Line-transect estimation of abundance of narwhals (*Monodon monoceros*) in Scoresby Sund and adjacent waters

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An aerial line transect survey of narwhal (*Monodon monoceros*) abundance in Scoresby Sund and adjacent fjords in East Greenland was conducted in September 1983 and 1984. An effort of 1747 and 1973 linear kilometers resulted in 66 and 19 primary sightings of narwhal pods in 1983 and 1984, respectively. The mean pod size increased slightly but not significantly from 1.99 to 2.56 between the two years. The resulting estimates of abundance of narwhals (not corrected for submerged animals) were 300 (95% CI 165–533) and 102 (95% CI 36–276) in 1983 and 1984, respectively. These two estimates are not significantly different. The difference between the two estimates is most likely due to annual variation, perhaps in combination with the formation of new ice in 1984, which could have forced the narwhals out of the study area.

Key words:
Narwhal, *Monodon monoceros*, Greenland, aerial survey, line transect.

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Introduction

Little information on the occurrence and distribution of whales exists from East Greenland. Despite exploitation of narwhals (*Monodon monoceros*) by hunting communities in this region (Sandell & Sandell 1991, Dietz *et al.* 1994), the population size of this species in East Greenland has so far not been estimated.

Several accounts indicate that the Scoresby Sund fjord system is one of the major summering areas for narwhals (Scoresby 1823, Bay 1896, Winge 1902, Pedersen 1930, Sølberg 1980), but give very little detailed information on distribution and abundance within the fjord system. The need for such information became apparent in relation to planned industrial activities in adjacent Jameson Land in the mid-1980's. As a consequence, aerial surveys were flown in 1983 and 1984 with the purpose of assessing the distribution and abundance of narwhals in Scoresby Sund and adjacent fjords. This paper describes the methods used and presents results of these surveys.

Materials and methods

Aerial surveys were flown from 9 to 21 September 1983 and from 18 to 24 September 1984. The surveys were designed as line-transect surveys covering Scoresby Sund, Hall Bredning and adjacent fjords, Kong Oscars Fjord and the coastal waters off Liverpool Land. Hall Bredning, Scoresby Sund and Kong Oscars Fjord were surveyed using transect lines separated by one nautical mile going east-west in Hall Bredning and north-south in Scoresby Sund and Kong Oscars Fjord. Lines to be flown were chosen at random without replacement from the total number of lines. In the narrower fjords it was considered impractical to fly randomly chosen transect lines and instead zig zag lines were used with transect legs incident to the coast line at about 45°. This procedure was also adopted along the coast of Liverpool Land. The zig zag lines were treated as one line for the estimation of sighting rates. The blocks NN, N, S and SE (Fig. 1) were surveyed twice in each year; all other areas were surveyed only once.

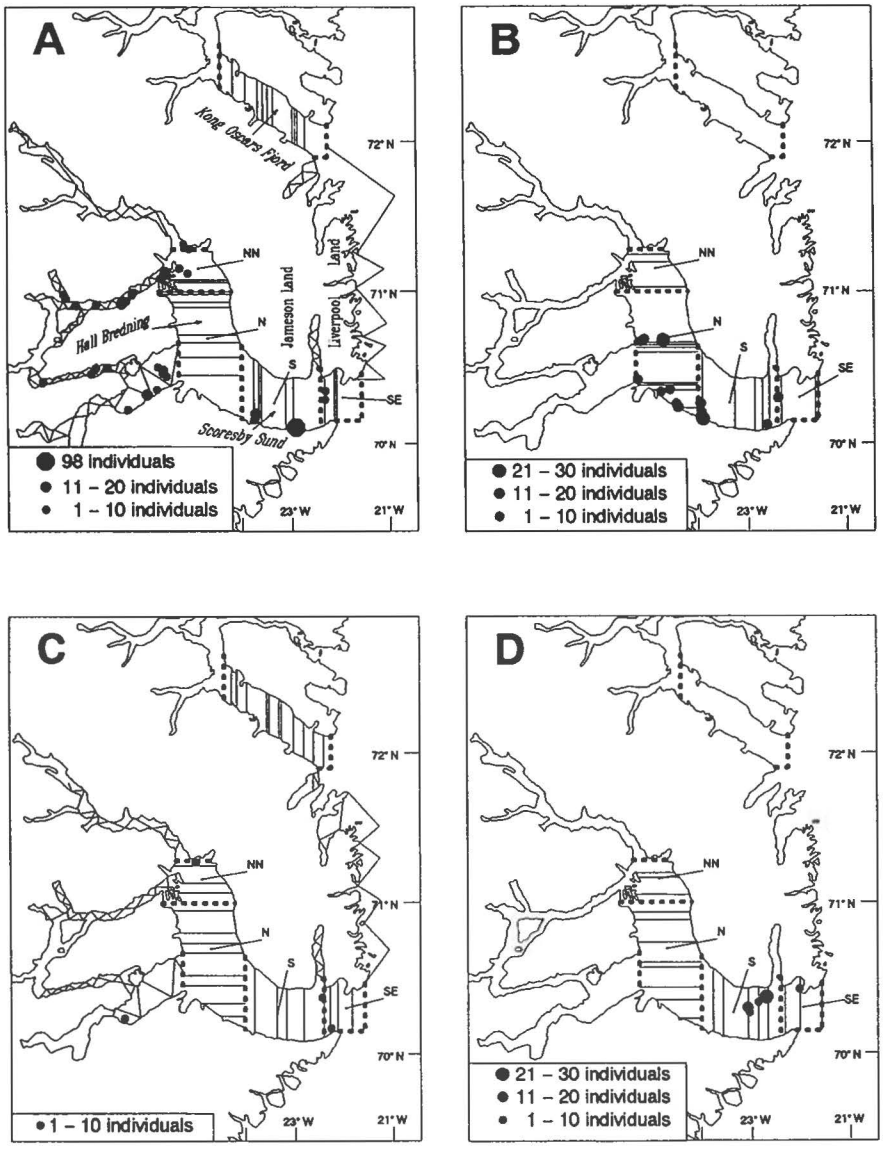

Fig. 1. Map of the study area with transect lines flown and positions of sightings of narwhals in Scoresby Sund and Kong Oscars Fjord and off Liverpool Land, September 1983 and 1984. NN, N, S and SE are main survey blocks. A) First coverage in 1983. B) Second coverage in 1983. C) First coverage in 1984. D) Second coverage in 1984.

The surveys were flown in a twin engine, high winged Partenavia P 68 Victor Observer (OY-CAG) equipped with a Collins VLF/OMEGA navigation system. The aircraft had standard flat windows at the observers' seats, resulting in poor coverage from the track line out to around 150 m perpendicular distance. Surveys were conducted at a target altitude of 183 m and an approximate ground speed of 167 km/h. The crew consisted of a pilot, two observers and one recorder. The observers were in the right front (copilot's) seat and in the left rear seat. The person recording was in the right rear seat. This person recorded information on all sightings of marine mammals into a portable tape recorder. The information included species, numbers, group and age structure, direction of movement, comments on behaviour and associated remarks about position and time of sighting, declination angle to the sighting when abeam, sea and ice conditions and visibility. The declination angle was measured by means of an inclinometer (Silva type 65) and used together with information on the altitude for calculating the perpendicular distance to all sightings of pods. A pod was defined as one or more whales moving together closely, usually less than a few meters from each other, and usually diving synchronously. Adult animals with a tusk were considered to be males, all other adults were considered to be females (see Fig. 3, below).

Estimation of abundance of narwhals was based on line-transect sampling theory as described by Burnham *et al.* (1980) and Buckland *et al.* (1993). For estimation of the effective search half-width (ESW) and its associated

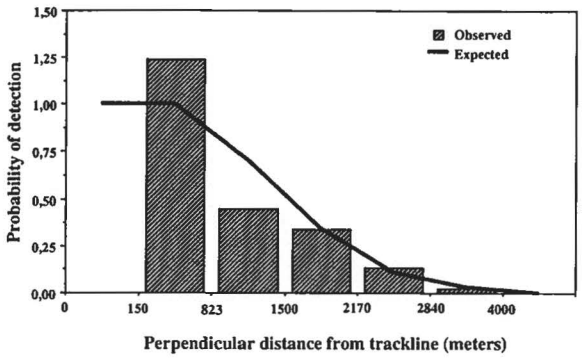

Fig. 2. Frequency distribution of narwhals at various distances from the trackline. Sightings from 0 to 150 m from the trackline and sightings more than 4000 m from the trackline were excluded. Data has been fitted with a Fourier series model with two cosine adjustment parameters and the fitted curve shows the expected number of sightings.

empirical variance we used the computer package "Distance" developed by Laake *et al.* (1993). Estimation of the ESW was based on all sightings with an associated distance, whereas estimation of densities was based on only primary sightings, *i.e.* sightings made from the transect line while on effort. The coefficients of variation (CV) were estimated as the standard error divided by the mean.

We assumed that the density estimates were log normally distributed and we applied 95% confidence intervals developed by Burnham *et al.* (1987, p. 212). Data to allow the estimation of the probability of sighting a pod on the transect line were not collected so the estimates of abundance of narwhals have not been adjusted to account for whales submerged during the surveys.

Results

During the survey in 1983 most areas in Scoresby Sund were covered by less than 3/10 ice and only the inner parts of the fjords had more than 7/10 ice. In 1984 new ice was found throughout most of Scoresby Sund with grey new ice in the inner parts of fjords.

An effort of 1747 linear km surveyed resulted in a total of 164 pods of narwhals with 311 animals observed in the study area in September 1983 (Fig. 1A-B). Because of the clumped distribution of the pods, only 66 of the 164 pods were primary sightings. All sightings were made in Scoresby Sund, Hall Bredning and adjacent fjords.

Of the 95 animals observed in narrow fjords in 1983 for which information on direction of movement is available, 79 (83%) were moving outwards, and of the 256 animals observed in Hall Bredning and Scoresby Sund 169 (66%) were moving outwards.

Of 164 pods for which information on pod composition is available, 21 were comprised of single males and 57 of single females. Of 63 pods with two or more adults only 7 (11%) were mixed male-female pods. A total of 73 neonates, corresponding to 23.5% of the total number of animals sighted, were seen during the surveys. Thirty of these were found in mother-calf pairs. The ratio of neonates to total number of adult females was estimated at 0.38. Average pod size was estimated at 1.99 (95% CI 1.72–2.08).

An effort of 1973 linear km surveyed resulted in the observation of a total of 25 pods of narwhals (64 whales including 7 neonates) in September 1984 (Fig. 1C-D). Nineteen of these pods were primary sightings. Except for four sightings, all pods were seen in the eastern part of Scoresby Sund. Only one of the four pods (25%) was moving outwards, and only 7 of the 19 pods (37%) found in the eastern part of Scoresby Sund were heading outwards. Neonates constituted 10.9% of the total number of animals sighted. Average pod size was estimated at 2.56 (95% CI 1.30–3.82).

The mean pod size did not differ significantly between years and the pooled mean pod size estimate was 2.03 animals (range:1–14).

The nineteen primary sightings from 1984 are too small a sample for estimating ESW for that particular year. Instead all sightings from 1983 and 1984 were pooled to derive a common detection function. This was justified by the use of identical survey techniques in the two surveys. Based on the chi-square value for the observed frequency distribution of sightings compared to the predicted (χ^2=0.92) a Fourier series model with two cosine adjustment parameters was chosen (Fig. 2).

Because the flat windows prevented observations directly below or very near the aircraft, the first 150 m from the trackline was omitted from the analysis of densities. Sightings more than 4000 m from the trackline (1% of the

Table 1. Line transect estimation of narwhal abundance in Scoresby Sund, Hall Bredning and adjacent fjords in 1983 and 1984. The Effective Search half-Width (ESW) was estimated by fitting a Fourier series model with two cosine adjustment parameters (see text and Fig. 2) to the frequencies of sighting distances (Fig. 2). The estimates of mean pod size include secondary sightings. CV is the coefficient of variation calculated as the standard error in proportion to the mean.

	1983	1984
Area (km²)	10993	10993
Effort (L, km)	1747	1973
No. of primary sightings (N)	64	19
Sighting rate (N/L)	0.037	0.010
CV	0.29	0.50
Mean pod size	1.99	2.56
CV	0.05	0.24
ESW (1/f(0), m)	1355	1355
CV	0.08	0.08
Density of narwhals	0.027	0.009
CV	0.31	0.56
Abundance estimate	300	102
Confidence interval	165–533	36–276

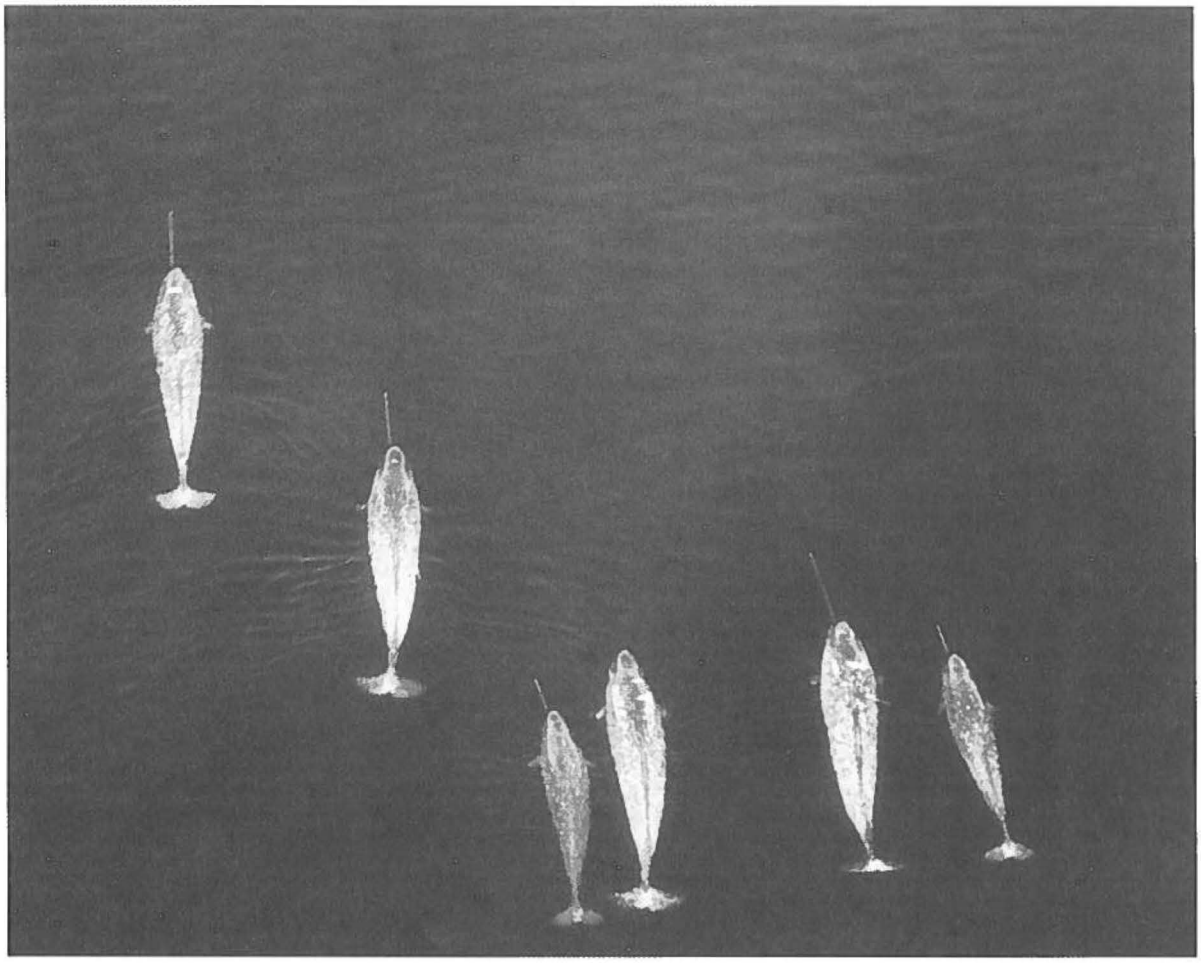

Fig. 3. A group of adult narwhal males in Scoresby Sund. Photo: A. R. Martin

total number of primary sightings) were also excluded to ensure a monotonically decreasing detection function.

The resulting estimates of relative abundance indicate that three times as many narwhals were present in Scoresby Sund in 1983 compared to 1984 (Table 1). However, the two estimates are not significantly different.

Discussion

The survey results from both 1983 and 1984 both indicate a great lack of survey precision which must be attributed primarily to the clumped distribution of the narwhals in Scoresby Sund (Fig. 1), which led to highly variable sighting rates.

The lower number of narwhals found in 1984 could be explained by this lack of precision or by annual variability in the presence of narwhals within Scoreby Sund. A contributing factor could be the widespread formation of new ice in the fjords in 1984. Narwhals leave Scoresby Sund in the autumn and are assumed to winter offshore in open water areas in the Greenland Sea. The formation of new ice in the inner parts of Scoresby Sund probably determines the timing of the departure of narwhals from these areas in the early autumn. More new ice was present during the survey in 1984 than in 1983, and this probably explains why so few narwhals were present in the inner parts of Scoresby Sund in 1984.

The information on the direction of movement of the narwhals observed in the different parts of the fjords in the two years does not obviously support this hypothesis. However, results from behavioural studies of narwhals in eastern Canada (Silverman 1979) suggest that tidal effects may be more important in determining the direction of movement at any given time.

It is evident that a relatively large number of narwhals can be found during the late summer in Scoresby Sund. None of the estimates are corrected for submerged whales and hence they must be considered to be biassed down-

wards in this respect. No correction factors are at present available for this type of survey, but an analysis of diving behaviour of narwhals in a similar habitat in eastern Canada indicates that multiplying by 1.5–1.8 may be appropriate (Martin *et al.* 1994). Another factor that could contribute to a downward bias is the left-truncation of the frequency distribution of primary sightings. The magnitude of this bias will depend on the actual shape of the distribution in the interval from the track line out to the truncation point.

The high number of neonates found in this study suggests that Scoresby Sund is an important calving or nursery area for narwhals. The proportions of neonates found in this study are high compared to results from other areas (*e.g.* Born *et al.* 1994). The observation on a number of occasions during the surveys of single neonates or neonates accompanied by only males suggest that the females may leave their calves at the surface when diving, so that these proportions may be biassed upwards. Segregation of the population, with mainly the adult females and calves summering in Scoresby Sund and adjacent fjords as indicated for other areas, *e.g.* Vibe (1950), may also contribute to the relatively high values of these proportions.

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