Abundance of ringed seals (*Phoca hispida*) in the Kong Oscars Fjord, Scoresby Sund and adjacent areas in eastern Greenland

E. W. Born[1], J. Teilmann[2] and F. Riget[3]

[1] *Greenland Institute of Natural Resources, c/o National Environmental Research Institute, Department of Arctic Environment, Tagensvej 135, 4th floor, DK-2200 Copenhagen, Denmark*
[2] *Danbiu ApS, Tornagervej 2, DK-2920 Charlottenlund, Denmark*
[3] *National Environmental Research Institute, Department of Arctic Environment, Tagensvej 135, 4th floor, DK-2200 Copenhagen, Denmark*

ABSTRACT

With the purpose of determining the distribution and abundance of ringed seals (*Phoca hispida*) hauling out on the ice, systematic strip census aerial surveys were flown in the Kong Oscars Fjord, Scoresby Sund and adjacent areas (between approximately 70°N and 72°30'N in eastern Greenland) from 7 to 13 June 1984. The study area comprised approximately 18,500km^2 mainly covered with smooth one-year-old shore-fast ice. The survey effort was concentrated in the afternoon during the presumed peak haul-out period. Main emphasis was given to surveying the Kong Oscars Fjord/Davy Sund and the Scoresby Sund/Hurry Fjord areas which were surveyed twice. Average densities in various sub-areas varied between 0.3 and 2.9 seals/km^2 and were similar to those reported from other Arctic areas. No significant differences in densities were found between sets of surveys of the same sub-areas. The mean density (2.00 seals/km^2, SD=0.22) in the Scoresby Sund area was significantly higher than that found in Kong Oscars Fjord (1.04 seals/km^2, SD=0.15) probably reflecting a higher overall marine productivity in Scoresby Sund. The sum of the point estimates of the visible part of the population in the different sub-areas was 28,882 seals.

INTRODUCTION

The ringed seal (*Phoca hispida*) is widely distributed in Greenland where it is the most common marine mammal inshore (Teilmann and Kapel this volume). In coastal regions ringed seals spend most of their time during winter in dens under the snow on the shore-fast ice and in the water (Frost and Lowry 1981, Helle 1992). However, after the breeding season (March - early May) they haul out on the ice to moult (Stirling 1975, Frost and Lowry 1981). The greatest number of seals haul out in late June, immediately prior to break up of the fast ice (McLaren 1958, Smith 1973a,b), and therefore aerial surveys to determine the distribution and relative abundance of ringed seals in shore-fast ice habitats have mostly been conducted during June (Stirling *et al.* 1977). Although the number of seals hauling out are influenced by several factors such as weather conditions, and in particular the wind-chill effect (Finley 1979, Smith and Hammill 1981), there is a tendency that the seals prefer to haul out on the ice in early to mid-afternoon (Burns and Harbo 1972, Smith 1973a, Finley 1979, Stirling *et al.* 1982, Kelly *et al.* 1986).

In connection with oil-exploration on the peninsula of Jameson Land, situated between Scoresby Sund/Hall Bredning and Kong Oscars Fjord/Davy Sund in eastern Greenland (Fig. 1), a variety of biological studies were conducted between 1981 and 1989 to provide back-ground information for an environmental impact assessment. Because oil could be shipped from Jameson Land via the surrounding fjords, and in

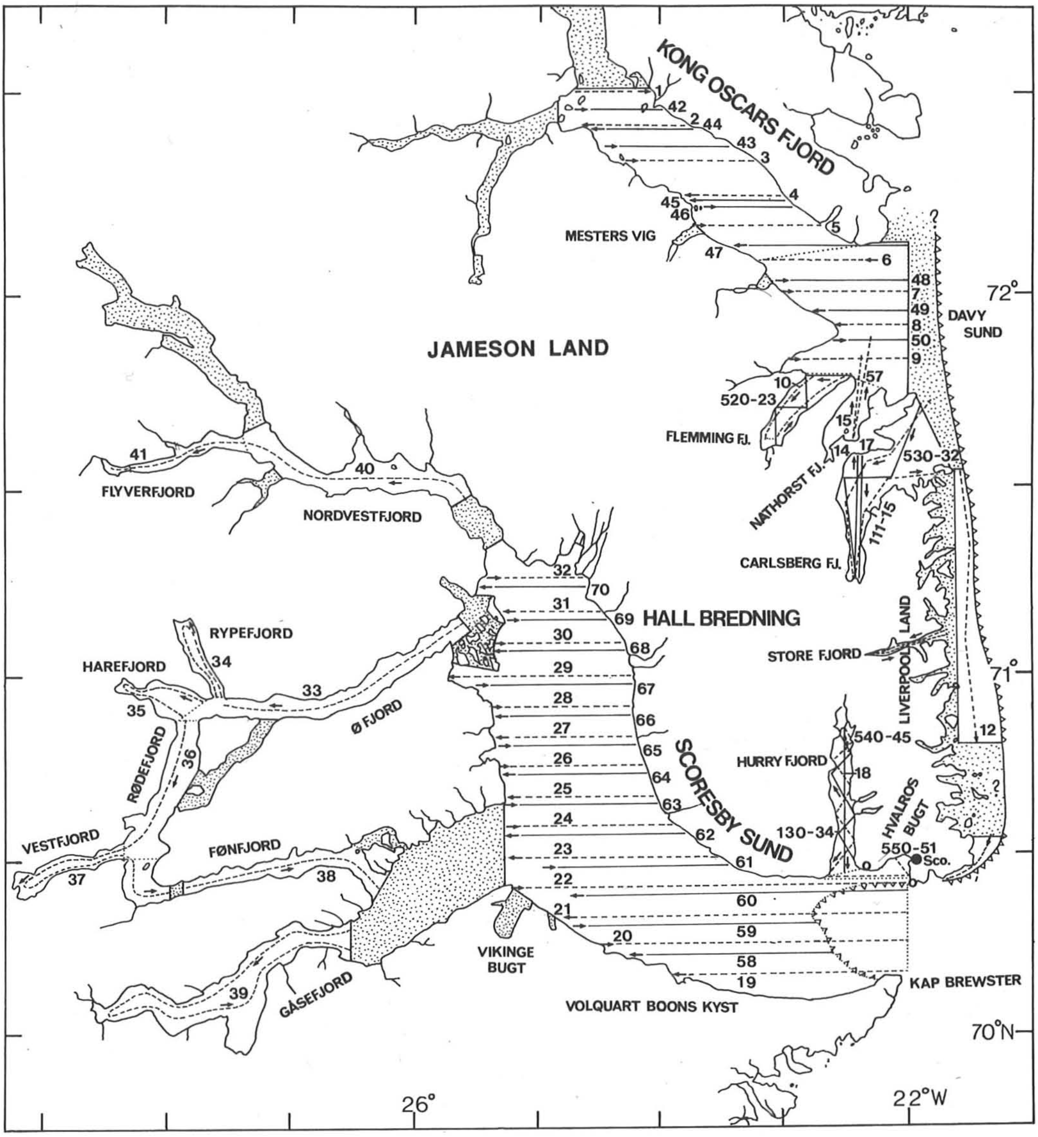


Fig. 1
The Kong Oscars Fjord - Scoresby Sund study area in eastern Greenland with transects flown during aerial surveys of ringed seals, June 1984. Transect numbers and direction of flights are indicated.

Legend:
---------- = 1st survey
________ = 2nd survey.
Dotted areas = not surveyed due to fog.
ΔΔΔΔΔ = Edge of shore-fast ice.
.... = delineation between different types of ice in the Kong Oscars Fjord - Davy Sund area.

The location of the three Inuit settlements at the entrance to the Scoresby Sound is indicated.

particular through either Scoresby Sund and Hurry Fjord, or Carlsberg Fjord and Kong Oscars Fjord/Davy Sund, aerial surveys were conducted in 1984 to determine the distribution and abundance of ringed seals in these areas. This study represents the only attempt so far to systematically assess the number of ringed seals in a Greenland shore-fast ice habitat. Preliminary results were presented in Born (1984, 1988).

In this paper results are presented on the distribution and abundance of ringed seals in the Scoresby Sund/Hall Bredning and Kong Oscars Fjord/Davy Sund and adjacent areas in June 1984.

MATERIALS AND METHODS

The study area

The Kong Oscars Fjord/Davy Sund and Scoresby Sund/Hall Bredning with tributary fjords comprised the study area (Fig. 1). These large fjords are partially sheltered from the East Greenland Current which brings water of Polar origin south along the eastern coast of Greenland (Sloth 1986). However, water from the East Greenland Current enters the entrance to Kong Oscars Fjord and Scoresby Sund. An eddy between this influx and a counter-acting efflux of water, in conjunction with up-welling, creates a polynya at the entrance to Scoresby Sund (Digby 1953); a phenomenon not present at the entrance to Kong Oscars Fjord. Outside Kong Oscars Fjord the East Greenland Current is forced away from land, and the current often has insufficient force to break up the fast ice, or transport ice away from the entrance (Anon. 1983, Rice 1983).

In both Kong Oscars Fjord and the main portion of Scoresby Sund/Hall Bredning water depth ranges between 200 and 600m (average depths around 400m) with shallower waters along the coasts of the peninsula of Jameson Land. In the western fjords of the Scoresby Sund fjord-complex (Fig. 1) water depths are greater being about 900-1,000m in Fønfjord and Øfjord, and more than 1,000m in Nordvestfjord (Navigational charts 2600 and 2701, Royal Danish Hydrographical Office, Copenhagen 1966).

In the Scoresby Sund region sunlight disappears on 26 November and reappears on 17 January. Midnight sun prevails between 17 May and 28 July (Anon. 1990a). Temperatures and precipitation reflect the High Arctic conditions of the region. Annual average temperatures are around -5°C, with positive mean temperatures during June-September (average in June: c. 2.5°C). Partially due to the presence of a dense and prolonged cover of pack ice along the eastern coast of Greenland precipitation is moderate for a major part of the year (<5cm/year) (Anon. 1990b).

The dense cover of land-fast ice breaks up around mid July in the Scoresby Sund fjord complex, but usually some 10 days earlier in Hurry Fjord. In the Kong Oscars Fjord area break up is a little later with fast ice sometimes persisting through August. New fast ice is usually formed in late September - early October (Rice 1983).

Winds are strongly affected by local topography in this highly mountainous region, with different winds blowing in places only a short distance apart. As registered at the entrance of Scoresby Sund about 30% of the time is calm in June when more than 30% of the wind comes from the east (Anon. 1990b).

Collection of data in the field

From 7 to 13 June 1984, systematic aerial surveys were flown over the ice covering the coastal areas between approximately 70°N and 72°30'N in eastern Greenland (Fig. 1). The surveys were designed as a systematic strip census (Stirling *et al.* 1982, Kingsley *et al.* 1985). The transects were oriented east-west in the large fjords and were spaced with five minutes latitude (9.3km; Fig. 1). During the second survey of the Scoresby Sund/Hall Bredning area, the transects were transposed two minutes latitude (3.7km) to increase the information about distribution. It was the intention to use the same design in the Kong Oscars Fjord/Davy Sund area. However, malfunctioning of the navigational system prevented a similar placement of transects in practice during the second survey of this area. Narrow fjords were surveyed in a zigzag pattern which was operationally convenient, or the flight tracks followed the mid-line of the fjords (Fig. 1).

The surveys were carried out in a Partenavia P68 Observer, a high-winged, twin-engine aircraft with a Plexiglas nose which allowed forward observations. Navigation was by a Litton 3000 Omega navigation system corrected by observations of recognisable land marks.

After initial tests, a total strip width of 1,000m was decided. The strip was divided into five zones; an inner and an outer zone on each side of the aircraft of 200m width each, and a 200m wide centre zone. Two rear observers covered the inner and outer zones, while the centre zone was covered by the pilot and the front observer. In the observers' field of view these zones were delineated by horizontal lines which were painted on the windows. The placement of the lines was first calculated, and their correct placement subsequently verified by flying past ground targets with known distance from the flight track.

The transects were flown at a target altitude of 150m (about 500ft), and an indicated airspeed of 120 knots (about 220km/h). All surveys were flown between 11:30a.m. and 6:00p.m. local time, with main effort in the afternoon. The observers maintained the same seats during all flights. The front observer was responsible for correcting the navigation and registration of all observations, ice conditions (type and cover), cloud cover (octas), wind and temperature (°C).

The front observer noted all observations on data-sheets at one-minute intervals.

The north-south oriented extension of the wide Scoresby Sund is called Hall Bredning (Fig. 1). However, for simplicity these two areas are subsequently referred to only as Scoresby Sund.

Analyses of data

In extension of Cochran's (1963) discussion of systematic versus random sampling, Kingsley and Smith (1981) argued that when sampling large areas with suspected trends in density, such as might be the case with ringed seal in inshore fast-ice habitat, systematic sampling might be preferable. Because a main purpose of this study was determining distribution, we chose systematic sampling which is also operationally easier to apply than random sampling.

The density ($\hat{R}$) in seals/km^2 was calculated as:

$$\hat{R} = \sum_{1}^{n} y_i / \sum_{1}^{n} z_i$$

Where y is the number of seals observed on the i'th transect, z the area (km^2) covered on the i'th transect, and n the number of transects. The estimate of abundance (N) (i.e. the visible part of the population of seals on the ice or at the water surface) was calculated as:

$$N = \hat{R} \times A$$

Where A is the total area covered in a sub-area (or stratum). The standard error (SE) of the abundance estimate given by Stirling *et al.* (1982) was calculated as:

$$SE = N \times S / \hat{R}$$

Where S is the standard deviation (=SD), and S^2 is the variance of the density estimate (R) for systematic surveys suggested by Kingsley and Smith (1981) (notation following Stirling *et al.* 1982):

$$S^2(\hat{R}) = n \times \sum_{1}^{n-1} (d_i - d_{i+1})^2 / 2(n-1) \times (\sum_{1}^{n} z_i)^2$$

where $d_i = y_i - (\hat{R} \times z_i)$.

The total number of seals observed within each 200m wide strip was compared (see Results). As a result of these comparisons only observations made within the inner strips were used for calculation of densities and abundance of seals.

Unpaired t-tests were used for testing for differences between mean densities obtained during the two surveys of various sub-areas, except in the case of the Scoresby Sund/Hall Bredning area where a paired t-test was applied because transects were displaced only 3.7km between the first and the second survey. Chi-square tests were used for testing differences in number of seals observed within each 200m wide strip.

RESULTS

Weather and ice conditions

Most of the area surveyed was covered by one-year-old even fjord ice covered with snow (Fig. 2, Table 1). In September 1983 it was observed that Nathorst and Carlsberg fjords were still covered by one-year-old fast ice (Born 1983), and therefore it was assumed that ice older than one year covered these fjords in June 1984. In Davy Sund and along the coast of Liverpool Land the ice consisted of consolidated pack ice (Table 1). In Rypefjord and in parts of Øfjord, Harefjord and Nordvestfjord in the western parts of the Scoresby Sund complex, the ice appeared bluish with a c. 0.5m layer of water on the surface. Flyverfjord, Vestfjord and the southwestern part of Gåsefjord and Nordvestfjord had a cover of 10/10 of rough and ridged ice composed of consolidated floes, with bergy bits and ice bergs from the many glaciers in these areas.

In general the weather conditions were good for aerial surveys of ringed seals. During the entire survey period the weather was fair, dominated by a stable high pressure. During each survey of a sub-area, weather conditions varied little, and were basically subject only to local variations related to topography, and cloud cover. However, in all cases where sub-areas were surveyed twice, average temperatures were highest during the second survey (Table 1). Fog banks which covered large areas during the night usually disappeared before noon. However, fog prevented some areas from being surveyed (Fig. 1).

Table 1. Ice and weather conditions during aerial surveys of ringed seals in Central East Greenland, June 1984.

Sub-area	Day	Ice conditions: Type (structure and age)	Ice conditions: Surface (morphology)	Weather conditions: Cloud cover (octas)	Weather conditions: Temperature (°C)	Weather conditions: Wind speed (m/s)
Kong Oscars Fjord	7	Fast ice, 1-year-old	Smooth	6-8	-2	0
	11	-	-	0	4	3
Davy Sund	7	Consolidated floes,1-year-old	Heavily ridged	6-8	-2	1
	11	-	-	0	3-4	2
Fleming Fjord	7	Fast ice, 1-year-old		2-3	-1	6
	11	-	-	0	6	5
Nathorst Fjord	7	Fast ice, 2-year-old?	Smooth	6-8	-2	6
	11	-	-	0	5	6-11
Carlsberg Fjord	7	Fast ice, 2-year-old?	Smooth	3-8	-2	5-8
	11	-	-	0	6-7	4
Liverpool Land	7	Consolidated floes, 2+ year	Heavily ridged	8	-1 to -2	7
	11	old offshore pack ice?	-	0	3-4	1-7
Storefjord	11	Fast ice, 1-year-old	Smooth	0	2	6
Scoresby Sund	8	Fast ice, 1-year-old	Smooth	7-8	-1 to +2	2-13
	13	-	-	1-8	0.5-2	2-10
Entrance to Scoresby Sund	8	1-year-old, floes	Smooth	7-8	-1	1
Hurry Fjord	7	Fast ice, .1-year-old	Smooth	8	0	6
	11	-	-	0	2-3	3
Hvalros Bugt	11	Fast ice, 1-year-old	Smooth	0	2	3
Gåsefjord	9	Fast ice, 1-year-old. SW parts with consolidated ice bergs and bergy bits	Ridged	0	2	6
Fønfjord	9	Fast ice, 1-year-old	Smooth	0	4	15
Vestfjord	9	Floes of fast ice, bergy bits and ice bergs	Heavily ridged	0	4	4
Rødefjord	9	Fast ice, 1-year-old	Smooth	0	4	5
Harefjord	9	Fast ice, 1-year-old	Smooth	0	2	5
Rypefjord	9	Fast ice, 1-year-old	Smooth	0	2-4	8
Øfjord	9	Fast ice, 1-year-old	Smooth	0-1	2	4
Nordvestfjord	9	Fast ice, 1-year-old; floes of fast consolidated with ice bergs and bergy bits in certain areas	Smooth. Some areas with a heavily ridged surface	4	1-3	11
Flyverfjord	9	Floes of fast ice, bergy bits and ice bergs	Heavily ridged	4	3	11

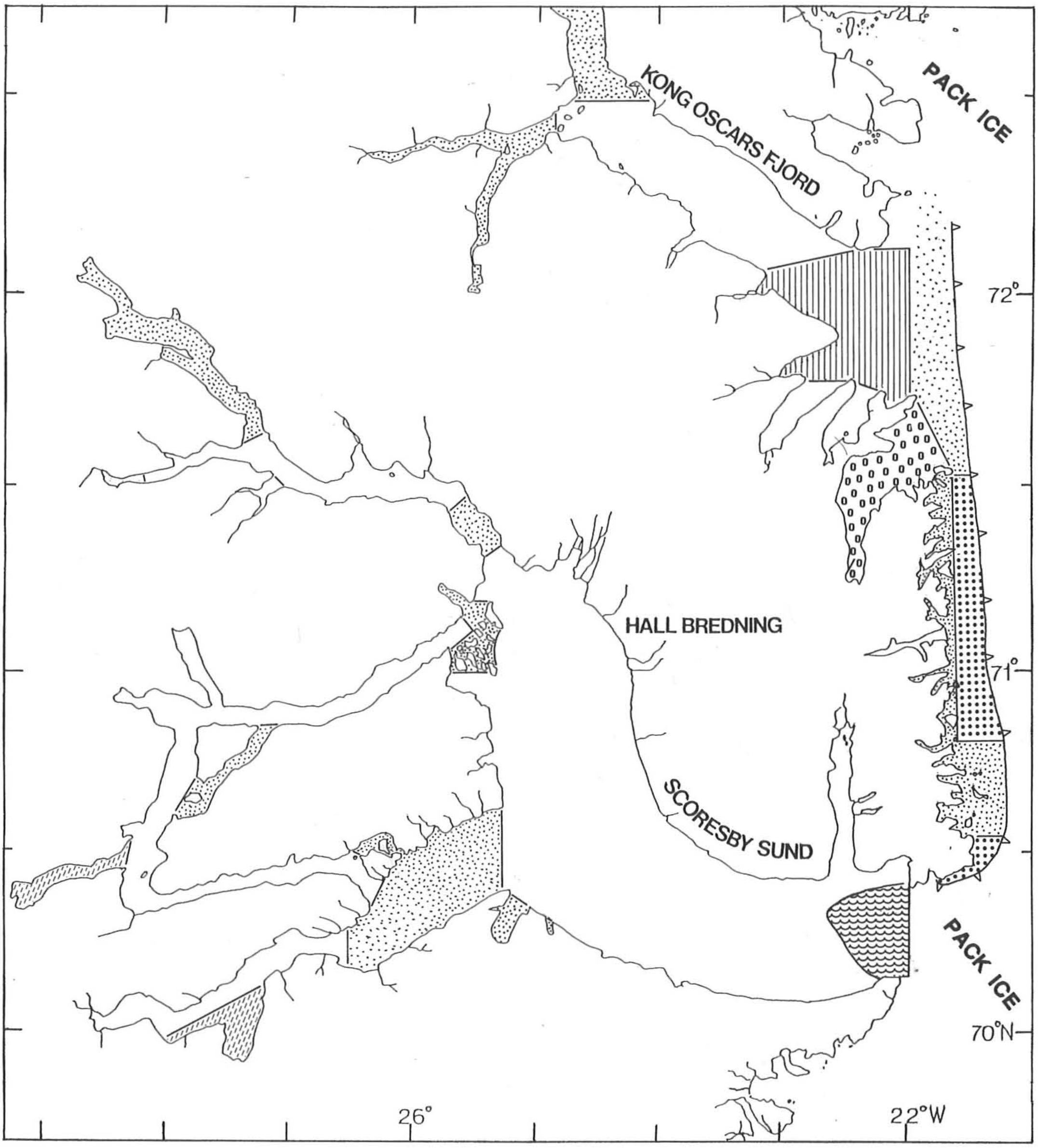


Fig. 2
Distribution of different types of ice in the Kong Oscars Fjord - Scoresby Sund study area during the ringed seal survey, June 1984.

Legend:

10/10 glacier ice

9-10/10 consolidated 1-yr-old floes;

9-10/10 consolidated multi-year pack ice:

10/10 more than 1-yr-old fast ice;

10/10 1-yr-old fast ice;

1-5/10 floes;

not surveyed

Densities and estimates of abundance

Selection of strips for estimation of densities

The total number of ringed seals observed in the centre, inner and outer zones differed significantly ($p<0.001$; Table 2). Furthermore, significantly higher numbers of seals were observed in the outer zones than in the inner zones ($p<0.05$). It was concluded that only in the two inner zones were the observations representative (see Discussion). Therefore only the observations from these two zones were used to estimate densities and abundance of seals (total strip width=400m).

Kong Oscars Fjord and Davy Sund

In this study a transition between relatively smooth ice in Kong Oscars Fjord and ice consisting of consolidated floes in Davy Sund (i.e. the entrance to Kong Oscars Fjord) was used to delineate these two sub-areas (Figs 1-2).

The estimates of average densities obtained during the two surveys of Kong Oscars Fjord did not differ significantly ($p>0.05$; Figs 1 and 3). The average density based on both surveys was 1.04 seals/km^2 (SD=0.15), and the corresponding estimate of abundance 2,501 seals (SE=361; Table 3).

Table 2. Total number of ringed seals observed within each 200m wide observation zone (total strip width = 1,000m) during aerial surveys in the Scoresby Sund and Kong Oscars Fjord areas, eastern Greenland, June 1984.

	Observation zones				
	Left			Right	
	Outer	Inner	Center	Inner	Outer
No. seals	1,324	899	606	889	1,131

Neither did the estimates of density obtained during the two surveys of the consolidated pack ice in Davy Sund differ significantly (p>0.05). However, the estimate of the average density from the two surveys combined (0.79 seals/km^2, SD=0.13; abundance=917 seals, SE=151; Table 3) was significantly lower than the average estimate of density of the smooth fast ice in Kong Oscars Fjord (p<0.01).

Fleming, Nathorst and Carlsberg fjords, Liverpool Land and Store Fjord
The surveys on 7 and 11 June of the small tributary fjords Fleming and Nathorst Fjord were more of a reconnaissance nature. The survey of Fleming Fjord (Fig. 4) resulted in an estimate of density of 0.84 seals/km^2 (SD=0.42) and an estimate of abundance of 157 ringed seals (SE=79; Table 3). Combining observations made in Nathorst Fjord during transit flights on 7 and 11 June (Fig. 4) resulted in a crude estimate of density of 1.95 seals/km^2 (no SD calculated), and an estimate of the visible population of 274 seals (Table 3).

The more than one-year-old fast ice of Carlsberg Fjord was surveyed twice (Figs 5a-b). However, the estimates of average density from the two surveys did not differ significantly (p>0.05). The mean density based on both surveys was 1.33 seals/km^2 (SD=0.46) with a corresponding estimate of abundance of 795 seals (SE=275; Table 3). Average seal density in this fjord did not differ significantly from average densities in any of the aforementioned areas which were covered with different types of ice (p>0.05).

During a reconnaissance flown on 7 June over parts of the consolidated shore-fast pack ice along the coast of Liverpool Land, a crude density estimate of 0.50 seals/km^2 was obtained (Fig. 3; Table 3). In contrast the sheltered and narrow Store Fjord of Liverpool Land had smooth one-year-old ice and an average density of 1.42 seals/km^2 (Table 3).

Scoresby Sund, Hvalros Bugt and Hurry Fjord
Ringed seals were widely distributed throughout Scoresby Sund (Fig. 3). The estimates of overall density obtained from the two surveys of this area did not differ significantly (p>0.05). However, the estimate of density based on both surveys (2.00 seals/km^2, SD=0.21) was significantly higher than that found in Kong Oscars Fjord (p<0.01).

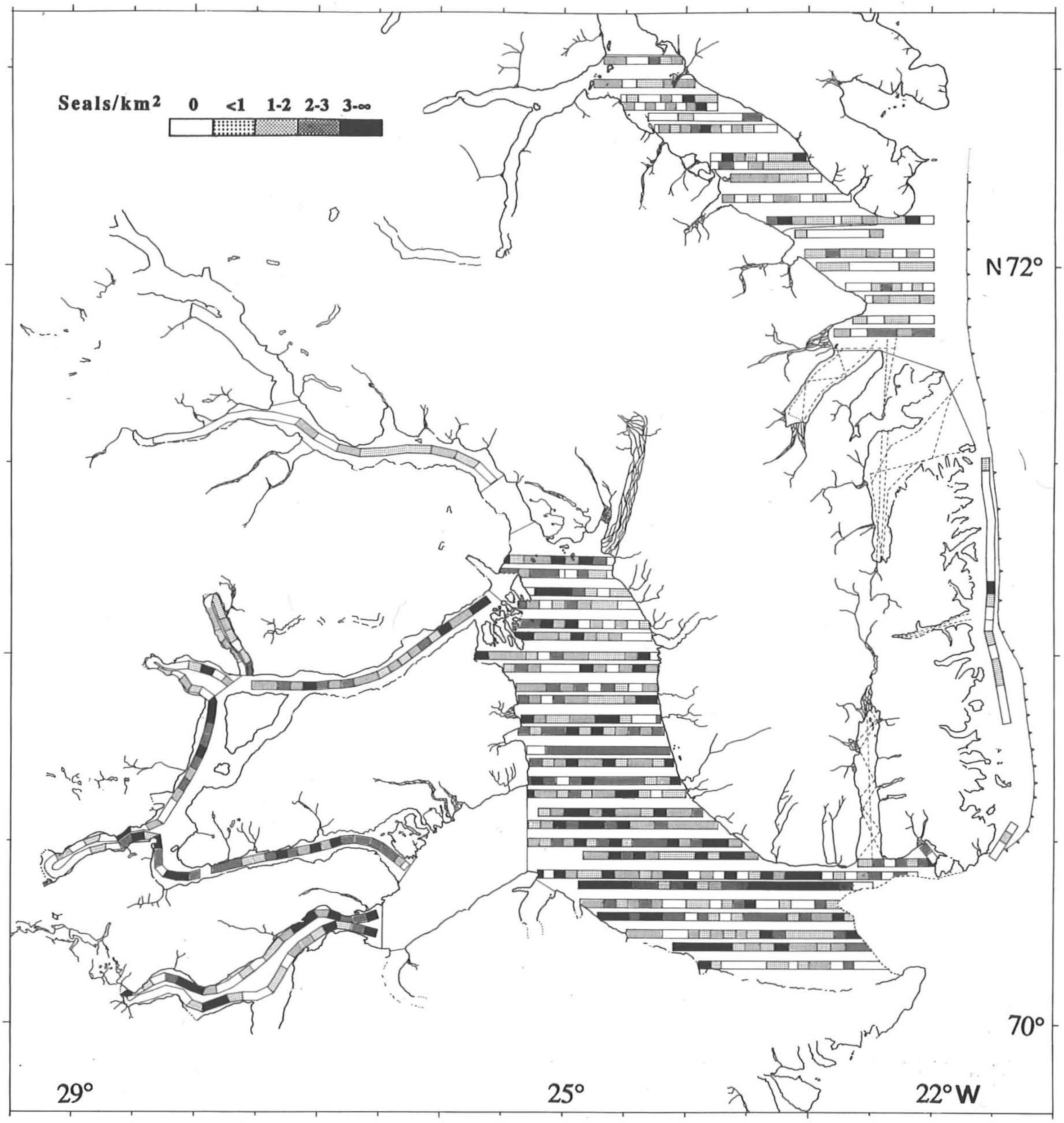
The estimate of the visible population of ringed seals in the Scoresby Sund area based on both surveys combined was 15,884 (SE=1,668; Table 3).

Observations made on 11 June in Hvalros Bugt situated in close proximity to the three settlements at the entrance to Scoresby Sund (Fig. 1) resulted in relatively high crude estimates of seal density and abundance: 1.84 seals/km^2 and 103 ringed seals, respectively (Table 3).

The entrance to Scoresby Sund (i.e. the area between the edge of the fjord ice and 22°W; Fig. 2), surveyed on 8 June, had 1-5/10 cover of ice floes and sea-state 0. During surveying of a total of 66 linear km, 9 ringed seals were observed, of which three were on the ice (Table 3).

Hurry Fjord was surveyed in a zig-zag pattern on 7 and 11 June (Figs 5c-d). Both surveys resulted in comparatively low estimates of densities that did not differ significantly (p>0.05). Density and estimate of the visible population of seals based on both surveys were 0.44 (SD=0.13) seals/km^2 and 114 (SE=34) seals, respectively. The average density in this fjord was significantly lower than that found in Scoresby Sund (p<0.01).

The western fjords of the Scoresby Sund complex
On 9 June a reconnaissance was flown in the fjords of the western parts of the Scoresby Sund



complex (Gåsefjord, Fønfjord, Vestfjord, Rødefjord, Harefjord, Rypefjord, Øfjord, Nordvestfjord and Flyverfjord; Fig. 1). This survey resulted in crude estimates of average densities ranging between 0.31 and 2.89 seals/km^2 for the different fjords (Fig. 3). The densities in the deep Nordvestfjord and Flyverfjord were remarkably low (0.45 and 0.31 seals/km^2). In all these fjords combined the overall estimate of density was 1.68 seals/km^2 with a corresponding estimate of the visible population of 7,553 seals (Table 3).

Aggregations of seals

Overall, 6.5% of all seals observed (n=1,981) occurred in pairs, the majority of which were found in the western parts of the Scoresby Sund complex. In a total of 10 cases, three to five seals were seen around a single breathing hole in the various sub-areas. In 11 cases seals aggregated along leads in the fast ice (3 to 12 seals). Such aggregations were also found in different sub-areas, i.e. central Kong Oscars Fjord, evenly distributed in Scoresby Sund, and in Gåsefjord.

Fig. 3
Densities of ringed seals (seals/km^2) in the Kong Oscars Fjord/Davy Sund, Scoresby Sund/ Hall Bredning and adjacent areas obtained during aerial surveys conducted during June 1984.

Table 3. Densities and relative abundance of ringed seals by subarea based on aerial surveys of the Scoresby Sund and Kong Oscars Fjord areas, eastern Greenland, June 1984.

Sub-area	Day (June 1984)	A - Total area (km^2)	% of A sampled	No. of transects	No. of seals observed	Density seals/km^2	SD	Abundance No. of seals	SE
Kong Oscars Fjord	7 and 11	2,398	5.5	11	138	1.04	0.15	2,501	361
Davy Sund	7 and 11	1,161	6.9	8	64	0.79	0.13	917	151
Fleming Fjord	11	187	9.5	4	15	0.84	0.42	157	79
Nathorst Fjord	7 and 11	141	9.1	1	25	1.95	[1]	274	-
Carlsberg Fjord	7 and 11	598	10.7	8	85	1.33	0.46	795	275
Liverpool Land	7	617	5.8	1	18	0.50	[1]	309	-
Storefjord	7	59	26.3	1	22	1.42	[1]	84	-
Scoresby Sund	8 and 13	7,942	7.2	27	1,150	2.00	0.21	15,884	1,668
Entrance to Scoresby Sund	8	562	4.7	3	9	0.34	0.37	191	208
Hurry Fjord	7 and 11	258	15.7	11	18	0.44	0.13	114	34
Hvalros Bugt	11	56	22.3	2	23	1.84	[1]	103	-
Western fjords in area S. [2]	9	4,496	5.5	1	414	1.68	[1]	7,553	-
All areas combined	7 through 13	18,475	6,8	78	1,981	1.58	[1]	2,882	-

1: Survey design did not allow for calculation of SD
2: Gåse-, Føn-, Vest-, Røde-, Hare-, Rype-, Ø-, Nordvest- and Flyver fjords (Fig. 1).

DISCUSSION

A difference was found in the number of seals observed in the different observation zones, and we excluded observations made in the centre and the outer zones. The relatively low number recorded for the centre zone can be explained by impaired visibility caused by reflections in the Plexiglas nose of the aircraft, and by a reduction in observation effort due to the other tasks of the pilot and the front observer. A suspected over-registration in the outer zones may have been caused by incorrect placement of the zone markers on the side windows, but more likely by the fact that unavoidable changing postures of the rear observers during the surveys resulted in different angles of view, and consequently in over-estimation of the width of the outer zone. This may also be true for the inner zones, although the error for this zone will be relatively smaller due to a higher declination (angle to surface).

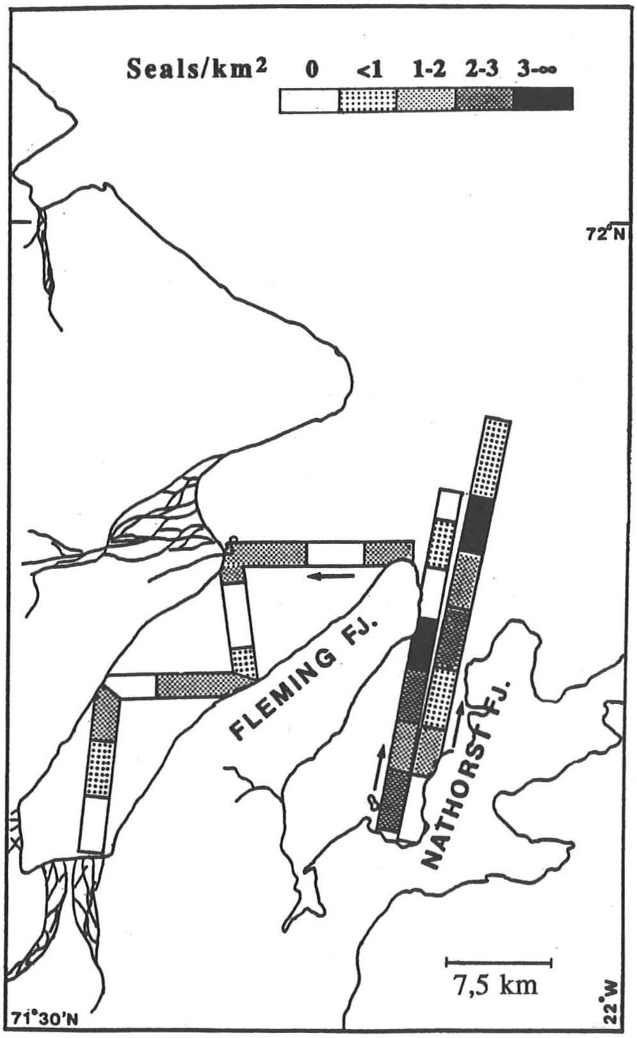


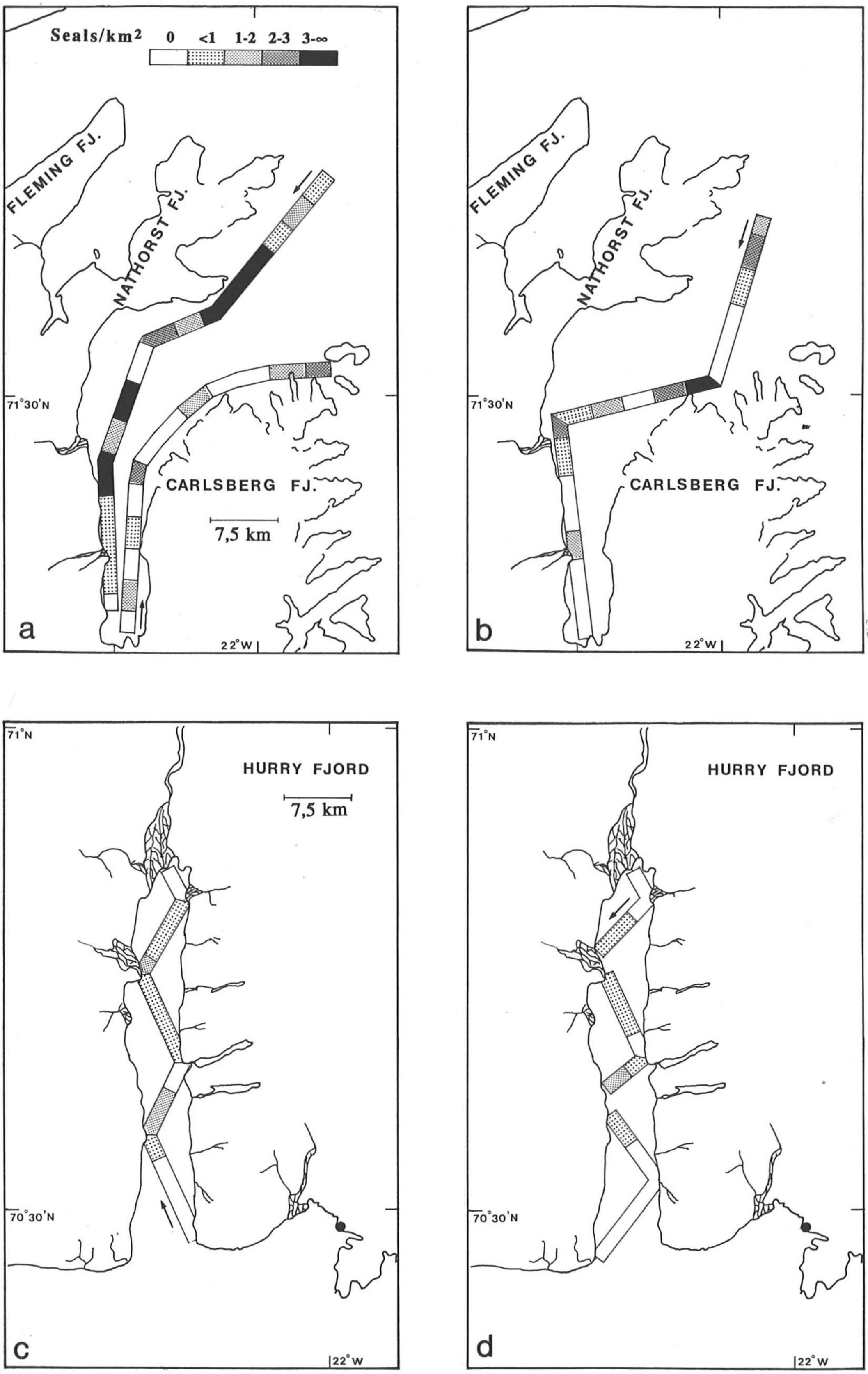
Fig. 4
Densities (seals/km²) obtained during aerial surveys of Fleming Fjord (11 June) and Nathorst Fjord (7 and 11 June), 1984. The number of transects are shown (for segments used for estimating variance of the densities see Table 3).

Use of the line transect technique was considered, which involves measuring the angle to all observation for a *post hoc* determination of the probability detection function (Burnham *et al.* 1981). It was, however, decided not to use this method because with relatively high densities of seals there was a risk that measuring angles would distract the observers from detecting all seals along the flight path. On the other hand, line transect methodology allows for determination of strip width (effective search width; Burnham *et al.* 1981) *post factum.* Using this method therefore has the advantage, amongst others, of eliminating potential problems associated with incorrectly placed zone markers and/or change of observers' posture during strip census surveys.

Relatively low densities found in the consolidated pack ice in Davy Sund and along Liverpool Land are typical for ice along exposed coasts (McLaren 1958). Densities found in our study were somewhat lower than densities found in the shelf ice along SE Baffin Island (Finley *et al.* 1983), but similar to those found in the pack ice in the Beaufort Sea (Stirling *et al.* 1982). In general, however, the densities of ringed seals found in this study did not differ from those reported for similar habitats in other Arctic areas (Miller *et al.* 1982).

The densities of ringed seals in the Scoresby Sund area were significantly higher than those found in the Kong Oscars Fjord area. It is suggested that the reason for this difference is a higher marine productivity in Scoresby Sund compared with the Kong Oscars Fjord area, perhaps related to differences in water circulation patterns. This circulation pattern creates a biologically rich polynya at the entrance to Scoresby Sund (Born 1983, Dietz *et al.* 1985). A similar polynya is not found at the entrance to Kong Oscars Fjord. Furthermore, the discharge of glacier ice is much higher in the Scoresby

Fig. 5
Densities (seals/km²) obtained during aerial surveys of Carlsberg Fjord on 7 (a) and 11 (b) June, and during surveys of Hurry Fjord on 7 (c) and 11 (d) June, 1984 (for segments used for estimating variance of the densities see Table 3).



Sund area than in Kong Oscars Fjord (Anon. 1990b). The movements and melting of these sometimes very large icebergs likely add to the mixing of the water column in Scoresby Sund, thereby enhancing marine productivity.

Miscellaneous observations summarised by Dietz *et al.* (1985) indicated that the densities of marine mammals in Kong Oscars Fjord and tributary fjords are generally low.

Low densities were found in the open water area at the entrance to Scoresby Sund. However, ringed seals are difficult to observe in water due to their small size and low colour contrast to the sea surface. Furthermore, during the survey many seabirds, e.g. little auk (*Alle alle*) and Brünnich's guillemot (*Uria lomvia*), were present in the open water making it difficult for the observers to detect ringed seals among the ice floes.

The reconnaissance in the western fjords of the Scoresby Sund complex indicated that these fjords could be divided into three categories according to densities of ringed seals: 1) in Gåsefjord, Fønfjord, Rødefjord and Øfjord relatively high densities were found similar to those in Scoresby Sund. In these fjords the moderately ridged one-year-old ice covered with snow appeared as a suitable ringed seal habitat; 2) the somewhat lower densities found in Vestfjord, Harefjord and Rypefjord may be explained by the large amount of glacier ice blocking Vestfjord, and the layer of melt water covering parts of the ice in the other fjords; 3) low densities found in Nordvestfjord and Flyverfjord may be attributed to low marine productivity in these fjords. This low productivity may be ascribed to the great water depths in these fjords with hydrographical conditions perhaps causing little vertical mixing of the water column.

Surveys of ringed seals usually have substantial variation of the estimates of abundance (Stirling *et al.* 1977, Helle 1980, Härkönen and Heide-Jørgensen 1990, Lunn *et al.* 1997). In this study the relative variation (SE) of the abundance estimates averaged 37% (range: 10.5-100%). The lowest variation was found in Scoresby Sund where the seals were fairly evenly distributed over a large area that was covered by relatively many transects, whereas in other areas variation was substantial due to few transects flown with variable number of seals.

The abundance estimates are conservative since they do not account for seals that were not hauled out during the surveys. The proportion of the seal population which is underneath the snow and the ice at any given time, and therefore is hidden from detection during a survey, varies greatly. According to Smith (1973 a,b) and Smith and Hammill (1981), about 50% of the seals may not be on the ice at any given time, whereas Finley (1979) estimated that about 70% of the population may haul out under good weather conditions during the midday period.

The number of seals that are available for detection on the ice during a survey is affected by several factors: 1) increasing proportion of seals hauling out to moult during spring; 2) diurnal cycle in haul-out activity; 3) weather conditions; 4) immigration or emigration.

In Frobisher Bay (Baffin Island, Canada) the number of seals on the ice doubled from the beginning to the end of June (McLaren 1966). At Victoria Island (central Canadian High Arctic) a similar increase was observed between 7 and 13 June (Smith 1973a: his Fig. 2), i.e. same period as in the present study. By monitoring the activity of radio-tagged ringed seals, Kelly *et al.* (1986) revealed that from March until June, the seals doubled the time out of the water.

Some studies have found a diurnal rhythm in the ringed seals' haul-out pattern. Finley (1979) and Stirling *et al.* (1982) found that the number of ringed seals hauling out on the ice peaked during mid-afternoon. However, Smith and Hammill (1981) did not find any clear pattern in diurnal haul-out activity.

The number of seals on the ice is also influenced by weather conditions. The density of seals on the ice has been found to be negatively correlated with wind speed (Smith 1973a, Finley 1979, Stirling *et al.* 1982). Furthermore, Finley (1979) reported that the number of seals on the ice tended to decrease on warm, clear and calm days, whereas Stirling *et al.* (1982)

stated that the seals preferred to haul out on clear and calm days.

The surveys were flown during a period of the year where the proportion of seals hauling out to moult is supposedly high, and with survey effort concentrated in the afternoon in favourable weather conditions. There were not, however, any information about the actual proportion of seals hauling out during the surveys. Therefore, it can only be speculated, by analogy with other studies (Smith 1973a,b, Finley 1979, Smith and Hammill 1981), by which factor the abundance estimates reported here must be raised to encompass the entire population of ringed seals within the surveyed areas.

It was assumed that the seals surveyed represent the resident population (i.e. those which had wintered in the areas). Numerous observations of ringed seals from the offshore pack ice in eastern Greenland have been reported (cf. Dietz *et al.* 1985). For example, Kolthoff (1901) reported the observation of hundreds of ringed seals and breathing holes in the pack ice between eastern Greenland and Svalbard, and he assumed that the ringed seals gave birth in the offshore ice fields in May (Kolthoff 1903). Ringed seals breeding in offshore pack ice have also been reported from other areas of the Arctic (Finley *et al.* 1983). It might be speculated that when the offshore pack ice breaks up in late spring some seals may migrate from there into the fast-ice habitats. Such an immigration would probably result in aggregations of ringed seals at leads in the fast ice, in particular in areas close to offshore areas. However, no remarkably large aggregations of seals were found in the survey area and it is believed that this study reflected the general distribution of resident ringed seals and their relative densities in the different areas.

ACKNOWLEDGEMENTS

This study was financed by and conducted for the Greenland Environmental Research Institute. We wish to thank the pilot Leif Petersen and the observers Arne Øland and the late Jens Thygesen for their enthusiastic participation in the field. Per Magne Jensen is thanked for giving valuable comments to an earlier draft of the paper. Two anonymous referees are thanked for providing constructive comments.

REFERENCES

Anonymous. 1983. An analysis of ice-conditions in Fleming Fjord, East Greenland. Unpubl. rept. prepared by Danish Hydraulic Institute, Hørsholm, Denmark, for Greenland Technical Organization, November 1983. 56 pp.

Anonymous. 1990a. *Greenland Atlas*. Pilersuiffik, Nuuk: 127 pp. + supplement.

Anonymous. 1990b. Ice data for Greenland Project - Final report. Unpubl. rept. prepared by Danish Hydraulic Institute, Hørsholm, Denmark, for ARCO International Oil and Gas Company, February 1990. 26 pp.

Born, E. W. 1983. Havpattedyr og havfugle i Scoresby Sund: Fangst og forekomst [Marine mammals and sea birds in Scoresby Sund: Hunt and distribution]. Unpubl. rept. to Råstofforvaltningen for Grønland og Grønlands Fiskeri- og Miljøundersøgelser from Danbiu ApS (Biological Consultants), Tornagervej 2, 2920 Charlottenlund, Denmark. 112 pp. (In Danish with English summary).

Born, E.W. 1984. Aerial surveys of ringed seals (*Phoca hispida*) in the Kong Oscars Fjord and Scoresby Sund areas (East Greenland) in June 1984. A preliminary report, 10 July 1984. Unpubl. rept. by Grønlands Fiskeri- og Miljøundersøgelser: 16 pp.

Born, E.W. 1988. Flyundersøgelser af ringsæl (*Phoca hispida*) i Kong Oscars Fjord - Scoresby Sund området, juni 1984 [Aerial surveys of ringed seals in the Kong Oscars Fjord and Scoresby Sund area, June 1984]. - Unpubl. rept. Grønlands Miljøundersøgelser, ISBN: 87-87838-72-9: 49 pp. (In Danish with English summary).

Burnham, K.P., Anderson, D.R. and Laake, J.L. 1981. Estimation of density from line transect sampling of biological populations. *Wildlife Monographs* 72. 203 pp.

Burns, J.J. and Harbo Jr., S.J. 1972. An aerial census of ringed seals, northern coast of Alaska. *Arctic* 25:279-290.

Cochran, W.G. 1963. *Sampling Techniques*. J. Wiley and Sons. New York, 2nd Edition. 413 pp.

Dietz, R., Heide-Jørgensen, M.-P. and Born, E.W. 1985. Havpattedyr i Østgrønland: En litteraturundersøgelse [Marine mammals in eastern Greenland: A literature survey]. Unpubl rept. to Råstofforvaltningen for Grønland og Grønlands Fiskeri- og Miljøundersøgelser from Danbiu ApS. (Biological Consultants). 277 pp. (In Danish with English summary).

Digby, P.S.B. 1953. Plankton production in Scoresby Sound, East Greenland. *J. Anim. Ecol.* 22:289-322.

Finley, K.J. 1979. Haul-out behaviour and densities of ringed seals (*Phoca hispida*) in the Barrow Strait area, N.W.T. *Can. J. Zool.* 57:1985-1997.

Finley, K.J., Miller, G.W., Davis, R.A. and Koski, W.R. 1983. A distinctive large breeding population of ringed seals (*Phoca hispida*) inhabiting the Baffin Bay pack ice. *Arctic* 36:162-173.

Frost, K. J. and Lowry, L. F. 1981. Ringed, Baikal and Caspian Seals, *Phoca hispida* Schreber, 1775; *Phoca sibirica* Gmelin, 1788 and *Phoca caspica* Gmelin, 1788. pp. 29-53 in S.H. Ridgway and R.J. Harrison (eds.) *Handbook of Marine Mammals, Volume 2 Seals*. Academic Press, London. 359 pp.

Härkönen, T. and Heide-Jørgensen, M.P. 1990. Density and distribution of the ringed seal in the Bothnian Bay. *Holarctic Ecol.* 13:122-129.

Helle, E. 1980. Aerial sensus of ringed seals (*Pusa hispida*) basking on the ice of the Bothnian Bay, Baltic. *Holarctic Ecol.* 3:183-189.

Helle, E. 1992. *Phoca hispida* Schreber, 1775 - Ringelrobbe [Ringed seal] pp. 138-161 in R. Duguy and D. Robineau (eds.) *Handbuch der Säugetiere Europas. Band 6: Meeressäuger.* Teil II: Robben - Pinnipedia. AULA-Verlag, Wiesbaden. (In German)

Kelly, B.P., Quakenbush, L.T. and Rose, J.R. 1986. Ringed seal winter ecology and effects of noise disturbance. Final Report Contract No. NA81RAC00045, Institute of Marine Science, University of Alaska, Fairbanks. 85 pp.

Kingsley, M.C.S. and Smith, G.E.J. 1981. Analysis of data arising from systematic transect surveys. pp. 40-48 in F.L. Miller and A. Gunn (eds) *Symposium on Census and Inventory Methods for populations and Habitats, 10 April 1980, Banff, Alberta.* Proceedings of Northwest Section, The Wildlife Society. Contribution No. 217.

Kingsley, M.C.S., Stirling, I. and Calvert, W. 1985. The distribution and abundance of seals in the Canadian High Arctic, 1980-82. *Can. J. Fish. Aquat. Sci.* 42:1189-1210.

Kolthoff, G. 1901. Till Spetsbergen och Nordöstra Grönland [To Spitzbergen and Northeast Greenland]. Fr. Skoglunds Forlag, Stockholm. 227 pp. (In Swedish).

Kolthoff, G. 1903. Bidrag till Kännedom om norra Polartrakternes Daggdjur og Fåglar [Contributions to the knowledge of northern Arctic mammals and birds]. *Kungl. Svenska Vet. Akad. Handl.* 36:1-104. (In Swedish).

Lunn, N.J., Stirling, I. and Nowicki, S.N. 1997. Distribution and abundance of ringed (*Phoca hispida*) and bearded seals (*Erignathus barbatus*) in western Hudson Bay. *Can. J. Fish. Aquat. Sci.* 54:914-921.

McLaren, I.A. 1958. The biology of the ringed seal (*Phoca hispida* Schreber) in the eastern Canadian Arctic. *Bull. Fish. Res. Bd Can.* 118. 97 pp.

McLaren, I.A. 1966. Analysis of an aerial census of ringed seals. *J. Fish. Res. Bd Can.* 23: 769-773.

Miller, G.W., Davis, R.A. and Finley, K.J. 1982. Ringed seals in the Baffin Bay region: habitat use, population dynamics and harvest levels. Unpubl. rept. by LGL Ltd., Toronto, for Arctic Pilot Project, Calgary. 93 pp.

Rice, R.B. 1983. East Greenland satellite imagery analysis for Scoresby Sound, Jameson Land, Carlsberg Fjord and offshore pack for July, August, September 1973, 1975-1982. Unpubl. rept. prepared by Weather Services Corporation, Bedford, Massachusetts, for ARCO International Oil and Gas Co., July 1986. 73 pp.

Sloth, P. 1986. Oceanografiske, ismæssige og meteorologiske forhold. Jameson land, Østgrønland. En litteratur oversigt [Oceanographic, ice and meteorological conditions around Jameson Land, eastern Greenland: A literature survey]. Unpubl. rept. by Grønlands Fiskeri -og Miljøundersøgelser, København. 106 pp. (In Danish.)

Smith, T.G. 1973a. Censusing and estimating the size of ringed seal population. *Fish. Res. Bd Can. Tech. Rep.* 427: 18pp.

Smith, T.G. 1973b. Population dynamics of the ringed seal in the Canadian eastern Arctic. *Bull. Fish. Res. Bd Can.* 181. 55pp.

Smith, T.G. and Hammill, M.O. 1981. Ecology of ringed seal, *Phoca hispida*, in its fast ice breeding habitat. *Can. J. Zool.* 59:966-981.

Stirling, I. 1975. Factors affecting evolution of social behaviour in the Pinnipedia. *Rapp. P.-v. Réun. Cons. inst. Explor. Mer.* 169:205-212.

Stirling, I., Archibald, W.R. and DeMaster, D. 1977. Distribution and abundance of seals in the eastern Beaufort Sea. *J. Fish. Res. Bd Can.* 34:976-988.

Stirling, I., Kingsley, M.C.S. and Calvert, W. 1982. The distribution and abundance of seals in the eastern Beaufort Sea, 1974-79. *Can. Wildl. Serv. Occ. Pap.* 47. 23 pp.

Teilmann, J. and Kapel, F.O. (This volume.) Exploitation of ringed seals (*Phoca hispida*) in Greenland