

Status of the endangered ivory gull, *Pagophila eburnea*, in Greenland

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Abstract The ivory gull, a rare high-Arctic species whose main habitat throughout the year is sea ice, is currently listed in Greenland as 'Vulnerable', and as 'Endangered' in Canada, where the population declined by 80% in 20 years. Despite this great concern, the status of the species in Greenland has been largely unknown as it breeds in remote areas and in colonies for which population data has rarely, if at all, been collected. Combining bibliographical research, land surveys, aerial surveys and satellite tracking, we were able to identify 35 breeding sites, including 20 new ones, in North and East Greenland. Most colonies are found in North Greenland and the largest are located on islands and lowlands. The current best estimate for the size of the Greenland population is approx. 1,800 breeding birds, but the real figure is probably >4,000 adult birds (i.e.

>2,000 pairs) since all colonies have not yet been discovered and since only 50% or less of the breeding birds are usually present in the colonies at the time the censuses take place. Although this estimate is four to eight times higher than that previously arrived at, the species seems to be declining in the south of its Greenland breeding range, while in North Greenland the trends are unclear and unpredictable, calling for increased monitoring efforts.

Keywords *Pagophila eburnea* · Greenland · Endangered species · Satellite tracking · Climate change · Sea-ice

Introduction

The ivory gull (*Pagophila eburnea*) is one of the most remote and poorly known breeding birds in the northern hemisphere. Over its entire breeding range (Canadian Arctic, Greenland, Svalbard and Russian Arctic islands), it breeds either on inland cliffs and 'nunataks', i.e. rocky outcrops emerging from icecaps, or on high-Arctic barren islands or flatlands. The size of its entire circumpolar population is believed to range between just 8,000 and 11,500 breeding pairs (Gilchrist et al. 2008).

Because the ivory gull spends most of its life cycle on sea ice, a habitat that is currently shrinking during the summer season (Gascard 2008; Holland et al. 2006; Perovich and Richter-Menge 2009), the species could soon face a dramatic decline, at least in some parts of its breeding range. In Canada, where the status of the species has recently been updated to 'Endangered', recent studies claim that 80% of the breeding population has already been lost during the past 20 years (Gilchrist and Mallory 2005). Although its status is still under evaluation in all other

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countries holding breeding populations, this alarming situation has drawn wide attention to the species (Krajick 2003) and an international circumpolar ‘Conservation Strategy and Action Plan’ has recently been presented by leading seabird experts of the Arctic countries (Gilchrist et al. 2008). Despite that Greenland, where the species is considered ‘Vulnerable’ (Boertmann 2008a), is believed to hold a significant part of the world population of the ivory gull, published data are sparse for the country. The data only refer to a limited number of colonies and, with a few exceptions, have not been updated since the colonies were first described.

The main aims of our study, based on a review of published sources, extensive recent survey from 2003 to 2008 as well as coupled satellite monitoring and aerial surveys, were, therefore:

- to complete and compile the mapping of Greenland breeding sites of ivory gull to improve future monitoring and conservation of these sites
- to estimate the size of the breeding population of ivory gull in Greenland to update its numerical contribution to the world population and to assess past or future changes.

Materials and methods

Data used in this paper have three main origins: published sources, coupled satellite tracking and aerial surveys, and direct surveys (land and aerial).

Published data are few and far between. They are easy to locate since most biological expeditions investigating the Greenland bird fauna often used to publish a summary of their field observations in the Danish Ornithological Journal: ‘*Dansk Ornithologisk Forenings Tidsskrift*’. Furthermore, several syntheses have already summarized past studies (Boertmann 1994; Falk et al. 1997; Gilg et al. 2003; Salomonsen 1950, 1961), and the ‘Greenland seabird database’ maintained by the National Environmental Research Institute (NERI) in Denmark also aims to maintain updated information on all seabird breeding sites known in Greenland (see, e.g. Boertmann 2008b).

Satellite tracking was initiated on ivory gulls in North Greenland in 2007 (Gilg et al. 2008a, 2008b) in two of the largest breeding colonies known in the country (i.e. Station Nord and Henrik Krøyer Holme; Table 1; Fig. 1). A total of 13 and 5 birds were fitted with satellite transmitters in 2007 and 2008, respectively. The primary aim of this study was to document movements, phenology and site fidelity of the species. However, since most birds tagged at Station Nord, where anthropogenic food supplies (i.e. organic wastes from the station’s kitchen and leftover dog food) are abun-

dant, appeared to be visitors from other colonies (Gilg et al. unpublished), satellite tracking also rapidly appeared to have great potential to locate new colonies or to confirm occupation of known colonies (all tracked birds were adults with incubation patches). To assess this assumption, we first listed all inland sites that had been visited more than ten times within a time period of more than 20 days by a single bird during the breeding season (between 1 July and 15 August 2007, and 15 June and 1 August 2008). Eight of the 11 resulting ‘suspected breeding sites’ could be checked by one of us (DB) during aerial surveys conducted between 30 July and 1 August 2008, i.e. during the chick rearing period (see below) in order to (1) validate the method, and (2) eventually estimate the size of the occupied colonies.

Direct surveys, on land or from the air, have been undertaken by the authors since 2003 in order to assess site fidelity and population size at most of the known breeding sites. All but a few of the breeding sites known for Greenland could be visited during the course of the two summers, 2007–2008, alone. Most of them had not been revisited since their discovery. Several new colonies were also found during our aerial surveys, both in south-east Greenland and in North Greenland.

In addition to these three main sources of information, we also located three new colonies (two ascertained and one suspected) by inquiring with individuals (i.e. geologists, geographers or mountaineers) that we knew had visited the poorly known nunatak areas of East Greenland (68–70°N).

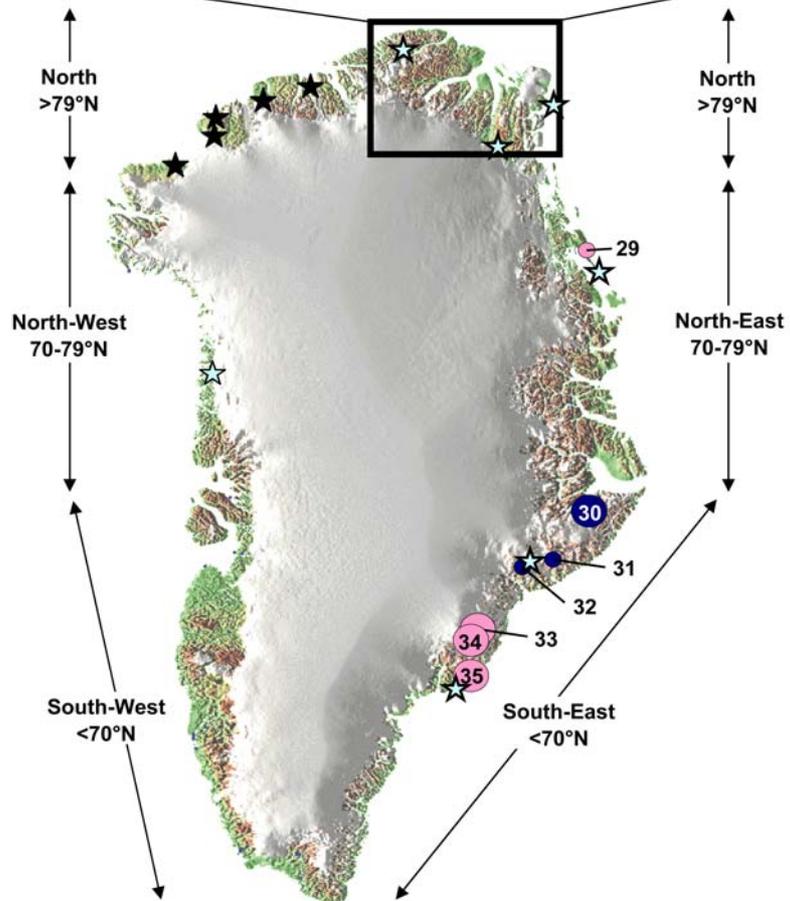
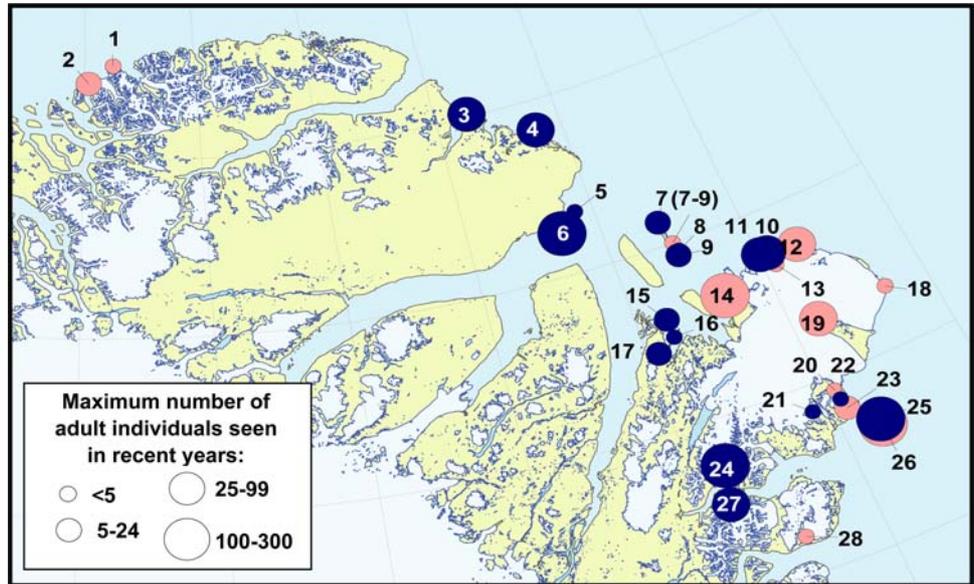
Colony sizes given in the results section relate to the ‘highest number of adult birds seen’ at the colonies from 1998–2008, or from 1978–2008 if no census data were available for the period 1998–2008.

Results

Breeding sites

Altogether, 35 breeding sites are currently (i.e. since 1978) known in south-east ($n = 6$), north-east ($n = 1$) and North Greenland ($n = 28$; Table 1; Fig. 1). With the exception of three sites discovered in 1908 (Renskaeret; Manniche 1910), 1910 (Nakkehoved; Mikkelsen 1913; Salomonsen 1967) and 1961 (Station Nord; Salomonsen 1961), all these sites have been discovered recently (≥ 1978) and from a limited number of expeditions (Bennike and Higgins 1989; Bennike and Kelly 1986; Falk et al. 1997; Gilg et al. 2003; Håkansson et al. 1981; Hjort et al. 1988; Hjort et al. 1983; Wright and Matthews 1980; present study). The majority of these sites ($n = 20$) are presented here for the first time (Fig. 1: blue circles).

Fig. 1 New (*dark dots*) and formerly known (*light dots*) breeding sites of the ivory gull in Greenland and North Greenland (the latest region is detailed in *upper panel*). Dot size proportional to colony size (see legend box; uncounted sites included in the smallest class). *Numbers* on the map refer to colony descriptions in Table 1. Historical and unconfirmed breeding sites (see Table 1) are marked with dark and light stars, respectively



Three additional breeding sites have also been reported in north-west Greenland in the past (1854–1922; Bessels 1879; Salomonsen 1950) and six other sites are worth mentioning as possible breeding sites (Table 1; Fig. 1).

All but one of the six breeding sites found in south-east Greenland (sites # 30–35; south of 70°Lat N) are on nunataks

at altitudes ranging from 1,500 to 2,500 m a.s.l. (site # 35 is at approx. 1,150 m a.s.l.). On the other hand, all colonies found in North Greenland (sites # 1–28) are on islands, coastal lowlands, small cliffs or on much lower nunataks (maximum altitude: 1,000 m a.s.l.; all but two sites below 500 m a.s.l.). Figure 2 presents the main types of breeding sites.

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Table 1 Ivory Gull breeding sites and numbers in Greenland

Site#	Colony name (from north to south)	Lat. N	Long. W	Type of site	Date	Numbers	Source
1	J. V. Jensen Land— Kap Washington	c. 83°32'	c. 38°42'	n.d.	4 August 1980	“Small colony”	Bennike and Higgins (1989)
2	J. V. Jensen Land— Kap Kane	83°26'	39°48'	Cliff	1980	c. 20 ind.	Bennike and Kelly (1986)
3	E Peary Land— G.B. Schley Fjord (mouth)	83°01'	23°38'	Island/lowlands	1 August 2008	55 adults + chicks.	Present study
4	E Peary Land— East of Kap Erik Bunch	82°50'	21°05'	Island/lowlands (2 sub-colonies)	1 August 2008	37 adults	Present study
5	S Peary Land—Mouth Independence Fjord 1	82°20'	20°42'	Ice floe	July–August 2007	Occupied colony ^d	Present study
6	S Peary Land—Mouth Independence Fjord 2	82°14'	21°27'	Ice floe	July–August 2007 June 2008 1 August 2008	Probable colony ^d Occupied colony ^d 125 adults, many pulli	Present study Present study Present study
7	N Prinsesse Margrethe Ø (3 sub-colonies described in 2008)	82°07,8' 82°07,8' 82°08,4' 82°07,2'	17°53,4' 17°53,4' 17°54,5' 17°52,2'	Plateau on large island	3 July 2007 31 July 2008 30 July 2008 31 July 2008	A few breeding birds seen from plane 3 pairs 6 adults, pulli seen 5 adults	Present study Present study Present study Present study
7–9	Prinsesse Margrethe Ø (overall)	c. 82°	c. 17°40'	Plateau on large island	1978 ? 27 July 2003 2007 and 2008	“Colony” ^a >25 pairs No birds seen Occupied colony ^d	Håkansson et al. (1981) Falk et al. (1997) Present study Present study
8	SE Prinsesse Margrethe Ø	81°57'	17°34'	Plateau on large island	2007 and 2008	Occupied colony ^d	Present study
9	SW Prinsesse Margrethe Ø	81°55,5'	17°39'	Plateau on large island	30 July 2008	8 pairs	Present study
10	W. of Kap Prins Knud 1	81°46'	14°40'	Small gravel island (2 sub-colonies)	June 2008 1 August 2008	Occupied colony ^d 55 adults	Present study Present study
11	W. of Kap Prins Knud 2	81°46'	14°55'	Small rocky island	June 2008 30 July 2008	Occupied colony ^d 85 adults	Present study Present study
12	Nakkehoved	81°44.5'	13°33'	Cliff	c. 8 June 1910 1978 ? 10 July 2007 30 July 2008	Several nests “colony” ^a >25 pairs 30 ind. No birds seen	Mikkelsen (1913) Håkansson et al. (1981) Falk et al. (1997) Present study Present study
13	Flade Isblink	81°41'?	14°33'?	Coastal terrace	1978 15 July 2007 30 July 2008	“colony” ^a No birds seen No birds seen	Hakansson et al. (1981) Present study Present study
14	Station Nord	81°37–38'	16°39–42'	Coastal terrace	June 1961 ? 4 August 1998 End July 2001 2002 26 July/11 Aug 2003 20 July 2006	12 pairs >5 pairs 1 pair + 1 young (ca. 5km S of the colony) 20 breeding ad. + juv. 140–160 ad. and >40 juv. c. 250 ad. and >60 nests No breeding (>lm snow 20-7-06)	Salomonsen (1961) Falk et al. (1997) Ko de Korte (pers. com. 2009) Hans Meltofte (pers. com. 2003) Station staff (pers. com. 2002) Present study Tony Fox (pers. com. 2006)

Table 1 continued

Site#	Colony name (from north to south)	Lat. N	Long. W	Type of site	Date	Numbers	Source
					End Aug 2006	A few young only	Station staff (pers. com. 2007)
					1–10 July 2007	c. 60 birds visiting the Station	Present study
					12 July 2007	A few nest only (too much snow)	Present study
					2008	No birds seen	Present study
15	Prins Frederik Øer ^d	81°36'	18°56'	Coastal terrace on peninsula	June 2008	Occupied colony ^d	Present study
					1 August 2008	14 adults	Present study
16	Kongefjord	81°30'	18°54'	Small island	July 2007	Occupied colony ^d	Present study
					1 August 2008	No birds seen	Present study
17	Knud den Store Iskappe	81°26'	19°37'	Cliff in Canyon	June 2008	Occupied colony ^d	Present study
					1 August 2008	10 adults	Present study
18	Nordostrundingen	c. 81°20'	c. 11°30'	Coastal flatlands	1980	1 old nest	Hjort et al. (1983)
					10 July 2007	No birds seen	Present study
					1 August 2008	No birds seen	Present study
19	Kilen	c. 81°19'	c. 14°04'	Cliff	4 August 1980	75 ind. (incl. 15–20 juv.)	Hjort et al. (1983)
					8 August 1985	c. 40 ad. and >15 juv.	Hjort et al. (1988)
20	S Antarctic Bugt	c. 80°55'	c. 14°39'	Cliff	22 June 1980	1 pair	Hjort et al. (1983)
21	W Amdrup Land	80°51'	15°36'	Small Nunatak	July–August 2007	Occupied colony ^d	Present study
22	E Amdrup Land	80°51,5'	14°36'	n.d.	July–August 2007	Occupied colony ^d	Present study
23	S Amdrup Land	c. 80°48'	c. 14°32'	Cliff	10 August 1993	c. 6 pairs	Falk et al. (1997)
24	Prinsesse Elisabeth Alper	80°44'	18°54'	Nunatak	July 2007	Occupied colony ^d	Present study
					4 July 2008	>200 adults	Fin Bo Madsen (pers. com. 2008)
25	Henrik Krøyer Holme (northern Island)	80°40.3'	13°43.5'	Large Island	9 August 2003	c. 150 nests	Present study
					15 July 2007	(>300 ad.) 10 adults	Present study
					29 July 2008	No birds seen	Present study
26	Henrik Krøyer Holme (central Island)	80°38.5'	13°44'	Large Island (2 to 3 sub-colonies)	12 August 1980	10 ad. probably breeding	Hjort et al. (1983)
					12 July 1984	“Many breeding Ivory Gulls, some with eggs, others with young”	“Thore” (HKH Hyttebook)
					4/29 July 1993	>125 nests (c. 510 ind.)	Falk et al. (1997)
					8 August 2003	c. 135 nests (>300 ad.)	Present study
					12 July 2007	220–250 adults ^c	Present study
					29 July 2008	c. 290 adults	Present study
27	Caroline Mathilde Alper	80°31'	19°11'	Steep inland cliff	1 August 2008	40 adults	Present study
28	S Holm Land	c. 80°13'	c. 17°24'	Small Nunatak	10 July 1980	1 pair	Hjort et al. (1983)
29	Renskaeret	76°41'	18°31'	Small rocky island	18 July 1908	7 pairs	Manniche (1910)
					1993	1 territorial pair	J. Graugaard (in Boertmann 1994)
					21 August 2004	1 territorial pair	Present study
30	‘Hauge’s Nunatak’	69°45'	28°24'	Nunatak	1984 (beg. August?)	Several 100s ad. ^b	Hauge Andersson (pers. com. 2003)
					26 June 2007	35 adults ^b	Present study
31	Watkins Bjerger (South of point 2130)	68°38'	29°41'	Nunatak	26 June 2008	2 adults	Present study
32	Lemon Bjerger (East of point 2460)	68°30'	32°	Nunatak	1993	At least 4 breeding birds	Sir Chris Bonington (pers. com. 2004)
					26 June 2008	No birds seen	Present study

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Table 1 continued

Site#	Colony name (from north to south)	Lat. N	Long. W	Type of site	Date	Numbers	Source
33	Kronprins Frederik Bjerge Nunatak 1	67°53'	34°25'	Nunatak	11 August 1978 26 June 2008	>45 ad. +juv. No birds seen	Wright and Matthews (1980) Present study
34	Kronprins Frederik Bjerge Nunatak 2	67°38'	34°08'	Nunatak	7 August 1978 26 June 2008	30–45 ad. +juv. ≥25 adults	Wright and Matthews (1980) Present study
35	Kronprins Frederik Bjerge Nunatak 3	66°48'	34°25'	Nunatak	30 July 1978	>26 ad. + juv.	Wright and Matthews (1980)
Historical (<1925) or unconfirmed breeding sites:							
36	J. V.Jensen Land— Upper Harmsworth Glacier	83°10–20'?	34–36'?	n.d.	27 July–5 August 1969	16 sightings at camp (400 m.a.s.l.) 13 to 17 birds at nearby Frigg Fjord (mid August)	Grant (1972)
37	Hendrik Island, Warming Island & St George Fjord	c. 81°57'	c. 53°15'	n.d.	July 1917	“Suspected breeding”	Wulff (in Salomonsen 1950)
38	Hall Land—Newman Bay	81°10–55'?	57°–62'?	n.d.	11/14 June 1872	“breeding”	Bessels (1879)
39	Henrik Krøyer Holme (southern island)	81°38'	13°52'	Large Island	29 July 2008	1 possible breeding pair	Present study
40	Washington Land— Kap Constitution	c. 80.33'	c. 66°40'	Cliff	June 1854	6 ad. probably breeding	Morton (in Salomonsen 1950)
41	Washington Land— Cass Fjord	80°03'?	64°30'?	Cliff	19 June 1922	1 nest	L. Koch (in Salomonsen 1950)
42	Graeselv	79°57'	24°	n.d.	July 2003	n.d. (daily sightings of birds)	Present study
43	Inglefield Land	c. 79°05'	c. 67°22'	n.d.	?	“Breeding locally”	Rasmussen and Vibe (in Salomonsen 1950)
44	Traekpasset	76°09'	18°40'	Cliff	24 July 1974 2003 & 2004 30 May 2008	1 possible breeding pair No birds seen (only Glaucus gulls) No birds seen	Meltofte et al. (1981) Present study Present study
45	Kippaku Island	73°43'	56°38'	n.d.	July/August 1988	Vocalizing birds (≤7) regularly flying up and down the Fjord (to small Nunataks 50km to the E.?)	Peter Lyngs (pers. com. 2008)
46	Mitivajkat	68°33,5'	31°43'	Nunatak	1972	“possible breeding colony”	Wright and Matthews (1980)
47	KIV Steenstrups Glacier	c. 66°33'	c. 35°	n.d.	1974	“strongly suspected breeding site”	Wright and Matthews (1980)

^a Colony seen from distance

^b In 1984: seen from helicopter in 2 breeding cliffs; in 2007: seen from ground, only one breeding site left

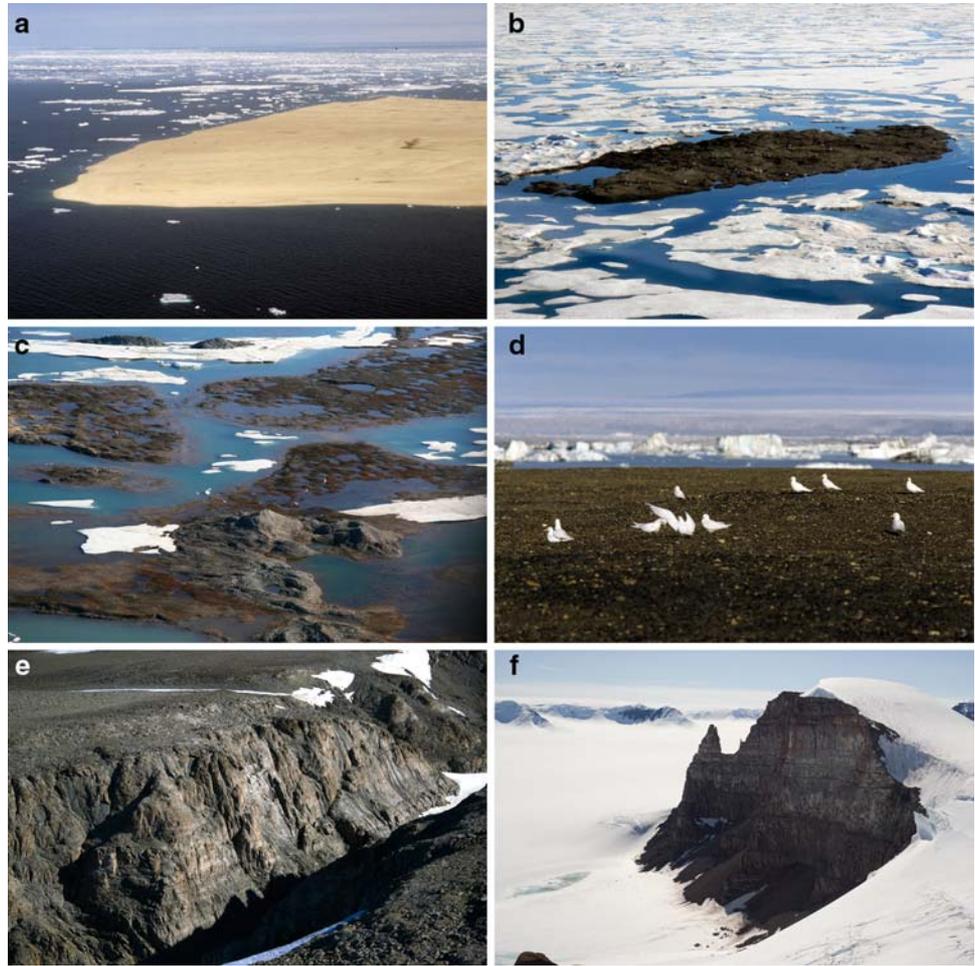
^c Several clutch found between 10–15 July 2007; all but a few predated by polar bears (daily visits)

^d Breeding site inferred from satellite monitoring (see text)

The distances between the 35 colonies and the nearest seashore vary from <1 km (for the 20 “coastal” colonies) to 48 km (mean: 7.4 km ± 12.5 SD). The colonies are located farther inland in the south (mean: 28.4 km ± 13.2 SD for the colonies located south of 70°N), where all ($n = 6$) are on nunataks, than in the north (mean: 3.0 km ± 6.7 SD; $n = 29$), where most colonies (69%) are coastal (i.e. located <1 km inland) and only three are located more than 10 km inland. It is worth mentioning that the distance that birds from site # 30 have to travel to reach the sea is probably

>130 km. Indeed, it is more likely that these birds feed on the outer Bløseville coast, where the species has regularly been reported during the breeding season over the last century (e.g. in D’Aunay Bugt and between Cape Vedel and Kangerdlugssuak: Amdrup 1902; Degerbøl and Møhl-Hansen 1935; Gilg et al. 2005; Glahder 1995; present study), than in the Scoresby Sund Fjord system, where some birds are regularly seen at the mouth of the fjord during migration (a few can also be seen feeding at glacier fronts in autumn) but rarely in the inner fjord system in summer

Fig. 2 Different types of breeding sites used by the ivory gull in Greenland: **a** large (i.e. >1 km wide) flat island (site # 26), **b** ice floe covered with gravel (site # 6), **c** small coastal lowlands/islands (site # 4), **d** coastal gravel terrace (site # 14), **e** small inland cliff below 1,000 m.a.s.l. (site # 17) and **f** steep inland nunatak above 1,000 m.a.s.l. (site # 30; photos: O.G. adf and D.B. bce)



(see, e.g. Gilg et al. 2005; Hørring 1939; Meltofte 1976b; Pedersen 1930; Petersen 1941). Even though such large distances between the colonies and the nearest feeding grounds appear important, they are not exceptional for the species, as shown by the long distances regularly travelled by coastal breeding ivory gulls monitored by satellite tracking in North Greenland (regularly more than 200 km per foraging bouts; Gilg et al. unpublished).

At the bottom of Table 1, we also present the historical or suspected breeding sites that need to be confirmed before they can be considered as current breeding sites. A few additional sites have not been considered in this table, despite that some authors have suggested they could hold breeding birds. For example, on the islets of Rosio off Cape Marie Valdemar, Manniche (1910; see also Meltofte 1975) suggested possible breeding activity, but we failed to find any birds at this location during an aerial survey in 2007. The numerous icebound islands between Skaerfjorden, Jøkelbugten and Nioghalvfjordsfjorden (77°30' to 79°40'N) are also looking very favourable for the breeding of ivory gull but the few biologists that have visited the area have not found any breeding sites to date (C. Bay in Boertmann

1994; Cabot et al. 1988; Bennike 2007). In addition, there are some old doubtful reports from Hochstetter Foreland (Løppenthin 1932), Hold with Hope (Boyd 1935), and Mallemukfjeld (Koch and Bertelsen in Manniche 1910).

Finally, it must be mentioned that at least three deserted colonies (former confirmed or suspected breeding sites) are currently used by other gull species. At Traekpasset (site # 44; Table 1), glaucous gulls (*Larus hyperboreus*) are nowadays regularly breeding on the cliff where Meltofte et al. (1981) suspected breeding of one pair of ivory gulls in 1974 (Gilg et al. 2003, 2005). On the eastern side of Renskaeret Island (site # 29; Table 1), where Manniche (1910) found a colony in 1908, black-legged kittiwakes (*Rissa tridactyla*) currently breed on the only available small cliff (Gilg et al. 2005). At Mallemukfjeld, where Koch and Bertelsen (in Manniche 1910) reportedly found 50 ivory gulls in 1907 (but see above), there are large colonies of black-legged kittiwake, northern fulmar (*Fulmarus glacialis*) and glaucous gulls (Falk and Møller 1997; Hjort et al. 1983; Manniche 1910). Hence, it cannot be ruled out that a number of historical colonies of ivory gull, especially coastal colonies between 75°N and 80°N, have been deserted in Greenland

during the twentieth century due to inter-specific competition.

Colony sizes

Colony sizes reported from Greenland ranged from one or a few pairs (several sites) to several hundred individuals (max. 125–150 nests and 300–510 adults on Henrik Krøyer Holme in 1993 and 2003). The number of breeding birds found in a colony can vary greatly from year to year. At Station Nord, for example, colony size varied from a few pairs (2001, 2006, 2007) to 150–250 breeding birds (2002, 2003). Very late snow cover (at Station Nord in 2006–2007) and systematic nest predation (by polar bears at Henrik Krøyer Holme in 2007) were the most likely causes of fluctuation at these sites. Non-breeding (in 2008 compared to 2007) could not be explained at two other sites where limitation due to snow cover (site # 16) or predation (site # 12) was unlikely.

If the colonies are sorted according to the ‘highest number of adult birds seen’ (see “Methods”), then 4 (i.e. 15%) out of the 26 breeding sites with positive counts (i.e. excluding 9 sites that are known but not censused) have less than 5 birds, 6 sites (23%) have between 5 and 24 birds, 10 sites (42%) between 25 and 99 birds and 5 sites (19%) between 100 and 300 birds (Table 1; Fig. 1). The average colony size is 69 birds (± 90 SD) but most birds are found in large colonies since the median is only 33 birds. Median colony size was significantly greater in islands/coastal lowland colonies than on inland cliffs/nunataks ($U = 38$; $P < 0.05$, Mann–Whitney U test).

Population size

Given the above-mentioned inter-annual fluctuation, and since most colonies have only been counted once since their discovery, the overall population estimate for Greenland must be considered with caution. If we sum the highest colony sizes reported for the 26 colonies that have ever been counted (i.e. we have known coordinates for nine colonies that have never been censused), we reach a total of approx. 1,800 adult birds, i.e. more than twice the population size previously estimated for Greenland (Gilchrist et al. 2008).

This number may be overestimated by double counts if we assume that some adult birds can change breeding sites on a yearly basis. However, if we sum the mean number of adult birds counted at each of these colonies (i.e. 1,336 birds for 26 colonies) instead of the maximum, and then extrapolate this result to all 35 colonies (to take into account the nine colonies that have been located but never counted), we also end up with a total of approx. 1,800 birds.

In addition, the count of 850 adult birds in 2003 at the three largest breeding sites and the total of 970 adults

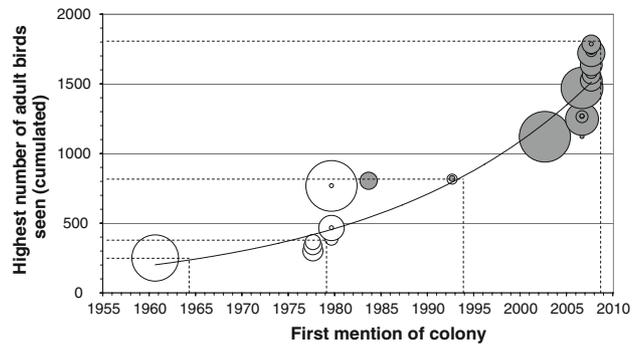


Fig. 3 Contribution of newly discovered breeding sites to our knowledge of the ivory gull population size in Greenland. Each circle presents a single colony, positioned (on the x axis) according to the date of its discovery, and with a radius proportional to the ‘highest number of adult birds seen’ at this site in recent years (see Sects. “Methods” and “Results”; grey circles for colonies first described in this paper). The y-value of any given colony is the sum of the ‘highest number of adult birds seen’ for all colonies that were known at that time. e.g. if no new colony had been found since 1964, 1979 or 1994, our best estimate for the size of the Greenland ivory gull population would only be 250, 364 or 820 adult birds, respectively, while it is currently close to 1,800 (i.e. roughly a twofold increase every 15 years; see dashed lines). The trend is exponential (given by the grey line)

reported in 2008 from 23 breeding sites (i.e. only two-thirds of the known colonies), excluding the three largest, also supports the view that previous published figures have considerably underestimated the current Greenland population.

Discussion

Our results, coupling satellite telemetry and direct surveys, were unexpectedly performing to locate new breeding sites. In 2008 only, the monitoring of six ‘transient’ birds (i.e. that did not breed at Station Nord where they were trapped) led to the discovery of six new colonies. More than half of the colonies, representing more than half of the current population size estimate, have been discovered within the last 5 years (2003–2008; Table 1; Fig. 3). Does this mean that the population is now satisfactorily known or, on the contrary, that many colonies are still unknown?

What is the real population size in Greenland?

In the results section, based on the number of adult birds attending colonies, we reported that the population size of Greenland ivory gulls was potentially as high as 1,800 adult birds ($\pm 25\%$), i.e. twice as high as previously estimated (Gilchrist et al. 2008). It is likely, moreover, that this should be considered a minimum.

First, because the ‘breeding population’ we are attempting to assess should also consider, in addition to the breeding adults censused at the breeding sites, the failed breeders

(some of which resume their breeding cycle and are overlooked at the time of the censuses) and possibly also a fraction of the large number of non-breeding adults reported for the species in some years at the breeding sites or offshore (Gilg et al. 2005; Joiris 1996; Tomkovich 1986; Volkov and Korte 2000). Indeed, if we acknowledge the fact that for ivory gulls non-breeding is an important but stochastic process resulting from extrinsic factors (e.g. local snow or ice cover, mass predation, etc.) and affecting entire colonies (rather than related to the individual condition of the birds), then it would be theoretically relevant to include these ‘non-breeding’ birds in an estimate of the overall breeding population estimate, since they clearly belong to the pool of potentially reproducing birds. This, however, remains a theoretical concern (probably relevant for other colonial breeders as well) since we have no data to test this bias at this time. It must be mentioned, however, that if inter-annual site fidelity (or breeding philopatry) is high in ivory gulls, as strongly suggested by Volkov and Korte (2000), then our ‘highest number of birds seen’ at each colony (see “Methods”) includes some of these birds, thereby reducing this bias.

Second, not all breeding birds attend their nests or young when the censuses take place (Volkov and Korte 2000). In fact, earlier studies have shown that for the ivory gull, the number of breeding adults reported from single censuses of a colony (e.g. all Greenland census presented in Table 1) is close to the total number of breeding pairs using the colony, hence advocating the use of a two-fold correction factor (Mallory et al. 2008; Robertson et al. 2007; H. Strøm, personal communication 2009). This low attendance rate is also evident from our satellite tracking data: the breeding birds we monitored in 2007, presumably mainly males, only spent approx. 50% or less of their time at the colony sites during the breeding period (Gilg et al. unpublished). Furthermore, even when both partners are present at the colony one is often resting or grooming on the ice within a few hundred metres of the nest, and therefore overlooked during the census.

Last, from our recent discovery of several new colonies, it can be assumed that several additional colonies in the remotest parts of Greenland have yet to be reported. Single birds seen in the north along frozen fjords during the breeding season (e.g. Jørgen Brønlund Fjord, Meltofte 1976a) are not particularly helpful in relation to the discovery of new colonies, since our satellite tracking results show regular movements of breeding birds over drift ice or fast ice at distances of more than 100 km from the colonies. On the other hand, based on our satellite tracking, ivory gulls almost never fly inland in summer, except to reach their colonies (during spring migration, some birds also cross the icecap, as indicated by 6–8 adult birds seen flying eastwards on 29 May 2006 at 67°28′32″N/41°28′23″W, i.e. 175 km from

the nearest nunatak; Johannes Lang, personal communication 2006). Therefore, based on repeated observations of birds flying inland during the breeding season, additional colonies are highly likely in North (e.g. sites # 36 and # 42) and north-west Greenland (site # 44). Finally, the recently discovered offshore island of Tobias Ø (79°20′N, 15°48′W; Bennike et al. 2006; Mohr and Forsberg 2001) should be checked carefully for ivory gulls in the future, since unidentified gulls have been reported here and due to its location (near the offshore ice edge) and flat topography, ivory gulls could potentially breed at this site.

Due to the above reasons, the estimate of 1,800 adult birds for Greenland is probably far below the true figure. It is not unrealistic to consider, for example, that non-attending breeding birds (the second source of underestimation presented above) are at least as numerous as the attending breeding birds counted at the colonies. Hence, the total population for Greenland could easily be >4,000 breeding adults (or >2,000 breeding pairs), i.e. four to eight times more than previously estimated (Gilchrist et al. 2008).

Population trends

The increase in the estimate for the Greenland population (see above) is mainly due to the recent (2003–2008) discovery of new colonies. If we had only summed the colony sizes (including those from recent censuses) reported for colonies discovered prior to 1990, then the estimated population size would just be approx. 800 birds (Fig. 3). Therefore, the apparent increasing trend shown in Fig. 3 cannot be used to support any true population change. This figure will probably continue to increase in the future, since it is likely that additional new colonies will be discovered.

Periodic non-breeding, a common feature in Arctic birds (Bertram and Roberts 1934; Bird and Bird 1940; Marshall 1952), including the ivory gull (Gilchrist et al. 2008; Robertson et al. 2007; Volkov and Korte 2000), is another obstacle to assess past and future population trends. Indeed, it is difficult to assess the true population trends in ivory gull colonies from the year of discovery because, by definition, the initial census is always positive, while subsequent censuses can be positive or null. This shortcoming can be overcome by (1) removing the first census (discovery) or (2) removing all subsequent zero counts. Since often only two censuses were available for a given colony for the present study, removing the first count was not a viable option; therefore, the second option was used in preparation of Table 2.

Until 2000, all but a few of the Greenland colonies had only been counted once and no reliable population trends could be presented (Boertmann 1994; Gilchrist et al. 2008). During the course of 2003–2008, we managed to visit most of the colonies that had previously been censused. Only five

Table 2 Ivory gull population trends inferred from positive multiple counts at eight breeding sites

Site #	Colony name (from north to south)	Period of reference			
		<1978–2008	1978–2008	1988–2008	1998–2008
12	Nakkehoved				–
14	Station Nord	+			±
19	Kilen		–		
25	Henrik Krøyer Holme (northern Island)				–
26	Henrik Krøyer Holme (central Island)		+	–	=
29	Renskaeret	–			
30	‘Hauge’s Nunatak’		–		
34	Kronprins Frederik Bjerger Nunatak 2		–		
Main population trend for the periods:		? (<i>n</i> = 2)	↓ (<i>n</i> = 4)	↓ (<i>n</i> = 1)	↓ (<i>n</i> = 4)

colonies (sites # 2, 35, 20, 23, 28), with earlier reports of limited numbers of breeding birds (20 and 26 birds; 1, 6 and 1 pairs, respectively), could not be checked. The trends are presented qualitatively (Table 2) for the eight colonies with accurate and positive multiple counts (details in Table 1). Empirically, Table 2 shows a dominant declining trend since 1978. This trend is particularly clear in south-east Greenland, where apparent declines or extinctions are reported for all monitored colonies (sites # 29–35; Table 1), including a dramatic (>80%) decline at the largest known colony in this region (site # 30) from 1984 to 2007 (declined from several 100 s of adults to only 35) and a 35% decline in a smaller colony (site # 34) from 1978 to 2008. The situation is more ambiguous in North Greenland where some colonies possibly have declined while others have increased over the long term, including two of the largest since their discovery in 1961 and 1980 (sites # 14 and # 26, respectively). Given the year-to-year variation in colony size (see above) and the limited data set, any further statistical analysis of the overall population trend would be of little confidence.

Scenarios for future population trends in Greenland

Although repeated counts that can be used to assess population trends are rare in Greenland, the available data seem to indicate that ivory gulls have declined in the southern colonies (south of 70°N), while trends in the north are unclear. The likely decline in southern colonies can be compared with recent trends reported for Canadian colonies (Gilchrist and Mallory 2005; Mallory et al. 2003; Robertson et al. 2007). In Canada, the 80% decline documented over a period of 20 years has been hypothesized to have resulted mainly from pollution and excessive hunting (e.g. in NW Greenland; Braune et al. 2006, 2007; Gilchrist and Mallory 2005). Because gulls declined over their entire Canadian breeding range, including very different habitats types and

regions, it has been suggested that these two negative factors act mainly during the winter period or migration. Indeed, post-breeding Canadian birds regularly move to West Greenland and especially the Thule area (Renaud and McLaren 1982), where hunting occurs. However, since all ivory gull populations probably use the same wintering grounds (i.e. the north-western part of the Atlantic Ocean; Strøm et al. unpublished), while only the Canadian population declined at such a dramatic speed (Gilchrist et al. 2008), we suggest that alteration of habitat (mainly the sea ice) in Northern Canada during summer and the migration period could also be a cause of the observed decline.

In any case, according to our current knowledge, it is difficult to forecast future changes in population sizes in Greenland or elsewhere. If the summer sea ice, and especially the ice edge, continues to move away from Svalbard and Franz-Joseph Land at the current speed (see, e.g. recent summer trends at <http://www.seaice.de>), it will be difficult for the species to continue to breed in these Arctic archipelagos. In North Greenland, summer sea ice should remain for a much longer period (ACIA 2005; Overland and Wang 2007). As a result, the population from North Greenland may decline in future in synchrony with other populations if it is limited by unfavourable conditions during the winter or migration periods, or remain stable, or even increase as a result of e.g. immigration of birds from Svalbard and north-western Russian colonies if it is the extent and quality of summer sea ice that drives the population dynamics of the species. We believe, moreover, that the recent discovery of several new colonies in North Greenland is best explained by previous poor knowledge rather than an increase in population size. However, future colonization of new sites should also be considered as a likely scenario in North Greenland. Especially, the coastal lowlands and small islands of eastern Peary Land (where sites # 3 and # 4 were discovered in 2008; see also Fig. 2c) and Johannes V. Jensen Land (including a very favourable area in Bliss Bay which was

surveyed for the species, unsuccessfully, in 2007; Gilg et al. 2008b) should be regularly monitored in the future to confirm or deny colonization.

Ivory gulls were probably among the first vertebrates to colonize North Greenland after the last ice edge. At least, they were already present approx. 4,000 years ago, according to remains found and dated in Eskimo settlements of Jørgen Brønlund Fjord (Grønnow and Jensen 2003). Today, their future is in jeopardy, with changes in the extent and quality of sea ice in summer being one of the main threats. The challenge this species will have to face in years to come is to adapt (see, e.g. Forcada et al. 2008) to this changing environment rapidly, or to relocate to more suitable breeding areas. Because North Greenland can be regarded as the last region in the Arctic where sea ice will remain in summer in the future (ACIA 2005), it might well also become the last region where this species may manage to breed. The current size of the regional population could even increase in the near future due to immigration of birds from Svalbard or north-western Russia (see above). Evidence of such long-distance relocation is still lacking (mark-recapture programs are in progress in Greenland, Svalbard and Russia but are hard to implement on a circum-polar scale and in such remote regions), but the recent discovery of 'offshore' colonies (i.e. birds breeding on ephemeral ice floes; Boertmann et al. 2010) in North Greenland is, at least, positive evidence that ivory gulls can relocate to locally more favourable breeding areas in the short term.

As the ivory gull could well be the first vertebrate species this century to become extinct as a consequence of human-induced climate change and the associated decline in summer sea ice (Gilg et al. 2008a), its main and almost exclusive habitat, Arctic biologists and conservation agencies should prioritize protection of its breeding areas (i.e. breeding sites and related feeding grounds) and regular monitoring of the species in North Greenland.

Acknowledgments We are very grateful to Freddy Mariaux, Luc Hardy, Benoît Sittler, Pierre Leguesdron, Vladimir Gilg, Kent Olsen and Lars Maltha Rasmussen who helped in the field, to captain Leif Petersen who navigated the aircraft in 2008, to Carey Smith, Hallvard Strøm, Maria Gavrilov, Andrei Volkov, Hans Meltofte and Niels Martin Schmidt who commented and improved previous drafts of the manuscript, to Ko de Korte, Hans Meltofte, Tony Fox, Fin Bo Madsen, Hauge Andersson, Sir Chris Bonington, Johannes Lang, Eckart Håkansson and Peter Lyngs for providing unpublished data, to John Lau Hansen (Greenland Command), the military staff of Station Nord, the Sirius Sledge Patrol, the Greenland Home Rule, the Danish Polar Center, Polog, Norlandair (formerly Air Iceland), Kirsten Fadnæs Eriksen, Nette Levermann, Kristbjörg Björnsdóttir, Hauge Andersson, Aka Lyng, Jan Almqvist, Sebastian Ravn Rasmussen, David Smari Johannsson and Friðrik Adólfsson who helped with the permits and the logistics. Funding and equipments were provided by the National Geographic Society, Prix GORE-TEX initiative, Fondation Avenir Finance, the Bureau of Minerals and Petroleum, Greenland Home

Rule, the Arctic Ocean Diversity Census of Marine Life Project, Magasins Intermarché, Société Henry Maire, Lestra, MSR, GREa, F. Paulsen and other contributors.

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