

Late winter distribution and abundance of sea-associated birds in south-western Greenland, the Davis Strait and southern Baffin Bay

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Sea-associated birds were recorded during systematic aerial surveys of marine mammals in south-western Greenland, the Davis Strait and southern Baffin Bay in March 1981, 1982, 1991, 1993 and in April 1990. Most surveys included the northern part of the south-west Greenland Open Water Area, which in most years lies between 62° and 67°N, but none of the area south of 63°N was surveyed. The bird data are generally semi-quantitative and provide information on distribution and relative abundance in different areas during different years, under different ice conditions.

In all years, regardless of ice conditions, large concentrations of king eiders *Somateria spectabilis* were found in waters <50 m deep on the shallow banks off south-west Greenland, especially on the northern portion of the Store Hellefiskebanke. We estimate that in 1981 and 1982 about 270 000 king eiders overwintered on the banks off south-west Greenland.

Compared to king eiders, flocks of common eiders *Somateria mollissima* were considerably more dispersed. They were found mainly close to shore off south-west Greenland, where they were distributed along rocky coastlines.

A few thousands of large guillemots *Uria spp.* were recorded in the study area in March 1981, 1982, 1991 and 1993, but large numbers (>65 000 birds) were recorded north of the south-west Greenland Open Water Area in April 1990, indicating that northward spring migration was underway at this time.

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Introduction

The south-west Greenland Open Water Area (Fig. 1) is known to be an important overwintering and staging area for many sea-associated birds when Baffin Bay and the northern and western portions of Davis Strait are ice-covered (Brown & Nettleship 1981). The south-west Greenland Open Water Area is not a true polynya, because it is open to the Labrador Sea south of the Greenland continental shelf. However, it provides early spring access to foraging for staging seabirds en route to breeding areas further north, as well as foraging areas for seabirds breeding in the area, as described for polynyas elsewhere in the Arctic (Brown & Nettleship 1981; Prach et al. 1981; Bradstreet 1982; Stirling 1997). Compared with populations further north in Baffin Bay (73–78°N) (Kampp et al. 1994; Boertmann et al. 1996), breeding populations of alcids and eiders in the south-west Greenland Open Water Area are small. The main importance of the south-west Greenland Open Water Area to seabird populations is as a northern

staging and wintering area. Large numbers of king eiders *Somateria spectabilis*, common eiders *S. mollissima* and Brünnich's guillemots *Uria lomvia* reportedly overwinter in the south-west Greenland Open Water Area (Salomonsen 1950, 1967, 1990; Abraham & Finney 1986; Reed & Erskine 1986; Boertmann 1994). Hunting bag records for the area during winter (125 000 Brünnich's guillemot and 50 000 eider spp. reported taken by hunters during winter 1995–96) further illustrate the importance of the area during winter (Mosbech, Boertmann et al. 1998).

Very few systematic surveys of overwintering birds have been conducted in south-western Greenland, the Davis Strait and southern Baffin Bay, and detailed information about the winter distribution, abundance and habitat preferences of sea-associated birds in this area is still limited. Such information is now particularly important because of the need (1) to conduct environmental impact assessments related to proposed oil exploration in the area (Mosbech, Dietz et al. 1996), and (2) to develop plans for the sustainable

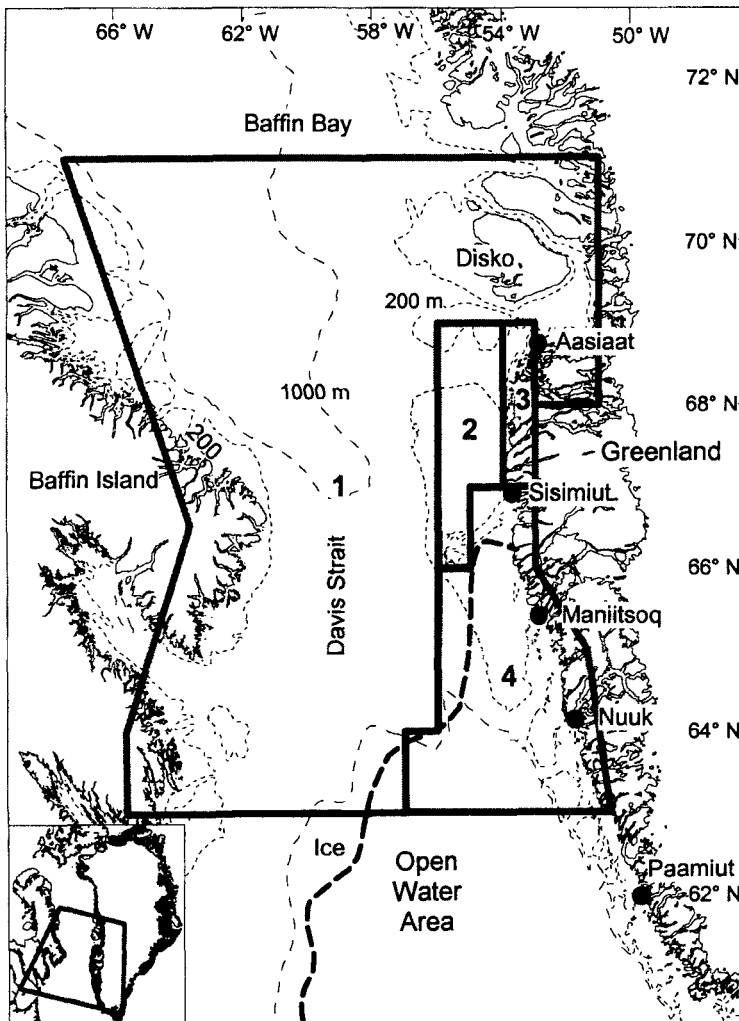


Fig. 1. Davis Strait and southern Baffin Bay with line (bold dashed) of average ice concentration of 50% in March (the month with the most extensive ice cover). 200 m isobath = short dashed line; 1000 m isobath = long dashed line. Main survey regions: 1) northern and western Davis Strait; 2) shelf north of the south-west Greenland Open Water Area; 3) coastal lead north of the south-west Greenland Open Water Area; and 4) northern part of the south-west Greenland Open Water Area.

management of the different populations of sea-associated birds using the area (CAFF 1996, 1997; Elliot 1997).

MacLaren-Marex (1979) conducted aerial surveys of marine mammals and birds in the southern Davis Strait in March 1978, but those surveys excluded most of the principal seabird wintering areas off south-west Greenland. Ship-based winter surveys were conducted in south-west Greenland coastal areas between 61°N and 64°N in February and March 1989 (Durinck & Falk 1996). The seabird atlas developed by the Canadian Wildlife Service (Brown et al. 1975; Brown 1986) was based primarily on ship-based surveys conducted between 1969 and 1983 and only covered the Davis Strait region during the July–October open

water period. The spring migration of seabirds in western Baffin Bay was studied by conducting systematic aerial surveys during late winter through spring (McLaren 1982; McLaren & McLaren 1982; Renaud et al. 1982).

This paper reports the distribution (including concentration areas) and relative abundance of sea-associated birds recorded during systematic aerial surveys of marine mammals in March 1981, 1982, 1991, 1993 and in April 1990. The 1981 and 1982 surveys were conducted in relation to potential year-round ice-breaking and shipping activity by tankers carrying Liquefied Natural Gas (LNG) from the Canadian High Arctic to southern markets via the relatively ice-free route along south-west Greenland (McLaren & Davis 1983;

Koski & Davis 1994). The objective of the surveys was to determine the distribution and abundance of marine mammals, mainly white whale *Delphinapterus leucas* and narwhal *Monodon monoceros*, in southern Baffin Bay and Davis Strait. The 1990, 1991 and 1993 surveys were conducted to monitor trends in white whale abundance in southwest Greenland (Heide-Jørgensen et al. 1993; Heide-Jørgensen & Reeves 1996).

Study area

The Davis Strait environment

The oceanography of the western and northern part of the Davis Strait and Baffin Bay (Fig. 1, Region 1) is dominated by the cold, southward flowing Labrador Current. During winter months, this area is typically dominated by dense pack ice. The eastern part of the Davis Strait is dominated by the northward flowing West Greenland Current. The surface layer (0–150 m) of the West Greenland Current consists of a cold, relatively fresh, water mass of polar origin from the East Greenland Current and an underlying layer (150–800 m) of warm and more saline water from the Irminger Current, a branch of the North Atlantic Current (Valeur et al. 1997). Mixing and heat diffusion between the two layers create a year-round open water area along south-west Greenland. Although ice conditions vary from year to year, this year-round open water area, here referred to as the south-west Greenland Open Water Area (Fig. 1), usually extends from Paamiut (62°N) in the south to Sisimiut (67°N) in the north (Valeur et al. 1996, 1997).

In most years, there is a narrow lead of open water (West Greenland Coastal Lead), with ice cover ranging from 0/10 to 5/10 stretching north along the coast or fast ice edge from the south-west Greenland Open Water Area towards Disko Bay (Fig. 1, Region 3). On the banks and continental shelf north and west of the south-west Greenland Open Water Area (Fig. 1, Region 2), there is usually first-year pack ice ranging from 1/10 to 8/10 coverage. Further offshore (Region 1), the ice cover is considerably denser; west of 56°W the pack ice ranges from 9/10 to 10/10 coverage. Ice cover in this offshore system is dynamic, however, and small cracks and leads may be present even in dense and heavily consolidated pack ice.

The south-west Greenland continental shelf is up to 120 km wide in the north and narrows down to 50 km in the south. It includes several large shoals or banks which range in depth from 20 m to 100 m. The coast and shelf off south-western Greenland are characterized by upwelling of nutrients from the bottom waters and stable stratification of water masses during summer. These are considered the most biologically productive areas in the Davis Strait (Steemann-Nielsen & Hansen 1961; Smidt 1979). The primary production in coastal waters shows a steep increase in March, a peak in April and remains high (with one or two maxima) during summer. The zooplankton biomass falls to a minimum in early spring and reaches a prolonged maximum in summer and autumn (Smidt 1979). Annual primary production is estimated to be $160 \text{ g C m}^{-2} \text{ year}^{-1}$ (Smidt 1979). The productivity of the marginal ice zone in this area has not been studied in winter and spring, and zooplankton and sympagic fauna available for seabird foraging have not been assessed. Thus it is not known if there is an ice-related coupling of primary production and seabird prey availability in the marginal ice zone in the area, as described by Hunt (1991) for other polar regions. It is known, however, that polar cod year classes I and II associate with the under-ice epontic community, and that they are a principal prey species for seabirds in pelagic ice-covered waters in both the Canadian High Arctic (Bradstreet & Cross 1982) and the eastern Svalbard region (Mehlum & Gabrielsen 1993).

Ice conditions during aerial surveys

Ice conditions during the aerial survey periods in all years are summarized in Table 1 and are based on descriptions in McLaren & Davis (1983), Heide-Jørgensen et al. (1993), Koski & Davis (1994) and Heide-Jørgensen & Reeves (1996). March 1981 was characterized by relatively little ice; a broad ice-free coastal zone and ice concentrations less than 8/10 were recorded on the banks. In contrast, March 1982 was characterized by heavy ice conditions with only a narrow coastal zone of unconsolidated ice cover north of 67°N and compact ice cover ranging from 9/10 to 10/10 on the western part of Store Hellefiskebanke. Ice conditions during 1990, 1991 and 1993 were intermediate between 1981 and 1982, with some compact ice on the north-western part of

Table 1. Estimates of ice cover (in tenths) during periods when aerial surveys were conducted.

Survey location	Year of Survey				
	1981	1982	1990	1991	1993
Shelf west of banks and north of 67°N	6–8	9–10	7–10	7–10	7–9
Northern Store Hellefiskebanke	6–8	8–10	7–10	4–6	6–8
Southern Store Hellefiskebanke	6–8	6–8	4–6	4–6	4–6
Lille Hellefiskebanke	4–6	6–8	4–6	0–4	0–4
Sukkertoppen Banke	0	6–8	ns ^a	ns	ns
Fyllas Banke	0	4–6	ns	ns	ns
Coast and fast ice edge north of 67°N	0	0–10	0–8	0–10	0–6
Coast and fast ice edge south of 67°N	0	0–8	0	0	0

^ans indicates that this area was not surveyed in this year.

Store Hellefiskebanke in 1990 and some compact ice on the north-eastern part of Store Hellefiskebanke in 1991. The winter of 1993 was extremely cold but gales created leads and cracks before the surveys started. Although most of these open water areas refroze during the survey period in 1993, substantial open water persisted in the area south of 68°N.

Methods

Aerial survey design

All aerial surveys were designed to obtain quantitative information on the distribution, relative abundance, and habitat use of marine mammals in the study area during winter. The 1981 surveys were conducted without prior knowledge of the distributions of marine mammals; thus relatively equal survey effort was spread over the entire study area (Fig. 2). In 1982, the survey effort focused on the area of open pack ice off West Greenland, from 66°N to 69°30'N, where most marine mammals were seen during the 1981 surveys. This area was surveyed twice in 1982, during 10–17 March (1982A) and again during 21–24 March (1982B). The 1982A survey also covered the closed pack ice further north, and the south-west Greenland Open Water Area north of 63°N.

Surveys in 1990, 1991 and 1993 covered the pack ice east of 56°W and from 66°N to 71°N, north of the south-west Greenland Open Water Area (Fig. 3). In 1993, the southern part of this area was surveyed twice, 16–20 March (1993A) and again 21–23 March (1993B). Surveys in 1981,

1982, 1991 and 1993 were conducted in mid- to late March; the 1990 survey was conducted in mid-April.

Survey procedures

The 1981 and 1982 surveys were conducted from a DeHavilland Twin Otter fixed-wing aircraft equipped with a radar altimeter and an Omega VLF Global Navigation System. Each transect consisted of two 800 m wide strips, one on each side of the aircraft. A blind strip 200 m wide beneath the aircraft reduced the effective transect width to 1400 m. Transects were generally orien-

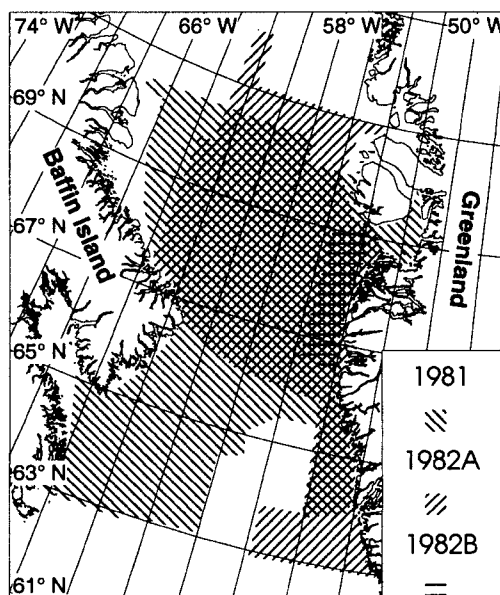


Fig. 2. Survey areas in 1981–82.

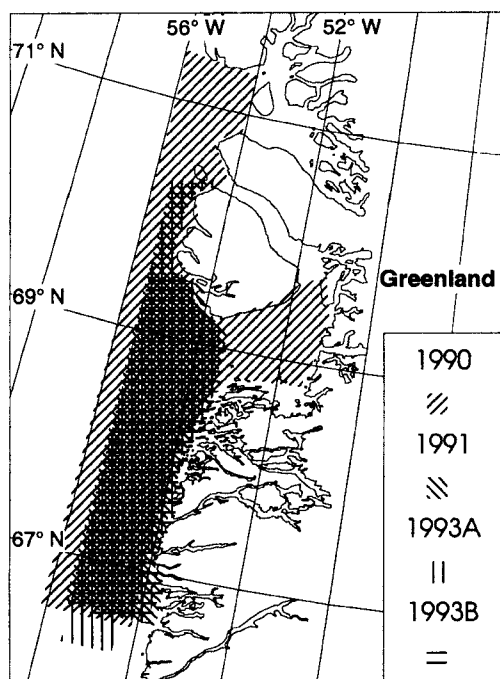


Fig. 3. Survey areas in 1990-93.

tated along lines of longitude and latitude and surveys were flown at an altitude of 150 m (482 feet) a.s.l. with a groundspeed of 200-240 km/h (108-130 knots).

Transects were subdivided into segments using a timer that produced a tone at two minute intervals to facilitate later determination of the positions of the observations. At a speed of about 220 km/h, each interval represented a segment length of approximately 7.3 km. At the end of each interval, such information as exact time, weather, visibility, ice conditions and sea state was recorded into a portable tape recorder. Information concerning all bird sightings, e.g. species identification, number of individuals, age, sex, behaviour and whether on- or off-transect were also recorded into the tape recorder. Individuals or groups sighted within the transect strip were considered "on-transect"; those sighted outside the strip were considered "off-transect". Whether sightings were on-transect or off-transect was determined with a hand-held inclinometer.

The 1990-93 surveys were conducted in a Partenavia Observer fixed-wing aircraft equipped with a Global Positioning System (GPS) and a

radar altimeter. These surveys were flown at a slightly higher altitude of 213-229 m (684-735 feet) a.s.l. and at a slower groundspeed of 156-203 km/h (84-110 knots) than during the 1981-82 surveys. At five second intervals the position of the aircraft was automatically logged on a portable laptop computer linked to the GPS system to facilitate later determination of the positions of the observations. Observations were recorded on tape via a headset microphone, and an automatic time signal was recorded concurrently with the observation on another track on the same tape. Percent ice cover and ice type were estimated every two minutes. In all years surveys were terminated when the sea state exceeded 3 on the Beaufort scale.

Bird observations and data analyses

In the 1981-82 surveys there was one observer at each side of the aircraft. All bird sightings were classified as either on-transect or off-transect and most taxa were identifiable and recorded as species. Some taxa were lumped, however: "eider spp." included undifferentiated common and king eiders; "large guillemots" included unidentified large alcids such as Brünnich's guillemot *Uria lomvia*, common guillemot *U. aalge* and razorbill *Alca torda*, but not black guillemot *Cephus grylle*; and some "glaucous gull" *Larus hyperboreus* sightings no doubt included some Iceland gulls *L. glaucoides*. Some small species, such as ivory gulls *Pagophila eburnea* and little auk *Alle alle*, are very difficult to detect and many were probably overlooked during the aerial surveys. These species were thus not included in our quantitative analyses.

During 1990, 1991 and 1993 most bird observations were recorded by the pilot, who had extensive experience in conducting bird surveys. Forward visibility was good, and he recorded observations on both sides of the aircraft. However, distance information or on-/off-transect information was not recorded. In 1991 and 1993, only eider spp. and large guillemot spp. were recorded systematically, and in 1990 only large guillemots spp. were recorded systematically. In addition, three large flocks of king eiders seen in 1993 were photographed and counted from the photos. Behaviour (flying, swimming or sitting on the ice) was recorded in some surveys; however, in this study all behaviour observations are combined.

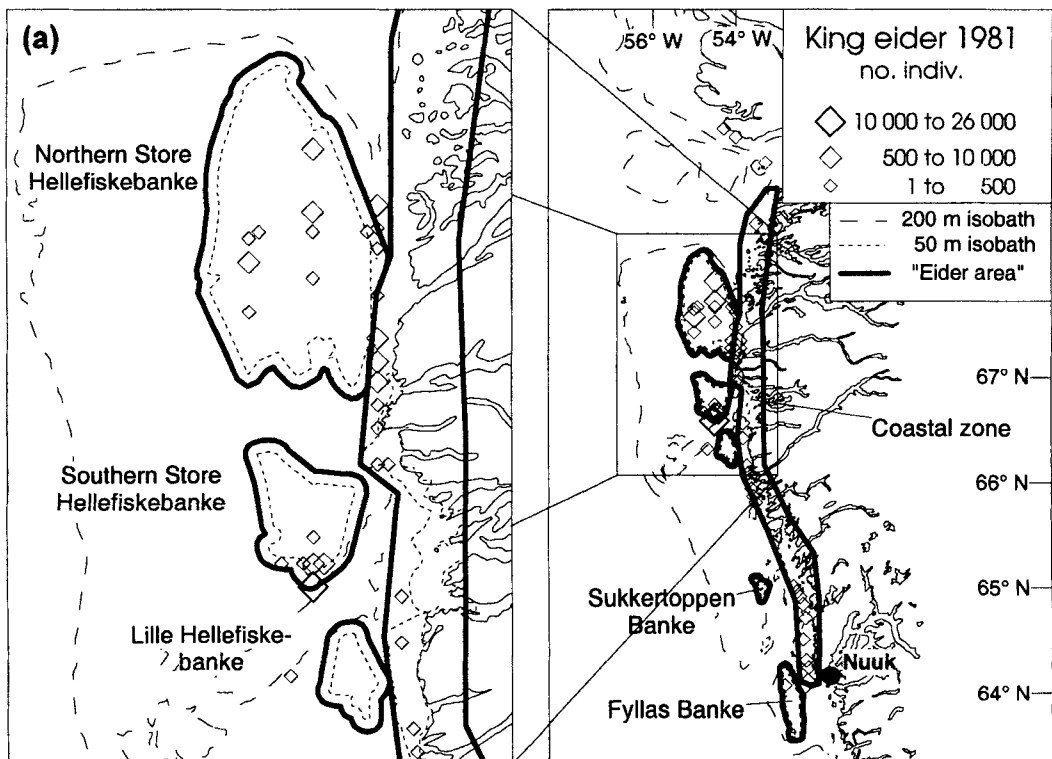
Because of the high altitude (150 m) maintained during the 1981–82 surveys of marine mammals, it is likely that some birds – especially toward the outer part of the strip – went undetected (see Pollock & Kendall 1987). Because of this detection problem, surveys of birds in 1981 and 1982 were regarded as semi-quantitative and thus provided only relative densities within the survey area. In 1990, 1991 and 1993 observations were recorded without information on transect width, or distance from transect mid-line. However, as a crude approximation, we assumed an observation efficiency (effective search width) equivalent to the 1400 m effective transect width in the 1981 and 1982 surveys. Thus the relative abundances in 1990, 1991 and 1993 are assumed to be comparable to the surveys of 1981 and 1982. In all surveys, relative abundances are expressed as linear densities, i.e. numbers of birds per km of transect. Linear densities are calculated as weighted means using linear densities on transects as sample units and transect lengths as the

weighting factor. Standard errors of the mean (SE) were calculated for transects on which birds were not too patchily distributed. Where data allowed, for example for large guillemots, glaucous gull/Iceland gull, and black guillemot, differences in linear densities among surveys were tested using paired sample t tests. Transect pairs with no observations in both surveys were omitted from the tests.

Based on oceanography and general ice conditions (see description of study area) the survey area was subdivided into four regions for analysis of distribution (Fig. 1): northern and western Davis Strait (Region 1); shelf north of the south-west Greenland Open Water Area (Region 2); coastal lead north of the south-west Greenland Open Water Area (Region 3); and northern part of the south-west Greenland Open Water Area (Region 4).

To facilitate more detailed analyses of eider distribution, the study area was subdivided into a number of offshore bank areas and a coastal zone

Fig. 4. (a) Distribution and abundance of king eiders in the eastern part of the Davis Strait in March 1981, and (b) in March 1982. Observations are mapped as number of individuals in 2-min observation periods. For definitions of "eider areas" see text.



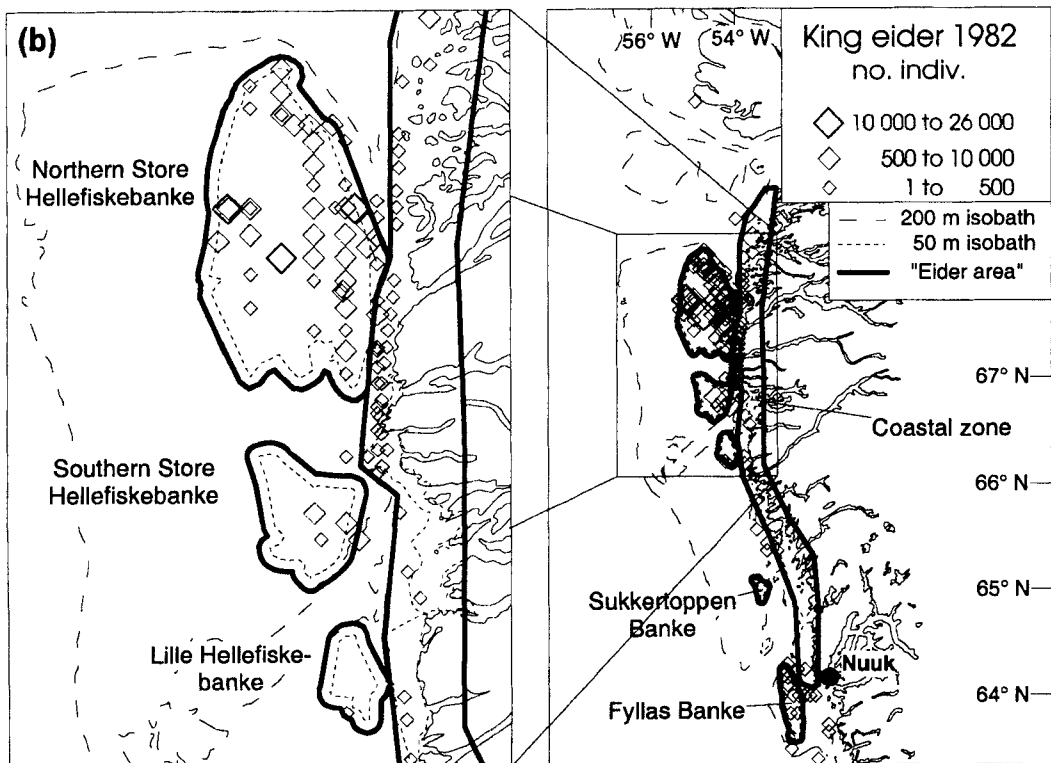
("Eider areas", Figs. 4 and 5). Nearly all of the offshore observations of king eiders were on banks in waters <50 m deep, or a few kilometres outside the 50 m isobath. Therefore the bank "Eider areas" were defined as including the area within the 50 m isobath and a 4 km zone surrounding it. The 50 m isobath has not been documented north of 69°N, but a small area shallower than 50 m is known to occur off the south-west coast of Disko Island. The coastal zone was delineated so all coastal areas shallower than 50 m are included within smoothed contours. Nevertheless, the coastal zone has a complex and sparsely documented bathymetry and includes several areas with depths >50 m.

For king eiders we used the ratio of on-transect to off-transect observations in 1981 and 1982 as an indication of whether on-transect detection efficiency was good enough to justify the calculation of strip census abundance estimates. We estimated density, abundance and associated standard error for king eiders in a number of defined bank areas in 1981 and 1982 using the ratio method described by Caughley & Grigg (1981) for transects of unequal length.

Results

Thirteen species or species groups of birds were recorded on-transect during the 1981 and 1982 surveys (Table 2). Additional species recorded off-transect and between transects included the gyrfalcon *Falco rusticolus* (16 individuals); the snowy owl *Nyctea scandiaca* (3 individuals), and the common raven *Corvus corax* (78 individuals). Only two major species groups, eider spp. and large guillemot spp., were recorded during the surveys of 1990, 1991 and 1993.

All species observed on-transect had the highest relative abundance off south-west Greenland (Regions 2, 3 and 4). The surveys did not cover the southern part (62–63°N) of the south-west Greenland Open Water Area, but they did provide information on the distribution and relative abundance of birds in most of the waters off south-western Greenland. However, the statistical significance of observed differences in relative density between years and regions is often obscured by the patchy distribution of the birds.



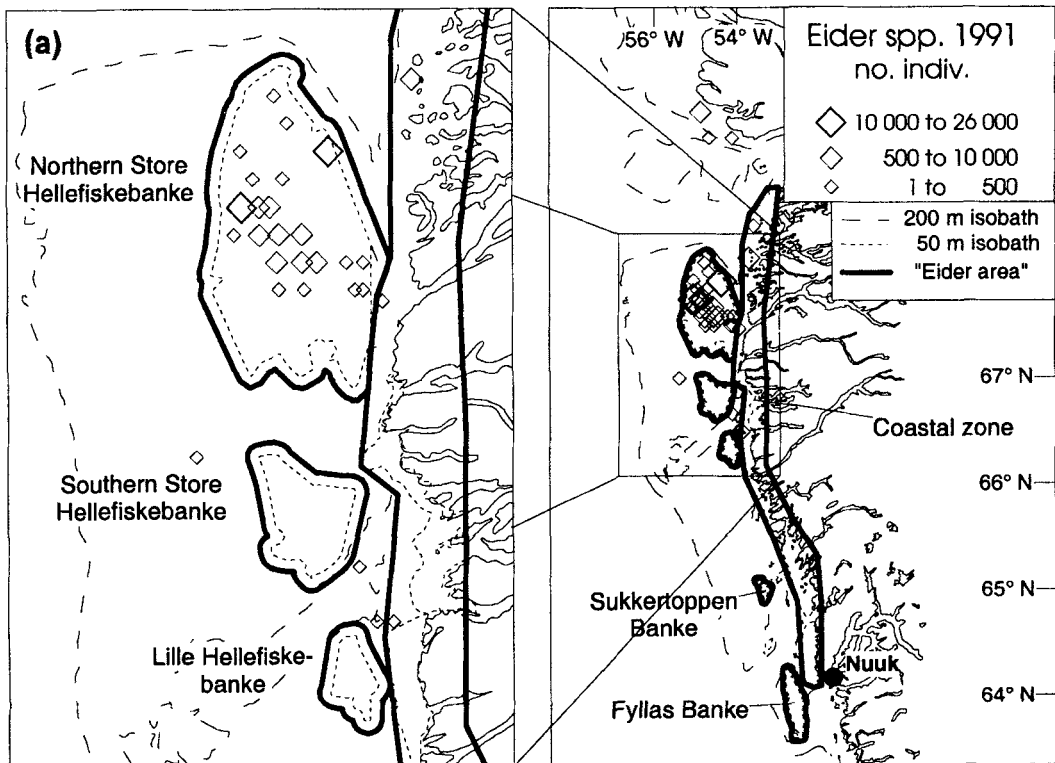
Eiders

Eiders, including king eiders, common eiders and unidentified eiders, were the most abundant and most widespread species recorded in March in all years. During the 1981 and 1982 surveys, common eiders were almost exclusively recorded in near-shore coastal areas. King eiders, in contrast, were recorded farther offshore on the banks, with smaller numbers seen along the coast or fast ice edge east of Store Hellefiskebanke between Sisimiut and Attu (67–68°N) (Fig. 4). Sightings of unidentified eiders during 1981 and 1982 were also predominantly from the latter area. King eiders were almost the only eiders identified on the offshore banks during the 1981 and 1982 surveys (<0.1% were common eiders); 11% (1981) and 6% (1982) of the eiders seen on offshore banks were recorded as unidentified eiders. In the 1991 and 1993 surveys, all eiders were classified as unidentified eiders. However, based on the distribution of common and king eiders in 1981 and 1982, we reclassified all unidentified eiders

seen on the banks in 1991 and 1993 as king eiders. This reclassification was supported by the fact that all eiders identified to species from the photographs taken on the banks were king eiders.

Most king eiders were recorded on Northern Store Hellefiskebanke, between 67°30'N and 68°N, and east of 55°30'W (Figs. 4 and 5). A smaller concentration was recorded on Southern Store Hellefiskebanke (Fig. 4a). In 1981 and 1982, an average of 88% of all king eiders were seen on the banks, about 10% were seen in the coastal/ice edge area, and about 5% were seen outside these areas. In 1991 and 1993, 77% of all eiders were seen on the banks, 9% were seen in the coastal/ice edge area, and 12% were seen outside these areas. King eiders seen in the coastal/ice edge zone were concentrated between 67°N and 67°40'N, but small flocks were seen all along the coast/ice edge in the survey area. In all years, a small number of eiders (common and king eiders in 1981 and 1982, and eider spp. in 1991 and 1993) were recorded south-west of Disko Island, outside the bank areas.

Fig. 5. (a) Distribution and abundance of eider spp. in the eastern part of the Davis Strait in March 1991, and (b) in March 1993. Observations are mapped as number of individuals in each observed flock. For definitions of "eider areas" see text.



About 75% of king eiders recorded in 1981 and 1982 were seen on-transect, and 25% were observed outside the transect strip (Table 3). The relatively high percentage of king eiders detected outside the transect strip width indicates that king eiders were detected efficiently within the transect strip. Therefore we calculated strip census abundance estimates using the number of birds seen on-transect in 1981 and 1982 (Table 4). Our estimates of the numbers of king eiders ranged between 104016 and 344720 (mean 199987; $n = 3$) on Northern Store Hellefiskebanke (Table 4) where the majority of king eiders were seen. A large number of king eiders (180300) was also estimated on Southern Store Hellefiskebanke in 1981, but few or none were observed there during later surveys. A significant number of king eiders (24356) was also estimated on Fyllas Banke, based on the early 1982 survey (1982A, coverage 6%; Table 4); this was the only survey with a coverage of more than 1% on Fyllas Banke. Total estimates for the bank areas for each of the 1981–82 surveys were computed by adding the estimated

numbers from the areas surveyed; the average was 270869 king eiders (range 139205–344720; $n = 3$). Because some transects in the coastal zone were flown along ice edges and coastlines only raw counts from the coastal zone (range 2722–4556) have been used in an estimate of total abundance for both banks and coastal zone averaging 274592 king eiders (Table 4). However, considering the low coverage in the coastal zone (2–6%) the true number of king eiders in the coastal zone could be several tens of thousands higher.

In the 1991 and 1993 surveys the effective search width, or strip width, is unknown. However, assuming as a crude estimate that the effective search width of the single front seat observer in 1991 and 1993 was equivalent to the 1400 m transect width in 1981 and 1982, then about 15% of the birds on Northern and Southern Store Hellefiskebanke were counted in 1991 and 1993. This assumption yields crude estimates of total abundance of king eiders for Northern Store Hellefiskebanke ranging between 142000 and

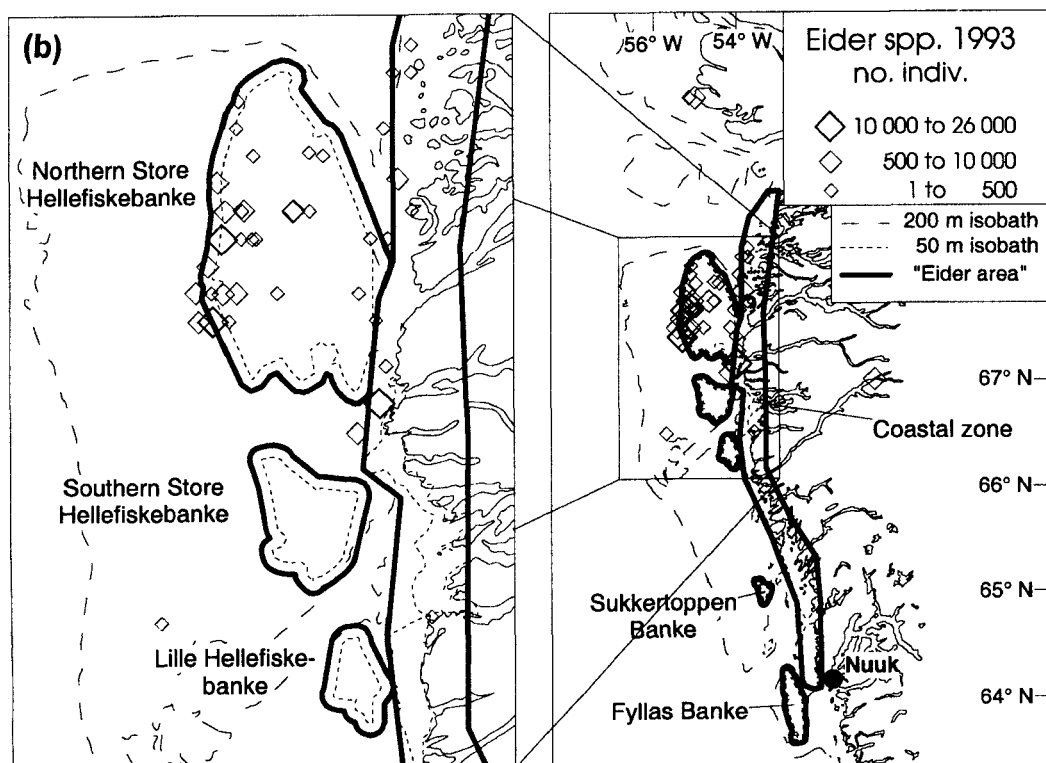


Table 2. Abundance of birds recorded during different aerial surveys in Davis Strait and Baffin Bay.

	Survey Periods During Different Years						
	1981 15 Mar.–1 Apr.	1982A 10–17 Mar.	1982B 21–24 Mar.	1990 13–14 Apr.	1991 19–24 Mar.	1993A 16–20 Mar.	1993B 21–23 Mar.
Total transect length (km)	12200	7900	4000	2300	3500	2400	1500
Species							
Fulmar	5857	647	0	– ^a	–	–	–
Cormorant spp.	15	0	0	–	–	–	–
Common eider	4914	8450	1721	–	–	–	–
King eider	39568	28834	71477	–	–	–	–
Eider spp.	7726	12250	3113	–	73413	46984	27048
Kittiwake	581	0	0	–	–	–	–
Glaucous/Iceland gull	5367	760	113	–	–	–	–
Great black-backed gull	124	203	40	–	–	–	–
Ivory gull	0	11	3	–	–	–	–
Gull spp.	10	88	0	–	–	–	–
Brünnich's guillemot	710	0	0	–	–	–	–
Large alcid	1225	828	30	65500	10238	4765	2208
Black guillemot	1175	615	300	–	–	–	–

^aDashes indicate that these species were not recorded during these years.

437000 (mean 261000; $n = 3$), while no king eiders were observed on Southern Store Hellefiskebanke in 1991 and 1993. Thus these crude estimates for 1991 and 1993 are at the same order of magnitude as the estimates for 1981–82.

Common eiders were recorded almost exclusively in the coastal zone of south-west Greenland. During the 1981 and 1982 surveys, 99% (4888) and 86% (8780), respectively, of the common eiders recorded were seen in coastal areas. In both years significant numbers of unidentified eiders (2973 in 1981 and 5141 in 1982) also occurred in the coastal zone. Most common eiders were observed in the Sassat archipelago ($66^{\circ}18'N$) and along the rocky coast between $67^{\circ}N$ and $68^{\circ}20'N$.

Compared to king eiders, far fewer common eiders were observed in 1981 and 1982. However, the common eider's main habitat along rocky coastlines, including shore leads and small open

water areas in the fiords, was not thoroughly surveyed. Because of a smaller survey effort in the coastal zone in 1991 and 1993, comparatively fewer eiders (all species) were seen in the coastal zone in these years than in 1981 and 1982.

Large guillemots

The large guillemots category includes Brünnich's guillemots, common guillemots, and razorbills, but not black guillemots. Most of the large alcids recorded were likely Brünnich's guillemots; this was the only large alcid identified to species in this study (Table 2) and in a ship-based survey of the area during winter where 15264 of 87224 large guillemots were identified as Brünnich's guillemots (Durinck & Falk 1996). Observations of large guillemots in this study have therefore been categorized as Brünnich's guillemots. In the 1981

Table 3. Total abundance (no. indiv.) of eiders observed on- and off-transect during aerial surveys in 1981 and 1982.

Species	1981		1982A		1982B	
	Abundance	Proportion on-transect	Abundance	Proportion on-transect	Abundance	Proportion on-transect
Common eider	4914	1.00	11108	0.76	1721	1.00
King eider	53168	0.74	37535	0.77	95837	0.75
Eider spp.	55047	0.14	13701	0.89	3453	0.9

Table 4. Estimates of wintering king eider population in south-western Greenland. Strip census estimates are given for bank areas, while numbers of birds along coasts/fast ice edges are expressed as raw counts, rather than estimated total abundance.

Location	Area (km ²)	1981 15–31 Mar.				1982A 10–17 Mar.				1982B 21–24 Mar.				All surveys
		Estimated		Estimated		Estimated		Estimated		Estimated		Mean/ Total abundance		
		% Area Surveyed	Density (no. km ⁻²)	Abundance (no. indiv.)	CV ^a %	% Area Surveyed	Density (no. km ⁻²)	Abundance (no. indiv.)	CV %	% Area Surveyed	Density (no. km ⁻²)		Abundance (no. indiv.)	
Northern Store	5085	10	30	151 225	44	20	20	104 016	36	20	68	344 720	37	199 987
Hellefiskebanke	1343	10	134	180 300	64	18	5	6833	34	19	0	0	nc	62 377
Southern Store	628	10	0	0	nc	17	0.1	91	69	5	0	0	nc	30
Hellefiskebanke	361	^b	–	–	–	14	0	0	–	–	–	–	–	0
Sukkertoppen Banke	1597	1	1	1156	–	6	15	24 356	85	–	–	–	–	12 756
Fyllas Banke	9014			332 681				135 205				344 720		270 369
Subtotal (all banks)	14 642	4	nc	3891		6	nc	4556		2	nc	2722		3723
Coast/Fast ice edge ^c	32 670			336 572				139 761				347 442		274 592
Total (all areas)														

^aCV = Coefficient of variation calculated as standard error in proportion to the mean.

^bDash (–) = not surveyed; nc = not calculated.

^cSampling along coasts/fast ice edges was not comparable to the systematic sampling conducted elsewhere.

and 1982 surveys, only 2773 Brünnich's guillemots were observed and nearly all were in the northern portion of the south-west Greenland Open Water Area (2525 birds, 0.57 ± 1.67 birds/km, $n = 61$). In 1982, when compact ice covered much of the study area in March (Table 1), Brünnich's guillemots were mainly seen south of Nuuk (64°N).

In the March 1991 and 1993 surveys, which only covered areas north of 66°N , 17211 Brünnich's guillemots were recorded. The highest density was recorded on the continental shelf north of the south-west Greenland Open Water Area (6.03 ± 4.90 birds/km, $n = 24$, in 1991; 1.53 ± 0.71 birds/km, $n = 48$, in 1993). Dispersed in small flocks and inconspicuous from the aircraft, Brünnich's guillemots were not detected efficiently in March. Accordingly, the numbers of Brünnich's guillemots recorded during March in all years was probably low compared to the numbers actually present. In 1990, surveys were conducted in mid-April, about a month later than in other years, and the distribution of Brünnich's guillemots was clearly different compared to other years. In this year very large flocks of Brünnich's guillemots were recorded on the continental shelf north of the south-west Greenland Open Water Area (65550 Brünnich's guillemots in 6 flocks, 54.58 birds/km).

Brünnich's guillemots tended to avoid compact ice on Store Hellefiskebanke. In 1990, when compact ice was most prevalent in the north-western part of Store Hellefiskebanke, Brünnich's guillemots were concentrated in the eastern part of this bank. In 1991, when the compact ice was most prevalent in the north-eastern part of Store Hellefiskebanke (where it actually merged with the fast ice edge), Brünnich's guillemots were concentrated in the central part of the bank.

Other species recorded in 1981–82

Fulmar Fulmaris glacialis. – Fulmars were found in patches throughout the portion of the south-west Greenland Open Water Area surveyed in 1981 and 1982, and were only found in this region (4). Their distribution extended further north in 1981 when ice conditions were lighter than in the heavy ice year of 1982, and many more fulmars (5847 birds, 5.61 birds/km, $n = 12$) were recorded in 1981 than in 1982 (85 birds, 0.02 birds/km, $n = 49$). Fulmars were concentrated on a few transects in the region: in 1981 fulmars were

recorded on 6 out of 12 transects, with one transect accounting for 87% of the birds; while in 1982 fulmars were recorded on 8 out of 49 transects, with one transect accounting for 42% of the birds.

Great cormorant Phalacrocorax carbo. – Great cormorants were seen in small numbers along the coast of the south-west Greenland Open Water Area (15 birds) and in the West Greenland Coastal Lead north of the Open Water Area (40 birds).

Kittiwake Rissa tridactyla. – Kittiwakes were only seen in 1981 and were only seen in the south-west Greenland Open Water Area (585 birds, 0.58 birds/km) where there was much less ice than elsewhere along Greenland's south-western coast.

Ivory gull Pagophila eburnea. – Ivory gulls were only observed in 1982, the year of heavy ice. They were seen sporadically in low numbers (14 birds) in the Open Water Area and the coastal lead. The detection efficiency for this small species was probably low, especially for individuals sitting on ice.

Glaucous gull and Iceland gull Larus hyperboreus and L. glaucoides. – Glaucous gull and Iceland gull observations were combined because these two species were usually not distinguishable during the aerial surveys. They were recorded in local concentrations as well as dispersed unevenly throughout the study area. The highest density that we recorded for this species complex was 0.66 birds/km ($n = 91$, 4451 birds) on the continental shelf north of the south-west Greenland Open Water Area. However, birds were only recorded on 10 out of 91 transects and 98% of the birds were recorded on one transect. Omitting this transect from the calculations yields a density of 0.01 birds/km, which is as low as the density of these gulls in central and western Davis Strait (0.01 birds/km, birds recorded on 5 out of 157 transects, 118 birds). The density of these gulls in the northern part of the south-west Greenland Open Water Area was 0.28 ± 0.59 birds/km (birds recorded on 39 out of 61 transects, 1252 birds), and the density in the West Greenland Coastal Lead north of the Open Water Area was 0.44 ± 1.75 gulls/km (birds recorded on 9 out of 15 transects, 320 birds). In all areas surveyed, densities were higher in 1981 than in 1982, although no statistically significant differences

were found because of the very patchy distributions of the birds.

Great black-backed gull *L. marinus*. – Great black-backed gulls were recorded in low numbers and were dispersed throughout the south-west Greenland Open Water Area (285 gulls, 0.06 birds/km), along the West Greenland Coastal Lead (21 gulls, 0.03 birds/km) and on the continental shelf north of the south-west Greenland Open Water Area (58 gulls, 0.01 birds/km).

Black guillemot *Cepphus grylle*. – Black guillemots were dispersed singly or in small flocks in both coastal and offshore pack ice throughout the study area. Because they are smaller (35 cm) than Brünnich's guillemot (42 cm), the efficiency with which they were detected from the aircraft (at 150 m a.s.l.) was low, as were estimated densities. In 1981, when the pack ice was less compact than in 1982, black guillemots tended to be more abundant throughout the northern and western parts of the Davis Strait than in 1982 (928 individuals, 0.10 ± 0.12 birds/km, $n = 122$, in 1981 versus 276 individuals, 0.05 ± 0.12 birds/km, $n = 35$, in 1982). In 1982, the linear density of black guillemots was significantly higher than in 1981 on the shelf north of the Open Water Area (0.17 versus 0.03 birds/km; $p = 0.032$, $n = 12$) and in the northern part of the Open Water Area (0.06 versus 0.01 birds/km; $p = 0.050$, $n = 8$). There was also a tendency for higher densities in the West Greenland Coastal Lead in 1982 (181 birds, 0.34 ± 1.87 birds/km, $n = 9$, in 1982 versus 7 birds, 0.04 ± 0.07 birds/km, $n = 6$, in 1981).

Snowy owl *Nyctea scandiaca*. – Snowy owls (3 birds) were seen in the compact pack ice up to 150 km from the coast flying over the ice (Region 1: $69^{\circ}12'N$, $54^{\circ}18'W$; $67^{\circ}N$, $58^{\circ}W$; Region 2: $67^{\circ}42'N$, $55^{\circ}W$).

Gyr Falcon *Falco rusticolus*. – Gyrfalcons (16 birds) were seen on sea ice from 0 to 300 km from the coast in 1981 and 1982. At least 13 gyrfalcons were seen perched on or flying around tall icebergs with some open water nearby. Presumably these falcons were feeding on seabirds (mainly black guillemots) attracted to the open water associated with large icebergs.

Common raven *Corvus corax*. – Common ravens (78 birds) were observed within a few tens of

kilometres from the coast, with only one observation more than 30 km offshore. About half of the ravens observed were associated with the West Greenland Coastal Lead (36 of 78 birds), but they occurred in all regions.

Discussion

While the south-west Greenland Open Water Area and the West Greenland Coastal Lead have long been recognized as an important winter area for seabirds (Salomonsen 1950), this study shows that the Greenland shelf north of the Open Water Area is also a very important wintering area supporting large concentrations of king eiders in March and April and large alcids (Brünnich's guillemots) in April. Furthermore, this study adds to the limited knowledge of offshore distribution and habitat preference for seabirds in the Davis Strait during winter, especially in the northern part, where survey coverage was most extensive.

King eiders

King eider concentrations were very localized on shallow banks (<50 m), especially on the northern part of Store Hellefiskebanke. King eiders have a maximum recorded diving depth of 55 m (Cramp & Simmons 1977), and outside the breeding range they feed mainly on benthic marine invertebrates (Cramp & Simmons 1977; Frimer 1997). They probably concentrate in the offshore bank areas because these provide good foraging and also because human hunting pressure is light there compared to that in shallow feeding areas along the coast. Concentrations of king eiders were usually recorded in moderate to heavy ice cover but appeared to be rather unaffected by different ice conditions on the banks. In a survey west of Nuuk Fjord in February 1989, Durinck & Falk (1996) found a significant positive correlation between high ice cover (8/10 to 9/10) and high densities of king eiders. The king eiders in their study were also concentrated in shallow waters (Fyllas Banke). It can be concluded that heavy ice does not exclude king eiders from an area if there are open areas of water situated over shallow banks which can offer nearby foraging opportunities; king eiders may actually prefer to rest on the ice. However, bathymetry is probably a more important distributing factor than ice. Because of

the strong affinity of king eiders for the shallow bank areas it thus seems unlikely that these birds forage on sympagic ice-associated fauna.

Alexander et al. (1997) discuss the factors affecting the distribution of king eiders during spring migration in the Beaufort Sea. They emphasize the importance of polynyas with predictable open water for eiders crossing the ice-bound Beaufort Sea. The banks north of the south-west Greenland Open Water Area where we found major king eider concentrations may at times have nearly 100% ice cover. However, ice conditions are very dynamic in this area; there are nearly always small leads or cracks which provide access to open water, and there is predictable open water a few hundred kilometres to the south.

During ship-based surveys in February 1989, Durinck & Falk (1996) estimated 280 000 king eiders in a 6000 km² area west of Nuuk Fjord (actual area surveyed 3.4%; ca 10 640 birds observed). Using 1982 aerial survey data we estimated 31 000 king eiders in the same 6000 km² area (actual area surveyed 6%; 1837 birds observed in 13 flocks). In 1982, a very large proportion (1580 of 1837; 86%) of the king eiders seen in this 6000 km² area west of Nuuk Fjord were recorded in the 1597 km² shallow part (<50 m deep) of Fyllas Banke, where we estimated 24 356 king eiders (Table 4). Durinck & Falk (1996) did not analyse the king eider distribution in relation to water depths; however, in 1989 king eiders were actually concentrated in the shallow part of Fyllas Banke as they were during the 1982 survey.

Based on these results from 1982 and 1989, it is clear that Fyllas Banke is an important over-wintering area for large concentrations of king eiders. The large difference between the estimates in 1982 and 1989 (31 000 and 280 000 respectively) was most likely due to the extreme ice conditions in 1989 when waters north of Nuuk were almost completely ice-covered by mid-February (Durinck & Falk 1996). The ice probably forced king eiders to move as much as 300 km further south than normal.

Our estimate of about 275 000 king eiders over-wintering in south-western Greenland in 1981 and 1982 is based on estimates with a large standard error. However, the figure seems reasonably conservative considering that (1) we used only raw counts for the coastal areas, (2) over-wintering king eiders may also occur in fiords that we did not survey, and (3) king eiders also

occur well to the south of our survey area (Durinck & Falk 1996).

Our king eider estimates for Store Hellefiskebanke in 1991 and 1993 average about the same as the 1981–82 estimate. However, the 1991 and 1993 estimates are less reliable because they are based on the assumption that the detection efficiency of the observer equalled the transect width used in 1981–82.

Common eiders

Common eiders were seen all along the coast, but especially large numbers were observed at Sassat (66°18'N), which is also known for large numbers of post-breeding eiders in September (Mosbech, Dietz et al. 1996), and between 67°N and the mouth of Afersiorfik Fjord (68°06'N), an area known among local people for open water and good eider hunting during winter (Petersen in press). The common eider eats benthic invertebrates, mainly molluscs, and has a maximum recorded diving depth of only 20 m (Cramp & Simmons 1977) compared to 55 m for the king eider. This preference for shallow water explains the coastal affinity of common eider because, with few exceptions, depths on the offshore banks greatly exceed 20 m.

Brünnich's guillemots

Brünnich's guillemots in this study tended to avoid dense pack ice and were variably abundant in all other ice conditions, which is consistent with results from ship-based surveys in coastal south-western Greenland (Durinck & Falk 1996) and the Barents and Greenland Seas (Mehlum 1997). In the Barents Sea, it has also been observed that Brünnich's guillemots avoid small leads in heavy ice during winter and occur mainly in the marginal ice zone (Hunt et al. 1996). Brünnich's guillemots are generally unable to take flight from ice floes or small leads and therefore risk becoming trapped if they forage in small leads in heavy ice (Bakken 1990). Bakken observed many Brünnich's guillemots in ice leads in the Barents Sea which flew up to 150 km south to spend the night in areas of open water, apparently to avoid being trapped if the leads closed after dark.

Apart from avoiding closed ice, the distribution of Brünnich's guillemots is probably governed by the availability of pelagic food. In a study of the diet of Brünnich's guillemots purchased from

hunters in coastal south-western Greenland during the winter 1988–89, Falk & Durinck (1993) found that capelin *Mallosus villosus* and euphasiids made up nearly 80% of the food by weight. South of 63°N the food consisted almost exclusively of fish, mainly capelin, while further north crustaceans played a significant role in the diet and became increasingly important as winter progressed. In contrast to studies in other ice-covered areas (Bradstreet & Cross 1982; Mehlum & Gabrielsen 1993), it is notable that the sympagic polar cod *Boreogadis saida* was insignificant in the diets of Brünnich's guillemots in coastal south-western Greenland in 1988–89 (Falk & Durinck 1993). The reason for the lack of polar cod in the diet could be explained by the fact that the birds analysed by Falk & Durinck were shot close to the coast.

The birds collected south of 63°N had higher fat indices, possibly related to feeding on the energy-rich capelin (Falk & Durinck 1993), and possibly indicating that the southern area provided better foraging. A more southerly distribution may also explain why Brünnich's guillemots were found in relatively low numbers in the northern portion of the south-west Greenland Open Water Area in March (MacLaren-Marex 1979). In contrast, during April 1990, large flocks of Brünnich's guillemots appeared on the banks north of the Open Water Area, probably staging while en route to colonies further north. However, the offshore distribution of Brünnich's guillemots is probably very variable from year to year depending on ice and prey distributions. In February–March of the severe winter of 1989, Durinck & Falk (1996) recorded two large flocks of Brünnich's guillemots (27000 and 33000 birds) west of Nuuk (64°N), and they estimated 170000 to be present in the 6000 km² area that they covered during their shipboard surveys of this area, which was regarded as the northernmost area with open water during this period.

Other species recorded in 1981–82

Pelagic seabirds tend to be concentrated in areas where prey is concentrated, and important foraging areas are often related to frontal zones or bathymetric features. Sea ice may also be a major factor determining the distribution (Hunt 1991). Sea ice can be a positive factor for seabirds which feed on ice-associated fauna; it can also be a negative factor insofar as it limits available open

water for surface feeding seabirds and pursuit diving seabirds.

The very different ice conditions and survey results in 1981 and 1982 provide insights into how ice conditions can affect the distribution of birds offshore. Some species were positively associated with ice and avoided offshore open water (e.g. black guillemot, ivory gull, gyrfalcon and snowy owl). Black guillemots and ivory gulls probably fed on sympagic fauna such as polar cod and epontic amphipods as has been described by Mehlum & Gabrielsen (1993) for the Barents Sea. Gyrfalcon and snowy owl probably fed on small seabirds, such as black guillemots, ivory gulls and kittiwakes, that are attracted to open water areas near large icebergs.

Ivory gulls were only recorded in the heavy ice year 1982 and not in 1981. During their coastal ship-based surveys off south-western Greenland in February–March 1989, Durinck & Falk (1996) did not record ivory gulls. An estimated 100 ivory gulls were observed during an aerial survey off Labrador in March 1981 (0.02 birds/km; LGL unpubl. data). This suggests that the main wintering area for this species is the western marginal ice zone, south of the area surveyed in this study, as suggested by Renaud & McLaren (1982; see also MacLaren-Marex 1979).

In both 1981 and 1982, black guillemots were widely dispersed in dense pack ice throughout the study area, including the western portion of Davis Strait. However, in 1982, when ice conditions were more severe, higher linear densities than in 1981 were recorded in eastern Davis Strait. Unlike Brünnich's guillemots, black guillemots are agile flyers that can take off from small leads and cracks in the ice. Bradstreet & Brown (1985) and Mehlum & Gabrielsen (1993) have described black guillemots feeding, mainly on polar cod, in Baffin Bay and Barents Sea pack ice.

Our results, and results from other studies (MacLaren-Marex 1979; Durinck & Falk 1996; Mehlum 1997), indicate that fulmars and kittiwakes – both surface feeders – avoid areas with ice coverage exceeding 5/10. The black-backed gull occurred mainly in the Open Water Area and distribution and abundance there was little affected by the different ice conditions. In contrast, a large local concentration of glaucous/Iceland gulls was observed on the continental shelf north of the Open Water Area during the light ice year of 1981, but not in the heavy ice year of 1982. The distribution of this species group in 1981 was

probably related to human fishing activity; glaucous gulls are known to feed on discards from fishing vessels (Cramp & Simmons 1977).

Store Hellefiskebanke: a seabird and marine mammal "hot spot"

This study has shown that the shallow shelf north of the Open Water Area, especially Store Hellefiskebanke, is an important area for king eiders and Brünnich's guillemots. In addition, these surveys have also documented important recurrent concentrations of several marine mammal species on Store Hellefiskebanke and its northern shelf slope. The Atlantic walrus *Odobenus rosmarus* was found to have its main concentration at Store Hellefiskebanke (mostly confined to waters less than 100 m deep) where there are shallow feeding grounds and suitable ice for hauling out (Born et al. 1994). The concentration of bearded seals *Erignathus barbatus* off western Greenland was found to be centred near the northern slope of Store Hellefiskebanke, at about 68°N (McLaren & Davis 1982). The main concentrations of white whales were found in the eastern part of Store Hellefiskebanke and at its north-eastern and south-eastern slopes less than 50 km from the Greenland coast (Heide-Jørgensen et al. 1993; Heide-Jørgensen & Reeves 1996). Thus, Store Hellefiskebanke, with its shallow feeding grounds and dynamic ice regime, is an important area for marine birds as well as marine mammals.

The surveys conducted in this study did not cover the fiords and all of Greenland's south-western coast, nor did they extend over the whole December–April winter period. More systematic surveys are required to supplement the results presented here. Nevertheless, the study identified areas of king eider and Brünnich's guillemot concentration where oil spills could have a significant impact on a very large proportion of south-western Greenland's wintering populations of these species.

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