Size and trends of the bowhead whale, beluga and narwhal stocks wintering off West Greenland

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ABSTRACT

To assess the size and trends of the abundance of the bowhead whale (*Balaena mysticetus*), the beluga, or white whale (*Delphinapterus leucas*), and the narwhal (*Monodon monoceros*) visual aerial surveys were conducted in West Greenland in March 1998 and 1999. An estimated 49 bowhead whales (95% CI: 13 to 188) were present at the surface in 1998. Data from land-based observations enabled correction for bowhead whales that were not available at the surface to be seen during the survey. By applying a rounded average of 80% (SE=3) for submergence an estimate of 246 bowhead whales (95% CI: 62 to 978) in 1998 was obtained. The 76 and 47 sightings of beluga pods in 1998 and 1999, respectively, had distributions similar to those of previous surveys with the highest concentration at the northern edge of the northern part of Store Hellefiskebanke. No belugas were seen in the southernmost area between Maniitsoq and Paamiut. The index estimate of the abundance of belugas comparable with previous surveys was 929 (95% CI: 563 to 1,533) in 1998 and 735 (95% CI: 436 to 1,239) in 1999. When analysing the sightings as a line-transect survey and correcting for whales that were either submerged or at the surface but missed by the observers an estimated 7,941 (95% CI: 3,650 to 17,278) belugas wintered in West Greenland in 1998-1999. The uncorrected estimate of narwhal abundance was 524 (95% CI: 214 to 1,284) and correcting for the same biases as for the belugas gives a total abundance of 2,861 (95% CI: 954 to 8,578) narwhals in 1998-1999.

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INTRODUCTION

At the time of its maximum extent the winter sea ice in Baffin Bay and Davis Strait usually leaves a stretch of open water along Greenland's west coast from Cape Farvel to Disko Bay. Normally the open water ends at the island Imerisoq, in the middle of the mouth of Disko Bay, but in mild winters it can reach as far as Qeqertarsuaq. North of Disko Bay closed pack ice prevails. The ice that extends from Baffin Island towards the west coast of Greenland (the so-called 'West Ice') reaches land approximately at Kangaatsiaq (68° N). The compact pack ice (>9/10) of the West Ice usually begins 50 to 80 km west of the coast of Greenland (Anonymous 1998).

During the winter considerable concentrations of seabirds and marine mammals can be found along the West Greenland coast south of Disko Bay, in the area where the ice cover meets the open water (cf. Mosbech and Johnson 1999). The relatively shallow water, the favourable conditions for biological productivity and the presence of open water makes it an ideal wintering ground for many species that summer further north. The ice distribution is governed

not just by wind and air temperatures but also by the influx of warm Atlantic water along the West Greenland coast. The annual variations in ice cover influence the presence, survival and productivity of wintering animal species (Porsild 1918, Jensen 1939, Siegstad and Heide-Jørgensen 1994).

Many of the seabirds and marine mammals that winter in the open water along the west coast of Greenland are actively hunted during this season. To evaluate the conditions of the stocks and their sensitivity to the hunt there is an obvious need to monitor changes in stock size and to assess the actual population size in particular for the three whale species wintering in West Greenland.

The population of bowhead whales (*Balaena mysticetus*) in the Baffin Bay and the Davis Strait has been estimated to have numbered at least 12,000 individuals in 1820. Before that time the population must have been even larger since the large catches in the 1700s had already caused a decline in the West Greenland population by the beginning of the 19th century (Reeves and Heide-Jørgensen 1996). Today the Baffin Bay population is considered to number between 250 and 350, of which only a small fraction occur in West Greenland (Finley 1990, Zeh *et al*. 1993). Reeves and Heide-Jørgensen (1996) constructed a core area for the main concentration of bowheads in West Greenland in the area where they had observed bowheads in recent surveys. Maximum numbers were observed in 1991, when they estimated the population as 51 individuals (95% CI: 21 to 119). This estimate was not corrected for animals that were not visible because they were diving or for visible whales that were missed by the observers. Harvesting of bowheads from this stock is only allowed in Canada, at a low level.

The occurrence of belugas (*Delphinapterus leucas*) in West Greenland has changed during the last 70-90 years and a large part of the change can be attributed to the hunt. Early in the 20th century hunters began using motorboats to chase belugas into narrow straits or bays and to block their escape by the use of nets (Heide-Jørgensen 1994). After a period with large catches in Nuuk (1906-22) and in Maniitsoq (1915-29), belugas disappeared from the area south of 66° N. Later (1927-51) there has been a period with large catches in the southern part of the municipality of Upernavik and since 1970 in northern Upernavik. Reported catches of belugas in the 1990s averaged about 700 whales/year (Heide-Jørgensen and Rosing-Asvid 2002).

The belugas that nowadays winter in the open water along the west coast of Greenland are thought to move to the central Canadian High Arctic where large numbers of belugas spend the summer (Smith *et al*. 1985, Innes *et al*. 2002). There is no connection between belugas in West Greenland and those from southeastern Baffin Island (Richard and Heide-Jørgensen unpublished data) and only some of the belugas from the Canadian High Arctic move to West Greenland for the winter (Richard *et al*. 2001, Heide-Jørgensen unpublished data).

As opposed to belugas, narwhals (*Monodon monoceros)* winter in more than 5/10 ice cover and are most often seen in 9/10 or denser pack ice (Heide-Jørgensen *et al*. 1993). They are present during winter throughout the close pack ice in northern Davis Strait and southern Baffin Bay (Heide-Jørgensen *et al*. 1993, Koski *et al*. 1994, Dietz *et al*. 2001). They are sighted along the west coast of Greenland in March and April primarily in the deep water at the southern entrance to Disko Bay (Heide-Jørgensen *et al*. 1993). In West Greenland narwhal are sometimes caught in winter as far south as 66° N, but the bulk of winter catches are taken between Kangaatsiaq and Qeqertarsuaq (Kapel 1977, Heide-Jørgensen 1994).

This report describes the results of the aerial survey of whales that took place between Paamiut and Qeqertarsuaq along the west coast of Greenland during March 1998 and 1999. The aim of the study was to assess the size of the population of belugas and its development since the last survey in 1994. It was also designed to gather data that could be used to assess the number of narwhals and bowhead whales present in the survey area. Furthermore it was attempted to quantify ice conditions by using video surveillance from the survey aircraft. The extent and type of the ice cover is

likely the cause of some of the variations in occurrence and abundance of some species in West Greenland, and its quantification may in the future contribute an explanatory variable to the assessment of the animal abundance.

Previous aerial surveys of belugas in West Greenland (1981, 1982, 1990, 1991, 1993 and 1994) have shown that their numbers within the survey area, over the thirteen years, have decreased by 62%, probably because of overharvesting (Heide-Jørgensen and Reeves 1996). The design of previous surveys has not allowed for correcting the number of whales for the fraction missed by the observers (perception bias) or submerged out of sight when the plane passes over (availability bias). In this study we attempt to estimate the perception bias (as in Marsh and Sinclair 1989) by the use of video surveillance of the track-line directly below the aircraft. The almost instant monitoring of the surveyed area accomplished by the video recording also allows for correcting for the 'availability bias' caused by submerged whales. The fraction of whales that are submerged out of sight (availability bias) was also estimated from whales equipped with satellite-linked time-depth-recorders (Heide-Jørgensen *et al*. 2001) (Fig. 1).

Hunters in Greenland have frequently argued that the surveys do not cover the entire area where belugas occur in winter in West Greenland. As a consequence a survey in 1994 was expanded with a reconnaissance flight to Paamiut and with the inclusion of a new stratum that covered the area between Sisimiut and Maniitsoq. In 1998 hunters again pointed out that belugas have been observed south of the area covered by the surveys and several sightings south of the survey area were relayed to us:
January 14. 1998: Several hundred belugas off Paamiut;
January 17. 1998: Plenty of belugas north of Paamiut;
January 25. 1998: Plenty of belugas outside of Kangaamiut; two whales captured;
March 2. 1998: 10 belugas seen west of Nuuk.
These observations were made about two months before the surveys, so these belugas could have moved north into the survey area by the time the survey was conducted. No beluga observations were reported from this southern area in 1999. We therefore decided to make an effort to find out if there were belugas to be found south of the traditional survey area. For that purpose two new strata were designed, one to cover the area from Maniitsoq to Nuuk and the other from Nuuk to Paamiut. Furthermore,

Fig. 1. *Satellite-linked radio transmitters provide important data on beluga movements and diving.*
(Photo: Rune Dietz)

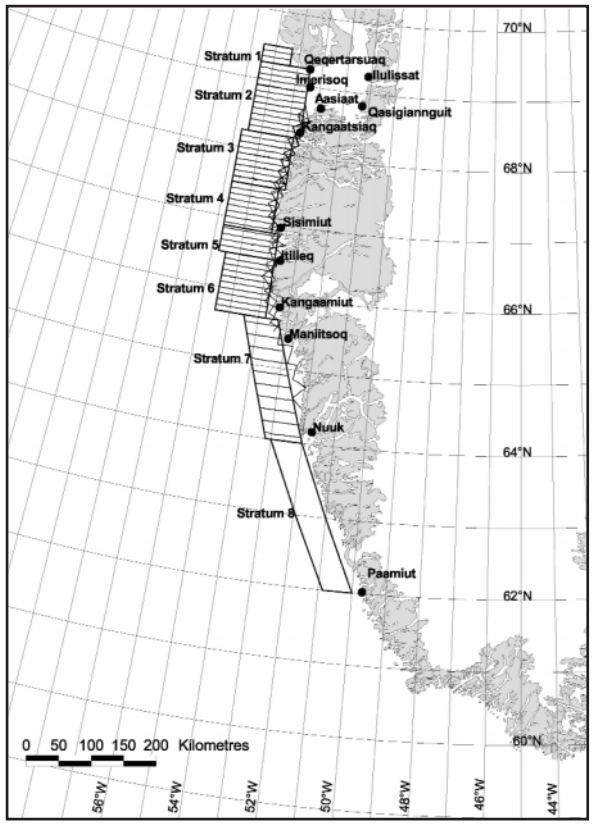

Fig. 2. *Transects and strata covered by the aerial survey between 15 March and 6 April 1998 in West Greenland.*

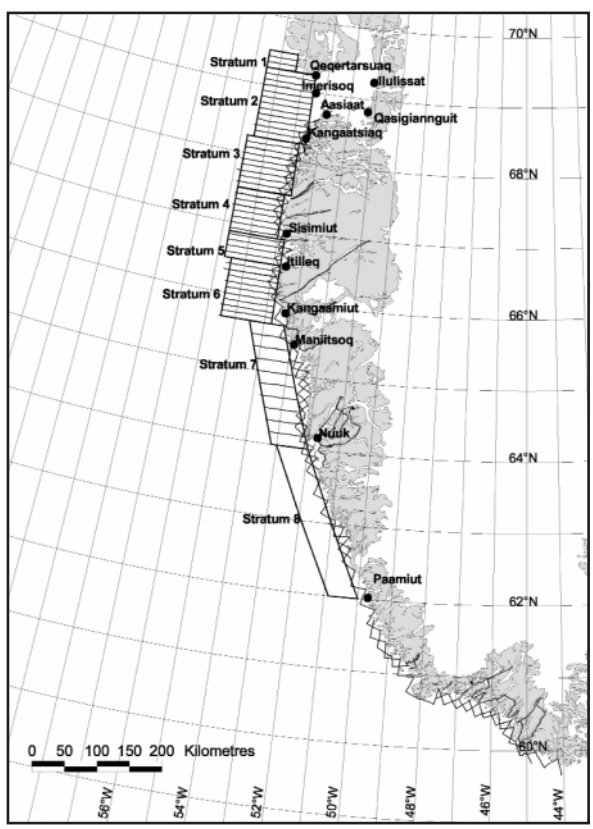

Fig. 3. *Transects and strata covered by the aerial survey between 16 March and 31 March 1999 in West Greenland.*

reconnaissance flights were conducted along the coast to the southern tip of Greenland and in all major fjord systems.

MATERIALS AND METHODS

Survey planning

The surveys were carried out from 15 March to 6 April 1998 and 16-31 March 1999 using a high-winged twin-engine Partenavia P-68 'Observer' equipped with bubble windows for both back seats and an observation recording system. The latter provided for the continuous recording of position, time, altitude, speed and course on each of the observers' tape recorders and on the video recorder.

Eight strata were established between Qeqertarsuaq (lat 69° 30' N) and Paamiut (lat 62° 00' N), some extending as far as 80 km west of the coast (Figs. 2 and 3). In each stratum the transect-web was composed of east-west transects separated by 5 nautical miles. The stratification followed the design previously used to survey winter abundance of belugas in West Greenland (see Heide-Jørgensen and Reeves 1996).

In order to survey seabirds along the coast, a separate web of zigzag transects was designed to cover the coastal area between Aasiat and the southern tip of Greenland (Figs. 2 and 3). These transect lines covered the area from the coast to the 50 m depth curve. These zigzag transects were flown at an altitude of 400 feet (122 m). Whale sightings on these transects were not used in abundance estimation but were used to illustrate whale distribution.

Visual observations

Observations of whales were made from the right and left rear seats. The vertical sighting angle to the centre of each pod was measured using an inclinometer when the pod was abeam. The distance from the transect line was calculated as follows:

(1) distance (m) =altitude * tan (90-angle)

Data on species, angle, pod size, reaction to the aircraft and position at passage were

recorded on tape together with UTC time code from the aircraft's GPS (Garmin 150).

Video surveillance of the transect line

Video recording of the area directly under the aircraft on the transect line was maintained to determine the number of whales missed by the observers and to quantify ice conditions. A Sony Hi-8 video camera equipped with a 12mm lens mounted almost vertically (forward pointing about 5°) in the front of the aircraft was used. Date, UTC-time, position, speed, course and altitude was tapped from the aircraft's GPS and continuously recorded as superimposed text on the video. By flying over a runway of known width it was determined that, at an altitude of 700 feet (213 m), the area covered by the camera and shown on screen corresponded to a rectangle of 45 x 60 m. Videotapes were played back on a high-resolution monitor with single-frame (3 frames/sec) still-picture adjustment of the video player.

Recording of ice conditions

Two classes of ice conditions were utilised from the video surveillance: water or ice. A change of class was determined when the screen (corresponding to 45 x 60 m of sea surface) was showing either water only or ice only. No differentiation between new ice and ice floes smaller than the screen was made. The positions for the changes between classes were noted from the GPS data superimposed on the image.

Estimations of abundance

To index the population trends and to compare results with previous surveys (1981, 1982, 1991, 1993 and 1994), strip transect estimates with a total strip width of 1,400 m were computed from the survey data from 1998 and 1999 following methods detailed by Heide-Jørgensen and Reeves (1996). The use of strip transects assumes a constant transect width within which all animals are recorded. Variance of strip transect abundance estimates was estimated as the empirical variance of bootstrapped values resampled 5,000 times within each stratum with each transect line as the bootstrapped unit.

The line transect method utilises measurements of the distance from the trackline to each observation, from which the distribution of sightings from the trackline can be established. From this the width of the effective survey area is determined (*ESW*=effective search half-width) by fitting several models (*i.e.* uniform, negative exponential, hazard-rate and half-normal) to the perpendicular distances by maximum likelihood estimation using the computer program 'Distance' (Laake *et al.* 1993). The performance of the different fits to the models was assessed by the Akaike's Information Criterion (Buckland *et al.* 1993) and uniform models with one and four cosine adjustments were chosen for the beluga sightings and the narwhal sightings, respectively:

$$(2) \qquad f(x) = 1/W + u\cos(i*p*x/W)$$

where u is a parameter depending on the data, x represents the distance measurements, i is the order of the cosine term and W is the width of the area searched on each side of the transect.

The abundances were assessed from line transect estimates determined as follows:

$$(3) \qquad N = A*[n*p/2*(g(0)/f(0))*L]$$

where N is the number of whales, A is the area of the region covered by the survey, n is the number of sightings of pods, p is the average pod size, $g(0)$ is the probability of seeing a whale on the transect line, $f(0)$ (=$1/ESW$) is the value of the density function of the observations on the transect line and L is the number of kilometres covered during the survey. Empirical variances were estimated for the sighting rates (n/L) and the pod sizes (p) and the variance of *ESW* was calculated using maximum likelihood estimation. The confidence interval (95%) was calculated from the stratum variance as:

$$(4) \qquad \mathrm{var}(N)=N^2(\mathrm{cv}(ESW)^2+\mathrm{cv}(n/L)^2+\mathrm{cv}(p)^2)$$

(Buckland *et al.* 1993)

where cv is the (error) coefficient of variance (standard error in proportion to the mean). Assuming that N has a log-normal distribution a 95% confidence interval is constructed as a lower and higher interval respectively N/V and $N*V$ where:

$$(5) \qquad V=\exp[1.96*\mathrm{sqrt}\{\mathrm{var}(\ln(N)\}]$$

(Burnham *et al.* 1987)

and

(6) $\text{var}(\ln(N)=\ln[1+\text{var}(N)/N^2]$

The confidence intervals for all the strata are calculated from the sum of the variance for the estimate of each stratum. Pod sizes were corrected by size-bias regression of ln of the observed pod sizes on the detection probabilities ($g(x)$), and examined at the point where detection is certain ($g(x)=1$).

Correcting for perception and availability bias

Perception bias

Visual observers miss sightings because of distracting ice floes, several simultaneous sightings, sun glare, observer fatigue etc. This perception bias (Marsh and Sinclair 1989) was estimated by a sight-resight model where the video surveillance provided the sightings and the visual observers provided the resightings on the trackline (x<30 m). The sighting probabilities by the two methods are clearly independent and heterogeneity should not cause bias in population estimates. Thus the 'full conditional independence assumption' for all distances can be relaxed and instead the less restrictive 'trackline conditional independence' sampling can reasonably be deployed (Laake 1999).

Availability bias

The time that whales spend at the surface is critical for the correction of aerial surveys that enumerate the fraction of the population available to be counted at the surface. Data on surface times of bowhead whales were collected by visual observations of individual bowheads at Imerisoq in Disko Bay (Fig. 2) in April 1999 and at Tremblay Sound (72° 20' N, 80° 30' W) on northern Baffin Island in August 1997. Surface times for belugas and narwhals were obtained from individuals instrumented with satellite-linked dive recorders (Heide-Jørgensen *et al*. 1998, 2001). Since the speed of the survey platform was high (approx. 40 m. sec^{-1}) relative to the dive cycle of belugas or narwhals (most dives last more than 1 minute (Heide-Jørgensen and Dietz 1995, Heide-Jørgensen *et al*. 1998)) it was assumed that no repetitive sightings of the whales were made during the passage of the plane and that the area searched by the video camera represents an instant image of the availability of whales.

Estimation of g(0) for belugas and narwhals

The perception and availability biases were combined to derive an estimate of $g(0)$ useful for correcting the abundance estimate for animals missed on the trackline. Unfortunately the sample size was low for the perception bias ($\hat{}$n=2) and no empirical variance could be estimated. Butterworth *et al*. (2002) proposed instead to treat the perception bias as binominally distributed with estimates of $\hat{p}$= r/t with variance $s^2=t*p(1-p)$ where t is the total number of sightings and r the number of resightings. The coefficient of variation for $g(0)$ (calculated as $\sqrt{\text{cv}(p)^2+\text{cv}(a)^2}$ where a is the availability bias) is incorporated in equation (4):

(4') $\text{var}(N)=N^2(\text{cv}(ESW)^2+\text{cv}(n/L)^2+\text{cv}(p)^2+\text{cv}(g(0))^2)$

Fig. 4. *Satellite photo showing ice conditions in Baffin Bay and Davis Strait from 24 March 1998 (NOAA 14 channel 1). The ice conditions observed during the aerial survey are indicated as presence of ice along the transects (white lines).*

RESULTS

Survey procedure

In both years the zigzag transects along the west coast of Greenland between 68° 40' N and 64° 00' N and the east-west oriented transects with-

in the 7 strata between 69° 15' N and 64° 00'N were covered (Fig. 2). In 1999 the coastal zigzag transects were extended south to 60° 00' N. However, owing to adverse weather conditions (too strong wind or too much fog) it was not possible to cover stratum 8 in any of the years. The other areas were surveyed under satisfactory weather conditions, *i.e.* sea state (Beaufort) <3 and visibility >10km.

Ice conditions

The general ice conditions in the eastern part of Baffin Bay and Davis Strait in the middle of March 1998 and 1999 corresponded to the expectations for that season (Figs 4 and 5, Anonymous 1998). There was somewhat more open water in the eastern part of Disko Bay in 1998 than normal but the western part of Disko Bay had consolidated ice. In 1999 there was no open water in Disko Bay and open water could only be found south of 68° N and in certain areas north of Disko Island known to have restricted open water areas in winter. In both years the ice cover varied between ice-free in Stratum 7 and 6 to almost complete ice coverage in strata 1, 2 and 3.

More than 45% of the ice floes were less than 1 km in diameter. Stratum 1 and 3 generally had the smallest ice floes and stratum 4 and 5 the largest. A comparison of the mean floe size revealed no significant differences in stratum 1, 4 and 5, whereas stratum 2, 3 and 6 had significantly larger ice floes in 1999 ($P < 0.05$). Also, the size of the ice floes in all strata combined was much smaller in 1998 (mean=3.3 km, SD=6.0, n=750) than in 1999 (mean=5.3 km, SD=13.3, n=415).

Distribution of bowhead whales

Eight bowhead whales were observed in 1998, of which 5 were at the northern edge of the northern part of Store Hellefiskebanke in the area where they have previously been observed in March (Fig. 6, see Reeves and Heide-Jørgensen 1996). The other 3 sightings were made southwest of Sisimiut in an area where they have not been sighted in earlier surveys. In 1999 only one bowhead whale was sighted (by the pilot) at 68° 09.929' N, 55° 35.277' W in an area known for the occurrence of bowhead whales. All the bowhead whale sightings were in dense pack ice (Figs 9 and 10).

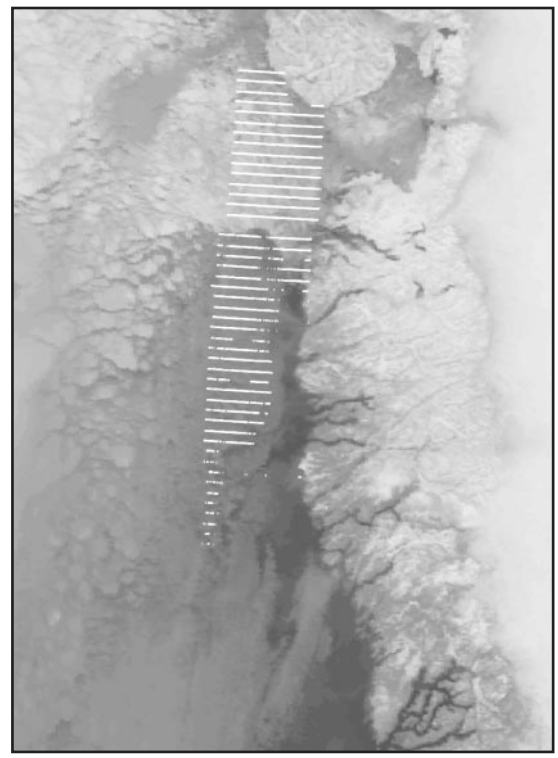

Fig. 5. *Satellite photo showing ice conditions in Baffin Bay and Davis Strait from 17 March 1999 (NOAA 14 channel 4). The ice conditions observed during the aerial survey are indicated as presence of ice along the transects (white lines).*

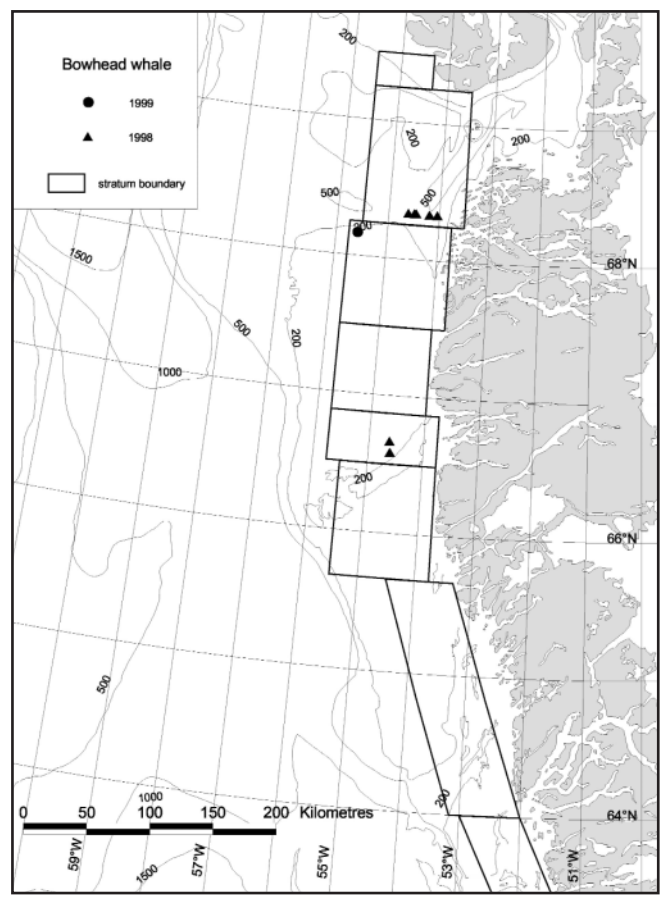

Fig. 6. *(Below) Sightings of bowhead whales in 1998 and 1999.*

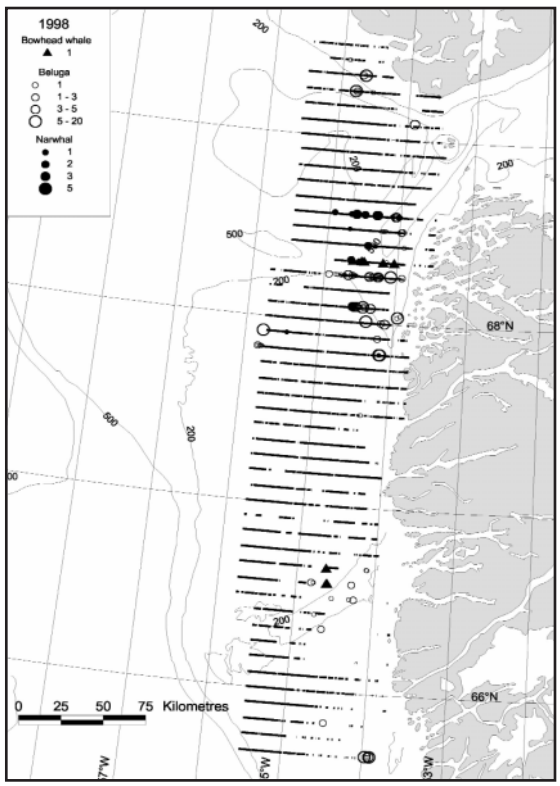

Fig. 9. *Sightings of marine mammals shown in relation to ice conditions and water depth in 1998.*

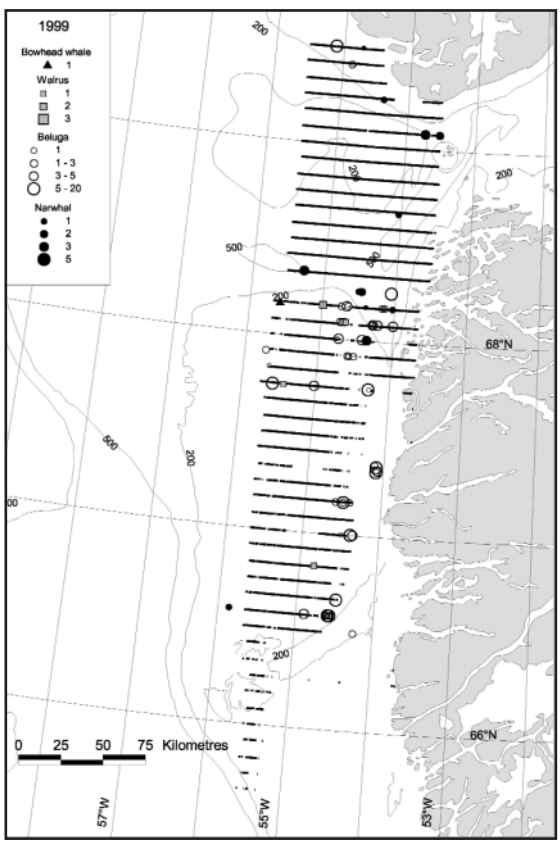

Fig. 10. *Sightings of marine mammals shown in relation to ice conditions and water depth in 1999.*

Estimation of bowhead whale abundance

The stratum used to estimate bowhead whale abundance in previous surveys was delimited by 69° 10' N, 56° 00' W in the northwest corner and 67° 00' N, 54° 00' W in the southeast corner (Reeves and Heide-Jørgensen 1996). Only the five northernmost sightings from 1998 were within this stratum. For 1998 it seems more reasonable to use the beluga strata (see below and Fig. 6) because the sightings of bowhead whales were from strata 2 and 5.

All sightings were less than 700 m from the track line, which allows the use of strip-transect analysis with 1400 m strip width as in previous surveys. This resulted in an estimated 32 bowhead whales (95% CI: 5 to 197) and 17 (3 to 92) within stratum 2 and 5, respectively. Altogether this gives a total of 49 bowhead whales (13 to 188) in West Greenland in 1998. No estimates can be derived for 1999.

A correction factor for the bowhead whales that were submerged during the survey in 1998 was derived from visual observations of the proportion of time spent at the surface (Table 1). From Disko Bay in April it was estimated that the whales spent 18% of their time at the surface whereas the estimate from Tremblay Sound in August was 21%. Using an estimate of 20% (SE=3) surface time reveals an estimate of 246 bowhead whales (95% CI: 62 to 978) in West Greenland in 1998. The estimate is not corrected for whales missed by the observers.

Distribution of belugas

The highest concentrations of belugas were found in stratum 3, especially in the northern area, in both 1998 and 1999, but large numbers were also found in the southern area of stratum 2 (Figs 7 and 8). This area, where most belugas congregate, is situated on the northern edge of the northern part of Store Hellefiskebanke where the slope of the sea bottom is steep and where the dense pack ice that covers the mouth of Disko Bay begins (Figs 9 and 10). In 1998 no belugas were seen in stratum 4; belugas were seen in strata 5 and 6 but not in stratum 7. In 1999 no belugas were found south of stratum 5 either on the coastal zigzag transects to the southern tip of Greenland, in strata 6 or 7 or in any of the fjord systems. There was a gradient

Table 1. Surfacing times (upper 5 m of the water column) for belugas and narwhals and time at surface for bowheads. The surfacing times were measured in 6 hour intervals and are given as a percentage of the total time for belugas and narwhals. The bowhead whales were visually observed during a variable period indicated as the 'monitoring time' and the time at surface is given in proportion to the total time of a diving and surfacing period. The standard error is given in brackets. Tremblay Sound is located at 72° 22' N, 81° 05 W, Jones Sound at 76° N, 80° W and Cumberland Sound at 65° N, 65° W.

Species	Area	Period	Surfacing time (percent)	Number of whales	Number of 6 hrs. intervals	Reference
Beluga	East of Jones Sound	November 1995	28.4 (0.71)	2	25	Heide-Jørgensen *et al*. 1998
Beluga	East of Jones Sound	November 1996	51.6 (1.29)	5	121	Heide-Jørgensen *et al*. 2001
Beluga	Cumberland Sound	November 1998	46.1 (2.83)	2	17	Heide-Jørgensen *et al*. 2001
Beluga	Cumberland Sound	November 1999	53.6 (1.33)	5	228	Heide-Jørgensen *et al*. 2001
Beluga	Cumberland Sound	December 1999	42.6 (1.96)	3	83	Heide-Jørgensen *et al*. 2001
Beluga	Cumberland Sound	January 2000	35.6 (1.51)	1	19	Heide-Jørgensen *et al*. 2001
Narwhal	Eastern Baffin Bay	November 1994	32.0 (1.23)	1	49	Heide-Jørgensen & Dietz 1995
Narwhal	Eastern Baffin Bay	November 1995	31.1 (0.65)	1	75	Heide-Jørgensen & Dietz 1995
Narwhal	Central Baffin Bay	Dec.-Feb. 1994-95	25.5 (1.49)	1	10	Heide-Jørgensen & Dietz 1995
Narwhal	Western Baffin Bay	November 1997	32.6 (1.68)	1	23	Heide-Jørgensen *et al*. 2001
Narwhal	Western Baffin Bay	November 1998	29.3 (0.71)	1	68	Heide-Jørgensen *et al*. 2001
Narwhal	Central Baffin Bay	December 1998	38.3 (0.84)	1	66	Heide-Jørgensen *et al*. 2001
Narwhal	Central Baffin Bay	January 1999	25.6 (0.44)	1	68	Heide-Jørgensen *et al*. 2001
					Monitoring time	
Bowhead	Imerisoq-Disko Bay	27 April 1999	19.3 (1.7)	1	52.67 min	Heide-Jørgensen unpubl. data
Bowhead	Imerisoq-Disko Bay	28 April 1999	17.2 (2.7)	1	40.75 min	Heide-Jørgensen unpubl. data
Bowhead	Tremblay Sound	10 August 1997	20.7 (6.2)	1	89.73 min	Heide-Jørgensen unpubl. data

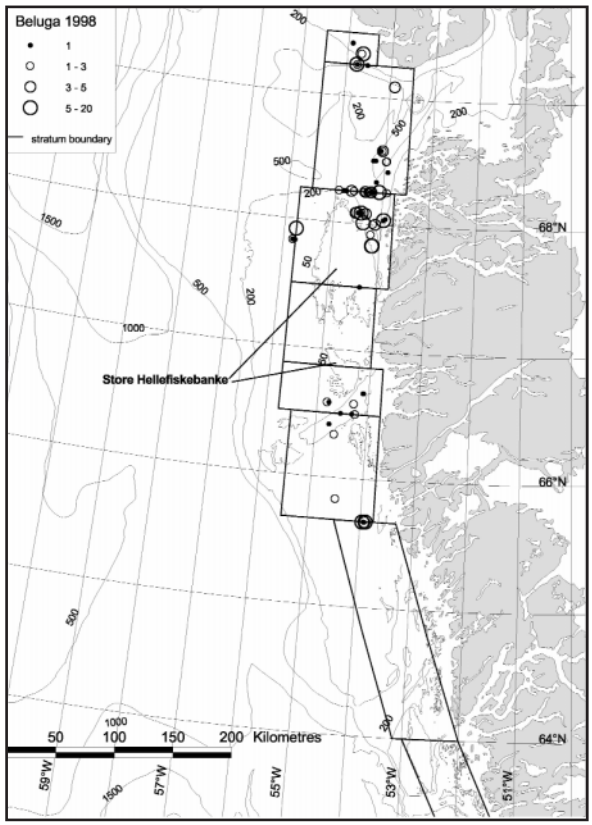

Fig. 7. *Sightings of beluga in the 7 strata, including sightings on the zig-zag transect web along the coast in 1998.*

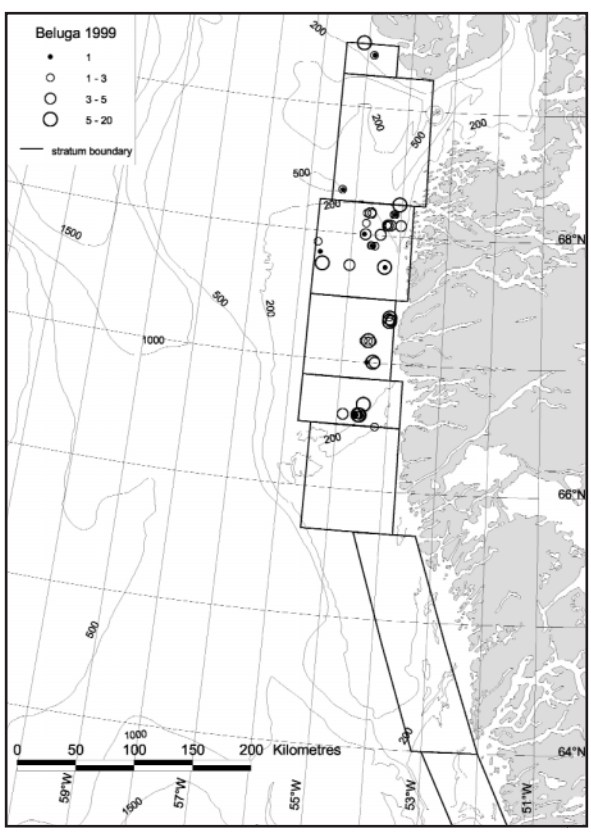

Fig. 8. *Sightings of beluga in the 8 strata, including sightings on the zig-zag transect web along the coast in 1999.*

with most observations close to shore and fewer westward, though some whales were sighted at the westernmost parts of the transects.

The belugas were found in the dense pack-ice north of 68° N in the persistent leads in the dense ice at the northern edge of Store Hellefiskebanke (Figs 9 and 10). Sightings of belugas south of 68° N were usually associated with the ice edge, which was evident in both years but was particularly pronounced in 1999 (Fig. 10). Few belugas were seen in completely ice-free waters and none were found in coastal waters or in fiords.

Estimation of beluga abundance

There were 123 pods of belugas sighted within the transect width in 1998 and 1999, of which more than half were seen in stratum 3. Judging from the relatively low cv's, also the most even distribution of belugas was found in stratum 3 (Table 2). However, the total variance of the sighting rate is largely due to the low number of sightings: on average there was 95 km between beluga sightings in 1998-99 combined.

The angles to 76 and 47 pods of belugas were measured in 1998 and 1999, respectively. Some of these pods (10%) were observed far away from the aircraft. These are probably extreme observations often of large pods, which have to be excluded from the calculations because at such distances one can no longer assume an even distribution of all pod sizes. Eliminating these 10% of the observations gave a maximum distance of observations (*W*) of 854 m and 1002 in 1998 and 1999, respectively. The frequency of sightings showed a clear peak on and close to the trackline (Fig. 11). The *ESW* was estimated as 427 m (*f(0)*=0.0024, cv=0.079) for the combined distribution of sightings in 1998 and 1999.

There is generally a greater chance to see a small pod of belugas close to the transect line than far away, so the proportion of larger pods sighted tends to be greater far away from the aircraft. The calculation of the average group size should ideally reflect this pod size bias in

Table 2. Abundance estimates of belugas in West Greenland in March 1998, March 1999 and both years combined. Estimates from 1993 and 1994 are provided for comparison. The estimates given are line transect estimates of the total population size, corrected for pod size bias and for whales that are submerged or missed by the observers (*g(0)*), The estimate is also determined as an index number comparable with the previous surveys (see Heide-Jørgensen *et al*. 1993 and Heide-Jørgensen and Reeves 1996). The numbers in brackets represent the cv calculated as standard error in proportion to the mean.

Stratum	Area (A, km^2)	Effort (L, km)	Sightings (n)	Sighting rate (n/L)	Corrected pod size (p)	Abundance estimate (N)	Observed pod size mean	Index number w=700m
1993								
1	1,247	111						0
2	8,664	485						0
3	6,795	1,391						297 (0.36)
4	5,185	1,058						389 (0.39)
5	3,522	859						214 (0.40)
Total		3,904						900 (0.22)
1994								
1	1,247	132						7 (0.84)
2	8,664	960						32 (0.65)
3	6,795	1,641						583 (0.24)
4	5,185	885						213 (0.37)
5	3,522	893						265 (0.39)
6	7,239							
Total								1,100 (0.17)
1998								
1	1,247	138	3	0.0217 (0.58)	0.910 (0.09)	23 (0.59)	4.000 (0.52)	26 (0.54)
2	8,664	1,046	15	0.0143 (0.46)	2.357 (0.22)	276 (0.52)	2.067 (0.22)	183 (0.46)
3	6,795	1,256	40	0.0318 (0.45)	3.409 (0.14)	694 (0.48)	3.000 (0.14)	452 (0.38)
4	5,185	529	0	-	-	0	-	0
5	3,522	441	8	0.0181 (0.42)	1.680 (0.24)	101 (0.49)	1.625 (0.20)	91 (0.45)
6	7,239	790	10	0.0127 (0.68)	1.804 (0.35)	156 (0.77)	4.100 (0.30)	177 (0.78)
7	10,602	553	0	-	-	0	-	0
Total	43,254	4,753	76	0.0176 (0.27)	2.718 (0.10)	1,250 (0.31)	2.671 (0.11)	929 (0.26)
1999								
1	1,247	138	1	0.0072 (1.00)	6.000 (0.00)	65 (1.01)	6.000 (0.00)	0
2	8,664	966	2	0.0207 (0.99)	1.500 (0.50)	32 (1.05)	1.500 (0.50)	19 (0.96)
3	6,795	1,003	27	0.0248 (0.28)	2.664 (0.14)	524 (0.33)	2.769 (0.12)	368 (0.23)
4	5,185	1,058	9	0.0085 (0.45)	5.280 (0.37)	278 (0.60)	5.778 (0.25)	91 (0.73)
5	3,522	440	10	0.0227 (0.76)	5.147 (0.24)	493 (0.80)	4.200 (0.18)	257 (0.65)
6	7,239	790	0	-	-	0	-	0
7	10,602	553	0	-	-	0	-	0
Total	43,254	4,948	47	0.0095(0.27)	2.765 (0.11)	1,392 (0.35)	3.447 (0.11)	735 (0.27)
1998-1999								
Total	43,254	9,701	112	0.0105 (0.21)	2.794 (0.08)	1,390 (0.23)	2.955 (0.08)	853 (0.21)
Total corrected for *g(0)* =0.175 (SE=0.06):						7,941 (95% confidence interval: 3,650-17,278)		
Index number 1998-1999:						855 (95% confidence interval: 584-1,251)		

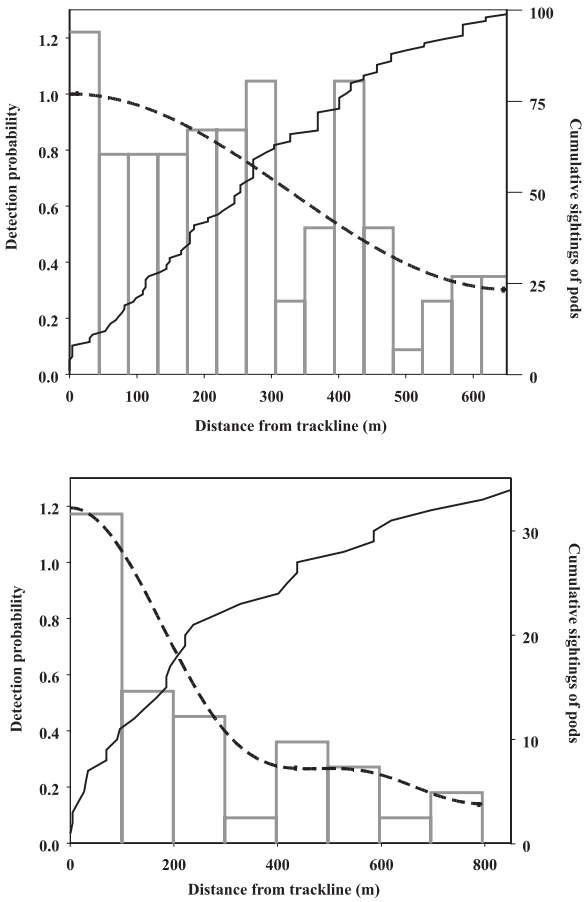

Fig. 11. *Distribution of perpendicular distances to sightings of belugas (above, n=111) and narwhals (below, n=32) from the trackline (histogram). About 10 percent of the most distant sightings have been excluded from the analyses and detection curves have been fitted by a Fourier series model (dotted line). The cumulated sighting curve is indicated with full line.*

surface by instrumenting whales with pressure transducers that record the time they spend at each given depth. The information is then relayed via satellite to a ground station. As the dive duration can vary with the season, this information ideally has to be sampled contemporarily or as close as possible to the timing of the surveys. Unfortunately no data are available on dive duration for belugas in March. Data for belugas and narwhals are available from early autumn through January (Table 1). Judging from these data belugas spend between 30% and 50% of their time in the upper 5 m of the water column on average. Probably the actual figure is closer to 30% than to 50% and is in any case not higher than 55% (Heide-Jørgensen *et al*. 1998, 2001). For the corrections of the present survey it is assumed that 35% (a=0.35) of the whales are available at the surface to be detected. Relatively low standard errors are reported in Table 1 for this estimator but only few animals have been studied and to account for the variability in the population being surveyed a standard error of 0.08 of a is assumed (cv=0.23).

detectability. Therefore the calculation of mean group size was corrected by regressing log-transformed pod size against the detection probability as estimated by the detection function, where the expected pod size is represented by the point where the detection probability for an observation is certain ($g(x)$=1). The mean group size calculated by this method was 2.955 (cv=0.08) whales per pod for both years combined. This is close to the simple mean pod size calculated without correcting for the distance to the sightings (Table 2).

Whales that are diving and are not seen by the observers – g(0)

Although it is possible from an aircraft to observe whales down to 4 to 5 m below the surface, there is always a proportion of whales that are diving even as the plane passes over and are therefore not visible to the observers. At present it is only possible to estimate the fraction present at any time at or near (within 5 m) of the

The video recording of the track line captured 8 pods of belugas and 2 pods of narwhals in 1998 (Table 3). Of the 10 pods captured by the video three beluga pods and both narwhal pods were also sighted by the observers and four beluga pods were not sighted (one comprising 17 whales). One visual sighting reported as a walrus (*Odobenus rosmarus*) was undoubtedly a beluga when examined on the video. If the narwhals are included - considering that they are more difficult to spot - there were 5 visual resightings of whale pods. In 1999 6 pods of belugas were captured by the video of which 3 were resighted by the observers. Whale pods were usually missed in high density areas where multiple sightings – also of other species *e.g*. walruses – were made during short periods.

Although they are based on a rather low number of video cȃptures the estimates of 50% of the whales being missed by the observers on the trackline are identical for 1998 and 1999 and no

Table 3. Pods of belugas, narwhals and walruses 'captured' by the video surveillance. The + sign represents a "recapture " by the observer, the – sign indicates that the pod was missed by the observer.

Stratum	Species	Number	Angle	Visual observation	
				Left observer	Right observer
1998					
2	Narwhal	4	90°	+	+
2	Beluga	1		-	-
3	Beluga	1	90°	-	reported as walrus
3	Beluga	1	90°	+	+
3	Beluga	1	89°	+	-
5	Beluga	17		-	-
3	Beluga	3	89°	-	+
3	Beluga	1		-	-
3	Narwhal	1	86°	-	+
3	Beluga	1		-	-
1999					
3	Beluga	5	86°	-	+
4	Beluga	2		-	-
5	Beluga	1		-	-
5	Beluga	3	89°	-	+
3	Beluga	2	90°	-	+
3	Beluga	2		-	-

empirical variance can be associated with the estimate. Combining the values for the perception bias (p=0.5, cv=0.25) and the availability bias (a=0.35, cv=0.23) gives an estimate of $g(0)$=0.175 with cv($g(0)$)= 0.34.

Population size and trends

The uncorrected line transect estimate of the number of belugas at the surface that are seen by the observers was 1,390 (95% CI: 893 to 2,162) for 1998 and 1999 combined. If this figure is corrected for whales diving during the passage of the aircraft and for whales missed by the observers the combined estimate for the seven strata surveyed in 1998 and 1999 is 7,941 (95% CI: 3,650 to 17,278). The corresponding value for 1993-1994 combined with the same $g(0)$ value is 11,563 (8,560 to 15,621).

The changes in relative abundance of belugas in West Greenland since 1981 can be indexed by treating subsequent surveys in the same way as for the data from 1981-1982. This index assumes that all whales within 700 m of the track line are observed, or at least that the same fraction of the whales is observed each year. There is no correction for diving whales or for whales missed by the observers. The index numbers for 1998 and 1999 are both significantly lower than the estimates from 1982 (see Heide-Jørgensen and Reeves 1996). Neither the indices nor the line transect estimates from the more recent surveys (1991, 1993 and 1994) differ from those from 1998 and 1999, even though both values from 1998-1999 are lower than in any previous years (Table 2). This means that no firm conclusion on the change in number of belugas after 1994 can be made from the two surveys. It is however clear that the results from 1998-1999 confirm that the number of belugas has declined since 1981-82 and that this decline probably continued after 1994.

Distribution of narwhals

The majority of the narwhal observations were made in stratum 2 in both 1998 and 1999 with a few in the neighbouring strata (Table 4). Narwhals were concentrated in the southern part of the mouth of Disko Bay, especially in the area with depths greater than 200 m (Figs 12 and 13) and almost always in close pack ice (Figs 9 and 10). In 1999 there were a few sightings in atypical areas such as west of stratum 5 and in stratum 7 (Table 4, Fig. 13).

Table 4. Abundance estimates of narwhals in West Greenland in March and early April (1990). The estimates given are line transect estimates of the total population size for 1991 through 1999, corrected for pod size bias and for whales that are submerged or missed by the observers *(g(0))*. The same value of *g(0)* as for belugas is used. The numbers in brackets represent the cv calculated as standard error in proportion to the mean. For the comparison with earlier years a strip census estimate with a fixed transect width of 700 m is calculated from 1981 through 1999.

Stratum	Area (km^2)	Effort (*L*, km)	Sightings (*n*)	Sighting rate (*n*/*L*)	Corrected pod size (*p*)	Abundance estimate (*N*)	Strip census estimate *w*=700m
1981							
1	1,247	45	6	0.1333 (0.81)			119 (0.58)
2	8,664	906	30	0.0331 (0.45)			205 (0.41)
3	6,795	519	1	0.0019 (1.04)			9 (0.99)
4	5,185	431	2	0.0046 (1.01)			17 (0.88)
5	3,522	310	1	0.0032 (0.60)			8 (0.73)
Total		2,211	40				358 (0.31)
1982							
1	1,247	155	3	0.0194 (0.90)			17 (0.86)
2	8,664	2,118	109	0.0515 (0.24)			319 (0.25)
3	6,795	1,873	28	0.0150 (0.55)			73 (0.49)
4	5,185	1,504	13	0.0086 (0.55)			32 (0.54)
5	3,522	810	0	0			0
Total		6,460	153				440 (0.20)
1990							
1	1,247	51	0	0			0
2	8,664	540	22	0.0441 (0.29)			252 (0.34)
3	6,795	329	0	0			0
4	5,185	343	0	0			0
5	3,522	264	0	0			0
Total	25,413	1,526	22				252 (0.34)
1991							
1	1,247	137	0	0	0	0	0
2	8,664	951	42	0.0441 (0.29)	2.37 (0.15)	261 (0.51)	273 (0.28)
3	6,795	746	0	0	0	0	0
4	5,185	595	0	0	0	0	0
5	3,522	439	0	0	0	0	0
Total	25,413	2,869	42			261 (0.51)	273 (0.28)
Total corrected for *g(0)* =0.175 (SE=0.06):					1,490 (95% confidence interval: 473-4,961)		
1993							
1	1,247	92	2	0.0217 (1.00)	1	19 (1.01)	8 (0.84)
2	8,664	485	2	0.0041 (1.00)	1	25 (1.01)	13 (0.87)
3	6,795	1,391	11	0.0079 (0.50)	1.91 (0.17)	57 (0.55)	42 (0.66)
4	5,185	1,058	0	0	0	0	0
5	3,522	859	0	0	0	0	0
Total	25,413	3,885	15			102 (0.46)	63 (0.48)
1994							
1	1,247	132	0	0	0	0	6 (0.86)
2	8,664	960	14	0.0146 (0.41)	2.57 (0.12)	405 (0.43)	141 (0.41)
3	6,795	1,641	0	0	0	0	39 (0.68)
4	5,185	885	0	0	0	0	0
5	3,522	893	0	0	0	0	0
6	7,239	399	0	0	0	0	0
Total	32,652	4,910	14			405 (0.43)	263 (0.36)

Table 4 (Continued)

Stratum	Area (km²)	Effort (*L*, km)	Sightings (*n*)	Sighting rate (*n*/*L*)	Corrected pod size (*p*)	Abundance estimate (*N*)	Strip census estimate *w*=700m
1993-1994							
Total	58,065	8,795	29		286 (95% confidence interval: 137-597)		
Total corrected for *g(0)* =0.175 (SE=0.06):					1,636 (95% confidence interval: 620-4,320)		
1998							
1	1,247	138	0	0	0	0	0
2	8,664	1,046	17	0.0163 (0.71)	2.55 (0.16)	572 (0.73)	189 (0.68)
3	6,795	1,256	6	0.0048 (0.69)	1.00 (0.00)	52 (0.73)	23 (0.67)
4	5,185	529	0	0	0	0	0
5	3,522	441	0	0	0	0	0
6	7,239	790	0	0	0	0	0
7	10,602	553	0	0	0	0	0
Total	43,254	4,753	23		1.87 (0.13)	624 (0.71)	213 (0.60)
1999							
1	1,247	138	1	0.0062 (1.00)	1	8 (1.00)	6 (0.86)
2	8,664	966	5	0.0044 (0.36)	3.6 (0.23)	138 (0.42)	141 (0.41)
3	6,795	1,003	4	0.0034 (0.68)	2 (0.20)	46 (0.71)	39 (0.68)
4	5,185	1,058	0	0	0	0	0
5	3,522	440	0	0	0	0	0
6	7,239	790	0	0	0	0	0
7	10,602	552	1	0.0016 (0.99)	1	16 (0.99)	14 (0.94)
Total	43,254	4,948	12			208 (0.33)	206 (0.32)
1998-1999							
Total	43,254	9,701	35		524 (95% confidence interval: 214-1,284)		
Total corrected for *g(0)* =0.175 (SE=0.06):					2,861 (95% confidence interval: 954-8,578)		

Estimation of narwhal abundance

The same procedure as for belugas was used to determine the abundance of narwhals. The angles to 23 and 12 pods of narwhals were reported in 1998 and 1999, respectively. About 10% of these were so far from the aircraft that they can be considered extreme and when discarded the largest distance of observation was 795 m (*W*) (Fig. 11). The *ESW* was estimated as 308 m (*f(0)*= 0.0033, cv=0.18) for the combined sightings in 1998-1999.

Surfacing time for narwhals is approximately the same as for belugas (35%) although none of the data have been gathered from the same time and place as the survey (Table 1). Not enough data has been collected to estimate the portion of missed narwhal sightings during the surveys, and it will be assumed that the perception bias for belugas also applies to narwhals (50%).

The estimated number of narwhals at the surface in 1998-99 was 524 (95% CI: 214-1,284). The large confidence interval is due primarily to the extremely variable sighting frequency. If the same correction factor as for belugas is deployed to account for diving narwhals and missed observations the resulting estimate was 2,861 (95% CI: 954 to 8,578, Table 4) in 1998-99.

Changes in narwhal abundance

Earlier surveys of narwhals have been designed as strip transect estimates with a strip width of 700 m on either side of the aircraft (see Heide-Jørgensen *et al*. 1993) and for the comparison with the recent surveys these are presented together with line transect abundance estimates (see Table 4). The strip census estimates show marked variations from 63 in 1993 to 440 in 1982, however, there is a declining trend that is significant when fitting a weighted linear model

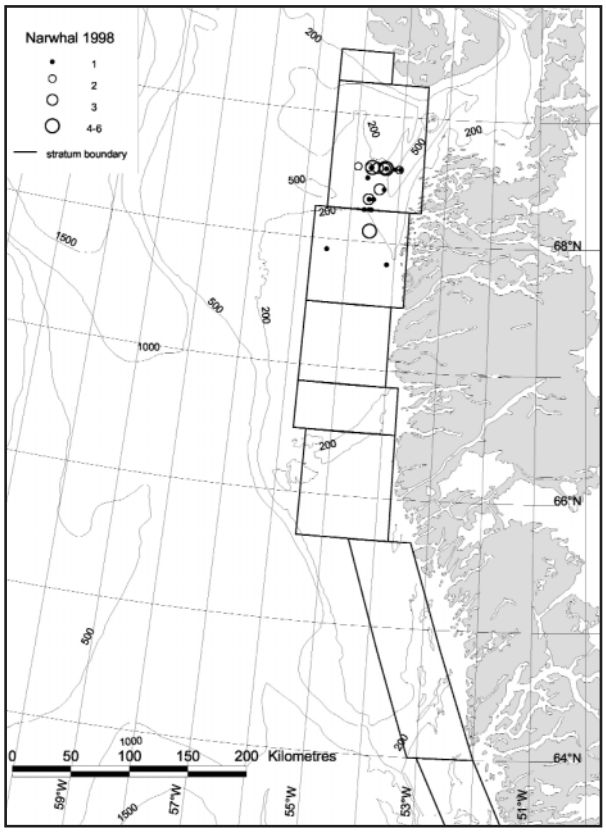

Fig. 12. *Sightings of narwhals in the 7 strata, including sightings on the zig-zag transect web along the coast in 1998.*

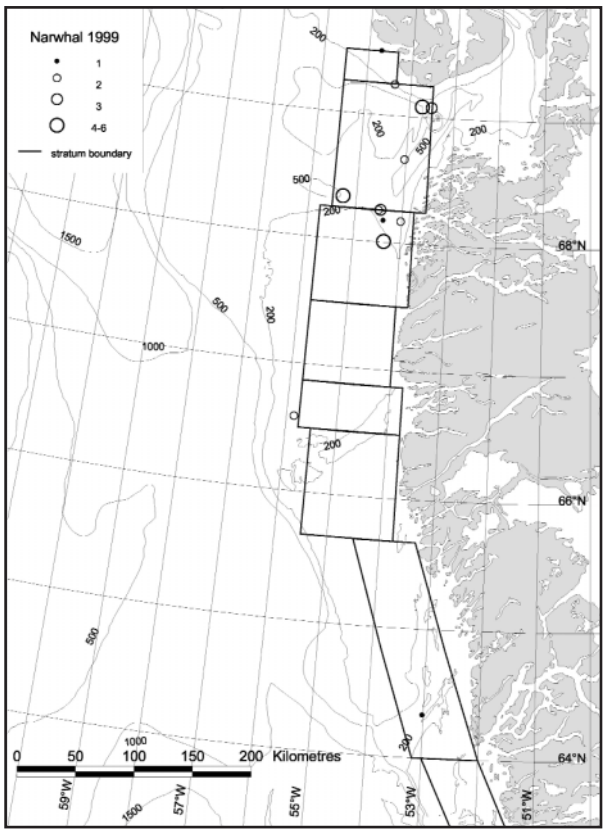

Fig. 13. *Sightings of narwhals in the 8 strata, including sightings on the zig-zag transect web along the coast in 1999.*

(p=0.02, weight =1/cv) with an annual decline of 3.0% (SE=0.9) but not for an exponential model (p=0.10) with an annual decline of 4.7% (SE=2.5). The line transect estimate from 1998-99 is larger than the previous estimate from 1993-94 albeit not significantly so.

DISCUSSION

Bowhead whales

The distribution of bowhead whales in 1998 was somewhat different from previous surveys, and a possible expansion of this species' range must be investigated in future surveys. There were no primary sightings of bowhead whales in 1999, which is the first time since the surveys started in 1981. However, during field work conducted in 1999 at Imerisoq (Fig. 2) bowhead whales were observed daily between 20 April and 5 May and up to four individuals were recorded during one day (Heide-Jørgensen unpubl. data). Thus nothing suggests an absence of bowhead whales in West Greenland in 1999.

The estimate of the abundance of bowhead whales in 1998 resembles the figures from the surveys between 1981 and 1994, but due to the different stratum design the 1998 area is about 40% smaller (Reeves and Heide-Jørgensen 1996). Re-analysis of the data from 1981 through 1994 using the five strata reveals estimates that are similar in magnitude to the result from 1998 and no trends can be detected.

The data presented on surfacing times for bowheads whales are perhaps not of an adequate magnitude for the purpose of correcting survey data, but they are supported by larger amounts of data derived from other studies (Dorsey *et al*. 1989, Würsig and Clark 1993, Finley and Goodyear MS 1993). It is uncertain how far below the surface a bowhead whale can reliably be observed from an airplane, but data collected from a satellite-linked time-depth-recorder in May 2001 showed that one instrumented bowhead whale spent 33.8% (SD 10.7, n=4) of its time above 9 m (Heide-Jørgensen *et al*. in press). The actual threshold for visual detection of bowhead whales is probably closer to the surface, suggesting that the value of 20% used as a correc-

tion factor for this survey is reasonable. Being rather imprecise, the estimate of the bowhead numbers present off West Greenland reflects the magnitude of what could be found there in 1998. It does not deviate significantly from previous estimates (see Reeves and Heide-Jørgensen 1996).

Belugas

The distribution of belugas seen in 1998 and 1999 along West Greenland resembles the pattern observed during earlier surveys where the great majority of observations were made within 50 km from shore and few beluga were found between 50 and 80 km west of the coast (Figs 7 and 8). However, in both 1998 and 1999 the centre of the sightings was in the southern part of stratum 2 and the northern part of stratum 3, whereas in 1993 and 1994 only few or no sightings were made in stratum 2. In all years stratum 3 has had the highest sighting rate. Also, no whales were seen in stratum 4 in 1998 (*i.e.* the area between Nassuttoq and Sisimiut) but some were seen in stratum 6 (*i.e.* the area between Itilleq and Maniitsoq); but not in 1999. In most other years stratum 4 has had lower densities than the two neighbouring strata.

There were no sightings of belugas in stratum 7 (*i.e.* the area between Maniitsoq and Nuuk) in any of the years and the coastal reconnaissance surveys south to the tip of West Greenland in 1999 and in the major fjord systems observed no belugas. Considering that no whales were observed in stratum 7 or on the coastal transects it is unlikely that there were large pods of belugas in the area south of stratum 7 (that is from Nuuk to Paamiut) at the end of March 1998 or March 1999. This is confirmed by the results from 1994 where coastal reconnaissance surveys gave no sightings of belugas between Maniitsoq and Paamiut (Heide-Jørgensen and Reeves 1996).

It is however surprising that there were more whales in stratum 6 in 1998 than in other years. This area has been covered in 1994 and partially in 1993, but in both years only a few belugas were seen in stratum 6 (Heide-Jørgensen and Reeves 1996). Earlier surveys in 1981 and 1982 recorded no sightings south of 66° 30' N (the northern boundary of stratum 6) in spite of intense coverage in 1982 (Heide-Jørgensen *et al*. 1993) and the survey in 1999 found no whales in stratum 6.

Apart from the areas covered by surveys there can be belugas in the northern part of Vaigat (see Heide-Jørgensen *et al*. 1993) and in Disko Bay. It is however unlikely that large numbers winter in these areas and they will at most contribute a few hundred belugas to the total estimate for West Greenland.

The 1998-99 survey was similar to earlier surveys for the following parameters; the distance function of the observations, the group size distribution and the large variation in number of sightings per kilometre. None of these conditions has changed significantly since the 1993-94 survey. The 1998-99 survey also confirms the decline in beluga abundance observed previously. Overharvesting has been identified as the most probable cause of the decline (Heide-Jørgensen and Reeves 1996, Butterworth *et al*. 2002, Innes and Stewart 2002).

The correction factor applied for belugas (and narwhals) includes an estimate of perception bias (proportion of visible whales on the track-line missed by the observers) of 50% with a relatively large uncertainty (cv=0.25). Evidently more robust methods for estimating perception bias and its variance are needed. The other component of the correction factor is the availability bias (proportion of whales not visible to the observers). It is likely that sufficient data has been collected to correctly estimate the magnitude of this correction, but more whales will have to be instrumented to estimate its variance. The standard error assumed here may well be too large.

Narwhals

Narwhals are distributed in the deep water in Baffin Bay and especially in winter they are found in the ice cracks in the compact pack ice in central Baffin Bay (Koski *et al*. 1994, Dietz and Heide-Jørgensen 1995, Dietz *et al*. 2001). The surveys along the West Greenland coast cover only parts of the winter-distribution of the narwhal population in Davis Strait/Baffin Bay. The fraction of narwhals that are found along the west coast of Greenland in March is proba-

bly subject to yearly variations depending on ice conditions and the abundance estimates are subject to considerable uncertainty, due to the small number of sightings.

The observed decline in narwhal abundance does not raise the same concern as for belugas because only a fraction of the narwhal occurrence was covered by the surveys and because the observed decline is of lesser magnitude than for the belugas. However, Heide-Jørgensen *et al*. (1993) argued that the early surveys (1981 and 1982) that revealed high number of whales are compatible – if not negatively biased – with the later surveys. The early abundance estimates are larger than the later estimates and this apparent decline raises the question of whether fewer narwhals are using the West Greenland area in recent years due to changes in ice or biotic conditions or if human exploitation is partly responsible for the decline. If the latter is the case the decline may be affecting a subpopulation with philopatry to West Greenland, and exploitation may need to be adjusted to levels that can be sustained by the numbers of narwhals wintering in West Greenland.

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REFERENCES

Anonymous 1998. Physical Environment of Eastern Davis Strait and Northeastern Labrador Sea. Mineral Resources Administration for Greenland. Copenhagen: 34 pp.

Buckland, S.T., Anderson, D.R. and Laake, J. L. 1993. *Distance sampling*. Chapman & Hall, New York: 446 pp.

Burnham, K.P., Anderson, D.R., White, G.C., Brownie, C. and Pollock, K.H. 1987. Design and analysis methods for fish survival experiments based on release-recapture. *Am. Fish. Soc. Monograph* 5.

Butterworth,D.S., Plagányi, É.E. and Geromont, H.F. 2002. Resource assessment and projections for the belugas off West Greenland using the population model of HITTER-FITTER. *NAMMCO Sci. Publ.* 4:211-224.

Dietz, R. and Heide-Jørgensen, M.P. 1995. Movements and swimming speed of narwhals, *Monodon monoceros*, equipped with satellite transmitters in Melville Bay, northwest Greenland. *Can. J. Zool.* 73:2106-2119.

Dietz, R., Heide-Jørgensen, M.P., Richard, P. and Acquarone, M. 2001. Summer and fall movements of Narwhals (*Monodon monoceros*) from Northeastern Baffin Island towards Northern Davis Strait. *Arctic* 54:244-261.

Dorsey, E.M., Richardson, W.J and Würsig, B.. 1989. Factors affecting surfacing, respiration, and dive behaviour of bowhead whales, *Balaena mysticetus*, summering in the Beaufort Sea. *Can. J. Zool.* 67:1801-1815.

Finley, K.J. 1990. Isabella Bay, Baffin Island: an important historical and present-day concentration area for the endangered bowhead whale (*Balaena mysticetus*) of the eastern Canadian Arctic. *Arctic* 43:137-152.

Finley, K.J. and Goodyear, J. D. (MS) 1993. Dive patterns and feeding habitat of the bowhead whale in Baffin Bay. 10th Biennial Conference on the Biology of Marine Mammals, Galveston, Texas, U.S.A., 11-15 November. Abstracts p. 48.

Harwood, L.A., Innes, S., Norton, P. and Kingsley, M.C.S. 1996. Distribution and abundance of beluga whales in the Mackenzie estuary, southeast Beaufort Sea, and west Amundsen Gulf during late July 1992. *Can. J. Fish. Aquat. Sci.* 53:2262-2273.

Heide-Jørgensen, M.P. 1994. Distribution, exploitation and population status of white whales (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) in West Greenland. *Meddr Grønland, Biosci.* 39:135-149.

Heide-Jørgensen, M.P. and Dietz, R. 1995. Some characteristics of narwhal, *Monodon monoceros*, diving behaviour in Baffin Bay. *Can. J. Zool.* 73:2120-2132.

Heide-Jørgensen, M.P. and Reeves, R.R. 1996. Evidence of a decline in beluga, *Delphinapterus leucas*, abundance off West Greenland. *ICES J. Mar. Sci.* 53:61-72.

Heide-Jørgensen, M.P. and Rosing-Asvid, A. 2002. Catch statistics for belugas in West Greenland 1862 to 1999. *NAMMCO Sci. Publ.* 4:127-142.

Heide-Jørgensen, M.P., Lassen, H., Teilmann, J. and Davis, R.A. 1993. An index of the relative abundance of wintering belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, off West Greenland. *Can. J. Fish. Aquat. Sci.* 50:2323-2335.

Heide-Jørgensen, M.P., Richard, P.R. and Rosing-Asvid, A. 1998. Dive patterns of belugas (*Delphinapterus leucas*) in waters near eastern Devon Island. *Arctic* 51:17-26.

Heide-Jørgensen, M.P., Hammeken, N., Dietz, R., Orr, J. and Richard, P. 2001. Surfacing times and dive rates for narwhals (*Monodon monoceros*) and belugas (*Delphinapterus leucas*). *Arctic* 54:284-298.

Heide-Jørgensen, M.P., Laidre, K.L., Wiig, Ø., Jensen, M.V., Dueck, L., Schmidt, H.C. and Hobbs, R.C. In press. From Greenland to Canada in ten days: Tracks of bowhead whales (*Balaena mysticetus*) across Baffin Bay. *Arctic* .

Innes, S. and R.E.A. Stewart. 2002. Population size and yield of Baffin Bay beluga stocks (*Delphinapterus leucas*). *NAMMCO Sci. Publ.* 4:225-238.

Innes, S., Heide-Jørgensen, M.P., Laake, J.L., Laidre, K.L., Cleator, H.J., Richard, P. and Stewart, R.E.A. 2002. Surveys of belugas and narwhals in the Canadian high Arctic in 1996. NAMMCO Sci. Pub. 4:169-190.

Jensen, A.S. 1939. Concerning a change of climate during recent decades in the Arctic and Subarctic regions, from Greenland in the west to Eurasia in the east, and contemporary biological and geophysical changes. *Det Kgl. Danske Videnskabernes Selskab, Biologiske Medd.* XIV, 8; 1-75.

Kapel, F.O. 1977. Catch of belugas, narwhals, and harbour porpoises in Greenland, 1954-75, by year, month and region. *Rep. int. Whal. Commn* 27:507-520.

Koski, W.R. and Davis, R.A. 1994. Distribution and numbers of narwhals (*Monodon monoceros*) in Baffin Bay and Davis Strait. *Meddr Grønland, Biosci.* 39:15-40.

Laake, J.L., Buckland, S.T., Anderson, D.R. and Burnham, K.P. 1993. Distance user's guide. V 2.1. Colorado Cooperative Fish & Wildlife Research Unit Colorado State University, Fort Collins, CO: 84 pp.

Laake, J. 1999. Distance sampling with independent observers: Reducing bias from heterogeneity by weakening the conditional independence assumption. In: Garner, G.W., Amstrup, S.C., Laake, J.L., Manly, B.F.J., McDonal, L.L. and Robertson, D.G. (eds), *Marine Mammal Surveys and Assessment methods*. A.A.Balkema, Rotterdam, Brookfield, pp. 137-148.

Marsh, H. and Sinclair, D.F. 1989. Correcting for visibility bias in strip transect aerial surveys of aquatic fauna. *J. Wildl. Man.* 53:1017-1024.

Mosbech, A. and. Johnson, S.R. 1999. Late winter distribution and abundance of sea-associated birds in south-western Greenland, the Davis Strait, and southern Baffin Bay. *Polar Res.*18 (1):1-17.

Porsild, M. 1918. On'Savssat': a crowding of arctic animals at holes in the sea ice. *Geogr. Rev.* 6:215-228.

Reeves, R.R. and Heide-Jørgensen, M.P. 1996. Recent status of bowhead whales, *Balaena mysticetus*, in the wintering grounds off West Greenland. *Polar Res.* 15:115-125.

Richard, R., Heide-Jørgensen, M.P., Orr, J., Dietz, R. and Smith, T.G. 2001. Summer and autumn movements and habitat use by belugas in the Canadian high Arctic and adjacent areas. *Arctic* 54:207-222.

Siegstad, H. and Heide-Jørgensen, M.P. 1994. Ice entrapments of narwhals (*Monodon monoceros*) and belugas (*Delphinapterus leucas*) in Greenland. *Meddr Grønland, Biosci.* 39:151-160.

Smith, T.G., Hammil, M.O., Burrage, D.J. and Sleno, G.A. 1985. Distribution and abundance of belugas, *Delphinapterus leucas*, and narwhals, *Monodon monoceros*, in the Canadian High Arctic. *Can. J. Fish. Aquat. Sci.* 42:676-684.

Würsig, B. and Clark, C. 1993. Behavior. In Burns, J.J., Montague, J.J. and Cowles, C.J. (eds). *The bowhead whale*. Society for Marine Mammology Special Publication 2, pp. 157-199.

Zeh, J.E., Clark, C.W., George, J.C.,. Withrow, D., Carroll, G.M., Koski, W.R. 1993. Current Population Size. In Burns, J.J., Montague, J.J. and Cowles, C.J. (eds). *The bowhead whale*. Society for Marine Mammology Special Publication 2, pp. 409-489.