Mysticete whale abundance and observations of prey associations on the central Bering Sea shelf

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ABSTRACT

Visual surveys for cetaceans were conducted along transect lines in the central Bering Sea in association with a groundfish stock assessment survey from 5 July to 5 August 1999. There were 125 sightings of single or groups of mysticete whales during 6,043km of survey effort. Fin whales were most common (60% of all sightings), with distribution clustered along the outer continental shelf break near the 200m isobath. In addition, there were 27 sightings of minke whales and 17 sightings of humpback whales. Minke whales were primarily found along the upper slope in water 100-200m deep, while humpbacks clustered along the eastern Aleutian Islands and near the USA/Russian Convention Line southwest of St. Lawrence Island. Abundance estimates for fin, humpback and minke whales were: 4,951 (95% CI = 2,833-8,653); 1,175 (95% CI = 197-7,009) and 936 (95% CI = 473-1,852), respectively. These three species were the only ones for which sufficient on-effort sightings were available to estimate abundance. Sei whales, a gray whale and a pair of northern right whales were also seen. Although right whales have been seen in this area before, some behavioural details are provided here because observations of these whales remain rare.

KEYWORDS: MYSTICETE WHALE; FIN WHALE; MINKE WHALE; HUMPBACK WHALE; NORTH PACIFIC RIGHT WHALE; DISTRIBUTION; ABUNDANCE; BERING SEA

INTRODUCTION

There have been few broad-scale surveys for whales in the central Bering Sea that were not associated with commercial whaling (e.g. Wada, 1981) and most contemporary references to mysticete whale distribution and abundance in this region rely on catch records (e.g. Springer *et al.*, 1996; 1999). North Pacific right whales (*Eubalaena japonica*), fin whales (*Balaenoptera physalus*) and humpback whales (*Megaptera novaeangliae*) were harvested predominantly south of the Aleutian Islands in the North Pacific, but there were also substantial takes in the central Bering Sea (Nasu, 1974; Miyashita *et al.*, 1995; Brownell *et al.*, 2001). From 1966-1990, minke whale (*Balaenoptera acutorostrata*) sighting rates from whaling or whaling-support vessels were highest in the western Pacific and Sea of Okhotsk, with comparatively few whales reported in the central Bering Sea (Miyashita *et al.*, 1995). Due to lack of broad-scale surveys dedicated to obtaining abundance estimates, it has been impossible to determine: (1) if populations of mysticete whales are recovering from the commercial harvests of the 20th century; and (2) their role in the ecology of the Bering Sea (Livingston, 1993).

A rare sighting of a small group of North Pacific right whales was made during a groundfish assessment survey in the eastern Bering Sea in July 1996 (Goddard and Rugh, 1998). This sighting prompted efforts to put marine mammal observers onboard a fishery research vessel in summer 1997. This opportunistic survey proved successful, as right whales were sighted and photographed in the anomalous coccolithophore (*Emiliania huxleyi*) bloom prevalent in the eastern Bering Sea that year (Vance *et al.*, 1998; Tynan, 1999). In 1999, scientists from the Alaska Fisheries Science Center/Resource Assessment and Conservation Engineering (AFSC/RACE) Division conducted another in a series of acoustic-trawl surveys for walleye pollock (*Theragra chalcogramma*) on the Bering Sea shelf. Biologists from the AFSC/National Marine Mammal Laboratory (NMML) joined the second leg of that cruise and conducted a visual survey along the lines RACE had developed for the pollock assessment. This opportunity provided a means to assess the central Bering Sea shelf for mysticete whales.

METHODS

Visual survey protocol

A line-transect survey for cetaceans was conducted from the flying bridge of the NOAA ship *Miller Freeman* (66m, 215ft), while the ship was in transit between trawling sites over the central Bering Sea shelf (Fig. 1). The survey design consisted of north-south transect lines spaced 37km (20 n.miles) apart, except in the 'Horseshoe Area' where spacing was 18.5km (10 n.miles). The survey proceeded from east to west starting at 171°26'W and ending at 178°55'W, with some survey effort conducted northeast of the Pribilof Islands and near Unimak Island en route to and from port at Dutch Harbor, Alaska. The vessel maintained a speed of 10-11 knots between trawling sites. Effort began and ended with available light (07:30-22:30 hours local time). Standard line-transect survey protocol was adopted (Barlow, 1988), except that the observers did not rotate stations. When weather conditions permitted (i.e. dry, visibility ≥ 1 km), two primary observers maintained a continuous watch for marine mammals at starboard and port stations on the flying bridge using 25×150 power binoculars (Fig. 1: on-effort). A data recorder, stationed between the primary observers, searched by scanning both sides of the ship with naked eye and using 7×50 hand-held binoculars. Observer eye height was 12m above the water line. The radial distance to sightings was estimated using the angle below the horizon measured with reticles in the binoculars (Lerczak and Hobbs, 1998 but also see associated Errata), or estimated by eye when animals were very close to the ship. The radial angle to the sighting was measured using an angle ring mounted on the 25×150 power binocular support column.

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In poor weather (i.e. rain, visibility ≤1 km), or areas of patchy dense fog, one observer maintained watch using hand-held binoculars from the bridge (Fig 1: bridge-effort). Survey effort was suspended whenever visual conditions deteriorated to ≤200m and while RACE biologists conducted fishing operations (Fig. 1: off-effort).

Data collection, oceanographic correlates and analysis

Variables related to marine mammal survey effort and sightings were recorded on a laptop computer and updated whenever conditions changed. At 5-minute intervals, the program automatically updated fields of time, date, latitude, longitude and other variables if they remained unchanged. Environmental and oceanographic data were obtained from instruments maintained by the RACE scientists. Along-track measurements of water temperature, salinity and fluorometer were recorded at 5-minute intervals from the ship's flow-through system, which sampled seawater at about 3m depth. Wind direction and speed, vessel heading and vessel speed were also recorded every five minutes. A bongo tow net system (60cm bongo frame with 505μ mesh nets and a 40kg lead weight) was deployed from the ship's starboard winch to collect samples in the vicinity of right whales in the coccolithophore bloom.

Mysticete whale abundance was estimated using line-transect analysis for each species with 10 or more on-effort sightings. Bridge-effort and off-effort sightings were not used for abundance estimation, but were plotted to depict species' distribution. Effective strip width, density and abundance were estimated using the program DISTANCE (Laake *et al.*, 1993). Abundance, N, was calculated as:

$$N = \frac{A\bar{s}n}{WL}$$

where:

A is the size of the study area;
$\bar{s}$ is the average number of whales per useable, on-effort sighting;
n is the number of useable on-effort sightings;
W is the effective strip width; and
L is the total length of the useable effort segments.

The study area was defined as the area enclosed by a boundary 10km beyond the limits of the survey tracklines (Fig. 1), calculated as 343,169km^2 using ArcView^{TM} (3.1).

The perpendicular distance between a sighting and the trackline was estimated as the product of the radial distance to sightings and the sine of the radial angle of the sighting. Perpendicular sighting distances were grouped into 0.5km bins. Where a gap of 1km or greater in the distribution of sightings from the trackline occurred, the maximum distance was truncated to eliminate the gap. Sightings beyond the truncation point were removed from the analysis. The probability of sighting with respect to perpendicular distance

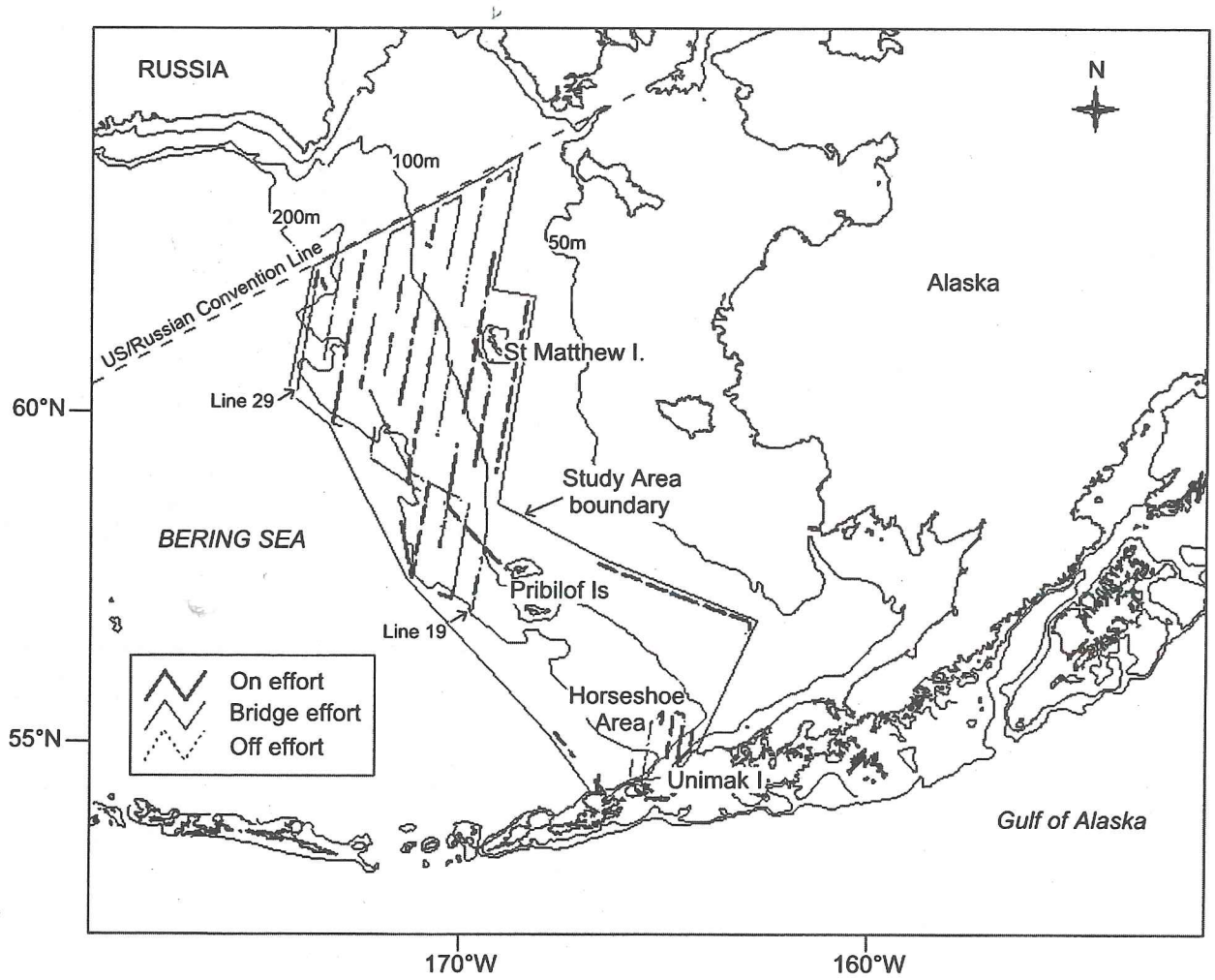


Fig. 1. Survey track of the NOAA ship *Miller Freeman* in the central Bering Sea shelf. See text for trackline designations: on-effort, bridge-effort and off-effort.

Table 1
Mysticete whale sighting summary.

Species	No. sightings	No. whales	% Total sightings
Fin whale	75	346	60
Minke whale	27	37	22
Humpback whale	17	39	14
Sei whale	4	6	3
Gray whale	1	1	0.5
N. Right whale	1	2	0.5

from the trackline was modelled using the half-normal and hazard-rate curves, using either the cosine or Hermite polynomial corrections and assuming that the probability of sighting a group on the trackline was 1. Akaiki Information Criteria (AIC) were used to determine the best model fit. The strip width was estimated as twice the integral of this curve over the perpendicular distance from the trackline to the truncation point. Tracklines began and ended whenever there was a significant shift in survey effort as indicated by changes in sighting conditions (visibility, Beaufort sea state), personnel, or vessel speed and direction.

RESULTS

The cruise began and ended in Dutch Harbor, Alaska and extended from 5 July to 5 August 1999. Although the acoustic trawl effort for pollock began on transect line 19 (56°20'N, 171°26'W) and ended with transect line 29 (60°65.9'N, 178°91.68'W), survey effort for marine mammals began on transit to and from these way points. The entire track of the marine mammal survey, including transect lines 19-29, the Horseshoe Area, and transits to and from Dutch Harbor, covered 6,043km (Fig. 1). Of the total track, 2,354km (39%) was surveyed on-effort, 2,017km (33%) was conducted by one person on the bridge in marginal weather conditions (i.e. bridge-effort), and the remaining 1,672km (28%) of trackline was covered while observers were off-effort.

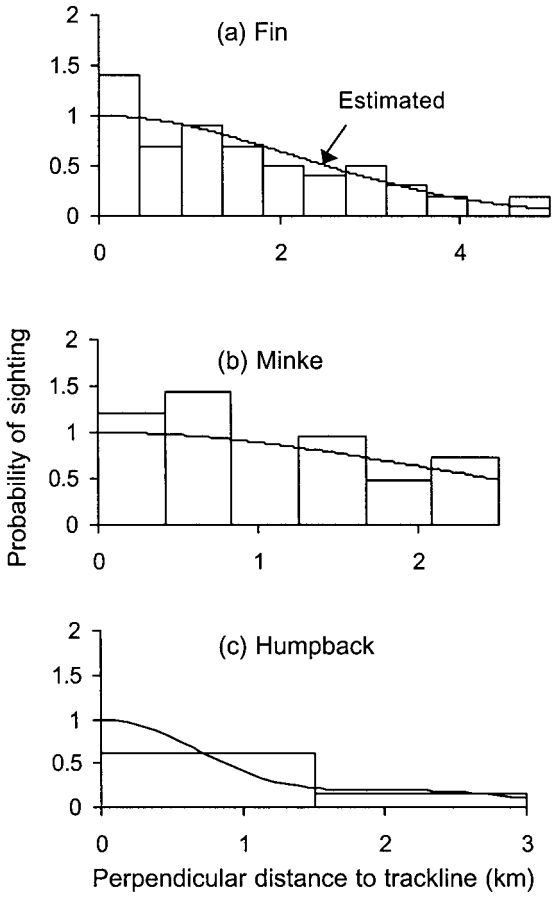


Fig. 2. Distribution of perpendicular sighting distances for fin, minke and humpback whales, with best-fit detection function [G(x)] curves.

Mysticete whale distribution and abundance

There was a total of 125 mysticete whale sightings; most (60%) were fin whales (Table 1). Of the 75 fin whale sightings, 58 were on-effort and used to estimate abundance (Table 2). Using a truncation distance of 5km (Fig. 2), the estimated abundance of fin whales was 4,951 (95%

Table 2
Abundance estimates. [ ] = Number of on-effort sightings.

Parameter	Point estimate	Standard error	% CV	95% Confidence Interval	
(a) Fin whales [58]				(Lower)	(Upper)
Truncation distance (km)	5.0				
Effective strip width (km)	2.6	0.3	10	2.1	3.2
Sightings per km	0.024	0.006	23	0.016	0.038
Sightings per km^2	0.0046	0.0012	25	0.0029	0.0076
Average pod size	3.1	0.4	14	2.3	4.1
Whales per km^2	0.014	0.004	29	0.008	0.025
Estimated abundance	4,951	1,434	29	2,833	8,653
(b) Humpback whales [10]					
Truncation distance (km)	3.0				
Effective strip width (km)	1.2	0.5	39	0.5	2.8
Sightings per km	0.004	0.004	105	0.001	0.023
Sightings per km^2	0.002	0.002	112	0.000	0.011
Average pod size	1.9	0.3	17	1.3	2.8
Whales per km^2	0.003	0.004	113	0.001	0.020
Estimated abundance	1,175	1,325	113	197	7,009
(c) Minke whales [20]					
Truncation distance (km)	2.5				
Effective strip width (km)	2.0	0.4	19	1.3	3.0
Sightings per km	0.0084	0.0019	22	0.0055	0.0130
Sightings per km^2	0.0021	0.0006	30	0.0012	0.0037
Average pod size	1.3	0.3	19	1.0	1.9
Whales per km^2	0.0027	0.0010	35	0.0014	0.0054
Estimated abundance	936	331	35	473	1,852

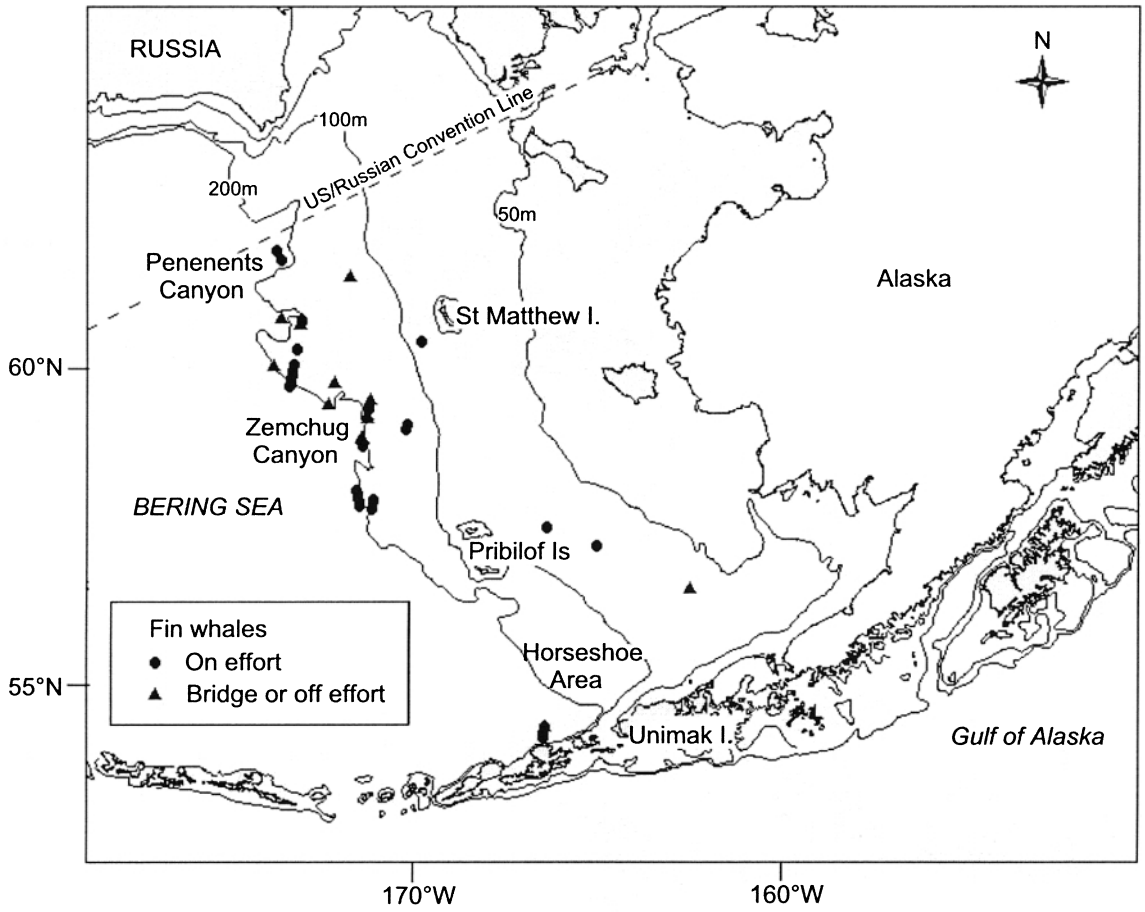


Fig. 3. Distribution of 75 sightings representing 346 fin whales.

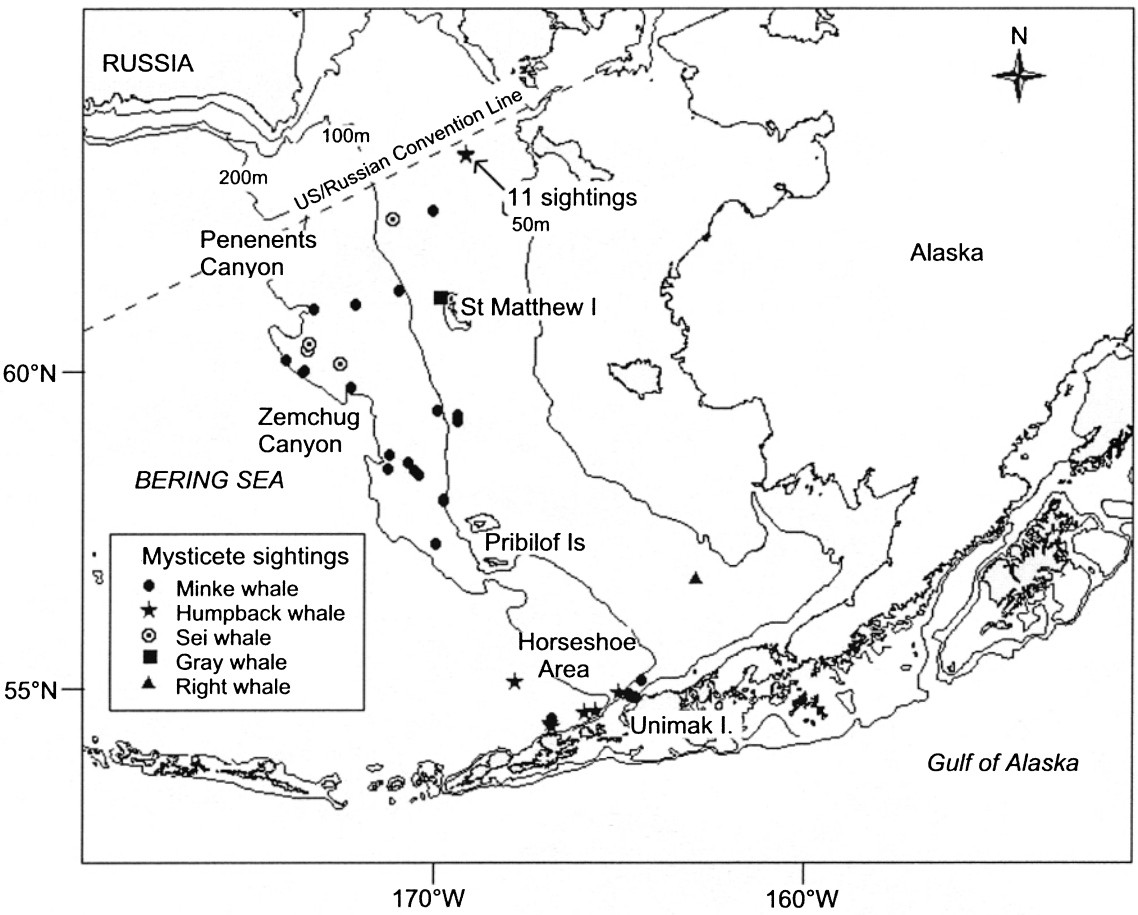


Fig. 4. Distribution of: 27 sightings representing 37 minke whales; 17 sightings representing 39 humpback whales; 4 sightings representing 6 sei whales; and single sightings of a gray whale and a pair of Northern right whales.

CI = 2,833-8,653). Fin whale sightings were clustered along the outer Bering Sea shelf break, primarily near the 200m isobath and near Zemchug Canyon (Fig. 3).

There were 27 sightings of minke whales and 17 sightings of humpback whales made during the cruise. Minke whales were distributed along the upper slope in water 100-200m deep, while humpbacks clustered along the eastern Aleutian Islands and near the USA/Russian Convention Line southwest of St. Lawrence Island (Fig. 4). Twenty of the minke whale sightings and 10 of the humpback sightings were on-effort, and used to estimate abundance (Table 2). Using truncation distances of 2.5km and 3km, respectively (Fig. 2), the estimated abundance of minke whales was 936 (95% CI = 473-1,852) and that of humpback whales was 1,175 (95% CI = 197-7,009). The wide confidence interval for the humpback whale estimate (CV = 1.13), reflects the paucity of on-effort sightings.

There were four sightings of six sei whales (*Balaenoptera borealis*); three sightings of five sei whales near the minke whales seen southeast of Pervenets Canyon shoreward of the 200m isobath, and one sighting of a lone sei whale closer to the Pervenents Canyon near the 100m isobath (Fig. 4). In addition, there were single sightings each of a gray whale (*Eschrichtius robustus*) near St. Matthew Island (60°35.19'N, 173°24.17'W), and a pair of North Pacific right whales in the eastern Bering Sea (56°58.33'N, 163°27.64'W; Fig. 4). Although North Pacific right whales have been seen in this area before, some additional details of this encounter are provided because observations of these whales are rare (see review in Brownell *et al.*, 2001).

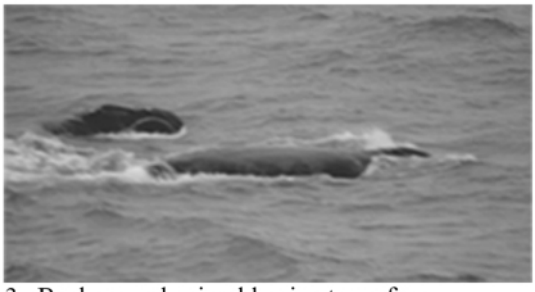
North Pacific right whale observations

On 31 July 1999, an extensive coccolithophore bloom was observed during a ten-hour, eastbound transit that began at approximately 12:30 local time (57°21.78'N and 166°28.07'W; Fig. 1). The vessel was in the bloom at least until sunset, approximately 22:45 local time (56°52.12'N and 163°32.92'W). Two North Pacific right whales were initially sighted by naked eye near the horizon, breaching at least five times. Species identification was confirmed with hand-held and subsequently 25 × 150 binoculars. The pair was seen near the only right whale sighting on Leg 1 of the *Miller Freeman* cruise (conducted in June 1999) and, as in 1997, the whales were well within the coccolithophore bloom. The right whales were approximately 5km (2-3 miles) from four fin whales and in the vicinity of right whale sightings made by researchers conducting aerial, vessel and acoustic surveys from 8-18 July 1999, just ten days before this sighting (R. LeDuc, pers. comm.).

The right whales remained within one body length of each other throughout the approximately one-hour observation period. They did not appear to respond adversely to the vessel and actually approached and swam across the bow, passing within 250m of the ship (Fig. 5). Observed behaviours included breaching, close contact, rolling to extend a pectoral fin in the air, a fluke-up dive, shallow dives of short duration (1-5 minute down time average) and slow-swimming in tandem. Both whales appeared healthy and robust, were similar in length (roughly 12-14m) and girth, and were free of natural or fishery gear-interaction scars or markings. Oddly, both animals lacked

1. V-shaped blow from foreground animal.

2. Foreground animal at peak of surfacing.



3. Background animal begins to surface.

4. Background animal blows.

5. End of surface sequence.

Fig. 5. Surfacing sequence for a pair of right whales as they passed the bow of the NOAA ship *Miller Freeman* on 31 July 1999.

white-coloured callosities typically associated with right whales. Instead, their raised callosity patches were a dark, rust-coloured hue.

Water depth at the whales' location was 70.6m, water temperature was 8.6°C, and salinity was 31.753 psu. Shortly after photographing the whales, two bongo nets (505μ mesh) were deployed and a tow taken near the bottom and within the coccolithophore bloom. During the tow, the whales remained within about 2km (1 n.mile) of the vessel. Samples from both nets collected from a bottom depth 70-71m included jellyfish and larval pollock.

Prey associations

Throughout the cruise there was often a positive association between mysticete whale aggregations and concentrations of zooplankton, euphausiids, pollock and other fish observed on the echosounder by RACE scientists from the Midwater Assessment Conservation Engineering (MACE) programme. Elevated fluorometer readings were often noted during these observations. Although a full analysis will be the subject of a future paper, it seems useful to summarise some of the more interesting observations here, especially those on the middle shelf along the 200m contour and adjacent to canyons.

On 14 July 1999 (line 21: 62°59.95'N, 173°58.75'W), large aggregations of 3-5 inch arctic cod (*Boreogadus saida*) occurred jointly with an aggregation of 17 humpback whales (in five groups), a group of eight killer whales *(Orcinus orca*), and approximately twenty species of sea birds, with pomerine jaegers (*Stercorarius pomarinus*) the dominant species. Five killer whales were observed chasing a single humpback whale, which responded by tail-slapping vigorously. Unfortunately, the vessel then left the area so observers were unable to determine the outcome of the killer whale/humpback whale interaction.

On 16 July 1999 (line 22: 57°14.97'N and 173°18.55'W), the MACE echosounder detected *ca* 40km (over 25 miles) of zooplankton and euphausiids echosign near Zemchug canyon (bottom depth 135-150m), including 7-8km (4-5 mile) intervals of strong fish echo within the longer stretch of zooplankton. Concurrently, marine mammal observers documented aggregations of 28 fin whales (in 10 groups) and 55 Dall's porpoise (in 15 groups), short-tailed shearwaters, fork-tailed storm petrels, Leach's storm petrels, long-tailed jaegers and Laysan albatross.

On 26 July 1999 (line 26: 58°39.38'N and 176°50.17'W), the MACE echosounder detected similar prey aggregations near Pervenents Canyon (bottom depth 150-200m), where dense pollock schools at times occupied the entire water column. Aggregations of 59 fin whales (in 21 groups), seven minke whales (in two groups) and three sei whales (in two groups) were documented, with all species lunge-feeding at the surface. The whales were accompanied by thousands of seabirds. Dominant bird species included short-tailed shearwaters, fork-tailed storm petrels, pomerine jaegers, Laysan albatross and an enormous flock of red phalaropes.

The largest aggregation of fin whales (> 100 animals) was seen off-effort on 27 July (line 27: 59°36.40'N and 177°09.80'W), within a 8-10km (5-6 mile) stretch of dense fish echosign within the coccolithophore bloom. Water temperature ranged from 6.0-8.9°C and peaked at 8.9°C; water depth ranged from 66-71m. Other marine mammals seen in the coccolithophore bloom included northern fur seals (9), harbour porpoise (nearly 30% of all sightings), and the pair of right whales (Fig. 4). Surprisingly, there were not

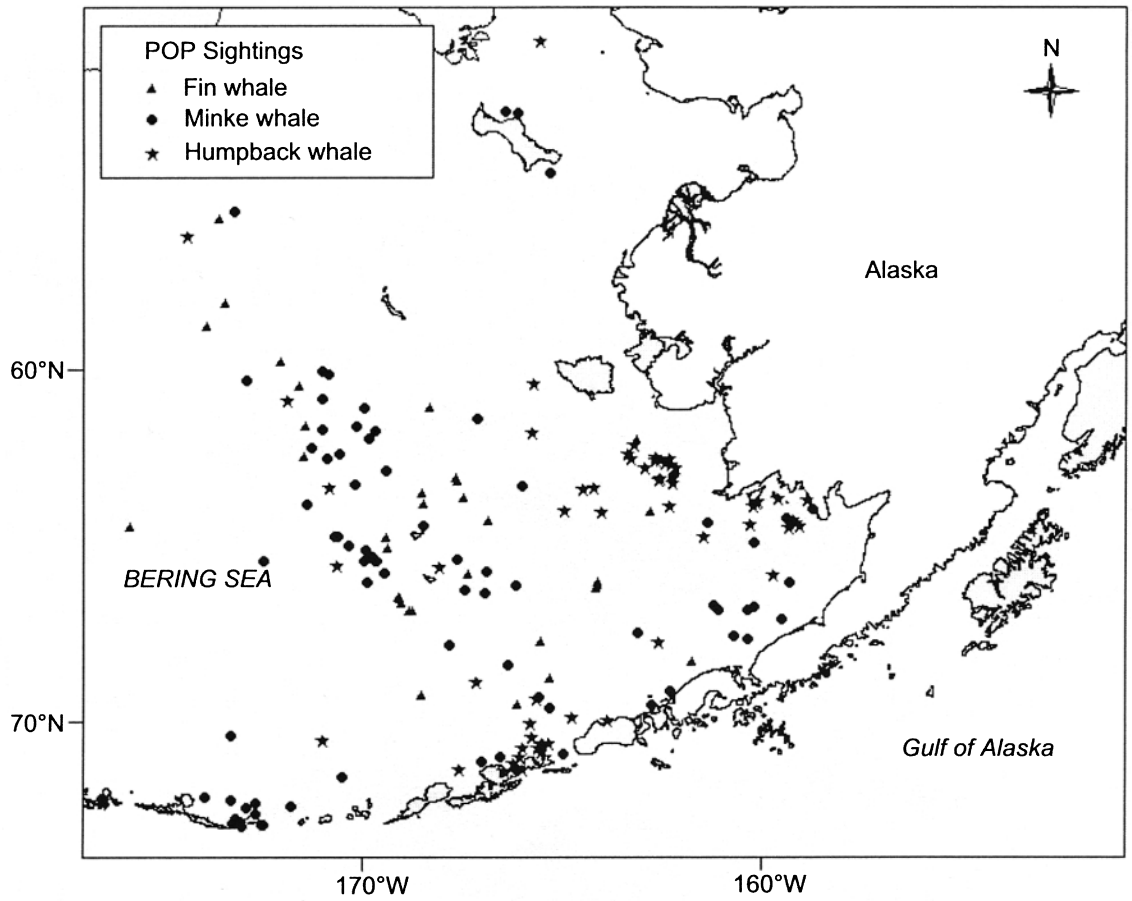


Fig. 6. Distribution of fin, minke and humpback whales in the central and eastern Bering Sea from NMML Platforms of Opportunity (PoP) database. Data from opportunistic sightings during June and July, 1980-99.

many seabirds. Species observed included the glaucous-winged gull, parasitic jaeger, Arctic tern and possibly an Aleutian tern.

DISCUSSION

The 1999 cruise aboard the NOAA ship *Miller Freeman* provided a valuable opportunity to conduct a line-transect survey for marine mammals in the central Bering Sea, and resulted in sufficient sightings data to support the calculation of abundance estimates for fin, minke and humpback whales. However, these are clearly *preliminary* in that the survey covered only a portion of the entire Bering Sea, and because the abundance estimates were not corrected for a number of factors including animals missed on the trackline, animals that were submerged, possible reaction to vessels etc. To emphasise this, a plot of June/July 1980-99 sightings of the three species was compiled from the National Marine Mammal Laboratory (NMML) Platforms of Opportunity (PoP) database (Fig. 6). Although unrelated to survey effort, the broad distribution of sightings for each species provides a clear indication that whales detected during any one survey will surely under-represent the overall distribution and abundance of mysticete whales in the eastern and central Bering Sea.

Until now, however, there has been no estimate of fin whale abundance in the Bering Sea (Hill and DeMaster, 1999). The uncorrected abundance estimate of 4,951 whales (95% CI = 2,833-8,653) reported here indicates that the Bering Sea is an important habitat for fin whales. From previous surveys (e.g. Buckland *et al.*, 1992) no correction is likely for fin whales and this, combined with the large number of sightings, suggests the estimate obtained represents a reasonable estimate of the number of fin whales in the research area at that time. For comparison, Ohsumi and Wada (1974) estimated 14,620 to 18,630 fin whales in the entire North Pacific in the late 1970s. Fin whale sightings were concentrated along the shelf edge and were often associated with dense concentrations of zooplankton and fish. Similarly, Nasu (1974) reported that fin whales in the Bering Sea were commonly associated with the oceanic front that occurs between water masses at the shelf break, while Springer *et al.* (1999) also reported fin whale distribution in the sub-Arctic North Pacific (based on whaling records) to coincide with zooplankton biomass.

Minke whales in the eastern North Pacific are separated into the Alaska stock and the California, Oregon and Washington stock based on distribution (Hill and DeMaster, 1999). During the *Miller Freeman* survey, minke whales were distributed throughout the study area, including nearshore regions (e.g., Unimak I.) and the upper shelf, suggesting widespread use of the Bering Sea. While there are reports of minke whale aggregations elsewhere in the Bering Sea, such as along the Chukotka coastline (e.g. Melnikov, 2000), there has been no abundance estimate available for the Alaska stock of minke whales in the Bering Sea. Therefore, the estimate of 936 whales (95% CI = 473-1,852), although uncorrected and covering only a small portion of the stock's range, provides a baseline minimum estimate for this population. Experience from other surveys (e.g. Schweder *et al.*, 1992; 1993) suggests that correction for animals missed is more important for minke whales than fin whales.

Little is known about humpback whale distribution and abundance in the Bering Sea (Perry *et al.*, 1999). Our estimate of 1,175 whales (95% CI = 197-7,009), despite the associated large uncertainty, indicates that humpback whales clearly use the Bering Sea as a summer feeding ground. As for minke whales, there are records of humpback aggregations along the Chukotka Peninsula (e.g. Melnikov *et al.*, 1999), so clearly the estimate here does not account for all humpbacks in the Bering Sea. Whaling records show that in the Bering Sea humpbacks were caught, mostly north of Unimak Pass (Reeves *et al.*, 1985), where sightings were clustered during our survey. Notably, humpback whales were not seen in the highly productive areas along the shelf edge where fin whales were found, suggesting temporal or spatial separation in foraging or differences in foraging threshold (Piatt and Methven, 1992) between the two species. It is not clear whether Bering Sea humpback whales all return to the same wintering grounds. Marking studies conducted during years of whaling found humpback whales marked in the Bering Sea moved between both Japanese waters and eastern North Pacific waters (Ohsumi and Masaki, 1975). Thus, more than one stock of humpback whales may be represented in the Bering Sea.

The only North Pacific right whales seen were observed in the eastern Bering Sea, near the location where they have been seen each summer since 1996 (Goddard and Rugh, 1998). As in 1997, the right whales were seen within a coccolithophore bloom (Tynan, 1999). Photographs taken of right whales in 1997 also show 'rust-coloured' callosities, similar to those photographed in 1999. A speculative explanation for the atypical callosity coloration might be a lack of diatoms in the coccolithophore bloom, which may somehow effect callosity coloration.

The opportunistic survey aboard the NOAA ship *Miller Freeman* provided a snapshot of fundamental information about mysticete whale populations in the central Bering Sea. It appears that substantial numbers of fin whales, minke whales and humpback whales occur there, and that they occupy somewhat dissimilar habitats. These preliminary abundance estimates provide a baseline for comparison to data it is hoped will be obtained in subsequent surveys. Finally, the observation of North Pacific right whales adds to the increasing information base regarding their behavioural ecology in the Bering Sea.

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