Winter seabird distribution and abundance off south-western Greenland, 1999

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South-western Greenland constitutes an internationally important wintering area for many seabird species. Several species of management concern have a predominantly near-coastal distribution, though available information about seabird numbers is mostly confined to offshore waters. Here we report on extensive aerial surveys conducted in March 1999, covering the coastal waters (up to 15 - 20 km from the mainland coast) and fjords of south-west Greenland. The most widespread and numerous species were estimated as 463 000 common eiders (*Somateria mollissima*), 153 000 king eiders (*S. spectabilis*), 125 000 thick-billed murres (*Uria lomvia*), 94 000 long-tailed ducks (*Clangula hyemalis*), and 12 000 black guillemots (*Cepphus grylle*). A total of 19 bird species were recorded. The estimates for common eider and long-tailed duck approximately represent the entire winter population in south-western Greenland while estimates for the other species represent only an unknown proportion since their distribution continues further offshore. Waters around Nuuk and within the Julianehåbsbugten (Julianehåb Bay) area were identified as areas of high seabird density. A large proportion of the common eider population was aggregated in the fjord systems (22 %), calling attention to the importance of fjords for this species. In contrast, pelagic seabird species appear to be absent from the fjords. The large winter population of common eider reveals the importance of south-western Greenland as a key wintering area for the eastern Canadian breeding population. The western Greenland breeding population is the only other contributor, probably amounting to no more than 15 000 pairs.

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The South-west Greenland Open Water Area is known to be an important overwintering area for several seabird species, including common eider (*Somateria mollissima*), king eider (*S. spectabilis*) and thick-billed murre (*Uria lomvia*), when Baffin Bay and the northern and western part of Davis Strait become ice-covered (Brown & Nettleship 1981). It provides staging and wintering areas for huge numbers of birds which in the summer occur at breeding grounds further north in western Greenland or in neighbouring Arctic countries. Marine birds migrate from the eastern Canadian Arctic, north-west Greenland, Iceland, Norway and Russia to winter here (Salomonsen 1967, 1990; Abraham & Finney 1986; Reed & Erskine 1986; Boertmann 1994; Mosbech & Boertmann 1999; Mosbech & Johnson 1999).

The international signficance of the Greenland

Open Water Area has great management and conservation implications for Greenland and circumpolar nations. Oil pollution may threaten seabirds in the future if current exploratory activities develop. Subsistence and commercial winter harvests are currently the most serious regional threat to seabirds. Subsistence harvest of seabirds in west Greenland has occurred at relatively low levels for hundred of years. However, human population growth, combined with technological advances in guns and boats, has increased harvest levels in recent decades (Nielsen 1999; Hansen 2002). Hundreds of thousands of seabirds are shot each year, the majority taken during winter in south-western Greenland (Frich 1997a, 1997b; Denlinger & Wohl 2001).

The sustainability of the Greenland winter seabird harvest is of great concern in both Canada and Greenland. The resident breeding thick-billed murre population in western Greenland has decreased seriously during the past 50 years, and it is likely that the overall decline may be as high as 50% (Kampp et al. 1994). Recent ground surveys have documented declines of up to 80% on common eider breeding grounds in mid- and north-western Greenland (Boertmann et al. 1996; Frich et al. 1998; Merkel 2002). Furthermore, the number of king eiders from the eastern Arctic moulting in fjords and coastal waters off western Greenland during July–September has suffered at least a 50% decline (Mosbech & Boertmann 1999). Circumstantial evidence links these declines to the winter harvest in south-western Greenland (Falk et al. 1997; Mosbech & Boertmann 1999; Natturufrædistofnun Islands 2000; Falk & Kampp 2001). However, more information on distribution and total abundance during winter is needed for these species to reliably assess the sustainability of the winter harvest in this region. For many marine species, this information might be achieved most effectively by monitoring in winter, when some species are less widely distributed.

Here we report on the results of an extensive aerial survey of seabirds found in fjords and coastal waters in south-western Greenland during winter. Seabird distribution in late mid-winter is presented, and for some species we produce the first available population estimates on the total number of birds wintering in the region. In light of the conservation concerns, the survey design prioritized coastal species. Previous winter surveys have covered only small proportions of the coastal waters in south-west Greenland (Durinck & Falk 1996; Mosbech & Boertmann 1999; Mosbech & Johnson 1999; Heide-Jørgensen et al. 1999). We also present results for several pelagic seabirds, although their offshore distribution ensures that their population was not fully covered by this survey.

Study area

The South-west Greenland Open Water Area

Baffin Bay and the western part of the Davis Strait is dominated by the cold, southward flowing Labrador Current. During winter, dense pack ice is formed in this area. On the opposite side, the north flowing West Greenland Current dominates the eastern part of the Davis Strait. The upper layer (0 - 150 m) of this current consists of cold water of polar origin from the East Greenland Current, where the bottom layer (150 - 800 m) of warmer water originates from the Irminger Current, a branch of the North Atlantic Current (Valeur et al. 1997). Both layers are transported round the southern tip of Greenland, Kap Farvel (Cape Farewell). As they mix and move north, they create a year-round open water area along south-west Greenland—referred to as the South-west Greenland Open Water Area. It usually extends from Sisimiut (67° N) in the north to Paamiut (62° N) in the south (Valeur et al. 1996, 1997; Mosbech et al. 2000). The southern pack ice originates in the Arctic Ocean, and by means of the East Greenland Current flows south to the south-western Greenland coast. It usually passes Kap Farvel in January/February. North of the Open Water Area there is often a narrow lead of open water (West Greenland Coastal Lead) stretching north along the coast or fast ice edge towards Disko Bay. References in this paper to the open water area of south-west Greenland include both the Greenland Open Water Area and the West Greenland Coastal Lead.

Ice conditions during the 1999 survey

South of 66° N the coastal survey area (Fig. 1) was characterized by open water, except for some minor concentrations of drifting brash ice between Maniitsoq and Nuuk, and around Ivittuut. No pack ice from the East Greenland Current had appeared from Kap Farvel at the time of the

Fig. 1. Aerial survey transects off south-west Greenland covered 27 February to 15 March 1999.

survey. North of 66° N, the coastal survey area became gradually more ice-covered, and north of 68° N heavy pack ice in the Davis Strait extended far to the east and covered most of our coastal survey area. Fjords had higher variable ice conditions, from ice-free to completely ice-covered. In general, though, the interior parts of the fjords were covered with fast ice. Based on the fjords surveyed in this study, for which we have full information about ice coverage, on average 32 % of the fjord areas were covered with fast ice.

Methods and equipment

Survey design

Systematic aerial surveys of seabirds were conducted from 27 February to 15 March 1999. Based on prior knowledge about the overall distribution tendency for various seabird species (Durinck & Falk 1996; Heide-Jørgensen et al. 1999; Mosbech & Johnson 1999), this aerial survey was designed to obtain quantitative information on the distribution, abundance and habitat use of seabirds within coastal waters and fjord systems of south-west Greenland.

Within a coastal zone from Aasiat in the north (68° 38' N) to Kap Farvel (59° 40' N), a double set of zigzag transects was assigned. As defined here, the coastal zone extends from the mainland coast to about 15 - 20 km to the west (Fig. 1). This zone largely comprises water less than 50 m deep (though it excludes the < 50 m deep banks, which are further offshore). However, the coastal zone has a complex and sparsely documented bathymetry and includes many areas with depths greater than 50 m. The coastal zone survey area contained 145 transects with an average length of 24.3 km, making the total transect line 3525 km long. To minimize off-transect effort, but still crossing any gradient of population density, transects were fixed in a north-east–south-west or north-west–south-east direction. All areas located east of the coastal zone were defined as fjords. The survey route in the fjords followed the coastline, the ice edge or a central line down the fjord.

Survey altitude was decided based on several test surveys conducted in March 1998. Two survey altitudes (250 and 400 feet) were tested for differences in the detectability of seabirds, and three altitudes (250, 400 and 700 feet) were compared regarding the ways the birds responded to the plane's approach. Conducting surveys at high altitudes (400 feet or higher) had the advantages of increasing the effective search width (ESW), with a higher total coverage as a result. Furthermore, flock size estimation varied less at 400 feet compared to 250 feet, maybe because observers had more time to do the estimate/count. On the other hand, detectability was worse at 400 feet than at 250 feet, mainly because of the greater influence of sea state at higher survey altitudes (Heide-Jørgensen et al. 1999). This is consistent with a more comprehensive study by Beavers & Ramsey (1998), who analysed the influence of variables such as weather, time of day, and observers on the detectability of animals in line transect surveys. They concluded that sea state level was the primary variable influencing detectability. We could not expect calm weather (sea state 1 or less) throughout all coastal sections of south-west Greenland, and therefore 250 feet was chosen as the survey altitude for line transects in 1999. Seabird behaviour detected at varying survey altitudes during the 1998 test surveys gave no reason to choose otherwise. Among five species tested—king and common eider, long-tailed duck, thick-billed murre and black guillemot—it was not possible to reduce the level of response caused by the approaching airplane by raising survey altitude to either 400 or 700 feet (Heide-Jørgensen et al. 1999). During line transect surveys we flew at the lowest ground speed possible: 150 - 170 km/h (85 - 95 knots).

Total count surveys in the fjords were conducted at a target altitude of 320 m (1000 feet) and a ground speed of 150 - 250 km/h (85 - 140 knots). This high survey altitude was chosen to enable us to cover each fjord with just a single transect. Otherwise, there would be a high risk of detecting identical birds more than once.

Survey effort 1999

With a total effort of 2863 km, the entire coastal zone was surveyed at least once. Except for six transects north of Maniitsoq, five south of Nuuk, five next to Paamiut and two south of Nanortalik, both sets of zigzag transects were flown (Fig. 1). A total length of 1798 km was searched in the fjords, and represents nearly complete coverage of the Nuuk fjord system, the Julianehåbsbugten (Julianehåb Bay) fjord system (Fig. 2) and several fjords between Nuuk and Kangaatsiaq (Fig. 1). Except for a minor section, the large and complex fjord system next to Kangaatsiaq was not surveyed. The fjord system was heavily iced at the time of the survey; however, the strong tidal currents in the area maintained ponds of open water, of which some were surveyed. No fjords between Nuuk and the Julianehåbsbugten area were surveyed.

Survey procedures

Data were collected from a Partenavia P-68 Observer (OY-CAG) aircraft. Two bird observers were placed in the seats behind the pilot where bubble windows allowed observations from below the plane (on the track line) and outwards. Observations of birds were made from each of the bubble windows, while the pilot made observations on weather and ice conditions. A third observer in the seat to the right of the pilot collected additional information on seabird behaviour, including their reaction to the approaching aircraft. The airborne observers were the same throughout the survey, except on 15 March 1999, when the right-seated observer was substituted. The observers and the pilot recorded their observations on independent tape recorders by speaking into their headset microphones. When activated, by a hand-held switch, the tape recorders received a synchronized time signal on another track of the same tape from a laptop computer linked to the aircraft's Global Positioning System (GPS). To facilitate later determination of the position of the observations, the position of the aircraft was automatically logged to the laptop computer at eight-second intervals. Altitude from a radar altimeter and ground speed was also logged to the laptop computer.

Observation procedure

Information about visibility, sea state and ice condition was recorded by the pilot at the starting point of each transect and whenever conditions changed. Sea state was classified using the Beaufort Scale, and surveys were terminated when sea state exceeded Beaufort Scale 3. The ice cover was classified in tenths. Real-time information on ice conditions was also obtained from NOAA-AVHRR satellite images provided by the Danish Meteorological Institute.

Bird sightings in the coastal survey area were recorded according to line transect methodology (Buckland et al. 1993). When a sighted bird or flock was at a right angle to the plane as the aircraft proceeded along the track line (i.e. the bird was abeam the plane), the angle downward to the single bird or the flock's centre on the water was measured by inclinometer. The distance of the observation from the track line was subsequently calculated:

$$\text{Distance} = \text{altitude} \cdot \tan(90 - \text{angle}).$$

In areas of high seabird density angles downward from the aircraft to the birds were measured for only a proportion of bird sightings. For quantitative analyses, it was assumed that birds observed without known distance from track line were distributed similarly to birds located at known distances.

A flock of birds was defined as two or more birds located close together and exhibiting the same behaviour (e.g. swimming or flying in the same direction), often forming a discrete group on the water. For small groups (less that ca. 20 birds), birds were counted individually. For larger groups, flock size was estimated or an estimated proportion of the flock was counted.

Each bird sighting was classified as: 1) on water, 2) on ice, 3) on ground, 4) about to dive, 5) rising from the water, or 6) flying. Flight direction of flying birds relative to the aircraft was recorded as: a) parallel to the track line, opposite direction of the aircraft; b) parallel to the track line, same direction as the aircraft; c) to the right or to the left, away from the track line; or d) to the left or to the right, towards the transect.

Most taxa were identifiable and recorded as species. However, all large alcids, except for black guillemots (*Cepphus grylle*), were identified as thick-billed murres (*Uria lomvia*) although a few may have been common murres (*Uria aalge*) or razorbills (*Alca torda*). Little auk (*Alle alle*) is very difficult to detect due to its small size, and scattered occurrences of this species were probably overlooked. Due to a much higher survey altitude within the fjords, it is also likely that single individuals of various species may have been overlooked there. A small proportion of eider ducks were lumped as undifferentiated eiders (king or common) (Table 1). Except for black-legged kittiwakes (*Rissa tridactyla*), gull species were not recorded systematically, and are therefore not presented in this paper. Aerial surveys in fjords were conducted as total count surveys, and information about numbers, species and sex was recorded for each sighting.

Analytical methods

Distance sampling software (version 3.5) was used for quantitative analyses (Thomas et al. 1998). Following Buckland et al. (1993), density (D) of sightings was given as

$$D = (n \cdot 1/ESW)/2L$$

where n is the total number of sightings, ESW is the effective strip width, and L is the total length of transect line searched. The abundance estimate, N, is thus given as

$$N = A \cdot s \cdot D$$

where A is the size of the study area and s is the mean (or corrected) flock size. To evaluate the ESW, we considered three types of models to fit the detection function for the distance data. Each model comprises a key function that can be adjusted by a series expansion containing one or more parameters. The models used were a half-normal, uniform or hazard-rate key function with either a simple or Hermite polynomial or a cosine series expansion (Buckland et al. 1993). We used the likelihood ratio test to select the number of adjustment terms for the key function, and the value of ESW was obtained from the most likely model with the minimum of Akaike Information Criterion (AIC). The modelling procedure was initially executed on ungrouped sighting data, and subsequently repeated on grouped data. Based on the grouped distance analyses, we carried out a goodness-of-fit chi-square probability test to compare the distribution of our distance data with the expected probability distribution—as expected from the detection function model. In cases where two models produced very similar AIC values, we chose the model that produced the smallest chi-square value. Prior to the modelling process, we truncated obvious outliers, based on visual inspection of the histogram of distances.

When calculating N we distinguished between mean observed flock size and expected flock size (as the expected mean value at distance 0). We used the mean observed flock size if size biased regression of *ln(flock size)* against *estimated g(x)* (probability of detection at distance x) was not significant ($\propto > 0.05$). The intention of this approach is to reduce bias if there is a tendency for smaller flocks to be missed more than larger flocks at large distances from the track line. The confidence interval (95 %) of N was calculated from stratum variation as

$$\mathrm{var}(N) = N^2(\mathrm{cv}(ESW)^2 + \mathrm{cv}(n/L)^2 + \mathrm{cv}(s)^2)$$

(Buckland et al. 1993)

where cv is the coefficient of variation, calculated as the ratio of the standard error to the mean. Assuming a lognormal distribution of N the 95 % confidence interval can be calculated as a lower and upper limit, given as N/V and $N \cdot V$ where

$$V = exp[1.96*sqrt\{var(ln(N)\}]$$

(Burnham et al. 1987)

and

Table 1. Bird species observed during aerial surveys off south-west Greenland, 27.02 – 15.03 1999.

	Coastal area[a]		Fjords		Sum	
	Sightings	Individuals	Sightings	Individuals	Sightings	Individuals
Seabird species						
Fulmar *Fulmaris glacialis*	82	1153			82	1153
Great cormorant *Phalacrocorax carbo*	61	556	8	136	69	692
Mallard *Anas platyrhynchos*	22	252			22	252
King eider *Somateria spectabilis*	599	36 352	40	3582	639	39 934
Common eider *Somateria mollissima*	2007	56 125	772	103 827	2779	159 952
Eider spp *Eider* spp.	52	9972	1	130	53	11 002
Harlequin duck *Histrionicus histrionicus*	3	41	1	4	4	45
Long-tailed duck *Clangula hyemalis*	413	3525	4	17	417	3542
Red-breasted merganser *Mergus serrator*	28	75	2	4	30	79
Kittiwake *Rissa tridactyla*	24	32	23	3200	47	3232
Glauceus gull *Larus hyperboreus*	+		+		+	
Iceland gull *Larus glaucoides*	+		+		+	
Great black-backed gull *Larus marinus*	+		+		+	
Thick-billed murre *Uria lomvia*	658	9993	7	215	665	10 207
Black guillemot *Cepphus grylle*	217	796	5	69	222	865
Other bird species						
White-tailed eagle *Haliaeetus albicilla*	5	5	2	2	7	7
Gyrfalcon *Falco rusticolus*	1	1			1	1
Purple sandpiper *Calidris maritima*	25	399	5	490	30	889
Raven *Corvus corax*	19	34	2	4	21	38

[a] Including off-transect observations, made during forced detours from transect lines.
+ Birds present but not systematically recorded.

$$var(ln(N) = ln[1+var(N)/N^2]$$

Determination of the confidence interval on summarized strata is based on the sum of variation from each stratum.

Graphic presentation

For density calculations the observations were summarized in small areas along the survey transects. Summary areas of 2 km length were established along the coastal survey transects, and densities for each species and for each summary area were calculated. The widths of the summary areas were the species specific ESW. All observations falling in these areas were summarized into one sum for the area. Areas used for summarizing observed birds in the fjords are approximately 10 km long. The summarized densities at the coastal area and in the fjords were interpolated using Inverse Distance Weighting to cover all areas within 6 km from the transect (for fjords, 8 km). Using this method each summarized observation is assumed to have a local influence that diminishes with distance. The observation closest to the observation in process is weighted higher than those farther from the observation. For this interpolation each processed unit has an area of 1 × 1 km resulting in 1 km^2 cells.

Results

General distribution

A total of 19 bird species were recorded during the survey, of which we have classified 15 as seabird species (Table 1). Most species had their main distribution area within the coastal survey area or at the outermost regions of the fjord systems. Only common eiders (Fig. 2) and kittiwakes occurred at high densities deep inside fjords. In general, species diversity was highest in the central region of the survey area, from around Maniitsoq south to Fiskenæsset (65° - 63° N), and in the Julianehåbsbugten area. Species like fulmar (*Fulmaris glacialis*), great cormorant (*Phalacrocorax carbo*), mallard (*Anas platyrhynchos*), red-breasted merganser (*Mergus serrator*) and kittiwakes were very rare outside these two areas. There was also a tendency of larger flock sizes and a more patchy distribution north of Sisimiut (67° N), coinciding with increasing ice coverage to the north.

Quantitative analyses: assumptions

Five seabird species were included in our quantitative analyses: common eider, king eider, long-tailed duck (*Clangula hyemalis*), thick-billed murre and black guillemot. All sightings of fulmar were of flying birds (Table 2), and therefore not appropriate for distance sampling. Observations of great cormorant were also inadequate for distance sampling since half the sightings were of flying birds, and the rest were taking off from the ground. They had been resting on small islands prior to the approach of the aircraft (Table 2). The rest of the species were too seldomly encountered to allow quantitative spatial analyses (Table 1).

In the process of estimating the abundance of each of the above-mentioned five species, we assumed that birds flying at the time of detection (Table 2) were distributed similarly to birds detected on the water. However, at the time of detection flying birds had moved from their original positions and therefore had to be excluded from the detection function analyses. Flying birds were also excluded from flock size calculation to avoid overestimating the mean flock size. The

Table 2. Seabird behaviour recorded by the backseat observers when passing the birds abeam.

Species	No. of sightings	On water %	Diving %	Rising %	Flying %
Common eider	1888	74	1	4	22
King eider	554	72	2	3	23
Long-tailed duck	373	61	1	6	32
Thicked-billed murre	652	88	8	0	4
Black guillemot	201	77	14	3	6
Great cormorant	50	0	0	52	48
Fulmar	81	0	0	1	99
Kittiwake	24	0	0	0	100

Table 3. Estimates of wintering eiders, long-tailed duck, thick-billed murre and black guillemot populations off south-west Greenland, 1999, derived from distance sampling analyses. Coastal strata 1 and 2 indicate geographical post-stratifications, whereas A, B and C indicate post-stratification by flock size (further details in Results). Coefficients of variation calculated as standard error in proportion to the mean are indicated in parentheses. (Table continues next page.)

Species and stratum	Area (km²)	ESW (km)	Right-truncation (m, % sight.)	Key function + series expan.	Effort *L* (km)	% area surv.	Sightings[a] (*n*)	Sighting rate (*n/L*)
Common eider								
Coastal A, S < 10	22250	0.140 (0.04)	280 (6)	hazard-rate + s.poly	2863	3.6	1440	0.50 (0.09)
Coastal B, 10 ≤ S< 100	22250	0.183 (0.04)	280 (17)	uniform + s.poly	2863	4.7	256	0.09 (0.11)
Coastal C, S ≥ 100	22250	0.280 (0)	280 (17)	strip census	2863	7.2	27	0.01 (0.33)
A+B+C	22250				2863	5.1	1723	
Fjords				total count	1798		772	
Total					4661		2495	
King eider								
Coastal 1, S < 100	3227	0.139 (0.03)	280 (2)	uniform + s.poly	486	4.2	13	0.03 (0.47)
Coastal 1, S ≥ 100	3227	0.280 (0)	280 (25)	strip census	486	8.4	16	0.03 (0.46)
Coastal 2	19023	0.139 (0.03)	280 (2)	uniform + s.poly	2377	3.5	510	0.22 (0.12)
1+2	22250				2863		539	
Fjords				total count	1798		40	
Total					4661			
Long-tailed duck								
Coastal 1	5198	0.109 (0.06)	240 (4)	half-normal	804	3.6	16	0.02 (0.38)
Coastal 2	17052	0.109 (0.06)	240 (4)	half-normal	2059	2.6	347	0.17 (0.11)
1+2	22250				2863	2.8	363	
Thicked-billed murre								
Coastal A, S ≤ 10	22250	0.104 (0.02)	300 (2)	uniform + cos	2863	2.7	383	0.13 (0.15)
Coastal B, S > 10	22250	0.156 (0.14)	350 (9)	half-normal	2863	4.0	84	0.03 (0.20)
A+B	22250				2863	3.3	467	
Black guillemot								
Coastal	22250	0.16 (0.06)	300 (2)	hazard-rate	2863	4.1	172	0.06 (0.15)

[a] Number of sightings used for the calculation of sighting rate (*n/l*). Represents all on-transect sightings, except for those eliminated by truncation. Number of sightings used when calculating ESW and flock size are less than indicated in this column, due to a minor proportion of sightings for which information about flock size or distance from track line is lacking.

Table 4. Estimates of some highly concentrated wintering seabirds in the Nuuk area and in the Julianehåbsbugten area (see Fig. 2 for boundaries). Coefficients of variation calculated as standard error in proportion to the mean are indicated in parentheses. (Table continues next page.)

Species and stratum	Area (km²)	ESW (km)	Right-truncation (m, % sight.)	Key function + series expan.	Effort *L* (km)	% area surv.	Sightings[a] (*n*)	Sighting rate (*n/L*)
Common eider								
Nuuk–Coast	1330	0.140 (0.07)	280 (6)	hazard-rate + s.poly	196	4.1	267	1.36 (0.24)
Nuuk–Fjords				total count	510		127	0.25 (-)
Nuuk–Total					706		394	
King eider								
Nuuk–Coast	1330	0.132 (0.06)	280 (2)	uniform + s.poly	196	3.9	110	0.561 (0.29)
Long-tailed duck								
Nuuk–Coast	1330	0.096 (0.12)		half-normal	196	2.8	72	0.37 (0.24)
Common eider								
Jul.bugt.[b]–Coast	3558	0.133 (0.05)	280 (6)	half-normal	554	4.1	365	0.66 (0.15)
Jul.bugt.–Fjords				total count	560		374	0.67 (-)
Jul.bugt.–Total					1114		739	

[a] Number of sightings used for the calculation of sighting rate (*n/l*). Represents on-transect sightings, except for those eliminated by truncation. Number of sightings used when calculating ESW and flock size are less than indicated in this column due to a minor proportion of sightings for which information about flock size or distance from track line are lacking.
[b] Julianehåbsbugten (Julianehåb Bay), 60° - 61° N.

Flock size S	Density D (no. km^{-2})	**Abundance estimate** N	95% conf. limits for estimate (N) lower	upper
2.3 (0.03) [b]	4.2 (0.10)	**92326**	75701	112603
23.9 (0.06)	5.9 (0.13)	**130134**	100862	167903
364.3 (0.39)	6.1 (0.51)	**136500**	53273	349747
		358960	243025	530202
134.5 (-)		**103834**	-	-
		462794	341573	627036
4.5 (0.24) [b]	0.4 (0.53)	**1394**	525	3702
602.5 (0.58)	35.4 (0.74)	**114301**	31170	419145
2.3 (0.06) [b]	1.77 (0.13)	**33621**	25929	43595
		149317	52838	421957
89.6 (-)		**3584**	-	-
		152901	55272	422971
6.9 (0.13)	0.6 (0.40)	**3279**	1530	7029
6.9 (0.13)	5.3 (0.18)	**91103**	63906	129875
		94382	66943	133070
1.7 (0.04) [b]	1.1 (0.16)	**23898**	17600	32449
48.5 (0.18)	4.6 (0.30)	**101542**	57024	180814
		125439	78091	201497
2.9 (0.40)	0.5 (0.43)	**12030**	5335	27128

[b] Expected flock size used in preference to mean flock size (see Methods).

Flock size S	Density D (no. km^{-2})	**Abundance estimate** N	95% conf. limits for estimate (N) lower	upper
3.8 (0.11)	18.6 (0.27)	**24783**	14 664	41 883
251.6 (-)		**31952**	-	-
		56735	44 962	71 589
4.1 (0.18) [c]	8.7 (0.35)	**11507**	5947	22 266
5.2 (0.13)	9.9 (0.30)	**13232**	7468	23 445
6.2 (0.10) [c]	15.3 (0.18)	**54550**	38 353	77 589
110.2 (-)		**41204**	-	-
		95754	78 256	117 165

[c] Expected flock size used in preference to mean flock size (see Methods).

risk of missing single birds or small flocks of birds increases as birds are moving away from the observer. The vast majority of flying birds took a flight direction away from the aircraft (perpendicular to the direction of the aircraft). Second, the risk of perceiving two distinct flocks of birds as a single one also increases as distance increases. Furthermore, we also observed that separate airborne flocks tended to unite in larger groups, as one flock apparently attracted the attention of another. Alternatively, exclusion of flying birds from flock size calculations could cause the mean size to be underestimated. This would occur if larger flocks tended to be more alert than smaller flocks and moved away to avoid the aircraft more often. However, observations from the co-pilot seat did not indicate this. No statistically signficant correlation was found between the distance from which eiders took flight and the flock size for either species: $r = 0.19$ for common eider ($n = 49$); $r = 0.09$ for king eider ($n = 23$); and $r = 0.21$ for both species combined ($n = 74$).

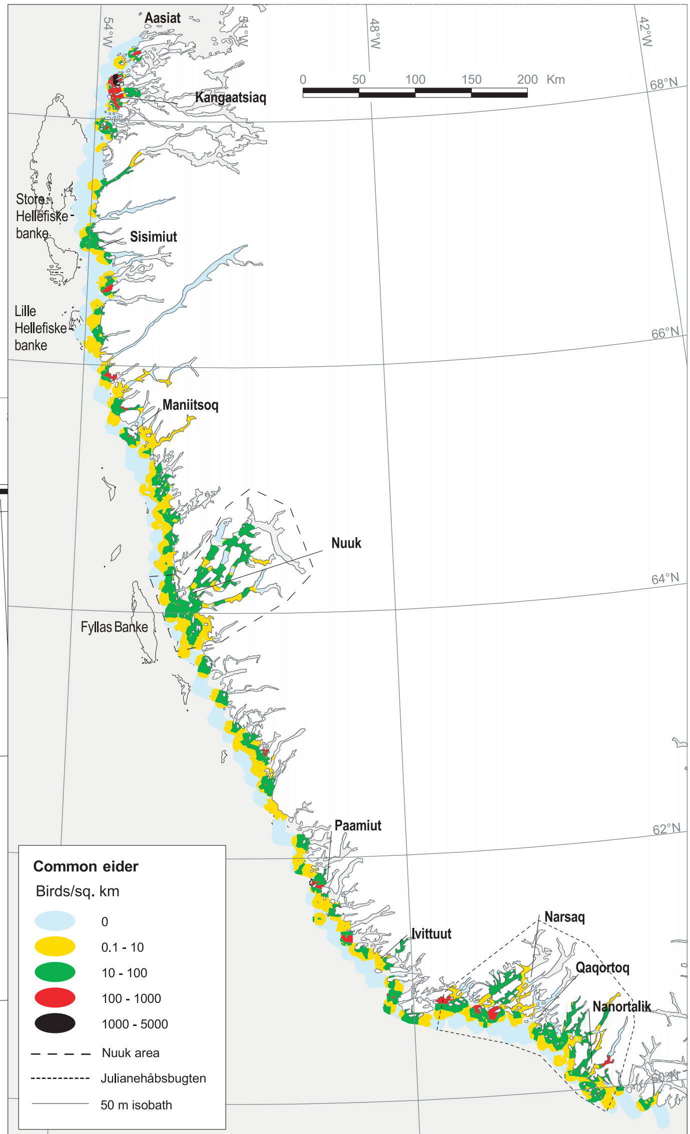
To include the "flying bird proportion" in the final estimate, sightings were entered when computing the mean sighting rate. A certain proportion of the sightings have been truncated, similar to the one effected on birds on the water. As the original position of the flying birds is unknown, we risk including birds that were originally outside the truncation distance. We suggest that this potential source of error may be counterbalanced by the risk of missing "inside" birds more often than expected from the detection function, due to a far-off position at the time of detection.

Common eider

Common eider had the most wide-ranging distribution and was also the most abundant species (Table 1). A total of 2779 sightings were recorded during the survey, of which 28% were made in the fjords. In general, sighting rate was high and flock size low at the coastal zone, whereas the opposite applied in the fjords. Only in the most northern part of the coastal zone, north of 68° N, was flock size high as in the fjords. At the coastal zone, common eiders were most frequently seen on near-shore shallow waters (Fig. 2).

On average, 74% of the sightings at the coastal zone were birds detected on the water, while the majority of the rest were flying when passed

Fig. 2 (right). Distribution and interpolated densities of common eider in south-west Greenland, February/March 1999.



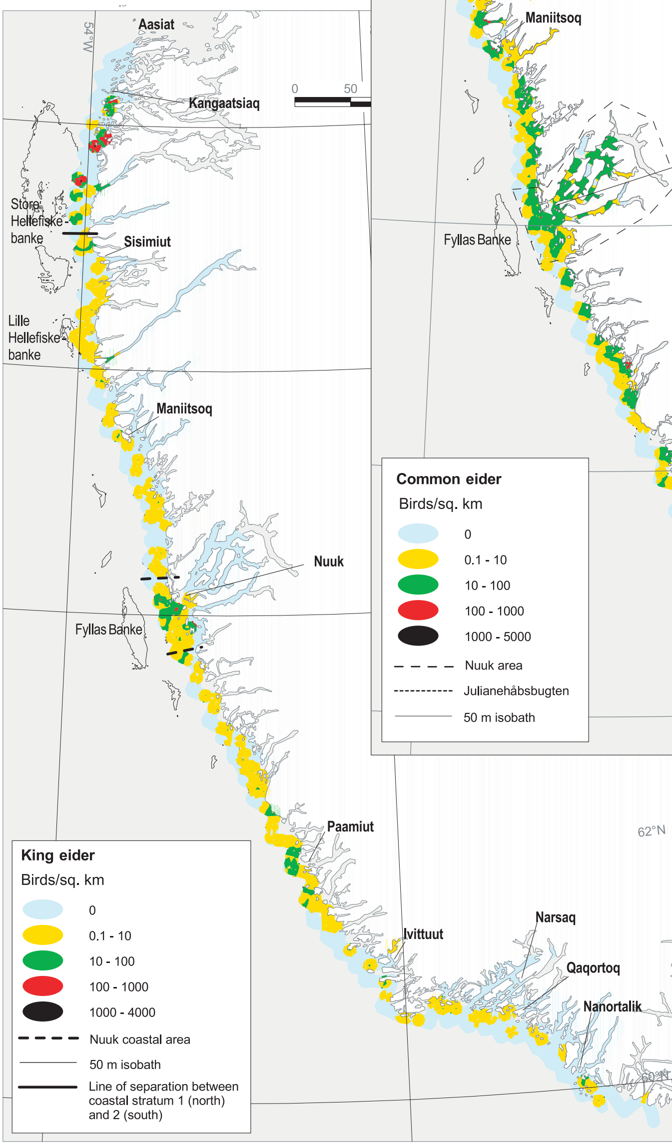


Fig. 3 (left). Distribution and interpolated densities of king eider in south-west Greenland, February/March 1999.

abeam (Table 2). Splitting this dataset at 66° N, 64° N and 62° N showed that the proportion of flying birds versus birds on the water was significantly higher in the most northern area (north of 66° N): 51 % flying birds in the northern area compared to 18 %, 10 % and 23 % at the three southern areas (χ^2_3 = 181.4; $P < 0.01$).

When estimating common eider abundance, the coastal survey zone was analysed as only one stratum due to the rather continuous distribution of birds along the outer coastline (Fig. 2). However, we post-stratified data according to flock size to overcome a very high degree of natural variation from this source. With flock sizes of 10 and 100 individuals as the points of separation, three datasets were produced. Each dataset was analysed separately (Coastal A, B and C) (Table 3). By assuming a 100 % detection efficiency of large eider flocks (≥ 100) within the whole transect width (2 × 280 m), dataset C was analysed according to strip census methodology. Flock size varied considerably (from 100 to 6500 birds). In dataset C, however, additional stratification was not possible because of the small sample size. The total number of common eiders at the coastal stratum was estimated at 358 960 birds (95 % CL: 243 025 - 530 202). Combined with a total count of 103 834 birds in the fjords, the total number of common eiders is estimated at 462 794 birds (95 % CL: 341 573 - 627 036) (Table 3).

At the coastal stratum there was a rather consistently high density of common eiders west of Nuuk (64° N, 18.6 birds/km^2) and in the Julianehåbsbugten area (15.3 birds/km^2) (Table 4). Along with high densities in the adjoining fjords, these areas constituted two very important common eider wintering sites in 1999 (Fig. 2). Based on separate analyses we estimated 56 735 (95 % CL: 44 962 - 71 589) common eiders in the Nuuk area, and 95 754 (95 % CL: 78 256 - 117 165) in the Julianehåbsbugten area. In both cases, approximately half the birds were located in the fjords (Table 4). A third area of equal importance may be the northern area between 67° 15' and 68° 45' N. Most observations of large eider flocks at the coastal stratum were detected here, leading to a high density around Kangaatsiaq. Due to poor coverage we are unable to document the importance of the adjoining fjords in this region.

King eider

Like common eider, king eider had a wide-ranging distribution at the coastal zone. However, in contrast to common eider, few king eiders were present in the fjords (Fig. 3). Only 6 % out of 639 sightings were detected in fjords (Table 1); king eiders were seen deep inside the fjords on only two occasions. Compared to common eiders, king eiders had a more uniform east–west distribution at the coastal zone, as they occupied deeper waters to the west. By sightings, king eider was the third most abundant species, the second most abundant when evaluated by number (Table 1).

King eider behaviour was very similar to common eider behaviour (Table 2). 72 % of the king eider sightings in the coastal zone were detected on the water, while 23 % were flying when passed abeam. As with common eider, the proportion of flying king eiders versus birds on the water were significantly higher to the north (χ^2_3 = 45.6; $P < 0.01$). North of 66° N, 43 % of the sightings were airborne compared to only 11 %, 19 % and 25 % south of 66° N, 64° N and 62° N, respectively.

North of Sisimiut (67° N) flock size was considerably higher than elsewhere at the coastal zone. As a consequence, the coastal zone was divided into two strata (Fig. 3), and distance data subsequently post-stratified and analysed according to this (Table 3). Furthermore, data from the northern stratum 1 were stratified according to flock size to overcome some of the variation from this source. As with the common eider, sightings of large king eider flocks (≥ 100) were analysed as strip census data, as we assumed 100 % detection efficiency within the truncation distance (280 m). The king eider coastal population was estimated at 149 317 birds (95 % CL: 52 838 - 421 957), of which ca. 78 % originated in the northern stratum 1 (Table 3). Another 3584 birds were detected in the fjords, making a total estimate of 152 901 (95 % CL: 55 272 - 422 971) king eiders. As indicated by the wide-ranging confidence limits, the abundance estimate is subject to major uncertainties. This is mainly due to the low sample size and wide-ranging flock size in coastal stratum 1 (Table 3). In contrast, sighting rate was high and flock size very uniform in stratum 2, and led to a much more accurate estimate of 33 621 (95 % CL: 25 929 - 43 595).

Densities within stratum 2 were highest west off Nuuk (8.7 birds/km^2), as was the case for common eider. A separate analyses estimated that 11 507 (95 % CL: 5947 - 22 266) king eiders

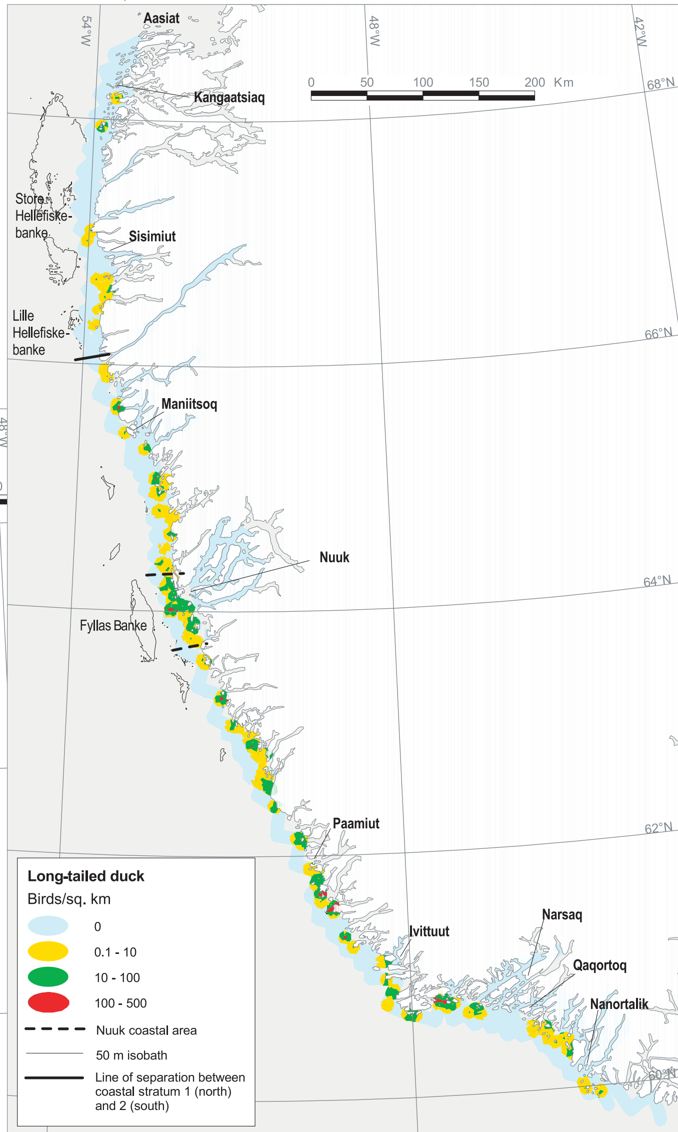


Fig. 4 (right). Distribution and interpolated densities of long-tailed duck in south-west Greenland, February/March 1999.

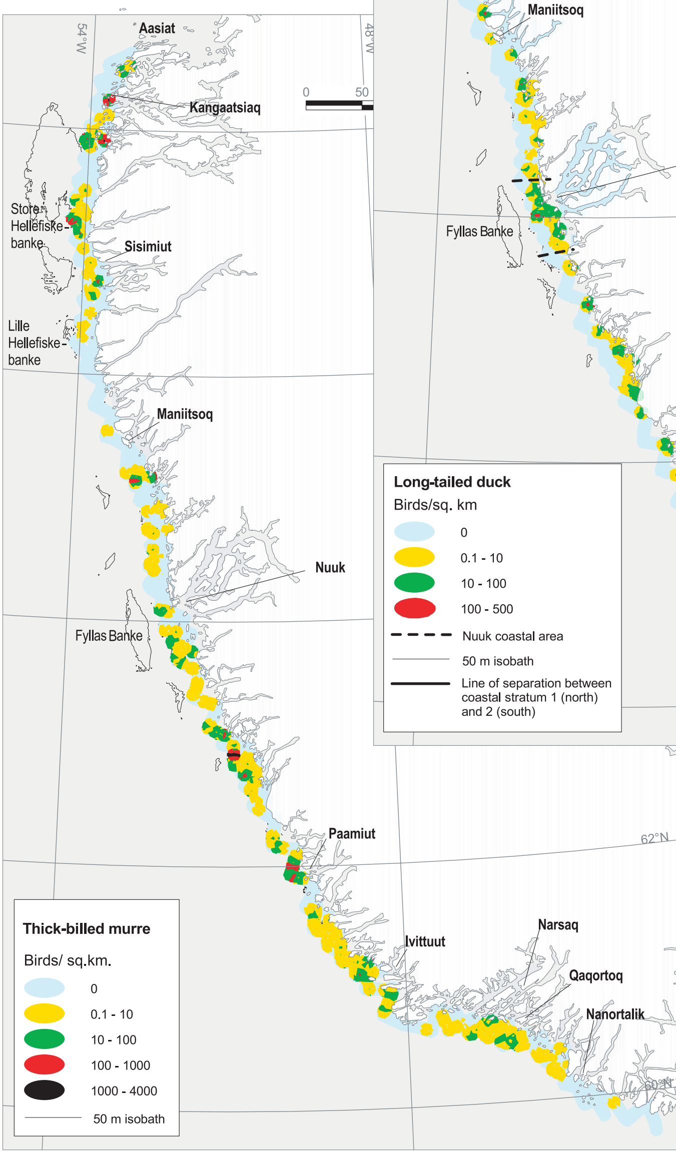


Fig. 5 (left). Distribution and interpolated densities of thick-billed murre in south-west Greenland, February/March 1999.

were present at the coastal zone just west of Nuuk (1330 km^2) (Fig. 3, Table 4).

Unidentified eiders

A total of 53 sightings were recorded as undifferentiated eiders. This constituted 1.5 % of all eider sightings (Table 1). Almost all of them were seen at the coastal zone north of Sisimiut. The vast majority was detected at very long distances (300 - 4000 m), which accounts for why they could not be identified to species. Most were gathered in large flocks, which explains why they were detected. All of these observations were disregarded in the quantitative analyses of eiders, as they would have been eliminated by truncation.

Long-tailed duck

Long-tailed ducks occurred entirely in near-shore coastal waters (Table 1, Fig. 4). Birds were distributed throughout the coastal zone, however. North of Nuuk (64° N) they became gradually less frequent, and north of Søndre Strømfjord (66° N) they were rare (stratum 1).

The proportion of long-tailed ducks that were detected as flying when passed abeam was higher than for both eider species—on average 32 %. Still, the majority of long-tailed ducks were detected on the water (61 %) (Table 2). Again, the proportion of flying birds versus birds on the water was significantly higher than in the north ($\chi^2_3 = 17.9$; $P < 0.01$), with 56 % of airborne sightings north of 66° N compared to only 26 %, 29 % and 37 % south of 66° N.

Compared to the eiders, long-tailed duck flock size variation was small (120 birds being the highest number recorded). Instead, substantial variance was added to the abundance estimate as a consequence of a rather variable sighting rate. To overcome some of it, distance data were post-stratified according to a northern and southern stratum, and a separate sighting rate was computed for each of them (Table 3). However, mean flock size and ESW was computed from all sightings. The distance analyses led to an estimated number of 94 382 (95 % CL: 66 943 - 133 070) wintering long-tailed ducks, of which only 3.5 % (3279 birds) originated in the northern stratum 1 (Table 3).

Once more, the Nuuk coastal zone turned out to be a high-density area at the time of the survey. We estimated that 13 232 (95 % CL: 7468 - 23 445) long-tailed ducks were present in the Nuuk coastal zone (Table 4). The average density of birds in this area was approximately twice the overall density of stratum 2 (10.0 birds/km^2 versus 5.3).

Thick-billed murre

The thick-billed murre was the second most frequent species encountered, by sightings (Table 1). Birds were seen throughout most of the coastal zone, although they were absent or scarce from around Maniitsoq (65° N) and 150 km to the north, and in a few minor areas elsewhere at the coastal zone (Fig. 5). Just as king eiders, the murres had a rather uniform east–west distribution within the coastal survey area, indicating that their presence continued further west. Very few birds were seen in the fjords (Table 1), and all were detected at the outermost regions of the fjord systems (Fig. 5).

Murres performed escape diving as the most pronounced response to the approaching survey airplane. On average, 8 % of the sightings were detected as diving birds when passed abeam (Table 2). Usually birds were visible several metres below the surface. Murres initially responded by swimming away from the flight path, and then some escaped by diving as the plane passed over them. There was a tendency for escape diving to occur most frequently close to the flight line. In a number of cases, birds did not dive until the airplane had already passed over them. In such cases birds were recorded as being "on the water". Therefore, the true magnitude of murres responding to the approaching airplane was probably somewhat higher than indicated by our records (Table 2). The proportion of diving birds versus birds on the water differed significantly between areas ($\chi^2_3 = 15.3$; $P < 0.01$). Escape diving response was most pronounced between 66° and 62° N (12 - 14 %), and less so north and south of this area (2-6 %). The number of airborne sightings also varied between areas, though in general few murres took flight (Table 2).

Murres often occurred singly or in small flocks (≤ 10 birds). However, for a minor proportion (20 %) of the sightings flock size ranged considerably (11 - 2000 birds). To reduce variance from this source we stratified the murre dataset according to flock size, with 10 individuals as

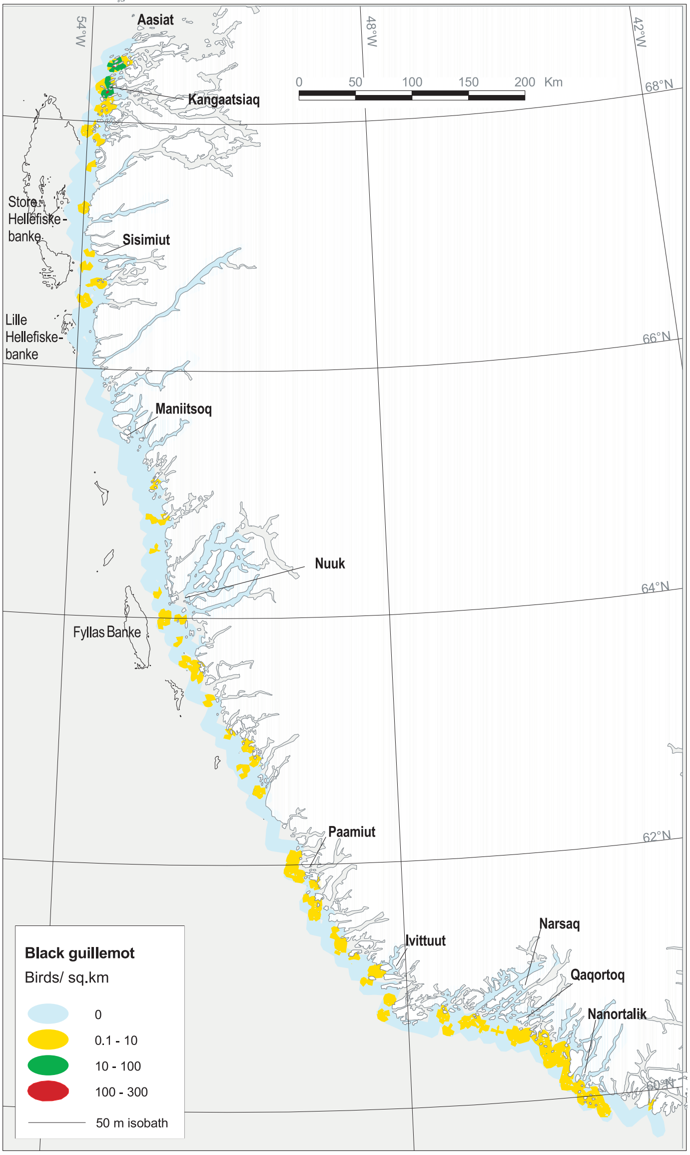


Fig. 6. Distribution and interpolated densities of black guillemot in south-west Greenland, February/ March 1999.

the separation point (Coastal A and B) (Table 3). Detectability of the murres was reduced close to the track line, due to the frequency of escape diving at this range. Furthermore, the white flank of the murres is not visible when observed directly from above, making them harder to detect close to the track line. As a consequence we left-truncated distance data at 50 m. For dataset A this implied a removal of ca. 27 % of the sightings, and for dataset B ca. 15 %. The final abundance estimate was calculated at 125 439 (95 % CL: 78 091 - 201 497) wintering murres at the coastal zone, of which more than 80 % were estimated from dataset B (S > 10) (Table 3).

Black guillemot

Black guillemot was the fifth most common bird observed in the survey (Table 1), with an average density of 0.5 birds/ km^2 (Table 2). Birds were dispersed singly or in small flocks throughout most of the coastal survey area (Fig. 6). The highest density was observed in the northern dense pack ice around Kangaatsiaq, but density was also high around Nanortalik, where there was no ice. From around 65° to 66° 30' N, and at a small area north of Paamiut, no birds were seen at all; these were the same places at which thick-billed murres were very scarce. In some areas black guillemot were most abundant to the west in the survey area, indicating that their presence continued further west. Birds were seldom seen in the fjords; only five sightings were detected (Table 1).

Black guillemot responded to the approaching survey airplane much like the murres did, mainly by escape diving (Table 2). The proportion of diving birds versus birds on the water differed between areas, though this was not statistically significant ($\chi^2_3=3.8$; $P=0.28$). As with the murres, there was a tendency for escape diving to occur most frequently close to the track line.

As with the murres, data were left-truncated at a distance of 50 m, corresponding to a 13 % reduction in sample size. In spite of a rather variable sighting rate at the coastal zone, the most robust abundance estimate was produced without any geographical post-stratification. The number of wintering black guillemots at the coastal zone was estimated at 12 030 (95 % CL: 5335 - 27 128) birds. Most of the abundance variance can be ascribed to a minor proportion of the sightings, for which flock size was higher and more variable than for the majority. As much as 75 % of the sightings consisted of single bird observations (Fig. 6).

Non-quantified species

Fulmar.—Eighty-two sightings of fulmars with a total of 1153 birds were detected during the survey (Table 1). Except for a single observation, all fulmars were airborne at the time of detection (Table 2), rendering the sightings inadequate for distance sampling analyses. Fulmars were detected on 22 of 127 transects, of which 21 were positioned within the most central portion of the open water area (65° 50' - 62° 35' N). Here birds occurred in patches with the highest concentration to the west, indicating a further distribution to the west. One transect at the southern tip of Greenland accounted for 35 % of all detected birds. Apart from this transect, no birds were detected north and south of the specified area or in the fjords.

Great cormorant.—Great cormorants were found throughout the coastal zone, although very scarce at some regions. Regular findings were done from Kangaatsiaq and halfway to Sisimiut (68° 20' - 67° 43' N), between Maniitsoq and Nuuk (65° 10' - 63° 45' N), and in the Julianehåbsbugten area (60° 42' - 59° 50' N). Birds were recorded on 40 of 127 transects, with a total number of 556 individuals (Table 1). Birds were confined to near-shore coastal areas, and were often resting on small islands. They all took flight at the approach of the survey airplane (Table 2). Additionally, 136 birds were seen in the fjords, mainly in the Julianehåbsbugten area.

Mallard.—Mallards were seen in near-shore local concentrations at the coastal zone, mainly around Nuuk and at the Julianehåbsbugten area. A total number of 252 birds were recorded on 13 of 127 transects (Table 1). No mallards were detected north of 64° 52' N or in the fjords.

Harlequin duck (Histrionicus histrionicus).—Only four sightings (45 birds) of harlequin duck were made during the survey. These were located at Ydre Kitsissut (60° 45' N), an area specifically searched as some of the uplinks from Canadian satellite tracked birds came from these islands (Brodeur et al. 1998), and at two locations south of Nuuk (63° 59' N and 63° 3' N). Many individuals of this species must have been overlooked by this survey, partly because of their small size, but mainly due to its habitat preferences.

Red-breasted merganser.—Red-breasted merganser was occasionally seen in small numbers at the coastal zone, strictly confined to the coastline. Birds were most regularly encountered from around Nuuk and 180 km to the south, and in the Julianehåbsbugten area. A total of 79 birds were recorded (Table 1).

Kittiwake.—At the coastal zone kittiwake sightings were restricted to the most central region (60° 42' - 59° 50' N), a distribution tendency similar to the one observed for fulmars. Birds were distributed, in small numbers, almost evenly in this area (Table 1). High densities of kittiwakes were found in the fjord system around Maniitsoq. A total number of 3200 birds were counted here. The Maniitsoq fjord system is also known as the most important kittiwake breeding site in Greenland (Boertmann et al. 1996). Kittiwakes were not seen elsewhere in fjords.

Discussion

Overall distribution and abundance

Surveying the entire coastal zone for the first time, this study confirms that coastal habitats off south-west Greenland are important seabird wintering grounds (Salomonsen 1950, 1979; Durinck & Falk 1996). This study also documents the importance of several fjord systems as winter habitats for common eider.

Common eider, king eider, long-tailed duck, thick-billed murre and black guillemot were the most widespread and numerous species, with a combined estimate of 850 000 birds. Considering that aerial surveys normally produce conservative estimates (see below), and the fact that not all fjords were surveyed, is it likely that the actual total winter population of these five seabird species exceeds one million birds within the fjords and coastal areas covered in this study. With high densities and species diversity at the coastal zone, and highly concentrated aggregations of common eiders in the adjoining fjord systems, the waters around Nuuk and the Julianehåbsbugten area were identified as important seabird areas.

Distribution and abundance: coastal species

Among the 15 seabird species recorded, six had their predominant distribution confined to shallow waters at the coastal zone or parts of fjord systems. These species—common eider, long-tailed duck, great cormorant, mallard, harlequin duck and red-breasted merganser—are all associated with shallow waters. They feed on molluscs, crustaceans, echinoderms or fish (Salomonsen 1967; Cramp 1977). Except for the harlequin duck, these species were ideal to monitor with the present survey design, although mallards and red-breasted mergansers were too few in number to allow quantitative analyses. Distribution and abundance of moulting/wintering harlequin ducks has since been studied by alternative survey methods (Boertmann & Mosbech 2001; Boertmann & Mosbech unpubl. ms.)

This study has produced the first available estimates for common eider and long-tailed duck. Our estimate represents the total number of wintering birds off south-west Greenland, although these numbers may to be conservative for the following reasons. First, we only surveyed about 45 % of all fjord areas. Although fjords believed to harbour high densities of eiders were preferentially selected for surveying, and many non-surveyed fjords between Ivittuut and Nuuk (61° - 64° N) are usually completely ice-covered (Mosbech et al. 2000), there were very likely some birds in the unsurveyed fjords. In addition, aerial surveys conducted in March/April 1998 indicated that a few common eiders might occur to the west of the coastal survey area (Heide-Jørgensen et al. 1999). Common eider has a maximum recorded diving depth of around 20 m (Bustness & Lønne 1997; Cramp 1977), and water depths within this range do occur at offshore banks, although they are rare (Mosbech & Johnson 1999). They might also use offshore waters as resting locations, or to avoid human hunting along coasts.

The 1998 aerial survey also showed that long-tailed ducks occasionally could be seen west of the coastal zone (Heide-Jørgensen et al. 1999). However, observations were very rare, and limited to seven sightings within an area of 43 250 km^2 (Fig. 1). Except for our 1998 survey, no previous surveys have reported long-tailed duck west of the 1999 coastal survey zone (Durinck & Falk 1996; Mosbech & Johnson 1999). Apparently, long-tailed ducks are absent in fjords, and therefore the coastal survey zone covers the entire long-tailed duck winter distribution range in west Greenland. We consider the estimate of 94 382 birds (95 % CL: 66 943 - 133 070) to represent the total number of long-tailed ducks wintering off south-west Greenland.

Distribution and abundance: offshore species

King eider, thick-billed murre, black guillemot, fulmar and kittiwake were all frequently observed in the coastal survey area. However, we anticipated on the basis of earlier surveys that these species—in contrast to the coastal species—would be distributed west of the coastal zone as well. Characteristically, they were distributed rather evenly from east to west at the coastal survey zone, and some of them even concentrated offshore to the west. Previous aerial and ship-based surveys conducted in February–April found king eiders at high densities on offshore shallow banks (Store Hellefiskebanke and Fyllas Banke). Thick-billed murres occurred offshore on the continental shelf as well as on shallow banks, black guillemots on offshore pack ice throughout the Davis Strait and Baffin Bay, and fulmars and kittiwakes dispersed on most ice-free waters (Durinck & Falk 1996; Heide-Jørgensen et al. 1999; Mosbech & Johnson 1999). Thus, the abundance estimates for king eider, thick-billed murre and black guillemot published in this paper represent only birds found coastally, and constitute an unknown proportion of the south-west Greenland winter population: this survey cannot estimate population sizes for these species nor serve as a basis to detect population trends with future surveys. In addition, ice conditions—shown to be crucial for the offshore distribution of several species (Mosbech & Johnson 1999)—in the Davis Strait vary considerably from one year to another.

Detection efficiency

An assumption of the line transect survey method is that all individuals on the track line are detected (Buckland et al. 1993). However, in practice weather conditions may reduce detectability, or birds may behave in such a way that they are hard to detect. In this study we conducted several test surveys to provide more precise estimates and facilitate reproducible surveys (Heide-Jørgensen et al. 1999).

Submergence, the predominant avoidance response among thick-billed murre and black guillemot (Table 2), clearly brought down the detection efficiency on the track line to below 100 %. As the response occurred most frequently close to the track line, the problem could partly be solved by a left truncation of the distance data. Still, we must expect some degree of escape diving beyond the truncation distance of 50 m. This behaviour was most pronounced for the alcids, making aerial surveys less suitable for counting them. For all other species, including eiders, submergence appeared to be a minor problem (Table 2).

Non-alcid birds took flight as the most frequent response to the approaching airplane. In contrast to the diving response, this often took place some distance ahead of the airplane. The behaviour as such did not reduce detectability, but the important question is whether airborne sightings can be represented by the parameters (flock size, ESW) calculated from sightings detected on the water. However, as earlier argued, we believe this is justified in a conservative estimate.

For both eider species and long-tailed ducks, a significantly higher proportion of birds took flight north of 66° N. We cannot explain why this is so. However, we speculate that it might be related to the frequency of human disturbance in this region. At the coastal areas with low flight reaction, weather had been rough for several days prior to the survey, preventing hunting and postponing our own surveying. Maybe this period of non-disturbance reduced the alertness of the birds. Another possible explanation is that the sound pressure of the airplane noise might be influenced by ice coverage, which certainly was higher to the north.

Detectability is also related to the efficiency of the observers. It has long been recognized as a methodological problem for line transect surveys that the assumption of 100 % detectability on the track line fails due to observers overlooking individuals (Pollock & Kendall 1987). Using traditional methods to solve this problem, e.g. double-observer experiments, is seldom an option in bird cases as densities of birds are usually too high to allow positive recapture identification. During this survey, a video recorder was attached at a bottom window of the airplane. However, the method turned out to be inadequate as birds could not be positively identified on the videotape. Clearly, methods to derive correcting factors for missed bird observations on the track line are needed.

Conservation concerns

The high density of seabirds throughout the coastal zone accentuates several management issues of concern, including vulnerability to oil pollution (Mosbech et al. 1996). Exploratory drilling has already taken place in the Fylla area (summer 2000), and more is expected. This study clearly shows that exposure to oil of any littoral region along south-west Greenland is likely to impact a substantial number of seabirds. An unknown proportion of common eider may avoid oil deep inside the fjords, assuming they never travel to the coastal zone.

Seabirds are heavily hunted at the coastal zone. Hunters' reports on monthly bags (1994–99) produce a minimum average number of 165 000 thick-billed murres and 55 000 eiders (king and common) that are harvested each winter in south-west Greenland (the actual takes are probably higher). These numbers represent 80 % and 70 % of the total annual catch of murres and eiders in Greenland, respectively (Dept. of Fishing and Hunting, Greenland Home Rule). As south-west Greenland is an important international wintering area for both thick-billed murres, king and common eider, there is concern that an excessive harvest might affect various breeding populations within the circumpolar region. Serious declines have been detected at colonies of thick-billed murre and common eider in Greenland (Kampp et al. 1994; Frich et al. 1998; Merkel 2002), thick-billed murre colonies in Iceland (Gardarson 1995; Natturufrædistofnun Islands 2000), and eastern Canadian king eiders moulting in west Greenland (Gratto-Trevor et al. 1998; Mosbech & Boertmann 1999). It is generally assumed that these cases are related to the harvest in Greenland; however, due to insufficient information about the size of the total winter population it is unclear to what extend the winter harvest is responsible. Our estimates for common eider and long-tailed duck greatly improve the possibility of assessing the sustainability of the winter harvest. As argued, the estimates are considered rather conservative. From a management perspective, this is not a major drawback as it will lead to management on the safe side rather than promoting unsustainable over-harvesting. Furthermore, it should also be taken into consideration that the hunting statistics upon which management is partly based are likely influenced by under-reporting (Frich 1997b; Falk & Kampp 2001). Thus, while actual bird numbers may be somewhat higher than reported here, so are hunting offtakes.

For the common eider this study emphasizes the importance of south-west Greenland as a wintering area for the eastern Canadian breeding population. For quite some time it has been known that nearly all the king eiders originate in the Canadian Arctic (Salomonsen 1968). However, for common eider (*S. m. borealis*) the magnitude of influx from Canada has been uncertain. From band recoveries it is known that only birds from western Greenland and eastern Canadian Arctic winter in south-west Greenland (Salomonsen 1967; Abraham & Finney 1986; P. Lyngs, pers. comm. 2000). Based on recently conducted surveys, it is estimated that a maximum number of 15 000 pairs breed in western Greenland (Merkel 2002), implying that the vast majority of the conservatively estimated number of 463 000 wintering common eiders originate in the eastern Canadian Arctic.

Recommendations for management and future studies

Future aerial surveys of south-west Greenland waters should preferably be extended to include the offshore shallow banks, Store Hellefiskebanke, Lille Hellefiskebanke and Fyllas Banke since this would permit a complete coverage of the king eider distribution range. Recently conducted satellite telemetry of king eiders in west Greenland suggest that there is only little interchange between coastal birds and birds using the offshore shallow bank Store Hellefiskebanke (Mosbech et al. 2001).

To include the total distribution range of thick-billed murre, as well as other offshore species, would mean a further extension of the survey area. This would be difficult, considering the unstable weather conditions in south-western Greenland at this time of year.

For the common eider we recommend using the population estimate presented here to advance the assessment of the sustainability of the winter harvest in west Greenland. In fact, this process has already been initiated, and a preliminary computer model that simulates population dynamics for the northern common eider population (*S. m. borealis*) in Greenland and Canada has now been developed (Gilchrist et al. 2001). A similarly useful estimate now exist for the long-tailed duck population wintering in west Greenland. However, hunters are not currently bound to supply bag records for the harvest of this species. Unfortunately this means that sustainable harvest assessments are yet not possible for this species. Long-tailed duck is a fairly common game bird during wintertime, and future inclusion in the bag record programme would be highly recommended.

Fjord systems obviously provide important winter habitat for the common eider. However, judging by bird distribution and behaviour, the fjords might also play a somewhat different role from coastal habitats. The fjord birds congregate to form huge and very densely packed flocks. In contrast, eiders at the coastal zone are distributed rather evenly as individuals or in small groups. From an ecological point of view, as well as for management purposes, it is necessary to study the relationship between coastal and fjord birds. Currently, it is not known whether these populations are distinct, or if fjord eiders move out to join coastal populations throughout the winter or vice versa. If little or no interchange occurs, the coastal eider population is certainly exposed to a steadily high hunting pressure.

Based upon this study, the Nuuk and Julianehåbsbugten areas support one third of the total common eider winter population (Table 4). Cities and settlements within these two areas also support about 40 % of the Greenlandic human population and, in consequence, both areas are heavily hunted. Approximately 25 000 eiders are shot each winter (1994–99), comprising almost half (45 %) of the eider harvest in southwest Greenland (Dept. of Fishing and Hunting, Greenland Home Rule). Moreover, associated disturbances might affect body condition in such a way that reproductive performance is reduced. Such issues need attention.

Finally, in the context of oil pollution seabird studies that aim at forecasting their distribution and abundance during winter are recommended. Studies that relate bird distribution to habitat factors such as salinity, temperature, depth, ice cover etc. would allow elaboration of forecast scenarios.

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