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Abundance, trends and distribution of baleen whales off Western Alaska and the central Aleutian Islands

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Abstract

Large whales were extensively hunted in coastal waters off Alaska, but current distribution, population sizes and trends are poorly known. Line transect surveys were conducted in coastal waters of the Aleutian Islands and the Alaska Peninsula in the summer of 2001–2003. Abundances of three species were estimated by conventional and multiple covariate distance sampling (MCDS) methods. Time series of abundance estimates were used to derive rates of increase for fin whales (*Balaenoptera physalus*) and humpback whales (*Megaptera novaeangliae*). Fin whales occurred primarily from the Kenai Peninsula to the Shumagin Islands, but were abundant only near the Semidi Islands and Kodiak. Humpback whales were found from the Kenai Peninsula to Umnak Island and were more abundant near Kodiak, the Shumagin Islands and north of Unimak Pass. Minke whales (*B. acutorostrata*) occurred primarily in the Aleutian Islands, with a few sightings south of the Alaska Peninsula and near Kodiak Island. Humpback whales were observed in large numbers in their former whaling grounds. In contrast, high densities of fin whales were not observed around the eastern Aleutian Islands, where whaling occurred. Average abundance estimates (95% CI) for fin, humpback and minke whales were 1652 (1142–2389), 2644 (1899–3680), and 1233 (656–2315), respectively. Annual rates of increase were estimated at 4.8% (95% CI = 4.1–5.4%) for fin and 6.6% (5.2–8.6%) for humpback whales. This study provides the first estimate of the rate of increase of fin whales in the North Pacific Ocean. The estimated trends are consistent with those of other recovering baleen whales. There were no sightings of blue or North Pacific right whales, indicating the continued depleted status of these species.

Keywords: Distribution; Population number; Population density; Conservation; Whales; North Pacific; Aleutian Islands; Gulf of Alaska

1. Introduction

The Gulf of Alaska and the Aleutian Islands are highly productive areas in the North Pacific Ocean and support large biomasses of a variety of species, including marine mammals (Pfister and DeMaster, 2006). Migratory baleen whales concentrate in these areas during their feeding season in the spring and

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summer. Areas of high density, such as feeding grounds, were viewed as ideal for whaling because large aggregations maximized catch and reduced costs (Tønnessen and Johnsen, 1982). Large whale species were heavily exploited by both aboriginal and commercial whaling in the North Pacific Ocean (Nishiwaki, 1966; Pike, 1968; Wada, 1981; Breiwick and Braham, 1984; Miyashita et al., 1995; Perry et al., 1999). Total catches are unknown, but nearly 400 thousand whales of eight species were taken in the 20th century alone (Breiwick and Braham, 1984; Horwood, 1987; Perry et al., 1999). Currently, six of these species are listed as endangered under the United States Endangered Species Act, and many stocks are classified as protected by the International Whaling Commission (IWC) (e.g. Perry et al., 1999; IWC, 2005).

A substantial proportion of whale catches were taken in coastal waters of the Aleutian Islands and the Alaska Peninsula by both pelagic and coastal whaling (Nishiwaki, 1966; Wada, 1981; Brueggeman et al., 1985; Reeves et al., 1985). The most important species taken were right (*Eubalaena japonica*), blue (*Balaenoptera musculus*), fin (*B. physalus*), sei (*B. borealis*), humpback (*Megaptera novaeangliae*), and sperm whales (*Physeter macrocephalus*). Other species such as the minke (*B. acutorostrata*) and the killer whale (*Orcinus orca*) were also occasionally hunted (Reeves et al., 1985). Pelagic whalers operated in both the Bering Sea and the North Pacific side of the Aleutian chain, and in the Gulf of Alaska. In addition, coastal whaling stations operated on Akutan Island (54°08′S, 165°56′W) and at Port Hobron on Sitkalidak Island (57°70′N, 153°13′W) (Nishiwaki, 1966; Reeves et al., 1985). The whaling grounds of vessels operating from these stations were usually within 180 km of the landing locations (Reeves et al., 1985).

Despite the massive removal of whales and the endangered status of most species, relatively few dedicated surveys were conducted after the whaling era to investigate whale abundance, recovery rates and distribution patterns off the Aleutian Islands and the western Gulf of Alaska. Stewart et al. (1987) flew aerial surveys over the Bering Sea and Pacific sides of Unimak Pass and Unalaska Island in the eastern Aleutians in the summer of 1984. These surveys investigated whale occurrence in the whaling grounds off the Akutan whaling station. Brueggeman et al. (1987, 1988) investigated whale distribution and abundance in the eastern Aleutian Islands and the western Gulf of Alaska from 1985 to 1987. Subsequently, Forney and Brownell (1996) conducted a ship line transect survey in 1994 along the southern portion of the Aleutian Islands from east of Kodiak (150°W) to Tanaga Pass (~180°W), and Moore et al. (2002) reported on the abundance of cetaceans and their relationship with oceanographic and topographical features in the southeastern Bering Sea, north of the Aleutian Islands.

In July and August of 2001, 2002 and 2003 line transect surveys were conducted in coastal waters from the central Aleutian Islands to the Kenai Peninsula with the objective of estimating cetacean abundance and collecting photo-identification data, acoustics data, and biopsy tissue samples. In this paper, the current distribution of baleen whales in this area is described. In addition, estimates of abundance for fin, humpback and minke whales are presented, and trends in abundance for fin and humpback whales are examined.

2. Material and methods

2.1. Study area

Surveys were conducted in central Alaskan coastal waters from Resurrection Bay (~60°N, 150°W) to Seguam Pass (~56°N, 172°W) in 2001 and to Amchitka Pass (~57°N, 178°W) in 2002 and 2003, in the Central Aleutian Islands (Fig. 1). Cruises covered the southern portion of the Alaska Peninsula, usually within the 1000 m isobath, and both the northern and southern sides of the Aleutian Islands as far as 85 km offshore.

2.2. Survey design and period

Surveys were conducted from high points on the deck of the F/V *Aleutian Mariner* (in 2001) and the M/V *Coastal Pilot* (in 2002 and 2003). The *Aleutian Mariner* is 38 m long and has an outside observation platform 3.8 m above the sea level while the *Coastal Pilot* is 53 m long and has a bridge height of 7.5 m. Assuming an average observer's eye height of 1.7 m, the observation heights were 5.5 and 9.2 m.

The three surveys were conducted in the summer, ranged from 40 to 43 days and were divided into two legs of approximately 3 weeks each. The 2001 survey was conducted between 17 July and 5 August (Leg 1) and 8 and 25 August (Leg 2). The 2002 survey took place from 10 to 30 July (Leg 1) and from 31 July to 21 August (Leg 2), while the 2003

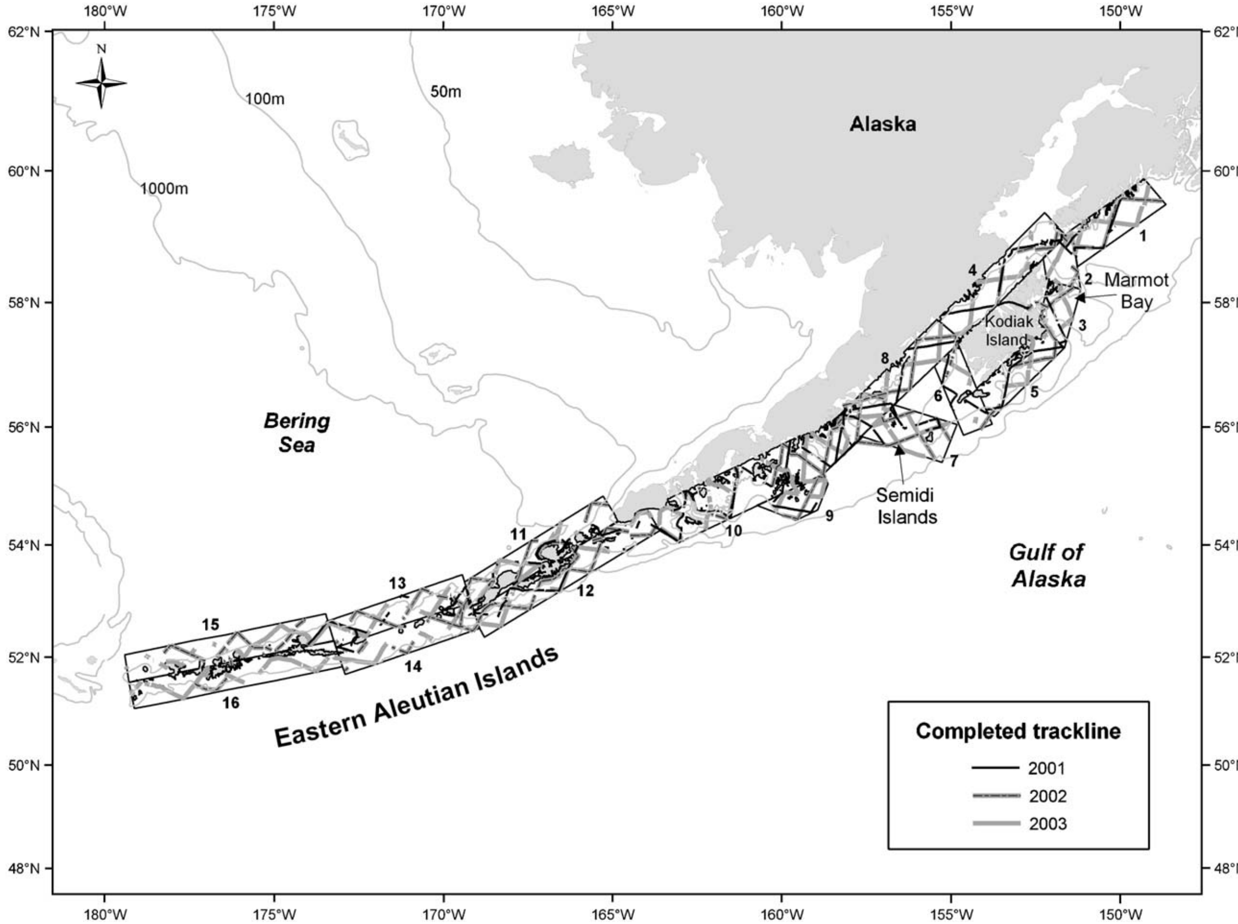

Fig. 1. Completed transect legs and blocks for whale line transect surveys in central Alaska coastal waters.

cruise was conducted between 3 and 24 July (Leg 1) and 27 July and 12 Aug (Leg 2).

The survey track followed a sawtooth (zig-zag) pattern inside a rectangle (hereafter called a block), where the offshore boundary of the block was drawn to parallel the major axis of the coastline (Fig. 1). Multiple blocks (Table 1 and Fig. 1) were established and used as the basis for a stratified survey design. Blocks 1–14 were surveyed in 2001. In subsequent years, the study area was expanded to the west, and two additional blocks were added (numbers 15 and 16 in Fig. 1). The total area surveyed was 173 636 km^2 in 2001 and 217 063 km^2 in 2002 and 2003.

Proposed effort per year was 4250 km (2001), 5470 km (2002) and 5400 km (2003). Effort per unit of area was kept constant across all proposed blocks. This provides the greatest flexibility in analysis, as a constant search effort allows pooling for analysis if desired, while still allowing for abundance and density in individual blocks to be considered. A random number generator was used to position the first transect leg in each block. Line transect legs were numbered sequentially. This survey design ensures that the tracklines provide equal coverage probability of the study area. When sighting conditions were good, the observer teams maintained marine mammal watches while transiting between transect legs. These off-effort legs were designated transit legs. Although this effort was not used for estimating density, line transect protocol was maintained because perpendicular distance information could potentially be included in estimating the detection function for line transect analysis, and sightings contributed to distribution information.

Table 1
Survey blocks, area and effort

Block	Area (km^2)	Effort (km)			
		2001	2002	2003	Years pooled
1	9060	114.2	193.3	201.3	508.8
2	3910	28.5	42.5	88.7	159.7
3	4926	116.6	125.5	97.5	339.6
4	13190	222.7	159.9	202.4	585.0
5	9757	189.6	132.2	136.1	457.9
6	7809	130.5	42.1	63.6	236.2
7	10250	95.2	231.5	187.5	514.2
8	14464	274.4	315.6	278.6	868.7
9	5487	98.9	142.9	124.5	366.3
10	28827	493.9	514.6	448.7	1457.2
11	14919	256.1	278.0	225.8	759.9
12	20214	84.1	388.2	306.5	778.9
13	15647	44.6	270.4	185.1	500.0
14	15726	182.7	235.8	135.3	553.8
15	22161		320.5	219.7	540.2
16	21266		55.4	371.8	427.2
Total	217613	2332.0	3448.5	3273.2	9053.6

2.3. Field methods

Data were collected from observation platforms on the *Aleutian Mariner* and the *Coastal Pilot*. Six observers rotated through three observation positions (starboard, recorder and port). A full observation period lasted 2 h (40 min in each position) and was followed by a 2-h rest period. The order with which individual observers rotated through the schedule was randomized. Starboard and port observers were stationed on the outside observation platform, and the data recorder was positioned inside the bridge at a computer station. Starboard and port observers used 7×50 Fujinon binoculars with reticules to search from 10° on the other observer's side of the ship's bow to 90° on their side of the ship. The data recorder searched the trackline while scanning through the viewing areas of the two primary observers. Each observer and the data recorder had an angle board to determine horizontal angle from the trackline to observed cetacean groups. If the data recorder saw a cetacean group first, he or she would alert one of the observers of a sighting and receive the necessary information from the primary observer (described below). When a sighting was made, the observer alerted the recorder of incoming information and determined the horizontal angle and number of reticules from the horizon to the sighting when it was first seen. Additional information collected was sighting cue, course and speed, species identity, and best, low and high estimates of group size. The computer program WINCRUZ (available for free download at http://swfsc.nmfs.noaa.gov/PRD/softwares/software.html) was used to record all sighting and environmental data (e.g., cloud cover, wind strength and direction, and sea conditions). The computer was interfaced to a portable GPS unit to gather positional and navigational information.

Searching effort was continuously maintained from about 30 min after sunrise to nearly 30 min before sunset, unless weather and visibility conditions (rain and fog) were poor or sea-state was above Beaufort 5. Under unacceptable weather conditions, the recorder stayed on watch at the bridge to record off effort sightings and environmental data. Most of the survey was done in passing mode with occasional switching to closing mode for some species. Passing mode was usually maintained for sightings of Dall's porpoise (*Phocoenoides dalli*), minke whales, and many sightings of large whales. The observers would sometimes briefly go off effort to confirm species identification of sightings of large whales or beaked whales, without having the vessel approach (close on) the animals. Closing mode was used for all sightings of killer whales. Killer whale groups were approached to estimate group size and to prepare for photo-identification and biopsy data collection. Closing mode was occasionally used for sightings of large whales, particularly humpback, fin and sperm whales, again for the purpose of photo-identification and biopsy sampling. When effort resumed, the survey would recommence on a convergent course and would return to the original trackline within a few miles.

Radial distance to each sighting was calculated using 'approximation 2' of Lerczak and Hobbs (1998, erratum) from the binocular reticule measurements and platform height. Perpendicular distance was calculated by multiplying the radial distance by the sine of the horizontal angle obtained with the angle board.

Sightings made by the ship's crew, off-watch observers or during unfavorable weather conditions were recorded as off-effort and were not used in density estimate calculations.

2.4. Estimation of detection probability

Detection probability (P) was estimated by modeling ungrouped perpendicular distance data using both conventional (CDS) and multiple covariate distance sampling (MCDS) approaches (Buckland et al., 2001; Marques and Buckland, 2003). MCDS differs from CDS because it allows for the inclusion of environmental covariates in the estimation of detection probability. Covariates are incorporated via the scale parameter σ (e.g. Innes et al., 2002; Marques and Buckland, 2003). Models were proposed to investigate the effects of covariates on P. Sea conditions were determined according to the Beaufort Scale, which is an index of wind speed, estimated from the effect of wind on the surface of the sea. Beaufort and group size were treated as continuous covariates. A third covariate, "ship", was a two-factor variable used to investigate the effects of different observation platform heights. The observation platform on the *Aleutian Mariner* was substantially lower than the one on the *Coastal Pilot*. For each species, covariates were tested singly or in additive combination. A set of 16 candidate models was proposed to fit perpendicular distance data of fin and humpback whales. Because of small sample size, only eight models (with single covariates) were considered for minke whales. It is expected that P is positively correlated with cluster (group) size and platform height, but negatively correlated with Beaufort sea state. If proposed models were inconsistent with these expectations, models were deleted from the analysis before model selection and model averaging were performed. Models were ranked according to the Akaike Information Criterion (AIC) (Akaike, 1985). Unconditional model selection variance was incorporated in the estimates and confidence intervals through model averaging (Burnham and Anderson, 2002).

The probability of detecting whales on the trackline was assumed to be unity ($g[0] = 1$) (but see discussion regarding minke whales).

2.5. *Group size estimation*

Group sizes have the potential to affect estimates of P. If larger groups are easier to detect further away from the trackline, use of average group size can bias estimates. Exploratory analysis (regression of group size versus detection probability, Buckland et al., 2001) suggested that detections were independent of group size for the species considered in this study. Therefore, mean group sizes were used to estimate abundance with CDS models. For MCDS models, individual group sizes were used in the estimation of detection probability, and an estimate of the expected mean group size was obtained as suggested by Marques and Buckland (2003, Eq. (16)).

2.6. *Abundance estimation*

Abundance was estimated for each model of P considered. Population size was estimated for the three sequential years in order to obtain a time series of population size estimates for each species in the area. A combined estimate was also calculated and is considered an average 'best' estimate for each species in the region during the survey period (field seasons spanning just over 2 years). For combined years, effort in each block was pooled across years, and a single block-specific estimate was obtained. Perpendicular distances were pooled across blocks and years. Total abundance is the sum of the abundance in each block. For individual year estimates, effort was kept separated, and the number of blocks differs between 2001 ($n = 14$) and the following 2 years ($n = 16$). However, perpendicular distance data were pooled across years to estimate P.

Abundance and variance were estimated as in Innes et al. (2002) and Marques and Buckland (2003). Log-normal 95% confidence intervals (Buckland et al., 2001) were calculated for the model-averaged parameter estimates after unconditional variance was derived.

2.7. *Estimates of rate of increase and trends in abundance*

The rate of increase was calculated for fin and humpback whales using estimates of density obtained in 1987 (Brueggeman et al., 1988, 1989) and in 2001–2003 (this study). While survey conditions were relatively similar between these two studies, area covered and analytical methods were slightly different, and therefore adjustments were needed to make estimates comparable.

Brueggeman et al. (1988, 1989) conducted line transect ship surveys over the continental shelf and upper slope south of the Alaska Peninsula from 150°W to 164°W in the summer. The survey area was divided into three strata: Cook Inlet, Kodiak and Shumagin (Fig. 14.4 in Brueggeman et al., 1988). The Cook Inlet and Kodiak strata were subsequently pooled in their analysis, and therefore separate abundance estimates were obtained for the

Shumagin and the Kodiak-Cook Inlet strata and a total abundance for the two regions pooled. The longitudinal sector of the area surveyed in 1987 overlapped with the area covered by blocks 2–10 in the 2001–2003 cruises. The Kodiak-Cook Inlet and the Shumagin strata corresponded, respectively, to blocks 2–6 and 7–10. A few lines in the 1987 survey were placed further offshore than the lines surveyed in the present study and estimated abundance in 1987 was extrapolated to an area 26% greater than the area surveyed in 2001–2003.

In 1987, searching for cetaceans was conducted in good to acceptable visibility conditions (e.g. Beaufort sea-state 0–5) from the flying bridge of the ship at about 10 m above sea level (Brueggeman et al., 1988, 1989). One observer collected sighting data by searching a 45° area centered on the bow of the ship; radial distance and angle were determined with a sighting gauge graduated at 0.46 km (0.25 nm) and a compass. CDS methods were used to estimate density. Perpendicular distance data for fin and humpback whales were pooled and truncated at 4 km. A Fourier series model (equivalent to a uniform key function with a cosine series expansion, Buckland et al., 2001) was used to estimate detection probability (*f*[0]; see Fig. 10 in Brueggeman et al. 1988). Density was estimated by multiplying the estimated detection probability by the average group size and the encounter rate.

Effort allocation in 1987 was not proportional to the areas of the blocks proposed in 2001–2003. Because density estimates in 1987 were extrapolated for the area surveyed in 2001–2003, they needed to be adjusted to make the estimates comparable across years. Effort in 1987 was calculated by scanning and saving Fig. 14.4 in Brueggeman et al. (1989) as a digital file. This file was imported into ArcMap 8.2 as a raster dataset layer and subsequently saved as a georeferenced map. Surveyed transects were redrawn and converted to a shapefile, which was then used to measure effort. The proportion of effort in blocks 2–10 was calculated for 1987. Area (D_A) and effort (D_L) weighted densities were derived according to the following equations:

$$D_A = \frac{\sum \hat{D}_i A_i}{\sum A_i} \text{ and } D_L = \frac{\sum \hat{D}_i L_i}{\sum L_i},$$

where $\hat{D}_i$ is the density estimated in block i in 2001–2003; A_i is area of block and L_i is effort of the 1987 survey in block i.

The correction factor is then given by D_A/D_L. Density estimates from Brueggeman et al. (1988, 1989) for each stratum were multiplied by the correction factor and the size of the stratum to obtain the corrected estimates of abundance. This adjustment assumes that abundance may have changed through time, but that the distribution of whales has not changed within the two strata.

Rates of increase were estimated for the Kodiak-Cook Inlet (blocks 2–6) and Shumagin (blocks 7–10) strata, and for the whole survey area (blocks 2–10) by fitting an exponential growth model to the estimated abundances assuming a log-normal error distribution. In this model, the instantaneous intrinsic rate of increase (r) in the population (N) is constant over time (t): $N_t = N_0 e^{rt}$. The rate of increase can be estimated in a linear regression framework ($\ln[N_t] = \ln[N_0] + rt$, where r is the slope of the regression). In order to account for the variability in precision, the estimates of abundance were weighted by the inverse of their CV^2. Confidence intervals of the estimated rate of increase were calculated as: 95% $CI = r \pm t_{0.05,\ df}$ $*SE(r)$. The instantaneous rates (r) were converted into annual rates of increase ($e^r - 1$).

3. Results

Approximately 60% of the proposed trackline was surveyed in acceptable weather conditions covering 9053.6 km during 2001–2003 (Table 1). A total of 276, 406 and 95 sightings (565, 762 and 98 individuals) of fin, humpback and minke whales, respectively, were recorded (Table 2).

3.1. Distribution

The distribution of fin, humpback and minke whale sightings is illustrated in Figs. 2–4.

3.1.1. Fin whale

The distribution of sightings of fin whales was consistent across years with virtually all records occurring from the Kenai Peninsula to the Shumagin Islands (Fig. 2). Only a few whales were seen in the Aleutian Islands, and all of them were to the north on the Bering Sea side. Very large concentrations were found on the south side of the Alaska Peninsula in the region around the Semidi Islands. In the Kodiak Island area, there appears to be a shift between years. In 2001, a few sightings occurred approximately 50 km south of the Kenai

Table 2
Summary of sightings and total number of individuals (in parentheses) observed

Species	On effort			Off effort			Total		
	2001	2002	2003	2001	2002	2003	2001	2002	2003
Fin whale	79 (185)	130 (251)	46 (94)	7 (19)	12 (14)	2 (4)	86 (204)	142 (265)	48 (96)
Humpback whale	134 (263)	118 (207)	108 (204)	18 (31)	13 (25)	15 (32)	152 (294)	131 (232)	123 (236)
Minke whale	30 (31)	20 (20)	22 (23)	3 (4)	16 (16)	4 (4)	33 (35)	36 (36)	26 (27)

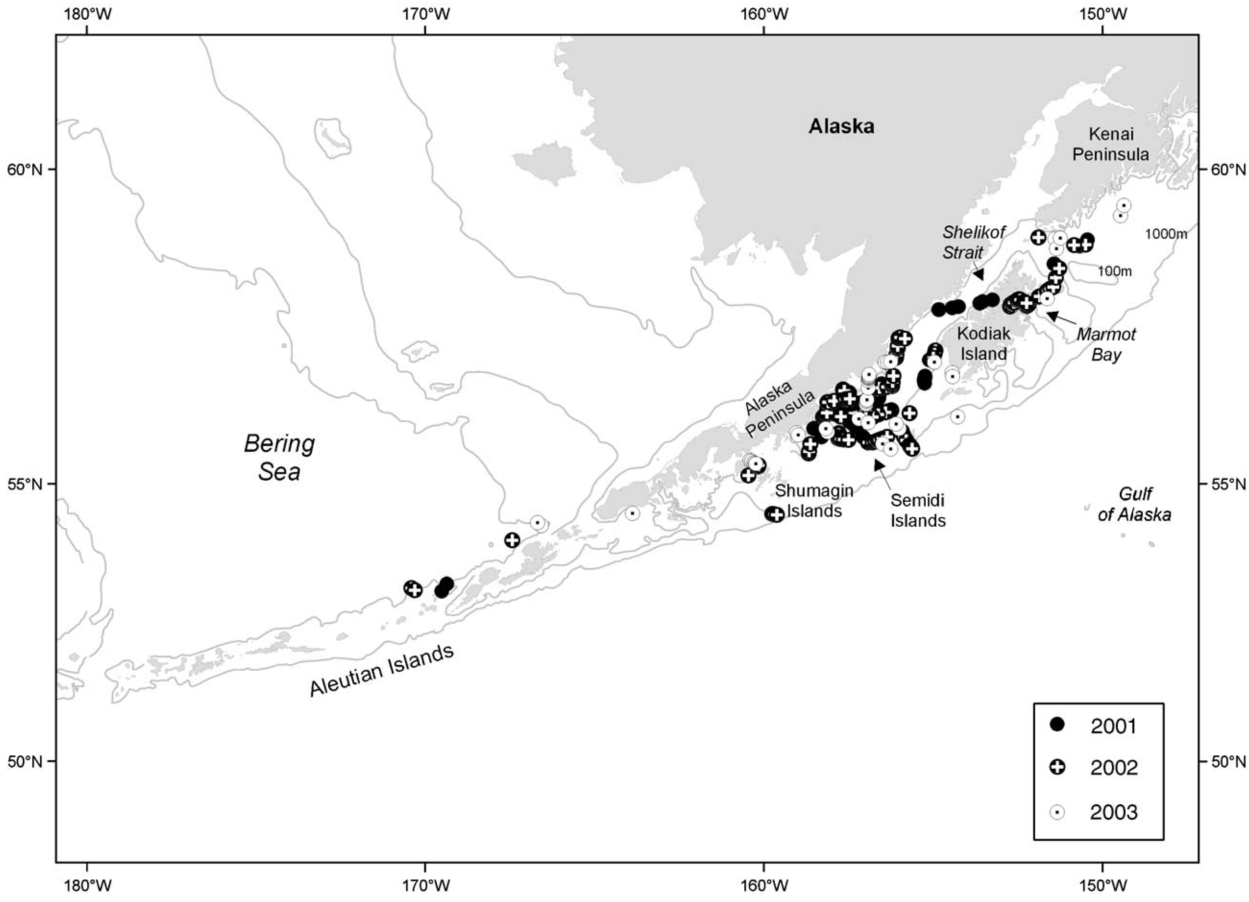

Fig. 2. Fin whale sightings off the Alaska Peninsula and Aleutian Islands.

Peninsula, and in 2002 a high concentration was observed in Marmot Bay (NE Kodiak Island) and along the east side of Afognak Island. In 2003, a few fin whale sightings were recorded south of the Kenai Peninsula. This species was the most commonly seen large whale species in Shelikof Strait.

3.1.2. Humpback whale

Humpback whales were observed from the Kenai Peninsula to Umnak Island in the eastern Aleutian Islands (Fig. 3). The Aleutian Islands west of Umnak Island show a clear absence of sightings. The distribution of this species between Unalaska

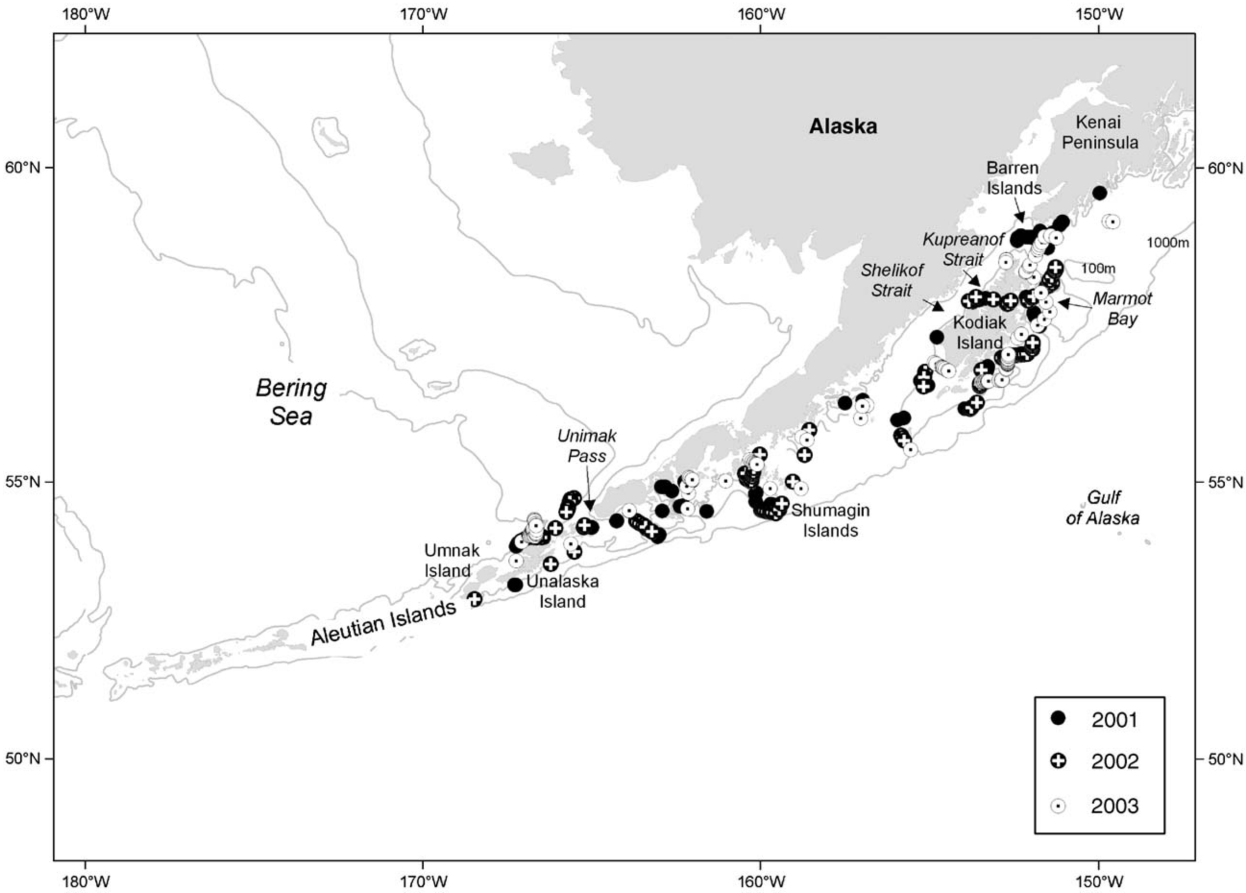

Fig. 3. Humpback whale sightings off the Alaska Peninsula and Aleutian Islands.

Island and the Shumagin Islands was consistent across years, with high concentrations on the north side of Unalaska Island to Unimak Pass and from Unimak Pass to the Shumagin Islands (some apparent differences may reflect differences in survey effort across years). In the Kodiak Island region, humpback whales were found along the southwest side of Kodiak Island, in Kupreanof Strait, and in and around Marmot Bay in all years. However, some differences in highly concentrated areas were found across years. In 2001, a high aggregation of the species was found around the Barren Islands to the Kenai Peninsula. In 2002, none were found in this same area, but instead a large concentration occurred approximately 70 km south on the east side of Afognak Island (north of Kodiak Island). The large aggregation observed on the east side of Kodiak Island (in waters off Sitkalidak Island to Ugak Island) in 2002 was not found in 2001. In 2003, humpback whales were concentrated west and north of Kodiak Island and, as in 2001, near the Barren Islands. The species was rarely seen in the Shelikof Strait area.

3.1.3. Minke whale

The distribution of minke whale sightings (Fig. 4) was concentrated in the eastern Aleutian Islands with a few scattered observations along the Alaska Peninsula and Kodiak Island. Local aggregations were highly consistent across years in and around Seguam Pass, and around the Islands of the Four Mountains. A few sightings were observed in each year between Unalaska Island and the Shumagin Islands, but minke whales were not observed in the Semidi Island area. A few observations occurred along the Pacific (south/eastern) side of Kodiak Island.

3.2. Density and abundance

Model parameter estimates for fin, humpback and minke whales are presented in Table 3. Table 4

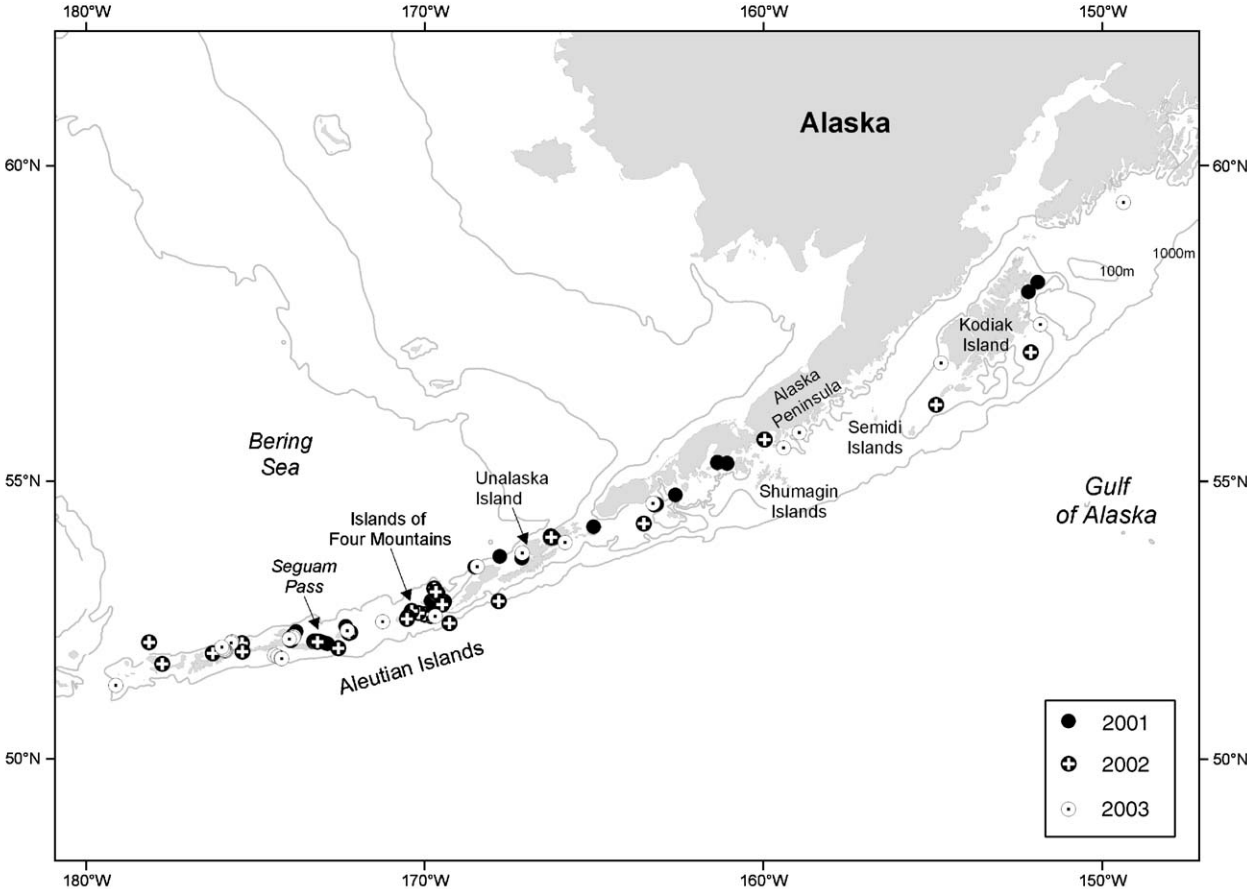

Fig. 4. Minke whale sightings off the Alaska Peninsula and Aleutian Islands.

summarizes model-averaged total and block-specific density and abundance estimates for individual and pooled years.

3.2.1. Fin whale

A total of 13 models to estimate probability of detection was considered for fin whale sightings. The best model was the hazard rate with ship and group size as covariates (Table 3 and Fig. 5). Models with the hazard rate function received more support than those with half-normal function, for which ΔAIC was above 5.2. The hazard rate model without covariates ranked fourth in the model selection process, but it was still relatively well supported (ΔAIC = 2.63).

The density of fin whales was highest southwest of Kodiak Island and around the Semidi Islands (0.035 whales/km^2). In other areas of fin whale occurrence, density was substantially less: 0.008 whales/km^2 north of Kodiak and in the Shelikof Strait, and 0.003 whales/km^2 west of the Shumagin Islands. Overall density was 0.007 whales/km^2 and average abundance across years was 1517 whales (95% CI = 1039–2212).

3.2.2. Humpback whale

Seven models were considered to estimate detection probability of humpback whales. The hazard rate model with ship as a covariate was the best model (Table 3 and Fig. 5). The hazard rate model without covariates was the second best model (AIC = 0.95). Two half-normal models with covariates received slightly less support (AIC = 1.71 and 9.64).

Density of humpback whales was greatest in the Kodiak Island region. Average density on the northeast, east and southeast sides of the island, including Marmot Bay, was 0.054 whales/km^2. Densities in the Shumagin Island area and west of Unimak Pass were, respectively, 0.02 and 0.012 whales/km^2. Overall density across the study

Table 3
Summary of model selection and parameter estimates for models proposed to fit perpendicular distance data for fin, humpback and minke whales

Model, covariates	ΔAIC	w_i	Par. no.	Model parameters													
				$\hat{N}$	CV($\hat{N}$))	$E(S)$	$\bar{P}$	B	SE	θ_0	SE	$\theta_{Beaufort}$	SE	θ_{ship}	SE	θ_{size}	SE
Fin whale																	
hz, ship + size	0.00	0.35	4	1488	0.19	1.89	0.428	1.818	0.282	−0.247	0.307			0.439	0.220	0.149	0.091
hz, ship	0.67	0.25	3	1570	0.20	2.08	0.433	1.812	0.286	0.055	0.228			0.437	0.216		
hz, size	2.08	0.12	3	1494	0.18	1.85	0.418	1.673	0.265	−0.061	0.246					0.168	0.098
hz	2.63	0.09	2	1595	0.18	2.05	0.422	1.646	0.262	0.262	0.172						
hz, beauf + ship	2.66	0.09	4	1567	0.20	2.08	0.434	1.820	0.291	0.083	0.316	−0.007	0.075	0.436	0.216		
hn, beauf + ship	5.23	0.03	3	1398	0.17	2.07	0.490			0.737	0.155	−0.081	0.044	0.258	0.103		
hn, beauf + ship + size	5.85	0.02	4	1364	0.17	1.97	0.488			0.351	0.233	−0.080	0.043	0.265	0.102	0.055	0.043
hn, ship	6.56	0.01	2	1374	0.17	2.07	0.493			0.516	0.078			0.263	0.100		
hn, ship + size	7.16	0.01	3	1340	0.17	1.98	0.491			0.404	0.112			0.267	0.100	0.054	0.043
hn, beauf	8.04	0.01	2	1373	0.16	2.05	0.495			0.917	0.117	−0.080	0.070				
hn, beauf + size	8.86	0.004	3	1341	0.16	1.97	0.493			0.810	0.134	−0.078	0.039			0.048	0.044
hn	9.62	0.003	1	1348	0.16	2.05	0.498			0.702	0.049						
hn, size	10.29	0.002	2	1315	0.16	1.97	0.499			0.602	0.090					0.049	0.043
Humpback whale																	
hz, ship	0.00	0.33	3	2648	0.17	1.90	0.425	2.321	0.295	0.273	0.130			0.227	0.132		
hz	0.95	0.20	2	2704	0.16	1.89	0.422	2.249	0.277	0.390	0.102						
hz, beauf + ship	1.44	0.16	4	2652	0.17	1.90	0.423	2.301	0.291	0.380	0.203	−0.037	0.054	0.217	0.134		
hn, ship	1.71	0.14	2	2547	0.16	1.89	0.440			0.403	0.065			0.277	0.082		
hz, beauf	2.07	0.12	3	2712	0.16	1.89	0.418	2.225	0.272	0.523	0.189	−0.049	0.055				
hn	9.64	0.003	1	2547	0.15	1.89	0.447			0.586	0.037						
Minke whale																	
hn, beauf	0.00	0.52	2	1062	0.27	1.02	0.392			−0.234	0.167	−0.238	0.090				
hz, beauf	1.85	0.20	2	1392	0.31	1.03	0.301	1.658	0.419	−0.804	0.396	−0.261	0.176				
hz	1.94	0.20	3	1573	0.34	1.03	0.291	1.508	0.394	−1.342	0.387						
hn	3.63	0.08	1	1093	0.28	1.03	0.418			−0.562	0.080						

hz—hazard rate, hn—half-normal, beauf—Beaufort covariate, ship—ship factor covariate, size—group size covariate, w_i—Akaike weight, P—average detection probability, SE—standard error.

Table 4
Density and abundance estimates of fin, humpback and minke whales in coastal waters of the Alaska Peninsula and Aleutian Islands

Block	Combined years											
	Fin whale				Humpback whale				Minke whale			
	D	*N*	CV	95% CI	*D*	*N*	CV	95% CI	*D*	*N*	CV	95% CI
1	0.008	72	0.36	36–144	0.002	21	0.44	9–47				
2	0.003	11	1.03	2–58	0.052	205	0.25	126–331				
3	0.019	94	0.77	24–356	0.046	227	0.37	113–454	0.006	28	0.74	7–103
4	0.005	68	0.64	21–216	0.013	169	0.99	33–850				
5					0.066	645	0.32	350–1187				
6	0.038	294	0.56	105–818	0.061	474	0.46	202–1110	0.004	35	0.90	7–157
7	0.021	211	0.34	111–401	0.004	46	0.67	13–151				
8	0.040	577	0.28	334–993	0.002	25	0.72	7–89				
9	0.005	29	1.25	4–190	0.020	110	0.61	36–328				
10	0.004	107	0.42	48–234	0.012	344	0.34	178–661	0.002	63	0.52	24–162
11												
12	0.002	23	0.58	8–67	0.020	302	0.56	108–837	0.003	40	0.74	10–145
13					0.004	80	0.40	37–171	0.004	89	0.71	25–310
14	0.001	14	0.76	3–52					0.013	204	0.85	48–859
15	0.001	17	0.85	3–70					0.017	262	0.40	123–554
16									0.016	365	0.63	117–1132
17									0.007	147	0.81	36–592
Total	0.007	1517	0.19	1039–2212	0.012	2648	0.16	1933–3624	0.006	1232	0.34	646–2346
Year	Yearly estimates											
	Fin whale				Humpback whale				Minke whale			
	D	*N*	CV	95% CI	*D*	*N*	CV	95% CI	*D*	*N*	CV	95% CI
2001	0.007	1615	0.38	789–3301	0.011	2402	0.37	1191–4841	0.011	2460	0.37	1212–4992
2002	0.008	1685	0.23	1083–2619	0.012	2604	0.23	1676–4045	0.003	635	0.39	305–1316
2003	0.004	956	0.34	498–1831	0.013	2945	0.18	2090–4148	0.007	1575	0.38	771–3215

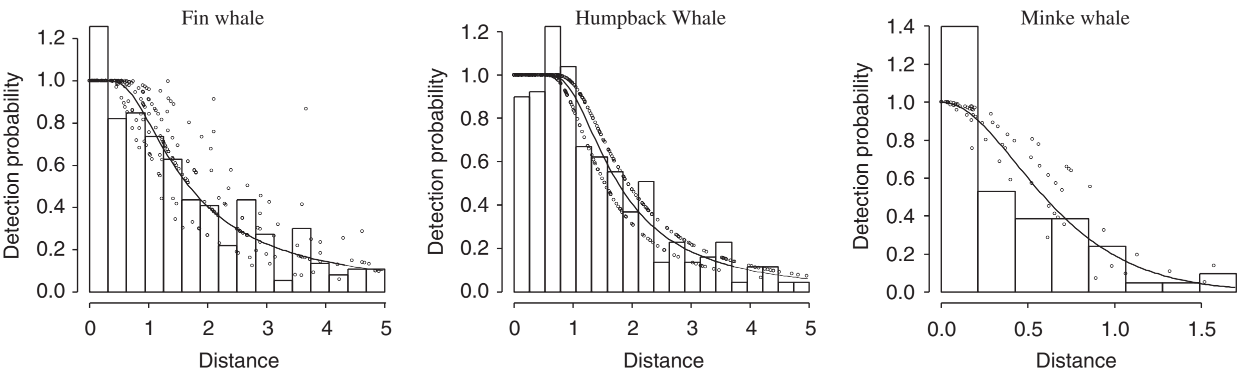

Fig. 5. Histograms of perpendicular distance (km) and fitted detection functions for best AIC selected model (dots represent detection probability for each individual sighting).

area was 0.012 whales/km^2 and average abundance from 2001 to 2003 was 2648 whales (95% CI = 1933–3624).

3.2.3. *Minke whale*

Four models were considered to estimate minke whale detection probability. The half-normal model with Beaufort sea state as covariate was selected as the best model (Table 3 and Fig. 5). The hazard rate and the half-normal models without covariates were not as well supported by the data (AIC = 1.94 and 3.50, respectively).

Average density of minke whales was greater west of Unimak Pass (0.01 whales/km^2) than in the southern portion of the Alaska Peninsula and Kodiak Island (0.001 whales/km^2). Areas with higher density were the southern portion of the Unalaska and Umnak Island and Samalga, Amukta and Seguam Passes. Overall density of minke whales across the study area was 0.006 whales/km^2, and average abundance through the study period was 1232 individuals (95% CI = 646–2346).

3.3. Rate of increase and trends in abundance

Estimates of abundance for the Shumagin and Kodiak areas, and for both strata pooled, are presented in Table 5, and estimates of annual rates of increase are presented in Table 6. The estimates indicate that fin and humpback whale populations increased in the last 15 years, but only the trend for humpback whales was significantly different from zero. Estimated rates of increase were higher in the the Kodiak-Cook Inlet than the Shumagin area for humpback whales, but the opposite was observed for fin whales.

Table 5
Estimates of abundance of fin and humpback whales used in the estimation of rates of increase

Year	Kodiak stratum		Shumagin stratum		Combined Strata	
	N	95% CI	*N*	95% CI	*N*	95% CI
Fin whale						
1987	142	51–395	607	214–1716	742	322–1737
2001	561	149–2107	883	400–1945	1444	666–3126
2002	403	167–967	1113	726–1704	1516	1008–2277
2003	198	122–320	604	247–1474	802	390–1647
Humpback whale						
1987	616	299–1265	214	74–614	830	458–1502
2001	1701	758–3813	490	214–1117	2191	1145–4189
2002	1544	918–2596	593	238–1472	2137	1343–3398
2003	1931	1527–2440	494	216–1126	2425	1845–3186

4. Discussion

4.1. Distribution

The western Gulf of Alaska and the Aleutian Islands are historical feeding grounds for several large whales (e.g. Nishiwaki, 1966; Rice, 1998). The distribution of sightings of fin, humpback and minke whales observed during the present study is consistent with previous surveys conducted in the area (e.g. Brueggeman et al., 1988, 1989; Forney and Brownell, 1996), but differs for some species from historical catch data (e.g. Nishiwaki, 1966; Reeves et al., 1985), at least in coastal areas.

4.1.1. Fin whales

Fin whale distribution in the Aleutian Chain and the Alaska Peninsula is relatively restricted if compared to other species. Whales were most abundant near the Semidi Islands, where very limited intra-annual variation in sighting distribution was observed. Fin whales were also common around Kodiak Island and in the Shelikof strait, where some variation in their occurrence was observed across years. Records of fin whales around Kodiak and in the Shelikof Strait were common both during and after the whaling period. Reeves et al. (1985) documented early 20th century commercial catches from two coastal whaling stations in Alaska, Akutan (Unimak Pass) and Port Hobron (Sitkalidak Island, southeast of Kodiak Island). Reported fin whale catch locations off Port Hobron and current sighting data are consistent, indicating that the species is currently found in the same area where they were once captured. In addition, surveys

Table 6
Annual rates of increase of fin and humpback whales in western Alaska and the Aleutian Islands (period 1987–2003)

Stratum	Fin whale			Humpback whale		
	Increase rate (%)	95% CI	*p*	Increase rate (%)	95% CI	*p*
Kodiak/Cook Inlet	2.8	−15.2–30.9	0.628	7.3	3.2–11.7	0.016
Shumigan	4.0	−10.7–22.3	0.489	6.0	1.2–11.0	0.033
Total	3.6	−9.9–22.4	0.444	6.6	5.2–8.6	0.003

in the 1980s (Brueggeman et al., 1988, 1989) as well as platform of opportunity data from 1958 to 1997 (S. Mizroch, pers. comm.) also show the occurrence of fin whales off Kodiak Island and in the Shelikof Strait. The presence of a large concentration of whales near the Semidi Islands was not so clear in previous catch data (Reeves et al., 1985; S. Mizroch, pers. comm.), possibly because of a lack of observation effort or local shifts in distribution, or both.

Only a few fin whales were seen west of 160°W in coastal waters of the eastern and central Aleutian Islands. This is somewhat inconsistent with both pelagic and coastal whaling records. Catch data suggested that the fin whales were common north of the central Aleutian Islands from Unalaska Island to Seguam Pass in July and August (e.g. Nishiwaki, 1966; S. Mizroch pers. comm.). While some whales were possibly taken further offshore, many catches close to shore were also observed. Fin whales were the most important species for Akutan whalers, and whaling records also showed that the species was common on the Bering Sea side of the Aleutian Chain (Reeves et al., 1985). Other recent data confirm our observations. Aerial surveys conducted in the vicinity of the whaling grounds off Akutan resulted in only three fin whale sightings (Stewart et al., 1987). Platform of opportunity sightings (S. Mizroch, pers. comm.) in the Aleutian Islands and the Bering Sea show only a few nearshore records off the northern side of Unalaska Island. In contrast, fin whales are more common further north in the Bering Sea, where the species is known to be currently abundant (Moore et al., 2002). Thus, contemporary sighting data reinforce the results that fin whales are not common in the former whaling grounds in coastal waters of the eastern Aleutian Islands.

4.1.2. Humpback whales

Humpback whales are known to feed in the summer in several areas in the North Pacific Ocean (Nishiwaki, 1966; Calambokidis et al., 1996; Rice, 1998). Pelagic and coastal whaling catch records indicated that humpback whales were regularly taken along the Aleutian Islands and south of the Alaska Peninsula (Nishiwaki, 1966; Wada, 1981; Reeves et al., 1985), but provided limited data on small-scale patterns of distribution.

Post-whaling studies on the feeding grounds have primarily been concentrated along the western coast of North America, southeastern Alaska and Prince William Sound (Baker et al., 1986; von Ziegesar et al., 1994; Calambokidis et al., 1996). In the early 1990s, a series of ship surveys provided new data on the occurrence of humpback whales south of the Alaska Peninsula and along the eastern Aleutian Islands (M.E. Dahlheim and J.M. Waite, pers. comm.; Forney and Brownell, 1996; Waite et al., 1999). These surveys identified humpback whale aggregations around Kodiak Island, in the Shumagin Islands and north of Unalaska Island (Waite et al., 1999). An extensive photo-identification study has been conducted on the aggregation near the Shumagin Islands (Witteveen et al., 2004). A few offshore sightings south of the Alaska Peninsula were also made (Forney and Brownell, 1996). In this study, humpback whales were found from the western Gulf of Alaska to Unalaska Island. Although the distribution is continuous from the western Gulf of Alaska to Unimak Pass, areas of aggregation are consistent with previous studies. In addition, data presented in this study indicate that humpback whales are common in their former whaling grounds off Port Hobron and Akutan, though this does not necessarily mean that they are fully recovered.

The results presented here show an interesting pattern in the distribution of humpback and fin whale sightings south of the Alaska Peninsula. Fin whales were concentrated near the Semidi Islands, where very few humpback whales were recorded. In contrast, the latter were found in relatively large numbers south and west of Kodiak and near the Shumagin Islands, where fin whales were relatively rare. This pattern was consistent across three summers and is suggestive of habitat partitioning. This was not evident in the whaling records, which indicated an overlap in fin and humpback whale distribution (Reeves et al., 1985). Historical information on the food habits of these species suggest that fin whales consumed mostly euphausids in the Gulf of Alaska, while the humpback diet consisted of both schooling fishes and euphausiids (Thompson, 1940). The observed differences in the current distribution pattern may suggest that fin and humpback whales are consuming different prey during their feeding season in coastal waters of the Gulf of Alaska, or taking the same prey but with different patch or depth characteristics. Further studies should be conducted to better understand these differences and the preferred habitat of large baleen whales in this area.

4.1.3. Minke whales

Limited information on minke whale distribution is available from whaling periods because the species was not harvested in the northern North Pacific Ocean and the Bering Sea (Reeves et al., 1985). Survey data revealed that minke whales are relatively common in the Bering Sea and the Gulf of Alaska, where they are usually found within the 200 m contour (Brueggeman et al., 1987, 1988; Moore et al., 2002). In this study, minke whales were found mostly west of Unimak Pass, with few records off the Alaska Peninsula and Kodiak Island. Also, most of the sightings were very close to shore. This is consistent with both ship and aerial surveys conducted in the area in the past 15 years (Brueggeman et al., 1987; Forney and Brownell, 1996).

4.1.4. Other whales

The region surveyed in the present study was a historical summering area and an important whaling ground for other large whale species. North Pacific right and blue whales were taken in large numbers during whaling periods in the area (Nishiwaki, 1966; Reeves et al., 1985; Scarff, 2001, Shelden et al., 2005), but no sightings of these species were made during this study. This supports current beliefs that these populations are still severely depleted in the North Pacific Ocean (Perry et al., 1999; Angliss et al., 2001; Angliss and Lodge, 2002; Brownell et al., 2001). In the past 20 years, few records of these species are available. Brueggeman et al. (1987, 1988, 1989) conducted aerial and ship surveys in the southern Bering Sea and south of the Aleutian Islands in 1985 and did not report any blue or right whale sightings. Similarly, Stewart et al. (1987) did not detect any blue or right whales in the vicinity of Akutan. Nine years later, Forney and Brownell (1996) conducted ship surveys off the southern portion of the Alaska Peninsula and the Aleutian Islands and also did not report any sighting of these species. A small number of right whales have been observed in the southeastern Bering Sea in recent years (Goddard and Rugh, 1998; Moore et al., 2000; LeDuc et al., 2001; Waite et al., 2003). Only one of these sightings has been made near the Aleutian chain, just north of Unimak Pass in April (Shelden et al., 2005). Blue whales have not been visually recorded recently, but recent acoustic recordings indicate that blue whales are found in the offshore Gulf of Alaska from mid-July through mid-December (Stafford, 2003).

4.2. Abundance

Estimates of abundance presented in this study assumed that no whales were missed on the trackline ($g[0] = 1$). Failure to meet this assumption is common in marine mammal surveys and causes negative biases in density estimates (Laake, 1999; Buckland et al., 2001). The magnitude of this bias is possibly small in the estimates of large whales with visible bodies and conspicuous blows such as fin and humpback whales. Correction factors for whales missed on the trackline derived for humpback and blue whales suggest that detection during ship surveys is nearly 90–100%, depending on visibility conditions and group size (Barlow, 1995; Barlow and Gerrodette, 1996; Calambokidis and Barlow, 2004). On the other hand, the lack of a $g(0)$ correction factor likely causes substantial bias in the estimation of minke whale abundance. Skaug and Schweder (1999) estimated that 56–68% of groups are missed in ship surveys for minke whales in the North Atlantic Ocean. No attempt to correct for this negative bias has been made in this study, so estimates of minke whale abundance presented here must be viewed as minimum estimates.

This study differs from many previous large whale line transect analyses because it incorporates covariates in detection probability estimation. The Beaufort covariate was an important factor in estimating the detection probability of minke whales, but not as important for fin and humpback whales. A reasonable explanation for these results is the difference in the visibility of sighting cues between these species. Fin and humpback whales have conspicuous sighting cues (e.g. tall blows, large body), which are usually visible in the range of sea conditions (Beaufort 0–5) examined in this study. In contrast, minke whales are small and present inconspicuous cues (e.g., no blow). Therefore, it is expected that detection of this species is much more affected by sea conditions and other environmental variables than detection of larger whales. Group size was an important covariate in models for fin whales, but not for the other species. Minke whales observed during this study were usually solitary, with 97% of the sightings being of single animals. Thus, it was expected that group size would not play an important role in the probability of detecting minke whales. The range of group sizes was greater for fin and humpback whales, but still an overwhelming proportion of sightings were of small groups (95% and 97% $\leqslant 4$ individuals for fin and humpback whales, respectively). Humpback whale models with group size as a covariate were inconsistent with the expectation that detection probability and size of groups are positively correlated and therefore were not considered. Finally, the ship covariate was important in fin and humpback whale models, showing that the height of the observation platform indeed affects the probability of detection. Mean detection (radial) distances for fin and humpback whales in the ship with the lower observation platform were 2.72 and 2.66 km, respectively. For the ship with the higher platform they were 3.2 and 3.4 km. The lack of effect of ship's height for minke whales is likely explained by the fact that this species is usually seen at close range. Therefore, ship height is not expected to affect sightability as long as the height of the observation platform results in a horizon that is greater than the typical range over which minke whales are detected. In this study, mean detection distance for the low and high platforms was similar (1.32 and 1.34 km, respectively) for this species.

One of the major advantages of using MCDS methods is to minimize heterogeneity and reduce bias and variability in estimating sighting probability (Marques and Buckland, 2003). In this study, MCDS models were usually selected as better than CDS models, but estimates of abundance and precision obtained with these two categories of models were quite similar for species with conspicuous cues and small variation in group size. Possible explanations for the small difference between conventional and covariate models include (1) relatively homogeneous sighting conditions throughout the study area and (2) that the covariates selected do not affect detectability when sighting conditions vary within the range in which data were collected (e.g., good visibility and relatively low [0–5] Beaufort sea state). While there are benefits in using MCDS models (e.g., Marques and Buckland, 2004), in the present study this was evident only for minke whales.

Ship surveys presented in this study covered a portion of the range of whale stocks in their feeding grounds. Therefore, they likely refer to an unknown fraction of the total populations in the North Pacific Ocean. Fin whales are found in the Bering Sea, and in the central and eastern Gulf of Alaska in the summer (Forney and Brownell, 1996; Moore et al., 2002; S. Mizroch pers. comm.), but the current stock size is unknown. Moore et al. (2002) estimated a total of approximately 4000 fin whales in the Bering Sea in the summer 1999/2000, while the present study indicates that nearly 1600 whales occur in coastal waters south of the Alaska Peninsula between 150° and 160°W. The two estimates (Bering Sea + Alaska Peninsula) combined correspond to about 5600 fin whales.

Humpback whales are known to occur to the south of the Aleutian Islands as far offshore as the 200 nm United States Economic Exclusive Zone (Forney and Brownell, 1996); to the north, over the continental shelf of the Bering Sea (Moore et al., 2002); and to the east in the Gulf of Alaska (Perry et al., 1990; Baker et al., 1992; von Ziegesar et al., 1994, Witteveen et al., 2004). Thus, the abundance estimation reported here, nearly 2650 whales, represents only a portion of the total number of humpback whales presumably feeding in high-latitude waters of the North Pacific Ocean. In fact, the most complete recent estimate of North Pacific humpback whale abundance was conducted using mark-recaptures of individual whales photo-identified between 1990 and 1993. This study yielded an estimate of 6000–8000 whales (Calambokidis et al., 1997, 2001). Witteveen et al. (2004) estimated that 410 humpback whales ($CV = 0.275$) inhabited the Shumagin Islands in 2002. The figures presented here are consistent with this estimate: line transect methods resulted in an estimated abundance of 454 individuals ($CV = 0.31$) in the region near the Shumagin Islands (blocks 9 and 10 in the present study) for the period 2001–2003.

Abundance of minke whales is unknown in the eastern North Pacific except for an estimate of 1015 individuals ($CV = 0.73$) from offshore California, Oregon and Washington states (Barlow, 2003). While the numbers provided are not corrected for whales missed on the trackline, they represent a minimum estimate of the population summering in the area covered in this study.

4.3. Rates of increase and trends in abundance

Estimates of rates of increase indicate that humpback and fin whale populations have been growing in the Gulf of Alaska. The trend for humpback whales was positive and significantly different from zero, but, while positive, the trend for fin whales was not significant. This was largely caused by the relatively low fin whale abundance estimated in 2003, which is 40–43% lower than in the previous years. A possible explanation for this decrease in abundance is an increase in the proportion of whale sightings classified as 'unidentified' in 2003. Overall, this proportion rose from an average 0.16 in 2001/2002 to 0.31 in the following year. This is particularly noticeable in areas of high fin whale density, where these proportions were 0.21 (2001/2) and 0.49 (2003). The increase in the proportion of 'unidentified' whale sightings was likely caused by the introduction of new observers in 2003, some of whom had limited previous experience in identifying large whales, particularly those of the genus *Balaenoptera*. Although not recorded in this study, other species such as blue and sei whales have been previously recorded in the area and can be confused with fin whales at sea (Leatherwood and Reeves, 1983; Leatherwood et al., 1988; Rice, 1998), so caution is used in making species identification at long range while surveying in passing mode.

The estimates of abundance could be corrected by pro-rating the unidentified sightings according to the proportion of identified whales in each surveyed block (e.g. Calambokidis and Barlow, 2004), but unfortunately the number of unidentified large whale sightings was not available for 1987. Also, that correction would assume that all species are equally likely to be identified, and we know from experience that humpback whales are more easily identified. Thus, a more reliable estimate of trends in abundance of North Pacific fin whales is obtained by excluding the 2003 data. Removal of these data resulted in the following estimates of annual increase rates: 7.9% [95% CI $= -1.4$–18.5%, $p = 0.174$] for the Kodiak stratum, 4.0% [95% CI $= -3.2$–11.5%, $p = 0.25$] for the Shumagin stratum, and 4.8% [95% CI = 4.1–5.4%, $p = 0.0016$] for the two strata pooled.

An increase in the proportion of 'unidentified' whale sightings could have a similar effect on the estimates of the rate of increase of humpback whales. However, this species is usually easier to identify at sea because it presents a typical hump in front of the dorsal fin and fluke-lifting behavior before beginning a dive (e.g. Leatherwood et al., 1988). The proportion of 'unidentified' whales in areas of high humpback whale density from 2001/2 and 2003 were, respectively, 0.18 and 0.23, a difference that is much smaller than for fin whales. In fact, an analysis similar to the one presented for fin whales above suggested that the estimated annual increase rate did not change substantially for humpback whales if the 2003 estimate is excluded (7.4% [95% CI = 6.2–8.6%, $p = 0.008$] for Kodiak, 5.6% [95% CI $= -3.5$–15.6%, $p = 0.082$] for Shumagin, and 6.9% [95% CI = 4.4–9.6%, $p = 0.018$] for the whole area).

It is important to mention caveats for the analysis presented here. First, the density estimates used to estimate the rate of increase are far apart in time. The estimated trends rely heavily on population estimates for a single year. Therefore, potential biases in the 1987 estimates likely substantially affect the estimate of the rate of increase. Second, the interpretation of the rates of increase reported in this study and their association to a specific population are difficult because of uncertainties in the population structure of humpback and fin whales in the North Pacific. Humpback whales feeding along the coast of Alaska migrate from different wintering grounds. While whales identified in the Kodiak Archipelago and the Shumagin Islands migrate predominantly from Hawai'i, individuals from Japan and Mexico have also been recorded in these feeding areas (Urbán et al., 2000; Calambokidis et al., 2001; Witteveen et al., 2004). Therefore, whales from different stocks apparently intermingle on the feeding grounds and the rate of increase presented here is likely a combination of the rates of different populations. Less is known about the population structure of fin whales in the North Pacific. The IWC considers fin whales in the North Pacific as a single stock (Mizroch et al., 1984). However, there is some evidence for population structure (Fujino, 1960; S. Mizroch pers. comm.). Third, the area sampled in this study corresponds to only a proportion of the range of both humpback and fin whale stocks, and therefore the trend may not reflect the actual growth of the whole population, but the population inhabiting the area surveyed. In addition, potential changes in distribution may also affect interpretation of the growth rates.

Despite these caveats, the estimated growth rates provided here are consistent with other estimates of growth rates of large whales reported in the literature. Estimates of annual rates of increase of fin whales were obtained for the feeding grounds in the Antarctic, but are likely biologically implausible (IWC, 2005). The numbers presented here are within the range of the observed rates for other recovering balaenopterid whales (Best, 1993; Stevick et al., 2003; Branch et al., 2004) and are the first available for North Pacific fin whales. Annual rates of increase reported for humpback whales range from nearly 3–15% (Best, 1993; Bannister, 1994;

Sigurjónsson and Gunnlaugsson, 1990; Barlow and Clapham, 1997; Clapham et al., 2003; Stevick et al., 2003; Mizroch et al., 2004), but rates above 13.4% are considered biologically implausible (Clapham et al., 2001). Mizroch et al. (2004) estimated that the growth rate of the central North Pacific humpback whale population was 10% (CI = 3–16%) in the period 1980–1996. The estimate presented in this study and its confidence intervals fall within the confidence intervals of the Mizroch et al. (2004) estimate.

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References

Akaike, H., 1985. Prediction and entropy. In: Atkinson, A.C., Fienberg, S.E. (Eds.), A Celebration of Statistics: the ISI Centenary Volume. Springer, New York, pp. 1–24.

Angliss, R.P., Lodge, K.L., 2002. Alaska marine mammal stock assessments, 2002, US Department of Commerce, Seattle, WA. NOAA Technical Memorandum NMFS-AFSC-133, 224pp.

Angliss, R.P., DeMaster, D.P., Lopez, A.P., 2001. Alaska marine mammal stock assessments, 2001. US Department of Commerce, Seattle, WA. NOAA Technical Memorandum NMFS-AFSC-124, 203pp.

Baker, C.S., Herman, L.M., Perry, A., Lawton, W.S., Straley, J.M., Wolman, A.A., Kaufman, G.D., Winn, H.E., Hall, J.D., Reinke, J.M., Östman, J., 1986. Migratory movement and population structure of humpback whales (*Megaptera novaeangliae*) in the central and eastern North Pacific. Marine Ecology-Progress Series 31, 105–119.

Baker, C.S., Straley, J.M., Perry, A., 1992. Population characteristics of individually identified humpback whales in southeastern Alaska: Summer and fall 1986. Fishery Bulletin 90, 429–437.

Bannister, J.L., 1994. Continued increase in humpback whales off Western Australia. Report on International Whale Commission 44, 309–310.

Barlow, J., 1995. The abundance of cetaceans in California waters. Part I: Ship surveys in the summer and fall of 1991. Fishery Bulletin 93, 1–14.

Barlow, J., 2003. Preliminary estimates of the abundance of cetaceans along the US west coast: 1991–2001. Southwest Fisheries Science Center Administrative Report LJ-03-03. Available from SWFSC, 8604 La Jolla Shores Dr., La Jolla, CA 92037, 31pp.

Barlow, J., Clapham, P.J., 1997. A new birth-interval approach to estimating demographic parameters of humpback whales. Ecology 78, 535–546.

Barlow, J., Gerrodette, T., 1996. Abundance of cetaceans in California waters based on 1991 and 1993 ship surveys. NOAA Technical Memorandum, NOAA-TM-NMFS-SWFSC-233, 15pp.

Best, P.B., 1993. Increase rates in severely depleted stocks of baleen whales. ICES Journal of Marine Science 50, 169–186.

Branch, T.A., Matsuoka, K., Miyashita, T., 2004. Evidence for increases in Antarctic blue whales based on Bayesian modelling. Marine Mammal Science 20 (4), 726–754.

Breiwick, J., Braham, H. (Eds.), 1984. The Status of Endangered Whales. Marine Fisheries Review 46(4), 1–64.

Brownell Jr., R.L., Clapham, P.J., Miyashita, T., Kasuya, T., 2001. Conservation status of North Pacific right whales. Right whales: worldwide status. Journal of Cetacean Research Management (special issue 2), 269–286.

Brueggeman, J.J., Newby, T.C., Grotefendt, R.A., 1985. Seasonal abundance, distribution and population characteristics of blue whales reported in the 1917 to 1939 catch records of two Alaska Whaling Stations. Report on International Whale Commission 35, 405–411.

Brueggeman, J.J., Green, G.A., Grotefendt, R.A., Chapman, D.G., 1987. Aerial surveys of endangered cetaceans and other marine mammals in the northwestern Gulf of Alaska and southeastern Bering Sea. Contract Report OCSEAP Research Unit 673. Contract number 85-ABC-00093 to the Minerals Management Service Alaska OCS Office and NOAA Office of Oceanography and Marine Mammal Assessment Alaska Office.

Brueggeman, J.J., Green, G.A., Tressler, R.W., Chapman, D.G., 1988. Shipboard surveys of endangered cetaceans in the northwestern Gulf of Alaska, US Department of Commerce, NOAA, OCSEAP Final Report 61, pp. 125–188.

Brueggeman, J.J., Green, G.A., Grotefendt, R.A., Tressler, R.W., Chapman, D.G., 1989. Marine mammal habitat use in the North Aleutian Basin, St. George Basin and Gulf of Alaska. In: Jarvela, L.E., Thorsteinson, L.K. (Eds.), Proceedings of the Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information Update Meeting, pp. 97–108. Available from

NOAA, NOS, Office of Oceanography and Marine Assessment, 222, W. Eight Avenue No. 56, Anchorage, AK 99513–7543 (Chapter 14).

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., Thomas, L., 2001. Distance Sampling: Estimating Abundance of Biological Populations. Oxford University Press, London.

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference. Springer, New York.

Calambokidis, J., Barlow, J., 2004. Abundance of blue and humpback whales in the eastern North Pacific estimated by capture-recapture and line-transect methods. Marine Mammal Science 20, 63–85.

Calambokidis, J., Steiger, G.H., Evenson, J.R., Flynn, K.R., Balcomb, K.C., Claridge, D.E., Bloedel, P., Straley, J.M., Baker, C.S., von Siegezar, O., Dahlheim, M., Waite, J.M., Darling, J.D., Ellis, G., Green, G.A., 1996. Interchange and isolation of humpback whales off California and other North Pacific feeding grounds. Marine Mammal Science 12, 215–226.

Calambokidis, J. Steiger, G.H., Straley, J.M., Quinn, T., Herman, L.M., Cerchio, S., Salden, D.R., Yamaguchi, M., Sato, F., Urban, J.R., Jacobsen, J., VonZeigesar, O., Balcomb, K.C., Gabriele, C.M., Dahlheim, M.E., Higashi, N., Uchida, S., Ford, J.K.B., Miyamura, Y., Ladron de Guevara, P., Mizroch, S.A., Schlender, L., Rasmussen. K., 1997. Abundance and population structure of humpback whales in the North Pacific basin. Final Contract Report 50ABNF500113 to Southwest Fisheries Science Center, P.O. Box 271, La Jolla, CA 92038, 72pp.

Calambokidis, J., Steiger, G.H., Straley, J.M., Herman, L.M., Cerchio, S., Salden, D.R., Urbán, R.J., Jacobsen, J.K., von Ziegesar, O., Balcomb, K.C., Gabriele, C.M., Dahlheim, M.E., Uchida, S., Ellis, G., Miyamura, Y., Ladrón de Guevara, P., Yamaguchi, M., Sato, F., Mizroch, S.A., Schlender, L., Rasmussen, K., Barlow, J., Quinn II, T.J., 2001. Movements and population structure of humpback whales in the North Pacific. Marine Mammal Science 17 (4), 769–794.

Clapham, P., Robbins, J., Brown, M., Wade, P., Findlay, K., 2001. Appendix 5—a note on plausible rates of population growth in humpback whales. Journal of Cetacean Research and Management 3 (Suppl.), 196–197.

Clapham, P.J., Barlow, J., Bessinger, M., Cole, T., Mattila, D., Pace, R., Palka, D., Robbins, J., Seton, R., 2003. Abundance and demographic parameters of humpback whales from the Gulf of Maine, and stock definition relative to the Scotian Shelf. Journal of Cetacean Research and Management 5, 13–22.

Forney, K.A., Brownell Jr., R.L., 1996. Preliminary report of the 1994 Aleutian Island marine mammal survey. Paper SC/48/O11 presented to the International Whaling Commission Scientific Committee, 15pp.

Fujino, K., 1960. Immunogenetic and marking approaches to identifying sub-populations of the North Pacific whales. Scientific Reports of the Whales Research Institute 15, 84–142.

Goddard, P.D., Rugh, D.J., 1998. A group of right whales seen in the Bering Sea in July 1996. Marine Mammal Science 14, 344–349.

Horwood, J., 1987. The Sei Whale: Population Biology, Ecology and Management. Croom Helm, London.

Innes, S., Heide-Jørgensen, M.P., Laake, J.L., Laidre, K.L., Cleator, H.J., Richard, P., Stewart, R.E.A., 2002. Survey of belugas and narwhals in the Canadian High Arctic in 1996. NAMMCO Scientific Publishers 4, 169–190.

International Whaling Commission, 2005. Annual Report of the International Whaling Commission 2004, 171pp.

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.J.F., McDonald, L.L., Robertson, D.G. (Eds.), Marine Mammal Survey and Assessment Methods. A.A. Balkema, Rotterdam, pp. 137–148.

Leatherwood, S., Reeves, R.R., 1983. The Sierra Club Handbook of Whales and Dolphins. Sierra Club Books, San Diego.

Leatherwood, S., Reeves, R.R., Perrin, W.F., Evans, W.E., 1988. Whales, Dolphins and Porpoises of the Eastern North Pacific and Adjacent Arctic Waters: A Guide to their Identification. Dover Publications, Inc., New York.

Leduc R.G., Perryman, W.L., Gilpatrick, J.R., Hyde, J., Stinchcomb, C., Carretta, J.V., Brownell Jr., R.L., 2001. A note on recent surveys for right whales in the southeastern Bering Sea. Journal of Cetacean Research and Management (special issue 2), 287–289.

Lerczak, J.A., Hobbs, R.C., 1998. Calculating sighting distances from angular readings during shipboard, aerial, and shore-based marine mammal surveys. Marine Mammal Science 14 (3), 590–599 (see also errata. 1998. Marine Mammal Science 14(4), 903).

Marques, F.F.C., Buckland, S.T., 2003. Incorporating covariates into standard line transect analyses. Biometrics 59, 924–935.

Marques, F.F.C., Buckland, S.T., 2004. Covariate Models for the detection function. In: Buckland, S.T., Anderson, D.R., Burnham, K.A., Laake, J.L., Borchers, D.L., Thomas, L. (Eds.), Advanced Distance Sampling. Estimating abundance of biological populations. Oxford University Press, Oxford, UK, pp. 31–47 (Chapter 3).

Miyashita, T., Kato, H., Kasuya, T., 1995. Worldwide Map of Cetacean Distribution based on Japanese Sighting Data, vol. 1. National Research Institute of Far Seas Fisheries, 134pp.

Mizroch, S.A., Rice, D.W., Breiwick, J.M., 1984. The fin whale (*Balaenoptera physalus*). Marine Fisheries Review 46 (4), 20–24.

Mizroch, S.A., Herman, L.M., Straley, J.M., Glockner-Ferrari, D.A., Jurasz, C., Darling, J., Cerchio, S., Gabriele, C.M., Salden, D.R., von Ziegesar, O., 2004. Estimating the adult survival rate of central North Pacific humpback whales (*Megaptera novaeangliae*). Journal of Mammalogy 85 (5), 963–972.

Moore, S.E., Waite, J.M., Mazzuca, L.L., Hobbs, R.C., 2000. Mysticete whale abundance and observations of prey associations on the central Bering Sea shelf. Journal of Cetacean Research and Management 2, 227–234.

Moore, S.E., Waite, J.M., Friday, N.A., Honkalehto, T., 2002. Cetacean distribution and relative abundance on the central-eastern and southeastern Bering Sea shelf with reference to oceanographic domains. Progress in Oceanography 55, 249–261.

Nishiwaki, M., 1966. Distribution and migration of the larger cetaceans in the North Pacific as shown by Japanese whaling results. In: Norris, K.S. (Ed.), Whales, Dolphins and Porpoises. University of California, Berkley, CA, pp. 171–191.

Perry, A., Scott, C.S., Herman, L.M., 1990. Population characteristics of individually identified humpback whales in the central and eastern North Pacific: a summary and critique. Report on International Whale Commission (special issue 12), 307–317.

Perry, S.L., DeMaster, D.P., Silber, G.K., 1999. The great whales: history and status of six species listed as endangered under the US Endangered Species Act of 1973. Marine Fisheries Review 61 (1), 1–99.

Pfister, B., DeMaster, D.P., 2006. Changes in marine mammal biomass in the Bering Sea/Aleutian Island region before and after the period of industrial whaling. In: Estes, J., Williams, T., Doak, D., DeMaster, D.P., Brownell, Jr., R. (Eds.), Whales, Whaling, and the Marine Ecosystem. University of California Press, Berkeley, CA, pp. 117–134.

Pike, G.C., 1968. Whaling in the North Pacific—The end of an era. Canadian Geographical Journal 76 (4), 128–137.

Reeves, R.R., Leatherwood, S., Karl, S.A., Yohe, E.R., 1985. Whaling results at Akutan (1912–39) and Port Hobron (1926–37), Alaska. Report on International Whale Commission 35, 441–457.

Rice, D.W., 1998. Marine Mammals of the World. The Society for Marine Mammalogy Special Publication No. 4.

Scarff, J.E., 2001. Preliminary estimates of whaling-induced mortality in the 19th century North Pacific right whale (*Eubalaena japonicus*) fishery, adjusting for struck-but-lost whales and non-American whaling. Journal of Cetacean Research and Management (special issue 2), 261–268.

Shelden, K.E.W., Moore, S.E., Waite, J.M., Wade, P.R., Rugh, D., 2005. Historic and current habitat use by North Pacific right whales *Eubalaena japonica* in the Bering Sea and Gulf of Alaska. Mammal Review 35 (2), 129–155.

Sigurjónsson, J., Gunnlaugsson, T., 1990. Recent trends in abundance of blue (*Balaenoptera musculus*) and humpback whales (*Megaptera novaeangliae*) off West and Southwest Iceland, with a note on occurrence of other cetacean species. Report on International Whale Commission 40, 537–551.

Skaug, H., Schweder, T., 1999. Hazard models for line transect surveys with independent observers. Biometrics 55, 29–36.

Stafford, K.M., 2003. Two types of blue whale calls recorded in the Gulf of Alaska. Marine Mammal Science 19 (4), 682–693.

Stevick, P.T., Allen, J., Clapham, P.J., Friday, N., Katona, S.K., Larsen, F., Lien, J., Mattila, D.K., Palsbøll, P.J., Sigurjónsson, J., Smith, T.D., Øien, N., Hammond, P.S., 2003. North Atlantic humpback whale abundance and rate of increase four decades after protection from whaling. Marine Ecology-Progress Series 258, 263–273.

Stewart, B.S., Karl, S.A., Yochem, P.K., Leatherwood, S., Laake, J.L., 1987. Aerial surveys for cetaceans in the former Akutan, Alaska, whaling grounds. Arctic 40 (1), 33–42.

Thompson, R.J., 1940. Analysis of stomach contents of whales taken during the years 1937 and 1938 from the North Pacific. M.Sc. Thesis, University of Washington, Seattle, WA.

Tønnessen, J.N., Johnsen, A.O., 1982. The History of Modern Whaling. C. Horst & Co., London.

Urbán, R.J., Jaramillo, A., Aguayo, L., Ladron de Guevara, P., Salinas, M., Alvarez, C., Medrano, L., Jacobsen, J., Balcomb, K., Claridge, D., Calambokidis, J., Steiger, G., Straley, J., von Ziegesar, O., Wate, M., Mizroch, S., Dahlheim, M., Darling, J., Baker, S., 2000. Migratory destinations of humpback whales wintering in the Mexican Pacific. Journal of Cetacean Research and Management 2 (2), 101–110.

Von Ziegesar, O., Miller, E., Dahlheim, M.E., 1994. Impacts on humpback whales in Prince William Sound. In: Loughlin, T.R. (Ed.), Marine Mammals and the Exxon Valdez. Academic Press, New York, pp. 173–191.

Wada, S., 1981. Japanese whaling and whale sightings in the North Pacific 1979 season. Report on International Whale Commission 31, 783–792.

Waite, J.M., Dahlheim, M.E., Hobbs, R.C., Mizroch, S.A., von Ziegesar-Matkin, O., Straley, J.M., Herman, L.M., Jacobsen, J., 1999. Evidence of a feeding aggregation of humpback whales (*Megaptera novaeangliae*) around Kodiak Island, Alaska. Marine Mammal Science 15, 210–220.

Waite, J.M., Wynne, K., Melinger, D.K., 2003. Documented sighting of a North Pacific right whale in the Gulf of Alaska and post-sighting acoustic monitoring. Northwestern Naturalist 84, 38–43.

Witteveen, B.H., Straley, J.M., von Ziegesar, O., Steel, D., Baker, C.S., 2004. Abundance and mtDNA differentiation of humpback whales (*Megaptera novaeangliae*) in the Shumagin Islands, Alaska. Canadian Journal of Zoology 82, 1352–1359.