FINAL REPORT FOR THE APRIL 2009 GULF OF ALASKA LINE-TRANSECT SURVEY (GOALS) IN THE NAVY TRAINING EXERCISE AREA

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by
Brenda K. Rone[1], Annie B. Douglas[2], Phil Clapham[1], Anthony Martinez[3], Laura J. Morse[1], Alexandre N. Zerbini[1] and John Calambokidis[2]

(1) National Marine Mammal Laboratory, 7600 Sand Point Way N.E., Seattle, WA 98115
(2) Cascadia Research Collective, 218 ½ W Fourth Ave., Olympia, WA 98506
(3) NOAA Fisheries Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL 33149

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SUMMARY

Little is known about the occurrence of cetaceans found in offshore waters in the Gulf of Alaska; however, whaling records and a few recent surveys have shown this area to be important habitat. The United States Navy maintains a maritime training area in the central Gulf of Alaska, east of Kodiak Island, and has requested additional information on marine mammal presence and use of this area. To determine the occurrence and distribution of marine mammals in and around the Navy training area, a line-transect visual and acoustic survey was conducted 10-20 April 2009 from the NOAA R/V *Oscar Dyson*. The primary survey area encompassed nearshore, shelf and offshore pelagic waters of the central Gulf of Alaska. Survey lines were designed to provide equal coverage of the nearshore and offshore habitat.

During this project, the visual survey covered a total of 760 kilometers (410 nautical miles) on-effort while transit and fog effort legs accounted for 553 km (298 nm). There were a total of 96 sightings (453 individuals) of 11 confirmed marine mammal species; these included fin, humpback, gray, and minke whales as well as killer whales, Dall's and harbor porpoise, Pacific white-sided dolphins and Steller sea lions, harbor seals and sea otters. Additionally, there were 36 sightings (46 individuals) of unidentified large whales, dolphins and pinnipeds. Acoustically, operations were conducted 24-hours/day surveying a total of 3,519 km (1,900 nm) and recording 49 acoustic detections of sperm whales and killer whales. Photographs of nineteen individual killer whales and four fin whales were obtained on this cruise and compared to existing catalogs.

Density and abundance estimates were calculated for fin and humpback whales by stratum using several models. All results were fairly similar given the constraints of the sample sizes involved. Best estimates were obtained using additional sightings from a previous cruise on a similar vessel for calculating the sighting detection function (distances at which whales were sighted from the transect line). These yielded estimates of 594 (CV=0.29) and 889 (CV=0.57) fin whales for the inshore and offshore stratum, respectively, and 219 (CV=0.57) and 56 (CV=0.57) humpback whales in the inshore and offshore stratums, respectively. A small proportion of large whales were not identified to species but were most likely fin or humpback whales and estimates of these unidentified whales could be assigned to these species based on the proportion of fin and humpback whales identified in each stratum. This raised fin whale estimates of abundance to 666 and 938 (inshore and offshore stratums, respectively) and humpback whale estimates to 265 and 63 (inshore and offshore stratums, respectively).

Despite a number of logistical and time limitations, the survey achieved its primary objectives and provided new information on marine mammal occurrence and abundance in the region. Sightings were adequate to allow density and abundance estimates for fin and humpback whales. Identification photographs obtained on this cruise provide verification of seasonal presence of individual fin and killer whales in a study area that is rarely accessible.

INTRODUCTION

The Gulf of Alaska U. S. Navy maritime training area is located south of Prince William Sound and east of Kodiak Island. The training area encompasses various marine habitats, both shelf and pelagic, that support most species of marine mammals found in the Gulf of Alaska. Twenty-six species of marine mammals are known to reside in or seasonally frequent the Gulf of Alaska. Although marine mammals are present year-round in the Gulf of Alaska, the greatest number of animals occurs during the spring and summer. Three of the whale species present in the Gulf of Alaska, humpback, fin and right whales feed in the outer continental shelf and slope waters during the summer into early fall, while blue, sei and sperm whale species are thought to be more pelagic (Berzin and Rovnin 1966, Rice 1974). Gray whales are present seasonally and are thought to migrate along the shore of the Gulf of Alaska (Rice and Wolman 1982). From sea otters to blue whales, most species of marine mammals found in the Gulf of Alaska were aggressively hunted from land and/or vessel until the passage of the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973 (Rice and Wolman 1982, Scheffer 1972). In 1980, a survey conducted and described by Rice and Wolman (1982) determined that the populations of all great whales in the Gulf of Alaska had been severely depleted. Since that time some of these species have shown signs of recovery; however, only the eastern North Pacific gray whale has experienced a seemingly complete population recovery (Rough *el al.* 2005).

Historically, distribution of cetaceans in the Gulf of Alaska has been based on commercial catch records (Nishiwaki 1966, Townsend 1935) and whaling related scouting vessel data (Berzin and Rovnin, 1966; Wada, 1979). For pinnipeds and sea otters species that are found close to land seasonally, current abundance and distribution estimates are available (Angliss and Allen, 2009); however, for most cetacean species in Gulf of Alaska the occasional marine mammal survey that transits through the area has not generated sufficient sighting data to create abundance estimates. Absence/presence data is available from the 2004 Southwest Fisheries Science Center vessel-based marine mammal survey for humpback whales that crossed through the Gulf of Alaska Navy training area (Barlow and Henry 2005). In addition, bottom mounted hydrophones in the Gulf of Alaska recorded calls from both northwestern and northeastern Pacific blue whales, suggesting that both stocks could be present in the Gulf of Alaska throughout the year (Stafford, 2003).

Despite the challenges of studying marine mammals at sea in the Gulf of Alaska, a deeper understanding of these populations is necessary to manage these species, especially those that inhabit pelagic waters with limited survey effort. To determine marine mammal distribution and abundance in the Gulf of Alaska U.S Navy training area, the Navy provided funds for a vessel based line-transect survey in the Gulf of Alaska during April, 2009.

OBJECTIVES

The overall goal of this study was to document the distribution and occurrence of marine mammals within the U.S. Navy maritime exercise area. Little is known about the distribution and abundance of species found in the Gulf of Alaska during this time period due to limited survey effort.

The specific objectives were:

1) To visually assess the distribution and occurrence of marine mammals in the Gulf of Alaska with specific focus on the U.S. Navy maritime exercise area.
2) To conduct 24-hour acoustic operations to record the presence of marine mammals in the U.S. Navy maritime exercise area in coordination with and in addition to visual operations using a two-element towed array.
3) To conduct 24-hour acoustic stations to record the presence of low frequency baleen whales using Difar sonobuoys supplied by the U.S. Navy.
4) To document individual animals through photo-identification and biopsy sampling.

METHODS

Surveys

The survey was conducted using the NOAA Ship *Oscar Dyson,* a 63 m fisheries research vessel from 10 – 20 April, 2009. Two strata were proposed and tracklines were designed to provide a uniform spatial coverage of the study area (Table 1, Figure 1). The proposed design allowed for the computation of abundance estimates (if results would allow given the limited survey coverage).

Table 1 – Strata and Proposed Effort Allocation in the Study Area

Stratum	**Area (km^2)**	**Number of Tracklines**	**Total Effort (km)**
Inshore	47,411	12	1,905
Offshore	98,253	10	1,944
Total		22	3,849

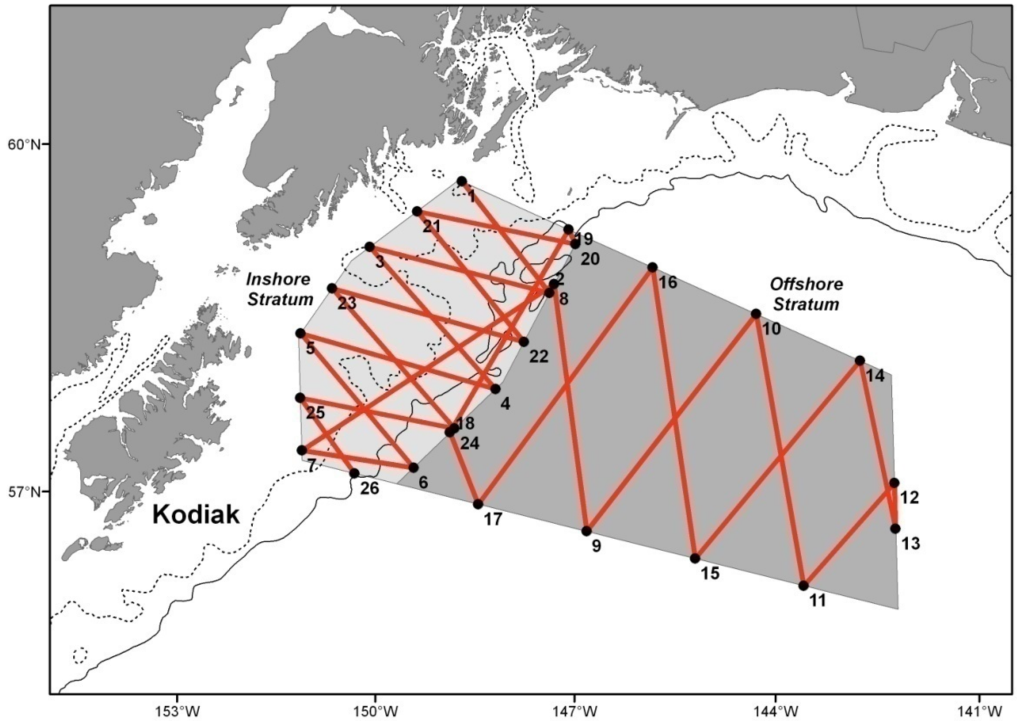

Figure 1 – Tracklines for the 2009 GOALS study.

A rotating team of three scientists using standard line-transect methods collected sighting data. Operations began at 07:20h and ceased at 20:00h, or as long as conditions would allow. A full observation period lasted two hours (40 minutes in each position) and was followed by a two-hour rest period. All three observers (starboard and port observers and data recorder) were stationed on the flying bridge. Starboard and port observers used 25-power 'big-eye' binoculars with reticles to scan from 10° on the opposite side to 90° abeam. The data recorder surveyed the trackline with 7X50 binoculars while scanning through the viewing areas of the two primary observers. In addition, an independent observer scanned for animals using 7X50 binoculars and recorded marine mammal sightings not detected by the three observers. When a sighting was made, the observer alerted the recorder of incoming information and determined the horizontal angle and number of reticles from the horizon to the initial sighting. Additional information collected was sighting cue, course and speed, species identity, and best, low and high estimates of group size. The computer program WINCRUZ was used to record all sighting and environmental data (e.g. cloud cover, wind speed and direction, and sea conditions).

Under unacceptable weather conditions, two observers stayed on watch on the bridge to record off-effort sightings and environmental data. Given the limited time to cover the tracklines and because acoustic operations could be conducted despite weather conditions, the ship continued along the transect lines and visual operations were conducted when possible. On-effort status was defined as a visible horizon, sea state 5 or lower, and survey speed of 10 knots through the water. Lines connecting the end/start points of designated tracklines as well as lines to and from the survey area were classified as ‘transit lines’ and were surveyed using on-effort protocols whenever possible; however, typically they were conducted at 12 knots through the water. Fog effort corresponded to observations conducted under poor visibility (no horizon) but with a seastate 5 or less and was conducted on both designated tracklines and transit lines. Under unacceptable weather conditions (visibility $\leq$0.5nm and/or seastate $\geq$ 6), off-effort watches on the bridge were conducted. At the cruise leader’s discretion, line-transect survey effort was temporarily suspended to allow closer approaches to sightings for photo-identification. No biopsy sampling was conducted due to the limited survey time and limited opportunities from the ship.

Ship-based Passive Acoustics (two-element towed array)

Passive acoustic operations were conducted on a continuous basis throughout the survey area. During periods of favorable daytime conditions, the passive acoustic survey was conducted in concert with the visual survey effort. The towed acoustic array was used to collect high quality examples of vocalizations and to determine the presence or absence of acoustically active cetaceans at times when no visual survey effort was possible due to high sea states and winds, or darkness.

Passive acoustics were conducted using a two-element towed hydrophone array. This towed array was a 400 meter long Kevlar reinforced, multi-conductor, armored cable assembly with an oil filled tow section at the end of this cable. The array could be towed at any speed up to 12 knots. For this survey, the array was deployed 200 m astern of the vessel. The tow section contained two Teledyne Benthos AQ-4 high gain hydrophones with a designed frequency response of 10 Hz to 15 kHz. These hydrophones along with their associated signal conditioning and line drive electronics were separated by three meters within the oil filled tow section.

The array signals were continuously monitored in real-time by an acoustics operator. The analog acoustic signal was passed into the acoustics lab for filtering, amplification, recording and monitoring. The analog signal was digitized via a National Instruments DAQCard-6062E at a sampling rate of 96 kHz. Recordings were downloaded to hard disk on a continuous basis and saved as WAV files of 10 minute duration. The software package Ishmael[1] was used to monitor signals and make high bandwidth recordings. The relative bearing of manually selected signals of interest could be calculated by Ishmael utilizing the difference in the time of arrival of a signal at each hydrophone. These relative bearings could then be sent to a second computer for display. This computer was connected to a GPS receiver and loaded with the WhalTrak2 software package (created by Glen Gailey at Texas A&M University). WhalTrak2 displayed the ship’s current position and track in a graphic display window, overlaying lines of bearings as instructed by the operators. This provided the acoustics team with a picture of how acoustic detections related to visual sightings of cetaceans and other possible sources of sound, such as ship traffic. WhalTrak2 was also programmed to record ship position, effort, weather, and general comments to a Microsoft Access data file.

Ship-based Passive Acoustics (DIFAR Sonobuoys)

The GOALS survey was to be supplied with 96 (2-pallets/ 48 each) AN/SSQ-53F sonobuoys supplied by the U.S. Navy. Three attempts were made to deliver them to the Kodiak Coast Guard station. Initially, they were scheduled to be flown in by a C130 from Whidbey

Island on 26 March; however, due to the eruption of the Redoubt volcano, the flight was suspended. The second flight was scheduled to fly in on 04 April; however, the C130 was grounded due to mechanical issues and no other flight was scheduled for that day. A third flight was planned for 05 April; however, the palettes were not delivered to the Coast Guard station. The next possible flight available was on 13 April; however, the survey was leaving on 10 April (after a delayed departure) and the sonobuoys were declined due to late arrival.

Photo-identification

Identification photographs of target species were obtained to allow evaluation of movements of animals based on resightings of identified individuals during the survey or with animals identified elsewhere and maintained in existing catalogs. Highest priority species for photo-id on the Gulf of Alaska survey were North Pacific right whale, blue whale, and fin whale. High priority species were humpback, sperm, minke, Baird's beaked whale and mesoplodon beaked whale. When the observers located a target species, the visual survey effort was suspended and the primary survey vessel was directed to obtain photographs of the animals. The vessel was positioned for the best lighting and angle so that photographs could be obtained of the dorsal fin as well as the chevron on fin whales, flukes of humpback whales and saddle patches of killer whales. Photographs were taken using Nikon D-200 and Canon 20D autofocus digital cameras equipped with a 70-300mm or a 100-400mm zoom lens. All photographs were reviewed, and the highest quality identification photograph(s) of each animal were selected to be compared to existing photo identification catalogs from the northeastern Pacific and the Gulf of Alaska.

Line transect analysis of fin whale data

Line-transect analysis for densities and abundance were conducted for fin, humpback and unidentified large whales only. Detection functions were fit using data from all three species and assuming that these present the same detection probability. Line-transect analysis combined effort conducted under appropriate survey conditions in on-effort, on-transect and transit lines with good visibility and sea conditions. Sighting data collected during transect lines were used in estimation of detection probability and density while data collected in transit was only used for detection probability estimation. We also evaluated whether acoustic detections of sperms whales could be used to estimate a line-transect density but this did not appear possible because many acoustic detections could not be localized.

Initially, to determine the detection probability only sighting data from GOALS 2009 were used. Due to the small sample size of perpendicular distance data, data were left untruncated and only two conventional distance sampling (CDS) models were used for fitting a detection function: the hazard rate and the half normal. To increase sample size to estimate detection probability, fin (n=57), humpback (42) and unidentified large whale (1) sightings collected during a research cruise conducted by the National Marine Mammal Laboratory in the Gulf of Alaska in 2003 aboard the NOAA vessel *Miller Freeman* were included in the analysis of a detection function (a model of the distances sightings are made from the transect). This cruise was carried out on a similar platform and followed searching methodology consistent with those employed during GOALS 2009 so detection functions would be expected to be similar. The addition of such sightings, not only provided additional data for estimating detection probability with better precision, but also allowed the use of more sophisticated models including covariates (multiple covariate distance sampling methods – MCDS). Exploratory analysis revealed that model fit to perpendicular distance data truncated at distances greater than 4.5km was relatively poor. Therefore, all data were truncated at 5km for estimation of detection functions. Sightings (n=9) seen at greater distances were removed from the analysis. This resulted in a slightly reduced dataset (n=138).

Once a best truncation strategy was found, more sophisticated models were run to fit perpendicular distance data. In particular, MCDS models were tested in addition to CDS key functions. The following covariates were included in the models: Year (2003 and 2009), method (big-eye binoculars and naked eye sightings), and sea state (Beaufort scale). All covariates were modeled as factor covariates. Models that did not conform to this detection probability hypothesis were excluded from the analysis. For example, detection probability is expected to increase as group size increases. However, if model parameters indicated otherwise, models were not considered.

Encounter rate and its variance were empirically estimated from the data (Buckland *et al.*, 2001). For CDS models, size bias regressions were computed to investigate whether group sizes were influencing detection probability (Buckland *et al.*, 2001). If the regression was significant to an alpha=0.15 level, then the size bias regression coefficients were used to estimate average group size. Otherwise, a simple mean was computed. For MCDS models, group sizes were estimated by dividing the estimated density of individuals by the estimated density of groups in the study area (Marques and Buckland, 2003).

For density estimation, stratum-specific abundance estimates were calculated using the CDS and MCDS modeling strategies as presented in Buckland *et al.* (2001) and Marques and Buckland (2003). For the purpose of this analysis, detection probability on the trackline was assumed to be unit (g[0]=1). All parameter estimates were computed using the software Distance 5, release 2 (Thomas *et al.*, 2006).

RESULTS

Visual survey effort and sightings

Survey effort is shown in Figure 2, Table 2. The offshore stratum was not surveyed in its entirety due to limited survey time resulting from delayed departure. The survey covered a total of 760 km (410 nm) on-effort while transit and fog effort legs accounted for 553 km (298 nm).

Table 2 – Completed Effort.

Stratum	Effort (km)
Inshore	460
Offshore	300
Total on effort	*760*
Transit	384
Fog effort	169
Total	*1,313*

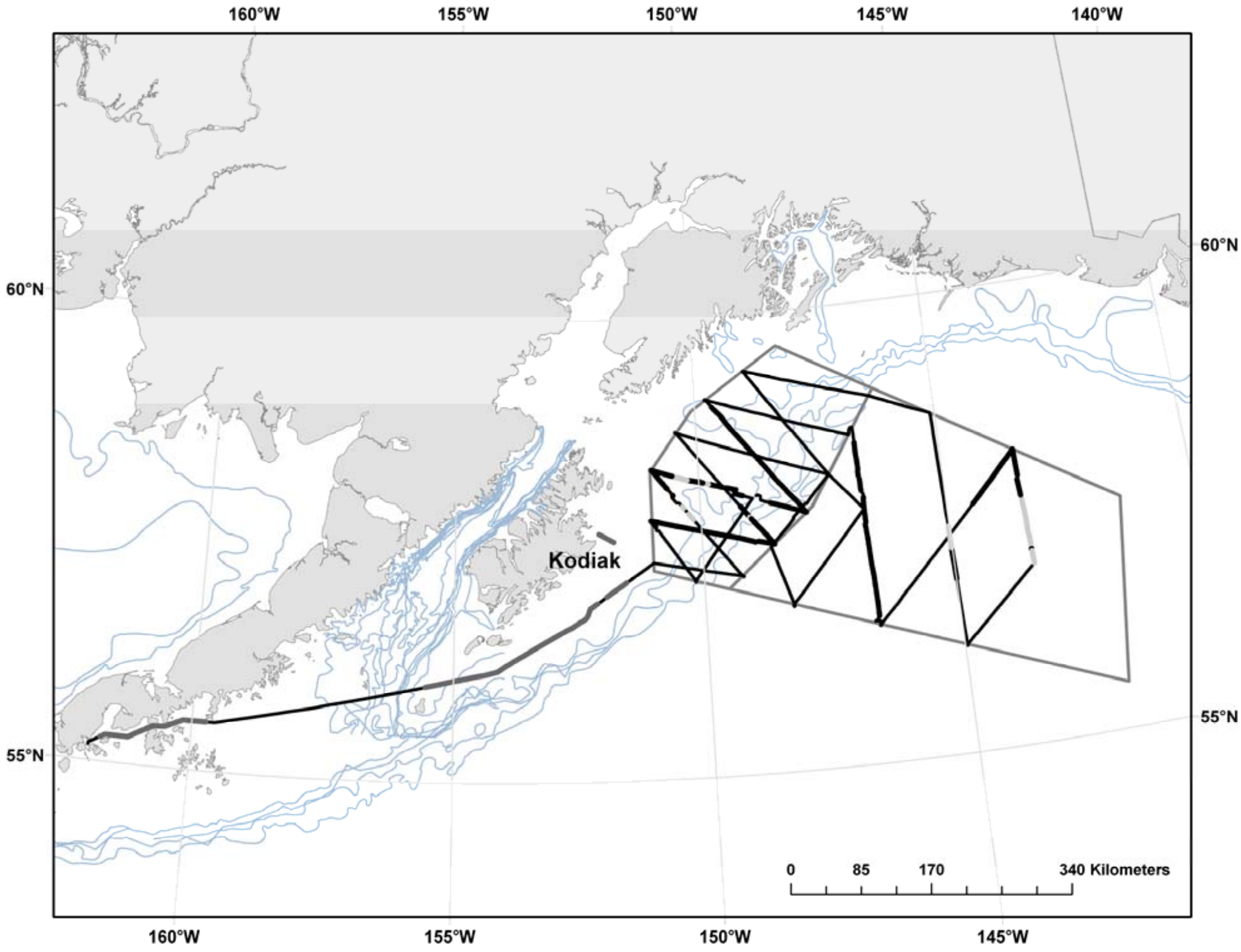

Figure 2 – Completed visual and acoustic effort (visual and acoustic on effort – bold black; fog and acoustic effort – light gray; transit and acoustic effort – dark gray; acoustic effort only – thin black).

There were a total of 96 sightings (453 individuals) of 11 confirmed marine mammal species; these included fin, humpback, gray, and minke whales as well as killer whales, Dall's and harbor porpoise, Pacific white-sided dolphins and Steller sea lions, harbor seals and sea otters. Additionally, there were 36 sightings (46 individuals) of unidentified large whales, dolphins and pinnipeds (Table 3, Figures 3-6).

Table 3 – Marine mammal sightings (individuals) from GOALS 2009 research cruise.

Species	On Effort	Off Effort	Total
Cetaceans			
Fin Whale	20(56)	4(8)	24(64)
Humpback Whale	10(19)	1(1)	11(20)
Gray Whale	1(2)	2(6)	3(8)
Minke Whale	2(3)	-	2(3)
Killer Whale	6(119)	-	6(119)
Dall's Porpoise	10(59)	-	10(59)
Harbor Porpoise	30(89)	-	30(89)
Pacific white-sided	1(60)	-	1(60)
Unid Large Whale	22(31)	6(7)	28(38)
Unid. Small Whale	2(2)	-	2(2)
Unid.Dolphin/Porpoise	2(2)	-	2(2)
Total Cetacean	*106(442)*	*13(22)*	*119(464)*
Pinnipeds and Otters			
Steller's Sea Lion	6(28)	-	6(28)
Harbor Seal	2(2)	-	2(2)
Sea Otter	1(1)	-	1(1)
Unid. Pinniped	4(4)	-	4(4)
Total Pinniped	*13(35)*	-	*13(35)*
Total	***119(477)***	***13(22)***	***132(499)***

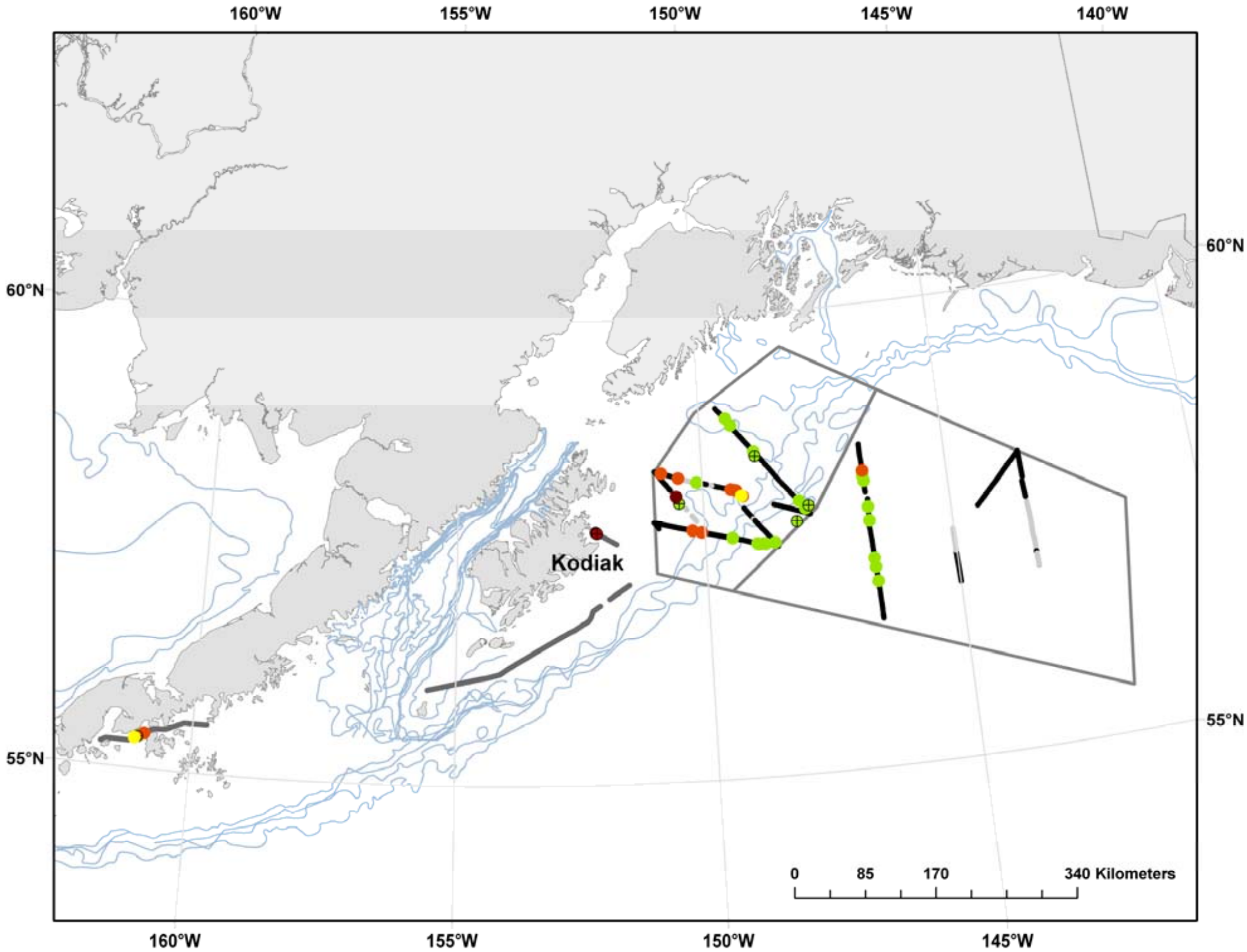

Figure 3 – Baleen whales sightings during GOALS 2009 research cruise (green = fin whales, red = gray whales, orange = humpback whales, yellow = minke whales; open circles = on effort sightings, crossed circles = off effort sightings)

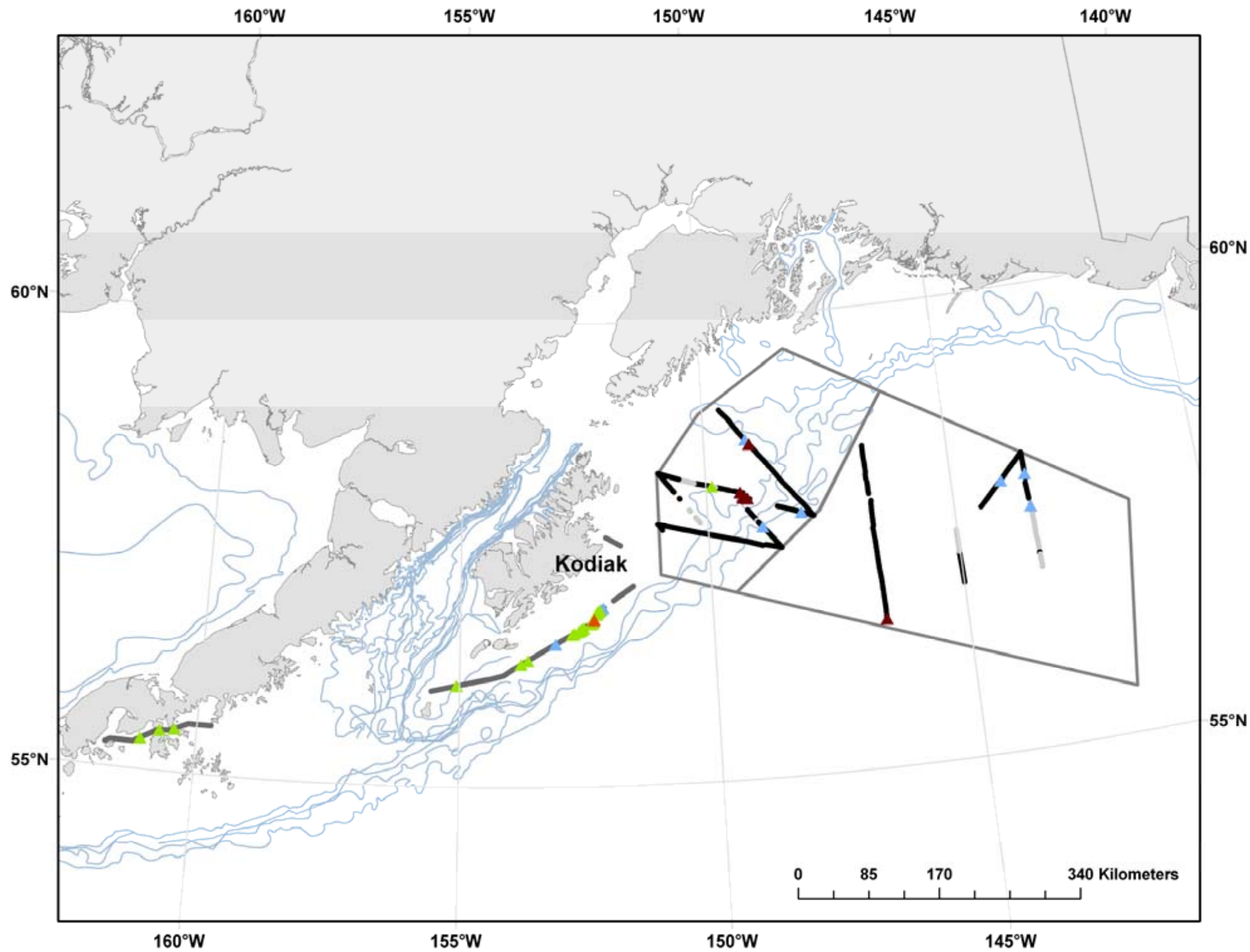

Figure 4 – Toothed whales sightings during GOALS 2009 research cruise (green = harbor porpoise, blue = Dall's porpoise, red = killer whale, orange = Pacific white-sided dolphin; open triangles = on effort sightings)

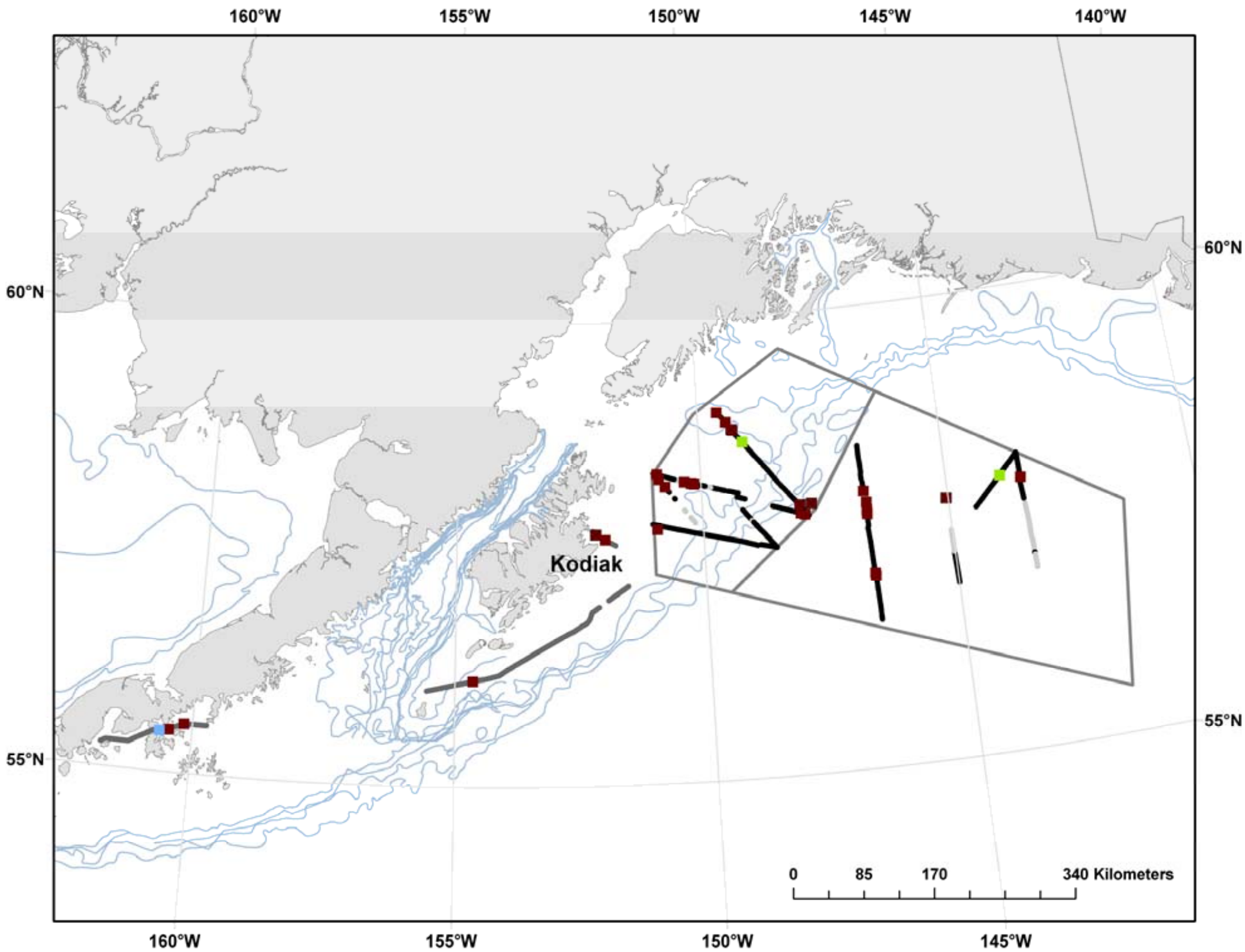

Figure 5 – Unidentified cetaceans sightings during GOALS 2009 research cruise (red = large whale, green = dolphin/porpoise, blue = small whale; open squares = on effort sightings, crossed squares = off effort sightings).

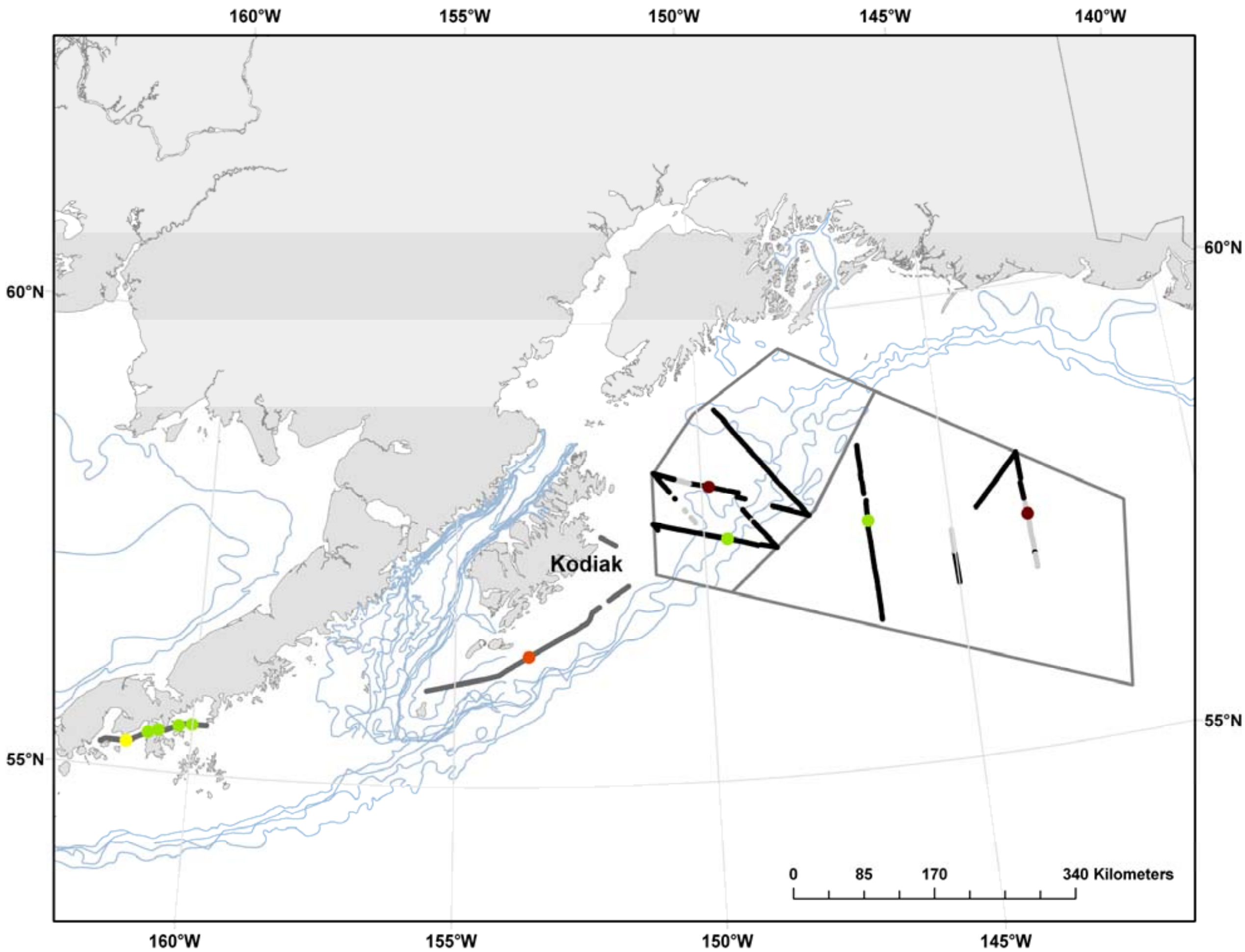

Figure 7 – Pinniped and otter sightings during GOALS 2009 research cruise (green = Steller sea lion, orange = sea otter, yellow = harbor seal, red = unidentified pinniped; open circle = on effort sightings).

Ship-based Passive Acoustics (two-element towed array)

Acoustic effort is shown in Figure 8. Acoustic effort covered approximately a total of 3519 km (1900 nm) with 760 km (410 nm) conducted during full visual effort.

There were a total of 49 acoustic detections, nine during full visual effort, and 40 during "acoustics only" effort periods (Table 4). Of these detections, eight were localized to a position located equidistant right or left of the trackline. This towed array configuration and methodology does not allow for resolution of the right/left ambiguity of relative bearings without purposely altering the ships heading during the detection period. Constraints on survey time did not allow for this resolution throughout the survey. Three detections were matched to visual sightings of killer whales.

Killer whales (16) and sperm whales (28) were the only identified species acoustically detected. The unidentified odontocetes (5) are probable killer whales but calls were too weak or indistinct to classify with certainty. Acoustic identification was based on published call type descriptions. Group size estimates will not be possible for the killer whale detections due to limitations of available sound processing software.

As expected, low frequency baleen whale calls could not be detected due to the masking effect of flow noise as the array was towed through the water.

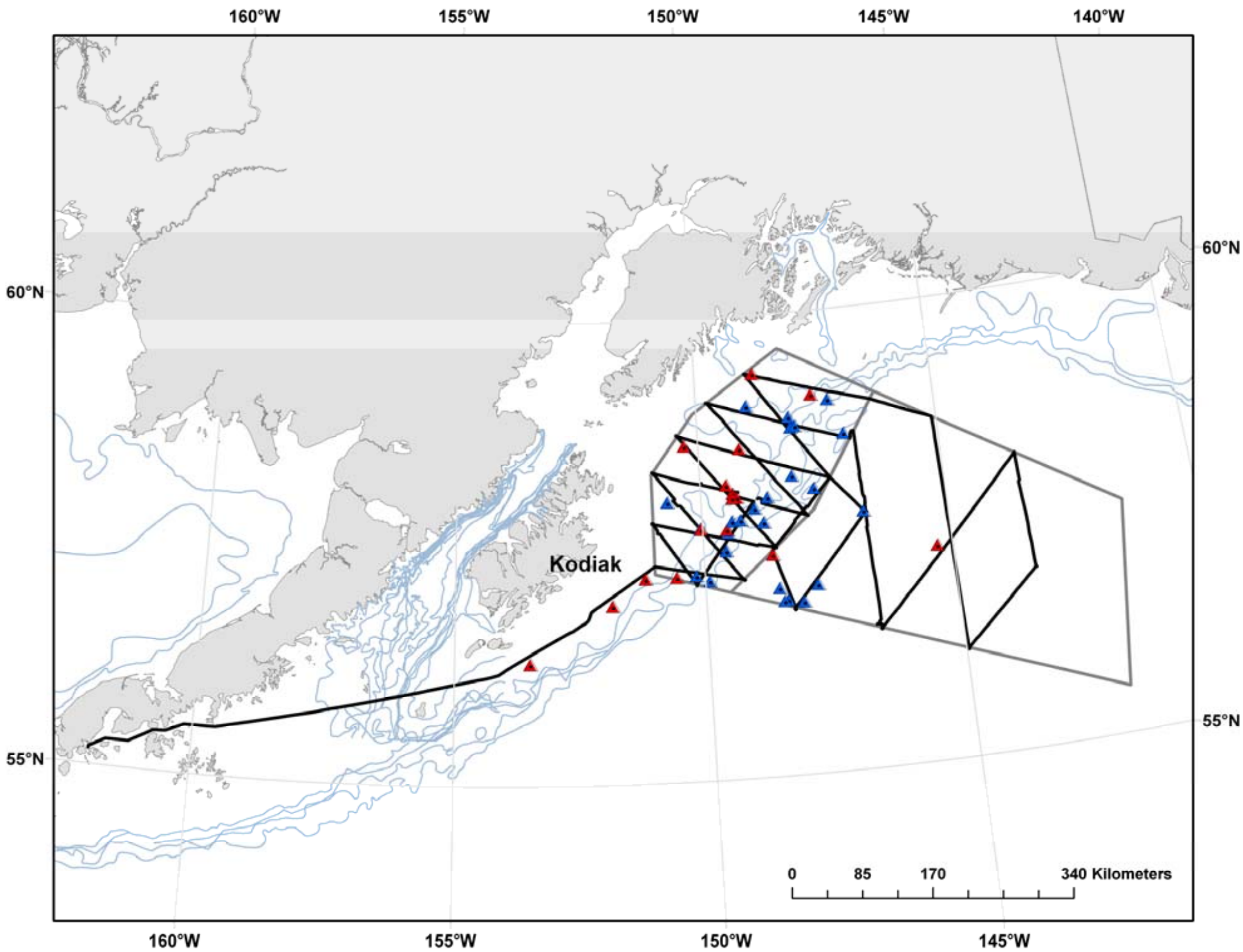

Figure 8 – Acoustic effort and detections during GOALS 2009 research cruise (red = killer whale, blue = sperm whale).

Table 4 – Acoustic Detections using two-element towed array for GOALS 2009 research cruise.

Species	Detections During Visual Effort*	Detections During Acoustic only Effort	Total
Cetaceans			
Killer Whale	8(3)	8	16
Sperm Whale	1	27	28
Unidentified Odontocete	-	5	5
Total Cetacean	*9*	*40*	*49*

* Acoustic detections matched to visual sightings

Photo-identification

Results of photo-identification are summarized in Table 5. Photographs were taken on three separate days. There were a total of 721 photographs collected during encounters with fin whales and killer whales. Results from photo analysis are in Appendix I.

Table 5 – Summary of photo-identified individuals collected during GOALS 2009.

Species	11 April 09	12 April 09	18 April 09	Total
Fin Whales	4			4
Killer Whales		5	14	19
			Total	*23*

The four fin whale identification photographs (left sides) were compared to approximately 100 fin whales from the Gulf of Alaska and 79 fin whales from Southern California; many photographs from existing catalogs were only rights sides. No matches were made between the fin whale photographs collected on this survey and the two collections. The 19 individual killer whales were compared to 1,237 western Alaska resident killer whales from the Aleutian Islands and Bering Sea as well as 400 transient killer whales from the same areas. No matches were found between the killer whales photographed on this cruise and the existing catalogs.

Line transect analysis of fin whale and humpback data

Line transect analysis was conducted using the two strata, an inshore (area = 47,411 km^2) and an offshore stratum (area = 98,253 km^2) (Fig 1). In the inshore stratum, six lines representing 460 km were visually surveyed on-effort in acceptable conditions, and offshore, 300km on three fully or partially visually surveyed lines were completed in acceptable conditions (other sections of lines were completed in either limited visibility or with acoustics only). In addition, 384 km were surveyed in transit and 169 km under foggy conditions. A total of 19 fin whale sightings were observed on effort within the survey area during GOALS 2009. Eleven were documented in transects on the inshore stratum and seven on the offshore stratum. One sighting was recorded during transit. Eight humpback whale sightings were recorded on effort, seven in the inshore and one in the offshore stratum. Additionally six sightings were made of unidentified large whales, five in the inshore and one in the offshore and these most likely represented fin or humpback whales based on the identified sightings.

For the dataset using the GOALS 2009 data only for the detection probability, only CDS models with or without series expansions were fit to the GOALS data because of the relatively small sample size of sightings. Model parameter estimates are provided in Table 6 and density and estimates for the best model in Table 7. Model #1 (Half normal without series expansions) provided the best fit.

Table 6 – Model parameter of detection probability estimation for GOALS 2009 fin whale sighting data.

Model #	Model	# par	Delta AIC	ESW (km)	ESW CV
1	Half normal without series expansions	1	0.00	2.91	0.15
2	Hazard rate without series expansions	2	1.54	3.17	0.17

par – number of parameters, AIC – Akaike Information Criterion, ESW – effective search half-width, CV – coefficient of variation

Table 7 – Estimation of density and abundance of fin, humpback, and unidentified large whales using the GOALS 2009 data only.

	Fin whale		Humpback whale		Unidentified Large Whale	
	Inshore	Offshore	Inshore	Offshore	Inshore	Offshore
# sightings	11	7	7	1	5	1
Encounter rate (ER)	0.067	0.050	0.024	0.003	0.013	0.003
ER CV	0.29	0.57	0.61	0.56	0.50	0.57
Group Size	2.81	2.14	1.57	1	1.2	1
Group Size CV	0.23	0.07	0.12	0	0.17	0
Model 1						
Density (ind/km^2)	0.011	0.009	0.004	0.0005	0.002	0.0005
Density 95% CI	(0.005, 0.024)	(0.001, 0.068)	(0.000, 0.017)	(0.000, 0.005)	(0.000, 0.008)	(0.000, 0.005)
Abundance	548	843	194	56	106	56
CV	0.33	0.59	0.63	0.59	0.53	0.59

For the combined detection function (GOALS 2009 and Miller Freeman 2003 data) results from best CDS and MCDS models (those within Delta AICs = 3) are summarized in Table 8. Overall the best model was the half normal with Method as covariate (Table 8). The combined detection function resulted in a slightly lower calculation of effective search half-width (a measure of the decline in sighting detection in relation to distance from the transect line) than using the GOALS data alone and a slightly lower CV (0.08 for best combined detection function versus 0.15 for best GOALS only CV). The lower effective strip width based on the combined dataset resulted in estimated density and abundance that were about 15% higher and with final CVs that were lower with the combined dataset versus GOALS alone.

Table 8 – Model parameter of detection probability estimation for GOALS 2009 large whale sighting data.

Model #	Model	# par	Delta AIC	ESW (km)	ESW CV
3	Half normal with Method covariate	2	0.00	2.69	0.08
4	Half normal without covariate	1	0.38	2.72	0.07
5	Half normal with Ship covariate	2	2.03	2.71	0.07
6	Half normal with Species covariate	3	2.57	2.70	0.08

par – number of parameters, AIC – Akaike Information Criterion, pdf(0) – probability density function evaluated at zero distance, ESW – effective search half-width, CV – coefficient of variation

Estimates of density and abundance for the best fit model (Model #3) are shown in Table 9 using the detection function from the combined GOALS 2009 and Miller Freeman 2003 data. Density and abundance estimates were only slightly higher with the combined detection function compared to GOALS 2009 only, and CVs were lower due to the larger combined sample.

Table 9 – Estimation of density and abundance of large whales using the GOALS 2009 and Miller Freeman 2003 data.

	Fin whale		Humpback whale		Unidentified Large Whale	
	Inshore	Offshore	Inshore	Offshore	Inshore	Offshore
# sightings	11	7	7	1	5	1
Encounter rate (ER)	0.067	0.050	0.024	0.003	0.013	0.003
ER CV	0.29	0.57	0.61	0.56	0.50	0.57
Group Size	2.81	2.14	1.57	1	1.2	1
Group Size CV	0.23	0.07	0.12	0	0.17	0
Model 3						
Density (ind/km^2)	0.012	0.009	0.004	0.0005	0.003	0.0005
Density 95% CI	(0.006, 0.025)	(0.000, 0.083)	(0.001, 0.017)	(0.000, 0.005)	(0.000, 0.009)	(0.000, 0.005)
Abundance	594	889	219	56	118	56
CV	0.29	0.57	0.57	0.57	0.52	0.57

All results are fairly similar given the constraints of the sample sizes involved. Because of the lower CV and lowest AIC score, we recommend the results of the combined dataset for the detection function and Model 3 as the best estimate of density and abundance. These yielded estimates of 594 (CV=0.29) and 889 (CV=0.57) fin whales for the inshore and offshore stratum, respectively, and 219 (CV=0.57) and 56 (CV=0.57) humpback whales in the inshore and offshore strata, respectively. Because unidentified large whales were most likely fin or humpback whales, estimates of unidentified large whales could be assigned to these species based on the proportion of fin and humpback whales identified in each stratum. This would raise fin whale estimates of abundance to 666 and 938 (inshore and offshore strata, respectively) and humpback whale estimates to 265 and 63 (inshore and offshore strata, respectively).

DISCUSSION

The survey faced several challenges including limited survey time, a large survey area, inclement weather, and the lack of sonobuoys. Despite these limitations, the survey was extremely successful and provided an unexpectedly large number of visual sightings and acoustic detections. The visual sightings generated density and abundance for fin, humpback and unidentified large whales. Although a density estimate may be produced for harbor and Dall's porpoise in the future, both these species are known to have reactive movement to ships that will need to be considered in the analysis. Although this survey produced the highest number of acoustic detections and localizations of sperm whales in comparison with previous surveys, there were not enough positive range and bearings to provide a density estimate at this time. The key variable of group size is less of an issue in this region since single animals are predominately detected (primarily males use northern waters (Kasuya and Miyashita 1988). The lack of availability of sonobuoys resulted in no detections of baleen whales. While a loss of this component prevented potential acoustic detections of some rare species like blue and right whales, it was less critical than the towed array and sonobuoy detections for determining density or abundance estimates.

Fin whales were the most common large cetacean sighted visually in the cruise. Fin whales are encountered seasonally off the coast of North America and in the Bering Sea. Based on data from bottom-mounted offshore hydrophone arrays, there were peaks in call rates occurring during fall and winter in the central North Pacific and the Aleutian Islands. Fewer calls were recorded during the summer months (Moore *et al.* 1998, Stafford *et al*. 2007, Watkins *et al*. 2000). Presence/absence of recorded calls may not reflect actual presence/absence of fin whales since there may be a seasonal pattern to their call rates or difference in oceanographic properties. Current reliable estimates for fin whales do not exist for the Gulf of Alaska; however, sighting data from coastal surveys between the Kenai Peninsula and Amchitka Pass conducted July-August 2001-2003 have generated a population estimate of 1,652 (95% CI: 1,142-2,389) (Zerbini *et al.* 2006). Density estimates of fin whales vary in the Pacific Ocean, off of California. Fin whales are observed year-round with an estimated 1.1 fin whales per 1,000 km^2 (Barlow 1995, Forney *et al.* 1995). In Hawaiian waters where sightings of fin whales are extremely rare, passive acoustic monitoring has been used to determine a density of 0.081 fin whales per 1,000 km^2 (McDonald and Fox 1999).

Although the visual observers never sighted sperm whales, they were the most common acoustically detected species during the survey. Sperm whales are known for their long dive times and have a loud echo-location click that explains the high acoustic detections of this species and absence of visual sightings. Sperm whales are distributed widely throughout the North Pacific. While sperm whale females and young generally remain in the tropical and temperate waters year-round, males are thought to move north in the summers to feed in the Gulf of Alaska and Bering Sea (Kasuya and Miyashita 1988). Although a minimum population estimate is not available for sperm whales in the Gulf of Alaska, results from data collected during visual surveys conducted by NMML during summer months between 2001 and 2006 have shown that sperm whales have been the most frequently sighted large cetacean (NMML unpublished data *in* Angliss and Allen 2009).

Sightings of humpback whales on GOALS 2009 provide important data on spring-time distribution in the Gulf of Alaska. Humpback whales were the second most common whale encountered on the survey. Other than a single sighting in the offshore stratum, humpback whales were found exclusively within the inshore stratum of effort and this is reflected in the higher density and abundance estimates for the inshore stratum. Our findings of higher humpback whale abundance in the inshore stratum agrees with past line-transect surveys of the area that found 93% of humpback whales groups were observed in water depths between 25 and 100 fathoms (Brueggeman *et al.* 1988). Humpback whales encountered during the summer along southeast Alaska, and the northern Gulf of Alaska migrate primarily to the Hawaiian Islands, and Mexico (Calambokidis *et al.* 2008). Current estimates of abundance for humpback whales based on photo-identification and line transect surveys in the western and northern Gulf of Alaska during summers 2004, 2005 and 2006 is 3,000-5,000 animals (Calambokidis *et al.* 2008). Because humpback whales generally spend the winter months on lower latitudes and are just returning to their feeding grounds in early spring when the GOALS cruise occurred, our estimates likely represent only a portion of the summer abundance in the study area. Gray whales were the third most common large whale sighted on the GOALS cruise and while this provides important data on spring-time distribution it is not adequate for an abundance or density estimate. Gray whales pass through the Gulf of Alaska twice each year as they migrate to feed in the northern Bering and Chukchi seas. They migrate back down to calving and breeding lagoons along Baja California (Braham 1984). In recent years, a large aggregation of gray whales has inhabited the Kodiak Island area throughout the entire summer (Moore *et al*. 2007). Reflecting their more inshore distribution, gray whales were only sighted in the inshore stratum.

Even though small boat operations were not possible during the cruise, efforts to obtain photographic identifications of fin and killer whales were very successful (See Appendix). Although none of the whales photographed matched existing catalogs, the photographs obtained on this cruise provide seasonal identifications of fin and killer whales in a difficult study area. Due to survey limitation, we were unable to document both sides of the fin whales. Therefore, matching to existing catalogs was limited to the one available side of the animal. However, due to the distinct dorsal fins of these four whales, there is a high probability that each animal could be matched if it already existed in the catalogs.

The 19 killer whales identified from two encounters on the GOALS cruise did not match the available catalogs; however in the months to come there may be an opportunity to compare these photographs to one additional collection. Investigations (including collection of identification photographs) on resident and transient killer whales commenced in Prince William Sound in the 1970's (Hall, 1981), and are ongoing in southeastern Bering Sea, eastern/central Aleutian Islands region and the western and central Gulf of Alaska (Dahlheim, 1997; Ellis, 1984, 1987; Leatherwood *et al.* 1984).

Overall the cruise provided valuable new data about the presence of marine mammals in the Gulf of Alaska during spring, and analyses of the visual data provided an abundance estimate and density for fin and humpback whales.

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APPENDIX I

Catalog of individuals photographed during GOALS 2009 research cruise

Fin Whales

CRC-BP-temporary 001-20090411-D6_0011edit Cascadia Research Collective, Annie B. Douglas

CRC-BP-temporary 002-20090411-D6_0019edit NMML, Brenda K. Rone

CRC-BP-temporary 003-20090411-D6-0027edit Cascadia Research Collective, Annie B. Douglas

CRC-BP-temporary 004-20090411-D6-0037edit Cascadia Research Collective, Annie B. Douglas

Killer whales

CRC-OO-temporary 001-20090412 -30D_0164edit-OO7 right Cascadia Research Collective, Annie B. Douglas

CRC-OO-temporary 001-20090412-30D_0184edit OO7 left Cascadia Research Collective, Suzanne Yin

CRC-OO-temporary 002-20090412-30D_0181edit OOg left Cascadia Research Collective, Annie B. Douglas

CRC-OO-temporary 007-20090418-30D-0066edit OOc Cascadia Research Collective, Annie B. Douglas

CRC-OO-temporary-005-20090412-30D_178edit OOc Cascadia Research Collective, Suzanne Yin

CRC-OO-temporary 009-20090418-30D-0066edit OOd Cascadia Research Collective, Annie B. Douglas


CRC-OO-temporary 011-20090418-30D-0060edit OOg
Cascadia Research Collective, Annie B. Douglas


CRC-OO-temporary 012-20090418-30D-0060edit OOh
Cascadia Research Collective, Annie B. Douglas


CRC-OO-temporary-003-20090412-30D-0172edit OOa
Cascadia Research Collective, Suzanne Yin


CRC-OO-temporary 010-20090418-30D-0071edit OOe
Cascadia Research Collective, Annie B. Douglas


CRC-OO-temporary 014-20090418-30D-0073edit OOk (right) Cascadia Research Collective, Annie B. Douglas


CRC-OO-temporary 015-20090418-30D-0076edit OOL
Cascadia Research Collective, Annie B. Douglas


CRC-OO-temporary 016-20090418-30D-0080edit (L)
OOM Cascadia Research Collective, Annie B. Douglas


CRC-OO-temporary 016-20090418-30D-0089edit OOm(r)
Cascadia Research Collective, Annie B. Douglas


CRCRC-OO-temporary17-20090418-30D 0120edit OO N
Cascadia Research Collective, Annie B. Douglas


CRC-OO-temporary 018-20090418-30D-0127edit OO P
Cascadia Research Collective, Annie B. Douglas


CRC-OO-temporary 019-20090418-30D 0083edit OOq(r)
Cascadia Research Collective, Annie B. Douglas


CRC-OO-temporary 020-DY0905_18-Apr-09_S57 60
63_BKR_8441 OOa NMML, Brenda K. Rone


CRC-OO-temporary -024-20090418R-30D-0069edit OOb
Cascadia Research Collective, Annie B. Douglas


CRC-OO-temporary-025-20090418-D6-0086edit OOs
Cascadia Research Collective, Suzanne Yin


CRC-OO-temporary-021-20090412-D6-0048 OO1
Cascadia Research Collective, Annie B. Douglas