**A Spatio-Temporal Characterization of Pinniped Strandings and Human Interaction Cases along the Oregon and Washington Coasts, 1989 - 2016**

Amanda J. Warlick,1 Stephanie A. Norman,2 Lesanna L. Lahner,3 Jessica L. Huggins,4 Erin D'agnese,5 James M. Rice,6 Jennifer Oleson,7 Joseph K. Gaydos,8 Victoria Souze9, Alysha Elsby9, Deborah A. Duffield,10 Dyanna M. Lambourn11, and John Calambokidis4

*1. ECS Federal, LLC, 6520 24th Ave NE, Seattle, WA 98115, USA E-mail:* [*amandajwarlick@gmail.com*](mailto:amandajwarlick@gmail.com)  
*2. Marine-Med: Marine Research, Epidemiology, and Veterinary Medicine, 24255 15th Place SE, Bothell, WA 98021 USA*  
*3. SR3: Sealife Response, Rehab, and Research, P.O. Box 1404 Mukilteo, WA 98275, USA*  
*4. Cascadia Research Collective, 218 1/2 W 4th Ave, Olympia, Washington 98501, USA*  
*5. University of California, Davis, California USA*  
*6. Marine Mammal Institute, Oregon State University, 2030 SE Marine Science Drive, Newport, Oregon 97365, USA*  
*7. The Whale Museum, PO Box 945, Friday Harbor, WA 98250, USA*  
*8. University of California Davis, UC Davis Wildlife Health Center–Orcas Island Office, 942 Deer Harbor Road, Eastsound, Washington 98245, USA*  
*9. Whatcom Marine Mammal Stranding Network, Washington USA*  
*9. Biology Department, Portland State University, P.O. Box 751, Portland, Oregon 97207, USA*  
*10. Washington Department of Fish and Wildlife, Marine Mammal Investigations, 7801 Phillips Rd, Lakewood, Washington, USA*

**Abstract**

Marine mammal strandings can be used as a proxy to assess pinniped health and the impacts of anthropogenic activities in the local marine environment. Stranding data from Washington and Oregon between 1989-2016 were used to examine regional and temporal patterns in strandings and human interaction cases across age and sex for six species. Over the study period, 14,939 pinnipeds were reported stranded along the coasts of Washington and Oregon, 11% of which were documented as human interaction cases. Gunshot wounds and fisheries entanglements constituted the majority of human interaction cases (37% and 21%, respectively), though the prevalence of these cases varied across species. Total strandings and the number and prevalence of reported human interaction cases increased over time in certain regions. The spatial distribution of strandings is highly dependent on species, with a higher proportion of California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), and northern elephant seals (*Mirounga angustirostris*) stranding in Oregon whereas the majority of strandings in Washington were harbor seals (*Phoca vitulina*). Though patterns varied across species, seasons, and regions, pups (28% of total strandings) and adults (23%) stranded in higher numbers than yearlings and subadults. Males constituted 34% of total cases, though the proportion of human interaction cases was similar for both sexes. Stranding hotspots were different across species and types of human interactions, likely due to the differential distribution of species and human activities along the coast. Despite the challenges and uncertainties inherent in using stranding data as an indicator of pinniped health and anthropogenic impacts, modeling spatio-temporal patterns will be useful for stranding response practitioners and natural resource managers in evaluating the scope and magnitude of threats to pinniped populations.

Keywords: pinnipeds, stranding, human interactions, spatio-temporal hotspots, Pacific Northwest, anthropogenic impacts.

**Introduction**

Pinnipeds are subject to a wide range of natural and human-related causes of illness or injury, and studying the spatio-temporal patterns of pinniped strandings can provide insight into the dynamic and interconnected factors influencing the health of populations vulnerable to human activities. Pinnipeds are often considered sentinels of ocean health (Aguirre & Tabor, 2004; Bossart, 2006; Ross, 2006; Moore, 2008; Bossart, 2011), as they are top predators living at the land-sea interface and strand onshore, exhibiting direct evidence of the threats they encounter in their environment. However, factors influencing where and when an animal strands are diverse, numerous, and interdependent, including ocean conditions, prey availability, susceptibility to disease, and changes in abundance, pupping season, or species range (Woodhouse, 1991; Brabyn & McLean, 1992; Wilkinson & Worthy, 1999; Norman et al., 2004; Pyenson, 2010; Osinga et al., 2012; Berini et al., 2015; Johnston et al., 2015). Stranding records can therefore provide insight into marine mammal life history, biology, and changes in their environment due to natural fluctuations and human-related activities.

Stranding records have been used globally to learn more about the demographics of wild populations, how a population may be affected by oceanographic conditions, the vulnerabilities of certain demographic groups, and how specific threats or conditions may be changing over time. For instance, strandings of both pinnipeds and cetaceans have been found to correlate with prevailing oceanographic conditions, changing species abundance and distribution, and increased reporting effort (Norman et al., 2004; Leeney et al., 2008; Pikesley et al., 2014; Berini et al., 2015; Huggins et al., 2015a; Prado et al., 2016). As examples, gray seal (*Halichoerus grypus*), harbor seal (*Phoca vitulina*), and harp seal (*Pagophilus groenlandicus*) strandings in the northeast U.S. increased from the late 1990s to early 2000s likely due to a combination of these factors (Soulen et al., 2013; Johnston et al., 2015). Similarly, gray and harbor seal strandings in the Netherlands increased likely due to growing populations and the resulting changes in seasonal and spatial distribution (Osinga et al., 2012).

On the U.S. West Coast, researchers have extensively studied stranding trends in California sea lions, northern elephant seals, and harbor seals in central California and generally found that strandings and documented human interaction cases have increased over time, that males and pups strand in greatest numbers, and that strandings have been elevated during El Niño events (Stewart & Yochem, 1987; Goldstein et al., 1999; Greig et al., 2005; Melin et al., 2000, 2008, 2010; Moore et al., 2009; Keledjian & Mesnick, 2013). In the Pacific Northwest, researchers have used stranding data to identify mortality rates and causes, primarily for harbor seals (Stroud & Roffe, 1979; Huggins et al., 2013; Lambourn et al., 2013). Norman et al. (2004) identified cetacean stranding hotspots in the Pacific Northwest and attributed the observed summer peak in reported strandings to the seasonal rise in beach attendance and a greater cetacean presence in the area due to seasonal inshore upwelling. Patterns in harbor porpoise and killer whale strandings have been used to examine long-term mortality trends and highlight the importance of consistent stranding response effort and data collection protocols in the region (Barbieri et al., 2013; Huggins et al., 2015a). However, few spatio-temporal analyses have been conducted on long-term stranding patterns for pinnipeds.

The quantity and consistency of information contained within stranding records can vary over time and across regions, particularly in an area such as the Pacific Northwest that is characterized by diverse topography (including remote beaches) and a large number of response groups. In this region, stranding response effort relies heavily on reports from the public, which can vary by region due to the degree of residential development, public awareness, and community interest (Huggins et al., 2015b). This illustrates the importance of acknowledging and contextualizing the uncertainty and variability inherent in stranding data when using it as a window into the health, status, or threats facing pinniped populations. Despite these caveats, however, stranding records are often the best and only available data.

We used data from stranding response networks to characterize spatio-temporal trends in age, sex, species, and human interaction cases in Oregon and Washington over a longer time period than has been assessed to date. We hypothesized that the number of reported strandings and human interaction cases will have risen over the study period due to a combination of growing populations, range expansion, and the enhanced stranding response capacity that occurred in the mid-2000s. We also expected that strandings for different species would not be uniformly distributed along the coast, with hotspots for human interaction cases likely occurring in areas with higher levels of human activity. This study provides an initial investigation into the complexities of co-occurring human and pinniped uses of a diverse and changing coastal landscape, which is particularly relevant given recent and possible future anomalous ocean conditions in the area (National Oceanic and Atmospheric Administration [NOAA], 2016). Analyses of stranding data are critical to natural resource managers tasked with assessing and monitoring pinniped populations and are additionally useful to ensure that stranding network practitioners have the necessary resources to study, collect, and evaluate stranded marine animals.

*Study Area and Species*  
The coastlines of Oregon and Washington have variable natural landscapes (*e.g.*, rocky intertidal zones, sandy beaches, estuarine embayments), public accessibility, and degree of development (*e.g.*, residential and commercial districts, shipping channels, ports, fishing activities, ecotourism). Six pinniped species inhabit the coastal and inland waters of the Pacific Northwest for some or all of their lives, each with unique life history characteristics, behavioral traits, local abundance, and dynamic population trends that influence their presence within the study area, and therefore their spatio-temporal stranding.

Harbor seals are the most abundant and widely distributed pinniped in Washington State waters and are found along the entire West Coast of the United States (Jeffries et al., 2000). Harbor seals are separated into five stocks: California, Oregon/Washington Coast, and newly delineated inland stocks of Southern Puget Sound, Washington Northern Inland Waters, and Hood Canal (Huber et al., 2012; Carretta et al., 2016). The Oregon/Washington Coast and inland stocks are presumed to have stabilized and reached carrying capacity (Jeffries et al., 2003). Based on a survey conducted in 1999, the coastal stock is estimated to be the largest (over 24,700 individuals in 1999), followed by the Northern Inland Waters stock (11,036 individuals), with much smaller estimates for the Hood Canal (1,088 individuals) and Southern Puget Sound (1,568 individuals) stocks (Carretta et al., 2016). Harbor seals exhibit high haul-out fidelity and choose sites depending on time of day, tides, season, or food availability (Thomas et al., 2011; London et al., 2012). The timing of peak pupping varies for different areas, ranging from mid-April in the Columbia River, mid-May along the Oregon coast, and late summer and early fall throughout Puget Sound (Jeffries et al., 2000).

California sea lions (*Zalophus californianus*) are the most abundant pinniped off the coast of California, numbering nearly 300,000 individuals and growing approximately 5.4% per year (Carretta et al., 2016). Adult females remain near to the primary rookeries off the coast of southern California, making shorter local foraging trips until pups are weaned (Melin et al., 2008). Adult and subadult males make winter migratory foraging trips as far north as Alaska and return south in late spring (Lowry & Forney, 2005). Because of these life history and migratory patterns, individuals found in the Pacific Northwest are usually non-breeding males utilizing feeding areas in fall, winter, and spring months, though an increasing number of females have been sighted in the area and even into Alaska in recent years (Maniscalco et al., 2004).

Steller sea lions (*Eumetopias jubatus*) range from Japan throughout the North Pacific and south into California, with two recognized distinct populations: Western and Eastern. The Eastern population has an estimated 60,000 to 75,000 individuals with breeding and haul-out sites located along the coast of southeast Alaska, British Columbia, Washington, Oregon, and California (DeMaster, 2014; Carretta et al., 2016). Population demographics vary by region, with numbers decreasing at California rookeries in recent years but increasing in the northern part of their range (Carretta et al., 2016). During the summer breeding season, adult males remain ashore while females and juveniles make short foraging trips (National Marine Fisheries Service [NMFS], 2013).

Northern elephant seals (*Mirounga angustirostris*) range from Mexico to the Aleutian Islands, making seasonal migrations from rookeries in California and Oregon to feeding areas in Alaska and the central North Pacific. Females and males have vastly different energetic demands and therefore different seasonal migration patterns. Males make spring and fall feeding trips and females make an initial two-month foraging trip after weaning pups in late winter and then another eight-month foraging trip during gestation before returning to the rookery to give birth and breed (Le Beouf et al., 2000). Individuals can also be found hauled out during molting in the Pacific Northwest. The California breeding stock has grown by 3.8% per year in recent decades and was estimated at 179,000 individuals in 2010 (Lowry et al., 2014).

Northern fur seals (*Callorhinus ursinus*) range from southern California far into the North Pacific, with two recognized stocks: California and Eastern Pacific (Carretta et al., 2016). Primary rookeries are located on the Pribilof and Bogoslof Islands in the Bering Sea, and to a lesser extent islands off southern California (the latter comprising just 1% of the population during the summer breeding season) (Gelatt et al., 2015). Individuals may also haul out along the coast in the Pacific Northwest or British Columbia outside of the breeding season. Adults are onshore throughout the summer breeding season and then remain at sea for seven to eight months, with adult females and pups from both stocks migrating to foraging areas off the West Coast (Lea et al., 2009; Orr et al., 2012). Population growth and demographics of the California stock are changing due to the co-occurrence of emigration and El Niño events.

Guadalupe fur seals (*Arctocephalus townsendi*) were nearly extirpated in the late 1800s, with the remaining population centered around islands off the coast of Baja California, Mexico. The population is listed as Threatened under the ESA but has been rebuilding, increasing by 13-21% each year (Esperon-Rodriguez & Gallo-Reynoso, 2012). Individuals have been sighted in the Channel Islands and strandings have occurred as far north as Oregon and Washington, suggesting recolonization and expansion of their historic range (Hanni et al., 1997; Lambourn et al., 2015). Similar to other otariids, pupping occurs in early summer with females remaining close to the rookeries and making brief foraging trips for approximately eight months until pups are weaned (Figueroa-Carranza, 1994).

**Methods**

*Data Sources and Characterization*

Data for this analysis were drawn from the NOAA National Marine Fisheries Service national stranding database (accessed February 2017) that contains standardized "Level A" information submitted by stranding responders, including a field ID number, observation date, stranding location, latitude and longitude coordinates, age, sex, species, stranding condition (live or dead), and other observational comments including visible evidence of injury, illness, or human interaction. A pinniped is defined as being stranded when it is either dead or still alive on the beach but in need of medical attention or unable to return to the water on its own (Marine Mammal Protection Act of 1972). Animals are also reported by the public when they are simply resting or molting, and responders frequently monitor these situations (particularly if the animal is located in a populated area) and document the case in the stranding database. Therefore, reported strandings for some species in some areas (particularly for elephant seals and harbor seal pups in inland Washington waters) may over-represent the true number of stranded animals that are sick or injured. We have not excluded these in this analysis because such cases are inconsistently documented across networks and are therefore difficult to systematically extract from such a large sample size. Furthermore, they do represent the true number of cases that require time and resources from response networks.

The total number of pinnipeds reported stranded in Oregon and Washington from 1989 to 2016 (*n* = 14,939 records) were characterized according to sex, age class, and species, and then aggregated by month, year, and stranding location (county). Inland Washington waters were distinguished from coastal Washington counties because the life history traits of the species that live and strand in these two sub-regions are very different. For this analysis, we assume stranding location can be used as a relative approximation for where strandings and human interactions actually took place, though carcasses can drift for some time before making landfall, and entangled animals can migrate with entangling debris from a different region.

In addition to examining total stranding cases, the number of human interaction (HI) cases were also examined. Human interaction cases are recorded on the Level A stranding intake form, with "Yes," "No," or "could not be determined (CBD)" designations for whether there is evidence of fisheries entanglements, gunshot wounds, boat collisions, or "other" human interactions. Descriptions of "other" human interactions can include indeterminate blunt trauma, dog bites, debris entanglement, oil staining, and humans harassing or illegally relocating animals. The “CBD” designation includes a variety of possible situations, ranging from an unexamined animal to an animal with suspected but unconfirmed HI. Thus, the number of confirmed HI cases is a conservative estimate. Records for dead or decomposed animals can be missing specification in certain fields, resulting in "Unknown" or "Unidentified" age, sex, or even species designations, and were therefore only included in analyses of total strandings.

Two measures of the prevalence of HI cases were examined: (1) the annual proportion of total strandings made up of both combined and individual HI types over time (*e.g.*, number of fisheries entanglements divided by total stranding cases), to reveal variation in the magnitude of HI, independent of changes in population demographics, and (2) the percent composition of human interaction cases (*e.g.*, number of fisheries entanglements divided by total human interaction cases) to examine which type(s) of anthropogenic activity may have a greater effect on a given age, sex, or species). It is important to note, however, that stranding response networks with the capacity to conduct detailed necropsies on a higher percentage of stranded individuals will likely report a higher incidence of positive HI findings, while those that conduct fewer or less detailed necropsies may report a higher incidence of CBD findings. Therefore, results examining the spatial differences in the prevalence of HI cases must be interpreted within this context, though we expect useful information at a broader regional level despite network differences.

*Statistical Analysis*  
Age class, sex, and species - To determine whether the number of strandings were significantly different across categorical variables such as age class, sex, species, or location, we conducted pairwise Kruskal-Wallis Nemenyi tests (posthoc.kruskal.nemenyi.test function in the PMCMR R package) with age class, sex, and species as independent variables and the number of stranding cases as the dependent variable. The classification of “yearling” has changed over time, and results must therefore be interpreted with this inconsistency in mind. Summary statistics were examined both at the regional level (*i.e.*, by state) for management-relevant analyses and on a more local level (*i.e.*, by county) useful for stranding response practitioners.

Temporal patterns - To determine whether strandings and HI cases have changed over the study period, we examined both the *number* and *prevalence* over time. We used negative binomial general linear model (GLM) regressions (to account for overdispersion and correct for standard error estimates that might be biased downwards in a Poisson regression model; using the glm.nb function in the MASS R package) for total annual stranding cases against year. Regressions were repeated for total strandings and HI cases for each species. Regression coefficients reported using this technique were back-transformed, resulting in a "fold increase" (*e.g.*, y = 1.051x being equivalent to a 5.1% increase per year). Time series figures were fit with a loess regression line ("locally weighted regression", Cleveland & Devlin, 1988) to allow for a dynamic, changing, and unknown relationship between explanatory and response variables over time, which could arise from changes in stranding network capacity and reporting effort over the study period, among other things. Annual timeseries trends were also explored using Chow's breakpoint test (strucchange package in R) to determine whether interannual changes in stranding numbers reflect known changes in stranding network capacity, effort, and funding over time. To examine changes in the prevalence of HI cases, we used a binomial logistic GLM regression with the logit link function, resulting in untransformed regression coefficients.

The presence of seasonal patterns was tested using post-hoc pairwise Kruskal-Wallis Nemenyi tests, as above, with month as the independent variable and total monthly stranding cases as the dependent variable. We also tested for the presence of a seasonal effect with ANOVA comparisons of negative binomial GLM regression models with and without stranding month as an interaction term. Any monthly analyses were conducted on the subset of individuals that were recorded as being either alive or freshly dead at the time of observation in order to best capture the temporal component of the stranding event.

Spatial patterns - To determine possible spatial patterns in overall strandings and HI cases, we again used negative binomial GLM regression and pairwise Kruskal-Wallis Nemenyi tests using stranding location (county) as the independent variable and total monthly stranding cases as the dependent variable. Stranding hotspot maps were generated with a kernel density estimation (Gatrell et al., 1996) derived from the ggplot2 function geom\_density2d in R. Because this function does not account for the fact that strandings occur only on the coast, these maps are intended as a qualitative visualization rather than a statistical probability for predicting the spatial distribution of stranding cases.

*Caveats*  
Stranding response network members have grown in their capacity and coverage over the study period, particularly in the mid-2000s with the implementation of the John H. Prescott Marine Mammal Rescue Assistance Grant Program[[1]](#footnote-22), which could in part account for a rise in reported strandings. Not all historical records prior to the implementation of this grant program have been digitized, and may therefore be excluded from this analysis. One of the challenges of using data from this compilation of stranding reports is that beach coverage, response capacity, and even data-reporting protocols vary between network members and over time. Thus, any apparent patterns must be interpreted in the context of those challenges. However, when combined, these data illustrate what is known and what remains uncertain about strandings throughout the region.

**Results**

From 1989-2016, local stranding response networks identified and recorded 14,939 stranded pinnipeds along the coasts and inland waters of Oregon and Washington. Approximately 28% (*n* = 4,222) were alive and 31% (*n* = 4,557) were freshly dead at the time of recovery, with the remaining being in various states of decomposition. Evidence of human interaction was noted in 11% (*n* = 1,628) of all stranding cases over the study period, including fisheries entanglements (*n* = 336, 21% of all human interaction cases), gunshot wounds (*n* = 598, 37%), boat collision injuries (*n* = 76, 5%), and "other" (*n* = 648, 40%).

*Age Class and Sex*  
All stranding cases - Annual strandings differed significantly by both sex (*χ*2 = 119.3, *p* < 0.001) and age class (*χ*2 = 232.6, *p* < 0.001), but remained relatively consistent throughout the study period. From 1989-2016, 34% of all stranding cases were male, 17% female, and 49% unidentified (Table 1). Across all strandings, the majority were pups (28%) and adults (23%), with significantly fewer yearlings (7%) and subadults (6%), and the remainder unidentified (Table 1). Pairwise comparisons showed that annual strandings for pups and adults were significantly higher than yearlings and subadults.

Additionally, the sex composition of strandings varies depending on age class and species, with the proportion of females ranging from 12% for subadults to 26% for pups and the proportion of males ranging from 27% of pups to 60% of adults. For California sea lions, 77% were male, while the sex composition was more equal for the other species (Table 2). For California sea lions and Steller sea lions, more than half of identified strandings were adults, while the majority for the other four species were pups and yearlings (92% for Guadalupe fur seals) (Table 2).

Human interaction cases - Similar to overall strandings, the *number* of HI cases is significantly higher for males compared to females (*χ*2 = 119.2, *p* < 0.001), but the proportions are similar for both sexes (~ 16%; Table 1). The prevalence of fisheries interactions and boat injuries is similar between males and females, though gunshot wounds are more prevalent for males (Table 1). For specific age classes, the number of HI cases is significantly higher than average in pups (t = 2.9, *p* < 0.01) and adults (t = 5.9, *p* < 0.001) and lower in yearlings (t = -3.7, *p* < 0.001) and subadults (t = -2.8, *p* < 0.01) (Table 1). Fisheries interactions are the most common type of HI case for yearlings (39% of all yearling HI cases) and significantly less for pups and adults (18%). Gunshot wounds, however, are most prevalent in adults (58% of adult HI cases) and subadults (51%) and less so for pups (4%). Boat collisions comprise a small proportion (5-7%) of HI cases for all age classes (Table 1).

*Species*  
The majority of total strandings were harbor seals (58% of all cases) and California sea lions (19%), followed by smaller numbers of Steller sea lions (7%), northern elephant seals (3%), Guadalupe fur seals (1%), and northern fur seals (1%) (Table 3). Average annual strandings were significantly different across species over the study period (*χ*2 = 9.8, *p* < 0.01), ranging from 5 per year for northern fur seals to 312 per year for harbor seals (Figure 1a, Table 3). Similar to all strandings, harbor seals constituted the majority of HI cases (54%) followed by California (28%) and Steller sea lions (12%).

The proportion of HI cases (*i.e.*, the number of cases with evidence of human interaction divided by total number of cases), and the composition of HI cases (*i.e.*, the number of human interaction cases involving gunshot wounds versus fisheries entanglements) differs between species. The proportion of HI cases ranges from 8% for northern elephant seals up to 18% for Steller sea lions and 25% for northern fur seals, the latter species occurring in lowest numbers in the study area (Table 3). The composition of HI types varies considerably across species. Gunshot wounds constituted 74% of human interaction cases for Steller sea lions and 58% for California sea lions, but only 21% for harbor seals. In contrast, fisheries interactions made up a lower proportion of human interaction cases for those three species but amounted to 65% and 75% of human interaction cases for Guadalupe and northern fur seals, respectively (Table 3). Boat collision injuries are encountered much less frequently than the other types of HI cases but are most prevalent in northern elephant seals, amounting to 11% of HI cases (Table 3 and Figure 1b). The changes in these proportions over time are detailed below.

*Temporal Patterns*  
All stranding cases - Since 1989, the number of reported stranding cases increased significantly over time (z = 5.4, *p* < 0.001). An annual average of 329 individuals stranded per year throughout the 1990s and 666 per year since 2000. However, annual strandings are changing differently over the study period for each species; significantly increasing for harbor seals (z = 6.2, *p* < 0.001), California sea lions (z = 7.7, *p* < 0.001), Steller sea lions (z = 8.3, *p* < 0.001), Guadalupe fur seals (z = 2.0, *p* < 0.05), and northern fur seals (z = 2.2, *p* < 0.05) (Figure 2a), and no significant change detected for northern elephant seals.

Human interaction cases - The overall number of HI cases increased significantly from 1989-2016 (z = 7.8, *p* < 0.001). An annual average of 21 cases were documented throughout the 1990s and 82 per year since 2000. Specifically, there was an increasing number of gunshot wounds (z = 4.6, *p* < 0.001), fisheries entanglements (z = 8.3, *p* < 0.001), and boat injuries (z = 3.3, *p* < 0.01) over the study period (Figure 3b). The prevalence of HI cases has also increased overall (z = 15.5, *p* < 0.001) and specifically for gunshot wounds (z = 6.4, *p* < 0.001), fisheries entanglements (z = 5.3, *p* < 0.001), and boat injuries (z = 4.2, *p* < 0.001) (Figure 4b). The prevalence of combined HI case types exceeded 20% in 2012, 2013, and 2015.

Examining whether human interaction cases are changing over time is most meaningful at the species level. Similar to overall strandings, the number of documented HI cases increased for harbor seals (z = 8.7, *p* < 0.001), California sea lions (z = 6.3, *p* < 0.001), Steller sea lions (z = 5.3, *p* < 0.001), and Guadalupe fur seals (z = 2.1, *p* < 0.05) (Figure 3a). The prevalence of HI cases increased for harbor seals (z = 11.4, *p* < 0.001), California sea lions (z = 3.8, *p* < 0.001), and northern elephant seals (z = 3.5, *p* < 0.001), and decreased for Guadalupe fur seals largely due to the increase in overall strandings of the species (Figure 4a). In terms of specific HI types, the prevalence of gunshot wound cases increased significantly for California sea lions (z = 2.8, *p* < 0.05), fisheries entanglement cases decreased for California sea lions (z = -2.1, *p* < 0.05) and increased for harbor seals (z = 5.4, *p* < 0.001), and boat-related injuries increased for harbor seals (z = 3.4, *p* < 0.001).

A seasonal peak in total strandings is evident, with strandings being significantly different across months of the year (*χ*2 = 4615, *p* < 0.001) and highest from May through October. However, the timing of this peak is different for each species. Examining pairwise Tukey comparisons showed that harbor seal strandings are significantly higher from June through September. Though not statistically significant, California sea lion strandings exhibit a peak in May and again from August through November. The age class composition of stranded animals varies seasonally, with pups (just over 90% of which were harbor seals) stranding in higher numbers from June through September (*χ*2 = 503.8, *p* < 0.001). None of the other age classes exhibited statistically significant seasonal stranding patterns. Seasonal patterns were similar across male and female strandings.

The number of combined HI cases is significantly higher in the summer (July) for harbor seals and pups (Figure 5a, b). Though not statistically significant, the different HI case types exhibit seasonal patterns depending on sub-region. Boat collision cases only occur from April to October in inland Washington waters and are highest in August. Fisheries entanglements are highest in May and June in Oregon and highest in August in inland Washington waters. Gunshot wound cases exhibit a discrete peak in March on the Washington coast and in August in inland Washington waters. Gunshot wounds account for an average of 13% of all cases in March compared to an average of 4% of all monthly cases the rest of the year.

*Spatial Patterns*  
Over the study period, a higher volume and increasing number of strandings occurred in inland Washington and along the Oregon coast compared to the Washington coast (Figure 2b). The proportion of total annual strandings occurring in Oregon ranged from 8% to 58%, averaging 35% for the whole study period. The proportion of annual strandings occurring along the Washington coast ranged from 2% to 23%, averaging 8% for the whole study period. The proportion of annual strandings occurring along the shores of inland Washington waters ranged from 38% to 83%, averaging 57% for the whole study period.

The distribution of HI cases between these three sub-regions is similar to that of overall strandings, with 34% of all HI cases occurring in Oregon, 50% in inland Washington waters, and the remaining 16% along the Washington coast. However, the distribution of specific types of HI cases is different between the three sub-regions, with only 31% of boat collisions and 16% of "other" cases occurring in Oregon and 68% and 72% occurring in inland Washington waters, respectively. Approximately 25% of gunshot wounds reported during the study period occurred along the Washington coast.

At the county level, strandings were not evenly distributed along the coast (*χ*2 = 1191.3, *p* < 0.001). In Washington, strandings were highest in San Juan, Island, King, Pierce, and Grays Harbor counties (Figure 6a). Similarly, the number of HI cases were significantly higher in Grays Harbor, Pierce, and Pacific counties, with a disproportionately higher number of cases in Pacific county compared with all strandings, the majority of which were gunshot wounds (Figure 6b). Combined human interaction cases increased in Pierce (z = 3.0, *p* < 0.01), Pacific (z = 2.7, *p* < 0.01), King (z = 2.7, *p* < 0.01), Whatcom (z = 3.0, *p* < 0.001), and Jefferson (z = 2.2, *p* < 0.05) counties. In Oregon, the majority of strandings occurred in Clatsop, Tillamook, Coos, and Lincoln counties (Figure 6a). These counties were also where the majority of HI cases occurred, though a disproportionately higher number occurred in Clatsop, the majority of which were gunshot wounds. Combined human interaction cases increased in Clatsop county (z = 3.9, *p* < 0.001). Kernel density plots show different hotspot areas for different human interaction types, with boat collision injuries and fisheries interactions largely occurring throughout inland Washington waters and around the mouth of the Columbia River, while the most significant hotspot for gunshot wounds centered around the Columbia River (Figure 7).

Species - Individual species strandings were not equally distributed between the three sub-regions. Approximately 60% of Guadalupe fur seal, northern elephant seal, and northern fur seal strandings occurred in Oregon and 40% in Washington. Similarly, approximately 70% of California and Steller sea lions occurred in Oregon and 30% in Washington. In contrast, approximately 15% of harbor seal strandings occurred in Oregon and 85% in Washington (Table 3). Stranding hotspots were apparent throughout inland Washington waters for harbor seals, and distributed along the coast for the other species (Figure 8). In varying degrees for all species except northern fur seals, kernel density hotspots are slightly different for all strandings versus human interaction cases (Figure 8). For example, northern elephant seal human interaction cases are centered further north than overall strandings and exhibit a hotspot in inland Washington waters. Harbor seal human interactions exhibit an additional cluster near the mouth of the Columbia River and HI cases for both Steller sea lions and Guadalupe fur seals are more tightly clustered around the mouth of the Columbia River relative to the distribution of overall strandings (Figure 8).

**Discussion**

Our results highlight spatio-temporal stranding hotspots for pinnipeds in Oregon and Washington from 1989-2016. Harbor seals are the most commonly stranded species in inland Washington waters while other species strand more frequently in Oregon. In addition, strandings exhibit a seasonal peak that varies by species, and more males have stranded than females, though the sex composition varies by age and species. Furthermore, the prevalence of human interactions varies by sex, age class, and species, the number of strandings and human interactions have changed over time, and strandings and specific human interaction types are clustered in certain counties along the coast. Huggins et al. (2015b) found that the proportion of total strandings that were actually reported in this region both changed over time and varied across species, seasons, and network areas. However, this variation likely remains relatively consistent over time. Therefore, while reported strandings underestimate the true volume of strandings, the long-term spatio-temporal patterns across sex and age class and the relative changes in the prevalence of human interactions cases over time reflect and can be explained by natural and anthropogenic characteristics of the region and respective species, as described in more detail below.

*Age Class and Sex*  
Patterns in the age class and sex of strandings remained relatively constant over time, with males, pups, and adults stranding in higher numbers overall and the sex composition varying across age classes and species. These findings are similar to other studies that have found a higher proportion of males in stranding records compared to females for northern elephant seals (Colegrove et al., 2005), California sea lions (Greig et al., 2005), and harp seals (*Pagophilus groenlandicus*) (Soulen et al., 2013). Many studies have found a higher number or incidence of HI cases in males of various age classes (but particularly young animals) (Greig et al., 2005, Delong et al., 1990, Kiyota & Baba, 2001; Kaplan Dau et al., 2009), while here we found that while there were a higher number of male HI cases, the proportion of human interaction cases was similar for both males and females (~16%).

Adults constituting a higher percentage of overall strandings compared to other age classes differs from other studies where young animals have comprised the majority of strandings and human interaction cases (Greig et al., 2005; Goldstein et al., 1999; Hanni & Pyle, 2000; Kaplan Dau et al., 2009). This disparity is likely due to a combination of factors, including public perception of certain species as nuissance animals, more adults migrating through or hauling out in the region, and some species not having rookeries in the area compared to other study regions (such as California where there is a higher prevalence of pups). Similarly, the slightly higher proportion of HI cases in adults and subadults rather than pups and yearlings (16% versus 8-11%) as in other studies is likely due to the spatial distribution of different age classes for each species. Our age class results must also be interpreted with the knowledge that strandings of pups in inland Washington may be higher due to dedicated pup mortality surveys of haul-out areas not publicly accessible.

*Species*  
Looking more closely at the composition of age class and sex of strandings is more informative at the species level, as the different demographic and behavioral characteristics of each species largely determines when and where pupping, weaning, and foraging occur along the coast. For example, the majority of California sea lion strandings were male and occurred in May as well as the fall, reflecting the fact that males are making migrations through the area while many females largely stay around the rookeries in California. Similarly, harbor seal strandings are highest throughout the pupping season from June through October.

Our finding that California sea lion strandings were primarily males while Steller sea lion strandings were more equitably distributed between the sexes was consistent with the findings of other studies in the Oregon and southern Washington area (Lee, 2016). The prevalence of harbor seal pups in inland Washington waters is similarly attributable to the presence of haul-outs in the area and a population that has grown to carrying capacity in recent decades. Further analysis of each individual species could potentially elucidate the connections between stranding patterns and the seasonal use of important reproductive and foraging habitat at a finer spatio-temporal scale using known haul-outs (Jeffries et al., 2000), proxies for upwelling, wind and current patterns, or specific prey distributions.

The species in this study each have different behaviors, preferred prey, foraging strategies, and adaptability to changes in their environment that could affect their likelihood of encountering human activities and becoming entangled, shot, struck by a vessel, or ingesting marine debris. It is therefore not surprising that the number and prevalence of HI cases varies across species (Table 3 and Table 1), similar to the variation noted by others (Moore et al., 2009; Bogomolni et al., 2010). For example, species that forage further offshore would be least likely to encounter vessel traffic, those that haulout at popular beaches might have a higher prevalence of public harassment cases, and those whose foraging overlaps with a particular fishing season or area might have a higher prevalence of entanglements and gunshot wounds.

California sea lions and male pups have been cited as being particularly inquisitive and therefore more likely to become entangled, though entanglement rates of California sea lions were second to northern fur seals and Steller sea lions in this study. Anecdotal observations made by response practitioners suggest that these three species are affected by different types of entangling materials. In Oregon, plastic packing bands and rubber bands (likely from fish bait boxes and crab pots) account for most California sea lion and Steller sea lion entanglements, respectively, while trawl nets are the most prominent in northern fur seal entanglements (*pers comms*, J. Rice 2017).

Similar to our findings, studies have noted northern fur seals as having a relatively high prevalence of entanglement, evident in rookery field surveys and stranding data (Fowler, 1987, Delong et al., 1990; Antonelis et al., 2006). Additionally, Colegrove et al. (2005) found the prevalence of human interaction cases in central California varied annually, but was higher in harbor seals than northern elephant seals, also similar to the results presented here. The overall prevalence of human interaction cases for all species over the study period was approximately 11%, similar to that observed in California (3-16%) and Cape Cod (10%) (Goldstein et al., 1999; Kaplan Dau et al., 2009; Moore et al., 2009; Bogomolni et al., 2010; Keledjian & Mesnick, 2013). However, the prevalence of HI can also be influenced by the levels of examination each species typically receives (*i.e.*, Endangered Species Act-listed and infrequently stranded species such as the northern fur seals might garner greater scientific interest and therefore more extensive examinations that would reveal evidence of human interaction).

*Temporal Patterns*  
Our results indicate that total annual reported strandings significantly increased over the study period, though this pattern is different for each species. This observed increase in the number of reported strandings likely reflects increasing abundance and increasing stranding response effort rather than being symptomatic of declining population health, as noted by Huggins et al. (2015a). The noticeable and extended seasonal peak in harbor seal strandings likely reflects that these strandings are primarily pups, and pupping in Washington occurs from April to October depending on the area.

The number of HI cases increased over the study period for harbor seals, California sea lions, Steller sea lions, and Guadalupe fur seals, mirroring the rise in overall strandings. These changes in the number of certain types of cases for certain species are likely the product of both endogenous factors (those related to the animals and their environment) and exogenous factors (human activities, policies, pollution events). For example, the implementation (or the relaxation) of a policy or outreach effort can manifest itself in stranding data, such as when local law enforcement officials patrol beaches or initiate enhanced outreach efforts to fishermen. This type of activity resulted in noticeably decreased gunshot wound cases in 20XX followed by a rise shortly thereafter. Such events could also explain the noticeable spike in gunshot wound cases in the early 1990s.

The prevalence of HI cases has increased significantly over time for California sea lions, harbor seals, and northern elephant seals. More specifically, the prevalence of gunshot wounds increased in reported California sea lion strandings and the prevalence of fisheries entanglements increased for California sea lions and harbor seals. The prevalence of HI cases reported here is similar to the range documented in California, amounting to between 7.5% and 16% of cases (Goldstein et al., 1999; Keledjian & Mesnick, 2013). It is difficult to identify possible explanations for these observed trends as both pinniped populations and human activities can be simultaneously changing, additionally complicated by the fact that our ability to detect certain injuries or illnesses also improves over time (Gulland & Hall, 2007). However, it would be possible to compare interannual changes in the number or prevalence of HI to proxies for fishing effort or other human activities, though data over time and space can be sparse.

*Spatial Patterns*  
Overall strandings - The number and relative distribution of species stranded in inland waters and along the coasts of Oregon and Washington (Table 3) can be largely explained by the local abundance and demographic characteristics of each species. The number and relative distribution of strandings were different across species, and stranding hotspots are similar to those that have been previously identified for cetaceans and pinnipeds in the area (Norman et al., 2004; Lee, 2016). In Washington, harbor seals primarily stranded throughout inland waters due to the area having a large number of haul-outs, rookeries, and public reporting. In contrast, fewer harbor seal strandings are reported along the Washington coast, largely due to the fact that many beaches are isolated or inaccessible. Guadalupe fur seal stranding hotspots occur around the mouth of the Columbia River and Willapa Bay on the outer coast (Figure 8), likely reflecting the fact that few individuals range into inland Washington waters given their highly pelagic nature. Similarly, northern fur seal strandings did not exhibit clustering in northern or inland Washington, possibly due to individuals spending more time foraging offshore or near rookeries in Alaska. Approximately two-thirds of Steller sea lion strandings during the study period occurred in Oregon, likely due to the three large breeding sites along the coast. These results align with findings from other coastal areas where patterns in marine mammal strandings reflect either local abundance or seasonal distribution of species (Woodhouse et al., 1991; Norman et al., 2004; Maldini et al., 2005; Leeney et al., 2008; Pyenson, 2010; Peltier et al., 2013; Frungillo & Read, 2014; Pikesley et al., 2014; Johnston et al., 2015).

Over the study area, kernel density plots show that human interaction cases are more concentrated in specific places compared to overall strandings. In Washington, human interactions were disproportionately higher in Pacific and Pierce counties, which accounted for 30% of human interactions cases in Washington but less than 19% of total strandings. In Pacific county, 66% of HI cases were gunshot wounds. The higher percentage of "other" HI cases (blunt trauma, missing appendages, dog bites, oil staining, animal harassment) in inland Washington is likely due to the fact that the majority of thosethe result of a higher number of HI cases areinvolving harbor seal pups in this region, and a the disproportional number of harbor seal stranding that occurs in Washington, as described above. The higher percentage of boat-related injuries in inland Washington could be attributed to the presence of ferry and shipping traffic and recreational boating opportunities throughout inland waters. In Oregon, human interactions were disproportionately higher in Lincoln, Tillamook, Coos, and Clatsop counties. Nearly half of all HI cases in Oregon were recorded in Clatsop, the majority of which were gunshot wounds. Clatsop county includes Astoria, an economically important fishing port, and the area has seen an increased number of fisheries interactions in recent years (Lee, 2016), particularly with animals foraging up into the Columbia River. However, this higher number of HI cases could also be attributed to the higher necropsy rate in the northern part of the state (Lee, 2016).

*Future Directions*  
This characterization and hotspot mapping analysis is important for informing management and conservation measures and can support decision-making for stranding response practitioners. Though these results present one of the most comprehensive summary statistics of human interactions cases for pinnipeds in this region, further analysis of each individual species could ascertain whether it is likely that certain age classes overlap to a greater extent in time and space with anthropogenic activities in areas we identified as hotspots for human interaction cases. While strandings and human interaction cases can coincide with or have a higher reporting rate from dense human population centers, they can also occur offshore or in more isolated areas, and therefore go undetected. Further refining the parameters of the kernel density function or using saTScan analysis (Kulldorff & Nagarwalla, 1995; Kulldorff, 2001, Kreuder et al., 2003; Kulldorf et al., 2005; Norman et al., 2011) could be explored in the future to refine these hotspot maps. Additioinally, more refined spatio-temporal predictive modeling that includes measures of pinniped abundance, prey distribution, and proxies for oceanographic conditions (as in Evans et al., 2005, Soulen et al., 2013, Peltier et al., 2013, Truchon et al., 2013, and Berini et al., 2015) could further elucidate the spatial distribution of strandings, and therefore areas or species that are at a higher risk for human impacts and in need of management attention.

**Conclusion**  
Spatio-temporal patterns in the age and sex of pinniped strandings in Oregon and Washington varied for each of the six species in the study area. Patterns in the distribution and number of strandings along the coast and throughout the year are likely due to the local abundance and demographic characteristics of each species, with harbor seal pups stranding primarily throughout inland Washington waters during pupping season, and other species stranding more broadly across all age classes and along the coast. The number of strandings and the prevalence of human interaction cases increased over time, largely attributed to a combination of changing population dynamics, enhanced stranding response effort and public awareness, and continued coastal socioeconomic development. More refined spatio-temporal modeling techniques could further elucidate the connections between stranding clusters, forage species availability, prevailing oceanographic conditions, and anthropogenic activities that all impact the short and long-term health of these pinniped populations in a changing environment. Stranding hotspot maps show discrete areas of high-density strandings, which are different across species and types of human interaction cases. Identifying and monitoring stranding hotspots can be helpful in a variety of contexts, including detecting and investigating unusual mortality events, informing disentanglement response or beach clean-up efforts, implementing targeted outreach about non-lethal deterrents in areas where gunshot wounds are prevalent, establishing baseline health information, and evaluating whether human-related mortalities approach or exceed established limits under the Marine Mammal Protection Act. Stranding data may contain gaps, biases, and inconsistencies, but are an invaluable resource for conservation and management of these marine mammal species.

**Acknowledgements**  
This research was made possible through the hard work and dedication of all stranding response network work members in the Pacific Northwest, including Cascadia Research Collective, Central Puget Sound Marine Mammal Stranding Network, Dungeness National Wildlife Refuge & Protection Island, Feiro Marine Life Center, Makah Tribe, Marine Animal Rescue Center, MaST Center Stranding Team, Olympic Coast National Marine Sanctuary, Oregon State University Marine Mammal Institute, Port Townsend Marine Science Center, Portland State University, San Juan County Marine Mammal Stranding Network, Seal Sitters, Seaside Aquarium, Sno-King Marine Mammal Response, The Whale Museum, Vashon Hydrophone Project, Washington Dept of Fish and Wildlife Marine Mammal Investigations, and Whatcom Marine Mammal Stranding Network. In addition to the numerous volunteer hours invested in collecting the data presented, many stranding networks were the recipients of numerous U.S. Federal grants through the John H. Prescott Marine Mammal Rescue Assistance Grant Program, which supplied essential funding for this work.

**Figures and Tables**

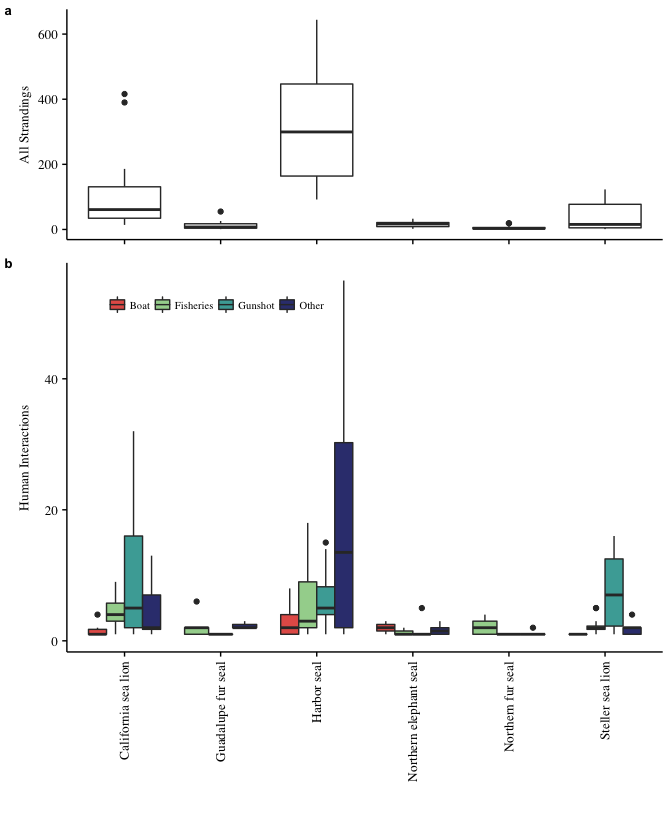


Figure 1: Boxplots of (a) annual stranding cases for each species, and (b) annual human interactions by case type.

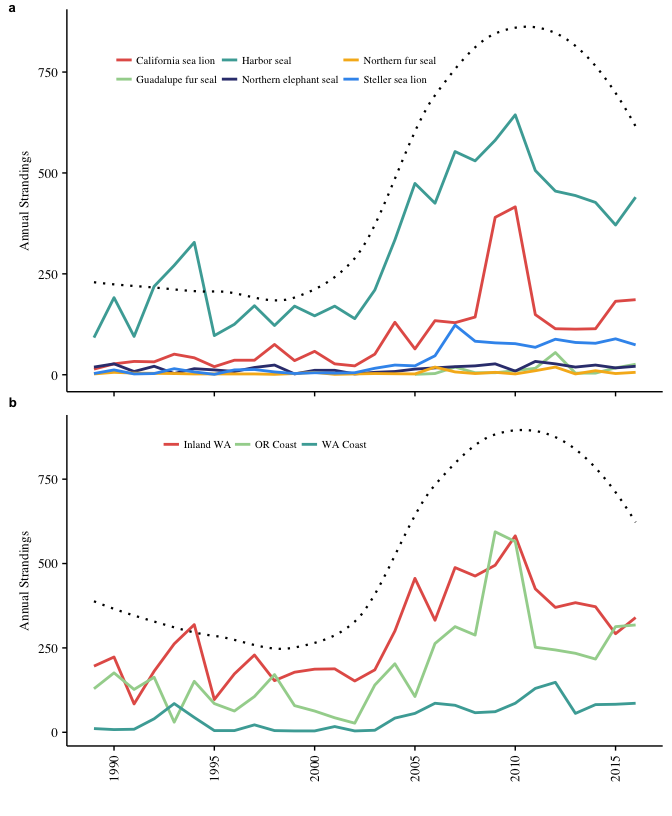


Figure 2: (a) Increasing total reported strandings across all species (*n* = 14,939) (black dotted loess regression line) and increasing for harbor seals (y = 1.057x, z = 6.2, *p* < 0.001), California sea lions (y = 1.098x, z = 7.7, *p* < 0.001), Steller sea lions (y = 1.143x, z = 8.3, *p* < 0.001), Guadalupe fur seals (y = 1.159x, z = 2.0, *p* < 0.05), and northern fur seals (y = 1.044x, z = 2.2, *p* < 0.05); (b) annual strandings increasing in Oregon (y = 1.052x, z = 3.78, *p* < 0.001), inland Washington waters (y = 1.040x, z = 4.95, *p* < 0.001), and, though in smaller numbers, along Washington coast (y = 1.074x, z = 3.62, *p* < 0.001).

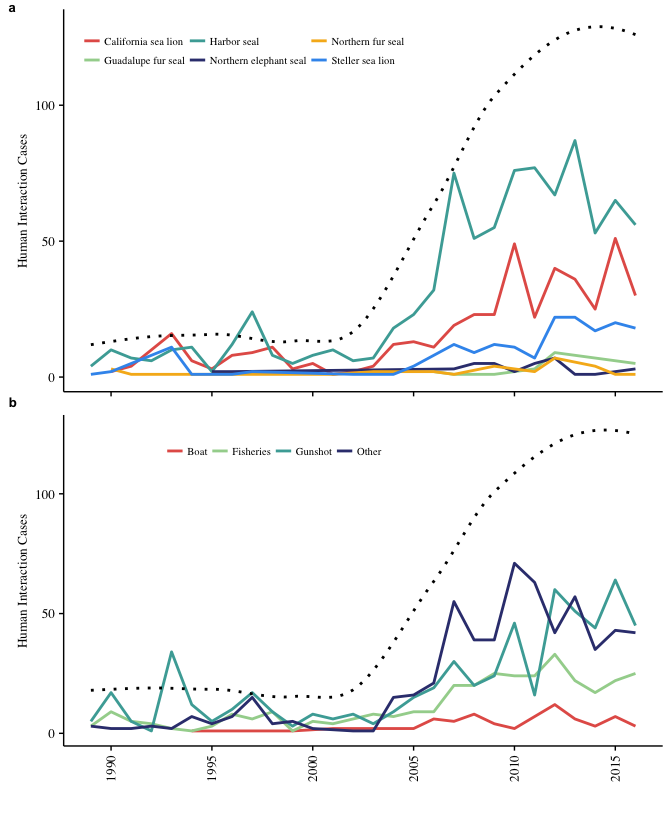


Figure 3: (a) Annual HI cases combined (black loess regression line) and for each species illustrate increasing cases for harbor seals (y = 1.114x, z = 8.7, *p* < 0.001), California sea lions (y = 1.099x, z = 6.3, *p* < 0.001), Steller sea lions (y = 1.095x, z = 5.3, *p* < 0.001), and Guadalupe fur seals (y = 1.173x, z = 2.1, *p* < 0.05) and (b) increasing number of gunshot wounds (y = 1.073x, z = 4.6, *p* < 0.001), fisheries entanglements (y = 1.090x, z = 8.3, *p* < 0.001), and boat injuries (y = 1.087x, z = 3.3, *p* < 0.01).

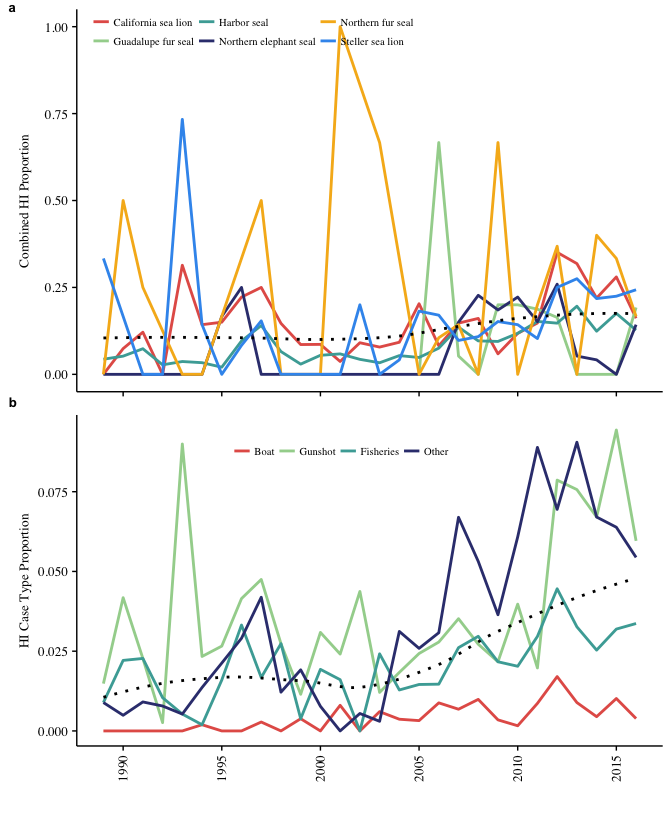


Figure 4: Prevalence of human interaction cases (a) significantly increasing for all combined species (black dotted regression line, y = 0.06x, z = 15.5, *p* < 0.001) and for harbor seals (y = 0.06x, z = 11.4, *p* < 0.001), California sea lions (y = 0.03x, z = 3.8, *p* < 0.001), and northern elephant seals (y = 0.09x, z = 3.5, *p* < 0.001); (b) increasing for all HI types combined (black dotted regression line, y = 0.06x, z = 15.5, *p* < 0.001) and for each HI case type: gunshot wounds (y = 0.039x, z = 6.4, *p* < 0.001), fisheries entanglements (y = 0.043x, z = 5.3, *p* < 0.001), and boat injuries (y = 0.087x, z = 4.2, *p* < 0.001).

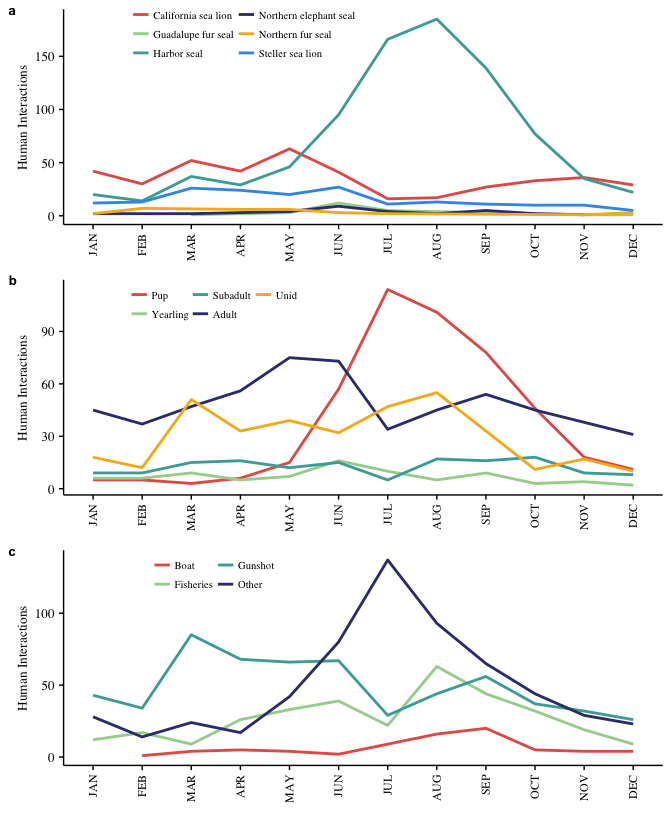


Figure 5: Sum of human interaction cases across years for each month according to (a) species, (b) age class, and (c) human interaction type.

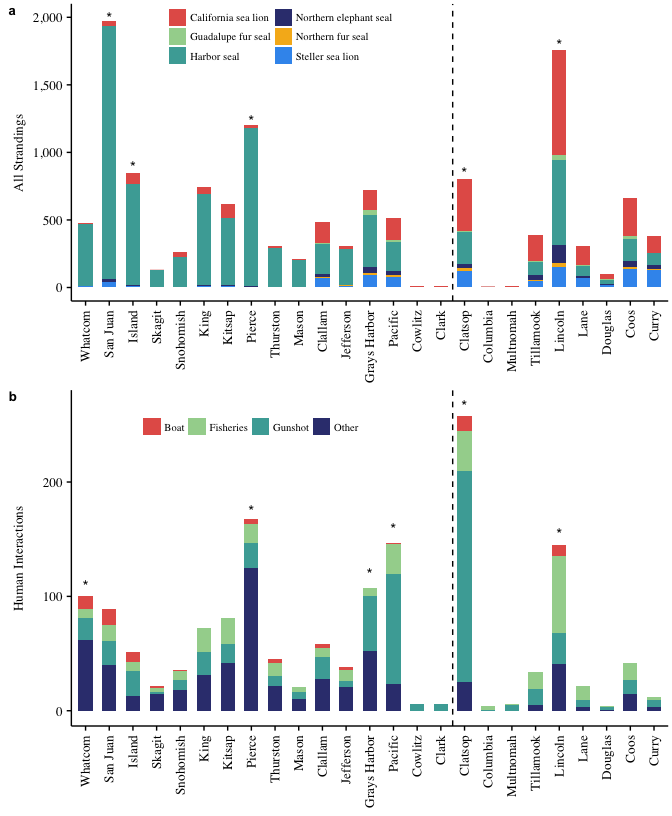


Figure 6: (a) Total strandings by species in Washington (left of dashed line) and Oregon (right of dashed line); and (b) total human interaction cases by type. Asterisks indicate counties where counts of total strandings or HI cases are significantly higher than the mean across all counties (*p* < 0.05).

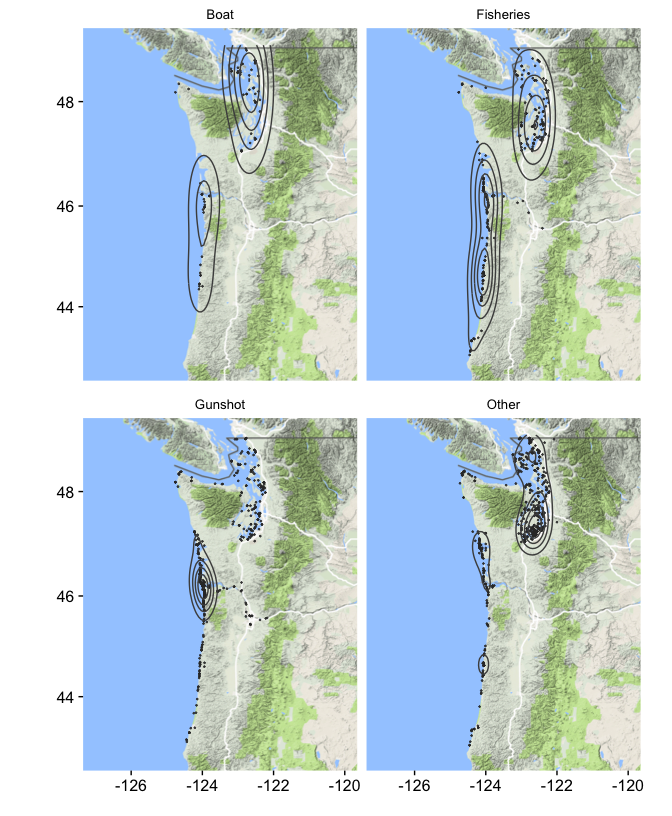


Figure 7: Strandings (grey points) and kernel density hotspot contour lines showing hotspots of human interaction cases, with fisheries and boat collisions distributed throughout inland Washington waters and at the mouth of the Columbia River, and a gunshot wound cluster centered at the mouth of the Columbia River.

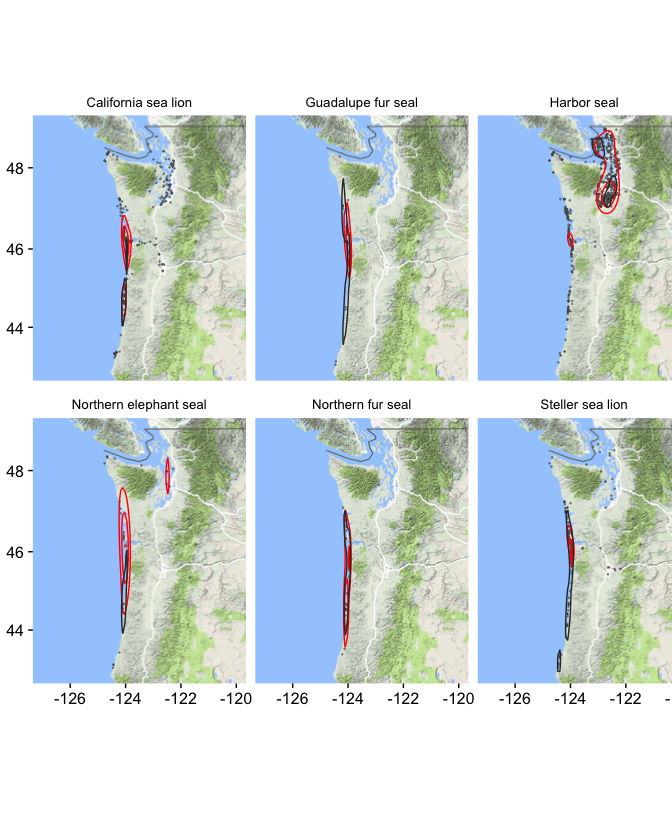


Figure 8: Strandings (grey points) and kernel density hotspot contour lines showing overlapping hotspots for all strandings (black) and human interaction cases (red) for all species, with hotspots occurring throughout inland Washington for harbor seals and along the outer coast near the mouth of the Columbia River for the other species.

Table 1: Sex and age composition of all strandings (*n* = 14,939), the prevalence of human interaction cases for each age class, and the composition of human interaction type for each age class.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Class | Total (n) | All Strandings (%) | OR Coast (%) | WA Coast (%) | WA Inland (%) | HI Proportion (%) | Fisheries Interactions (%) | Gunshots (%) | Boat Injuries (%) | Other (%) |
| Female | 2,570 | 17.2 | 22.8 | 10.6 | 66.6 | 16.2 | 18.3 | 32.4 | 5.4 | 43.8 |
| Male | 5,021 | 33.6 | 41.5 | 11.5 | 47.1 | 16.8 | 15.4 | 47.2 | 4.9 | 32.5 |
| Unid. Sex | 7,348 | 49.2 | 38.3 | 6.5 | 55.2 | 5.0 | 34.7 | 19.4 | 3.3 | 42.5 |
| Pup | 4,242 | 28.0 | 15.7 | 4.6 | 79.8 | 10.8 | 17.5 | 4.2 | 6.8 | 71.6 |
| Yearling | 998 | 7.0 | 58.6 | 11.5 | 29.9 | 8.2 | 38.8 | 21.2 | 5.0 | 35.0 |
| Subadult | 936 | 6.0 | 53.7 | 17.7 | 28.6 | 15.9 | 20.9 | 51.4 | 4.7 | 23.0 |
| Adult | 3,444 | 23.0 | 52.6 | 14.1 | 33.3 | 16.8 | 16.4 | 57.9 | 4.7 | 20.9 |
| Unid. Age | 5,319 | 36.0 | 36.1 | 6.9 | 57.0 | 6.7 | 26.7 | 40.9 | 2.0 | 30.4 |

Table 2: Age and sex composition and weighted averages of all strandings (*n* = 14,939) by species shows higher proportion of males and adults for California and Steller sea lions and a higher proportion of pups for harbor seals.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Total (n) | Male (%) | Female (%) | Unid. Sex (%) | Pup (%) | Yearling (%) | Subadult (%) | Adult (%) | Unid. Age (%) |
| California sea lion | 2823 | 77.4 | 1.0 | 21.6 | 0.2 | 9.0 | 14.7 | 53.1 | 23.0 |
| Guadalupe fur seal | 165 | 31.5 | 30.9 | 37.6 | 1.2 | 91.5 | 2.4 | 2.4 | 2.4 |
| Harbor seal | 8730 | 24.5 | 23.2 | 52.3 | 45.3 | 4.4 | 3.7 | 14.3 | 32.3 |
| Northern elephant seal | 445 | 34.8 | 13.3 | 51.9 | 19.8 | 18.0 | 11.9 | 5.6 | 44.7 |
| Northern fur seal | 122 | 23.8 | 39.3 | 36.9 | 25.4 | 31.1 | 8.2 | 4.9 | 30.3 |
| Steller sea lion | 1040 | 41.6 | 33.3 | 25.1 | 13.5 | 7.7 | 11.7 | 54.7 | 12.4 |
| Average | -- | 17.2 | 33.6 | 49.2 | 28.4 | 6.7 | 6.3 | 23.1 | 35.6 |

Table 3: Species composition of all strandings (*n* = 14,939), the prevalence of human interaction cases (HI/all cases) for each species, regional distribution, and the composition of human interaction type (number of specific type/all HI cases) for each species.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Species | Total (n) | All Strandings (%) | OR (%) | WA Coast (%) | WA Inland (%) | HI Proportion (%) | Fisheries (%) | Gunshot (%) | Boat (%) | Other (%) |
| California sea lion | 2823 | 18.9 | 69.2 | 11.1 | 19.7 | 15.2 | 18.3 | 58.5 | 3.5 | 19.7 |
| Guadalupe fur seal | 165 | 1.1 | 60.6 | 33.9 | 5.5 | 13.9 | 65.2 | 4.3 | 0.0 | 30.4 |
| Harbor seal | 8730 | 58.4 | 15.3 | 6.8 | 77.9 | 9.9 | 18.7 | 20.7 | 6.0 | 54.5 |
| Northern elephant seal | 445 | 3 | 66.3 | 16.3 | 17.4 | 8.1 | 11.1 | 33.3 | 11.1 | 44.4 |
| Northern fur seal | 122 | 0.8 | 60.7 | 24.6 | 14.8 | 24.6 | 75.0 | 3.6 | 0.0 | 21.4 |
| Steller sea lion | 1040 | 7 | 67.3 | 16.8 | 15.9 | 17.5 | 15.7 | 74.2 | 1.7 | 8.4 |
| Average | -- | -- | 36.7 | 8.9 | 54.4 | 10.9 | 20.5 | 37.1 | 4.7 | 37.7 |

**Supplemental Information**

Table 4: Proportion of all strandings, proportion of human interaction cases (%), and the composition of human interaction case types for each county in Washington (*n* = 9,413).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| County | All Strandings (%) | HI Proportion (%) | Fisheries (%) | Gunshot (%) | Boat (%) | Other (%) |
| Clallam | 6 | 6 | 14 | 33 | 5 | 48 |
| Clark | 0 | 1 | 0 | 100 | 0 | 0 |
| Cowlitz | 0 | 1 | 0 | 100 | 0 | 0 |
| Grays Harbor | 8 | 10 | 7 | 45 | 0 | 49 |
| Island | 9 | 5 | 16 | 43 | 16 | 25 |
| Jefferson | 4 | 4 | 26 | 13 | 5 | 55 |
| Jefferson County | 0 | 0 | 0 | 0 | 50 | 50 |
| King | 9 | 7 | 29 | 28 | 0 | 43 |
| Kitsap | 8 | 8 | 28 | 20 | 0 | 52 |
| Mason | 2 | 2 | 24 | 29 | 0 | 48 |
| Pacific | 6 | 14 | 18 | 66 | 1 | 16 |
| Pierce | 13 | 16 | 10 | 13 | 3 | 74 |
| San Juan | 21 | 8 | 16 | 24 | 16 | 45 |
| Skagit | 2 | 2 | 18 | 5 | 9 | 68 |
| Snohomish | 3 | 3 | 22 | 25 | 3 | 50 |
| Thurston | 3 | 4 | 27 | 18 | 7 | 49 |
| Whatcom | 5 | 10 | 8 | 19 | 11 | 62 |

Table 5: Proportion of all strandings (%), the proportion of human interaction cases (%) and the composition of human interaction case types for each county in Oregon (*n* = 5,435).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| County | All Strandings (%) | HI Proportion (%) | Fisheries (%) | Gunshot (%) | Boat (%) | Other (%) |
| Clackamas | 0 | 1 | 0 | 100 | 0 | 0 |
| Clatsop | 16 | 49 | 14 | 72 | 5 | 10 |
| Columbia | 0 | 1 | 75 | 25 | 0 | 0 |
| Coos | 13 | 8 | 36 | 29 | 0 | 36 |
| Curry | 8 | 2 | 25 | 50 | 0 | 25 |
| Douglas | 2 | 1 | 25 | 50 | 0 | 25 |
| Lane | 7 | 4 | 59 | 27 | 0 | 14 |
| Lincoln | 44 | 27 | 46 | 19 | 7 | 28 |
| Multnomah | 0 | 1 | 17 | 83 | 0 | 0 |
| Tillamook | 9 | 6 | 44 | 41 | 0 | 15 |

**References**

Aguirre A.A. & Tabor G.M. (2004). Marine vertebrates as sentinels of marine ecosystem health. EcoHealth. 1: 236–238.

Antonelis, G.A., J.D. Baker, T.C. Johanos, R.C. Braun, & A.L. Harting. (2006). Hawaiian monk seal (*Monachus schauinslandi*): status and conservation issues. Atoll Research Bulletin 543: 75–101.

Barbieri, M., Raverty, S., Hanson, M.B., Venn-Watson, S., Ford, J.K., & Gaydos, J.K. (2013). Spatial and temporal analysis of killer whale (*Orcinus orca*) strandings in the North Pacific Ocean and the benefits of a coordinated stranding response protocol. Marine Mammal Science 29.4: E448-E462.

Berini, C. R., Kracker, L. M. & McFee, W.E. (2015). Modeling pygmy sperm whale (*Kogia breviceps*, De Blainville 1838) strandings along the southeast coast of the United States from 1992 to 2006 in relation to environmental factors. NOAA Technical Memorandum NOS NCCOS 203. 44 pp.

Bogomolni, A., K.R. Pugliares, S.M. Sharp, K. Patchett, C.T. Harry, J.M. LaRocque, K.M. Touhey, & M. Moore. (2010). Mortality trends of stranded marine mammals on Cape Cod and southeastern Massachusetts, USA, 2000 to 2006. Diseases of Aquatic Organisms 88: 143-155.

Bossart, G.D. (2006). Marine mammals as sentinels species for oceans and human health. Oceanography 19(2): 134-37.

Bossart, G.D. (2011). Marine mammals as sentinel species for oceans and human health. Veterinary Pathology 48(3): 676-90.

Brabyn, M. W. & McLean, I. G. (1992). Oceanography and coastal topography of herd stranding sites for whales in New Zealand. Journal of Mammalogy 73: 469–76.

Carretta, J.V., Oleson, E.M., Baker, J., Weller, D.W., Lang, A.R., & others. (2016). U.S. Pacific marine mammal stock assessments: 2015. NOAA-TM-NMFS-SWFSC-561. Washington, DC. National Oceanic and Atmospheric Administration.

Cleveland, W.S. & Devlin, S.J. (1988). Locally weighted regression: an approach to regression analysis by local fitting. Journal of American Statistical Society 83, 596–610.

Colegrove, K.M., Greig, D.J., & F.M.D. Gulland. (2005). Causes of live strandings of northern elephant seals and Pacific harbor seals along the central California coast, 1992-2001. Aquatic Mammals 31(1): 1-10.

DeLong, R.L., Gearin, P.J., Bengston, J.L., Dawson, P. & Feldkamp, S.D. (1990). Studies of the effects of entanglement on individual northern fur seals. In: R.S. Shomura and M.L. Godfrey (eds.), Proceedings of the Second International Conference on Marine Debris, 2–7 April, 1989, Honolulu, Hawaii. NOAA Technical Memorandum NMFS SWFSC 154. pp. 492–493.

DeMaster, D. (2014). Results of Steller sea lion surveys in Alaska, June-July 2013. Memorandum to J. Balsiger, J. Kurland, B. Gerke, and L. Rotterman, NMFS Alaska Regional Office, Juneau AK. Alaska Fisheries Science Center, NMFS, 7600 Sand Point Way NE, Seattle, WA 98115.

Esperon-Rodriguez, M. & Gallo-Reynoso, J.P. (2012). The re-colonization of the Archipelago of San Benito, Baja California, by the Guadalupe fur seal. Revista Mexicana de Biodiversidad 83:170-176.

Evans, K., Thresher, R., Warneke, R., Bradshaw, C.J.A., Pook, M., Thiele, D., & Hindell, M.A. (2005). Periodic variability in cetacean strandings: links to large-scale climate events. Biology Letters 1(2): 147-150.

Figueroa-Carranza, A.L. (1994). Early lactation and attendance behavior of the Guadalupe fur seal females (*Arctocephalus townsendi*). M. Sc. Thesis. University of California, Santa Cruz.

Fowler, C.W. (1987). Marine debris and northern fur seals: a case study. Marine Pollution Bulletin 18: 326–335.

Frungillo, J. & Read, A. (2014). An analysis of gray and harbor seal strandings in Cape Cod, MA from 1999 to 2012. Master’s thesis project, Nicholas School of the Environment of Duke University, NC.

Gatrell A.C., Bailey, T.C., Diggle, P. & Rowlingson, B.S. (1996). Spatial Point Pattern Analysis and its Application in Geographical Epidemiology, Transactions of the Institute of British Geography 2: 256- 274.

Gelatt, T., R. Ream, & Johnson, D. (2015). Callorhinus ursinus. The IUCN Red List of Threatened Species 2015:e.T3590A45224953. Available at: <http://www.iucnredlist.org/details/3590/0>

Goldstein, T., Johnson, S.P., Phillips, A.V., Hanni, K.D., Fauquier, D.A. & Gulland, F.M.D. (1999). Human-related injuries observed in live stranded pinnipeds along the central California coast 1986–1998. Aquatic Mammals 25: 43–51.

Greig, D. J., Gulland, F. M. D., & Kreuder, C. (2005). A decade of live California sea lion (*Zalophus californianus*) strandings along the central California coast: Causes and trends, 1991-2000. Aquatic Mammals 31(1): 11-22.

Gulland, F.M.D., & Hall, A.J. (2007). Is marine mammal health deteriorating? Trends in the global reporting of marine mammal disease. EcoHealth 4(2): 135-150.

Hanni, K.D., Long, D.J., Jones, R.E., Pyle, P., & L.E. Morgan. (1997). Sightings and strandings of Guadalupe fur seals in central and northern California, 1988-1995. Journal of Mammalogy 78(2): 684-690.

Hanni, K.D., & P. Pyle. (2000). Entanglement of pinnipeds in synthetic materials at south-east Farallon Island, California, 1976–1998. Marine Pollution Bulletin 40: 1076–1081.

Harris, D.E. & S. Gupta. (2006). GIS-based Analysis of Ice-breeding Seal Strandings in the Gulf of Maine. Northeastern Naturalist 13(3): 403-420.

Huber, H.R., B.R. Dickerson, S.J. Jeffries, & D.M. Lambourn. (2012). Genetic analysis of Washington State harbor seals (*Phoca vitulina richardii*) using microsatellites. Canadian Journal of Zoology 90(12): 1361-1369.

Huggins, J.L., Leahy, C.L., Calambokidis, J., Lambourn, D., Jeffries, S.J. & others. (2013). Causes and patterns of harbor seal (*Phoca vitulina*) pup mortality at Smith Island, Washington, 2004-2010. Northwestern Naturalist 94(3): 198-208.

Huggins, J. L., Raverty, S. A., Norman, S. A., Calambokidis, J., Gaydos, J. K., Duffield, D. A., & ... Barre, L. (2015a). Increased harbor porpoise mortality in the Pacific Northwest, USA: understanding when higher levels may be normal. Diseases of Aquatic Organisms, 115(2), 93-102.

Huggins, J.L, Oliver, J., Lambourn, D.M., Calambokidis, J., Diehl, B. & S. Jeffries. (2015b). Dedicated beach surveys along the central Washington coast reveal a high proportion of unreported marine mammal strandings. Marine Mammal Science 31(2): 782-789.

Jeffries, S.J., P.J. Gearin, H.R. Huber, D.L. Saul, & D.A. Pruett. (2000). Atlas of Seal and Sea Lion haul-out Sites in Washington. Washington Department of Fish and Wildlife, Wildlife Science Division, 600 Capitol Way North, Olympia WA. pp. 150.

Jeffries, S. J., Huber, H. R., Calambokidis, J. & Laake, J. (2003). Trends and status of harbor seals in Washington State: 1978–1999. Journal of Wildlife Management 67:207–218.

Johnston, D.W., Frungillo, J., Smith, A., Moore, K., Sharp, B., Schuh, J. & Read, A. (2015). Trends in stranding and bycatch rates of gray and harbor seals along the Northeastern coast of the U.S.: evidence of divergence in the abundance of two sympatric phocid species? PLoS ONE 10(7): e0131660.

Kaplan Dau, B., Gilardi, K.V.K., Gulland, F.M., Higgins, A., Holcomb, J.B., St. Leger, J., & Ziccardi, M.H. (2009). Fishing gear-related injury in California marine wildlife. Journal of Wildlife Diseases 45(2): 355-362.

Keledjian, A.J., & Mesnick, S. (2013). The Impacts of El Niño Conditions on California. Sea Lion Fisheries Interactions: Predicting Spatial and Temporal Hotspots Along the California Coast. Aquatic Mammals 39(3), 221-232.

Kiyota, M. & Baba, N. (2001). Entanglement in marine debris among adult female northern fur seals at St. Paul Island, Alaska in 1991–1999. Bulletin of the National Research Institute of Far Seas Fisheries 38: 13-20.

Kreuder, C., Miller, M.A., Jessup, D.A., Lowenstine, L.J., Harris, M.D., Ames, J.A., Carpenter, T.E., Conrad, P.A., & Mazet, J.A. (2003). Patterns of mortality in southern sea otters (*Enhydra lutras nereis*) from 1998–2001. Journal of Wildlife Diseases 39:495–509.

Kulldorff, M., & Nagarwalla, N. (1995). Spatial disease clusters: Detection and inference. Statistical Methods 14:799–810.

Kulldorff, M. (2001). Prospective time periodic geographical disease surveillance using a scan statistic. Journal of Royal Statistical Society 164(1): 61-72.

Kulldorff, M., Heffernan, R., Hartman, J., Assuncao, R., & Mostashari, F. (2005). A space-time permutation scan statistic for disease outbreak detection. PLoS Med 2(3): e59.

Lambourn, D.M., Garner, M., Ewalt, D., Raverty, S., Sidor, I., Jeffries, S. Rhyan, J., & Gaydos, J.K. (2013). *Brucella pinnipedialis* infections in Pacific harbor seals from Washington State, USA. Journal of Wildlife Disease 49(4): 802-815.

Lambourn, D., D’Agnese, E., Jeffries, S., Wilkinson, K., Huggins, J., Rice, J., Duffield, D., Smith, W., Grigg, M., Raverty, S. (2015). Return of the Guadalupe fur seal to the Pacific Northwest: Stranding and sightings. 21st Biennial Conference on the Biology of Marine Mammals. Dec. 13-18. San Francisco, CA.

Leeney, R.H., Amies, R., Broderick, A.C., Witt, M.J., Loveridge, J., Doyle, J., & Godley, B.J. (2008). Spatio-temporal analysis of cetacean strandings and bycatch in a UK fisheries hotspot. Biodiversity and Conservation 17: 2323.

Le Boeuf, B.J., Crocker, D.E., Costa, D.P., Blackwell, S.B., Webb, P.M., & D.S. Houser. (2000). Foraging ecology of northern elephant seals. Ecological monographs 70(3): 353-382.

Lea, M.A., Johnson, D., Ream, R., Sterling, J., Melin, S., & Gelatt, T. (2009). Extreme weather events influence dispersal of naïve northern fur seals. Biology Letters 5: 252–257.

Lee, K. (2016). Stranding mortality patterns in California sea lions and Steller sea lions in Oregon and southern Washington, 2006 to 2014. Dissertations and Theses. Paper 2995. Portland State University.

London, J.M., Ver Hoef, J.M., Jeffries, S.J., Lance, M.M., & Boveng, P.L. (2012). Haul-out behavior of harbor seals (*Phoca vitulina*) in Hood Canal, Washington. PLoS ONE 7(6): e38180.

Lowry, M.S. & Forney, K.A. (2005). Abundance and distribution of California sea lions (*Zalophus californianus*) in central and northern California during 1998 and summer 1999. Fishery Bulletin 103:331-343.

Lowry, M.S., R. Condit, B.Hatfield, S.G. Allen, R. Berger, P.A. Morris, B.J. Le Boeuf, & Reiter, J. (2014). Abundance, Distribution, and Population Growth of the Northern Elephant Seal (*Mirounga angustirostris*) in the United States from 1991 to 2010. Aquatic Mammals 40(1): 20-31.

Maldini, D., Mazzuca, L., & Atkinson, S. (2005). Odontocete stranding patterns in the main Hawaiian Islands (1937–2002): how do they compare with live animal surveys? Pacific Science 59, 55–67.

Maniscalco, J.M., Wynne, K., Pitcher, K.W., Hanson, M.B., Melin, S.R., & Atkinson, S. (2004). The occurrence of California sea lions (*Zalophus californianus*) in Alaska. Aquatic Mammals 30(3): 427-433.

Melin, S.R., DeLong, R.L., & Thomason, J.R. (2000). Attendance patterns of California sea lion (*Zalophus californianus*) females and pups during the non-breeding season at San Miguel Island. Marine Mammal Science 16(1): 169-185.

Melin, S. R., DeLong, R. L., & Siniff, D. (2008). The effects of El Niño on the foraging behavior of lactating California sea lions (*Zalophus californianus*) during the non-breeding season. Canadian Journal of Zoology 86: 192-206.

Melin, S.R., Orr, A.J., Harris, J.D., Laake, J.L., & DeLong, R.L. (2010). Unprecedented mortality of California sea lion pups associated with anomalous oceanographic conditions along the central California coast in 2009. California Cooperative Oceanic Fisheries Investigations Report 51: 182-194.

Moore S.E. (2008). Marine mammals as ecosystem sentinels. Journal of Mammalogy 89(3): 534–540.

Moore, S.E., Lyday, S., Roletto, J., Litle, K., Parrish, J.K., Nevins, H., ... Kell, S. (2009). Entanglements of marine mammals and seabirds in central California and the north-west coast of the United States 2001-2005. Marine Pollution Bulletin. 58: 1045-1051.National Marine Fisheries Service. 2008. Recovery Plan for the Steller Sea Lion (*Eumetopias jubatus*). Revision. National Marine Fisheries Service, Silver Spring, MD. 325 pp.

National Marine Fisheries Service. (2013). Status Review of The Eastern Distinct Population Segment of Steller Sea Lion (Eumetopias jubatus). 144pp. Protected Resources Division, Alaska Region, National Marine Fisheries Service, 709 West 9th St, Juneau, Alaska 99802.

National Oceanic and Atmospheric Administration. (2016). Annual summary of ocean ecosystem indicators for 2016 and pre-season outlook for 2017. NOAA Northwest Fisheries Science Center, <https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/b-latest-updates.cfm> accessed 2/1/2017.

Norman, S.A., Bowlby, C.E., Brancato, M.S., Calambokidis, J., Duffield, D., Gearin, P.J., Gornall, T.A.... & Scordino, J. (2004). Cetacean strandings in Oregon and Washington between 1930 and 2002. Journal of Cetacean Research and Management 6:87–99.

Norman, S.A., Huggins, J., Carpenter, T.E., Case, J.T., Lambourn, D.M., Rice, J., Calambokidis, J.... & Klope, M. (2011). The application of GIS and spatio-temporal analyses to investigations of unusual marine mammal strandings and mortality events. Marine mammal science 28(3): E251-E266.

Orr, A.J., Melin, S.R., Harris, J.D., & R.L. DeLong. (2012). Status of the northern fur seal population at San Miguel Island, California during 2010 and 2011. Pp. 41-58, In: Testa, J. W. (ed.), Fur seal investigations, 2010-2011. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-241. 77 pp.

Osinga, N., Shahi Ferdous, M.M., Morick, D., Garcia Hartmann, M., Ulloa, J.A., Vedder, L.... & Kuiken, T. (2012). Patterns of Stranding and Mortality in Common Seals (*Phoca vitulina*) and Grey Seals (*Halichoerus grypus*) in The Netherlands between 1979 and 2008. Journal of Comparative Pathology 147(4): 1-16.

Peltier H., Baagøe H.J., Camphuysen K.C.J., Czeck R., Dabin W., Daniel P., Deaville, R… & Ridoux, V. (2013). The Stranding Anomaly as Population Indicator: The Case of Harbour Porpoise (*Phocoena phocoena*) in North-Western Europe. PLoS ONE 8(4): e62180.

Pikesley, S.K., Witt, M.J., Hardy, T., Loveridge, J., Loveridge, J., Williams, R., & Godley, B.J. (2011). Cetacean sightings and strandings: evidence for spatial and temporal trends? Journal of the Marine Biological Association of the United Kingdom: 1-12.

Prado, J.H.F, Mattos, P.H., Silva, K.G, & Secchi, E.R. (2016). Long-term seasonal and interannual patterns of marine mammal strandings in subtropical Western South Atlantic. PLoS One 11(1): e0146339.

Pyenson, N.D. (2010). Carcasses on the coastline: measuring the ecological fidelity of the cetacean stranding record in the eastern North Pacific Ocean. Paleobiology 36: 453–480.

Ross, P.S. (2000). Marine mammals as sentinels in ecological risk assessment. Human and Ecological Risk Assessment 6(1): 29–46.

Soulen, B.K., Cammen, K., Schultz, T.F., Johnston, D.W. (2013). Factors Affecting Harp Seal (*Pagophilus groenlandicus*) Strandings in the Northwest Atlantic. Plos One 8(7): e68779.

Stewart, B.S., & Yochem, P.K. (1987). Entanglement of pinnipeds in synthetic debris and fishing net and line fragments at San Nicolas and San Miguel islands, California, 1978-1986. Marine Pollution Bulletin 18: 336-339.

Stroud, R.K., & Roffe, T.J. (1997). Causes of death in marine mammals stranded along the Oregon coast. Journal of Wildlife Diseases 15(1): 91-97.

Thomas, A.C., Lance, M.M, Jeffries, S.J., Miner, B.G., & Acevedo-Gutiérrez, A. (2011). Harbor seal foraging response to a seasonal resource pulse, spawning Pacific herring. Marine Ecology Progress Series 441:225–239.

Wilkinson, D. & G. Worthy. (1999). In: Conservation and Management of Marine Mammals (Twiss, J. R. and R.R. Reeves, eds.). Smithsonian Institute Press, Washington, pp. 396-411.

Woodhouse, C.D. (1991). Marine mammal beachings as indicators of population events. Marine mammal strandings in the United States: proceedings of the second marine mammal stranding workshop. US Dep Commerc., NOAA Technical Report. NMFS 98:111-115. 157pp.

1. See <http://www.nmfs.noaa.gov/pr/health/prescott/> for more information. [↑](#footnote-ref-22)