Chukotka Peninsula counts and estimates of the number of migrating bowhead whales (*Balaena mysticetus*)

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ABSTRACT

In May and June 2000-01, shore-based counts of migrating bowhead whales (*Balaena mysticetus*) were conducted from Cape Pe'ek on the Chukotka Peninsula, Russia. These counts, designed to permit estimation of the number of whales migrating past Cape Pe'ek from mid-May to mid-June, were similar to those of bowhead whales migrating past Barrow, Alaska and of gray whales migrating past Granite Canyon, near Monterey, California, except that no experiments designed for estimating detection probabilities P were conducted at Cape Pe'ek. Under the assumption that P=1 (all whales passing during watch with acceptable visibility conditions were seen), the estimated number of migrating bowheads was 430 (CV 22%) in 2000 and 558 (CV 31%) in 2001. The weighted geometric mean of these estimates is 470 with 95% confidence interval 332-665. If P was assumed to be similar to the detection probabilities estimated from the Barrow bowhead count or the Granite Canyon gray whale count, the weighted geometric mean estimate was approximately twice as large. Of at least 94 bowhead whales seen from Cape Pe'ek in June of 2001, at most one could have been among those counted by the survey near Barrow that year.

KEYWORDS: ABUNDANCE ESTIMATE; BERING SEA; BOWHEAD WHALE; MIGRATION; SURVEY-SHORE-BASED

INTRODUCTION

It has been known for some time (e.g. Bogoslovskaya *et al*., 1982) that bowhead whales (*Balaena mysticetus*) can be found around the Chukotka Peninsula in summer and early autumn. To better quantify sighting records, a new programme began in 1990 using shore-based observations of bowhead whales from capes of Chukotka. Melnikov *et al*. (1998) summarised summer and early autumn sightings made between 1990 and 1996, as well as earlier sightings reported in the literature. It is not known whether bowhead whales seen off Chukotka spend all or part of some summers in the Beaufort Sea or, alternatively, represent a separate feeding aggregation that does not go there. It is also not known whether these whales mix with the rest of the Bering-Chukchi-Beaufort Seas stock during the breeding season or, alternatively, represent a separate biological stock.

Bowhead whales are subject to a subsistence hunt by Russian and Alaskan Eskimos. For example, during the period 2001-05, the average number of bowhead whales struck and killed per year in the Russian hunt was around two and around 51 per year in the Alaskan hunt. Since 2002, the International Whaling Commission Scientific Committee (IWC SC) has provided advice to the Commission on the maximum number of strikes that should be allowed using a Strike Limit Algorithm, the *Bowhead SLA* (IWC, 2003, pp.19-23). The *Bowhead SLA* was developed and tested under the assumption that there is a single Bering-Chukchi-Beaufort (B-C-B) Seas stock of bowhead whales (Rugh *et al*., 2003). If the whales found around the Chukotka Peninsula in summer could represent a separate population, precautionary management requires that the *Bowhead SLA* be tested under two-stock scenarios to determine whether the catches set by the *SLA* are sustainable for both populations. A key piece of information needed for designing plausible two-stock *SLA* trials is an estimate of the abundance of the population around Chukotka, if indeed it is a separate population.

In May and June 1999-2001, shore-based counts of migrating bowhead whales were conducted in the Cape Dezhnev area of the Chukotka Peninsula. The objective of these surveys was to count whales migrating from the Bering Sea through the western Bering Strait into the Chukchi Sea from an observation post in the Cape Dezhnev area (Melnikov *et al*., 2004, p.291). The effort conducted in 1999 was treated as a feasibility study, and the counts from Cape Pe'ek in 2000 and 2001 were used to estimate the number of whales migrating through the viewing area in the Bering Strait. The Cape Pe'ek surveys were similar to those of bowhead whales near Barrow, Alaska (George *et al*., 2004) and of gray whales (*Eschrichtius robustus*) near Monterey, California (Buckland *et al*., 1993; Hobbs *et al*., 2004; Rugh *et al*., 1993) except that no experiments designed for estimating detection probabilities were conducted at Cape Pe'ek, and the Cape Pe'ek observation perch was higher above sea level (around 65m, making it possible to see whales at ranges exceeding 20km when visibility conditions were adequate) than the sites at Point Barrow (<16m) or in California (22m).

METHODS

In general, three teams of two observers stood watch twice a day for 4h, covering 20-24h per day. Observers used binoculars with built-in magnetic compasses and with vertical and horizontal scales so that bearing and range could be estimated. When a bowhead whale sighting was made, the time, compass information and number of whales were recorded. The whales were scored as new (N=not previously recorded), conditional (C=status uncertain) or duplicate (D=previously recorded) based on the observers' judgment. Information on whale behaviour and environmental variables were also recorded. Visibility, a key environmental variable, was coded on the same scale – excellent (EX), very good (VG), good (G), fair (F), poor (P), unacceptable (UN) – used by George *et al*. (2004) and Hobbs *et al*. (2004).

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Range R from the observation perch to a whale was estimated as

$$R = (\ \arcsin[\ \sin(\pi/2 - \theta) \times (r_3 + h) / r_3\ ] - (\pi/2 - \theta)\ ) \times r_3$$

where r_3 = radius of the earth = 6,371,200m, h = height (m) of the observation perch and θ = angle in radians from the horizon to the target. This method, equivalent to that of Lerczak and Hobbs (1998), takes account of the curvature of the earth. This expression for R is only usable when $\theta = \geq 0.0046$ radians, so θ was replaced by max(0.0046, θ) in our calculations. Therefore all whales with $R > 18.2$km were estimated to have $R = 23.8$km.

The geographic coordinates of the observation stations were determined using a Global Positioning System (GPS). Based on the azimuth and the distance to the whale from the observation station, the whale's coordinates were calculated (Fig. 1).

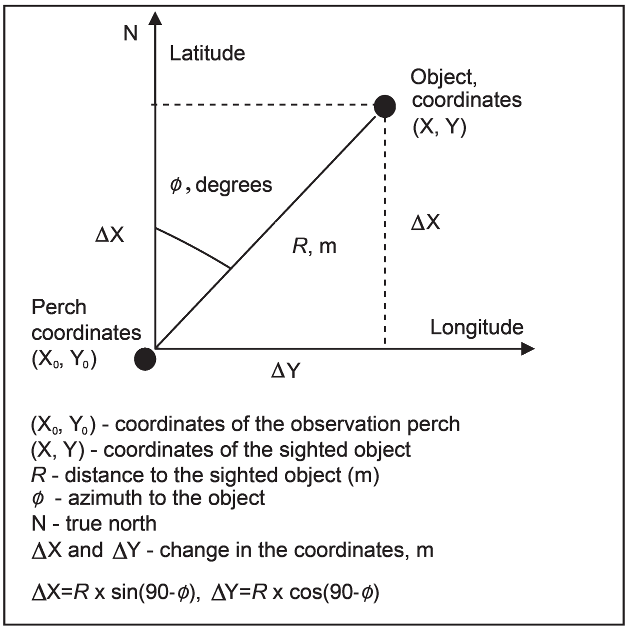

Fig. 1. Method for determining the geographic coordinates of the whales' surfacings.

To convert from the metric system to the geographic coordinate system, it was assumed that 1 nautical mile (1,863m) equals 1 longitudinal minute. The equivalent in degrees of 1m on the earth's surface was determined to be:

$$\text{for latitude : } 1\text{m} = \frac{1°}{60 \times 1{,}863} = k_X\ ,$$

$$\text{for longitude: } 1\text{m} = \frac{180°}{\pi \times r_3 \times \sin\left(90° - \alpha\right)} = k_Y\ ,$$

where: r_3 = the earth's radius (6,371,200m);
α = latitude of the observation station.

The coordinates of the sighted object are calculated from the formulae:

$$X = X_0 + R \times \sin(90\text{-}\phi) 3\ k_X$$
$$Y = Y_0 + R \times \cos(90\text{-}\phi) 3\ k_Y$$

For graphic mapping of the calculated coordinates of the animal's position and for simplifying how they are used in a Geographic Information System, GIS (e.g. *ArcView* 3.2a), a conversion was made to the geographic coordinates system. In doing so, it was assumed that along the entire extent of the route, the angle formed by the direction to the magnetic pole and the latitude equaled 102° taking into account magnetic declination there at that time was 12°10'E.

Both bowhead and gray whales were seen during the counts. In most cases, distinguishing between whale species was not difficult, because gray whales migrate along the edge of the shorefast ice, much closer to shore than bowhead whales. However, very occasionally gray whales migrate far offshore, too. These cases cause difficulties. When gray whales migrate far offshore, reliable signs are the fluke when gray whales dive and short dive times (2-4min). Bowhead whale dive times are 15-20min. Any sightings that could not be unambiguously identified to species using these behavioural differences were eliminated from the bowhead datasets for 2000 and 2001. Our knowledge of bowhead whale diving behaviour was also used to avoid counting the same whale more than once.

Whales per sighting was estimated as (number recorded)/(detection probability, P). The primary analyses assumed P=1 (all whales passing during watch under EX-F conditions were seen) because the Cape Pe'ek surveys did not collect data that could be used to estimate P. The effects of assuming that P was similar to the bowhead detection probabilities of Zeh and Punt (2005) or the gray whale detection probabilities used by Buckland *et al*. (1993) were also explored; see Melnikov and Zeh (2006) for details. Although detection probabilities from these surveys clearly cannot be assumed to apply to the Cape Pe'ek surveys, they indicate what the numbers of migrating whales might be if detection probabilities at Cape Pe'ek are more like those of similar surveys than like P=1.

Methods of estimating the number of migrating whales from the Cape Pe'ek data and the assumptions on which the methods were based were similar to those used to estimate the number of bowhead whales passing Barrow. The migration period at Cape Pe'ek was assumed to extend from the first day a bowhead whale was seen, through to the last day a bowhead whale was seen in each year. Whales were assumed to migrate continuously throughout this period, regardless of weather, time of day and whether or not observers were counting them. Days were defined as 'watched' if observers counted for more than 2h with EX-F visibility and 'unwatched' otherwise. The estimate for a watched day is

$$(N + C/2) \times 1{,}440/(\text{watched minutes})$$

where N and C are the total whales/sighting summed over sightings scored as N and C, respectively. Watched minutes are those with EX-F visibility and 1,440 is the number of minutes in a day. Following Zeh *et al*. (1986) and Rugh *et al*. (1993), minutes with watch when visibility was P or UN were treated as unwatched and the single bowhead whale sighting under P visibility conditions each year was not included in N.

The season total estimate for each year is the sum of the daily estimates over all the days in the migration period, with a mean estimate used for the unwatched days. The mean estimate is:

$$1{,}440 \times (\Sigma N + 0.5 \times \Sigma C) / (\Sigma \text{ watched minutes})$$

where the sums are over all watched minutes, even those on days defined as unwatched. In other words, it was assumed that the mean whales per watched minute over the season provides the best estimate of the mean on an unwatched day. A jackknife on watched days provides the standard error

(SE) for the season total estimate. When each watched day was left out during the jackknife computations, it was treated as if there were no watched minutes on that day, and watched minutes and whale counts on that day were omitted from the mean estimate used for it and other unwatched days. Confidence intervals (CIs) were computed as recommended by Buckland (1992).

A weighted average of the 2000 and 2001 season total estimates, T, was computed on a log scale to give the two years more equal weight; the coefficients of variation (CVs) of the season total estimates were more constant than the SEs. $CV^2(T)$ estimates var [log(T)], where log is the natural logarithm. Thus the weighted geometric mean estimate is:

$$\exp(\,[\log(T_{2000}) / CV^2(T_{2000}) + \log(T_{2001}) / CV^2(T_{2001})] \,/\, [1 / CV^2(T_{2000}) + 1 / CV^2(T_{2001})]\,).$$

An unweighted geometric mean was also computed.

RESULTS

Fig. 2 shows Cape Pe'ek, as well as the villages on the Chukotka Peninsula and along the coast of Alaska where whales may be taken. Fig. 3 shows the locations of the whales seen in 2000 and Fig. 4 shows the locations of the whales seen in 2001.

The observed migration period in 2000 was 31 days long (14 May-13 June) with 18 (58%) watched days. During this period, 155 N whales and no C whales were seen. The observed migration period in 2001 was 24 days long (23 May-15 June) with 14 (58%) watched days. During this period, 148 N whales and 26 C whales were seen. In 2001, watches began on 20 May and continued until 17 June, but visibility was predominantly P or UN and no bowhead whales were seen on the days before 23 May or after 15 June. See Melnikov *et al.* (2004) for more detailed information regarding visibility conditions by day throughout the surveys in 2000 and 2001. Each watched day in both years had at least 300 watched minutes (5h).

Estimation results by year are summarised in Table 1. Fig. 5 shows the daily estimates that were summed to obtain the season total estimates in Table 1. In each plot of this figure, a horizontal line shows the value used for unwatched days. The estimated number of bowhead whales migrating past Cape Pe'ek in 2000 is 430 (CV 22%, 95% CI 280 to 660) compared to 558 (CV 31%, 95% CI 310 to 1,010) in 2001. Weighted and unweighted geometric means of the 2000 and 2001 results are also given in Table 1, with the SE, CV and 95% CI. The weighted geometric mean estimate is 470 with a 95% CI of 332-665.

The 2000 and 2001 estimates do not differ significantly, but the 2000 estimate is lower. Visibility scores were somewhat better in 2000 than in 2001: 53.2% *vs* 59.3% of hours during the count scored as P or UN (Melnikov *et al.*, 2004); 88% *vs* 79% of sightings made under G, VG or EX visibility conditions. However, wind speeds were higher in 2000 (>5m s^{21} for 21% of the sightings, compared to 1% in

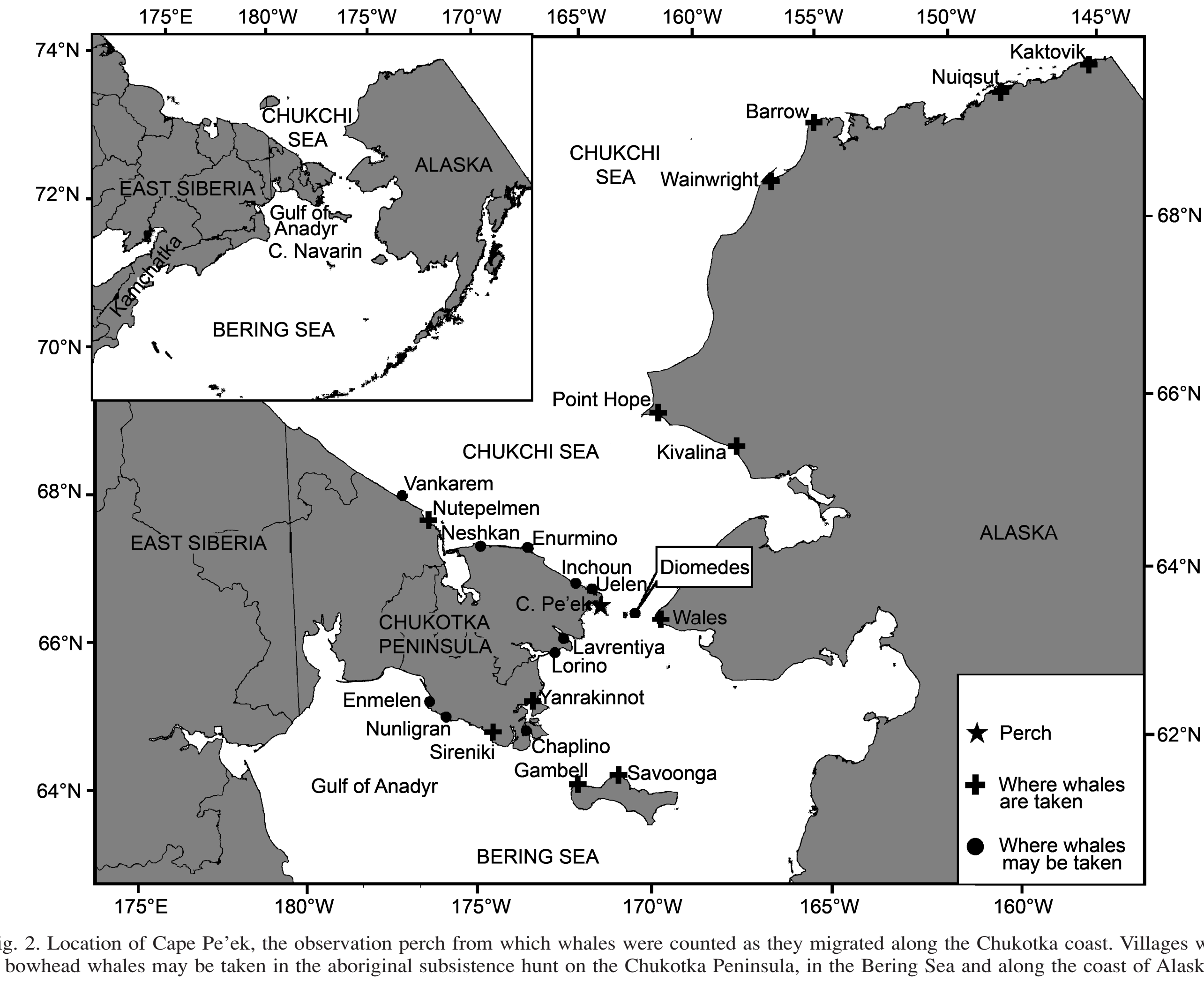

Fig. 2. Location of Cape Pe'ek, the observation perch from which whales were counted as they migrated along the Chukotka coast. Villages where bowhead whales may be taken in the aboriginal subsistence hunt on the Chukotka Peninsula, in the Bering Sea and along the coast of Alaska are also shown.

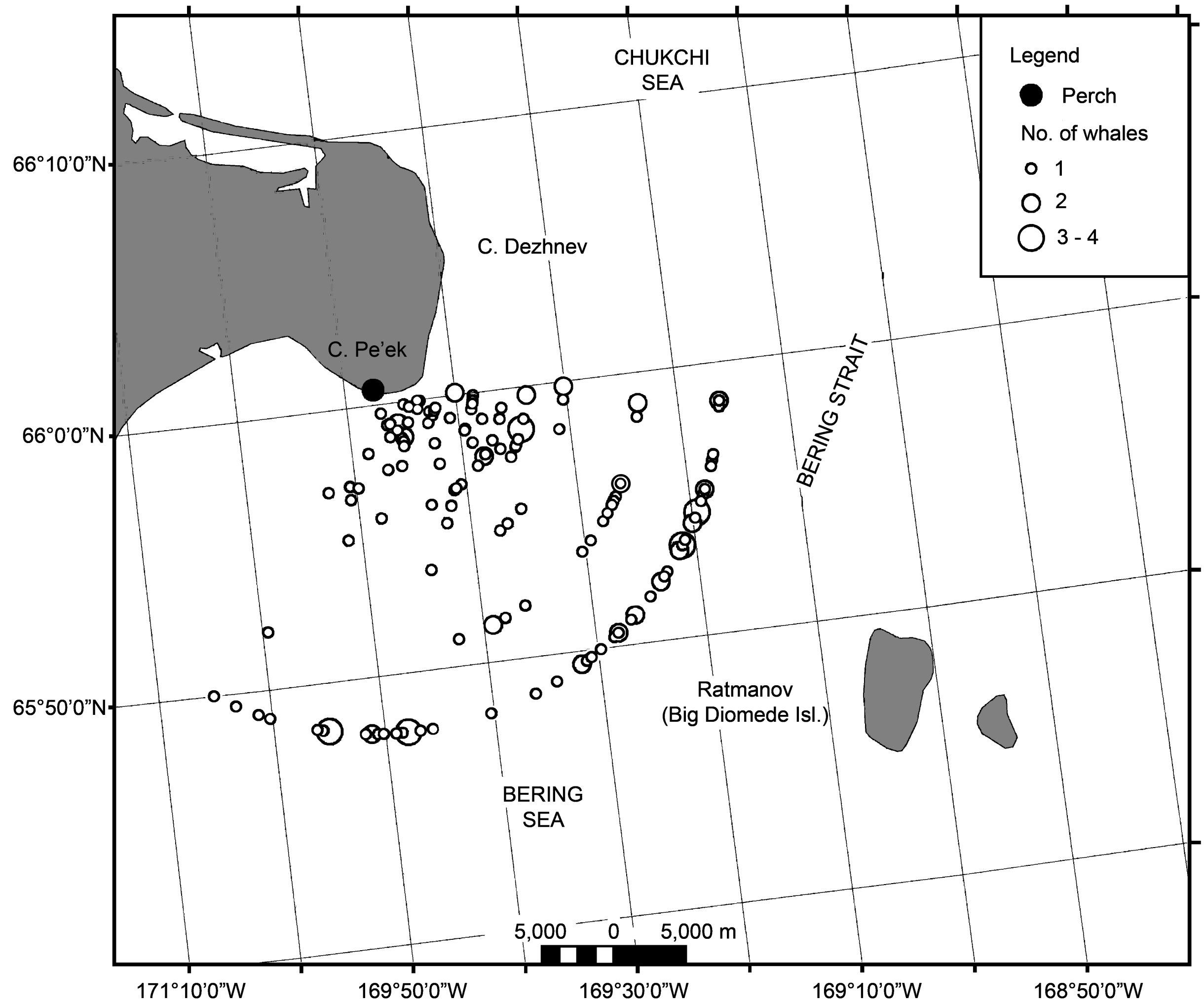

Fig. 3. Locations where bowhead whales were seen during the Cape Pe'ek count in 2000. Only the first sighting of each whale is shown.

2001.) Slightly more sightings (60%) were beyond 10km in 2000 than in 2001 (56%). However, 42% of the days in both 2000 and 2001 were unwatched, so it is likely that the difference between the estimates is mainly a function of the rate of whale passage on days when visibility was too poor to permit effective watches.

DISCUSSION

Estimates based on the assumption that detection probability P=1 are almost certainly negatively biased. Melnikov *et al.* (2004) noted that bowhead whales migrating past Cape Pe'ek appeared to be spread somewhat evenly over the 40km distance between Cape Pe'ek and Ratmanov (Big Diomede) Island, with over half of the whales sighted at distances exceeding 10km. This is quite different from the situation at Point Barrow, where bowhead whales are generally constrained by ice conditions to be closer to the observation perches. Only when visibility was excellent was it possible to see Ratmanov Island from Cape Pe'ek, so an unknown number of whales migrating far offshore were obviously missed when visibility was less than excellent. If P based on the bowhead whale detection probabilities of Zeh and Punt (2005) is used, computed as described by Melnikov and Zeh (2006), the weighted geometric mean estimate is 943 (compared to 470 when P=1) with SE=155 and a 95% CI of 680-1,300. This CI does not overlap the one shown in Table 1 for the weighted geometric mean when P=1 is assumed. Using P based on the gray whale detection probabilities of Buckland *et al.* (1993), the weighted geometric mean estimate is 826 with SE=138 and 95% CI from 600 to 1,140. Here the CI does overlap the one in Table 1, perhaps because the gray whale detection probabilities do not involve distance offshore.

Evidence that distant whales can be missed by counts like the one conducted at Cape Pe'ek is provided by Rugh and Cubbage (1980). They counted bowhead whales from sites 100-281m high on a bluff near Cape Lisburne, Alaska, during the spring migration of 1978. The whales passed at an average distance of 4.5km, and the maximum distance recorded was 14.8km based on a theodolite with angular precision to 20". During the spring migration of 1978, whales were also being counted at Point Barrow (Braham *et al.*, 1979). If hourly rates for each day computed from the Point Barrow counts are compared to the hourly rates tabled by Rugh and Cubbage (1980), 25% of the days at Point Barrow have higher rates than the maximum rate recorded at Cape Lisburne. A total of 1,394 N and 216 C whales were counted from South Perch at Point Barrow in 1978, compared to 280 whales categorised as either N or C at Cape Lisburne. In other words, many more whales were missed at Cape Lisburne than at Point Barrow. According to Rugh and Cubbage (1980), 14.8km 'approaches the outer limit of reliable visibility under excellent conditions.' It is likely that their distances were computed as $h \times \tan(\pi/2 - \theta)$ and did not incorporate a correction for curvature of the earth. Had

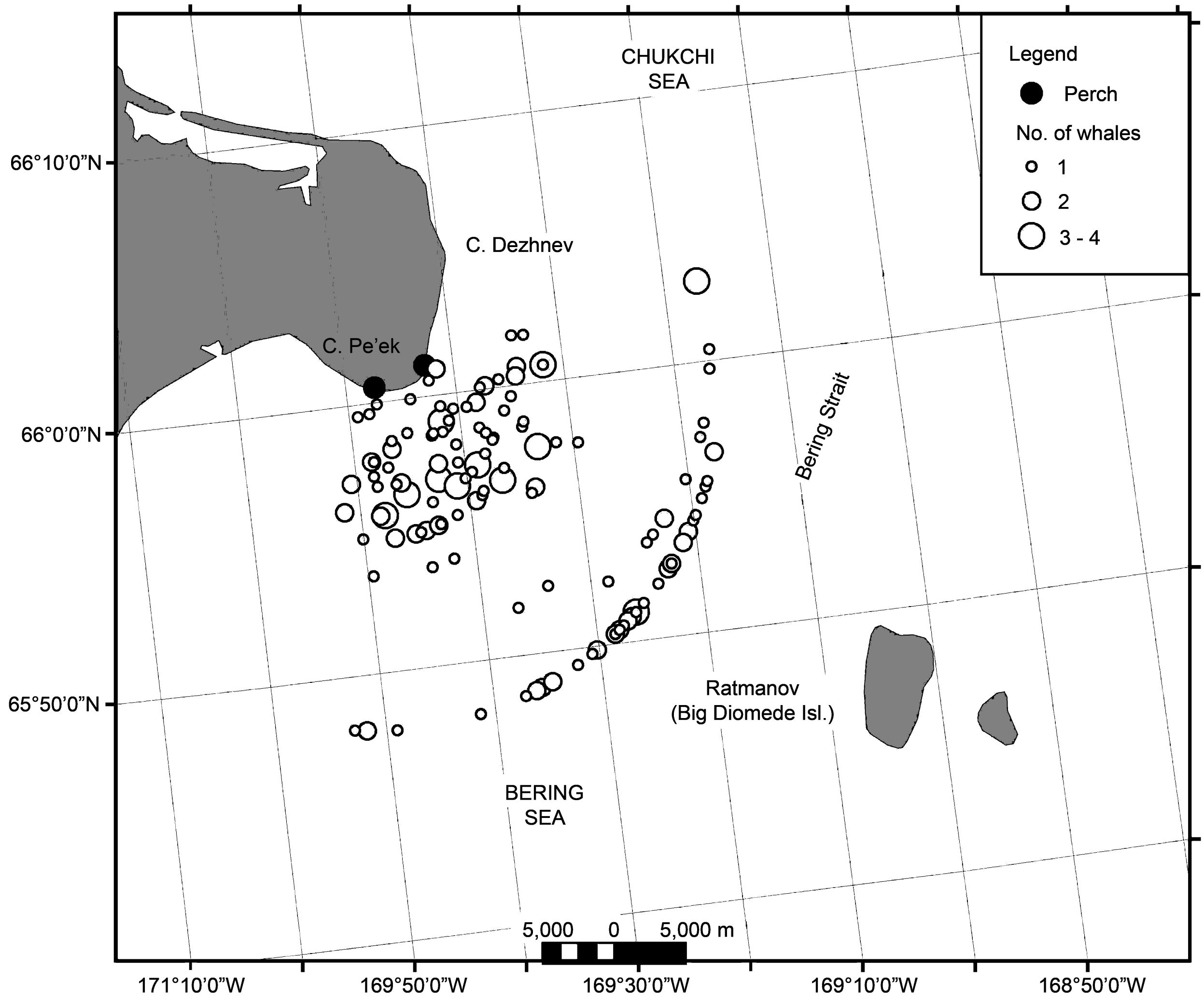

Fig. 4. Locations where bowhead whales were seen during the Cape Pe'ek count in 2001. Only the first sighting of each whale is shown.

Table 1

Season total estimates of the number of bowhead whales migrating past Cape Pe'ek in May and June of 2000 and 2001. These estimates assume that detection probability = 1, i.e. all whales passing during watch with fair to excellent visibility are assumed to have been seen.

Estimate	2000	2001	Weighted geometric mean	Unweighted geometric mean
Number of watched days	18	14		
Number of unwatched days	13	10		
Estimate used for unwatched days	14.57	21.30		
Season total	430	558	470	490
SE (CV)	95 (22%)	172 (31%)	84 (18%)	93 (19%)
95% CI	(280, 660)	(310,1010)	(332, 665)	(339, 708)

we computed distances using this formula, our maximum computed distance at Cape Pe'ek would have been 14.1km, reasonably comparable to theirs, instead of 23.8km.

The equation used to estimate the distance R is extremely sensitive to small changes in the angle θ when θ is small. This is because it treats the expression $\sin(\pi/2 - \theta) \times (r_3 + h) / r_3$ as the sin of an angle, so this expression must be 1 or less. When θ is small, $\sin(\pi/2 - \theta)$ is very close to 1, and the expression can exceed 1, so that R cannot be computed. For example, when θ increases from 0.0046 to 0.005, R decreases from 23.8km to 18.2km. Large values of R should be viewed as only approximate.

In addition to distant whales at Cape Pe'ek, visibility was a problem. Due to the large number of hours during the migration with P or UN visibility, 42% of the days during the migration period were unwatched in both years. With such a large fraction of unwatched days, significant pulses of whales may have been missed, as noted by Melnikov *et al.* (2004). In 2001, there were also unwatched days before the first whale was seen and after the last whale was seen, so whales may have been missed at the start or end of the migration.

However, it is also possible that the unwatched days had lower rates of passage than the watched days. Melnikov *et al.* (2004) stated that the migration seemed to stop when there were high winds or storms. Thus we may have overestimated the number of migrating whales by assuming that the migration continued even on stormy days. However, stormy weather does not appear to stop the migration near Barrow. It is possible that the lack of sightings from Cape

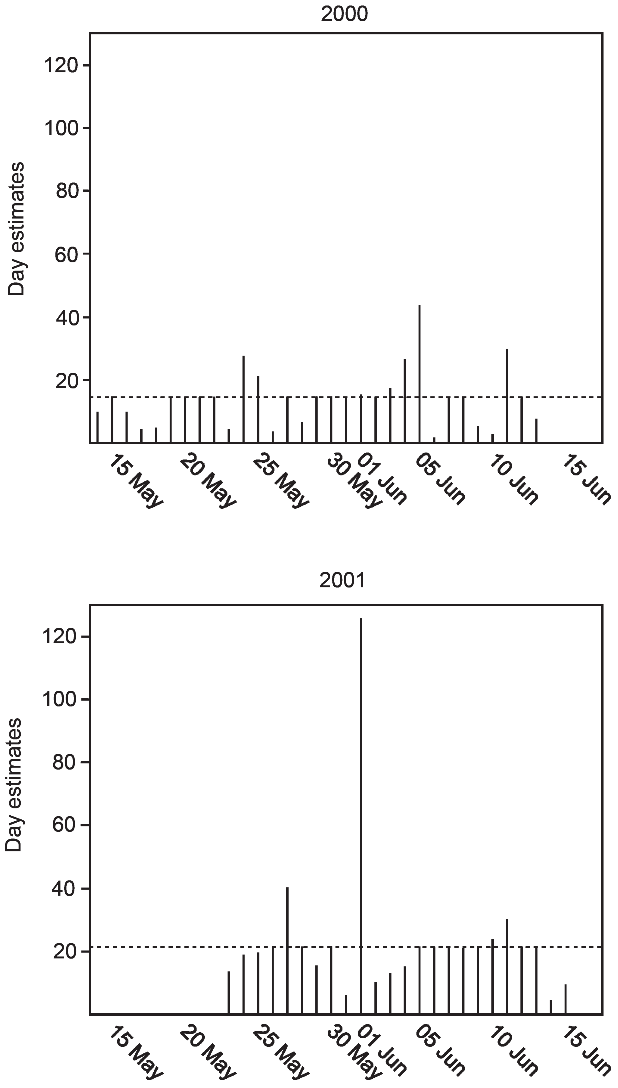

Fig. 5. Daily estimates of bowhead abundance in the viewing area for both years under the assumption that detection probability P=1 (i.e. all whales passing during watch with fair to excellent visibility are assumed to have been seen). Dotted lines give the mean estimates used for unwatched days.

Pe'ek during bad weather related to shorter watches on stormy and windy days or to greater difficulty in seeing whales on those days.

To resolve some of the uncertainties discussed above, it would be useful to repeat the Cape Pe'ek survey in a future year with some methodological additions. First, an 'independent observer' experiment designed to estimate detection probability at Cape Pe'ek should be conducted. Second, acoustic monitoring and location analysis (George *et al*., 2004) or visual counts from Ratmanov Island should be used to estimate how many whales pass beyond the visual range from Cape Pe'ek. Acoustic monitoring would also provide information about whale passage on unwatched days. Theodolites should be used in addition to binoculars for determining the positions of sightings. The theodolites will provide much higher precision, but the binoculars will still be needed because it is difficult to find distant whales in the narrow field of view of a theodolite. Some additional research on limits of visual range and estimation of R near these limits might also be useful.

As bowhead whales were counted at Point Barrow in 2001 as well as at Cape Pe'ek, it is of interest to consider whether the same whales might have been counted in both places. Cape Dezhnev is about 930km from Point Barrow. Melnikov *et al*. (2004) estimated a mean migration speed of 8.4km h^{-1} in 2001, or 4.6 days travel time from Cape Dezhnev to Barrow. That is, a bowhead whale seen near Cape Dezhnev on 23 May would arrive at Point Barrow on 27 May or 28 May assuming it maintained a constant travel rate. However, no bowhead whales seen at Point Barrow between 27 May and 6 June (the last day any were seen) in 2001 were travelling at a speed that high. The median speed at Point Barrow during that period was 4.6km h^{-1}, possibly because the whale migration slowed down as it went past this point of land.

Melnikov *et al*. (2004) noted that northbound water currents are stronger near Cape Dezhnev than on the other side of the Bering Strait. If any whales counted at Cape Pe'ek travelled to Point Barrow, their average migration speed over the entire route was probably between 4.6 and 8.4km h^{-1} and their transit time 5 days or more. At least 94 bowhead whales were seen from Cape Pe'ek in June of 2001 but only three were seen by the Point Barrow survey, two on 1 June and 1 on 6 June. Thus, at most, one of the whales passing Cape Pe'ek in June of 2001 could have been among those counted at Point Barrow.

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REFERENCES

Bogoslovskaya, L.S., Votrogov, L.M. and Krupnik, I.I. 1982. The bowhead whale off Chukotka: migrations and aboriginal whaling. *Rep. int. Whal. Commn* 32: 391-99.

Braham, H., Krogman, B., Leatherwood, S., Marquette, W., Rugh, D., Tillman, M., Johnson, J. and Carroll, G. 1979. Preliminary report of the 1978 spring bowhead whale research program results. *Rep. int. Whal. Commn* 29: 291-306.

Buckland, S.T. 1992. Report of the Scientific Committee, Annex H. Proposal for standard presentation of abundance estimates. *Rep. int. Whal. Commn* 42: 235.

Buckland, S.T., Breiwick, J.M., Cattanach, K.L. and Laake, J.L. 1993. Estimated population size of the California gray whale. *Mar. Mammal Sci*. 9(3): 235-49.

George, J.C., Zeh, J., Suydam, R. and Clark, C. 2004. Abundance and population trend (1978-2001) of western Arctic bowhead whales surveyed near Barrow, Alaska. *Mar. Mammal Sci*. 20(4): 755-73.

Hobbs, R.C., Rugh, D.J., Waite, J.M., Breiwick, J.M. and DeMaster, D.P. 2004. Abundance of eastern gray whales on the 1995/96 southbound migration. *J. Cetacean Res. Manage*. 6(2): 115-20.

International Whaling Commission. 2003. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 5:1-92.

Lerczak, J.A. and Hobbs, R.C. 1998. Calculating sighting distances from angular readings during shipboard, aerial, and shore-based marine mammal surveys. *Mar. Mammal Sci*. 14(3): 590-99. [See Errata. 1998. *Mar. Mammal Sci*. 14(4):903].

Melnikov, V. and Zeh, J. 2006. Chukotka Peninsula counts and estimates of the number of migrating bowhead whales. Paper SC/58/BRG15 presented to the IWC Scientific Committee, May 2006, St. Kitts and Nevis, West Indies. 10pp. [Paper available from the Office of this Journal].

Melnikov, V.V., Litovka, D.I., Zagrebin, I.A., Zelensky, G.M. and Ainana, L.I. 2004. Shore-based counts of bowhead whales along the Chukotka Peninsula in May and June 1999-2001. *Arctic* 57(3): 290-98.

Melnikov, V.V., Zelensky, M.A. and Ainana, L.I. 1998. Observations on distribution and migration of bowhead whales (*Balaena mysticetus*) in the Bering and Chukchi Seas. Paper SC/50/AS3 presented to the

IWC Scientific Committee, April 1998 (unpublished). 31pp. [Paper available from the Office of this Journal].

Rugh, D., DeMaster, D., Rooney, A., Breiwick, J., Shelden, K. and Moore, S. 2003. A review of bowhead whale (*Balaena mysticetus*) stock identity. *J. Cetacean Res. Manage.* 5(3): 267-79.

Rugh, D.J., Breiwick, J.M., Dahlheim, M.E. and Boucher, G.C. 1993. A comparison of independent, concurrent sighting records from a shore-based count of gray whales. *Wildl. Soc. Bull.* 21(4): 427-37.

Rugh, D.J. and Cubbage, J.C. 1980. Migration of bowhead whales past Cape Lisburne, Alaska. *Mar. Fish. Rev.* 42(9-10): 46-51.

Zeh, J.E., Ko, D., Krogman, B.D. and Sonntag, R. 1986. A multinomial model for estimating the size of a whale poulation from incomplete census data. *Biometrics* 42: 1-14.

Zeh, J.E. and Punt, A. 2005. Updated 1978-2001 abundance estimates and their correlations for the Bering-Chukchi-Beaufort Seas stock of bowhead whales. *J. Cetacean Res. Manage.* 7(2): 169-75.

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