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Acoustic and visual monitoring for cetaceans along the outer Washington coast

by

Erin M. Oleson, John Calambokidis, Erin Falcone, Greg Schorr,
and John A. Hildebrand

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13. ABSTRACT *(maximum 200 words)*

Since July 2004, visual and acoustic monitoring efforts for marine mammals have been conducted in waters off the outer Washington coast. These efforts have been specifically to determine the seasonal occurrence of marine mammal species and to estimate their relative abundances, particularly in the area of the proposed expansion of the U.S. Navy's Quinault Underwater Tracking Range (QUTR) of the Northwest Range Complex. This has resulted in the first multi-year, year-round effort in 20 years to document and understand the presence of marine mammal species in this region. This report summarizes all data so far collected, presenting analyses of seasonal occurrence, variation in sighting distribution, and evaluation of relative abundance for all species that can be consistently identified from the visual and acoustic data sets.

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FY07 Grant Report:
Acoustic and Visual Monitoring for Cetaceans along the Outer Washington Coast

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Project Impact

In September 2003, the U.S. Navy proposed expansion of its Quinault Underwater Tracking Range (QUTR), part of the Northwest Range Complex (Federal Register, **Vol. 68**: 53599-53600, 11 September 2003), further west into offshore waters and south along the shelf. In July of 2004, we initiated an acoustic and visual monitoring effort for marine mammals within the boundaries of the proposed expansion area. This effort was designed to allow for: 1) characterization of the vocalizations of species present in the area, 2) determination of the year-round seasonal presence of all marine mammal species, and 3) evaluation of the distribution of marine mammals near the Navy range. Two High-frequency Acoustic Recording Packages (HARPs) were deployed near the QUTR, one in deep water within Quinault Canyon (Figure 1: S1) and a second in inshore waters on the shelf (S2). In conjunction with the acoustic monitoring, visual surveys have been conducted roughly monthly by Cascadia Research Collective since August 2004.

In July 2007 the Navy renewed its intent to issue an Environmental Impact Statement (EIS/OEIS) for the range expansion (Federal Register, **Vol. 72**: 41712. 31 July 2007). It is our intent, as part of this grant report, to provide the most up-to-date and complete information available from our monitoring efforts for inclusion in the EIS for the QUTR expansion. Our study provides the first multi-year and year-round effort to document and understand the presence of marine mammal species in this region in nearly 20 years. In addition, we present the first year-round visual and acoustic study for this region, a mode of surveying which provides greater opportunity to survey all marine mammal species, ranging form those that are commonly seen but rarely heard, such as gray whales, to those that are highly vocal but surface infrequently, such as sperm whales.

Project Background

The outer Washington coast of the United States is a highly productive marine ecosystem, home to many species of marine mammals, including beaked whales, killer whales, and several other odontocete, mysticete, and pinniped species. Expansion of the QUTR into deep-water habitats used by beaked and sperm whales and south along the shelf where coastal cetaceans forage could impact these marine mammal communities.

In the late 1980s, extensive year-round aerial surveys were conducted along the Oregon and Washington coasts (Green *et al.* 1992). Fourteen species of cetacean were observed during these surveys, with the most common being the Risso's dolphin, Pacific white-sided dolphin, northern right whale dolphin, harbor porpoise, Dall's porpoise, and gray whale. The study yielded estimates of seasonal distribution and abundance for the most common cetacean species.

Since that time, cetacean surveys in this region have generally been limited to the summer and fall, including broad-scale visual and acoustic ship surveys (Barlow 1994, 2003) conducted by NOAA Fisheries, and fine-scale ship-based surveys along the northern Washington coast (Calambokidis *et al.* 2004a) conducted by the Olympic Coast National Marine Sanctuary (OCNMS). Very few winter and spring surveys have been conducted, including winter aerial surveys along the northern Washington coast conducted by NOAA Fisheries (Shelden *et al.* 2000). Year-round acoustic monitoring from NAVY SOSUS arrays has provided information on the seasonal occurrence of blue, fin and humpback whales (Watkins *et al.* 2000, Stafford *et al.* 2001), although these arrays are located further offshore and provide only low frequency listening capabilities. No acoustic surveys for odontocetes have been conducted in this region, with the exception of occasional ship-based acoustic recordings from summer and fall NOAA surveys.

In July 2004 a visual and acoustic monitoring effort for marine mammals was initiated off the outer Washington coast. This effort was specifically designed to determine the seasonal occurrence of marine mammal species and estimate their relative abundances. Visual and acoustic data collection has continued since 2004, resulting in four full years of survey data in this region.

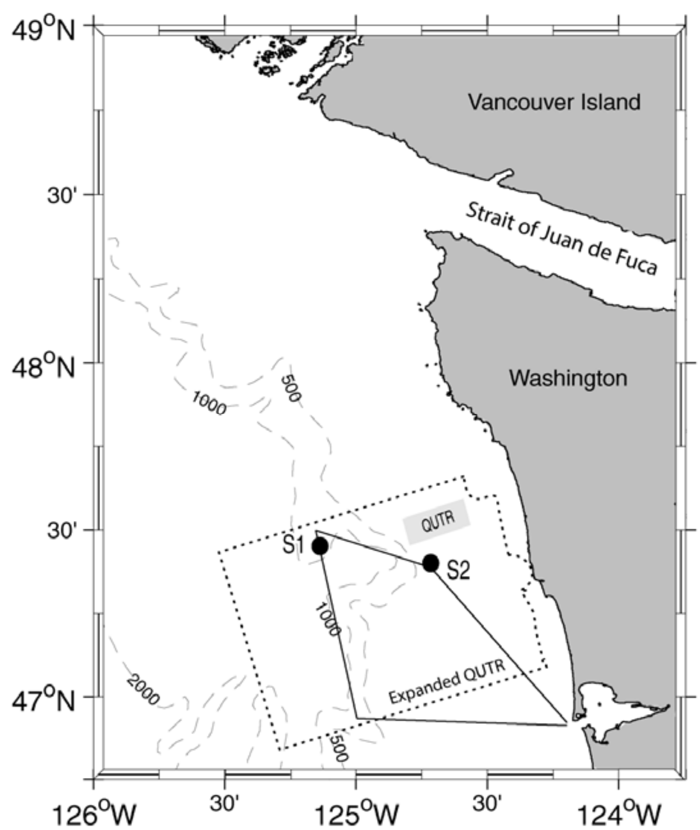

Figure 1. Locations of two High-frequency Acoustic Recording Packages, S1 and S2, and the monthly visual survey track (solid line) from Westport harbor.

Data Collected to Date

A total of 59 months of acoustic data have been collected at two sites using autonomous High-frequency Acoustic Recording Packages (HARPs). From July 2004 to July 2007, acoustic data were collected at an 80 kHz sample rate, either continuously or at 1/3 duty cycle (Table 1). A software bug resulting in an abandonment of the duty cycle on 1 January produced shorter recordings than expected. In order to sample the spring period in 2007, both HARPs were re-fitted with new batteries in April of that year. In July and October of 2007 the offshore and inshore HARPs, respectively, were redeployed with a higher sample rate (200 kHz) specifically targeting beaked whales and other very high-frequency odontocetes. Due to the increase in acoustic sampling rate, the duty-cycle was necessarily lengthened, resulting in year-round recordings, but with longer off periods between recording segments (Table 1). These data were retrieved in June 2008. Acoustic data collection continues at both sites.

A 5.3 to 5.9 m rigid hull inflatable was used to conduct surveys out of Grays Harbor, Washington. The goal was to conduct surveys during periods of good weather, with an emphasis on sampling as consistently as possible across different seasons through an entire year. Weather was monitored and surveys only attempted during periods of forecast good weather. Two to three people including the driver were aboard during each survey, and visual observations were maintained for marine mammals during the entire survey. Weather and time permitting, the surveys followed a similar route: 1) Grays Harbor to the Quinault Canyon, stopping at both of the HARP locations there; 2) Quinault Canyon south along deeper waters down to Grays Canyon; and 3) Grays Canyon back to Grays Harbor. Slight variations to this route were made as necessitated by weather and time constraints and in response to sightings.

Table 1. Acoustic data collection near QUTR since July 2004. Ongoing acoustic data collection is shown in italics.

Acoustic Monitoring Period	Sample Rate & Duty Cycle (on/off, min.)	S1: Offshore	S2: Inshore
OCNMS01: July – October 2004	80 kHz continuous	Yes	Instrument lost
OCNMS02: October 2004 – July 2005	80 kHz 10/20	Data ended 1/05	No recording
OCNMS03: July 2005 – August 2006	80 kHz 6/12	Data ended 2/06	No recording
OCNMS04: August 2006 – March 2007	80 kHz 6/12	Data ended 2/07	Yes
OCNMS05: April – July 2007	80 kHz continuous	Yes	Yes
OCNMS06: July 2007 – June 2008	200 kHz 5/35	Yes	
OCNMS07: October 2007 – June 2008	200 kHz 5/30		Yes
OCNMS08: June 2008 – June 2009	*200 kHz 5/35*	*Ongoing*	*Ongoing*

When marine mammals were encountered we recorded the time, position, species, number of animals, behavior, environmental conditions, and water depth. For large cetacean sightings, especially humpback, gray, and killer whales, photographs were taken to document species and to allow photographic identification of individual animals. Photographic identification was conducted using methods established in past work along the west coast on gray whales (Calambokidis *et al.* 2004b) and humpback whales (Calambokidis *et al.* 2004a, Calambokidis and Barlow 2004). Biopsy samples were also collected from many of the humpback whales encountered using a small dart fired from a crossbow.

Joint visual-acoustic surveys were conducted in collaboration with the Olympic Coast National Marine Sanctuary during July 2007 and June 2008. These surveys were carried out aboard the NOAA Ship *MacArthur II*, and consisted of a team of three visual observers on watch from the flying bridge of the *MacArthur II* while two acousticians monitored a towed hydrophone array for marine mammal vocalizations. These surveys allowed for collection of acoustic data from visually identified species to aid in species-discrimination algorithms, and will serve to provide an opportunity to directly compare visual and acoustic detection rates for some species.

In FY07 the project goals included 1) analysis of the existing acoustic and visual data, 2) assessment of environmental datasets for development of a habitat model for cetaceans in the region, and 3) continued data collection for an additional year. This report will summarize all data collected to date and will present analyses of seasonal occurrence, variation in sighting distribution, and evaluation of relative abundance for all species that can be consistently identified from the visual and acoustic data sets.

Results

Visual Surveys

Table 2. Visual survey sighting summary for all surveys conducted from August 2004 through September 2008. Tables of sightings during each survey can be found in the appendix.

	Species	Sightings	Animals
Baleen whales			
	Humpback Whale	80	147
	Gray Whale	55	116
	Minke Whale	1	1
	Fin whale	1	2
	UnID Whale	2	2
Odontocetes			
	Killer Whale	6	51
	Cuvier's beaked whale	1	3
	UnID beaked whale	2	3
	N. Right Whale Dolphin	3	59
	Pac. White-sided Dolphin	18	1681
	Risso's dolphins	2	38
	Harbor Porpoise	114	244
	Dall's Porpoise	44	206
Pinnipeds			
	California Sea Lion	25	187
	Steller Sea Lion	11	56
	Northern Fur Seal	60	157
	Harbor Seal	27	723
	Northern Elephant Seal	10	10
	UnID Pinniped	3	5
Total		**465**	**3691**

A total of 42 small boat surveys were conducted over a 4-year period between 16 August 2004 and 2 September 2008 representing 414 hours and 5,353 nmi of survey effort (see Appendix Table I). Surveys were conducted at roughly monthly intervals as weather allowed throughout the year. Maps indicating the location of each dolphin and porpoise (Figure 2), whale (Figure 11), and pinniped (Figure 20) sighting are included. A total of 465 sightings of 3,691 marine mammals were made during the small boat surveys (Table 2) representing 11 cetacean and 5 pinniped species. Harbor porpoise were the most frequently sighted marine mammals overall (114 sightings), although, due to their larger average group size, Pacific white-sided dolphin had the largest number of animals sighted (1,681). Among baleen whales, sightings were dominated by humpback and gray whales, with only single sightings of fin and minke whales.

Habitat Analysis from Visual Survey Data

There were significant differences in key habitat variables for different species, highlighting the differences in their occurrence within the study area (Table 3). Distance from shore was significantly different by species (ANOVA: F=55.5, df=18, p=0.000). Similar significant differences were also found by species for distance from the 200 m depth contour (ANOVA: F=42.2, df=18, p=0.000) and water depth (ANOVA: F=26.0, df=18, p=0.000).

Table 3. Key habitat variables by species, including distance from shore, distance from 200 m depth (shelf break), and water depth. N represents the total number of sightings of each species or species group.

		Dist. (km) from shore		**Dist. (km) from 200 m**		**Water depth (m)**	
Species	**N**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Minke whale	1	14	-	38	-	-38	-
Fin whale	1	63	-	5	-	-968	-
Gray whale	55	13	11	37	11	-46	81
- S migration Dec.-Jan.	10	29	13	22	10	-126	171
- N migration Feb.-April	30	9	5	42	6	-26	16
- Summer feeding May-Oct.	15	12	9	39	9	-33	23
Humpback whale	80	35	14	17	10	-187	265
Killer whale	6	36	22	17	16	-342	407
Risso's dolphin	2	34	1	3	0	-129	5
Northern right whale dolphin	3	56	9	12	6	-964	377
Pacific white-sided dolphin	18	56	11	13	8	-801	534
Beaked whale	3	61	4	14	8	-906	415
Dall's porpoise	44	46	15	12	9	-501	526
Harbor porpoise	114	10	9	40	9	-31	26
Northern fur seal	60	55	14	11	7	-754	477
Steller sea lion	11	13	10	35	13	-42	37
Elephant seal	10	59	8	13	4	-905	334
Harbor seal	27	11	15	42	14	-56	165
California sea lion	25	21	14	28	15	-78	98

Acoustic Monitoring

To date, several species have been detected within the acoustic data set, including Pacific white-sided dolphins, Risso’s dolphins, beaked whales, killer whales, sperm whales, humpback whales, blue whales, and fin whales. Also, a number of sounds have not yet been classified to species. Acoustic classification is carried out either from comparison to species-specific spectral characteristics or through analysis of the time and frequency characters of individual clicks. Other species are known to occur in this area, though species-specific information on their sounds has not yet been identified.

In general there are nearly twice as many detections of marine mammal sounds at the offshore acoustic monitoring site than at the inshore site. Some species have a distinct seasonal pattern, while others are present year-round. Species-specific trends in vocal activity are described below.

Findings by Species

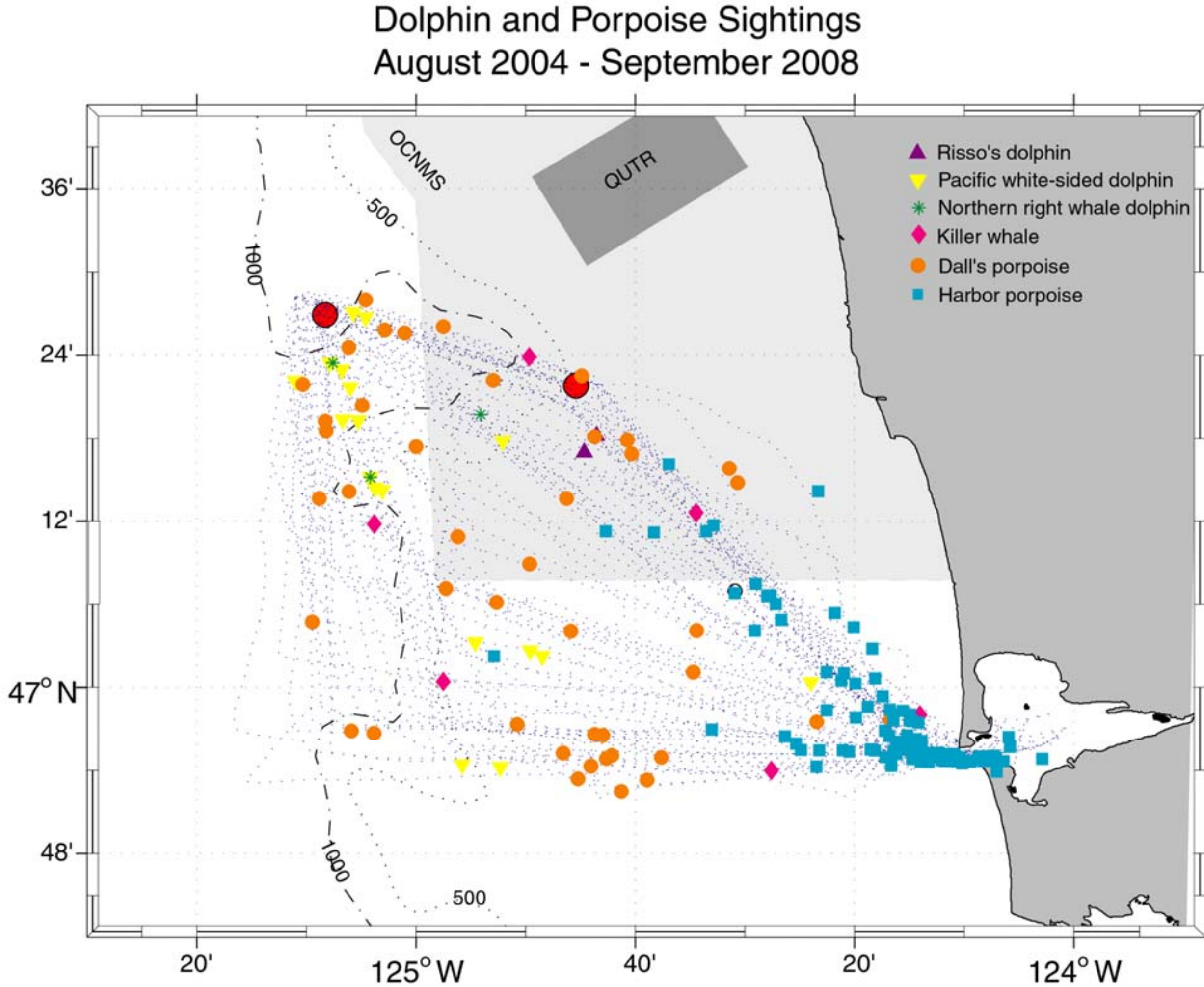

Figure 2. Dolphin and porpoise sightings during visual surveys since August 2004. Although sightings of Dall's and harbor porpoise are common in all months, the remaining delphinids have been seen on very few surveys, primarily during the summer.

Harbor and Dall's Porpoise

Harbor and Dall's porpoise were the most frequency sighted marine mammals during visual surveys, with 158 total combined sightings. The echolocation clicks of both of these species are thought to be higher in frequency than the HARP is currently able to record, such that no acoustic detection data are available for either of these species. Some unidentified high-frequency clicks-- lower in frequency than porpoise clicks are thought to be emitted, yet higher in frequency and lower in bandwidth than the clicks of many other odontocetes-- were recorded on the HARP. It is possible these clicks are those of either harbor or Dall's porpoise. The seasonal occurrence of these clicks is presented below for unidentified odontocetes.

Harbor porpoise sightings varied significantly by season for distance from shore (ANOVA: F=5.3, p=0.002), distance from the shelf edge (F=5.6, p=0.001), and water depth (F=5.5, p=0.002), with fall sightings closest to shore, farthest from the shelf edge, and in shallower water versus summer sightings (farthest from shore, closest to the shelf edge, and in deeper water).

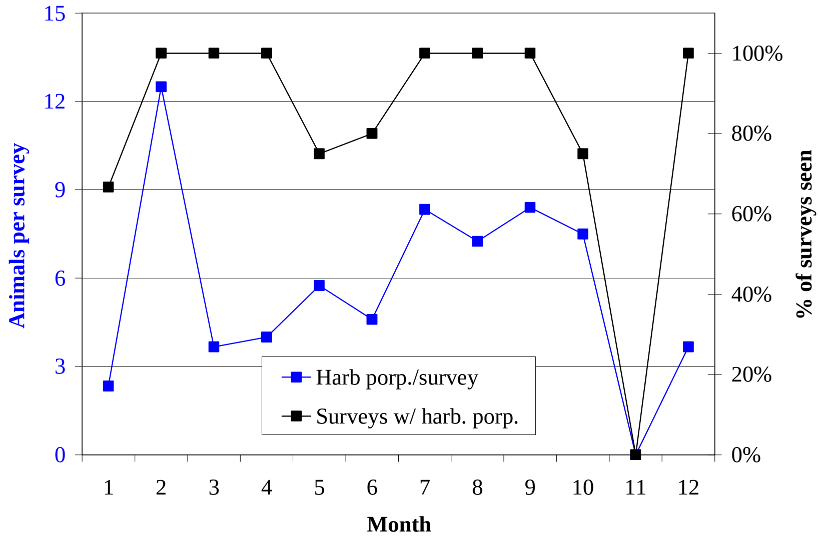

Figure 3. Seasonal occurrence of harbor porpoise based on visual survey sightings from August 2004 through September 2008. As an indicator of relative density, the average number of animals seen per survey per month is compared to the percent of surveys per month in which harbor porpoise were sighted.

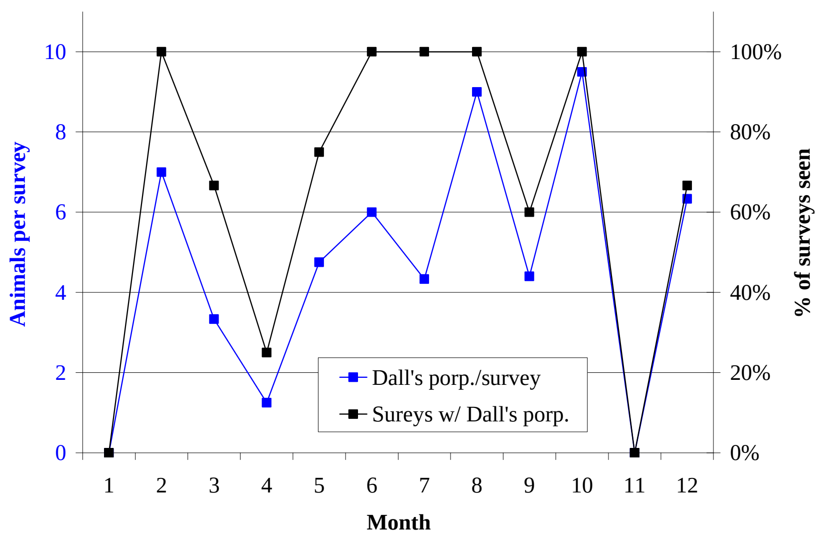

Figure 4. Seasonal occurrence of Dall's porpoise based on visual survey sightings from August 2004 through September 2008. As an indicator of relative density, the average number of animals seen per survey per month is compared to the percent of surveys per month in which Dall's porpoise were sighted.

Although Dall's and harbor porpoise occurrence appears to be tightly correlated (Figures 3 and 4), it is unclear whether this represents an actual coupling in the occurrence of these species or is more indicative of weather conditions during the surveys. Porpoises are difficult to see in moderate weather conditions. Harbor porpoise are much more common close to shore, while Dall's porpoise are sighted throughout the study area (Figure 2).

Pacific White-sided Dolphins

Pacific white-sided dolphins are the most commonly detected odontocete in the acoustic dataset. White-sided dolphins were heard for nine to ten months each year, with a distinct absence in April and May of most years (Figure 5). The specific timing of arrival and departure

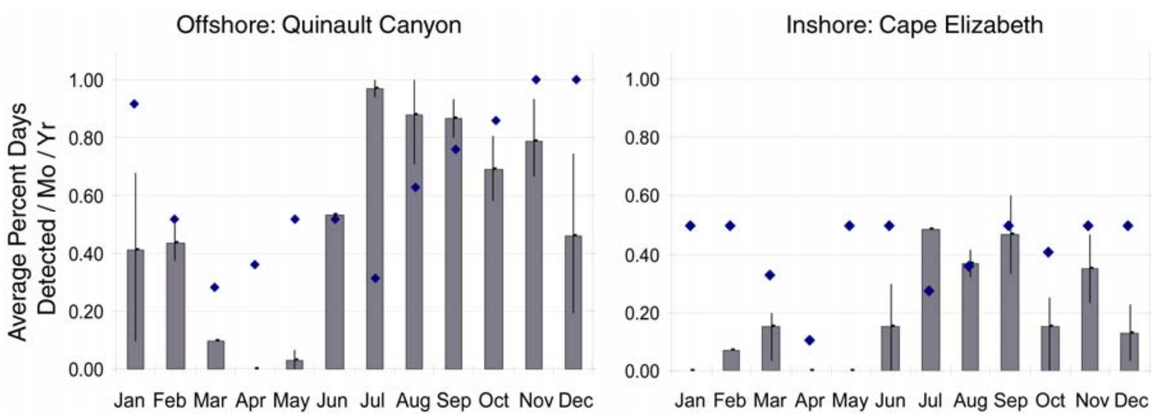

Figure 5. Average seasonal occurrence of Pacific white-sided dolphin echolocation clicks at the offshore and inshore acoustic monitoring locations. The gray bars represent the mean detection rate across all years of acoustic monitoring effort and error bars indicate minimum and maximum acoustic detection rates. Blue diamonds indicate the average acoustic monitoring effort for each month, with 100% (shown as 1.00 on the y-axis) effort indicating monitoring all month over all four years of data collection.

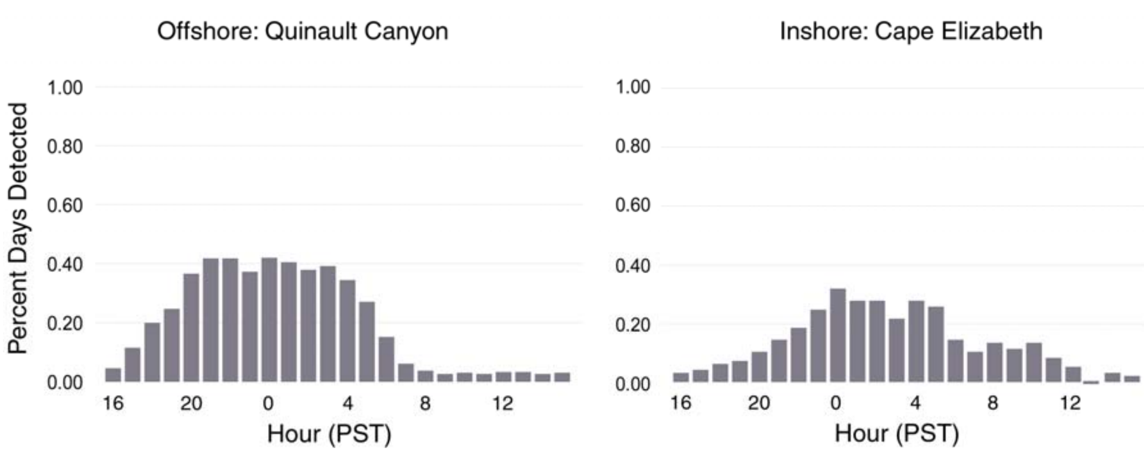

Figure 6. Occurrence of Pacific white-sided dolphin clicks by hour of the day. Pacific white-sided dolphins are significantly more common at night than during the day at both locations.

from the area fluctuated somewhat among years, though 2007-08 had particularly low rates of white-sided occurrence in the winter and spring. A peak in Pacific white-sided dolphin detection occurs in the summer at both acoustic monitoring sites, though high levels of detection continue at the offshore site through November.

A significant daily pattern of acoustic detection is evident at both the inshore and offshore monitoring locations for this species (Kruskal Wallis: inshore, $\chi^2=51.84$, df=100, $p<0.0001$; offshore, $\chi^2=431.73$, df=466, $p<0.0001$). At both sites Pacific white-sided dolphins are heard more commonly at night than during the day, with nighttime detection rates 8 times higher than daytime detection rates at the offshore location (Figure 6). These observations suggest nighttime monitoring will be required in order to reliably detect the presence of this species using its distinct echolocation clicks.

Pacific white-sided dolphins were observed 18 times over 7 surveys in the summer and fall. Though observed less commonly than several other species, the total number of individuals observed was highest for Pacific white-sided dolphins due to the large group sizes for this species in this region. The seasonality of Pacific white-sided dolphin sightings is consistent with the acoustic detection of this species; however, acoustic detections do indicate their presence over a much broader period than indicated by the visual sightings alone. This is likely due to marginal weather conditions during many fall and winter surveys. It is interesting to note that Pacific white-sided dolphins were among the most frequently sighted cetaceans during the OCNMS survey in this region in July 2007, though they were not seen at all in June 2008. It is not yet clear if the Pacific white-sided dolphins had not yet arrived in the region or if oceanographic factors may have led them to use alternative regions for feeding in 2008. Sightings during our visual surveys in summer were significantly farther offshore than those during fall (ANOVA: F=8.0, p=0.12).

Risso's Dolphins

Risso's dolphins were detected within the acoustic records an average of 5 to 6 days per year, but were sighted by visual observers only once in 4 years of surveying. Risso's dolphins also were not observed during the July 2007 and June 2008 OCNMS cetacean survey cruises. The low visual and acoustic detection rate in this region is in sharp contrast to the large number of Risso's dolphins observed during aerial visual surveys in the late 1980s (Green *et al.* 1992). During those surveys, Risso's dolphins were the most commonly sighted odontocete within the study area. Acoustic detections of Risso's dolphins during this study occurred throughout the year.

Unidentified Odontocetes

A large number of echolocation clicks, whistles, and burst-pulse sounds have been detected that cannot currently be identified to species. Several delphinid species are thought to occur here, including northern right whale dolphin and common dolphin, as well as pygmy and dwarf sperm whales, false killer whales, and several beaked whale species. We have catalogued those sounds that cannot yet be identified to species, and will compare them to new recordings of these species as they become available. Unidentified sounds are most common in the summer and fall, and are rarely heard in the spring (Figure 7). This pattern is quite similar to that of Pacific white-sided dolphin acoustic detections, suggesting a general summer and fall peak in occurrence for most delphinid species. It is also likely that many of the sounds within the unidentified category, particularly burst-pulse sounds which have not been adequately described for this species as yet, are those of Pacific white-sided dolphin.

Although there is a statistically significant daily pattern in the occurrence of unidentified sounds (Figure 8), it is slight, likely because the sounds of several species and that represent several behavioral states are lumped together, obscuring patterns that might otherwise be quite distinct.

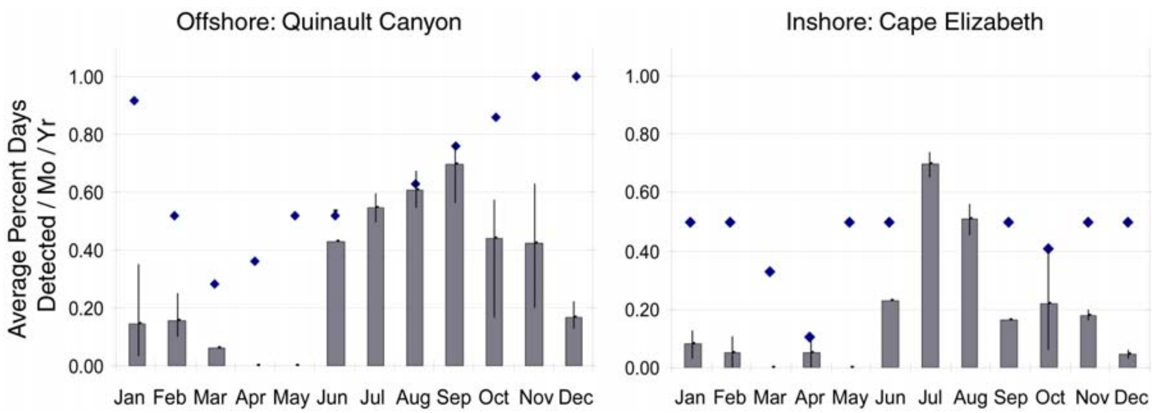

Figure 7. Average seasonal occurrence of whistles, burst-pulses, and echolocation clicks from unidentified odontocetes at the offshore and inshore acoustic monitoring locations. The gray bars represent the mean detection rate across all years of acoustic monitoring effort and error bars indicate minimum and maximum acoustic detection rates. Blue diamonds indicate the average acoustic monitoring effort for each month, with 100% (shown as 1.00 on the y-axis) effort indicating monitoring all month over all four years of data collection.

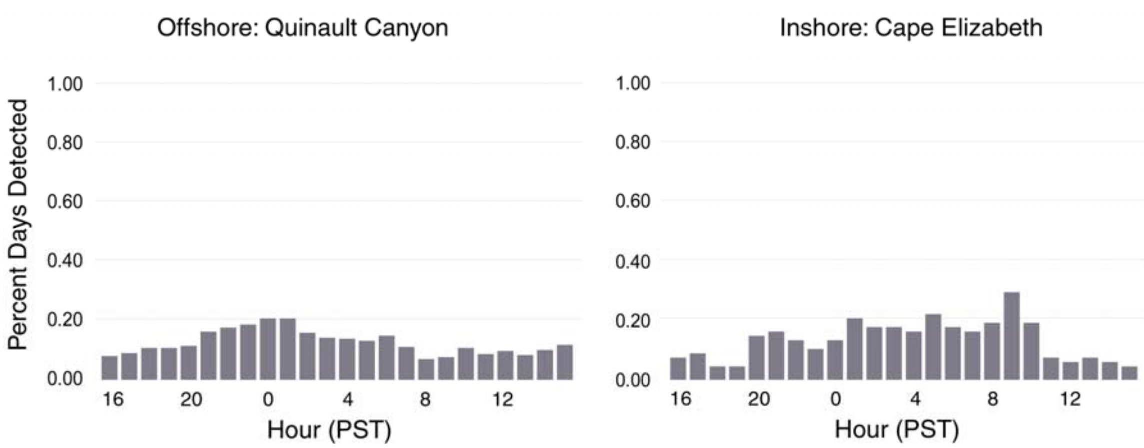

Figure 8. Occurrence of clicks, whistles, and burst-pulse sounds from unidentified odontocetes by hour of the day. Although the hourly pattern is significant, the inclusion of sounds from several species is likely muting patterns that would otherwise be more prevalent

In addition to the echolocation clicks, whistles, and burst-pulse sounds tallied above, we detected a new click type in 2007-08 due to the higher acoustic bandwidth available in this year.

Clicks series consisted of 8-10 clicks with -10 dB frequency from 57-75 kHz. The clicks were often quite faint and single series could be separated by long periods of absence. These clicks were heard at both acoustic monitoring locations, though the seasonal occurrence at the two sites does appear to be different (Figure 9). There is a clear peak in the occurrence of these high-frequency clicks in January at the offshore location, while the peak occurs somewhat earlier and later, in November and again in June, at the inshore location.

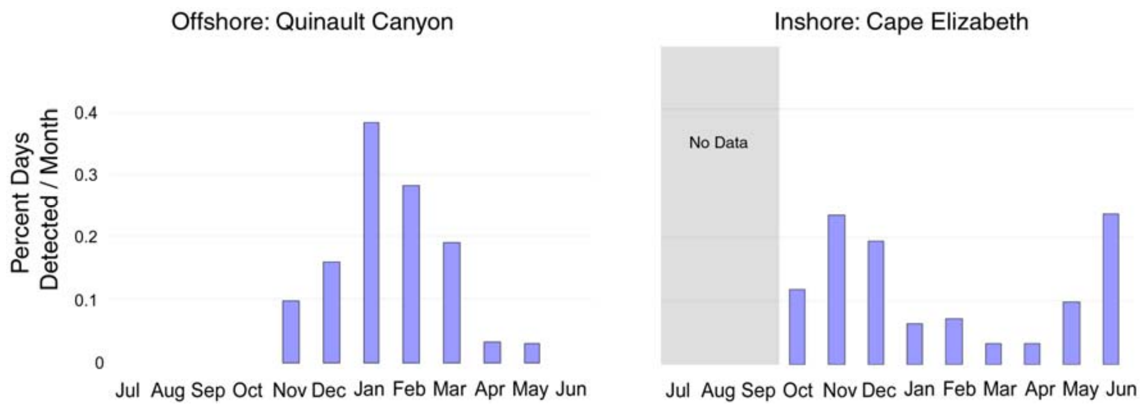

Figure 9. Seasonal occurrence of high-frequency clicks from an unidentified odontocete recorded from July 2007 through June 2008.

Killer Whales

Four killer whale communities have been detected at the acoustic monitoring sites, including Northern and Southern Residents, Offshores, and Transient ecotypes. Both the

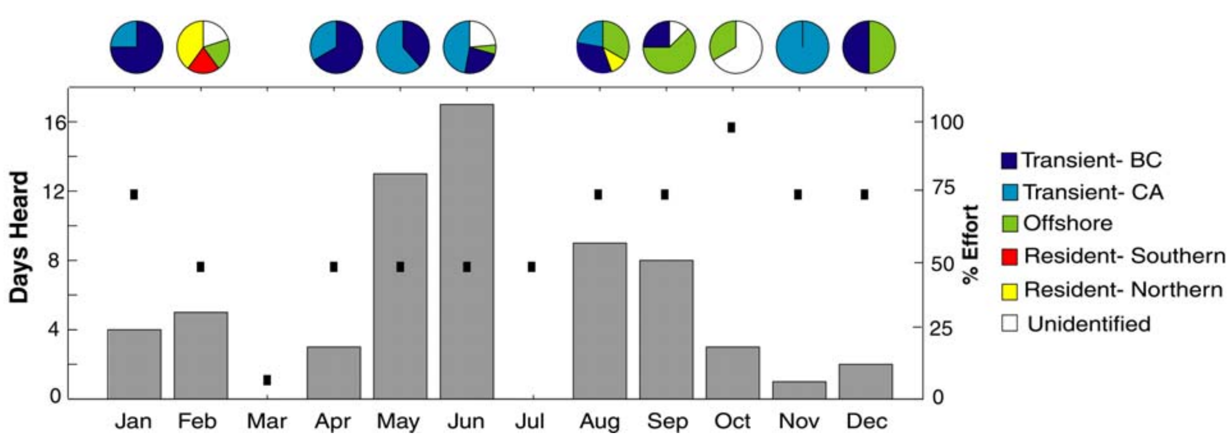

Figure 10. Seasonal occurrence through July 2007 of killer whale ecotypes recorded at both acoustic monitoring sites. Gray bars represent the average number of days that killer whales were heard per month from 2004 through 2007 and black dots represent the average number of days of effort per month in each year. The pie charts above the panel indicate the relative occurrence of each killer whale ecotype in each month. Killer whale calls detected from July 2007 through June 2008 have not yet been identified to ecotype and are not included in this figure.

California and British Columbia transient killer whale dialects of the West Coast Transient killer whale community have been recorded, occasionally within mixed groups. The seasonal and relative occurrence of the discrete calls of each killer whale ecotype is shown above for acoustic data collected through July 2007, with the grey bars of the histogram representing overall killer whale occurrence monthly, and the colored pie charts indicating the relative abundance occurrence of each ecotype. There were over 20 occurrences of killer whale calls within the July 2007-June 2008 data set. Identification of these calls to ecotype is ongoing.

There have been six sightings of killer whale groups during visual surveys (Figure 2). All but one of these encounters was of transient killer whales, with the remaining sighting being Southern Residents in April 2006 near Grays Harbor. Sightings of transient killer whales were spread across the study area and occurred throughout the year. When killer whales were seen, as many whales as possible were photographed for later identification in order to confirm their population identity and individual life history.

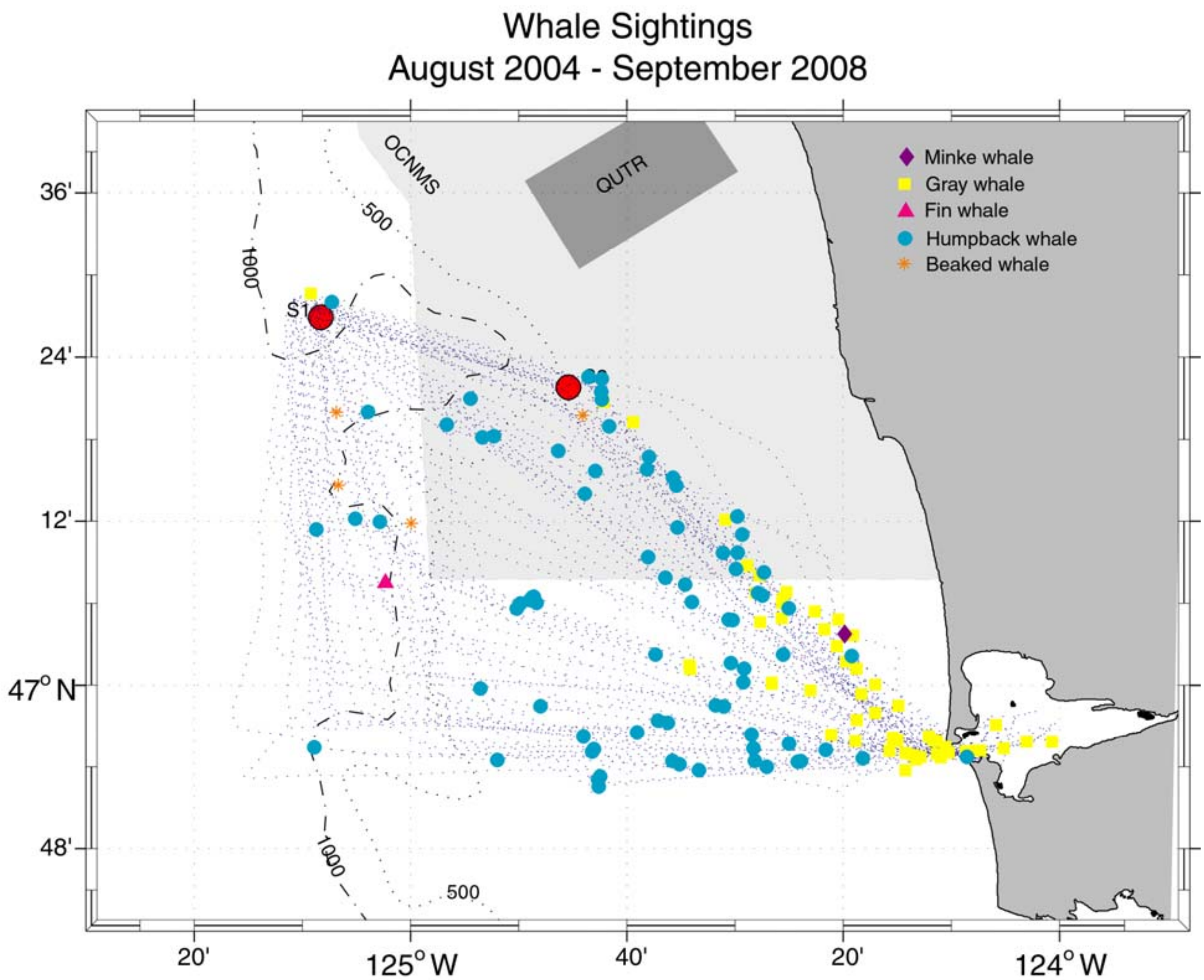

Figure 11. Large whale sightings during visual surveys since August 2004. Humpback whales are the most common large whale, though gray whales are also common in winter and spring. Beaked whales have been seen on three occasions along the shelf edge.

Beaked Whales

Upsweep clicks were detected twice, once in January and once in April 2008. Both bouts of upsweep clicks consisted of individual pulses 220 μs in duration with -10 dB bandwidth from 43 to 75 kHz, somewhat higher than clicks previously reported for either Cuvier's or Blainville's beaked whales. Although these clicks were likely produced by beaked whales, the species identity of the producer has not yet been determined. Cuvier's beaked whales have been observed once during visual surveys (Figure 11), with that sighting occurring near the offshore acoustic recording location prior to high-frequency data collection there. Two additional sightings of unidentified beaked whales have also occurred during visual surveys.

Sperm Whales

Although never seen during visual surveys conducted during this study, sperm whales are quite common within the acoustic dataset. Sperm whales are heard in all months of the year at the offshore site, with a peak in occurrence from April to August, and are heard from April to November, with one detection in January, at the inshore location (Figure 12). Not surprisingly, the detection rate at the inshore site is much lower than that at the offshore site, likely due to the shallow habitat surrounding the inshore site. Although there are periods of loud clicking at the inshore site suggesting that sperm whales are swimming nearby, most detections there of sperm whales are faint, potentially suggesting that the whales are offshore.

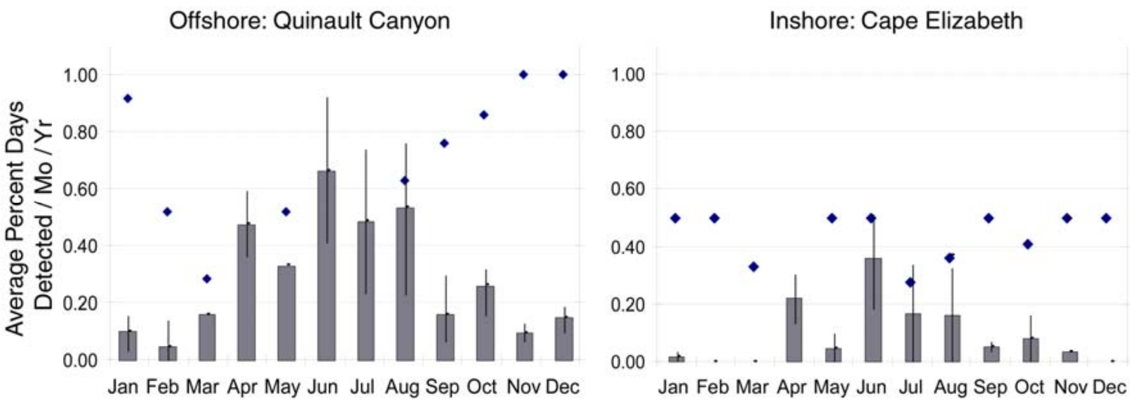

Figure 12. Average seasonal occurrence of sperm whale clicks at the offshore and inshore acoustic monitoring locations. The gray bars represent the mean detection rate across all years of acoustic monitoring effort and error bars indicate minimum and maximum acoustic detection rates. Blue diamonds indicate the average acoustic monitoring effort for each month, with 100% (shown as 1.00 on the y-axis) effort indicating monitoring all month over all four years of data collection.

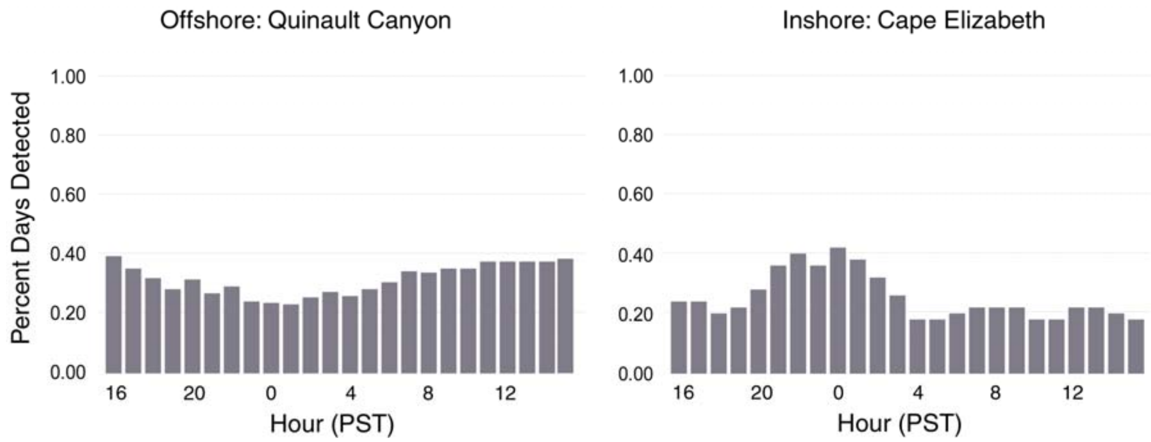

Figure 13. Occurrence of sperm whale clicks by hour of the day. The daily pattern of sperm whale clicks is significant at both sites, though barely so at the offshore site.

Although slight, there is a significant diel pattern in the occurrence of sperm whale clicks at each of the acoustic monitoring locations (Figure 13). At the offshore site, clicks are heard more commonly during the day (Kruskal Wallis: χ^2=14.48, df=223, p=0.0001), while they are more common at night at the inshore location (Kruskal Wallis: χ^2=7.16, df=51, p=0.0074). This difference in the day versus nighttime activity of sperm whales in these locations could be an indicator of diel movements up and down the slope in search of prey.

Humpback Whales

Sightings of humpback whales occurred widely throughout the survey area, but were most common in waters on the continental shelf deeper than 50 m. The high frequency of humpback whale sightings during the surveys was somewhat surprising and may represent a relatively recent development as humpback whales recover from commercial whaling. Close to 2,000 humpback whales were killed by up to four catcher boats operating out of Bay City in Grays Harbor generally in summer and fall between 1911 and 1925 (Scheffer and Slipp 1948). Sightings of humpback whales were rare offshore of Grays Harbor in the 1960s and 1970s. No sightings of humpback whales were reported between 1966 and 1976 from 47 day trips (similar to those we conducted) going offshore out of Grays Harbor and covering the continental shelf, slope, and sometimes deeper waters (Wahl 1977). During year-round aerial surveys in 1989 and 1990 off Oregon and Washington, sightings of humpback whales occurred primarily in May to September, but only a couple of sightings were reported from the area offshore of Grays Harbor to Quinault Canyon (Greene *et al.* 1992). From annual summer surveys from 1995 to 2002, Calambokidis *et al.* (2004a) reported frequent occurrences of humpback whales off northern Washington. Most of these sightings were concentrated near the Canadian border, and relatively few were sighted in the Quinault Canyon area and the portion of their survey area that overlapped with the area covered in this survey. While humpback whales are generally thought to occur primarily on low latitude breeding grounds in winter, sightings in other feeding areas in winter have been reported, including off northern Washington (Shelden *et al.* 2000).

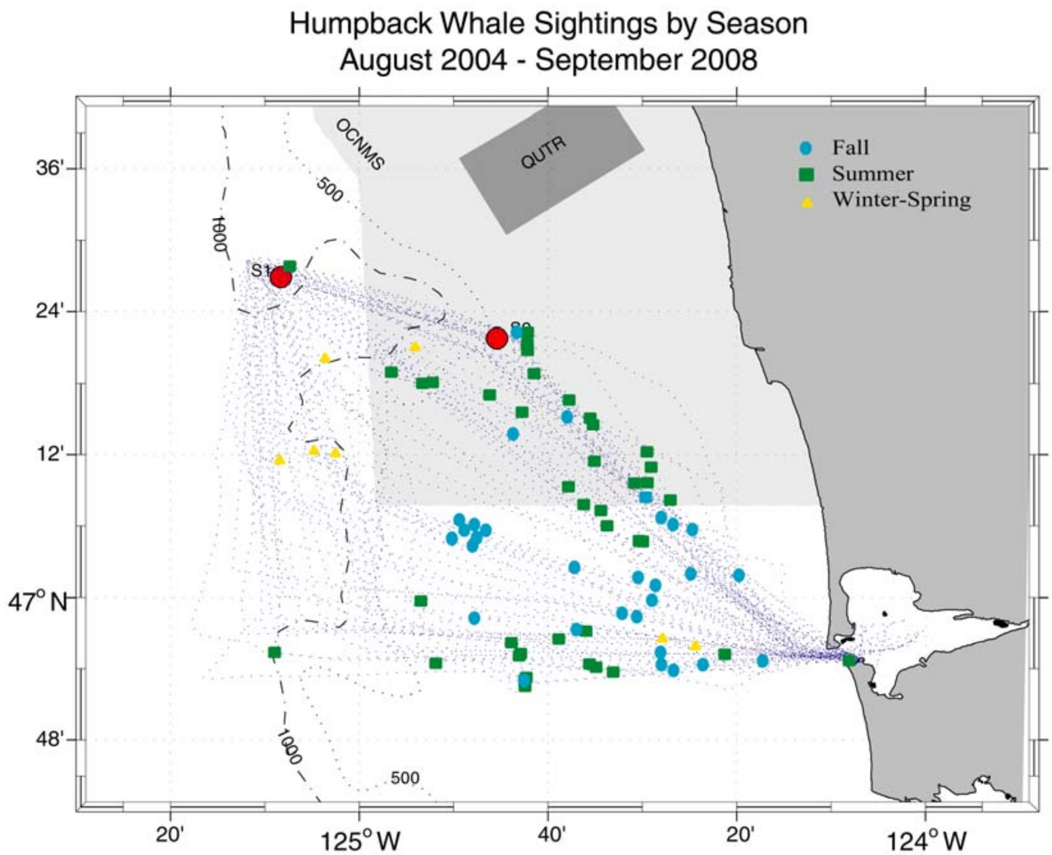

Figure 14. Seasonal distribution of humpback whale sightings over all surveys. Humpbacks were seen further offshore in winter and spring than during the remainder of year. This is also the period of lowest humpback occurrence in this region.

Sightings of humpback whales varied significantly throughout the year in distance offshore (ANOVA: F=3.2, p=0.027) and water depth (F=29.4, p=0.000), with winter-spring sightings being farther from shore and in deeper water compared to those from summer and fall. There was not a significant difference by season in distance from the shelf edge (p>0.05). One potential implication of this shift is that humpback whale sightings in winter were generally much closer to the offshore HARP site than in other seasons, potentially increasing the probability of detecting this species at the offshore HARP site. The mean of the distance of the humpback visual sightings to the offshore HARP did vary significantly by season (ANOVA: F=4.5, p=0.006), averaging less than 10 nmi in winter compared to more than 25 nmi in all other seasons. Mean distance to the inshore HARP did not vary significantly by season (p>0.05).

Humpback whale song or song components were commonly detected from later summer through early winter within the acoustic data at both the inshore and offshore monitoring locations (Figure 15). The peak in humpback acoustic detections occurred in October at both sites. While there was little humpback acoustic activity through the winter and spring, there were occasional detections of calls, especially from February through May at the inshore site.

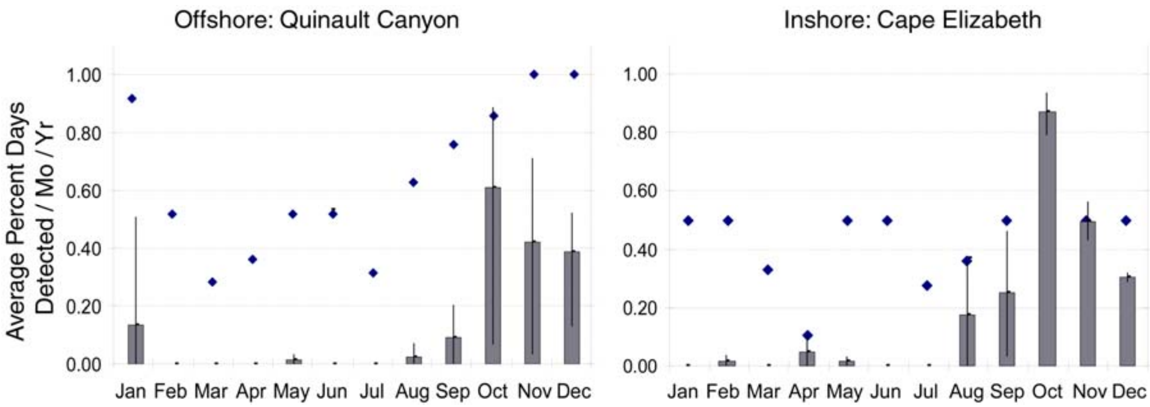

Figure 15. Average seasonal occurrence of humpback whale sounds (song and non-song) at the offshore and inshore acoustic monitoring locations. The gray bars represent the mean detection rate across all years of acoustic monitoring effort and error bars indicate minimum and maximum acoustic detection rates. Blue diamonds indicate the average acoustic monitoring effort for each month, with 100% (shown as 1.00 on the y-axis) effort indicating monitoring all month over all four years of data collection.

Humpback whale acoustic activity varied significantly throughout the day, with nearly 50% of nighttime hours containing song or song segments relative to a daytime low of near 1% of hours containing humpback sounds (Figure 16). These differences were statistically significant (Kruskal Wallis: inshore, χ^2=12.58, df=120, p=0.0004; offshore, χ^2=17.35, df=132, p<0.0001). The relative hourly occurrence of humpback sounds did vary between the sites, with a sharp onset of increased activity at both sites around 1800, but with a steady decline toward dawn at the offshore location versus a prolonged elevation of activity lasting until dawn at the inshore site. The level of daytime activity was also markedly lower offshore versus inshore.

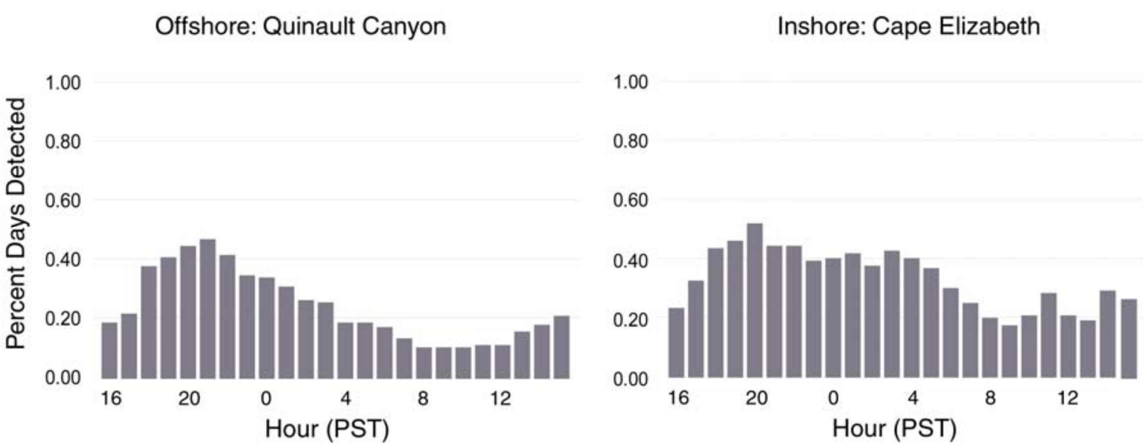

Figure 16. Occurrence of humpback whale sounds by hour of the day. Humpback whales sounds are significantly more common at night than during the day at both locations.

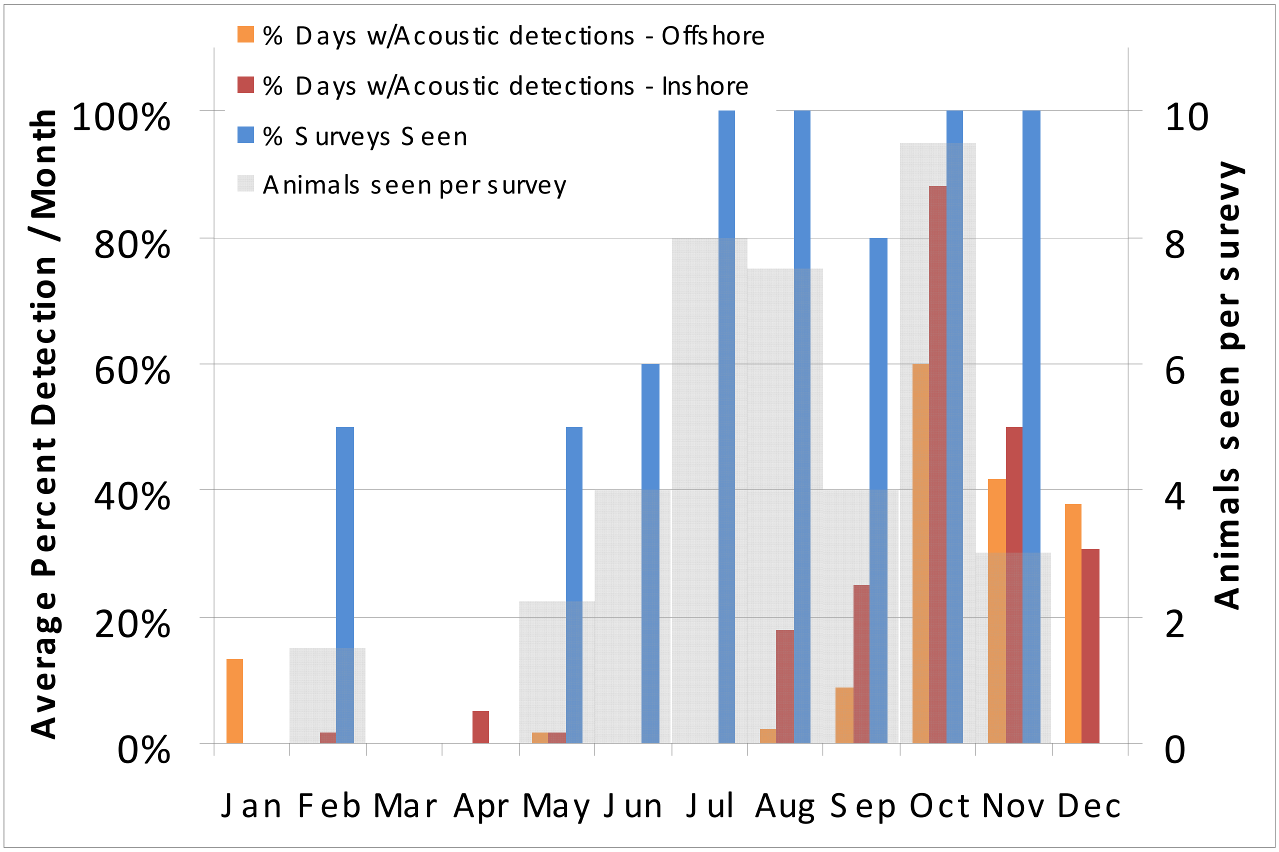

Figure 17. Seasonal occurrence of humpback whales based on visual survey sightings and acoustic detections from August 2004 through September 2008. As an indicator of relative density, the average number of animals seen per survey per month is compared to the percent of surveys per month in which humpback whales are seen.

The correlation between acoustic and visual detections of humpback whales by month was fairly weak. Acoustic detections as measured by percent of days monitored each month with acoustic detections showed a strong seasonal pattern, with highest detections in October to November and lowest in January to July. This contrasts and only slightly overlaps with the peak in visual detections in May to November. This may reflect in part the strong seasonal variation in singing behavior of humpback whales, that primarily sing on the winter breeding grounds but which are also known to vocalize on the feeding grounds, although most heavily nearer the time of winter breeding season (see, for example, Clark and Clapham 2004).

A total of 68 unique humpback whales were identified in the study area from 2004 through 2007. (Identifications from 2008 have not yet been compared.) Only two individuals were re-sighted within the study area, both within the same year: one seen in both June and October 2006 and the other in both June and September 2007. These results suggest that, while some animals do stay in the study area for longer periods within the season, many animals are using a broader feeding area than just our study area.

Matches of these humpback whale identifications to those in other areas within Cascadia Research Collective's catalog provide an important insight into the winter breeding area for these animals and the other areas that humpbacks go to feed. A total of 21 of the 68 whales identified in these surveys has also been seen in northern Washington, while much smaller numbers have been seen in other feeding areas, including California, Oregon, and British Columbia (Table 4). This finding contradicts an earlier conclusion that humpback whales in southern Washington were more likely part of the feeding aggregation off California and Oregon than the one off northern Washington and southern British Columbia (Calambokidis *et al.* 2004a). The Structure of Populations, Levels of Abundance and Status of Humpback whales in the North Pacific (SPLASH; Calambokidis *et al.* 2008) study utilized some of the identifications collected as a part of this study in 2004 and 2005. These photographs were compared to those from all other areas of the North Pacific. The matches indicate that humpback whales from the Washington-southern British Columbia area are a relatively distinct feeding aggregation numbering 200-400 whales with a very diverse set of winter breeding areas, including all three subareas of Mexico, Central America, and Hawaii (Calambokidis *et al.* 2008). The one good identification of a humpback whale obtained in the current study in winter (25 February 2005) revealed that this was an individual that had been seen in previous years in the summer off Oregon and Washington.

Table 4. Matches of individuals between the study areas and other feeding areas. (This does not include SPLASH results.)

Region	**# of individuals**
California	8
Oregon	3
N Washington	21
British Columbia	1

Gray Whales

There were seasonal differences in the distribution and habitat of gray whales. These were examined corresponding to three time period matching stages in the life cycle of the gray whale:

1) Winter (December and January): corresponding to the timing of the southbound migration of gray whales from their primary feeding ground in Alaska to their breeding grounds in Mexico.
2) Spring (February to April): corresponding to the timing of the northbound migration past Washington as the main population heads back to Alaskan waters.
3) Summer-Fall (May to October): when the gray whales that are present are primarily those that feed in Pacific Northwest waters, sometimes referred to as Seasonal Residents or the Pacific Coast Feeding Aggregation.

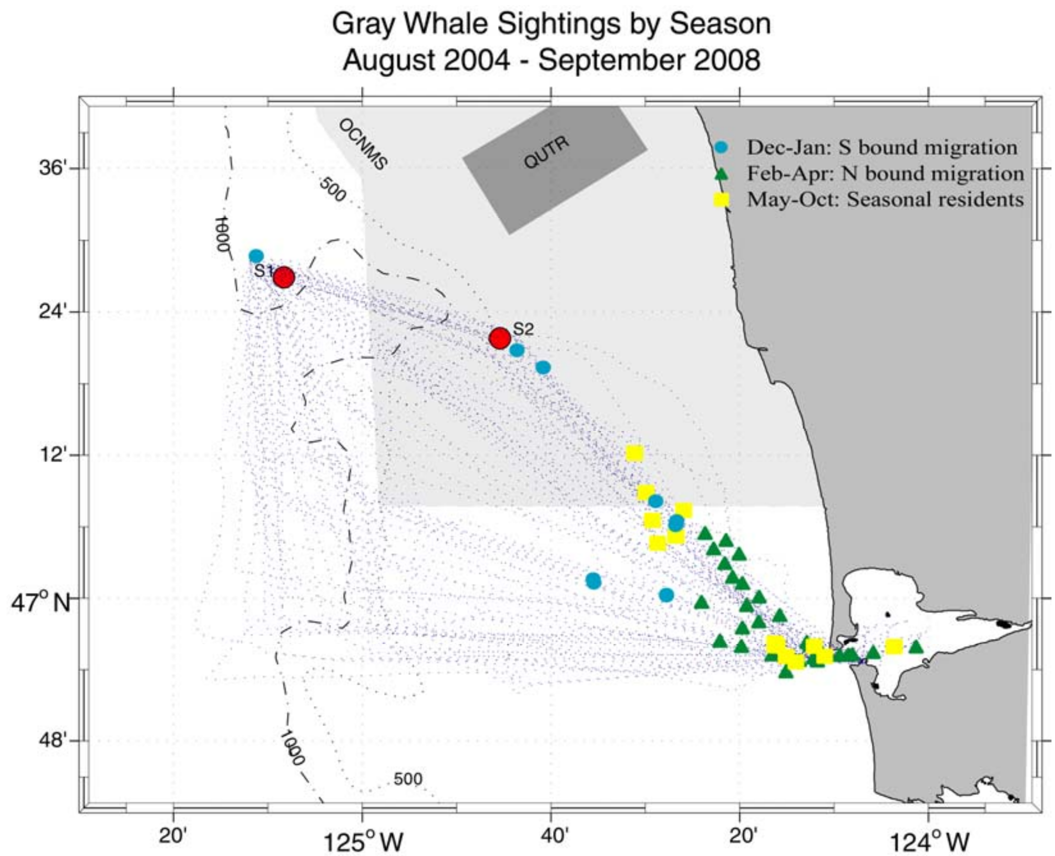

Figure 18. Seasonal distribution of gray whale sightings over all surveys. Gray whales were seen further offshore during the winter southbound migration than during the remainder of the year. Some gray whales also appear to remain in this region during summer and fall, when much of the greater eastern North Pacific population is found in the Bering and northern seas.

There were clear differences in the distribution of sightings during these periods, with highly significant differences (ANOVA) among these three time periods in distance from shore ($F=24.8$, $p=0.000$), distance from shelf break ($F=26.1$, $p=0.000$) and water depth ($F=7.3$, $p=0.002$). During the south-bound migration gray whales were sighted primarily offshore, including one sighting right at the offshore HARP (Figure 18). The average distance from shore (29 km) and water depth (126 m) for sightings in this period were more than twice that of the other two time periods. Sightings of gray whales during spring tended to be close to shore, mostly on a north-south distribution averaging about 10 km offshore. Sightings of gray whales during the summer and fall were clustered in two areas: in and around the entrance to Grays Harbor and then clustered in an offshore area 20-25 km offshore in about 60 m of water.

The offshore sightings of gray whales during the summer represented a surprising finding, given the typical pattern of gray whales feeding in the Pacific Northwest close to shore in shallow waters. These offshore sightings were all made between 8 June and 1 September 2007. While they were grouped into just 6 sightings, they totaled 42 whales, since each sighting represented a concentration of up to 14 whales in one area.

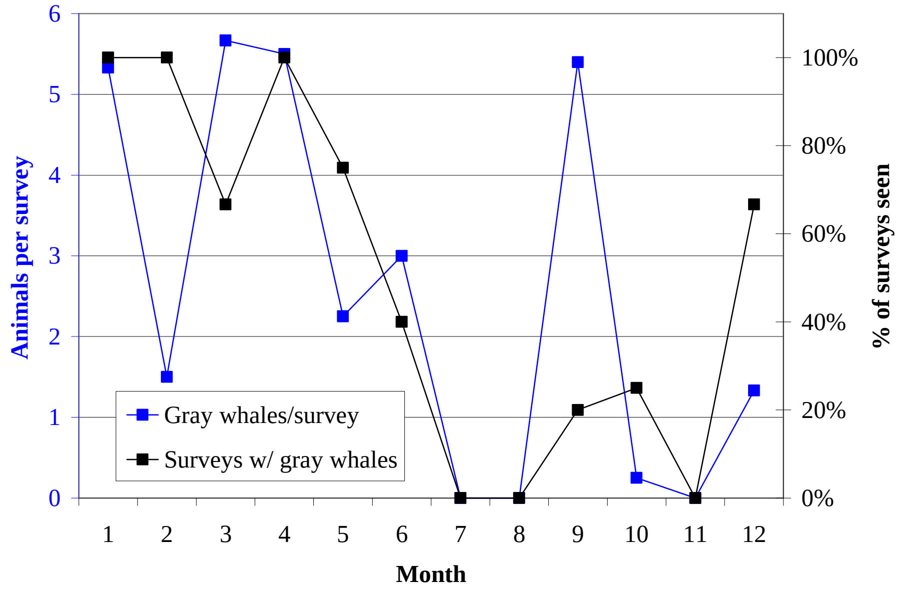

Figure 19. Seasonal occurrence of gray whales based on visual survey sightings from August 2004 through September 2008. As an indicator of relative density, the average number of animals seen per survey per month is compared to the percent of surveys per month in which gray whales were seen.

During the course of the surveys, individual identifications were made of 49 gray whales from 2004 to 2007. (Identifications from 2008 have not been matched yet.) Seven of these whales were seen on multiple surveys during the course of this study. Comparison of the identifications to the larger collection of identifications of "seasonal resident" gray whales that spend the spring through fall feeding in Pacific Northwest waters (see Calambokidis *et al.* 2002) indicated 33 of the 46 (71%) had been identified both in other areas of the Pacific Northwest and in other years from when they were seen on these surveys. Of the 13 whales that had not been seen in other areas, 10 were identified on the current surveys during the winter and spring, representing the time period when gray whales are on migration to and from their primary feeding area in Alaska.

Table 5. Gray whale identifications by year.

Year	IDs
2004	1
2005	3
2006	13
2007	37
Grand Total	54
Unique	49

Identifications from the concentration of gray whales found feeding almost 10 nmi offshore in summer and fall 2007 revealed this unusual offshore feeding concentration consisted almost completely of animals known as “seasonal residents” in other parts of the Pacific Northwest. All but one of the 28 individuals had been identified on other feeding areas in the Pacific Northwest.

Although some gray whale sound types have been characterized, no gray whale sounds have yet been detected within the acoustic datasets at either location. Gray whales are thought to be quiet during the northbound migration, presumably to avoid detection by killer whales, but are known to make sound on both the breeding areas and other feeding areas. Examination of the acoustic data for gray whale sounds continues, specifically during the period of gray whale feeding activity near the inshore HARP location in summer.

Pinnipeds

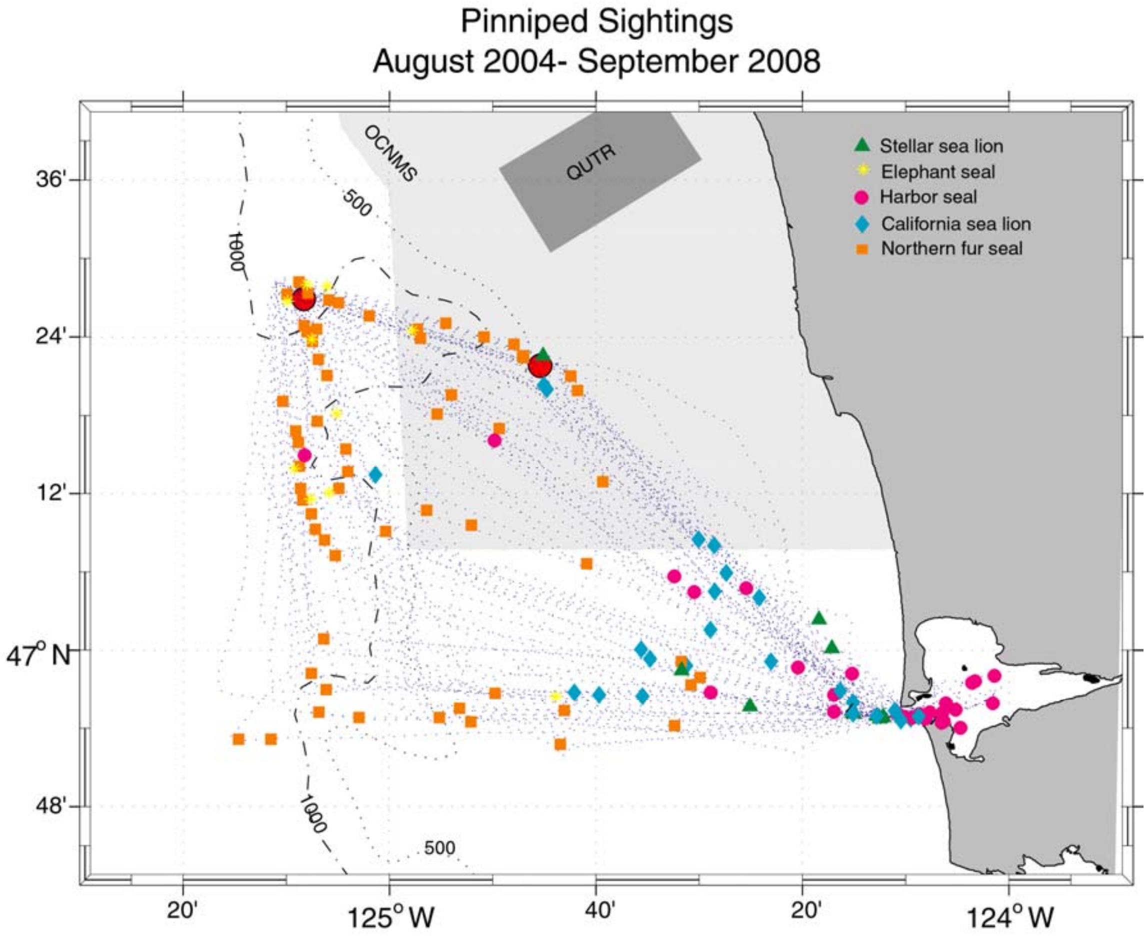

Figure 20. Pinniped sightings during visual surveys since August 2004. Northern fur seals are the most commonly observed pinniped.

Among the five pinniped species sighted during visual surveys, fur seals (thought to be northern fur seals, but which could include some Guadalupe fur seals) were the most common, although all species were seen at least 10 times. There were clear habitat differences in their distribution (Figure 20) and in their key habitat parameters (Table 3). Steller sea lion distance from the shelf edge varied significantly by season (F=5.2, p=0.033) as did water depth where the Steller sea lions were seen (F=5.4, p=0.03), primarily due to sightings close to the shelf edge and in deeper water in summer. Northern fur seals and elephant seals were both seen farthest offshore (>50 km) and in offshore deep water (> 500 m), while the other three species were sighted much closer to shore (< 25 km) and in water averaging less than 100 m. Even though harbor seals were primarily seen in coastal waters, there were a few sightings, especially in spring, in offshore waters out to 64 km, suggesting that harbor seals can range widely. These overall findings are consistent with the known feeding habitats of these species. Northern fur seals are known to feed in pelagic waters, elephant seals are known as deep diving specialists, and the other species are known to primarily feed in more coastal waters.

Although most species were seen year-round, there were some seasonal patterns worth noting in pinniped occurrence. California sea lions were seen primarily in spring and fall, coinciding with the period when males are known to migrate north from breeding areas in California and Mexico into Pacific Northwest waters. Harbor seals were seen in all seasons, although sightings were most common in spring during the pupping season. Northern fur seals were seen throughout the year, though large numbers of sightings occurred in summer months when most breeding animals are thought to have migrated to their breeding locations in the Pribilof Islands and San Miguel Island. All but one elephant seal sighting was made between January and June.

Publications and Presentations in FY08

Oleson, E.M., S.M. Wiggins, and J.A. Hildebrand. 2007. The impact of non-continuous recording on cetacean acoustic detection probability. *3rd Workshop on Detection and Classification of Marine Mammals using Passive Acoustics.* **24-26 July 2007**. Boston, MA

Calambokidis, J. Update on status of marine mammals in the Olympic Coast National Marine Sanctuary. 2008. *Presentation to the OCNMS Scientific Advisory Committee*. **30 May 2008**. Ocean Shores, WA.

Oleson, E.M., M.S. Soldevilla, J. Calambokidis, C. Collins, S.M. Wiggins, and J. A. Hildebrand. 2008. Distribution patterns of delphinids in the California Current ecosystem observed through acoustic monitoring of species-specific echolocation clicks. *Acoustics '08 Paris*. **29 June-4 July 2008**. Paris, France.

Several manuscripts are being prepared for submission to scientific journals. Two articles on the seasonal occurrence and distribution of Pacific white-sided and other delphinids in the Washington region and greater California Current are near completion, as well as an article on the relative occurrence of killer whales off the outer Washington coast detailed from the acoustic detection data. A fourth manuscript comparing the visual versus acoustic detection rates of humpback whales is also being prepared. Several other manuscripts are planned for the next year.

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Appendix.

Table I. Visual survey effort from August 2004 through September 2008.

Date	Beg.	End	Hrs.	nmi
16-Aug-04	9:01	18:30	9.5	130
21-Sep-04	8:25	16:51	8.4	112
11-Oct-04	7:32	17:28	9.9	122
27-Oct-04	11:26	13:31	2.1	11
9-Nov-04	7:47	13:41	5.9	33
23-Dec-04	8:00	17:05	9.1	121
28-Dec-04	7:50	16:45	8.9	113
17-Feb-05	7:25	16:59	9.6	119
25-Feb-05	7:49	16:54	9.1	122
24-Mar-05	7:15	17:23	10.1	133
26-Apr-05	7:00	18:45	11.7	133
26-May-05	6:38	18:52	12.2	130
3-Jun-05	9:34	19:14	9.7	100
29-Jun-05	7:13	15:35	8.4	122
29-Jul-05	7:12	19:18	12.1	94
31-Aug-05	7:36	18:57	11.3	132
28-Sep-05	8:37	19:20	10.7	127
20-Oct-05	8:31	16:54	8.4	91
18-Nov-05	7:50	17:50	10.0	127
8-Dec-05	7:58	16:53	8.9	126
12-Mar-06	8:04	16:40	8.6	132
20-Mar-06	7:27	17:28	10.0	131
05-Apr-06	8:00	18:18	10.3	123

Date	Beg.	End	Hrs.	nmi
21-May-06	6:52	16:15	9.4	94
12-Jun-06	10:10	19:08	9.0	140
30-Jul-06	7:46	19:23	11.6	139
8-Sep-06	9:32	17:55	8.4	117
10-Oct-06	7:57	17:28	9.5	143
12-Jan-07	9:11	15:56	6.7	124
31-Jan-07	8:15	16:11	7.9	136
3-Apr-07	7:42	18:42	11.0	141
16-May-07	9:06	18:18	9.2	149
8-Jun-07	7:30	18:46	11.3	148
26-Jun-07	6:48	18:31	11.7	148
30-Aug-07	8:00	19:10	11.2	147
1-Sep-07	8:30	20:15	11.8	144
31-Oct-07	7:40	17:31	9.9	146
23-Jan-08	6:30	16:33	10.1	111
5-Mar-08	11:15	13:35	2.3	30
1-Apr-08	8:31	16:38	8.1	147
29-May-08	7:39	18:00	10.4	134
2-Jul-08	8:46	18:44	10.0	158
10-Aug-08	7:50	19:40	11.8	133
2-Sep-08	7:55	16:00	8.1	140
Totals			414.3	5353

Table II. Sightings of cetaceans during each survey conducted from August 2004 through September 2008. (S = number of sightings, An = number of animals)

Date	Humpback Whale		Gray Whale		Minke Whale		Fin Whale		Killer Whale		UnID Whale		UnID Beaked Whale		Cuvier's Beaked Whale		N. Right Whale Dolphin		Pac. White-Sided Dolphin		Risso's Dolphin		Harbor Porpoise		Dall's Porpoise	
	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An
8/16/04	2	5																					5	12		
10/11/04	1	3	1	1																			1	2	2	12
11/09/04					1	1																	2	2	1	1
12/23/04			2	4																			3	7	1	9
12/28/04			1	1																			1	1	1	10
2/17/05			1	1									1	2									4	7		
2/25/05	2	3	1	2																			10	18	3	14
3/24/05			7	9																			3	4		
4/26/05			2	2							1	1											3	4	1	5
5/26/05	3	5	1	1																						
6/03/05	1	3							1	7							1	4	4	246					1	5
6/29/05																			7	242			5	14		
7/29/05	9	16															1	5	1	400			1	3		
8/31/05	6	12																					5	12	1	3
9/28/05	6	10																					5	12		
10/20/05	8	19							1	1													1	4	2	20
11/18/05	1	3																								
12/08/05							1	2	1	13			1	1									1	3		
3/12/06																							2	4	4	10
3/20/06			4	8																			1	3		
4/05/06			3	5					1	11													3	8		
5/21/06			6	6							1	1											2	2	1	5
6/12/06															1	3							2	6	1	8
7/30/06	6	7																			2	38	5	8	2	8
9/08/06	3	5																	2	306			5	20	3	9
10/10/06	5	8																							2	11
1/12/07			4	10																			4	5		
1/31/07			1	3																						

Date	Humpback Whale		Gray Whale		Minke Whale		Fin Whale		Killer Whale		UnID Whale		UnID Beaked Whale		Cuvier's Beaked Whale		N. Right Whale Dolphin		Pac. White-Sided Dolphin		Risso's Dolphin		Harbor Porpoise		Dall's Porpoise	
	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An	# S	# An
4/03/07			6	9					1	13													1	2		
5/16/07																										
6/08/07	7	11	1	12																					3	8
6/26/07	4	6	2	3															2	52			2	3	2	9
8/30/07	3	8															1	50	1	400			1	1	5	25
9/01/07	2	4	3	27																			1	3		
10/31/07	5	8																					9	24	2	6
1/23/08			2	3					1	6													1	2		
3/05/08			1	1																			2	2		
4/01/08			5	6																			1	2		
5/29/08	2	4	1	2																			12	21	2	14
7/02/08	1	1																	1	35			4	14	2	5
8/10/08	2	5																					3	4	1	8
9/02/08	1	1																					3	5	1	1
Total	80	147	55	116	1	1	1	2	6	51	2	2	2	3	1	3	3	59	18	1681	2	38	114	244	44	206

Table III. Sightings of pinnipeds during each survey conducted from August 2004 through September 2008. (S = number of sightings, An = number of animals).

	California Sea Lion		Steller Sea Lion		Northern Fur Seal		Harbor Seal		Northern Elephant Seal		UnID Pinniped	
Date	**# S**	**# An**	**# S**	**# An**	**# S**	**# An**	**# S**	**# An**	**# S**	**# An**	**# S**	**# An**
8/16/04					4	4						
10/11/04	2	2										
11/09/04							1	1				
12/23/04					3	3	1	1				
12/28/04					1	6						
2/17/05	3	4			1	1						
2/25/05	1	1	1	1	2	2	3	3				
3/24/05	3	4	1	1			1	1				
4/26/05					1	1	6	699				
5/26/05	1	10			5	80						
6/03/05					7	9			1	1		
6/29/05	1	1			5	7	1	1			2	2
7/29/05												
8/31/05												
9/28/05	1	1	1	1	1	1	1	1			1	3
10/20/05			2	8	2	2	1	1				
11/18/05	2	3										
12/08/05	1	1										
3/12/06	1	2			1	1						
3/20/06			1	1			5	7				
4/05/06												
5/21/06	1	1			1	1			3	3		
6/12/06					3	3						
7/30/06							1	1				
9/08/06												
10/10/06	1	2										
1/12/07					2	4			1	1		
1/31/07					1	1			1	1		
4/03/07					1	1	1	1				
5/16/07					1	1	1	1	1	1		
6/08/07	1	1			9	14			1	1		
6/26/07	1	1	1	1	2	8						
8/30/07					4	4						
9/01/07					1	1						
10/31/07	4	152	1	30			1	1				
1/23/08	1	1					1	1				
3/05/08												
4/01/08									1	1		
5/29/08			3	13	2	2	1	1				
7/02/08												
8/10/08												
9/02/08							1	2	1	1		
Total	25	187	11	56	60	157	27	723	10	10	3	5

Initial Distribution List

1.	Defense Technical Information Center 8725 John J. Kingman Rd., STE 0944 Ft. Belvoir, VA 22060-6218	2
2.	Dudley Knox Library, Code 013 Naval Postgraduate School Monterey, CA 93943-5100	2
3.	Erin Oleson National Marine Fisheries Service Pacific Islands Fisheries Science Center Honolulu, HI	1
4.	John Hildebrand Scripps Institution of Oceanography University of California La Jolla, CA	1
5.	John Calambokidis Cascadia Research Collective Olympia, WA	1
6.	Greg Schorr Cascadia Research Collective Olympia, WA	1
7.	Erin Falcone Cascadia Research Collective Olympia, WA	1
8.	Ching-Sang Chiu Naval Postgraduate School Monterey, CA	1
9.	Curtis A. Collins Naval Postgraduate School Monterey, CA	1
10.	Thomas A. Rago Naval Postgraduate School Monterey, CA	1
11.	Tetyana Margolina Naval Postgraduate School Monterey, CA	1

12.	Chris Miller Naval Postgraduate School Monterey, CA	1
13.	John Joseph Naval Postgraduate School Monterey, CA	1
14.	Katherine Whitaker Pacific Grove, CA	1
15.	Frank Stone CNO(N45) Washington, D.C.	1
16.	Jay Barlow Southwest Fisheries Science Center, NOAA La Jolla, CA	1
17.	CAPT Ernie Young, USN (Ret.) CNO(N45) Washington, D.C.	1
18.	Dale Liechty CNO(N45) Washington, D.C.	1
19.	Dave Mellinger Oregon State University Newport, OR	1
20.	Kate Stafford Applied Physics Laboratory University of Washington Seattle, CA	1
21.	Sue Moore NOAA at Applied Physics Laboratory University of Washington Seattle, WA	1
22.	Petr Krysl University of California La Jolla, CA	1
23.	Mark McDonald Whale Acoustics Bellvue, CO	1

24.	Ted Cranford Quantitative Morphology Consulting, Inc. AND San Diego State University San Diego, CA	1
25.	Monique Fargues Naval Postgraduate School Monterey, CA	1
26.	Mary Ann Daher Woods Hole Oceanographic Institution Woods Hole, MA	1
27.	Heidi Nevitt NAS North Island San Diego, CA	1
28.	Rebecca Stone Naval Postgraduate School Monterey, CA	1
29.	Melissa Hock Scripps Institution of Oceanography University of California La Jolla, CA	1
30.	Sean M. Wiggins Scripps Institution of Oceanography University of California La Jolla, CA	1
31.	E. Elizabeth Henderson Scripps Institution of Oceanography University of California La Jolla, CA	1
32.	Gregory S. Campbell Scripps Institution of Oceanography University of California La Jolla, CA	1
33.	Marie A. Roch San Diego State University San Diego, CA	1

34.	Anne Douglas Cascadia Research Collective Olympia, WA	1
35.	Julie Rivers Naval Facilities Engineering Command, Pacific Pearl Harbor, HI	1
36.	Jenny Marshall Naval Facilities Engineering Command San Diego, CA	1
37.	Chip Johnson COMPACFLT Pearl Harbor, HI	1
38.	CDR Len Remias U.S. Pacific Fleet Pearl Harbor, HI	1
39.	LCDR Robert S. Thompson U.S. Pacific Fleet Pearl Harbor, HI	1
40.	Jene J. Nissen U. S. Fleet Forces Command Norfolk, VA	1
41.	W. David Noble U. S. Fleet Forces Command Norfolk, VA	1
42.	David T. MacDuffee U. S. Fleet Forces Command Norfolk, VA	1
43.	Keith A. Jenkins Naval Facilities Engineering Command, Atlantic Norfolk, VA	1
44.	Joel T. Bell Naval Facilities Engineering Command, Atlantic Norfolk, VA	1
45.	Mandy L. Shoemaker Naval Facilities Engineering Command, Atlantic Norfolk, VA	1

46.	Anurag Kumar Naval Facilities Engineering Command, Atlantic Norfolk, VA	1
47.	Merel Dalebout University of New South Wales Sydney, Australia	1
48.	Robin W. Baird Cascadia Research Collective Olympia, WA	1