations (Gilchrist and Mallory 2005; Gilliland et al. 2009). However, there remain some Arctic marine bird species for which little of their reproductive ecology or population status is known. For example, Blomqvist and Elander (1981) reviewed the status of three ground-nesting Arctic gulls, ivory gull (*Pagophila eburnea*), Ross's gull (*Rhodostethia rosea*), and Sabine's gull (*Xema sabini*) and showed that many gaps existed in our knowledge of their ecology, populations, and movements.

In the three decades since that review, several new, small Ross's gull and ivory gull colonies have been found through survey work (e.g., Mallory et al. 2006; Robertson et al. 2007; Egevang and Boertmann 2008; Gilg et al. 2009). These surveys were prompted primarily because the Canadian Ross's gull population is listed as threatened (Franken and Mallory 2007) and the Canadian ivory gull population has become endangered (Stenhouse et al. 2006; Robertson et al. 2007), for reasons still largely unknown. Recent research has been undertaken on habitat use and threats to these species (Braune et al. 2007; Gilg et al. 2010), but no new studies have been initiated on their breeding biology. In contrast, several studies have contributed new information about Sabine's gull populations (Cornish and Dickson 1996; Johnston and Pepper 2009) and reproductive ecology (Abraham and Ankney 1984;

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Abraham 1986; Forchhammer and Maagaard 1991; Stenhouse et al. 2001, 2004, 2005a, b; Stenhouse and Robertson 2005), including an updated review of the species (Day et al. 2001).

Unlike the other two small, Arctic-breeding gulls, the Sabine's gull is a trans-equatorial migrant, traveling more than 13,000 km from its wintering grounds off of South America to the Arctic (Day et al. 2001). In Canada, our information on Sabine's gull biology comes from studies on the low Arctic mainland at 64°N near the southern limit of its breeding range (Abraham 1986; Stenhouse 2003), even though the breeding range of the species extends to approximately 77°N, some 1,500 km farther north (Day et al. 2001). In fact, the only information on Sabine's gulls breeding in the high Arctic comes from observations by Forchhammer and Maagaard (1991) on East Greenland, a study that did not encompass an entire breeding season. In other marine bird species, constraints imposed by high Arctic and low Arctic marine environments contribute to differences in the reproductive ecology of birds at colonies (Gaston et al. 2005; Mallory et al. 2008).

Here, we present the first study to document the reproductive ecology of Sabine's gulls in the high Arctic, from arrival at the colony until young departed. Our study location was at a small colony, located close to a declining colony of ivory gulls (Robertson et al. 2007), and to two small, intermittently occupied colonies of Ross's gulls (Mallory et al. 2006). Hence, certain aspects of our work may be useful in assessing factors influencing not only breeding requirements and success in Sabine's gulls, but may also be applicable to the other rare gulls. We compare breeding phenology, effort, and success as well as adult body mass of high Arctic-breeding Sabine's gulls to those from earlier studies in the Canadian low Arctic to assess whether reproductive ecology of Sabine's gulls differs between colonies in the high and low Arctic.

Methods

We studied the breeding biology of Sabine's gulls at a small colony on Nasaruaalik Island in Penny Strait, Nunavut (Fig. 1; 75° 49'N, 96° 18'W), between 15 June–9 August 2007, 16 June–17 August 2008, 16 June–29 July 2009, 15 June–7 August 2010, and 3 June–30 July 2011. The island is approximately 3 km × 1 km in size (Mallory and Gilchrist 2003) and is made of alluvial gravel that has risen from the surrounding sea due to isostatic rebound from historic glaciation. Our base camp was located approximately 1 km north of the colony, on a central plateau of the island approximately 30 m above sea level, and out of view of nesting gulls. The main gull colony is on the southwestern tip of the island, although in 2011, six pairs of

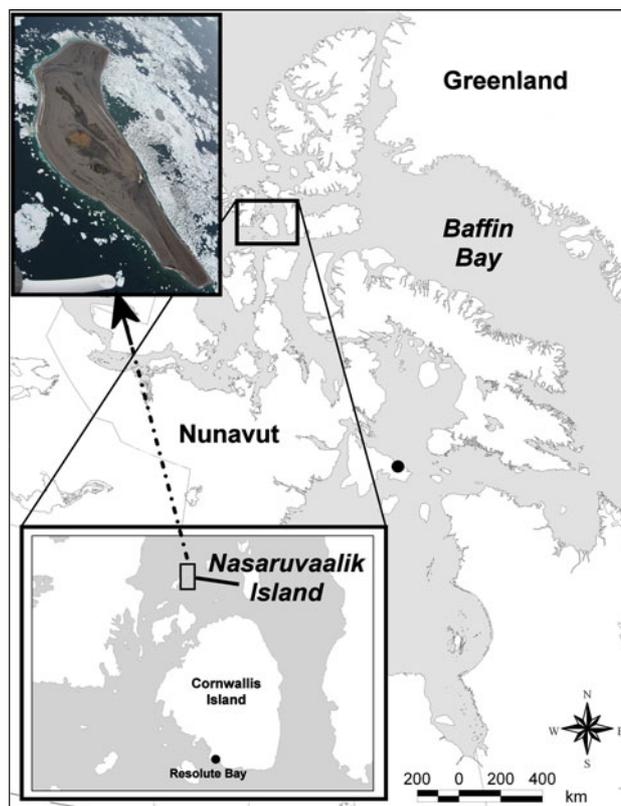


Fig. 1 The study location, Nasaruaalik Island, Nunavut, was located in the Canadian high Arctic (75° 49' N, 96° 18' W) in Penny Strait. The black dot represents the low Arctic location of earlier studies on Sabine's gulls by Abraham (1986) and Stenhouse (2003)

gulls nested at the northeastern end of the island. We walked from the camp to the colony several times daily (except in periods of rain or heavy fog), arriving at blinds (below) that were >150 m from the main nesting concentration of birds. Generally, our arrival did not cause an obvious change in behavior of the birds during nesting.

Old beach ridges are prominent features and provide the main relief on the island. However, the area occupied by breeding Sabine's gulls is only 0.125 km², and typically at elevations <5 m above sea level. The main Sabine's gull colony lies completely within the area where approximately 300 pairs of arctic terns (*Sterna paradisaea*) breed (Mallory et al. 2010), and there are also common eiders (*Somateria mollissima borealis*) and long-tailed ducks (*Clangula hyemalis*) nesting among the gulls and terns. The small Sabine's gull colony on the northeastern part of the island is also situated within a separate tern colony. Two viewing blinds (1.3 m × 1.3 m × 1.3 m and 2.6 m × 1.3 m × 1.3 m) were erected on the highest beach ridge, from which we could view most of the colony with binoculars or spotting scopes. Each day, two or three observers counted all Sabine's gulls within view on the island in the morning and evening (weather-permitting), and we used the maximum number

observed as our number of gulls on the colony that day. Upon our arrival at the field camp, we began watching for gulls settled on the ground, indicating nesting locations, which we checked immediately. If a nest was discovered, we recorded geographic coordinates with a GPS and visited the nest daily to establish egg-laying dates and sequence. When eggs were found, they were marked “A,” “B,” or “C,” weighed (± 0.2 g) using a 50-g Pesola spring scale, and length and breadth were measured (± 0.1 mm) using digital calipers. Starting 19 days after the first egg was laid, we made daily visits to each nest to determine date of hatching of each egg where possible. Once chicks were dry after hatching, we attached a metal band to their leg and weighed them with a 50-g Pesola spring scale. We continued to catch chicks as often as possible after they moved from their nest site to determine survival and to describe chick growth rates by taking their body mass (g) and length of their wing chord (mm; wrist to distal end of bent wing, or longest feather).

During incubation, we trapped adult gulls on their nest, weighed them with a 300-g Pesola spring scale, measured the maximum length of their natural wing chord (mm; wrist to longest primary feather), and attached a metal, uniquely numbered band as well as a unique combination of three colored Darvic bands to their tarsi.

Each day, we walked to the colony and elsewhere on the small island to work on marine birds (e.g., Mallory et al. 2010), and at the end of each day, staff pooled information on how many potential predators were observed (polar bear, *Ursus maritimus*; arctic fox, *Vulpes lagopus*; common raven, *Corvus corax*; glaucous gull, *Larus hyperboreus*; long-tailed jaeger, *Stercorarius longicaudus*; parasitic jaeger, *S. parasitica*; pomarine jaeger, *S. pomarinus*; peregrine falcon, *Falco peregrinus*; gyrfalcon, *F. rusticolus*). We used total avian predators observed daily as our index of predation levels on the colony, and we comment on specific instances of mammalian predation on the gulls below.

We recorded weather information using a Davis Vantage Pro2[®] weather station, set to record hourly measurements. Here, we present maximum daily temperatures and total precipitation as indices of breeding season weather patterns for 2007–2010.

Data were tested for approximation of normal distributions using Kolmogorov–Smirnov tests, and subsequent comparisons of annual means were conducted using analysis of variance (ANOVA) and Tukey–Kramer post hoc tests (when data approximated normality) or Kruskal–Wallis nonparametric ANOVA with Dunn’s multiple comparison tests (when data did not approximate normality, even after transformation). Proportions of hatching success and chick survival were compared using Fisher exact tests. Analyses were conducted using GraphPad Instat (GraphPad Software Inc. 2009). Means are presented \pm SD.

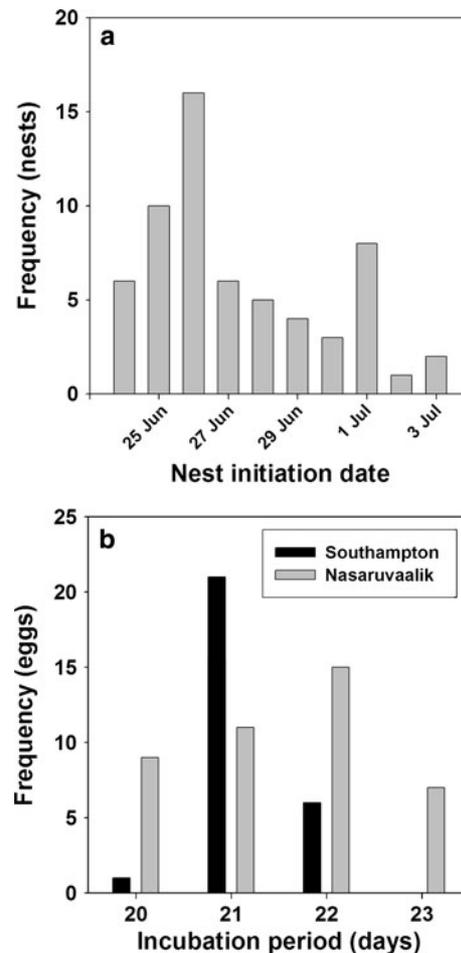


Fig. 2 The date of Sabine’s gull nest initiation **a** ranged from 24 June–3 July between 2007 and 2010 at Nasaruvaalik Island, and incubation period **b** ranged from 20–23 days at Nasaruvaalik Island (gray bars), whereas it was 20–22 days on Southampton Island (black bars, from Abraham 1986 and Stenhouse et al. 2001)

Results

Timing of breeding and colony size

Sabine’s gulls were first observed near the breeding colony in mid-June (12–20 June 2007–2011), and egg-laying was initiated 24 June–3 July (Fig. 2a). Gulls incubated eggs for 20–23 days (Fig. 2b), with the majority of chicks hatching 15–28 July. The small colony area meant that the breeding density in some years reached 150 pairs/km². Gulls nested in vegetated areas, notably in mossy depressions between beach ridges, usually within 50 m of the shoreline, resulting in a clumped distribution. Among years, the mean distance to the nearest conspecific nest was 43 ± 34 m ($n = 69$, range 5–177 m), and annual means did not differ significantly (Table 1; KW = 5.5, $P = 0.24$). In most years, 3- to 5-day-old chicks moved from their nest site to a 200-m strip

Table 1 Reproductive parameters of Sabine's gull from this study and previous studies on Southampton Island, Nunavut, Canada (1980: Abraham 1986; 1998–2001: Stenhouse et al. 2001; Stenhouse 2003)

Breeding parameter	Location and year									
	Southampton Island, Canada (low Arctic)					Nasaruaalik Island, Canada (high Arctic)				
	1980	1998	1999	2000	2001	2007	2008	2009	2010	2011
Mean internest distance (m; SD, <i>n</i>)	92 (120, 21)	87 (–, 23)	102 (–, 24)	101 (–, 25)	82 (–, 28)	38 (17, 9)	54 (38, 11)	28 (15, 11)	48 (30, 11)	45 (45, 26)
Median clutch initiation (<i>n</i>)	26 Jun (19)	15 Jun (18)	25 Jun (13)	27 June (20)	19 June (18)		27 Jun (16)	2 Jul (17)	28 Jun (13)	27 Jun (22)
Clutches	19	23	25	25	28	15	17	19	14 ^b	26
Eggs laid	53	59	57	59	75	42	47	50	28	61
Mean clutch size (eggs)	2.8 (0.1, 19)	2.6 (0.6, 27)	2.4 (0.6, 37)	2.4 (0.6, 25)	2.7 (0.6, 28)	2.8 (0.4, 15)	2.8 (0.6, 17)	2.6 (0.6, 19)	2.0 (0.7, 14)	2.3 (0.7, 26)
Mean egg length (SD, <i>n</i>)	45.1 (1.6, 55)	45.1 (1.7, 76)	45.5 (1.9, 54)	44.9 (2.3, 57)	44.0 (1.7, 42)	44.4 (1.9, 47)	44.4 (1.9, 47)	44.4 (1.6, 52)	44.2 (1.9, 28)	44.5 (1.7, 59)
Mean egg breadth (SD, <i>n</i>)	32.5 (0.8, 55)	32.6 (0.8, 76)	32.6 (0.8, 55)	32.4 (1.2, 57)	31.6 (1.0, 42)	31.6 (0.9, 47)	31.6 (0.9, 47)	31.8 (1.0, 52)	31.5 (1.0, 28)	31.5 (0.9, 59)
Mean egg mass (SD, <i>n</i>)	22.3 (0.4, 25)	23.8 (1.2, 55)	24.0 (1.5, 76)	24.0 (1.4, 54)	23.7 (2.1, 57)		22.8 (1.7, 46)	23.3 (1.8, 49)	23.5 (2.4, 18)	22.4 (1.4, 58)
Eggs depredated	3	16	43	16	21	0	0	3	0	1
Eggs abandoned	2	3	2	6	3	0	1	0 ^a	3	0
Eggs added	4	3	0	0	0	0	1	0 ^a	4	0
Eggs hatched	44	38	12	37	39	42	45	35 ^a	21	54 ^c
Eggs hatched/clutch	2.31	1.65	0.48	1.48	1.49	2.8	2.6	2.5 ^a	1.5	2.2 ^c
Median date of hatching (<i>n</i>)	17 Jul (18)	7 July (40)	17 July (13)	19 July (35)	11 July (39)	17 Jul (10)	17 Jul (11)	21 Jul (9)	19 Jul (10)	20 Jul (21)
Hatching success (% of eggs)	83	63	21	63	52	100	96	85 ^a	75	98 ^c
Adult body mass (g; SD, <i>n</i>)		198 (10, 26)	180 (10, 19)		186 (11, 6)	187 (12, 5)	187 (12, 20)	193 (11, 23)	186 (14, 22)	186 (16, 14)
Chick mortality to 7-days old	19% (3/37)								38% (8/21)	

“Clutches” refers to number of clutches followed regularly through that breeding season

^a Based on 41 eggs; fate of 9 eggs (4 clutches) unknown at time of researcher departure

^b 16, possibly 17 nests were initiated this year, but two or three nests went undetected until after eggs hatched

^c 6 eggs were damaged by tracking equipment and not included in calculations

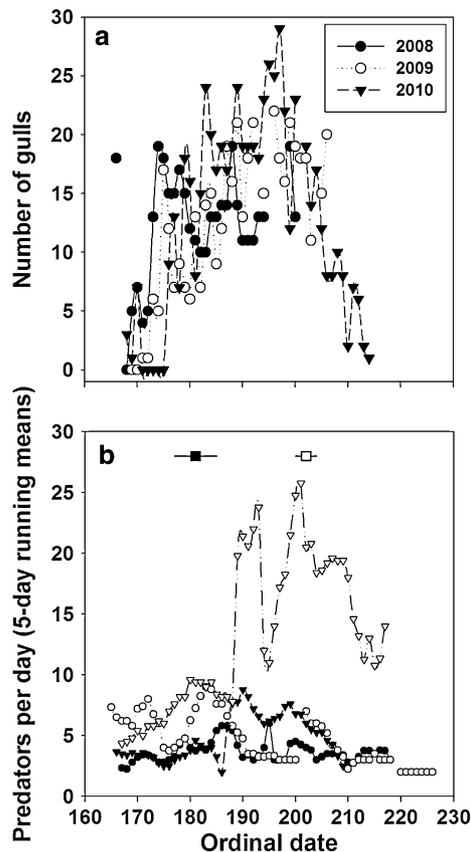


Fig. 3 The number of birds observed around the colony changed with date during the breeding season: **a** the maximum number of Sabine's gulls counted on the colony (ordinal date 170 = 19 June) and **b** the number of avian predators observed on the island per day (shown as 5-day running means; 2007—filled circles, 2008—unfilled circles, 2009—filled triangles, 2010—unfilled triangles). The mean (range) of nest initiation dates of Sabine's gulls is shown with a solid square and mean date of hatching as an unfilled square

of gravel beach on the southeast part of the island, and they fledged by 14 August.

Between 2008 and 2010, the mean number of Sabine's gulls counted each day on the colony during the main incubation period (25 June–19 July) differed (Fig. 3a; KW = 12.4, $P = 0.0021$), with more gulls observed daily in 2010 (18 ± 6 , $n = 25$) than in 2009 (14 ± 5 , $n = 23$) or 2008 (13 ± 2 , $n = 21$; Dunn's multiple comparison tests, $P < 0.05$).

Weather

During the nesting period (25 June–19 July), maximum daily temperatures were generally above 0°C at Nasaruaalik Island (Fig. 4a). Typically, nesting Sabine's gulls experienced a period of warmer temperatures in the middle of incubation, and then conditions cooled near the date of hatching (Fig. 4a), with the exception of 2009, which was a

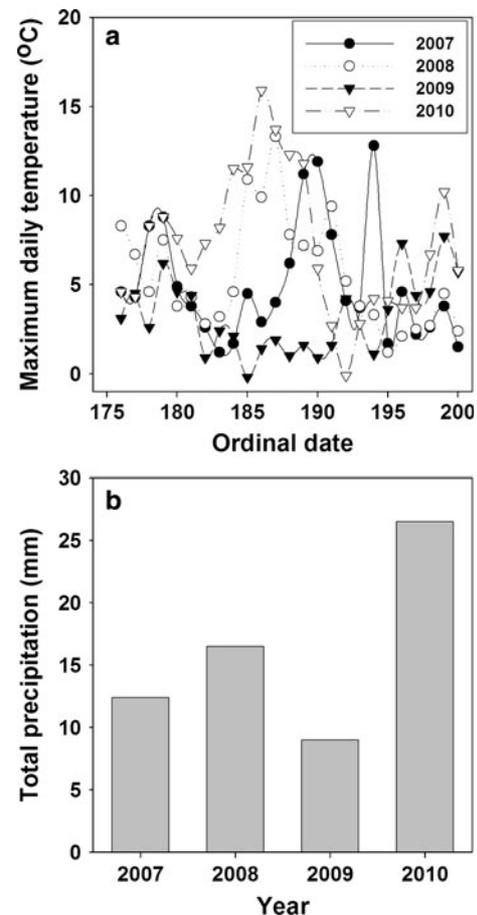


Fig. 4 Weather at Nasaruaalik Island differed among years, as shown here for **a** maximum daily temperature ($^{\circ}\text{C}$) and **b** total rainfall (mm) during the nesting period

uniformly cold year. In fact, mean maximum daily temperatures differed among the years of our study (2007: $5.0 \pm 3.3^{\circ}\text{C}$, $n = 25$; 2008: $5.6 \pm 3.1^{\circ}\text{C}$, $n = 25$; 2009: $3.2 \pm 2.1^{\circ}\text{C}$, $n = 25$; 2010: $7.3 \pm 3.9^{\circ}\text{C}$, $n = 25$; KW = 17.2, $P = 0.0006$), with 2009 being significantly cooler than 2010 ($P < 0.001$). In addition to being warmer, 2010 was also a relatively wet breeding season, with twice as much total precipitation falling on the colony in 2010 compared to 2007 or 2009 (Fig. 4b).

Egg, clutch, and adult size

Of 224 eggs laid by Sabine's gulls at Nasaruaalik Island, the mean length was 44.4 ± 1.8 mm and mean breadth was 31.6 ± 0.9 mm. For a subset of these ($n = 167$), mean fresh mass was 22.9 ± 1.7 g. Based on summary data, gulls nesting on Southampton Island in 1998–2001 (Stenhouse 2003) laid heavier eggs than at Nasaruaalik Island (Table 1: $t_{401} = 6.2$, $P < 0.0001$). The lighter eggs of high Arctic gulls were attributable to their smaller breadth (Table 1: $t_{461} = 10.8$, $P < 0.0001$) and shorter length (Table 1: $t_{463} = 4.7$,

$P < 0.0001$) compared to birds nesting at Southampton Island.

The mean clutch size for Sabine's gulls at Nasaruaalik Island was 2.5 ± 0.6 eggs ($n = 90$), with 60% of nests having three eggs. There was significant variation in clutch size among years (Table 1; KW = 17.3, $P = 0.0017$), with gulls laying smaller clutches in 2010 than in 2007 or 2008 (Dunn's multiple comparison tests, all $P < 0.05$). Collectively, mean clutch sizes during our study were similar to those from 101 clutches observed at Southampton Island (Table 1; 2.5 ± 0.6 ; Stenhouse 2003).

The mean adult body mass of Sabine's gulls captured during incubation was 188 ± 13 g (range 159–220 g; $n = 85$), and this did not differ significantly among years (Table 1; $F_{4,79} = 1.5$, $P = 0.2$). However, pooling all years at Nasaruaalik Island, birds breeding at this site differed in mass compared to gulls at Southampton Island (Stenhouse 2003: ANOVA based on summary data; $F_{3,132} = 8.7$, $P < 0.0001$), with Southampton gulls heavier in 1998 and lighter in 1999 than Nasaruaalik birds (Tukey–Kramer tests, $P < 0.05$). For 35 adult gulls captured in 2008 or 2011, their natural wing length was 275 ± 9 mm.

Breeding success

During the 5 years of study, hatching success was high at Nasaruaalik Island (Table 1: 197/213; 92%), although it declined in 2009 and 2010. Egg losses to predation, abandonment, or addling were higher in these 2 years, and overall reproductive effort (clutch size) was lower. We suspect that the poor reproductive year in 2009 was attributable to cold conditions prior to and during breeding (Fig. 4), as well as the presence of mammalian predators on the island (below). Similarly, in 2010, breeding Sabine's gulls experienced more than a twofold increase in the number of avian predators hunting on the island daily (Fig. 3). Nonetheless, hatching success of high Arctic Sabine's gulls was significantly greater than that of low Arctic gulls (Table 1: 126/251; 50%; Fisher Exact test, $P < 0.0001$). In the low Arctic, most eggs lost were due to predation (Table 1: 96/113; 85%), a markedly higher proportion than egg depredation at Nasaruaalik Island (4/13; 31%; $P < 0.0001$).

Annual median date of hatching varied by 12 days at a site in the low Arctic, but only by 5 days at our site in the high Arctic (Table 1). Hatching interval at Nasaruaalik Island between first and second chicks (1.4 ± 0.5 days, $n = 19$) did not differ significantly from that of second and third chicks (1.4 ± 0.4 days, $n = 13$; Mann–Whitney, $P = 0.86$). For 2 years where data were available, the survival of chicks to 7 days old was higher on Southampton Island (81%) than on Nasaruaalik Island (66%; Fisher exact test, $P = 0.027$). However, we suspect that chick survival was abnormally low in 2010. We found eight dead

chicks in 2010, but only two in 2009, and none in 2007 or 2008.

Predation

Numbers of potential avian predators on Sabine's gull eggs, chicks, or adults at the island varied among years and within the breeding season (Fig. 3b). Because the number of predators around the colony prior to egg-laying could influence reproductive effort, we compared mean numbers of avian predators observed daily from 17 June through 29 July across years. The mean number of predators observed daily in 2007 (3.8 ± 1.8 , $n = 34$), 2008 (5.7 ± 2.5 , 31), and 2009 (4.9 ± 2.6 , 37) did not differ significantly from one another, but all 3 years had lower numbers of avian predators observed than in 2010 (13.3 ± 11.7 , 40; KW = 53.8, $P < 0.001$, Dunn's multiple comparisons test, all $P < 0.001$). In 2010, a large flock of pomarine jaegers (≥ 15 individuals) remained on the island for most of the breeding season. Also in 2010, a peregrine falcon was observed regularly, and it killed at least one, 12-day-old Sabine's gull chick in addition to several adult terns.

Mammalian predators (bears, foxes) were intermittent threats to the colony. Polar bears were observed on the island 5 days in 2008, 9 days in 2009, and 10 days in 2007 and 2010. However, we never observed predation by bears on Sabine's gulls or their nests, although disturbance of nests by bears during rainy periods may have reduced tern nest success (K. Boadway, unpubl. data). In 2009, an arctic fox was resident on the island until part way through the gull incubation period (Table 1).

Chick growth

We were only able to follow 12 gull chicks to monitor growth, and each chick was caught and weighed two to five times. Because there were few data, and each bird contributed data unequally to the curve, we use the graphs in Fig. 5 to depict the general pattern of mass gain and wing cord development. At Nasaruaalik Island, Sabine's gull chicks grow rapidly, gaining approximately 12 g/day between day 2 and 10, and reaching adult body mass (~ 190 g) as early as 16 days old (Fig. 5a). At this age, their wing length is approximately 55% of the adult wing length, and growing at a rate of 10 mm/day (Fig. 5b).

Discussion

Sabine's gulls at Nasaruaalik Island nest semicolonially and in strong association with arctic terns—no nests have been found outside the limit of the tern colony in 5 years of study, similar to other small, island-nesting colonies in the

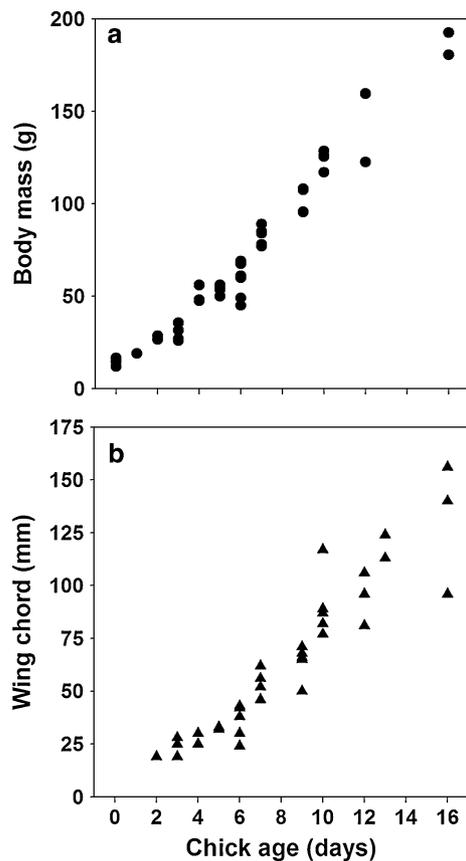


Fig. 5 Growth rates of Sabine's gull chicks at Nasaruaalik Island in 2010, as indexed by increases in **a** body mass or **b** length of the wing chord for 12 chicks

area (Mallory and Gilchrist 2003). This is consistent with many earlier studies and for some locations such as Greenland (reviewed in Day et al. 2001), with some authors suggesting that gulls accrue benefits nesting close to terns because of group colony defense (e.g., Larson 1960). However, Sabine's gulls exhibit intense nest defense and a variety of nest defense strategies (Day et al. 2001), initiate nests earlier than sympatrically breeding terns (K. Boadway, unpubl. data), and may nest in the vicinity of, but not in close association with, terns. This is seen in the more dispersed nesting found at East Bay, Southampton Island (Abraham 1986; Stenhouse et al. 2001), on Prince Charles Island (Johnston and Pepper 2009), and on western Victoria Island (Cornish and Dickson 1996). Although our data do not resolve why Sabine's gulls may nest colonially with terns, we note that in 2007 and 2008, we visited the Nasaruaalik Island beach area regularly during the chick-rearing period of the gulls to observe chicks (i.e., we disturbed the birds, but we did not recapture them), and the chicks remained in that area until they fledged. In 2010, however, we visited the beach every 3 days and caught some of the chicks, but in the first week of August, a complete breeding failure occurred in the tern colony, and all adult terns left

the colony by 7 August. This exact same date, Sabine's gulls moved their chicks to offshore ice to complete rearing, a behavior we had not observed previously. Given that the birds moved more than a week after we had started handling them, and they did not move when disturbed in the earlier years, we interpret their behavior as being consistent with the gulls moving to a safer rearing area (e.g., ice as opposed to a terrestrial island) in the absence of defense against predators by the surrounding terns. Collectively, the Canadian data suggest that Sabine's gulls nesting on small islands seem to collocate with arctic terns, but on larger islands (effectively mainland), Sabine's gull colonies may only be in loose associations with, or perhaps distinct from, tern colonies.

At our field site, Sabine's gulls nested at high density, but the mean distance to the nearest Sabine's gull nest (43 m) was similar to the "hotspots" noted by Abraham (1986; 57 m) on Southampton Island and noted by Brown et al. (1967) in Alaska. Stenhouse et al. (2001) found similar, high nesting densities on island sites within the overall colony, as did Forchhammer and Maagaard (1991) at their site in northeast Greenland. Thus, it appears that Sabine's gulls can nest in close proximity to each other and appear to do so regularly on islands, where they presumably perceive such habitats as having a lower risk of predation (below).

Blomqvist and Elander (1981:128) suggested that "the predominant clutch size among Sabine's gulls is two eggs, but clutches of three eggs or one do sometimes occur." Recent studies across the species' North American range suggest that typical clutch size is larger than two eggs (Table 1; Day et al. 2001), although there is clearly annual variation, and smaller clutches predominate in northeast Greenland (Forchhammer and Maagaard 1991). There is also an apparent pattern in egg sizes across the breeding range of Sabine's gull. In northeast Greenland, Forchhammer and Maagaard (1991) found that 15 Sabine's gull eggs had a mean length of 42.1 ± 0.6 mm and breadth of 30.8 ± 0.3 mm, both of which were smaller than the same measures at Nasaruaalik Island (*t* tests on summary data, $t_{35} > 8.2$, $P < 0.001$). In Alaska, egg size in Sabine's gulls nesting on the Yukon-Kuskokwim Delta was similar to that of another low Arctic site, Southampton Island (Day et al. 2001), and as shown in Table 1, gulls on Southampton Island typically lay larger eggs than at Nasaruaalik Island. Thus, there is a pattern of decreasing egg size with increasing latitude in Sabine's gulls from Alaska, Canada, and Greenland (Forchhammer and Maagaard 1991; Day et al. 2001; Stenhouse et al. 2001; Stenhouse 2003; this study).

Abraham (1986) suggested that the interval between hatching of second and third chicks was shorter than that between first and second chicks, a possible adaptation to minimize the risk of the third chick being abandoned in the nest. However, her study was based on a small sample size,

and we found no evidence to support this as the hatching interval between first and second compared to second and third chicks was 1.4 days.

In Alaska (61° 35'N, 166° 05'W), Brown et al. (1967) noted that Sabine's gulls were on the breeding grounds by 8 May, started laying eggs on 22 May, had their eggs hatch starting mid-June, and had fledged by the end of July, giving a breeding season (egg development to fledged chicks) of approximately 10 weeks (Day et al. 2001). Forchhammer and Maagaard (1991) also found the breeding season duration to be approximately 10–11 weeks in northeast Greenland (76° 41'N, 18° 31'W). In contrast, on Southampton Island, Canada (63° 58'N, 81° 50'W), Abraham (1986) found that the breeding season was just under 8 weeks, similar to what Parmelee et al. (1967) found for gulls nesting near Cambridge Bay, Victoria Island, Canada (69° 07'N, 105° 03'W). Our data (75° 49'N, 96° 18'W) were consistent with these latter two Canadian sites, where birds were first spotted near the colony around 13 June, approximately 10 days before the first eggs were laid. Fledged birds have been observed by 12–14 August, giving a breeding season of 7–8 weeks. Abraham (1986) argued that the compressed breeding schedule at Southampton Island was an accommodation to meet the shorter breeding season compared to Alaska (Brown et al. 1967), whereby Southampton gulls contracted their egg-laying period and departed the colony soon after fledging. Despite its more northern location, Forchhammer and Maagaard (1991) thought that the abundant open water near their location late into the season in northeast Greenland might explain why gulls there have a longer breeding season than gulls on Southampton Island. Stenhouse (2003) also found marked inter-year differences in nest initiation dates on Southampton Island.

The situation at Nasaruvaalik Island is somewhat different than these other locations. We arrived at the island by 15 June each year, at which time the colony habitat is typically <25% snow-covered (sometimes bare), and yet most of the gulls did not start entering the colony until approximately 20 June and soon after laid eggs. The island is surrounded by small polynyas, pockets of open water surrounded by sea ice, which provide critical foraging areas for the marine birds nesting on the island (Stirling 1997). Beyond these polynyas, relatively solid ice cover extends for >100 km in all directions. Sutton (1932), Abraham (1986), and Stenhouse et al. (2001) suggested that local environmental conditions, and particularly the timing of snowmelt, influenced nest initiation by Sabine's gulls. Stenhouse (2003) further postulated that nutrient reserves of arriving birds might influence their timing of nest initiation, supported by their observations of marked differences in adult body mass over the years at his site. In contrast to the conditions on Southampton Island (mainland-nesting,

higher predation risk), we found that nest initiation dates and adult body masses were more consistent across years at Nasaruvaalik Island, which may be attributable to the predictable, nearby food supplies provided by the polynyas. These conditions may allow the birds to arrive and start nesting quickly to complete a short breeding schedule before harsh weather conditions develop (e.g., the return of snow in September).

On Southampton Island, broods moved quickly after the hatching of the final egg to coastal ponds where they were reared (Abraham 1986; Stenhouse et al. 2001). However, on our small island, we observed that all broods moved to the nearby gravel coastline (<150 m from the farthest nest), similar to observations made in northeast Greenland (Forchhammer and Maagaard 1991). Although there are several freshwater ponds near our colony, they are not always full of water and may not provide sufficient prey to rear chicks. We suspect that chicks at our site were probably reared principally on a diet of marine prey, again similar to the results from island-nesting gulls in east Greenland (Forchhammer and Maagaard 1991). Forchhammer and Maagaard (1991) also found that chicks attained a body mass of 100 g by about 7 days old, approximately 1 day earlier than gulls at Nasaruvaalik Island (this study) or at Southampton Island (Abraham 1986). We found a growth rate of approximately 12 g/day for Sabine's gull chicks at Nasaruvaalik Island, similar to the 10–12 g/day found elsewhere (Abraham 1986: Fig. 2; Forchhammer and Maagaard 1991: Fig. 4; Stenhouse 2003: Fig. 2.2). Local differences in annual food supplies could account for minor differences in growth rates, but collectively, the available data suggest similar growth patterns for Sabine's gull chicks across the low and high Arctic.

Predation is a key factor determining nest site location and nesting success in birds (Lack 1954; Clark and Shutler 1999), and this has been demonstrated in many Arctic studies (e.g., Larson 1960; McKinnon et al. 2010). Stenhouse et al. (2001) suggested that predation was an important factor influencing choice of nest site, nesting success, and post-hatching behavior of Sabine's gulls. They referred principally to mammalian predation, particularly arctic foxes, which can markedly reduce reproductive success of birds in some years (e.g., Larson 1960). That gull nesting success was typically higher at island colonies (where foxes usually cannot reach; Forchhammer and Maagaard 1991, this study) compared to mainland-nesting gulls (Abraham 1986; Stenhouse et al. 2001) is consistent with this interpretation. We did not observe polar bears depredating gull nests, but nest predation in 2009 was almost certainly attributable to an arctic fox that made it onto the island. However, islands offer little safety from avian predators. In most years, Sabine's gulls exhibited intense nest defense against potential predators (jaegers, larger gulls), along

with the sympatrically nesting terns, and thus maintained higher nesting success than reported in most other studies. In 2010, however, many more avian predators frequented Nasaruvaaik Island (Fig. 3b), and this corresponded to the year of the lowest hatching success and higher chick mortality. We observed unusual nesting behavior at the time of hatching in 2010, as well. For example, in some cases, adults abandoned one young, hatched chick to return to complete incubation of the final egg and then shortly after abandoned that recently hatched chick. Consequently, we found eight dead chicks in or near nests (presumably starved or dead from exposure), and one older chick was killed by a peregrine falcon. Thus, while nesting success in the semicolonial situation on the small island was generally high, in years with intense predation pressure, nesting success declined considerably. With very few predators present in 2011 and abundant alternate prey available (lemmings, eider eggs; ML Mallory, unpubl. data), nesting attempts and success increased in 2011 compared to the previous 2 years.

Collectively, our data from a high Arctic colony of Sabine's gulls nesting on a small island suggest some differences in reproductive ecology compared to that of gulls nesting on the mainland at southern latitudes. In particular, high Arctic gulls exhibit more annual consistency in their nest initiation dates and adult body mass, they lay smaller eggs, and typically they have higher reproductive success. We posit that most of these differences are related to two markedly different features of the environment around our colony in the high Arctic: (1) recurrent polynyas are present near the island when the birds arrive from migration, and these provide access to predictable food supplies; and (2) by nesting on a small island and among arctic terns, the gulls at our site typically experience less predation pressure than conspecifics nesting at mainland sites farther south. Interestingly, the only sites in this region where Ross's gulls or ivory gulls breed are also offshore islands (Mallory and Gilchrist 2003), and for Ross's gulls, only within arctic tern colonies. Further study on the reproductive ecology of Ross's and ivory gulls is now required to assess whether the ecological needs, and thus management considerations for these rare species, can be modeled on our knowledge of the related Sabine's gull.

Acknowledgments We thank J. Akearok, K. Allard, V. Amarualik, J. Boadway, T. Boadway, C. Duval, A. Fontaine, S. Han, C. Mallory, D. Mallory, O. Mallory, K. McKay, C. Mischler, T. Noah, J. Panipak, M. Pelletier, T. Sailor, and C. Vallerand for field assistance. Financial and logistic support was provided by Environment Canada (CWS), Natural Resources Canada (PCSP), Indian and Northern Affairs Canada (NSTP), University of New Brunswick, Memorial University of Newfoundland, and the Natural Sciences and Engineering Research Council. All work was carried out under appropriate permits, including ACC, CWS, GN, NWB, and INAC.

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