Winter abundance of bowhead whales, *Balaena mysticetus*, in the Hudson Strait, March 1981

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ABSTRACT

Satellite tracking studies of bowhead whales (*Balaena mysticetus*) in West Greenland and the eastern Canadian Arctic have documented that Hudson Strait is an important wintering ground for animals summering in the Baffin Bay-Davis Strait area and the Hudson Bay-Foxe Basin area. In light of this new information, data were re-examined on abundance of bowhead whales at this wintering ground derived from a systematic strip census survey conducted in March 1981. Three strata in Hudson Strait were covered by equally spaced north-south transect lines. Most sightings were in the western stratum, with one and none in the central and eastern strata, respectively. Abundance estimates were corrected for whales at the surface missed by observers using data from a similar survey in the Beaufort Sea. Corrections for whales submerged when the survey aircraft passed were developed using new data from time-depth recorders deployed on seven bowhead whales in Disko Bay, West Greenland, in April-May 2002-05. The fully corrected abundance estimate for the Hudson Strait in March 1981 was 1,349 (95% CI 402-4,529) whales. Similar surveys were conducted along West Greenland in March 1981 and 1982; the combined estimate was 1,549 (95% CI 589-4,072). Other unsurveyed areas in Baffin Bay may contribute an additional 8% to this combined estimate. The projected population size for both areas was 3,633 (95% CI 1,382-9,550) in 2004, assuming a population growth rate of 3.4% per year (George *et al*., 2004), which may not be appropriate for this population. However, increased sighting rates and traditional knowledge reports confirm that the population is growing. The use of availability and detection biases together with the restricted seasonal distribution of whales in March makes this the most complete estimate of this population in the 1980s to date.

KEYWORDS: BOWHEAD WHALE; ARCTIC; ABUNDANCE ESTIMATE; HUDSON STRAIT; BAFFIN BAY; SURVEY-AERIAL; BEAUFORT SEA; DISTRIBUTION

INTRODUCTION

The International Whaling Commission has recognised two management stocks of bowhead whales (*Balaena mysticetus*) in the eastern Canadian Arctic and West Greenland (IWC, 1978; 1992): the Baffin Bay-Davis Strait (BB-DS) stock, believed to summer along the east coast of Baffin Island and in the fjords and channels of the Canadian High Arctic; and the Hudson Bay-Foxe Basin (HB-FB) stock, believed to summer in northern Hudson Bay and Foxe Basin and winter in the Hudson Strait. Recent results from studies of bowhead whales equipped with satellite transmitters suggest that both putative stocks overwinter in the Hudson Strait (Heide-Jørgensen *et al.*, 2006). Furthermore, satellite tracking of bowhead whales in Foxe Basin also indicates a shared summering area in the Prince Regent Inlet with whales from Baffin Bay (Dueck *et al.*, 2006). These two new pieces of evidence cast doubt over the current concept of two separate populations of bowhead whales.

Animals in the BB-DS area were severely reduced by commercial whaling between the early 1700s and the early 1900s from an estimated unexploited abundance of no less than 12,000 (Ross, 1993; Woodby and Botkin, 1993); after the cessation of whaling in 1915, their abundance was unknown (Ross, 1993). A population estimate from the mid 1980s suggested that the BB-DS animals numbered at least 350 (Zeh *et al.*, 1993) and therefore were still severely below the pre-whaling size. Local knowledge (NWMB, 2000) suggests that bowhead whale numbers have been increasing in recent years.

The majority of the available information on the winter distribution of bowhead whales in the Hudson Bay-Baffin Bay region has been obtained from whaling records drafted in the late 1800s and early 1900s, i.e. towards the end of the exploitation period (Ross, 1993). Based on these records, bowhead whales were noted to winter in two areas: (1) along the coast of West Greenland north to Disko Island; and (2) in Hudson Strait (Eschricht and Reinhardt, 1861; Brown, 1868; Low, 1906). Aerial surveys conducted over the past 20 years along the coast of West Greenland in March have detected a consistent, but low number of bowhead whales during winter (Born and Heide-Jørgensen, 1983; Reeves and Heide-Jørgensen, 1996; Heide-Jørgensen and Acquarone, 2002). Estimated bowhead whale abundance (corrected for submergence) in West Greenland in 1998 was 246 whales (95% CI 62-978, Heide-Jørgensen and Acquarone, 2002). A few bowhead whales were sighted in winter along the pack ice edge in Davis Strait but these were probably whales *en route* to West Greenland. Many bowhead whales were caught on the 'sou'west fishing grounds' along the edge of the pack ice off Cumberland Sound as early as March (Brown, 1868; Kumlien, 1879; Lubbock, 1937), but lack of catches in mid-winter suggest that those whales may have been early migrants from wintering areas in Hudson Strait (Anderson, 1934).

During the whaling era, the HB-FB population was also reduced from an unknown initial population of at least 580 animals (Mitchell, 1977, as modified by Woodby and Botkin, 1993). In 1995, the HB-FB population was estimated to be about 345 animals (DFO, 1999) based on surveys conducted by Cosens *et al.* (1997) and Cosens and

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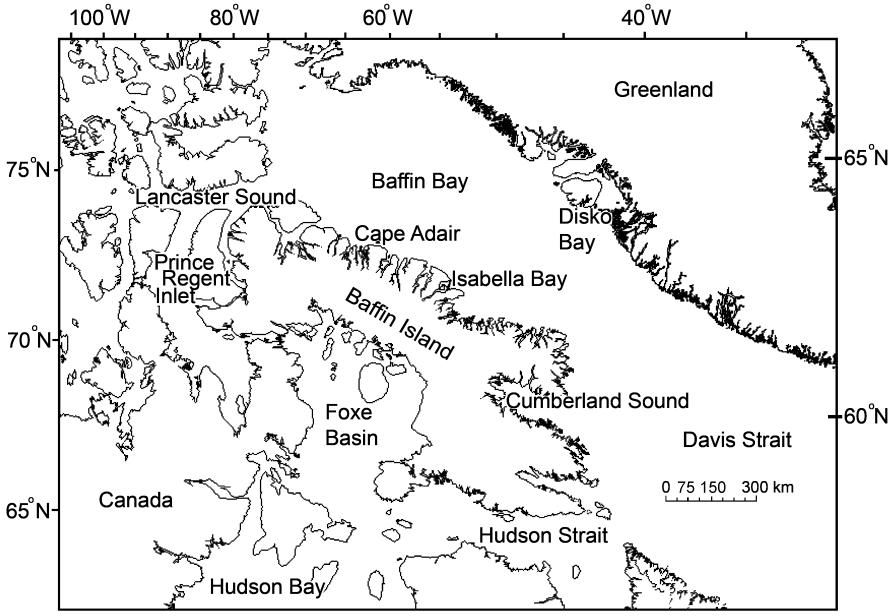

Fig. 1. Map of area and localities mentioned in text.

Innes (2000). This was probably a considerable underestimate since the estimate did not include a correction for animals below the water surface at the time of the survey.

Estimates of the winter abundance of bowhead whales in Hudson Strait in 1981 are presented in this paper. Although the survey was carried out some 25 years ago, it is the only survey undertaken in this area at this time of the year, recently recognised to be an important wintering ground for bowhead whales for animals from both the HB-FB and BB-DS areas (Heide-Jørgensen *et al.*, 2006). Consequently abundance estimates from 1981 are relevant to management decisions and population projections.

MATERIALS AND METHODS

Survey procedures

Systematic aerial surveys of wintering bowhead whales were conducted in Hudson Strait from 14-30 March 1981 (Fig. 1). The surveys were conducted in a deHavilland Twin Otter at a target altitude of 150m. Survey speed averaged 259km h^{-1}. Three observers were present and recorded sightings of bowhead whales. Sightings within 100-800m on either side of the aircraft were considered 'on transect' and those >800 or 0-100m from the centre line were considered 'off transect' and were not included in the density estimation. The inner and outer transect boundaries were marked on the wing struts and windows with tape. Bowhead sightings were circled to confirm species identification and group size. Sightings and effort within 100m of the centre line were excluded because visibility was seriously impaired in the Twin Otter with standard flat windows (see Thomas *et al.*, 2002). The Twin Otter was equipped with a VLF navigation system that determined aircraft position and a radar altimeter that assisted in maintaining the target altitude.

North-South transect lines were evenly distributed at 1° longitude (approx. 26km apart) from eastern Hudson Bay through Hudson Strait to the northern Labrador Sea (Fig. 2). The total study area was ~216,613km^2. Hudson Strait was divided into three strata of similar size; western, central and eastern. The survey area and transect lengths were estimated using a geographic information system and whale densities were extrapolated to the area of the strata.

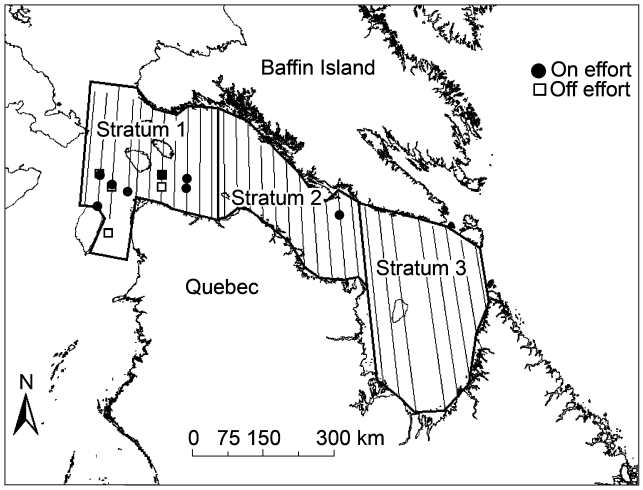

Fig. 2. Survey effort, location of bowhead sightings and stratification of the survey conducted in March 1981.

Correcting for perception and availability bias

Visual observers miss animals at the surface because of the difficulty of detecting whales among ice floes, simultaneous surfacing of several animals, sun glare impeding visibility or observer fatigue (Marsh and Sinclair, 1989). No survey specific correction factors for this perception bias were available from the original survey. Instead values were obtained from a recent double observer experiment on bowhead whales in the Beaufort Sea using a similar aircraft including one or sometimes both of the primary observers from the original survey (Thomas *et al.*, 2002).

The proportion of time that whales were at the surface and visible to observers was estimated using data on bowhead whale surface times from time-depth-recorders deployed on seven whales in May 2002 and 2003 and April 2005 in Disko Bay, West Greenland. The instruments were MK9 time-depth recorders (Wildlife Computers, Redmond, Washington, USA) mounted on a float tethered to the whale. The float had an additional two instruments used for tag recovery: a satellite transmitter for coarse positioning and a VHF transmitter for fine-scale positioning. The floats were attached to the whales with a harpoon head pushed under the

Table 1

Summary statistics for aerial surveys conducted during March 1981 in Hudson Strait. Strip width was 1,400m and numbers in parentheses are coefficients of variation (*CV*). Corrected density and abundance of whales includes correction factors for availability and perception bias (see text).

Stratum	Study area (km^2)	No. of transect lines	Survey effort (km)	No. of sightings on/off	Mean group size	Density of whales (no. km^2)	Corrected density of whales (no. km^2)	Corrected abundance of whales
1. Western Hudson Strait	72,688	11	2,346	8/7	1.25 (0.13)	0.003 (0.47)	0.02 (0.56)	1,236 (0.56)
2. Central Hudson Strait	55,713	11	1,960	1/0	1	0.0004 (0.99)	0.002 (1.03)	113 (1.03)
3. Ungava Bay and eastern Hudson Strait	88,211	8	2,531	0/0	0	0	0	0
Total	216,613	30	6,837	9/7				1,349 (0.60)

skin with an 8m long fibreglass pole. The float was released from the whale within 24h with a corrosive magnesium bolt. Processing of dive data included zero-offset correction using *Instrument Helper* (Wildlife Computers).

Sea ice concentration data for March 1981 were obtained from passive microwave telemetry (the Nimbus-7 Scanning Multichannel Microwave Radiometer) from the National Snow and Ice Data Center (NSIDC). Sea ice concentration (1% resolution) was derived using the bootstrap algorithm following the procedure of Comiso (1995), where daily sea ice concentrations were mapped to a polar stereographic projection (true at 70°N) at a 25km resolution. Sea ice data obtained from the NSIDC were converted from raw binary to ASCII format using a program written in Compaq Visual Fortran 90 and imported into a geographic information system (*ESRI ArcINFO 8.3*) as raster grids.

All estimates are presented with CV calculated as a standard error in proportion to the mean and 95% confidence intervals were constructed assuming a log-normal distribution of whale densities (see Burnham *et al.*, 1987).

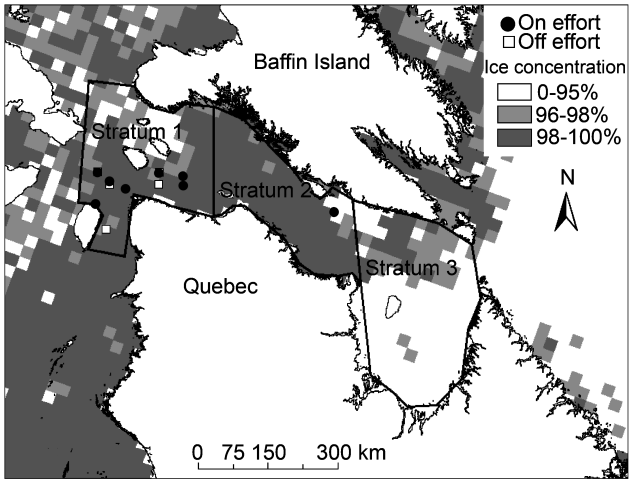

Fig. 3. Sightings of bowhead whales made on and off effort 14-30 March 1981 and SSMR/SSMI sea ice concentrations in 25 sq km pixels from 14 March 1981.

RESULTS

During the course of 6,837 linear km of survey, 16 separate sightings of 29 bowhead whales were obtained (Table 1; Fig. 2). Seven of these sightings were off transect (either outside the width of the census strip or during off-effort periods). The average group size of all sightings was 1.8 (range 1–7; SD 1.5). All sightings of bowhead whales were in >95% ice concentration even though areas with a larger fraction of open water were available (Fig. 3).

Despite evenly distributed survey effort across all three strata, all but one (in central Hudson Strait) sighting occurred in western Hudson Strait; no bowhead whales were observed in eastern Hudson Strait or Ungava Bay. The uncorrected density of bowhead whales in western and central Hudson Strait was 0.003 and 0.0004 bowhead whales km^{-2}, respectively (Table 1).

Since the speed of the survey platform was relatively rapid (approx. 40ms^{-1}) relative to the dive cycle of bowhead whales (most dives last more than 1min), it was assumed that no repeat sightings of the same whale were made. It was also assumed that the area searched by the observers represented a snapshot of the availability of whales. Thomas *et al.* (2002) estimated that the perception bias for a single set of visual observers flying a bowhead whale survey in a Twin Otter in the Beaufort Sea was 0.59 (CV=0.27). This value was applied to this study and used to correct for sightings missed by the observers.

Dive data collected from seven bowhead whales instrumented with time-depth recorders were used to calculate the fraction of time whales spent at the surface and estimate an availability bias across a range of depths (1-5m). The seven individuals spent, on average, 30.4% of their time (SD=1.0%) at =2m, probably the deepest depth at which bowhead whales are seen during surveys. This fraction varied widely with the selection of 'surface depth' mainly due to large differences in whale diving behaviour (Laidre, unpublished data). However for the case of surface time calculations, the selection of 2m provided an estimate with relatively low variability (Table 2).

The perception and availability biases were combined to derive an estimate of an overall correction factor useful for correcting the abundance estimate for animals missed within the survey strip. The combined values for the perception bias ($\hat{p}$=0.59, CV=0.27) and the availability bias (a=0.30,

Table 2

Surface times from 7 whales instrumented with time-depth recorders in Disko Bay, West Greenland, May 2002 and 2003 and April 2005. Proportion of time at the surface is indicated for 5 different depths (1-5m) where bowhead whales could be seen from the air.

Whale ID	Date tagged	Sample size (hr, min)	1m	2m	3m	4m	5m
02-01	5/5/02	2, 20	0.232	0.250	0.259	0.269	0.283
02-02	5/8/02	10, 12	0.193	0.371	0.523	0.653	0.718
02-03	5/12/02	12, 48	0.274	0.371	0.523	0.653	0.718
03-01	5/17/03	7, 50	0.383	0.470	0.501	0.520	0.530
03-02	5/18/03	8, 46	0.220	0.234	0.241	0.243	0.264
05-01	4/22/05	53, 5	0.171	0.201	0.228	0.242	0.257
05-02	4/23/05	20, 31	0.208	0.228	0.238	0.243	0.246
Mean (SD)			0.240 (0.071)	0.304 (0.101)	0.359 (0.147)	0.403 (0.197)	0.431 (0.219)

CV=0.13) resulted in an estimate of the overall correction factor of 0.18 with CV=0.30. Abundance estimates for bowhead whales corrected for both perception and availability bias were thus 1,236 (CV=0.56) in western Hudson Strait, 113 (CV=1.03) in central Hudson Strait, and 0 in eastern Hudson Strait (Table 1). This resulted in a total abundance of 1,349 (CV=0.60, 95% CI 402-4,529) whales for the entire survey region in March 1981.

DISCUSSION

The presence of a substantial number of bowhead whales in northeast Hudson Bay and western Hudson Strait in March, together with recent satellite tracking results documenting that whales arrive in Hudson Strait in November (Heide-Jørgensen *et al.*, 2006), indicate this is an important wintering area used by bowhead whales. The whales found in this area are probably the same whales that summer in Hudson Bay, Foxe Basin, Lancaster Sound and adjacent fjords and along the east coast of Baffin Island. Satellite tracking studies have documented the movement of animals into this area from all of these summer localities (Heide-Jørgensen *et al.*, 2006; Dueck *et al.*, 2006).

Coincident with the 6,837km survey reported here about 20,650km of surveys in other potential bowhead whale wintering habitat were conducted in northern Hudson Bay (including Roes Welcome Sound), off the Labrador coast, off SE Baffin Island, and over the pack-ice and open-water areas in southern Baffin Bay and northern Davis Strait during March and early April (see Koski and Davis (1994) for survey coverage in these areas). Only seven bowhead whales (including off effort sightings) were seen outside of the Hudson Strait and four of those were off West Greenland, in the area identified by Reeves and Heide-Jørgensen (1996) as a bowhead whale wintering area. Thus, 33 of 36 bowheads (92%, including off effort sightings) recorded during the late winter surveys in 1981 were either in Hudson Strait or off West Greenland, providing even further support that these two areas are the major wintering grounds.

The abundance estimate of 1,349 (CV=0.60) whales for Hudson Strait thus represents a major proportion of the population size in 1981. The average abundance estimate of bowhead whales wintering off West Greenland in 1981 and 1982 reported by Reeves and Heide-Jørgensen (1996) was 36 (95% CI 24-54), and if this estimate is corrected for the same availability and detectability biases as in Hudson Strait the resulting abundance in West Greenland would be 200 whales (95% CI 100-401). If these estimates are combined (West Greenland and Hudson Strait) then 1,549 bowhead whales (95% CI 589-4,072) were present in the northwestern Atlantic in 1982. This combined estimate does not incorporate the abundance contributed by the 8% additional bowhead whales sighted outside of these two localities or whales present in areas not covered during surveys such as the North Water polynya. Richard *et al.* (1998) surveyed the North Water polynya in March 1991 and sighted two bowhead whales, but surveys by Finley and Renaud (1980) in the same area in 1978 and 1979 did not find any, suggesting that although bowhead whales occur in the area it may not support a high abundance.

The most recent estimate of the summer abundance of bowhead whales in BB-DS (based on data collected in the late 1970s and mid-1980s) suggested that the BB-DS population was at least 350 animals (Zeh *et al.*, 1993). This estimate was obtained from a mark-recapture study of photographically identified whales in Isabella Bay in 1986-87, a late summer concentration area on the east coast of Baffin Island, plus an estimate of the number of bowheads that migrated past Cape Adair during late September to early October 1978 and 1979 (Davis and Koski, 1980). Zeh *et al.* (1993) noted that the Isabella Bay estimate included only 'marked whales' and was therefore a minimum estimate; however most whales seen in Isabella Bay are large well-marked animals so this negative bias may be small. In addition, it is highly likely that some bowhead whales migrated south after shore-based observations at Cape Adair ended because whales were observed on the last survey days in both 1978 and 1979. Satellite tracking results show that some bowhead whales do not enter Isabella Bay, and instead migrate past Cape Adair in late October (the period after the Davis and Koski (1980) surveys were completed), confirming as Zeh *et al.* (1993) noted, that their abundance estimate is negatively biased.

The HB-FB summer abundance of bowhead whales was estimated to be about 345 whales in 1995 based on aerial surveys partially covering the summer range (Cosens *et al.*, 1997; Cosens and Innes, 2000). However, large areas of potential summer distribution of bowhead whales were not surveyed and no complete estimate of summer abundance could be calculated. In addition, the HB-FB estimate did not include correction factors for availability bias at the time of the survey. When the negative biases associated with the mid-1980s BB–DS estimate and mid-1990s HB-FB estimate are considered, the combined estimates may not be significantly different from the estimate obtained from this study. However, the estimate presented here accounts for potential biases more completely than other presently available estimates.

Potential biases in this study result from lack of site-specific data on perception and availability bias. There is also a lack of data on the population growth rate if population projections are used to estimate current abundance. Bowhead whales missed by observers were corrected based on data from a summer survey in the Beaufort Sea using some of the same observers, the same type of aircraft and the same flying altitude. It is uncertain as to what extent this correction factor is applicable to the 1981 Hudson Strait survey; however, they are the best available data. It should be noted that a survey for white whales (*Delphinapterus leucas*) in West Greenland estimated a perception bias of the same magnitude (Heide-Jørgensen and Acquarone, 2002).

The corrections for availability bias for whales submerged below 2m were derived from time-depth-recorders deployed in April-May in West Greenland. It can be argued that this correction factor might differ for bowhead whales in Hudson Strait in March. However, the fraction of time near the surface (~30%) is similar to that reported for bowhead whales based on satellite-linked time depth recorders from other areas (Heide-Jørgensen *et al.*, 2003) and that reported for white whales and narwhals (*Monodon monoceros*; Heide-Jørgensen *et al.*, 2001; Heide-Jørgensen and Acquarone, 2002; Laidre *et al.*, 2002), although it is lower than for bowhead whales on their summer feeding grounds (Thomas *et al.*, 2002).

Bowhead whales observed during this survey were found in the heaviest pack ice in Hudson Strait and are apparently capable of wintering in dense ice conditions in other areas as well, including Hudson Bay and Baffin Bay (cf. Heide-Jørgensen and Laidre, 2004). The occurrence of bowhead whales in such severe pack ice in Hudson Strait may also explain why 19th century whalers did not realise this was a major concentration area for bowhead whales.

Local and traditional knowledge suggests that the bowhead whale population around Baffin Island and in West Greenland is increasing (NWMB, 2000; Heide-Jørgensen, unpubl. data). Beginning with the 1981-82 combined estimate, adding 8% for whales outside the surveyed area and assuming the central population growth rate of 3.4% per year until 2004 (George *et al*., 2004) results in a projected population size of 3,633 (95% CI 1,382-9,550) whales present in Hudson Strait and West Greenland in 2004. The use of the growth rate from the Bering-Chukchi-Beaufort Seas Stock may be too high, as it probably represents the maximum potential growth rate of the population. However, several other depleted populations of large cetaceans have demonstrated clear recoveries with growth rates in the same magnitude after a period of protection (Best *et al*., 2001; Stevick *et al*., 2003).

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