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Abstract

A small seabird community depends on the resources of the Northeast Water (NEW) polynya. In spring, at least 1000 King Eiders and 2500 Common Eiders form pre-breeding congregations at Ob Bank before dispersing in mid June to breeding areas. The most abundant species is the Fulmar, which breeds in six colonies with a total of 2550 "apparently occupied sites", corresponding to approx. 1475 active pairs in 1993. Kittiwakes occupied almost 900 sites at Mallemukfjeld, with an estimated 733 breeding pairs. The entire NEW area probably holds 400–500 pairs of Ivory Gulls, and about 500 individuals were associated with a colony on Henrik Krøyer Holme; this is one of the world's largest known colonies. Sabine's Gulls breed at the same islands and on Kilen (approx. 50 pairs in each place). Small colonies (total less than 1000 birds) of Arctic Terns are distributed along the edge of the polynya, with the largest colony of about 100 pairs on Henrik Krøyer Holme. The Black Guillemot is the only breeding auk species (< 20 pairs) in the area. Small numbers of Red Phalaropes were observed in the polynya in 1992 and 1993, and the species may have bred at Henrik Krøyer Holme in 1993; the polynya area may also serve as a staging area for transpolar migrants. In late summer a few hundreds of Ross's Gull—non-breeding adults and immatures—show up in and around the polynya, and in recent years a few cases of breeding have also been recorded. The relatively small seabird populations are evidence of a generally low carrying capacity of the polynya area.

Apart from the benthic foraging eiders and the Black Guillemot, the seabird community of NEW consists of surface feeders—Fulmars and gulls—dependent on small fish and zooplankton. During their stay in the NEW area, the five most abundant surface feeders will annually consume approximately 243,000 kg (wet weight) of food, of which the Fulmars alone take 67%. Food demand in relation to area of open water in the polynya is highest in spring (approx. 0.2 kg/km^2), which is

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very little compared to other studies. The eiders consume up to 300,000 kg food during their pre-breeding period. In terms of carbon flux, the surface feeders in the NEW polynya consume a minimum of 27,146 kg C annually, with a peak demand in early spring as low as 0.00003 g C m^{-2} day^{-1}. The eiders consume roughly 7245 kg C annually, mainly at Ob Bank, where peak turnover in spring may be around 0.00012 g C m^{-2} day^{-1}.

The Fulmar has the longest breeding season of all the species in the NEW area, and its three-month nesting period matches the normal open period of the polynya, and the chicks fledge shortly before the polynya freezes over.

Archaeological datings suggest that Fulmars were hunted by paleoeskimos living in the NEW area 2800–2400 years ago, and the Thule Culture people 500–300 years ago left remnants of Fulmar, King Eider, Ivory Gull and large gulls.

Keywords: polynya; seabird; breeding phenology; Arctic

1. Introduction

Seabirds need access to foraging areas, and high-arctic seabird colonies are often situated near ice edges, recurring leads or polynyas (Brown and Nettleship, 1981). This is also the case in Northeast Greenland, where the birds sustained by the Northeast Water (NEW) polynya have been utilized by local Inuit from at least 400 BC until some hundred years ago.

In 1906–1908, members of the "Danmark Expedition" provided the first written account of the NEW polynya and its wildlife, including some of the world's most extreme high-arctic colonies of Fulmars (*Fulmarus glacialis*) and Kittiwakes (*Rissa tridactyla*), and pre-breeding congregations of King Eiders (*Somateria spectabilis*) (Manniche, 1910). These findings were further substantiated during the "Dansk Nordøstgrønlands Expedition" 1938–1939 (Pedersen, 1942). After these pioneering surveys, geological expeditions since 1980 have considerably improved our knowledge of the area's wildlife. The Common Eider (*S. mollissima*), Sabine's Gull (*Larus sabini*), and Ross's Gull (*Rhodostethia rosea*) have been found breeding along the polynya and connected leads of open water, and Brent Geese (*Branta bernicla*) in the ice-free enclave Kilen (Hjort, 1980; Hjort et al., 1983, 1987a, 1988). In addition, seabird distributions in the polynya and surrounding areas have been recorded from multi-disciplinary research cruises of Swedish, German, and Norwegian vessels in the 1980s (Hjort et al., 1987b; Mehlum, 1989).

Previous visitors have had little opportunity to perform quantitative studies. However, as a part of the International Arctic Polynya Program (IAPP), seabird populations in the NEW area were studied by land-based field teams in 1993 (the NEWland sub-programme), with a brief follow-up in 1994, and from the research vessels *Polarstern* and *Polar Sea* in 1991, 1992 and 1993 (see Joiris et al., in prep.). The immediate objectives of the ornithological components of the NEW programme were (1) to survey the seabird populations in order to establish a reference for future monitoring, (2) to locate the pre-breeding congregations of eiders, (3) to map seabird foraging distribution in the polynya, and (4) to assess the resource use of seabirds utilizing the polynya. Much of the information will be published in separate manuscripts, but based on the information gathered since the area was first discovered to science in 1907, this paper provides an overview of current knowledge on population size, breeding phenology and general ecology of seabirds associated with the NEW, and considers the significance of the polynya in terms of the foraging needs of these populations. Details on the pelagic distribution of seabirds within the polynya are given by Joiris et al. (in prep.).

In addition, archaeological evidence for human exploitation of the seabirds in the polynya is briefly summarized.

2. Physical characteristics of the NEW and its surroundings

Although the Northeast Water has been considered a "summer polynya" (Anon, 1989), open water may occur all year. Satellite tracking of Walruses (*Odobenus rosmarus*) have revealed that they overwinter in the polynya (Born and Knutsen, 1992) and satellite imagery analyses also indicate the presence of open water all year (Pedersen et al., 1993). In average years, the area of open water increases gradually from mid May to form the "summer polynya'', reaches its maximum during August and starts to close again by rapid ice formation in mid September. When largest, the polynya reaches from Nordostrundingen at 82°N southward to 77°N, and covers an area of about 25,000 km^2. In most years, however, the open water area does not exceed 17,000 km^2 (Pedersen et al., 1993; Gudmandsen et al., 1993, 1995). The timing of opening and closing, as well as the size of the coastal polynyas and adjacent leads along Northeast and North Greenland is considered sensitive to climatic changes (Anon, 1989), and past climatic fluctuations and closing of the coastal winter polynyas and leads in Northeast Greenland may have caused the extinction of the Inuit population there (Bay et al., 1995).

The coastal areas along the NEW are extremely barren, with a long-lasting snow cover, and a vegetation cover of usually below 1%. Behind extensive marine forelands lie mountain plateaus of flat Palaeozoic limestone and sandstone rocks. Usually 350–500 m high cliffs and talus slopes face the sea and fjords, and much of the plateaus are covered by local ice caps with some outlet glaciers reaching sea level. Nordostrundingen has a narrow rim of low moraines and beach ridges between the sea and the large Flade Isblink ice cap on Kronprins Christian Land. Farther south is Kilen, a wedge-shaped ice free enclave reaching approximately 30 km inland. Henrik Krøyer Holme is a group of flat and barren islets nowhere reaching more than 20 m above sea level, located in the middle of the polynya, about 25 km off Amdrup Land.

2.1. Polynya generation and climate

Two quite different physical concepts are probably involved in generating and maintaining the NEW polynya. The open water in winter situated south of Nordostrundingen is most likely generated by the strong NW-winds, whereas the summer polynya is generated by heat and current (Schneider and Budéus, 1995). Measurements of wind force and direction from Henrik Krøyer Holme (80°38′N; 13°43′W) in the middle of the polynya are presented in Fig. 1, and supports the idea that the winter polynya is mainly driven by the NW winds that prevail at this time of the year. The strongest winds (> 30 m/s) were NW-gales recorded in winter, with very low air

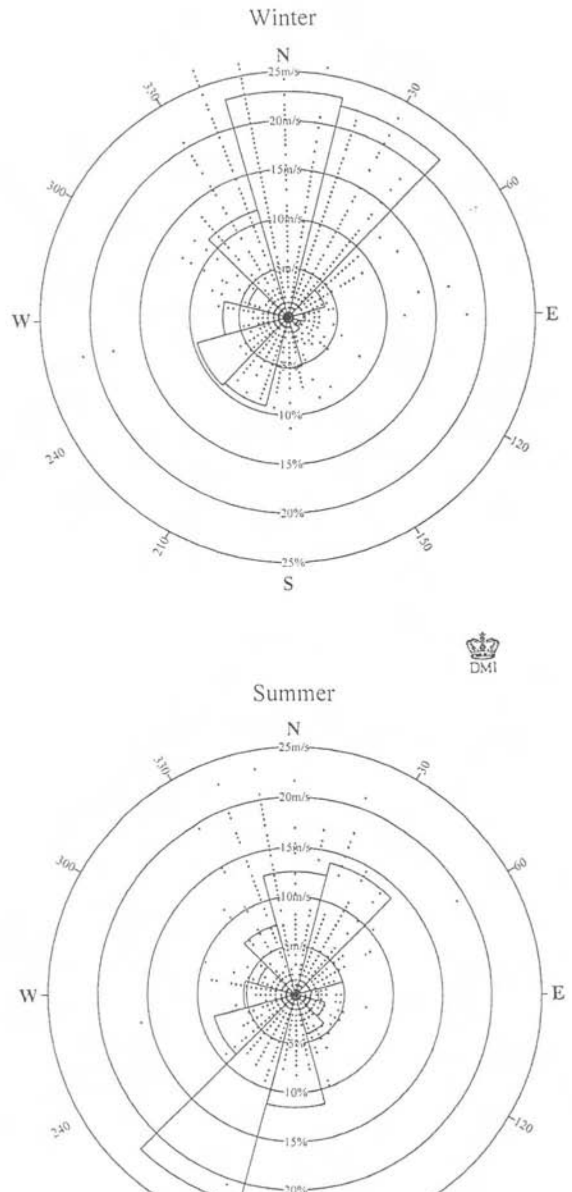

Fig. 1. Wind direction and wind force at Henrik Krøyer Holme during summer (1 May 1992–30 September 1992) and winter (1 October 1991–30 April 1992), respectively. The length of pie segments indicate proportions of wind readings from each 30° sector.

temperatures. For example, on 17 December 1990 the maximum wind speed recorded at Henrik Krøyer Holme was 31.6 m/s (NNW) and the air tempera-

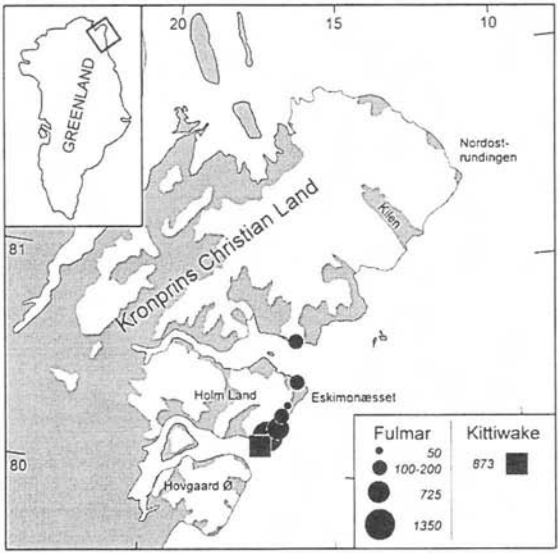

Fig. 2. Kittiwake and Fulmar colonies adjacent to the NEW polynya. Colony sizes indicated are numbers of "apparently occupied sites" in 1993.

ture −23°C, whereas at the same time Station Nord (81°36′N; 16°40′W) on the western side of Kronprins Christian Land (locations in Fig. 2) experienced only 16.1 m/s but had −31.6°C. In the summer, main wind direction is from southwest, but stronger winds still occur from the northern sector. The polynya has a moderating effect on the temperature, causing lower summer temperatures and much higher winter temperatures at Henrik Krøyer Holme compared to the more continental climate at Station Nord. For example, the minimum temperature recorded in the polynya during September 1990–September 1992 was −33.3°C (23 February 1991) and the maximum only 7.0°C (2 August 1991) compared to Station Nord's minimum of −41.7°C (20 February 1991) and maximum of 11.4°C (6 August 1991).

3. Methods

This paper deals with published information as well as original data from the field work performed in 1991, 1992 and 1993 (and the short visit in 1994), when methods applied included:

Colony surveys of colonial seabirds were carried out along the polynya. In 1993 field work commenced on 15 May, and surveys included Eskimonæsset (base camp), Sophus Müller Næs, Kilen (3–6 June) and Hanseraq Fjord (3 and 24 July). Henrik Krøyer Holme were visited by boat or helicopter on 22 July 1992, 4–5 and 29–30 July

Table 1
Phenology [a] and population size (estimates of total numbers of individuals) of the main seabird species utilizing the NEW polynya

Species	Arrival	Departure	Lay	Hatch	Population
Fulmar	APR	SEP	31 MAY [1]	16 JUL [1]	5100
King Eider	< 15 MAY	15 JUN [2]			1000 [3]
Common Eider	< 15 MAY	SEP	ca. 1 JUL	ca. 20 JUL	2500 [3]
Black Guillemot	MAY	SEP [4]	late JUN	late JUL	< 100
Glaucous Gull	MAY	SEP	MAY/JUN	JUN/JUL	200
Ivory Gull	APR	SEP	late JUN	late JUL [5]	1000
Kittiwake	ca. 15 MAY	1 SEP	18 JUN [6]	15 JUL [6]	2000
Sabine's Gull	early JUN	AUG/SEP	1 JUL	late JUL	400
Arctic Tern	1 JUN	1 SEP	late JUN	JUL	1000
Ross's Gull	JUL [7]	SEP			> 500

[a] Combining field data from 1991 to 1994 with information from Manniche (1910), Pedersen (1942), Hjort et al. (1983, 1987b).
[1] Median dates (laying range 21 MAY–13 JUN).
[2] Disperse to breeding areas in inland tundras and use the polynya very little later in the year.
[3] Pre-breeding congregations.
[4] May be able to winter in the high Arctic (Renaud and Bradstreet, 1980).
[5] Annual variation: in 1993 approx. mean hatch date 20 July; in 1994 approx. 30 July.
[6] Median dates (laying range 7 JUN–10 JUL).
[7] Failed and non-breeders entering from the east, and leaving eastwards in September (Meltofte et al., 1981).

Table 2
Aspects of feeding ecology, breeding biology and population parameters, applied in an estimate of food and energy flux to surface feeding seabirds in the NEW polynya

	Fulmar	Ivory Gull	Kittiwake	Sabine's Gull	Arctic Tern
Foraging behaviour	Surface feeder	Surface feeder, scavenger	Surface feeder	Surface feeder	Surf plunging
Major prey	Fish, crustaceans, cephalopods	Invertebrates, fish eggs, carrion, offal	Fish, crustaceans	Invertebrates, small fish	Small fish
Diving depth (m)	0–3 [1]	0–1	0–1	0.5	0.5
Approx. foraging range (km) [2]	500	80	95	(20)	20
Adult population in NEW [3]	5100	1000	2000	400	1000
Est. no. of breeding pairs	1475	300	733	100	300
Adult body mass (g) [4]	750	547	440	185	110
Adult ADEE [5]	995	958	792	451	314
Median clutch size	1	1.7	2.03 [6]	2	1.7
Total no. of eggs/chicks	1475/826 [7]	510	1481/1246 [7]	200	510
Food intake (kg/yr) [8]	162,425	33,077	37,413	3863	6103
Carbon intake (kg/yr) [9]	18,153	3697	4181	432	682

[1] Hobson and Welch (1992).
[2] Kittiwake: Hatch et al. (1993); Fulmar: Furness and Todd (1984), Falk and Møller (1995b); Sabine's Gull: own guess; others: Cramp (1977–1993).
[3] From Table 1.
[4] Glutz von Blotzheim (1969), and own data (Fulmar).
[5] ADEE = Average daily energy expenditure; data for Fulmar and Kittiwake from Diamond et al. (1993), others calculated from the figure for Kittiwake by substituting bird body mass in the formulas used by Diamond et al. (see Methods).
[6] Falk and Møller (in press), others from Cramp (1977–1993).
[7] Applying overall productivity of 0.56 young/egg (Fulmar) and 1.7 young/active nest (Kittiwake) (see Methods).
[8] Wet weight, fish and crustaceans, using energy contents of 6 kJ/g (Diamond et al., 1993).
[9] Assuming 1 kJ ingested equivalent to 19 mg C, or 0.17 g (w.w.) of prey (Schneider and Hunt, 1982; Diamond et al., 1993).

1993, and again by Twin Otter on 30 July 1994. During the short visits all adult birds were counted, and the breeding status assessed by checking a sample of nests for the presence of eggs or chicks. Census methods for the Fulmar, Kittiwake and Glaucous Gull breeding populations are described by Falk and Møller (1995a).

Aerial surveys from helicopters, provided by *Polarstern*, were made for mapping pre-breeding congregations of eiders in the open polynya early in the season (30 May–6 June and 15 June).

Eider diet analysis from stomach contents from 5 King Eiders and 5 Common Eiders collected at the pre-breeding congregation area off Kilen at 4 June 1993, and from droppings of Common Eiders at Eskimonæsset. Samples were sieved on a 200 μm mesh and all items identified from minor fragments.

In addition, we briefly refer to some information gathered by the ship-based observers.

To evaluate the seabird populations' food consumption we calculated the energy requirement of the most abundant surface feeders—Fulmar, Kittiwake, Ivory Gull, Sabine's Gull, and Arctic Tern (*Sterna paradisaea*). For Fulmar and Kittiwake, the species-specific values for egg formation periods, and for daily energy requirements for adults and chicks reported by Diamond et al. (1993) were adopted, while for the other three species we calculated approximate values from the figure for Kittiwake (assuming that the time budgets of these flapping-flight surface-feeders are similar) by substituting bird body mass in the formulas used by Diamond et al. with respective body masses from Cramp (1977–1993). From estimated arrival and departure dates, population size, and breeding success, we calculated daily energy requirements for the total population of adult birds, for egg-formation, and for chicks. The metabolic costs of egg formation were calculated as 1.33 × energy content of eggs (Bezzel and Prinzinger, 1990) using data on egg mass, yolk/albumen composition, and energy contents of yolk and albumen (Ricklefs, 1977; Cramp, 1977–1993; Warham, 1990).

Since we only had detailed information on the spread in laying dates, breeding success, and chick mortality for the two most significant species (Fulmar and Kittiwake) we assigned fixed laying dates for the other species according to field data from 1992 to 1994. In these species no correction for chick loss was made. We assigned median clutch size of 2 eggs for the Sabine's Gulls, and 1.7 egg for Ivory Gull and Arctic Tern, and assumed laying to be initiated in 100, 300, and 300 nests of the three species, respectively. Most basic parameters in calculations are included in Tables 1 and 2.

For a coarse assessment of the food consumption of the eiders in their pre-breeding congregation areas we used the estimated daily food intake for Common Eiders wintering in Canada, where each bird daily consumed approximately 2 kg (wet weight, including shells, etc.) of molluscs, sea urchins and crabs (Guillemette et al., 1992).

For estimates of carbon transfer to seabird populations we assumed 1 kJ ingested food (fish and crustaceans) equivalent to 19 mg C, or 0.17 g (wet weight) of prey (Schneider and Hunt, 1982, Diamond et al., 1993).

Archaeological evidence of the ancient bird fauna stems from bird bones found in eskimo ruins along the NEW polynya. Bird bones were excavated from four ruins: one site at Eskimonæsset from the paleoeskimo period from 800 to 400 BC (Independence II), and three Thule culture sites from the 15th century, one situated at Eskimonæsset (Holm Land), one at Sophus Müller Næs, and one at Dværgfjorden (Amdrup Land) (Bay et al., 1995).

4. Birds associated with the polynya

4.1. Fulmar

4.1.1. Breeding population in the NEW

The Fulmar breeds in six colonies along the edge of the NEW polynya. The northernmost colony is located at Kap Jungersen on Amdrup Land and the other five along the coast of Holm Land. The southernmost and largest colony is situated at Mallemukfjeld (Fig. 2). In 1993, a total of 1887 "apparently occupied sites" were recorded in the six colonies. This represents the minimum population size, and a corrected estimate amounts to 2550 "apparently occupied sites". When adjusting for the proportion of non-breeding site holders, the active breeding population is estimated at 1453–1485 pairs (Falk and Møller, 1995a). The colonies hold more birds than previously assumed (Hjort et al., 1983; Manniche, 1910), but there is no reason to suspect any significant population change.

The only other Fulmar colonies in Northeast Greenland are on Hvalrosø about 630 km south of Mallemukfjeld (approx. 150 individuals, Stemmerik, 1990), and at the mouth of Scoresby Sound. The nearest neighbours to the Fulmars of NEW are the large (at least 35,000 pairs) colonies of Spitsbergen 560 km to the east (F. Mehlum, Norwegian Polar Institute, pers. comm., 1994).

4.1.2. Foraging distribution in the NEW

The Fulmar was the most common bird species in the polynya. Immature, non-breeding Fulmars can usually be distinguished in summer by their moulted primaries, but only few moulting Fulmars were recorded from *Polar Sea* or at the colonies. This suggests that the polynya does not attract many immature birds so that most Fulmars occurring in the polynya are likely to be the site holders—breeders or prospectors—from the local colonies. In contrast, in June most of the dark phase Fulmars (non-local) around Jan Mayen were in primary moult (Camphuysen, 1993).

Fulmars were recorded in low densities all over the polynya area (Joiris et al., in prep.). Average densities recorded from ship surveys were rather low: in spring 1993 Joiris et al. (1994) recorded an average of only 2.7 Fulmars per 30 minutes of survey from *Polarstern*, and highest values recorded in late summer from *Polar Sea* was 1.2–2.5 birds per nautical mile (n.m.) of transect. For comparison, Fulmar densities exceeded 5 birds/n.m. near Jan Mayen and along the ice edge northwest of Spitsbergen, whereas in the open Atlantic Ocean average densities were 0.1–2.5 birds/n.m. (Camphuysen, 1993). Flocks of about 100 individuals were observed at the glacier front in Antarctic Bugt.

There are no quantitative data on the diet of Fulmars from the NEW area, but amphipods, Polar Cod (*Boreogadus saida*) and small (0.5 cm) beaks of unidentified squid (probably *Gonatus fabricii*), were noted in Fulmar regurgitates at Mallemukfjeld in June 1993.

4.1.3. Discussion in relation to the polynya

The active breeding population consists of about 3000 individuals, and if each non-breeding site also represents two birds (prospectors or non-laying pairs) a total of 5100 Fulmars are associated with the colonies and rely on the food resources of the polynya (Table 1).

Fulmars are efficient flyers. Satellite tracked birds from the NEW reached a maximum effective ground speed (straight line) of 25.8 km/h and were able to move up to 369 km in one day (Falk and Møller, 1995b). The ability to cover long distances at high speed, combined with long incubation shifts, makes feeding grounds outside the polynya accessible to the Fulmars of the study area. During an average off-duty period of 6.1 days (Falk and Møller, in press) a breeding bird moving at the maximum recorded ground speed would have a potential range of 944 km and still be able to spend half the time resting and foraging, and during a maximum leave from nesting duty the potential range would be more than 2000 km. Especially in early spring, when ice conditions could inhibit foraging in the polynya area, the Fulmars may seek distant foraging grounds to build up body reserves for breeding, while the need for regular provision of chick meals probably will restrict foraging to the polynya later in the year. Marginal ice zones are considered important feeding habitats for many polar seabirds (Bradstreet, 1988), and the satellite tracked birds seemed to select ice edges or areas with 10–60% ice cover.

In 1993 the median egg laying date was 31 May, range 21 May–13 June (Falk and Møller, in press). Fulmars attend their colonies periodically long before laying. It is likely that Fulmars in NEW polynya are present at the cliffs at least from April (Manniche, 1910), and from the 1993 data, it appears that the Fulmar's three-month nesting period rather accurately matches the normal open period of the NEW, so that the last Fulmar chicks will fledge shortly before the polynya freezes over again.

An estimated 56% of all eggs laid produced young compared with the average breeding success of 41% and 27% recorded during long term studies in southern Alaska and Scotland, respectively (Ollason and Dunnet, 1986; Hatch, 1987). The high breeding success combined with interpretations of breeding behaviour in the Fulmars suggest that in 1993 their food supply could be considered "moderate to good" (Falk and Møller, in press).

4.2. King Eider

4.2.1. Spring arrival and pre-breeding congregation

During the "Danmark Expedition" in 1907, "a great many" King Eiders were seen near Mallemukfjeld 9–10 June (Manniche, 1910), and similar observations of unidentified eiders were made off Amdrup Land in mid May 1939 (Pedersen, 1942).

In 1993, King Eiders had arrived at the polynya in mid-May; small flocks (< 10 birds) were encountered along the ice-edge off Eskimonæsset on 17 May, but no migration was noted.

No King Eiders were observed off Holm Land between 24 and 27 May 1993 in spite of extensive boat surveys along the coast and ice-edge. Nor did a helicopter survey between the north coast of Hovgaard Ø and Eskimonæsset reveal any eiders. The only major pre-breeding congregation of eiders in the area was located during a helicopter survey on 30 May along the coastline and ice-edge from Eskimonæsset northwards to Kilen. Large flocks of both eider species were seen on the water or resting on the ice off the southern tip of Kilen (Fig. 3). Counts from the ground on 2 June gave a total of 1000 King Eiders in mixed flocks totalling 3500 eiders. Most birds seemed to be paired, and courtship display was frequent.

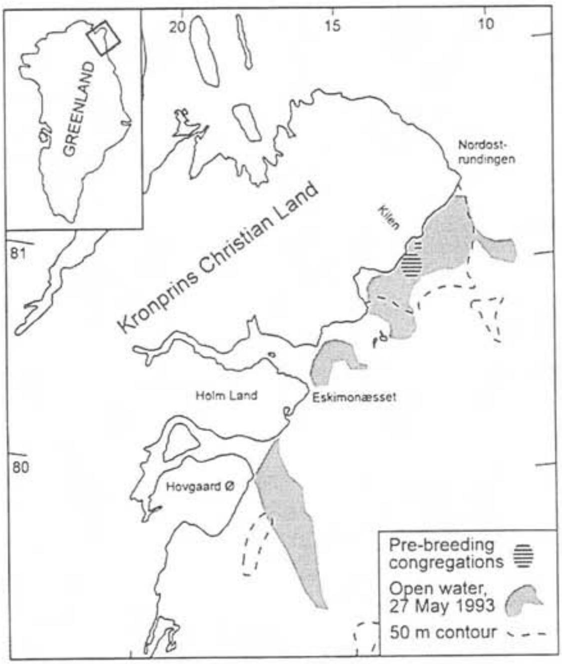

Fig. 3. Position of the major pre-breeding congregations of King Eiders and Common Eiders in May–June 1993, related to approximate limits of the 50 m water depth contour, and the ice free area according to satellite imagery of 27 May 1993.

By 6 June the numbers had decreased, and during a helicopter survey on 15 June only 200–300 eiders remained off southern Kilen and another 100 birds along the coast farther north. The disappearance on the outer coast coincides well with the arrival of King Eiders at their inland breeding grounds: on 15 June 1993, 30 newly arrived pairs were seen at the head of Danmark Fjord some 200 km to the west (Berg and Kapel, 1994), and Meltofte (1976), summarizing information from five years in southern Peary Land, reported first arrival dates between 6 and 12 June. Up to eight pairs stayed off Eskimonæsset from 12 June 1993, but no signs of breeding were noted anywhere along the NEW, and after the end of June only single birds or smaller flocks were observed around Eskimonæsset.

4.2.2. Post-breeding

No post-breeding congregations were observed and only about 50 resting or migrating King Eiders were noted between Mallemukfjeld and northern Amdrup Land during July and August 1993. Since almost all these birds were in brown plumage, they may have been failed breeders (females) or immatures.

4.2.3. Diet and relation to the polynya

It appears that the Northeast Water only serves as a pre-breeding congregation area where King Eiders gather to mate and build up reserves while awaiting access to the inland tundra lakes where they breed.

Being benthic foragers, both eider species need open shallow water—no more than 50 m deep, and preferably less than 6 m (Glutz von Blotzheim, 1969; Guillemette et al., 1992). Diet analysis of 5 King Eider stomachs from NEW indicated bivalve fragments of *Hiatella arctica* in two stomachs, *Serripes groenlandicus* in one, and the *Dacrydium vitreum* in four. One contained an unidentified ascidian (Ascidiacea). Parasites occurred in all stomachs. Isotopic determinations of trophic levels in the food web in NEW confirmed that both eider species sampled in the NEW were about one trophic level above the bivalve level (Hobson et al., 1995).

4.3. Common Eider

Common Eiders were not identified in the NEW area during the "Danmark Expedition", nor during "Dansk Nordøstgrønlands Expedition" (Manniche, 1910; Pedersen, 1942). They were documented breeding this far north in 1980 (Hjort et al., 1983).

4.3.1. Spring arrival and pre-breeding congregation

Common Eiders had also arrived to the NEW polynya in mid-May 1993; one pair was observed off Hanseraq Fjord on 15 May and small flocks (< 10) were encountered along the ice-edge off Eskimonæsset during the following days. From 20 May a weak northward migration (total of approx. 100 birds) was noted at Eskimonæsset, suggesting that the bulk of the Common Eiders arrive slightly later than the King Eiders.

Common Eiders were similar to King Eiders in that the only pre-breeding congregation area identified in 1993 was located off southern Kilen (Fig. 3), where about 2500 Common Eiders and 1000 King Eiders were present in mixed flocks. Only few (< 60 birds) were counted off the northern part of Kilen. Most birds seemed to be paired, and courtship display and copulation was frequently observed.

The dispersal from the congregation area took place during the second week of June (see King Eider), very similar to Common Eiders breeding at high-arctic Canadian polynyas (Prach et al., 1986).

4.3.2. Breeding population in the NEW area

In mid-June, for example, about 25 pairs of Common Eiders had gathered off Sophus Müller Næs, and 5 pairs off Sommerterasserne further south; at Eskimonæsset up to 25 pairs began reconnaissance flights over land around 20 June, indicating the beginning of the nesting period. The first nest was found on Eskimonæsset on 1 July. Subsequently, more than 50 nests were found on the coastal lowlands between Hanseraq Fjord and Amdrup Land, and on Henrik Krøyer Holme. Many broods (> 100) were later encountered along the same coast. No breeding Common Eiders have ever been found further north in North Greenland (Håkansson et al., 1981). It is therefore plausible that all the Common Eiders seen congregating during spring breed in the vicinity of the NEW polynya.

In 1993, Common Eider clutches contained 2–4 eggs, with 4 being most common. One newly hatched brood of 5 chicks was also noted. The first young were observed on 22 July at Eskimonæsset, and pulli were thereafter recorded in most places visited between Hanseraq Fjord and Antarctic Bugt, including Henrik Krøyer Holme.

4.3.3. Post-breeding

Post-breeding Common Eiders assembled off Holm Land with up to 103 males and 45 females recorded between 29 June and 3 July. Up to 65 males were seen off Mallemukfjeld 21 July and 100 males were present off southern Kilen 25 July.

4.3.4. Diet and relation to the polynya

The NEW constitutes an isolated breeding area for Common Eiders some 300 km north of other major breeding areas in eastern Greenland (Boertmann, 1994). In spring, the breeding population in the NEW relies on access to food on shallow water near the nesting area early in the season, and food analysis indicated that the diet is similar to that of King Eider: the bivalves *Hiatella arctica*, *Serripes groenlandicus* and *Dacrydium vitreum* in 3, 1 and 1 stomachs, respectively, and the polychaete *Errantia setae* in one. In 100 g dry weight of droppings from Common Eider, *Margarita groenlandicus* (Gastropoda) made up 70%, *Hiatella arctica* 10%, and *Gammarellus homari* (Gammaridae), *Errantia* sp., sea urchins (*Strongylocentrotus* sp.), and hydrozoans 5% each.

4.4. Skuas

The Long-tailed Skua (*Stercorarius longicaudus*) seems to be fairly common in and around the NEW during early summer, since at least 45 birds were seen on Kilen between 1–6 June 1993. During the first and second half of June, 12 and 11 birds, respectively, were noted at Eskimonæsset. Later on, however, the species became scarce, with only four birds being sighted along the coast through July and

August. In 1980 and 1985, very few Long-tailed Skuas were seen in the area during July and August (Hjort et al., 1983; Hjort et al., 1988). However, in the pack-ice south and east of the polynya, the species occurs fairly commonly; a total of 32 (70% of them immatures) were seen from *Polar Sea* in August 1993, in parties of up to 9 birds. Kleptoparasitism on Ivory Gull was observed several times in 1992.

The other North Atlantic skua species occur in the NEW and surroundings, but infrequently: two Pomarine Skuas (*S. pomarinus*) were seen from land in July–August 1993, and three single Arctic Skuas (*S. parasiticus*) were seen along the coast and one at Henrik Krøyer Holme; the earliest was on 9 June, the other three between 19–29 July. Two were seen on Kilen in August 1985 (Hjort et al., 1988). No indications of breeding in the area have been recorded. The Great Skua (*S. skua*) has now been recorded four times in the area, once in 1980 (Hjort et al., 1983) and thrice between 15 June and 6 August 1993, all of them single birds.

4.5. Kittiwake

4.5.1. Breeding population in the NEW area

The only known breeding colony of Kittiwakes in the NEW is at Mallemukfjeld, where 873 apparently occupied sites were counted in 1993 (Fig. 4). After adjusting for the proportion of non-breeding site holders (16%), the active breeding population were estimated at 733 pairs (Falk and Møller, 1995a). Manniche (1910) reported Kittiwakes breeding along the coastline from west of Mallemukfjeld to just north of Hanseraq Fjord, but in 1993 none were observed during visits to other seabird cliffs in the area. Manniche (1910: 163) also mentioned ''some 100 individuals'' at Mallemukfjeld and considered that ''it is however probable, that a greater number were nesting''. Thus, the colony could have been of similar size in 1907 as today, and there is no basis for assuming any significant trend in population size during this century. However, there are hints that breeding may not take place in NEW every year: In 1980 when the polynya opened particularly late (Pedersen et al., 1993), no Kittiwakes were present at Mallemukfjeld in July, and only two individuals were recorded at the eastern edge of the polynya

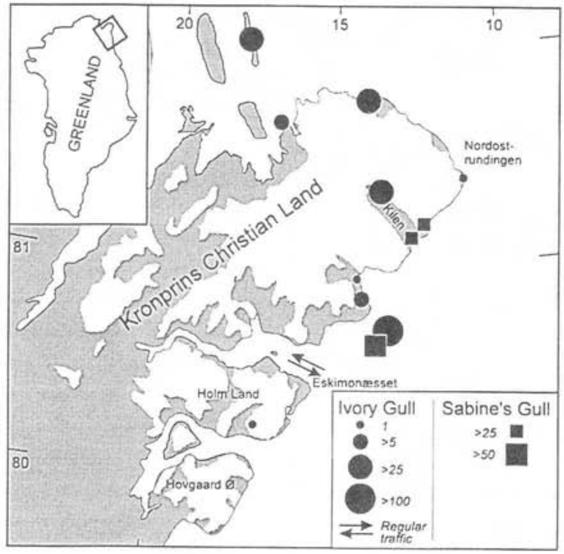

Fig. 4. Distribution of Ivory Gull and Sabine's Gull colonies (with estimated numbers of pairs) as recorded 1980–1994.

from the icebreaker *Ymer*, which made extensive surveys of the area (Hjort et al., 1987b; Mehlum, 1989). In contrast, during 1993 Kittiwakes were common, and 7.8 and 3.3 Kittiwakes per hour passed land-based observers at Eskimonæsset and Sophus Müller Næs, respectively (own unpubl. data).

The Kittiwake has recently established a small colony (8 pairs in 1989, ca 15 pairs in 1993) near Danmarkshavn about 390 km south of Mallemukfjeld (Boertmann, 1994).

Based on information from 1993 the Kittiwakes in the area laid eggs between 7 June and 10 July (mean and median 18 June). Overall clutch size was 2.03; 15% of the pairs laid 3-egg clutches. The estimated average breeding success was 1.7 chick per breeding attempt (Falk and Møller, in press).

4.5.2. Foraging distribution in the NEW

Kittiwakes were observed in most parts of the polynya in 1993, albeit in small numbers (Joiris et al., in prep.). Like other surface feeders, Kittiwakes gathered along the fast-ice edge and leads east of Hovgaard Ø, which is near the breeding colony at Mallemukfjeld. Along with Ivory Gulls, the Kittiwakes took advantage of the food—probably Polar Cod—that became exposed at the wake of the research vessels breaking ice (Kristensen and Kristensen, 1993; Joiris et al., 1994). This was particularly evident in areas where the sea ice was tinted by under-ice algae.

Kittiwakes usually forage relatively close to their breeding sites—ranges from 5 to 95 km are reported in the literature (cf. Hatch et al., 1993). Immature Kittiwakes may visit the NEW, but probably not in large numbers: very few second-year birds were recorded at sea in 1993 (for instance, only 2 of 247 individuals recorded from *Polar Sea*) and none in 1992. Immature Kittiwakes are known to concentrate in other areas, for example large groups have been noted off Northeast Iceland (Camphuysen, 1993).

4.5.3. Discussion in relation to polynya occurrence

The active breeding Kittiwake population in the NEW amounted to approximately 1500 individuals in 1993. Porter (1988) estimated that the proportion of non-breeders of breeding age (at least 3 years) was 23% of the number of breeding birds in a colony in Britain. If this figure is appropriate for the NEW population, the total number of birds of breeding age at Mallemukfjeld would be about 1800 individuals. In addition, some younger birds may visit the area, so in round figures about 2000 Kittiwakes may utilize the NEW in summer.

Due to the Kittiwake's relatively short feeding range, the breeders in NEW probably depend entirely on the production in the polynya. They may, therefore, be sensitive to the annual variations in weather, timing of summer polynya formation, and extent of the polynya. From other areas it is known that breeding Kittiwakes may fail completely in years with unfavourable conditions (Murphy et al., 1991; Hatch et al., 1993), cf. the almost total absence of Kittiwakes from the NEW in 1980, when the polynya did not expand until late June (Pedersen et al., 1993).

4.6. Ivory Gull

4.6.1. Breeding population in the NEW

The Ivory Gull is common in the NEW where breeding was first noted in 1910 (Mikkelsen, 1922). Breeding has been recorded at nine places around the polynya and along the north coast of Kronprins Christian Land (Fig. 4), where leads connect with the polynya (Salomonsen, 1961; Håkansson et al., 1981; Hjort et al., 1983, 1988). Five of these sites were on coastal or inland cliffs, the others on flat ground on the mainland coast or offshore on islands. Estimated colony sizes ranged from 5 to 300 pairs; there were also three cases of solitary breeding (Fig. 4). The largest colony was a flat-ground colony on Henrik Krøyer Holme, where c. 350 and 160 birds were counted in two sub-colonies on 4 July 1993, and where at least 125 broods of young were found on 29 July. This is the largest known colony in Greenland, and one of the largest known in the world. A minimum estimate of the total breeding population around the polynya is 400–500 pairs. More undiscovered colonies probably exist, as suggested by the regular passage of Ivory Gulls in and out of Ingolf Fjord (Fig. 4); birds moving from and towards Hovgaard Ø were also recorded by ship-based observers in 1992.

In 1993, the Ivory Gulls on Henrik Krøyer Holme had started egg laying when the islands were first visited on 4–5 July, and on 29–30 July the presence of 1–2 week old chicks indicated that laying had started shortly after mid-June (incubation period 24–25 days; Cramp, 1977–1993). During a short visit on 30 July 1994, half the nests visited contained small chicks and half contained eggs, indicating that laying that year occurred from 3 July onwards. The Ivory Gull may show considerable spread in laying date: in a small cliff colony (c. 6 pairs) on Amdrup Land both fledged juveniles and downy young were present on 10 August 1993.

4.6.2. Foraging distribution

The Ivory Gull is widespread throughout the polynya area; densities recorded from *Polar Sea* in late summer 1993 ranged between 0.2 and 2 birds/n.m.

Observations indicated that Ivory Gulls took amphipods and fish in the wake of the ice-breaking ships. Offal occasionally attracted the Ivory Gulls near the ships, and at Henrik Krøyer Holme we observed them attempting to seize eggs or chicks from nests of Sabine's Gull and Arctic Tern. Kleptoparasitism against Kittiwakes was noted several times in 1992.

4.6.3. Relation to the polynya

The breeding distribution of the Ivory Gull seems spatially related to the Northeast Water and the adjacent open leads northwestward to Peary Land. Breeding is confined to cliffs, offshore islands and glacier-surrounded lowlands where predation from Arctic Fox (*Alopex lagopus*) and Wolf (*Canis lupus*) is low or absent. The Ivory Gull is both a surface feeder and an opportunistic predator and scavenger, which makes it less dependent on direct access to the open water than other surface feeders.

4.7. Sabine's Gull

4.7.1. Breeding population in NEW

The Sabine's Gull population in the NEW area was first discovered in 1980 and further verified in 1985 (Hjort et al., 1983, 1988). Until then, the northernmost known colony in East Greenland was off Danmarkshavn about 300 km south of the NEW (Manniche, 1910; Meltofte, 1975; see also Forchhammer and Maagaard, 1991).

Sabine's Gull colonies were only found at Kilen and Henrik Krøyer Holme (Fig. 4). In 1985, 20–30 pairs were recorded on northern coastal Kilen (Hjort et al., 1988), and 75 adults were seen on southern Kilen on 25 July 1993. The observations suggest that 50 pairs or more nest in that area. On Henrik Krøyer Holme 200–300 adults were seen on 22 July 1992 (Kristensen and Kristensen, 1993), and the combined information from surveys on 4–5 and 29–30 July 1993 implies a minimum of 50 breeding pairs on the islands. The northernmost island in the group was not visited. Present data thus suggest a total breeding population in the NEW area of at least 100 pairs.

Forchhammer and Maagaard (1991) found evidence that adult non-breeders were present around the colonies off Danmarkshavn. The high number (200–300) seen on Henrik Krøyer Holme in 1992 may suggest the same. Immatures (in 1st summer plumage, hatched the previous year) have so far only been encountered on Kilen, where three were seen in early August 1985 (Hjort et al., 1988).

In 1993, Sabine's Gulls were present on Kilen during the first survey on 3–6 June, 2–3 weeks earlier than the arrival time estimated in 1980 and 1985 (Hjort et al., 1983, 1988). The presence of several one week old young on Henrik Krøyer Holme 30 July 1993 indicates that eggs were laid around 1 July, as was the case on Kilen in 1985 and off Danmarkshavn in 1987, 1988 and 1990 (Forchhammer and Maagaard, 1991). The incubation period is 23–25 days (Cramp, 1977–1993).

Breeding success is likely to vary depending on accessibility to the colony for mammalian predators. The known breeding areas both offer some protection against Arctic Foxes and Wolves. Kilen is surrounded by at least 20 km of glaciers in all directions except along the coast, and Henrik Krøyer Holme is protected by its offshore position. Although Wolf and fox tracks were seen, and an abandoned fox-den was found on Henrik Krøyer Holme, the birds may at least in some years experience a low predation level (1985 on Kilen and 1993 on Henrik Krøyer Holme). Both Glaucous Gulls and Ivory Gulls on Henrik Krøyer Holme probably prey on Sabine's Gull eggs and young (cf. Hjort et al., 1988).

4.7.2. Foraging distribution

The pelagic observations of Sabine's Gull in and around the NEW are few, totalling only 12 birds during the 1992 and 1993 *Polar Sea* and *Polarstern* cruises (Joiris et al., in prep.). Only one single Sabine's Gull was seen off the coast here during the *Ymer*-cruise in 1980 (Mehlum, 1989). The species thus seems to be a short-range coastal forager during the breeding season. During helicopter surveys (e.g. on 15 June 1993; see Joiris et al., 1994) 75–100 birds were observed foraging along the glacier front in Antarctic Bugt south of Kilen, probably utilizing food production related to upwelling water along the glacier (c.f. Mehlum, 1984). Such concentrated foraging behaviour was also noted by Forchhammer and Maagaard (1991) at the colonies off Danmarkshavn. No observations on the diet of Sabine's Gull have been made in the NEW area.

4.7.3. Relation to the polynya

As other ground nesting species, the Sabine's Gull population along the NEW takes advantage of relatively predator-free breeding habitats. Farther south in East Greenland colonies are mostly located on islands, often associated with early open water, where breeding may fail completely in years with late ice breakup (e.g. Forchhammer and Maagaard, 1991). In 1992, when an ice-bridge remained most of the summer between Amdrup Land and Henrik Krøyer Holme, the Sabine's Gulls apparently failed to produce chicks (Kristensen and Kristensen, 1993).

4.8. Ross's Gull

The observers of the *Ymer*-expedition in July-September 1980 established that substantial numbers of Ross's Gulls frequent the ice-filled waters north and northeast of Svalbard, and although the density of birds decreases towards the west, their range extends westwards to northeasternmost Greenland (Meltofte et al., 1981). The birds are believed to be non-breeders and failed breeders, since successful breeders remain on the East-Siberian breeding grounds until late July–early August (Potapov, 1990).

Ross's Gulls were encountered during the NEW-cruises in both 1992 and 1993 (Joiris et al., in prep.). To summarize the observations from the *Polar Sea*, a total of 238 Ross's Gulls were seen in 1993, of which most occurred east of 10°W, between 79° and 81°N. Average densities here were about 0.5 birds/n.m. Some were also seen in the eastern part of the polynya proper, penetrating some distance into ice-free waters. Few were seen in the pack-ice south of 80°N and west of 10°W (0.04 birds/n.m.). The species was much scarcer in 1992, only 29 were seen, all within a limited area between 80°18′–80°30′N and 8°43′–9°40′W (Kristensen and Kristensen, 1993).

Ross's Gulls seemed to prefer leads between large floes where they picked minute food items from the calm surface of the water, and where they found shelter from the wind at the lee side of the floes. They showed little interest in the ship but occasionally followed it for a while, generally staying far behind and so avoiding close encounters with Fulmars and Ivory Gulls in the ship's wake.

Ross's Gull has occasionally bred far outside its main breeding range between the Lena and Kolyma rivers in Siberia. Nesting has been recorded twice in northeasternmost Greenland, in 1979 in Peary Land (Hjort, 1980) and in 1993 on Henrik Krøyer Holme in the NEW.

4.9. Glaucous Gull

4.9.1. Breeding population in NEW

Twenty-two pairs of Glaucous Gulls nested at the six Fulmar cliffs, although this may be an underestimate (Falk and Møller, 1995a). The total number of Glaucous Gulls in the polynya is not known, but the species breeds on several other small colonies in the area (for example, on Henrik Krøyer Holme). The total population probably does not exceed a few hundred birds.

There are no data on breeding phenology except that one pair at Mallemukfjeld had laid on 1 June, and 2 newly hatched chicks occurred on 30 June.

4.9.2. Relation to the polynya

Glaucous Gulls are opportunistic foragers and powerful predators. Old pellets and prey remains accumulated around a gull nest at Mallemukfjeld showed that fish (Polar Cod), remnants of seals, and lemmings (*Dicrostonyx torquatus*) as well as Fulmars and Kittiwakes had been important in gull diet in previous years. Gulls were constantly patrolling the cliffs at Mallemukfjeld, and several eggs and chicks of Fulmars and Kittiwakes disappeared from the nests during the survey period. The Glaucous Gulls could obtain a considerable part of their food during the summer by preying upon the other species.

4.10. Arctic Tern

In 1993, the Arctic Terns arrived at the NEW in early June: six birds were seen off Kilen on 2 June. At Eskimonæsset, the first terns were noted on 11 June, and up to 10 birds remained throughout the month. Persistent nest defence behaviour started at the end of June and the first nest was found on Eskimonæsset on 2 July. Clutch sizes were 2–3 eggs. Small chicks were found at Hanseraq Fjord on 24 July and on Krøyer Holme 30 July (incubation period c. 22 days; Cramp, 1977–1993).

Solitary pairs bred along the coast of Holm Land and a colony of c. 25 pairs nested on an islet in Hanseraq Fjord. On Henrik Krøyer Holme, a colony of more than 100 birds was found on the southern tip of the main island and some 80 birds were encountered on the southern island. Scattered pairs also nested on Amdrup Land. The total tern population in NEW is fairly small, probably not exceeding 1000 birds.

4.11. Auks

Four auk species occur infrequently in the NEW, but only one of them, the Black Guillemot (*Cepphus* *grylle*), breeds in the area. At Mallemukfjeld, up to 20 Black Guillemots foraged daily along the ice-edge below the cliffs. Occasionally, a few were flying along the cliff edge, one carrying a fish on 29 July. Other possible breeding locations are Hanseraq Fjord (one pair on 3 August), Dværgfjorden (4 birds on 5 August), and Henrik Krøyer Holme (3 birds on 29 July).

Thick-billed Murres (*Uria lomvia*) occur sparsely at sea in and around the polynya, in open water or in leads in the pack-ice (Hjort et al., 1987b; Mehlum, 1989; Joiris et al., in prep.).

The Dovekie (*Alle alle*) occurs sparsely in the NEW (Mehlum, 1989). In 1993, it was mainly confined to the pack-ice south of the polynya. Only two birds were seen from land.

An adult Atlantic Puffin (*Fratercula arctica*) foraged near Mallemukfjeld on 30 July 1992. This is the first record from the NEW area.

4.12. Other species

One pair of Red Phalaropes (*Phalaropus fulicarius*) were seen off Eskimonæsset on 23 June, and 1 + 3 further off the coast in June/July (Joiris et al., 1994). On Henrik Krøyer Holme, 3 females, 2 males and one pair were seen on the southern island on 5 July, and one male on the main island on 29 July. One female was also seen here in late July 1992, and 2 birds on 30 July 1994. The species probably breeds on Henrik Krøyer Holme, but some of the observed birds could be migrants. Southward passage through the area (of Siberian, transpolar migrants?) was noted on Kilen in 1985 (Hjort et al., 1988).

Red-throated Divers (*Gavia stellata*) were recorded in small numbers (max. 5) around Eskimonæsset and near Mallemukfjeld in 1993. A nest with 2 eggs (5 July 1993) on the southern islet of Henrik Krøyer Holme, and an incubating bird at Sophus Müller Næs in August are the first breeding records in the NEW area. It is presumably a scarce breeder all along the north coast of Greenland (Boertmann, 1994).

The Long-tailed Duck (*Clangula hyemalis*) was seen near Mallemukfjeld in 1907, and found breeding at Kilen in 1985 (Manniche, 1910; Hjort et al., 1988). In 1993, 8 birds and one nest with eggs was found on Henrik Krøyer Holme; up to 7 birds stayed around Eskimonæsset between 21 and 25 June, and 3 birds off Kilen 2–5 June.

5. Bird fauna at archaeological sites by the NEW

The only bird bone found in the paleoeskimo site at Eskimonæsset was from a Fulmar, dating from 800–400 BC. The more recent Thule culture, however, left more clues: at Eskimonæsset bones were found in a 15th century tent ring that is normally associated with spring and summer habitation (Bay et al., 1995): King Eider, unidentified eiders, Fulmar, Ivory Gull, unidentified gulls, and a probable Brent Goose. A Thule ruin at Sophus Müller Næs, also from the 15th century, contained bones from Arctic Tern, Fulmar and eider; Ivory Gull remnants were also found at Dværgfjorden, in a site probably dating from the 15th century.

Although bird bones generally are poorly preserved in archaeological fauna assemblages—as was the case for these sites in the NEW area—the findings do suggest that birds were not hunted in large quantity. But birds may have been used to fill gaps in food provisioning when access to other game species was difficult. Also, bird eggs are generally important to eskimos in spring, but no egg shells were found in this survey. However, at Henrik Krøyer Holme we found paleoeskimo camps without any of the durable bones from seals or Walrus, implying that these camps could have been set up to exploit other resources that are hard to trace in the ruins. The camps would have been perfect bases for collecting eggs of eiders, gulls and terns if they did breed then on these islands (Bay et al., 1995).

The archaeological findings suggest that the seabird community hunted by the prehistoric people inhabiting the NEW area was similar to the present.

6. Seabird use of the resources in the NEW polynya

With the Fulmar as a possible exception, all the seabirds breeding in the NEW area have to obtain all their food for maintenance and reproduction from the polynya and its immediate surroundings.

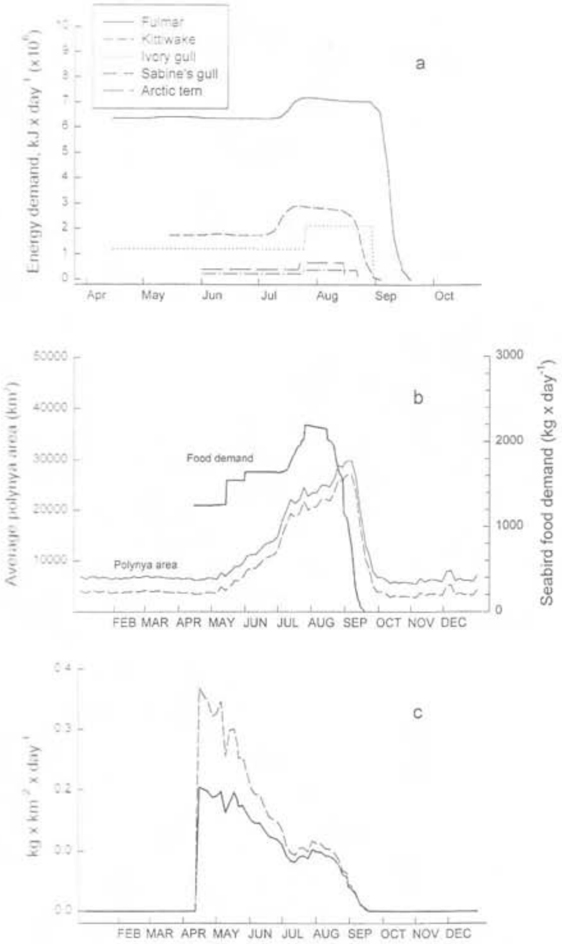

Fig. 5. Estimated energy/food demand by surface feeders in the NEW polynya in relation to average polynya open water area as measured from satellite imageries (Pedersen et al., 1993): (a) energy requirements in kJ/day for each of five seabird species (population estimates from Table 1), (b) total food demand in kg/day by the surface feeders, and the seasonal changes in polynya area (average for 1978–1990), (c) annual change in seabird food demand per unit area of open water in NEW, using ice index given by Pedersen et al. (1993) (solid line), or assuming −5% error in the index (dotted line, see text).

An estimate of seasonal variation in energy/food requirements of the surface-feeders is summarized in Fig. 5. For Fulmar and Kittiwake, data from the NEW colonies on the spread of laying/hatching dates and of chick survival rates have been applied, whereas for other species, for which local data are lacking, we have applied best estimates of median dates (Table 2). By far the majority of the seabirds breeding at the NEW are surface feeders. Assuming a mixed diet of zooplankton and fish (Bradstreet and Cross, 1982) with an average energy content of 6 kJ/g wet weight (a high value relevant to summer conditions only, Diamond et al., 1993), the five species considered consume an estimated total of 243,000 kg during the breeding season. Of this, 67% is ingested by the Fulmars, 15% by the Kittiwakes, and 14%, 2.5% and 1.6%, respectively, by Ivory Gulls, Arctic Terns and Sabine's Gulls (Table 2).

The total food demand of the species concerned gradually increases along with polynya area, and the peak is reached during late July–early August. Thereafter it drops sharply when young fledge and birds leave the area by August–September (Fig. 5b).

Since the Fulmars, Ivory Gulls, and probably even Kittiwakes, arrive in the breeding area before the polynya starts to expand in May, the peak energy demand *in relation to area of open water* occurs in early spring, when the total daily food requirement amounts to about 0.2 kg/km^2 of open water (Fig. 5c, solid line). Compared to other arctic areas, summarized by Diamond et al. (1993), this figure is extremely low: seabirds require from 0.5 (Hudson Bay) to 10.3 kg km^{-2} day^{-1} (Baffin Bay/Lancaster Sound) in May, and up to 25.5 kg km^{-2} day^{-1}in August (Baffin Bay/Lancaster Sound). In these areas, however, a very large proportion of the food demand refers to diving species (in July approximately 90%), in particular the Thick-billed Murre; the surface feeders only require between 0.1 kg km^{-2} day^{-1} (Hudson Bay and Strait) and 2.3 kg km^{-2} day^{-1}(Baffin Bay/Lancaster Sound) in July, and up to 8.8 kg km^{-2} day^{-1} in August (Baffin Bay/Lancaster Sound).

The estimates of open water area in the NEW polynya are based on ice index values generated from interpretations of satellite pictures (Pedersen et al., 1993). There may be a systematic error of up to ±5% in the ice index (L.T. Pedersen, pers. comm., 1995). For a "worst case ice scenario" (approx. 94% ice index before the summer polynya opens) the seabird food requirement per unit area of open water is doubled in early spring (Fig. 5c, dotted line).

In terms of carbon flux, the total transfer to the breeding populations of all surface feeders in the NEW polynya consume a minimum of 27,146 kg C annually between 15 April and 10 September. Relating this figure to the area of open water available to them, the highest demand (average for the entire polynya area) in spring is as low as 0.00003 g C m^{-2} day^{-1}, and gradually decreasing to zero by early September when the birds leave the high Arctic.

Now, if the seabird's food requirements really are that low, can the polynya provide adequate food to the surface feeders? In the NEW polynya Hirche et al. (1994) found that "the macrozooplankton data show an extremely low overall abundance and biomass during spring" that were "among the lowest ever recorded for boreal and polar regions". At two sampling stations within the NEW in 1991 the total biomass of all macrozooplankton (> 1 cm) taxa collected averaged 1.5 mg ash-free dry weight (AFDW) per m^3 (Hirche et al., 1994). Using the conversion factors adopted by Hirche et al., this corresponds to 10.6 mg wet weight/m^3. If we assume that this density is applicable to the upper 1 m surface layer potentially accessible to most surface feeding seabirds, a total of 10.6 kg macrozooplankton per km^2 may be available to them in spring. This estimate includes fish larvae, but not full grown fish and the small calanoid copepods (mesoplankton) that may also be taken by seabirds. If the seabirds require at least 0.2 kg/km^2 per day as estimated here, it appears that the zooplankton biomass could restrict seabird foraging; although the seabird populations are small, they may be limited by food availability in spring.

In the marginal ice zone towards the Atlantic, Hirche et al. (1994) recorded about twice as much macrozooplankton (2.7 mg AFDW/m^3) as found at the polynya sampling stations, mainly due to the occurrence of boreal euphausiids. The ship-based seabird surveys found higher densities of several species (of unknown origin), including the Fulmar, in the outer marginal ice zone than within the NEW polynya (Joiris et al., in prep.).

Only small populations of diving seabirds occur in the NEW; Black Guillemot and Red-throated Diver are scarce breeders, and the typical high-arctic seabirds Dovekie and Thick-billed Murre that are abundant at "neighbouring" Spitsbergen visit the polynya in small numbers during summer. The Black Guillemot can utilize a special niche, feeding on the under-ice fauna (Bradstreet, 1980; Bradstreet and Cross, 1982), and it seems to be the only seabird species capable of wintering in the high Arctic (Renaud and Bradstreet, 1980). The true diving zooplankter, the Dovekie, that have been shown to feed on calanoid copepods and amphipods in marginal ice zones in the Barents Sea (Mehlum, 1990) would have little food competition from other seabirds in the NEW area. But the extremely low abundance of all zooplankton might prevent the Dovekie from establishing colonies in the area.

If the polynya production sustained a considerable stock of Polar Cod (*Boreogadus saida*) there might be an unexploited niche for the murre—a pursuit diver preying on fish and zooplankton. Although fish stocks in NEW have not been quantified, available information suggests they may be poor (Hirche et al., 1994; Fortier et al., 1994). Nevertheless, the murre may not be barred from breeding in the area due to poor food availability alone, ice conditions may be another impediment: murre chicks cannot fly when they leave the colony and initiate a swimming migration. It would be very difficult for flightless murres to swim through the broad zone of pack ice between the NEW and the open sea.

In NEW, zooplankton seems to provide a weak coupling between the primary production and higher trophic levels in the pelagic food web, and the main part of the primary production may sediment and support a benthic food web (Hirche et al., 1994). This should benefit benthic foragers instead of surface feeding seabirds (Hunt, 1991), and the pre-breeding congregations of eiders are evidence of favourable local foraging conditions. However, since the eiders need access to shallow water, preferably much shallower than their maximum diving capacity of approximately 50 m, ice cover may limit the available foraging area in the polynya. According to available information on the bathymetry of the area, waters shallower than 50 m occur off shore at the Belgica Bank and at the Ob Bank south of Nordostrundingen (Schneider and Budéus, 1995) and, of course, as a narrow strip along the coast. Recurring open water occurs in spring between Nordostrundingen and Amdrup Land, so the coastal part of Ob Bank is the only extensive area potentially available to the eiders (Fig. 3). Indeed, that is where the pre-breeding congregations were located in 1993.

If we assume that each of the 3500 eiders reside

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in this area for 30 days, and consume about 2 kg invertebrates each day (including shells etc., Guillemette et al., 1992), they take at least 210,000 kg of the benthic invertebrates. If roughly half the birds are females that have to store energy for egg formation and incubation even more than 300,000 kg may be required. The total carbon transfer to the eiders is approximately 7245 kg C annually. Since they mainly forage at Ob Bank, where roughly 1400 km^2 of open water may be available to the eiders in spring (judged from satellite image of 27 May 1993, Fig. 3), the total transfer may be estimated at 0.0051 $g\ C/m^2$ year. Most of the food is consumed in the period mid-May to the end of June, when the turnover may be around 0.00012 $g\ C\ m^{-2}\ day^{-1}$. There is no quantitative information on prey density of the species utilized by the eiders on the Ob Bank for comparison with this consumption estimate (D. Piepenburg, pers. comm., 1995). It seems clear, however, that the prevailing ice conditions, ensuring open water near Kilen, are crucial to the eiders—they have no alternative areas to exploit. Any annual variation in ice cover that might hinder early-season polynya formation here would have immediate impact on the Common Eiders along the NEW, and on the King Eiders breeding in the inland tundra areas.

Although these projections on food consumption for the NEW populations are speculative, there is a congruence between the oceanographic and marine production studies and the seabird surveys. Both identify the NEW polynya as a relatively poor pelagic environment for secondary and tertiary consumers.

7. Conclusions

The information available on the bird fauna in or adjacent to the NEW polynya has developed substantially since 1980, and the NEW/NEWland efforts were significant steps that provided a reference for future monitoring of the polynya environment.

The polynya has allowed seabird populations to become established in this extreme high-arctic area, but the small populations of the breeding seabird species are evidence of generally sparse food supplies (low carrying capacity). Apart from the benthic-foraging eiders, the seabirds here are surface feeders.

The annual variation in ice and weather conditions affect the breeding performance of the birds, and available information suggests that the Kittiwake population was almost absent from the area in 1980 when the polynya opened very late. Quantitative information on breeding success is available for only one season (1993), which appears to have been favourable with high breeding output for Fulmars and Kittiwakes, and, apparently, Ivory Gulls. Nevertheless, comparison with other studies on Fulmar breeding behaviour suggested that Fulmars did not enjoy optimal foraging conditions even in 1993. Also, preliminary estimates of food demands versus availability hint at generally poor feeding conditions within the polynya, especially in spring.

To appraise seabird ecology in high-arctic polynyas, it would be valuable if future programmes could measure reproductive output in a number of species over several years.

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