

Seasonal Occurrence of Cetaceans along the Washington Coast from Passive Acoustic Monitoring

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Introduction

Estimates of cetacean abundance, density, and distribution are necessary to understand the role of cetaceans in marine ecosystems and to identify potential anthropogenic threats to managed and endangered cetaceans. Along the U.S. west coast, cetaceans are at risk of fishery interactions, entanglement, ship strike (Douglas et al., 2008; Carretta et al., 2014a), and anthropogenic sound sources such as seismic surveys, military sonar, and other vessel noise (Emmons et al., 2019).

Many cetacean species inhabit the outer coast of Washington State. These species are managed under the U.S. Marine Mammal Protection Act and

include several stocks listed under the U.S. Endangered Species Act (Carretta et al., 2014b). The abundance and population density of cetaceans in the California Current off the U.S. Pacific Coast, including the Washington coast, has been estimated from summer and fall ship and aerial surveys (Barlow and Forney, 2007; Barlow, 2010; Chandler and Calambokidis¹). However, species distribution in this area likely changes between seasons, since many cetacean species undertake long-distance annual migrations (Calambokidis et al., 2001). Forney and Barlow (1998) found that half of the abundance estimates for species surveyed off the California coast exhibited significant differences between the winter and summer surveys indicating that species' distribution in the California current changes seasonally. Determining cetacean seasonal distribution patterns is difficult and cost

prohibitive due to protracted periods of inclement weather, remote access, and short daylight hours.

Previous attempts to better describe the year-round occurrence of cetaceans along the Washington coast have been limited temporally and spatially. Aerial surveys were conducted in the late 1980's and again in the 1990's (Shelden et al., 2000; Green et al.²). More recently non-systematic ship surveys have been conducted to locate endangered southern resident killer whales, *Orcinus orca*, in winter and spring months along the Washington and Oregon coasts (Hanson et al., 2010). Acoustic monitoring and associated small boat surveys have been employed to monitor marine mammal occurrence in the U.S. Navy Northwest Training Range Complex (Oleson and Hildebrand, 2012; Trickey et al., 2015), but these have been limited in space to two sites on the central

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¹Chandler, T., and J. Calambokidis. 2003. 2002 aerial surveys for harbor porpoise and other marine mammals off Oregon, Washington and British Columbia. Unpubl. rep. on file at Marine Mammal Laboratory, Alaska Fish. Sci. Cent., NMFS, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115.

²Green, G. A., J. J. Brueggeman, R. A. Grotefendt, C. E. Bowlby, M. L. Bonnell, and K. C. Balcomb. 1992. Cetacean distribution and abundance off Oregon and Washington 1989-1990. In J. J. Brueggeman (Editor), OR and WA marine mammal and seabird surveys. Ebasco Environ. Rep., Bellevue, WA (unpubl.), p. 1-100.

ABSTRACT—Seasonal occurrence of cetaceans along the Pacific Coast of Washington has been difficult to characterize because decreased daylight and inclement weather conditions result in a lack of consistent survey effort. Therefore, passive acoustic recorders were deployed at four sites along the Washington coast from 2008 to 2013 to record and detect sound-producing cetaceans. The most frequently detected cetaceans were gray whales, *Eschrichtius robustus*; humpback whales, *Megaptera novaeangliae*; sperm whales, *Physeter*

macrocephalus; and killer whales, *Orcinus orca*. Unlike the results from previous surveys, year-round acoustic monitoring indicates that migratory species such as gray, humpback, and sperm whales use parts of the Washington coast throughout the year. This information is essential for estimating the potential for human interactions such as entanglement or ship strikes with these species.

Seasonal occurrence of the four species was variable between the four sites, even among those sites that were closest in

proximity. These results indicate that caution should be used when extrapolating the results from a single site to a larger scale. Combining multiple sites into a loose network of recorders allowed us to characterize the spatial and seasonal occurrence of these cetaceans on the Washington coast during times of the year when aerial and ship surveys are not feasible. Additionally, we provide a baseline for monitoring yearly shifts in occurrence due to changing population demographics, oceanographic conditions, or anthropogenic inputs.

Table 1.—Recording effort for each location.

Location	Dates of recording	Depth (meters)	Sampling rate (kHz)	Seconds on/off	Total recording time (days)
Cape Flattery offshore	Oct 2008–Mar 2009	174	25	30/420	154
	Sep 2010–Jul 2011	169	25	30/600	334
	Oct 2011–Aug 2012	170	25	30/600	336
	Sep 2012–Sep 2013	168	25	30/600	371
Total					1,195
Cape Flattery inshore	Oct 2008–Feb 2009	115	25	30/420	145
	Sep 2010–Apr 2011	120	25	30/600	216
	Oct 2011–Mar 2012	115	25	30/600	187
	Aug 2012–Nov 2012	115	25	30/600	99
Total					647
Westport	Oct 2008–Feb 2009	63	25	30/420	145
	Nov 2010–Aug 2011	64	25	30/600	308
	Oct 2011–Aug 2012	64	25	30/600	328
	Oct 2012–Jun 2013	64	25	30/600	222
Total					1,003
Columbia River	Mar 2008–Jul 2008	80	25	30/300	71
	Dec 2008–Apr 2009	80	25	30/420	150
	Oct 2010–Sep 2011	111	25	30/600	336
	Oct 2011–Nov 2011	115	25	30/600	53
Total					610

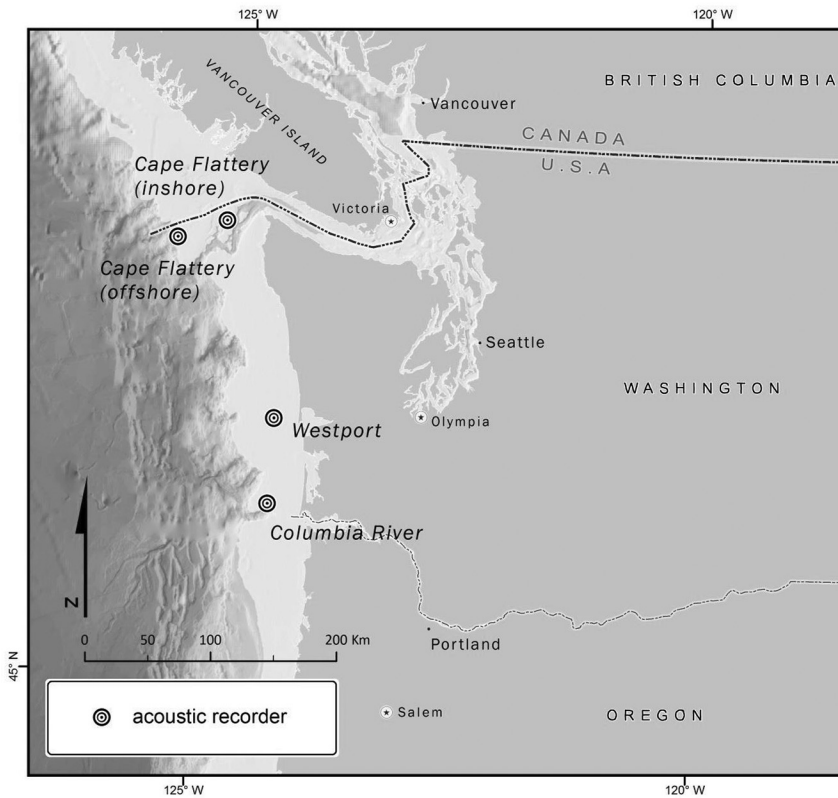


Figure 1.—Deployment locations of Ecological Acoustic Recorders (EAR's) on the Washington coast.

Washington coast. It is difficult to determine how representative these are of coastwide and year-round cetacean occurrence.

As a part of a larger monitoring effort to examine resident killer whale movements from central California to the northwest tip of Washington State

(Hanson et al., 2013), autonomous passive acoustic recorders were deployed at four sites along the Washington coast (Fig. 1). While the primary focus was to detect endangered southern resident killer whales during the winter and spring months, these recorders provided near year-round monitoring of sound-producing cetaceans. Here we describe the seasonal occurrence of the most frequently detected cetacean species along the Washington coast determined through passive acoustic monitoring: gray whales, *Eschrichtius robustus*; humpback whales, *Megaptera novaengliae*; sperm whales, *Physeter macrocephalus*; and killer whales, *Orcinus orca*. This will provide the data necessary for determining how representative the previous studies that were limited spatially and seasonally are of coast-wide occurrence patterns.

Methods

Study Area

Ecological acoustic recorders (EAR's) (Lammers et al., 2008) were deployed at four sites spanning the continental shelf along the Washington coast from April 2008 to August 2013 (Fig. 1, 2; Table 1). Each recorder was part of a subsurface mooring that positioned the recorder approximately mid-water column (Table 1). Acoustic recorder locations were selected based on various factors which included previous killer whale sightings, sites where enhanced productivity would likely be concentrated due to bathymetric features, i.e., canyons heads (Denman and Powell, 1984; Mackas et al., 1997; Allen et al., 2001), accessibility for mooring deployment and recovery, and to reduce the likelihood of interactions with local fisheries (Hanson et al., 2013).

Data Collection

Each EAR is composed of four principal components: 1) the environmental interface module (hydrophone and water/pressure proof case), 2) the signal-conditioning module including the analog-to-digital device, 3) the central processing and storage unit, and 4)

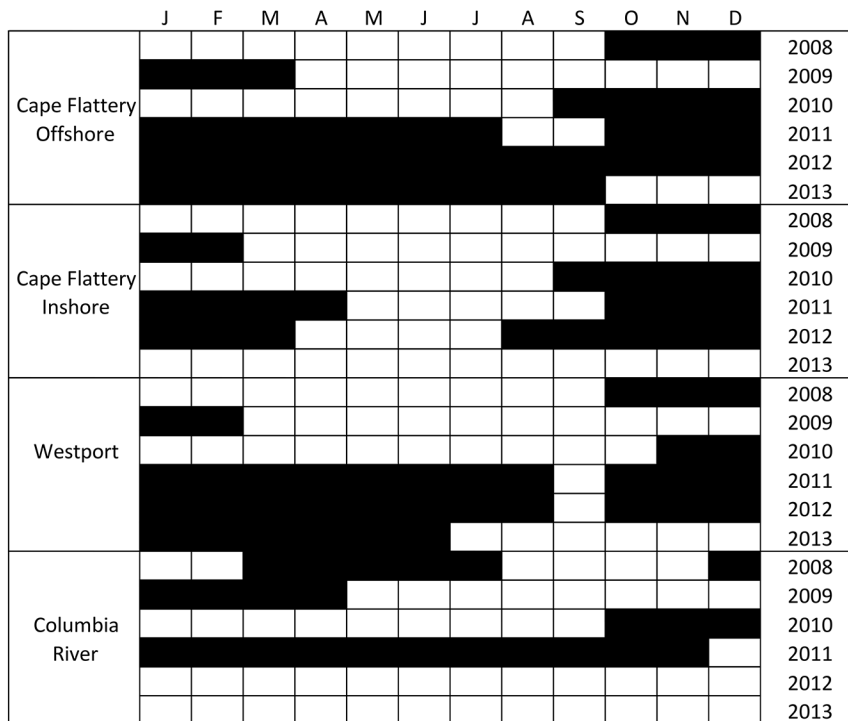


Figure 2.—Annual recorder effort by location.

the power supply. The system utilizes a hydrophone with a response sensitivity of -193.5 dB that is flat from 1–28 kHz (+/- 1.5 dB). Additional details on the specifications of the EAR are provided in Lammers et al. (2008).

In this study, EAR's were programmed to record on a 5–10% duty cycle depending on the year of deployment: 10% in 2008, 7% in 2009, and 5% for all subsequent years (Table 1). This resulted in 30 sec of continuous recording every 300 to 600 sec. Previous studies have shown that a reduced duty cycle may result in an underestimation of the time that species like killer whales, who vocalize in bouts, are acoustically present in the data set (Riera et al., 2013). Thomisch et al. (2015) found that a duty cycle which results in many short listening periods is preferred since it results in many daily samples, accounts for variability in vocal behavior, and is best suited for assessing acoustic presence.

To account for the differences in duty cycle between years, we used

daily vocal occurrence as our unit of measure as in Hanson et al. (2013), in which the results indicated that the decreased duty cycle did not negatively affect the monthly detection rate of resident killer whales. The combination of a longer duty cycle and larger battery packs allowed for a year-long service life, except in cases of delays in deployment schedules, mooring failures, instrument service life limitations, or fishing gear interactions (Table 1).

The sampling rate used on all deployments was 25 kHz which provided 12.5 kHz of bandwidth. This was chosen as a compromise between the need to preserve hard-drive space and battery life while also providing enough information from individual recordings to identify killer whales (Hanson et al., 2013). The restricted bandwidth, calls from allospecifics, and increased seasonal ambient noise below 500 Hz limited which species we were reliably able to detect and identify. Therefore, odontocete sounds above 12.5 kHz

and mysticete sounds below 500Hz were not included in this analysis.

For each deployment, all 30-sec recordings were sorted by day (the number of files per day was determined by the duty cycle) and then concatenated and converted into .wav files using a custom script in MATLAB³. The resulting files were reviewed visually and aurally in Raven Pro⁴, and the sound sources present in the frequency range monitored were classified manually by comparing them to previously published descriptions of species-specific call and click types (Table 2). Those .wav files containing killer whale sounds were further reviewed, and discrete calls were compared to a catalog of pod and community specific dialects to determine the killer whale ecotype, community, and pod, if possible (Ford, 1987).

For each species monitored, we determined the daily vocal presence, which indicates that one or more individual was in the detection range of the recorder and produced a call. Occurrence was summarized on a 3-month seasonal scale (fall: September–November, winter: December–February, spring: March–May, and summer: June–August) to account for gaps in monitoring due to equipment failure, fisheries interactions, and instrument deployment schedules while capturing migration patterns and changes in environmental conditions. Seasonal vocal presence for the study period was determined for each season by calculating the percentage of daily vocal presence normalized by the total number of days monitored in that season.

The observed and expected occurrence under a null model was summarized seasonally for each location using methods described in Hanson et al. (2013). To account for unequal sam-

³MathWorks. 2014. MATLAB release 2014b. The Mathworks, Inc. Natick, Mass. (<http://www.mathworks.com/products/matlab/>). Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

⁴Bioacoustics Research Program. 2011. Raven Pro: Interactive Sound Analysis Software (Version 1.4). The Cornell Lab of Ornithology, Ithaca, N.Y. (<http://www.birds.cornell.edu/raven/>).

Table 2.—Description of sounds used to identify species. Each spectrogram is 60 sec long and displays the full bandwidth, 12.5 kHz, monitored.

Species	Sound type	Description	References	Exemplars
Gray whale	M1 call, M3 call	<p>M1: series of knocks; dominant sound type in breeding lagoons; comprises about half of the repertoire during migration</p> <p>M3: simply structured low frequency sound; only makes up 7% of repertoire in the breeding lagoons but increases to over 50% during migration</p>	Dahlheim, 1987; Crane and Lashkari, 1996	
Humpback whale	Social sounds (non-song), song	<p>Social sounds: produced by males and females; "grunts," "wops," and "moans"; associated with feeding grounds, but also heard during migration and infrequently on breeding grounds</p> <p>Song: produced by males; associated with breeding grounds; complex and structured series of vocalizations</p>	Au et al., 2006; Stimpert et al., 2011	
Sperm whale	Usual clicks, slow clicks (rare)	<p>Usual clicks: broadband clicks with an interclick interval of 0.5–1 second; long-range echolocation</p> <p>Slow clicks: broadband clicks with an interclick of greater than 1 second</p>	Jaquet et al., 2001; Weilgart and Whitehead, 1988	
Killer whale	Pulsed calls, clicks, whistles	<p>Pulsed calls: stereotyped broadband calls; ecotype, community, and pod specific; group cohesion</p> <p>Clicks: short duration, broadband; echolocation</p> <p>Whistles: nonpulsed or continuous tones with average bandwidth of 4.5 kHz; close-range motivational sounds</p>	Ford, 1989; Barrett-Lennard et al., 1996; Thomsen et al., 2001; Foote and Nystuen, 2008	

pling between seasons, the expected occurrence was estimated by multiplying the total number of days with detections in a given season by the proportional contribution of days monitored in that season (total number of days for a season divided by the total number of days monitored during that

season in the study). For each species, differences in seasonal vocal presence and year-round occurrence at each location were determined using analysis of variance (ANOVA). Post hoc Tukey tests were also run to further investigate the differences between each pair of seasons and locations.

Results

Between 2008 and 2013, the number of days monitored at each site was variable (Fig. 2, Table 1). Since the primary interest in killer whale monitoring was to fill the data gap of winter and spring movements, de-

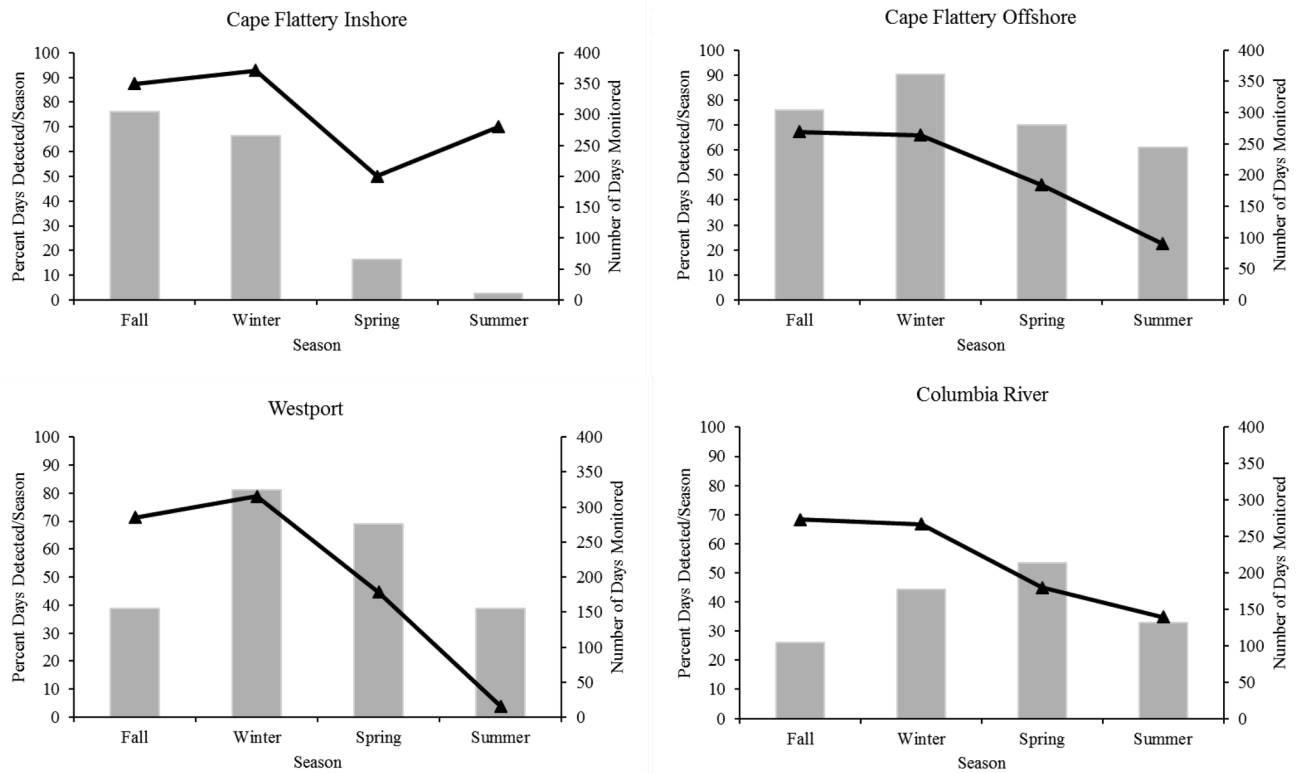


Figure 3.—Bars represent the seasonal recording effort. Diamonds represent the percentage of monitored days with gray whale detections at each location in a season.

ploysments and recoveries of moorings were scheduled during the summer and fall months. This, combined with fishing gear interactions and instrument life limitations, restricted the summer monitoring effort. The combination of a longer recording duty cycle and larger battery packs allowed for a year-long service life, which led to increased effort beginning in 2011.

The most common cetacean species detected during the monitoring period are, in decreasing order of occurrence: gray whales, humpback whales, killer whales, and sperm whales (60%, 46%, 19%, and 13% of all days monitored at all sites, respectively). Additionally, there were a number of sounds that have not been identified to species. These include unidentified delphinid clicks and whistles, pinniped calls, signals occurring below 500 Hz, and some sounds that did not have an adequate signal to noise ratio to be identi-

fied. Details of species-specific occurrence are described below.

Gray Whales

Detections of gray whales were most common at all four sites during the fall and winter seasons, declined during the spring season, and were the lowest during the summer (Fig. 3). This trend was the weakest at the Columbia River site. At both of the near-shore sites, Cape Flattery inshore and Westport, gray whales were detected on more days than expected during the fall and winter (Fig. 3). At all sites, occurrence during the spring matched the expected occurrence, while summer occurrence was higher than expected at the Cape Flattery offshore and Columbia River sites (Fig. 4). A one-way ANOVA showed a significant difference in the seasonal occurrence of gray whales at all sites combined ($F(3,44)=4.24$, $P=0.01$), with higher occurrence in fall than in spring

and summer (Tukey's test, $P < 0.05$). There was no significant difference in the year-round occurrence among the sites ($F(3,6)=2.55$, $P=0.068$).

Humpback Whales

Humpback whales were detected at each site in all seasons monitored with their occurrence peaking at all sites during fall months (September–November) and the lowest levels of occurrence during winter and spring months (Fig. 5). Occurrence in all seasons was lower than expected at the two southern sites, Westport and the Columbia River (Fig. 4). At the Cape Flattery inshore site, occurrence was higher than expected during the fall and winter (Fig. 3). The Cape Flattery offshore site had the highest occurrence of humpbacks whales throughout the year, and occurrence was higher than expected in all seasons (Fig. 4). A one-way ANOVA showed a significant difference in the seasonal occurrence of

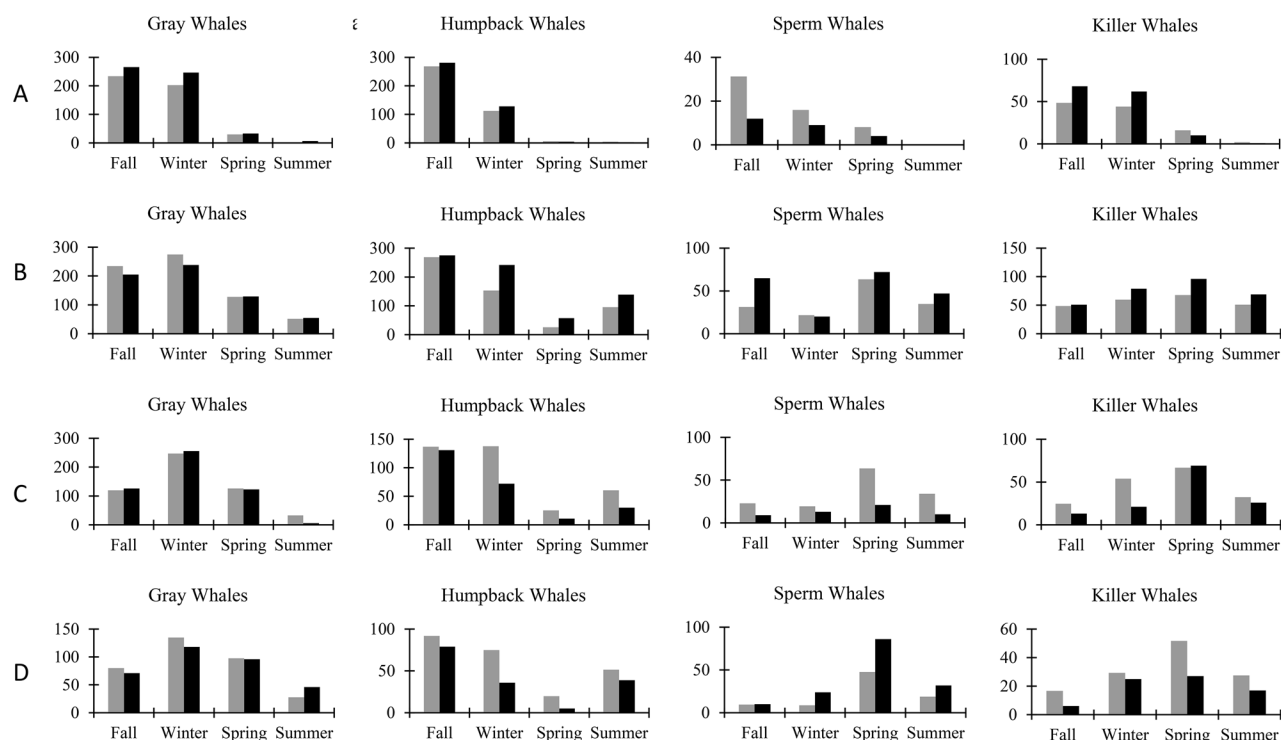


Figure 4.—Seasonal observed occurrence (black bars) versus expected occurrence (gray bars) for each species at (a) Cape Flattery Inshore, (b) Cape Flattery Offshore, (c) Westport, and (d) Columbia River.

humpback whales at all sites combined ($F(3,43)=2.82$, $P=0.00$), with higher occurrence in fall than in other seasons (Tukey's test, $P < 0.05$). There was no significant difference in the year-round occurrence among the sites ($F(3,43)=2.39$, $P=0.08$). Singing behavior was detected at all sites during the fall and extended into December and January in some cases, while social sounds were detected throughout the year at all sites.

Sperm Whales

Sperm whales were detected at all sites in every season, but their occurrence varied between sites and seasons (Fig. 6). The two near-shore sites had low levels of occurrence (<5% of days monitored) in each season with minor peaks in the spring. The occurrence at these two sites was less than expected in all seasons (Fig. 4). Sperm whales were more frequently detected at the Cape Flattery Offshore and

Columbia River sites. Occurrence at these sites was higher than expected in all seasons except during the winter at Cape Flattery offshore (Fig. 4). The spring peak in detections was greatest at the Columbia River site with sperm whales detected on 43.5% of days as opposed to 26.1% at the Cape Flattery offshore site. A one-way ANOVA indicated there was no significant difference in seasonal occurrence of sperm whales at all sites combined ($F(3,43)=0.849$, $P=0.5$). There was a significant difference in the year-round occurrence of sperm whales among the sites ($F(3,43)=8.25$, $P=0.00$), with significant differences between the near-shore sites and the Cape Flattery offshore and Columbia River sites (Tukey's test, $P < 0.05$).

Killer Whales

Killer whales were detected at each site in every month monitored (Fig. 7). In every season, killer whale de-

tectations were more frequent at the two northern sites, Cape Flattery inshore and offshore, and occurrence was greater than expected in all seasons at the offshore site and during the fall and winter at the inshore site (Fig. 4). At the two southern sites, Westport and the Columbia River, occurrence was less than expected in all seasons except for spring at the Westport site (Fig. 4). At both southern sites, fish-eating "resident" killer whales were most frequently detected between the months of January and June. All these resident detections were of the southern resident community except for one in March 2012. At the northern sites both northern and southern resident killer whales were detected frequently.

During the period that southern resident occurrence is highest at the southern sites (January–April) northern residents were detected at the northern sites more frequently. Additionally, there was an increase in north-

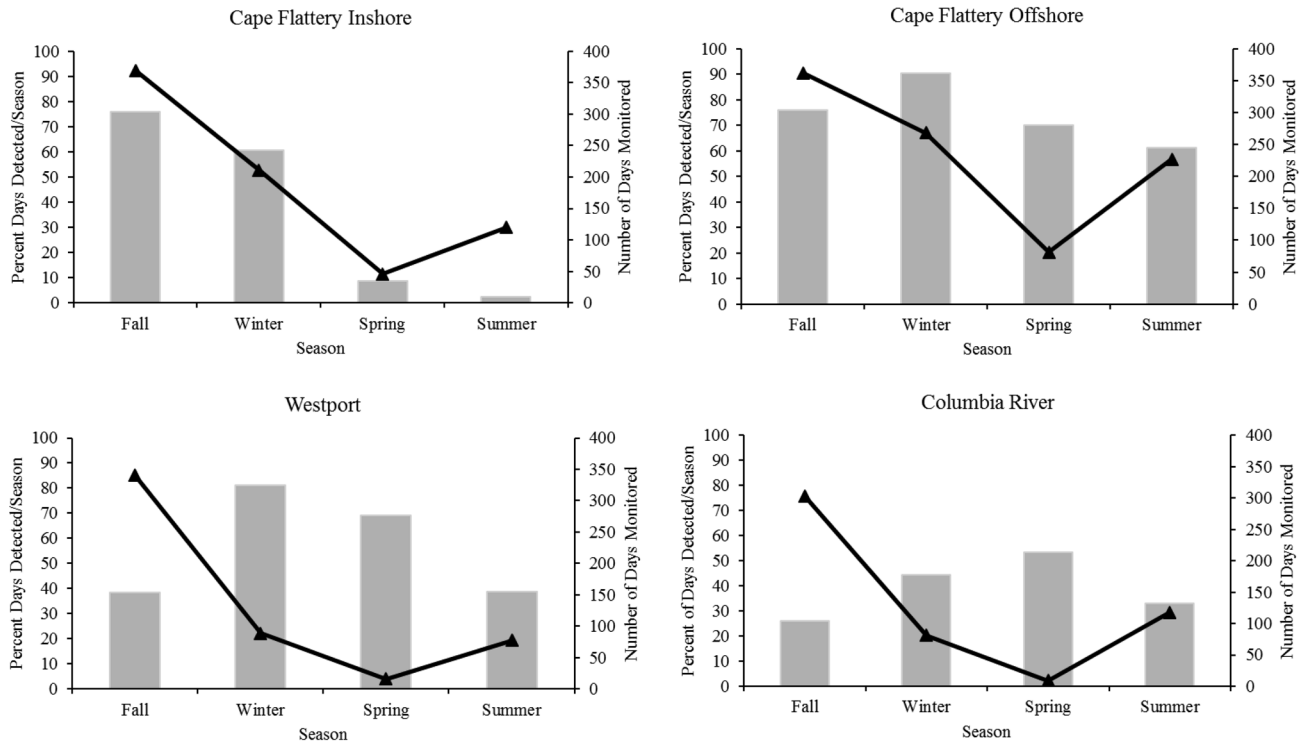


Figure 5.—Bars represent the seasonal recording effort. Diamonds represent the percentage of monitored days with humpback whale detections at each location in a season.

ern resident detections in the late summer/fall. Mammal eating “transient” killer whales were detected throughout the year at all sites.

There was not sufficient sample size to complete statistical analyses for each killer whale ecotype or group separately. A one-way ANOVA showed no significant difference in the seasonal occurrence of killer whales at all sites combined ($F(3,44)=2.17, P=0.11$). There was a significant difference in the year-round occurrence of killer whales among the sites ($F(3,44)=7.46, P=0.00$), with a significant difference between the Cape Flattery offshore site and the two southern sites (Tukey’s test, $P < 0.05$).

Discussion

Utilizing a loose network of passive acoustic recorders, we have been able to characterize the spatial and seasonal occurrence of several cetacean species on the Washington coast during times

of the year in which aerial and ship surveys are not practical. These results can also be combined with previous visual and acoustic survey results that have been limited temporally and spatially to describe year-round occurrence of these species. Additionally, we provide a baseline to monitor yearly shifts in occurrence due to changing population demographics, oceanographic conditions, or anthropogenic inputs.

Gray whale detections at all sites monitored corresponded with the timing of migration south to the breeding grounds off Baja, Calif., usually starting in November (Swartz et al., 2006) and back north to feeding grounds in the Bering and Chukchi Seas beginning in mid-February (Poole, 1984). The winter peak in detections was also found in previous acoustic monitoring at nearby sites along the southern Washington coast (Sirovic et al., 2011). The migration signal was weakest at the two more offshore sites and

strongest at the two inshore sites, which may be due to the tendency of this species to migrate close to shore (Shelden and Laake, 2002). The year round occurrence of gray whale detections at these sites, which were chosen due to their proximity to areas of high primary productivity, may be due to gray whales that do not migrate north and spend the summer feeding off the Oregon and Washington coasts (Calambokidis et al., 2002).

Humpback whale detections also corresponded to known migratory patterns (Calambokidis et al., 2001) with decreased detections in the winter and spring, the period that humpback whales are encountered on their breeding grounds in Hawaii and Mexico. While detections decreased during the winter and spring, the detections during these seasons indicate that humpback whales can be found along the Washington coast throughout the year.

These results are in agreement with

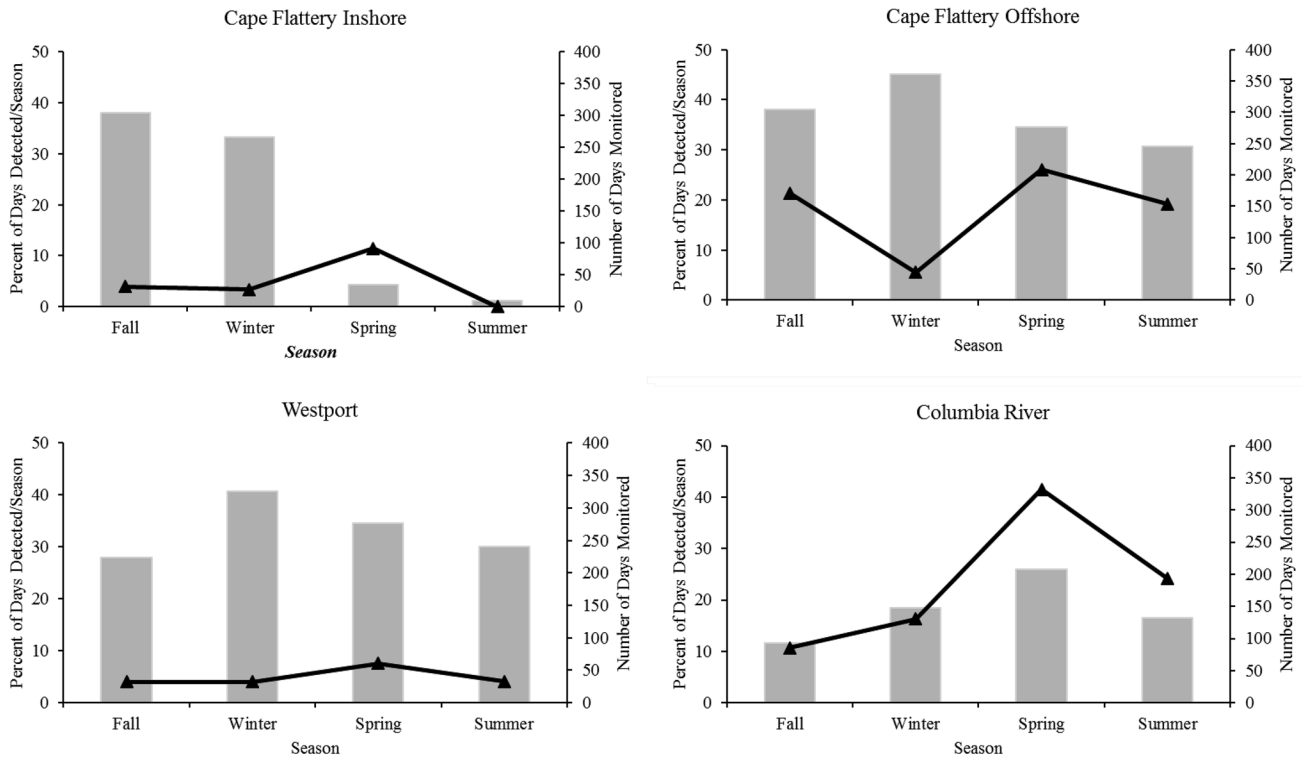


Figure 6.—Bars represent the seasonal recording effort. Diamonds represent the percentage of monitored days with sperm whale detections at each location in a season.

acoustic monitoring at two sites along the southern Washington coast beginning in 2004 (Sirovic et al., 2011; Sirovic et al., 2012; Trickey et al., 2015), but earlier winter systematic visual surveys did not observe humpbacks during winter months (Shelden et al., 2000; Green et al.²). This may be an emerging pattern of occurrence. The northeast Pacific humpback whale population has grown to pre-whaling estimates of abundance (Barlow et al., 2011) and has seasonally expanded its range to include areas previously not used (Seely et al., 2017). The higher occurrence at the Cape Flattery offshore site is probably due to its proximity to an important feeding area off the northern Washington coast (Calambokidis et al., 2004).

Sperm whales had previously been reported off the Washington Coast in all seasons except winter (Sirovic et al., 2011; Green et al.²), but in this study they were detected at each site

during these months at low levels. During previous systematic surveys, sperm whales were not observed in the shelf waters off the Washington coast (Barlow and Forney, 2007; Green et al.²) where all of our recorders were located. The greater number of detections at the Columbia River and Cape Flattery offshore sites may be due to proximity of these moorings to the Astoria and Nitinat canyons, respectively, as sperm whale density has been shown to be correlated with areas of steep underwater topography (Jaquet and Whitehead, 1996). The smaller numbers of detections at the Cape Flattery inshore and Westport sites may be indicative of whales transiting through the near-shore waters of Washington State, which has been observed in previous satellite tagging studies (Straley et al., 2014).

Moore and Barlow (2014) found that the number of sperm whales in the California Current has increased,

and estimate a two-fold increase from 1991 to 2008. These are most likely adult males traveling alone or in pairs. Sperm whale distribution is of particular management interest due to their endangered status and interactions with fisheries (Hucke-Gaete et al., 2004; Sigler et al., 2008), and visual surveys for this species can be challenging due to the limited amount of time they spend at the surface. While diving, sperm whales regularly make relatively loud clicks making them amenable to acoustic detection and monitoring to assess seasonal occurrence and distribution (Barlow and Taylor, 2005).

Killer whale occurrence at the two southern sites was highest from January to June. This is primarily due to the increased presence of southern resident killer whales, which is likely driven by the timing of Chinook salmon, *Oncorhynchus tshawytscha*, returning to the Columbia River (Han-

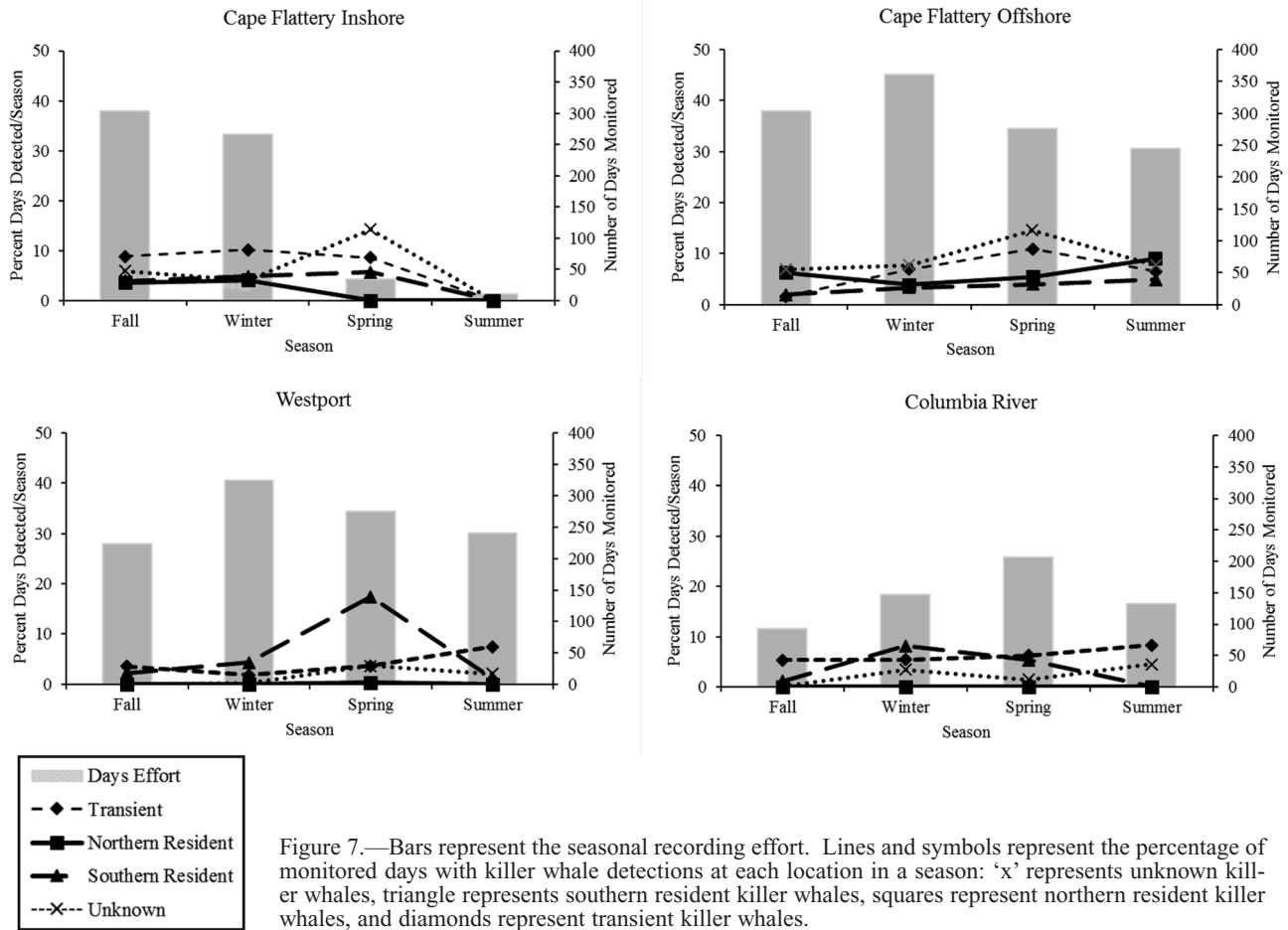


Figure 7.—Bars represent the seasonal recording effort. Lines and symbols represent the percentage of monitored days with killer whale detections at each location in a season: 'x' represents unknown killer whales, triangle represents southern resident killer whales, squares represent northern resident killer whales, and diamonds represent transient killer whales.

son et al., 2013; Rice et al., 2017). By June, transient killer whale detections become more common, even though they are detected at low levels at both sites throughout the year. Rice et al. (2017) also found increased transient killer whale detections in the spring and early summer at two sites along the Washington coast from 2004 to 2013. This timing corresponds to harbor seal, *Phoca vitulina*, pupping season on the Washington coast (Seekins⁵) and the usual return of resident killer whales to inland waters (Hauser et al., 2007). Both resident and transient killer whales were

⁵Seekins, B. 2009. Harbor seal pupping timeframes in Washington State (avail. online at http://www.westcoast.fisheries.noaa.gov/publications/gis_maps/maps/marine_mammals/seal-pups-timing.pdf (accessed 8 Apr. 2013)).

detected more often at the two northern sites which may be a result of the moorings proximity to important foraging areas and the Straits of Juan de Fuca (Baird and Dill, 1995; Ford et al., 2010; Hanson et al., 2010) and corresponds to previous monitoring in the area (Riera et al., 2011; Riera, 2012).

Passive acoustic monitoring has been shown to be an effective tool for examining cetacean occurrence and seasonality in areas of conservation or mitigation interest that are relatively small such as military ranges, renewable energy installations, and marine protected areas (Hazen et al., 2011; Oleson and Hildebrand, 2012; Lammers et al., 2013). It is unclear if it is appropriate to use the results from a single site to infer movements and seasonality on a larger scale, because little is known about

variability in distribution of many species across seasons and locations. The results of this study indicate that caution should be used when extrapolating the results of site-specific monitoring to a larger scale. The seasonal occurrence of the four species monitored was variable between the four sites, even amongst those sites that were closest in proximity. For example, gray whales were detected throughout the summer months at the Columbia River site, while they were absent during these months at the other southern site, Westport. And while the acoustic environment may differ among the sites, there were no consistent patterns observed that indicated reduced detection ranges at any given site.

Year-round acoustic monitoring also indicates that species that under-

take long-distance annual migrations, such as gray, humpback, and sperm whales, use parts of the Washington coast for the entire year. This information is essential for estimating the potential for human interactions, such as entanglement or ship strike, to these species and for monitoring changes in migration timing and seasonal occurrence over time.

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