



Stranding trends of Steller sea lions *Eumetopias jubatus* 1990–2015

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ABSTRACT: Distinct population segments of Steller sea lion (SSL) *Eumetopias jubatus* have experienced different population trends over the last 5 decades, rendering the need for retrospective study. By identifying long-term stranding trends of SSLs we can develop a better understanding of factors contributing to mortality that may affect SSL population dynamics. We characterized spatial and temporal trends of SSL strandings (n = 1507) in Alaska, Oregon, and Washington, USA, over a 25 yr period. Stranding reports were obtained from the Alaska and Northwest Region's Marine Mammal Stranding Networks. Temporal trends were assessed by identifying seasonal patterns across all years (1990–2015), analyzing sex, age class, body length, and characterizing signs of human interaction including factors contributing to mortality. An apparent increase in strandings occurred after 2000, likely due to increased stranding response effort resulting from increased federal grant awards. Adult males were the most frequently stranded sex and age class in the Alaska (AK) and Northwest (NW) Regions. Clear seasonality trends were evident, with the greatest reported stranding occurrences during the spring and summer. Gunshot wounds and fishery interactions accounted for a large proportion (90%) of human interaction cases. In Alaska, the southeast region had the highest number of strandings. In the NW Region, Oregon had the highest documented strandings. Despite caveats associated with stranding data, our findings suggest rapid timing of continued stranding response is imperative for a better understanding of cause-specific mortality trends and other factors contributing to stranding events.

KEY WORDS: Steller sea lions · *Eumetopias jubatus* · Strandings · Mortality trends · Alaska Region · Northwest Region

1. INTRODUCTION

Steller sea lions (SSLs) *Eumetopias jubatus* inhabit areas along the North Pacific rim from California, USA, to Japan, with about 70% of the population dwelling in Alaskan waters (National Research Council 2003). The eastern and western SSL stocks are federally recognized as being separated at Cape Suckling, 144°W longitude (see Fig. 1) (Allen & Angliss 2013). Many studies conducted after the well-known decline that began in the 1960s resulted in the listing of the western SSL stock as endangered and the eastern SSL stock as threatened under the

US Endangered Species Act (Loughlin & York 2000, Miller et al. 2005, Atkinson et al. 2008). Despite numerous proposed hypotheses, researchers have yet to determine a sole cause that led to the decline (National Research Council 2003, Hennen 2006, Atkinson et al. 2008). Disease, malnutrition, predation, climate change, entanglement in marine debris, and other factors may have contributed; however, there are limitations on assessing the myriad of possibilities affecting SSL populations (Loughlin 1998, Trites & Donnelly 2003, Burek et al. 2005, Atkinson et al. 2008). The divergent population trajectories of the eastern and western SSL stocks, including lack of a

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robust recovery of the western SSL stock and more recently recovered and delisted eastern SSL stock, demonstrate the need for further analyses of multiple factors driving SSL population dynamics over large spatial and temporal scales.

We used SSL stranding data collected from 1990–2015 to better understand trends in the spatial and temporal distribution of strandings across coastal Alaska, Washington, and Oregon. A stranding refers to an individual or group of animals found on a shore that are unable to return to their natural habitat or that are observed dead on shore (Geraci & Lounsbury 2005). Stranding data may be utilized to complement annual census surveys, by providing seasonal information on population distribution (Maldini et al. 2005) and potential issues occurring in nearshore environments, as the bulk of these strandings occur close to shore (Flint et al. 2015). Therefore, the present study contributes to our understanding of unknown SSL mortality trends and may give rise to conservation concerns associated with anthropogenic interactions or specific locations (Bossart 2011).

The National Marine Fisheries Service (NMFS) provides oversight of marine mammal stranding activities facilitated by the National Marine Mammal Stranding Network, which appoints stranding coordinators in 5 regions within the United States to assist with coordination of reporting stranded animals and identification of mass mortalities or strandings caused by disease, toxins, or other problems (NOAA 2019). Reporting of marine mammal strandings requires all members of stranding networks to collect Level A data, which includes animal ID, location of stranding, condition at examination, demographic information such as age class and sex, standard length, information on the purpose of samples collected, reasons for the stranding response, and details associated with the stranding event (NOAA 2017). Despite study constraints due to limited detail of pathological and histological data, Level A reports do provide the information needed to detect basic information on life history, biology, and general health of a population (NOAA 2017). An additional human interaction form is encouraged to be completed, but only required for marine mammal species listed as endangered/threatened species, and large toothed whales, baleen whales and all cetaceans that strand as alive, fresh dead or in a state of moderate decomposition (NOAA 2017). Cause of stranding or death cannot always be determined from this information alone.

The present study aimed to reveal the occurrence and overall distribution of SSL stranding incidents over a broad geographic range by compiling and synthesizing SSL stranding data collected between 1990 and 2015 from Alaska, Washington, and Oregon. These data were obtained from the Alaska (AK) Region and the Northwest (NW) Region National Marine Mammal Stranding Networks and the Alaska Department of Fish & Game. The main objectives of this study were to (1) map spatial trends in SSL strandings to aid in identifying geographic areas that may need improved stranding surveillance systems due to their lack of representation in the stranding reports, or detect high frequency stranding occurrences and locations; (2) identify annual and seasonal trends across a 25 yr period for both geographic regions; and (3) identify signs of human interaction in strandings across the AK and NW Regions, some of which may be categorized as contributing factors to SSL stranding mortalities.

These objectives may aid in refining our current understanding of potential impediments to the recovery of the western SSL stock. The robust period encompassed in these reports enables a thorough characterization of trends in SSL strandings, as typified in other stranding studies (MacLeod et al. 2004, Maldini et al. 2005).

2. MATERIALS AND METHODS

2.1. Animals and study area

Level A stranding data for SSLs ($n = 1507$) from 1990–2015 were obtained from the AK Region ($n = 544$) and NW Region ($n = 963$) Marine Mammal Stranding Networks. Data included date and location of stranding, standard length (tip of snout to tip of tail, measured in cm; Geraci & Lounsbury 2005), sex, age class, and details on signs of human interaction. The date of reported strandings was used as a proxy for time of death (Flint et al. 2015), and seasons were defined as summer (June–August), fall (September–November), winter (December–February), and spring (March–May) for summarizing trends. If coordinates were not provided, the centroid of the town closest to the stranding was used. Strandings occurred from as far northwest as St. Paul Island, Alaska (57.1867°N , 170.2575°W), to as far south as Medford, Oregon (42.3265°N , 122.8756°W), encompassing both eastern and western SSL stocks. We compared data obtained from the AK Region, which included strandings from both stocks, with data from the NW Region, which only contained strandings

from the eastern SSL stock. However, it should be recognized that the location of a stranding does not necessarily reflect its stock of origin. Age class ($n = 1120$), sex ($n = 955$), and standard length ($n = 969$) were documented for the majority of strandings, but decomposition of some carcasses prevented us from obtaining these data for all strandings. The AK Region data contained fetal cases solely as a result of more specific stranding reports submitted by the Alaska Department of Fish & Game. The basic detailed Level A information was the only information included in this data set from fetal cases. Fetal cases were not routinely identified as a category in Level A reports, which is why this category was excluded in the NW Region. One case was excluded from the NW Region stranding records because it occurred outside of US boundaries (i.e. British Columbia, Canada). Age class was subdivided into 5 categories in each region, including fetuses, pups, sub-adults, adults, and unknown in the AK Region; and pups, yearlings, sub-adults, adults, and unknown in the NW Region. Age class in the NW Region was defined using the NMFS examiners guide (NOAA 2017, p. 17): 'Pup: Animal is smaller than yearling size, or estimated to be younger than one year old. Yearling: Animal is judged to be approximately between one and two years old. Sub-adult: Animal is judged to be greater than two years old, but not yet mature. Adult: Animal is judged to be an adult; or found upon necropsy to be sexually mature. Unknown: Unable to determine the age class.'

Because stranding reports are only an index of a sighting/event, it would be less accurate to specify an age class as yearling, and therefore any cases that may have been yearlings were identified as sub-adults in the AK Region (K. Savage pers. comm.). Sex was categorized as female, male, or unknown by observing external genitalia.

Carcass condition upon examination was defined using the NMFS examiner's guide (NOAA 2017): Alive: The animal was found alive at initial observation. Fresh Dead: The animal was in good condition with normal appearance, but may have had some evidence of scavenger damage. Moderate Decomposition: The carcass was in fair condition and most organs were intact. Advanced Decomposition: The carcass was in poor condition with a strong odor, skin sloughing, severe scavenger damage and liquefied muscles. Mummified: The only remains were skeletal and the remaining tissues were desiccated. Condition Unknown: The stranded animal was found dead upon initial observation but additional information on the condition of the carcass was unavailable,

or it was unknown whether the animal was found alive or dead upon initial observation.

2.2. Data analysis

Age class used for analyses included pups, sub-adults, and adults. Yearling data were excluded because they were not available for the AK Region. All statistical analyses were conducted with R v.3.4.0 (R Core Team 2018). The 1-sample proportion z-test with continuity correction was used to determine if there was a significant difference between proportions of male and female strandings across both regions. Pearson's chi-squared test with Yate's continuity correction was used to determine significant differences in the proportion of carcasses between regions that were of unknown age class or unknown sex, and the differences in the proportion of strandings that occurred in the spring/summer and fall/winter between seasons.

2.3. Spatial and temporal analysis

A geographic information system (ArcGIS v.10.2.1; ESRI) was used to map all strandings. An adjusted scale and corresponding markers were used to document strandings using the best available information on location of stranding occurrence. As strandings are often reported based on a general location, if geographic coordinates were not available, the closest township was used. Strandings were grouped where the occurrence of 10 or more strandings were located in a given area, which was usually associated with a town or human population center. Temporal trends were illustrated in a line chart using the annual number of strandings per year. Box plots were used to examine seasonal trends in each region (R Core Team 2018). Five generalized linear models (GLMs) were used to determine if the probability of a stranding occurrence in the spring/summer versus fall/winter differed based on all combinations of 2 categorical covariates: age class (pups, sub-adults, and adults) and region (AK and NW Region). There was no control for the group of covariates because the study was purely observational. For the binary logistic regression model, season was represented by 0 for fall/winter months (September–February) and 1 for spring/summer months (March–August). Five GLMs were constructed to represent all subsets of age class and season. Akaike's information criterion (AIC) was used for model selection.

2.4. Signs of human interaction and contributing factors to SSL mortality

Signs of human interaction were categorized for all cases and placed into the following 2 categories: yes or no. Cases where sign of human interaction could not be determined were categorized appropriately as ‘CBD’. Human interactions do not imply cause of stranding or death; however, certain signs of human interactions were considered contributing factors to mortality, including boat collisions, gunshot wounds, fishery interactions, and other human interactions (i.e. ingested plastic, debris entanglement, wounds from other weapons, non-boat vessel related injuries, mutilation, etc; NOAA 2017). The data synthesized in this study provided very little information on other details of human interaction.

2.5. Stranding effort

The present study attempted to normalize the stranding data by accounting for effort following the distribution of the John H. Prescott Marine Mammal Rescue Assistance Grant Program in 2001. An over dispersed Poisson regression model was used to compare the number of stranding reports before and after the Prescott grant was awarded. Furthermore, Prescott grant recipients changed following 2010, and similar data from 2011–2015 were unable to be obtained for the purpose of this study. Although not all stranding data effort was accounted for in this study, quantification of effort did provide some explanation for observed temporal trends.

3. RESULTS

The proportion of male strandings in both regions was significantly greater than female strandings ($p < 0.0001$; Table 1). A greater percentage of carcasses defined as unknown sex (56%, $n = 307$) were collected from the AK Region than in the NW Region, in which 25% ($n = 245$) of cases were defined as unknown sex ($\chi^2 = 142.52$, $df = 1$, $p < 0.0001$; Table 1). Of the carcasses identified as unknown sex in the AK Region, 40% were in a state of moderate or advanced decomposition upon initial sighting, which contributed to the difficulty in identifying the sex of the stranded animal.

For cases where age class was determined, adults were the highest reported stranding age class in both the AK (32%) and NW (54%) Regions. The AK

Table 1. Percentages and sample size of each sex from stranded Steller sea lions in Alaska (AK) and Northwest (NW) Regions (1990–2015). (*) Significant difference from females in each region ($p < 0.0001$)

Sex	AK stranding incidents (%)	NW stranding incidents (%)
Unknown	56.4 (n = 307)	25.4 (n = 245)
Female	11.2 (n = 61)	33.7 (n = 326)
Male	32.4 (n = 176)*	40.7 (n = 392)*
Total no. stranded	544	963

Region had a higher percentage of unknown age classes at 49% ($n = 265$) in comparison to the NW Region with 13% ($n = 122$, $\chi^2 = 191.79$, $df = 1$, $p < 0.0001$; Table 2). Due to inconsistency in age classes identified between the regions, as well as varying sample sizes, a robust comparison of standard length across each age class was not possible. There was great variation across all age classes, with exception of the fetal age class (Table 2).

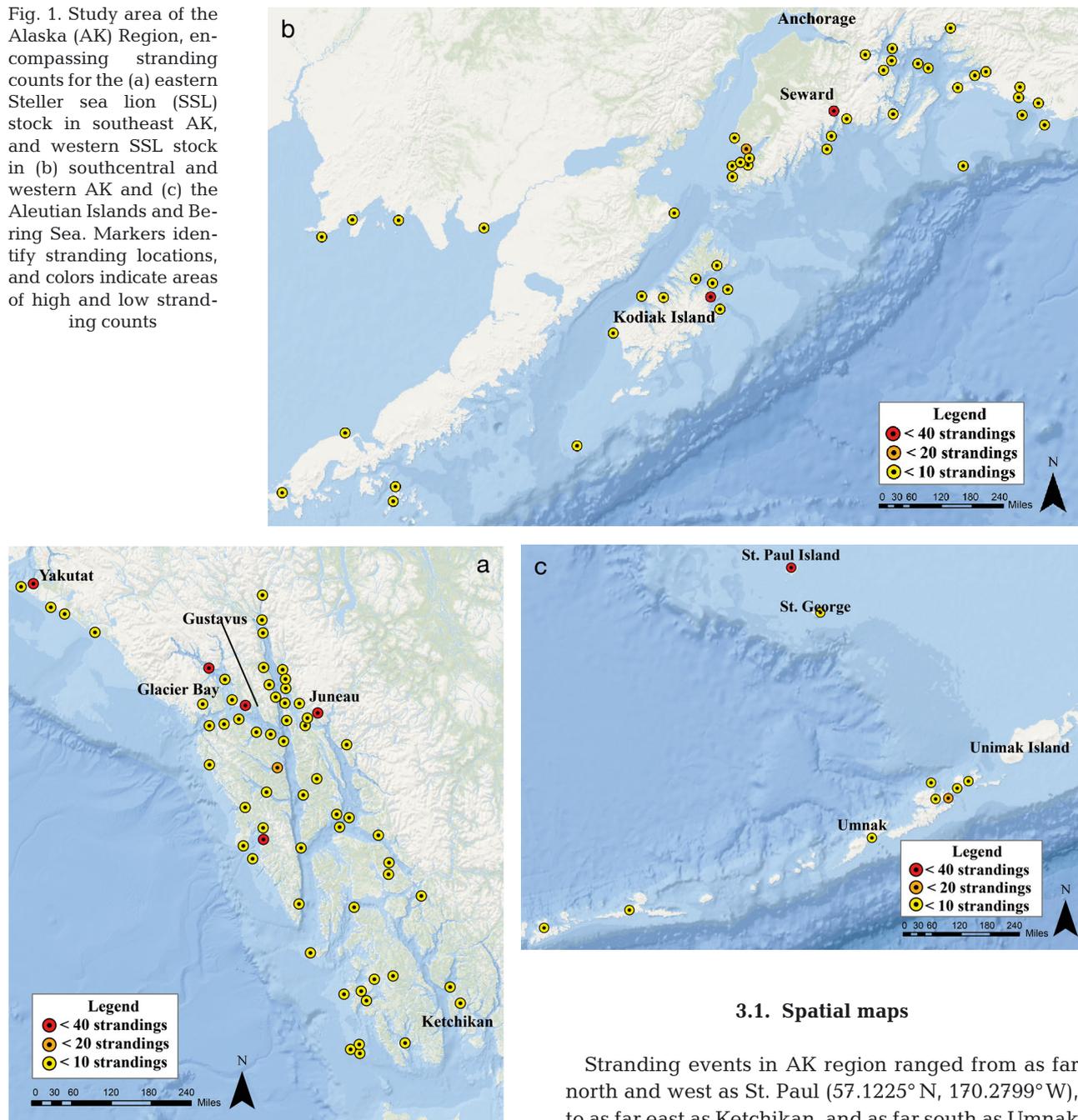
Table 2. Number of Steller sea lion strandings in each age class and their mean (\pm SD) standard lengths occurring in the Alaska (AK) and Northwest (NW) Regions. Note that the age classes are defined slightly differently in each region, explaining the missing cells. NA: not applicable

Age class	AK		NW	
	Stranding incidents	Standard length (cm)	Stranding incidents	Standard length (cm)
Fetus	4	78 \pm 0.0		
Pup	25	89.4 \pm 24.6	66	127.9 \pm 19.1
Yearling			136	100.6 \pm 17.3
Sub-adult	76	187.0 \pm 46.0	120	191.2 \pm 41.8
Adult	174	265.3 \pm 53.7	519	241.7 \pm 51.3
Unknown	265	NA	122	NA
Total	544	NA	963	NA

Table 3. Percentages and sample size of Steller sea lion (SSL) carcass condition at examination in the Alaska (AK) and the Northwest (NW) Regions. The percentage of stranding incidents to categorize carcass condition was based on observation at the time of stranding

Initial condition	AK stranding incidents (%)	NW stranding incidents (%)
Alive	23.7 (n = 129)	9.1 (n = 88)
Fresh dead	24.2 (n = 132)	20.7 (n = 199)
Moderate decomposition	22.2 (n = 121)	27.1 (n = 261)
Advanced decomposition	16.4 (n = 89)	35.9 (n = 346)
Mummified	3.9 (n = 21)	2.7 (n = 26)
Condition unknown	9.6 (n = 52)	4.5 (n = 43)
Total no. of SSL stranding incidents	544	963

Fig. 1. Study area of the Alaska (AK) Region, encompassing stranding counts for the (a) eastern Steller sea lion (SSL) stock in southeast AK, and western SSL stock in (b) southcentral and western AK and (c) the Aleutian Islands and Bering Sea. Markers identify stranding locations, and colors indicate areas of high and low stranding counts



3.1. Spatial maps

Stranding events in AK region ranged from as far north and west as St. Paul (57.1225° N, 170.2799° W), to as far east as Ketchikan, and as far south as Umnak on the Aleutian archipelago (53.2238° N, 168.4319° W; Fig. 1a–c). There were 292 (54%) strandings reported from the eastern SSL stock in the AK Region and 252 (46%) strandings reported within the western SSL stock; however, stranded animals may or may not have originated from these stocks. The areas of Juneau (58.3019° N, 134.4197° W), Glacier Bay (58.6658° N, 136.9002° W), and Gustavus (58.4133° N, 135.7369° W) accounted for the highest number of strandings in the AK Region (Fig. 1a). Kodiak (57.7900° N, 152.4072° W), St. Paul, and Seward (60.1042° N, 149.4422° W)

The initial condition upon examination of the stranded SSLs varied by region (Table 3). In the AK Region, the initial condition of the majority of strandings was alive (24%), fresh dead (24%), or in a state of moderate decomposition (22%). In the NW Region, 36% of carcasses were in a state of advanced decomposition and 27% of carcasses were in a state of moderate decomposition, with a smaller percentage of strandings reported as alive (9%; Table 3).

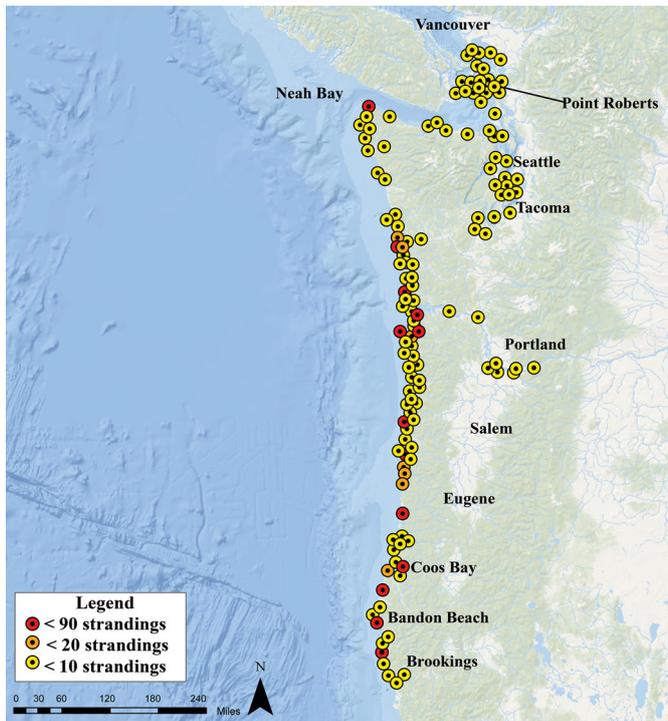


Fig. 2. The NW Region study area, including a portion of the eastern stock of the Steller sea lion population that extends from northern Washington to southern Oregon. Markers identify stranding locations, and colors indicate areas of higher and lower density strandings over the entire time 25 yr time period (1990–2015). The study area includes stranding incidents from as far north as Point Roberts, Washington (48.5912°N , 123.0528°W) and as far south as Brookings, Oregon (42.327°N , 124.1711°W)

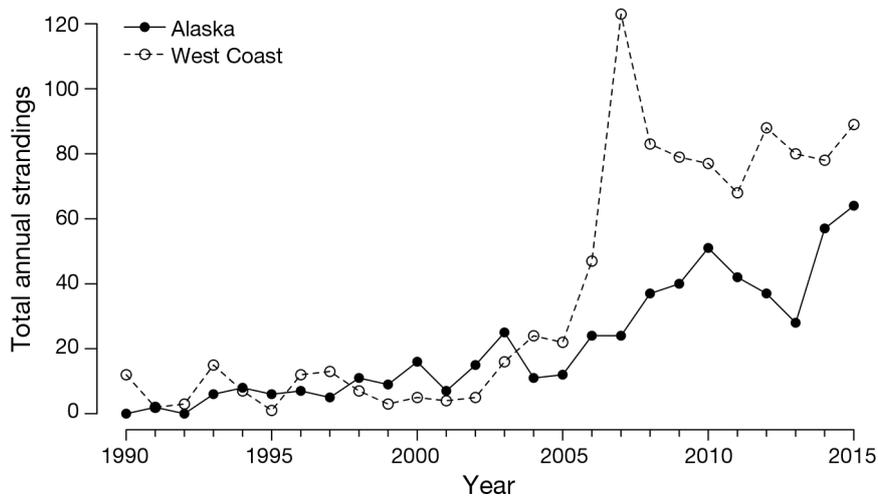


Fig. 3. Annual number of Steller sea lion strandings from 1990–2015. Data encompass the Alaska (AK) Region (solid circles), which includes stranding incidents from the Gulf of Alaska and the Bering Sea, and the Northwest (NW) Region (open circles), which includes strandings in the north eastern Pacific Ocean, along the coast of Oregon and Washington. Data are not corrected for surveillance and stranding response effort

had the second highest numbers of strandings (Fig. 1b,c).

The most northern location of strandings in the NW Region was near the town of Point Roberts, Washington (48.5912°N , 123.0528°W); the most southern stranding location was near the town of Brookings, Oregon (42.327°N , 124.1711°W ; Fig. 2). The highest frequency of strandings was in Bandon Beach, Oregon, with 89 strandings, which was 9% of the total number of strandings occurring in the NW Region (Fig. 2). The second highest frequency of strandings occurred in Neah Bay, Washington, representing roughly 3% of the total number of stranding incidents. In the NW Region more strandings occurred on the Oregon coastline (67.6%) than the Washington coastline (32.4%).

3.2. Temporal analysis

There was no apparent increase in annual strandings reported from 1990–2004; however, beginning in 2005, there was an overall increase in the annual number of strandings in both the AK and NW Regions (Fig. 3). Analysis of the proportion of strandings by age class indicated that adults accounted for the largest proportion of strandings across all years, with the exception of 1998–2000 in the AK Region (Fig. 4). Across all 25 yr, the mean number of monthly strandings was $0.42 \pm 0.11 \text{ mo}^{-1}$ in the AK Region and $3.10 \pm 0.4 \text{ mo}^{-1}$ in the NW Region. There was an increase in mean number of monthly strandings, from 1.83 ± 1.75 in 2005 to 10.25 ± 2.63 in 2007 ($W = 2$, $p < 0.05$) in the NW Region.

There was a significant difference in the proportion of strandings in spring and summer between the AK Region (78%) and the NW Region (66%) ($p < 0.0001$). However, there was no significant difference between the percentage of pups (73%), sub-adults (68%), and adults (69%) stranding in spring and summer ($p > 0.05$). The number of stranding reports in the spring and summer months was significantly higher than the number of

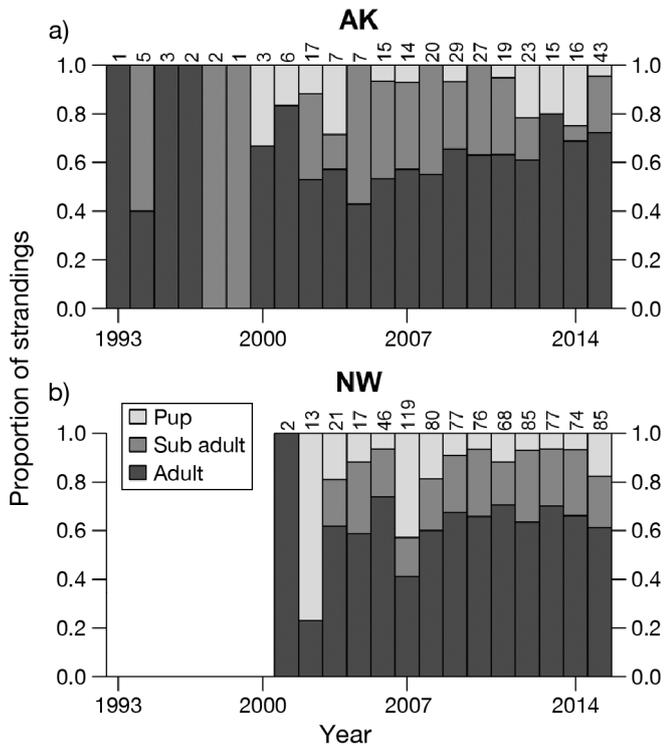


Fig. 4. Proportion of Steller sea lion strandings in (a) Alaska (AK) and (b) Northwest (NW) Regions for each age class across years where data were available. Sample size of known age classes is presented above each bar. Age class was unknown for all strandings from 1993–2000 in the NW Region

stranding reports in the fall and winter months ($\chi^2 = 21.17$, $df = 1$, $p < 0.0001$; Fig 5a), with the highest stranding occurrences documented in the summer (max. = 21) and the lowest in winter (max. = 5; Fig. 5a). Raw data from the AK Region indicated the highest total number of strandings across all 12 mo occurred in July with 118 strandings and in June

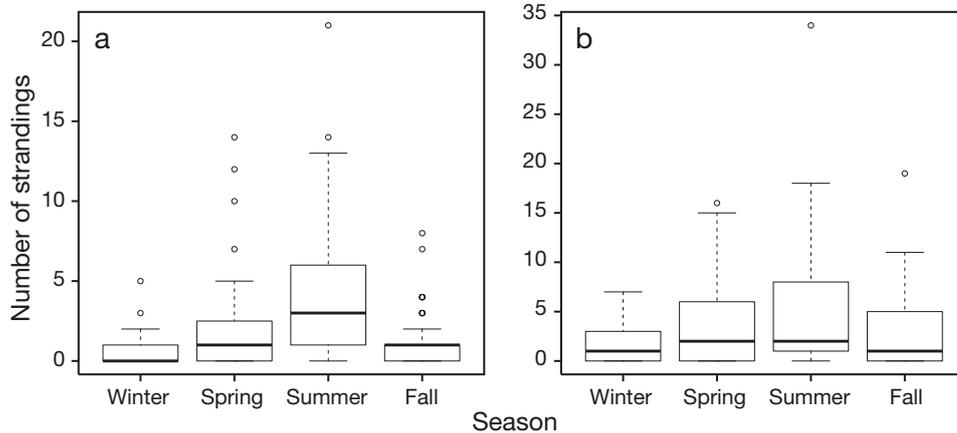


Fig. 5. Variability in the total number of Steller sea lion stranding events occurring each season over a 25 yr period from 1990–2015 in the (a) Alaska (AK) and (b) Northwest (NW) Region. Horizontal line: median

with 98 strandings. In Juneau, 45% of the strandings were reported in the summer months.

The NW Region also had clear seasonal trends, with the number of stranding reports in the spring and summer months significantly higher than in the fall and winter ($\chi^2 = 103.04$, $df = 1$, $p < 0.0001$; Fig. 5b). Raw data from the NW Region indicated the highest number of stranding occurrences (149 in July and 111 in August) across the time series. AIC analyses showed that Model 1 had the best fit (AIC = 1351.94), carrying 57% of the model weight, indicating that region was more important than age at explaining variability and timing of stranding. The estimated relationship for Model 1 was: $\text{logit}(p) = (\beta_0) + 0.77 (\text{region})$, where p is the probability of strandings occurring in the spring and summer for region β_0 is the log odds of strandings in spring and summer, pooled, in AK (Table 4).

3.3. Signs of human interaction

Overall, signs of human interaction could not be determined for the majority of cases (AK: $n = 339$, NW: $n = 681$; Table 5); 50% of these cases in the AK Region and 67% of these cases in the NW Region were categorized as being in a state of moderate or advanced decomposition. However, 81% of human interactions were identified between 2008 and 2015 in both regions. Human interaction accounted for 27% in the AK Region and 18% of strandings in the NW Region and included boat collisions, gunshot, fishery interactions, and other interactions (Table 5). In both regions, gunshot and fishery interactions accounted for 90% of strandings identified as exhibiting signs of human interaction. A smaller proportion exhibited signs of other human interactions,

Table 4. Five generalized linear models for Steller sea lion strandings, including the covariates age class and region, where p = probability of a stranding occurring in the spring/summer as opposed to fall/winter for region i . Akaike's information criterion (AIC) was used for model selection

Model	AIC	Δ AIC	AIC weight
$\text{logit}(p) = B_0 + B_1 \times \text{Region}$	1351.94	0	0.57
$\text{logit}(p) = B_0 + B_1 \times \text{Region} + B_2 \times \text{Age}$	1353.00	1.06	0.33
$\text{logit}(p) = B_0 + B_1 \times \text{Region} + B_2 \times \text{Age} + B_3 \times \text{Region} \times \text{Age}$	1355.43	3.48	0.10
$\text{logit}(p) = B_0$	1372.69	20.75	0
$\text{logit}(p) = B_0 + B_1 \times \text{Age}$	1375.10	23.16	0

Table 5. Percentages and sample size of Steller sea lion–human interaction cases in the Alaska (AK) and Northwest (NW) Regions. Total number of stranding incidents does not equal the sum of interactions in the NW Region as some cases had more than one interaction

Human interaction type	AK stranding incidents	NW stranding incidents
Boat collision	<1 (n = 4)	<1 (n = 4)
Fishery interaction	20.7 (n = 113)	<2.7 (n = 26)
Gunshot	5.1 (n = 28)	12.7 (n = 122)
Other	<1 (n = 2)	2.2 (n = 21)
Suspected	<1 (n = 5)	
No	9.7 (n = 53)	12.4 (n = 119)
Could not be determined	62.3 (n = 339)	69.9 (n = 681)
Total no. of human interaction incidents	147	173
Total no. of stranding incidents	544	963

at <1 % in the AK Region and 2 % in the NW Region. Other detailed pathologic findings that would provide more information of signs of human interaction were limited because necropsies were only conducted on roughly 26 % of strandings across both regions.

3.4. Stranding effort

The annual number of stranding reports was ~5 times higher in the AK Region and ~8 times higher in the NW Region after the Prescott grant was awarded in 2001 ($p < 0.05$). There is insufficient evidence to suggest that the mean number of annual stranding reports differed significantly between regions before the Prescott grant was awarded ($p = 0.805$). However, the annual number of stranding reports did significantly differ after the Prescott grant was awarded ($p < 0.05$). The effects of the Prescott grant on strandings did not differ significantly between the 2 regions ($p > 0.05$). In the AK Region, the number of agreement holders and covered participants was highest in

southeast Alaska, with the second highest being in the southcentral area which includes Seward and Kodiak (NOAA 2016). Despite the higher number of stranding reports in Oregon, Washington had more stranding agreement holders and covered participants than Oregon (NOAA 2016). The higher number of strandings in Oregon may be due to the higher number of haulouts and rookeries in Oregon compared to Washington.

4. DISCUSSION

The age class of stranded marine mammals is an important parameter when evaluating abundance trajectories of endangered or depleted populations. Elasticity analyses conducted by Maniscalco et al. (2015) and age-structured modeling (Holmes et al. 2007) indicate population growth rate is most sensitive to changes in adult survival. Reports of adult strandings in the present study occurred most frequently, with the exception of a large number of cases in the AK Region for which age classes were unidentifiable. The large proportion of known adult SSL strandings observed across both regions

serves as a potential indicator of a higher percentage of SSL adult mortalities, which could have implications for the recovery of the western SSL stock. Some of the unknown age classes may be due to small SSLs potentially being subjected to greater scavenging or movement of the carcass due to tides washing them away (Norman et al. 2012). Our findings are contrary to a live pinniped stranding study, in which adult harbor seals *Phoca vitulina* and elephant seals *Mirounga angustirostris* from healthy populations accounted for a small proportion of total live strandings across all age classes (Colegrove et al. 2005), although the majority of the SSL strandings were not alive.

Decomposed carcasses can inhibit the determination of certain factors such as age, sex, cause of death, or size of the stranded sea lion. Of the cases where sex was determined, male SSLs stranded more frequently than females in both regions. This information is consistent with other studies that reported SSL males to have higher mortality rates across all age classes (Calkins & Pitcher 1979). Shuert et al. (2015) also found the mean survival rate for female SSLs to be slightly higher than males. In general,

males have more extensive and variable movements (Raum-Suryan et al. 2002), which may help to explain the higher frequency of male strandings. The higher number of male strandings may also be attributed to higher nutritional requirements by larger males and male–male competition during active reproduction and time spent on rookeries (Hogg & Forbes 1997, Clutton-Brock & Isvaran 2007). Although prior research findings provide support for observed stranding trends in sex and age class, Peltier et al. (2014) stressed the need for information on physical components that include processes which will determine carcass drift, including tides, currents, and winds.

4.1. Spatial analysis

The greatest number of strandings occurred in southeast Alaska, which is also where the highest number of agreement holders are located. The second highest number of strandings was in south-central AK, again reflective of the second highest number of agreement holders in the AK Region. Although the distribution and number of stakeholders in Alaska is not known for the entire time series, it was known for a substantial portion of the time series (2001–2010), including an increase of 5 stranding stakeholders in this region following 2010. We would expect to see a higher number of strandings in waters inhabited by the eastern stock due to their increasing population abundance and distribution at $>3\% \text{ yr}^{-1}$ since the 1970s (Pitcher et al. 2007) and more recent delisting of the stock's prior 'threatened' status (Fritz et al. 2014). The uneven distribution of stranding stakeholders and tourist destinations across Alaska influences the effort of finding stranded SSLs, and thus may not reflect true SSL abundance and distribution. Therefore, the spatial trends observed appear to be reflective of SSL population abundance, stranding effort distribution, and human population proximity to the marine environment. Due to differences in stranding response effort across the AK Region, the sample size for the western SSL stock was relatively low. This did not allow for comparisons between SSL stocks, but did allow for robust comparisons between the 2 regions.

The distribution of strandings in the NW Region did not reflect stranding response effort when considering the number of stranding stakeholders present in Oregon and Washington, which was contrary to the patterns observed in the AK Region. More stakeholders were present in Washington, yet nearly 68% of the NW Region's stranding reports occurred

on the Oregon coastline. This suggests that increased response effort did not result in increased number of stranding reports in Washington. The California current flows south from Washington through Oregon and may have contributed to the greater abundance of strandings in Oregon due to carcass drift (NOAA 2016). In addition, there is only one SSL rookery complex in Washington, which could account for the low occurrence of strandings as there would be fewer aggregations of SSL and pups in the summer. The high number of strandings occurring around Coos Bay, Oregon, could be a result of increased anthropogenic interaction considering that Coos Bay has a large population center with an associated commercial fishing hub and, perhaps, increased likelihood of strandings being reported (Lee 2016). The second highest number of strandings occurred along the coastal zone of Curry County, Oregon, in relatively close proximity to Pyramid Rock, Long Brown, and Seals Rock, which are sites that were designated as critical habitat for SSL, and should be further monitored post-delisting for elevated numbers of strandings (NMFS 2008). Further investigation of distribution of prey persistence and correlated SSL movement patterns may help to better interpret the spatial trends observed in the NW Region (Womble et al. 2009).

4.2. Temporal analyses

Temporal analyses revealed that the mean number of stranding reports increased after 2002, which is likely a result of the distribution of federal funds through the Prescott Awards and not reflective of SSL population changes. However, the apparent steep incline in the mean number of annual stranding reports from 2005–2007 in the NW Region is difficult to interpret. Many of these carcasses were categorized as being in a state of advanced decomposition, causing difficulty with identifying potential signs of human interaction and carcass examination to determine possible causes of death. Although the present study did not analyze oceanographic or atmospheric data relative to SSL stranding frequencies, it did consider that stranding occurrences and mortalities were associated with storm surges and El Niño events (Greig et al. 2001, Maniscalco et al. 2008). Prior studies have shown a correlation between El Niño events and a higher number of California sea lion strandings (Greig et al. 2005), which may not necessarily be the same effects found in the Pacific Northwest. Fritz & Hinckley (2006) examined data and found little sup-

port for the hypotheses that the shift in prey was responsible for the decline in the western population of SSL. A weak El Niño did occur during the time period of increased SSL strandings (2006–2007), but likely had little effect on food availability considering it was a weak event. Therefore, the cause of the increase in stranding events remains unknown. Furthermore, during the moderate El Niño period from 2009–2010, there was no apparent increase in mean number of annual SSL strandings, suggesting weak and moderate El Niño events have little influence on SSL strandings observed in these data sets. Future research on other oceanographic and atmospheric anomalies that may have contributed to the temporal trend observed here is encouraged.

Additional temporal analyses indicated clear seasonal patterns, with higher strandings occurring during summer (June–August) across both regions. These findings are consistent with Lee (2016), who also identified that the highest number of SSL strandings occurred in July and August for 2006–2014 in the Pacific Northwest. In the present study, the proportion of strandings in spring and summer was significantly higher in the AK Region versus the NW Region, suggesting region, or latitude, may account for the observed seasonal variation. If we consider the expansive coastlines in Alaska and lower ability to have coverage year-round in comparison to Washington and Oregon, we would expect a higher number of strandings to be reported in Alaska in the spring and summer. In the NW Region, milder climates and higher, more equally distributed human populations inhabiting coastal areas allow for more consistent stranding effort to occur, during 3 seasons (spring, summer, fall) or year-round.

4.3. Signs of human interaction

Signs of human interaction were not determined for a substantial percentage of cases in both regions due to carcass condition. This is likely a direct result of the condition many of these carcasses were in upon initial examination, making it difficult to observe signs of human interaction. Across the entire 25 yr time period of the study, a large proportion of human interaction cases (i.e. 81%) were identified between 2008 and 2015 in both regions. It is difficult to ascertain reasons for this increase in reporting other than it being a result of increased effort and public awareness. In stranding cases where human interaction was identified, fishery interaction was the most common human interaction type in the AK

Region and gunshot in the NW Region. Other studies have indicated that the most common cause of serious injuries for the eastern and western SSL stocks in Alaska, Oregon, and Washington waters was some type of fishery interaction, including entanglement in marine debris and injuries related to ingestion of various fishing gear (Helker et al. 2017). One notable finding from our study was that 40% of the cases had gunshot wounds in 2015, and a high proportion (88%) of them occurred during the summer and spring months in one particular area. These cases were not part of a unique survey, and likely represent an ongoing problem for this species that is under-reported, especially considering that pinnipeds with gunshot wounds reported to NMFS Alaska Regional Stranding Network are assumed to be struck and lost animals associated with an Alaska Native subsistence hunt unless there is evidence indicating the animal was unlawfully shot (Helker et al. 2017). More detailed reports were obtained from the Alaska Department of Fish & Game (ADF&G) and revealed 7 of the 11 cases to be considered part of a group event that occurred in Cordova, near the Copper River commercial salmon drift gillnet fishery. Five of these cases were males, 4 were identified as adults, and 3 as juvenile/sub-adults. In that same year, a climate anomaly was documented, also known as the marine heatwave (Bond et al. 2015, Di Lorenzo & Mantua 2016). This has been identified as a causative agent of a major shift in the forage food base and subsequent changes in prey availability and distribution (NMFS unpubl. data), which may have affected SSL behavior and resulted in increased numbers of SSL targeting fishing nets.

4.4. Continued utilization of the stranding database and implications for conservation

Although the eastern SSL stock was recently delisted, the present study provides information about some threats and encourages future post-delisting monitoring through the stranding network. The use of the NW Region and AK Region stranding data allows us to investigate and illustrate patterns in SSL stranding trends to better understand how characteristics of stranding incidents may change over space and time, and how stranding response efforts may directly affect these changes. This may have implications for managers when assessing the costs and benefits of mitigating documented anthropogenic hazards to endangered species populations (Chaloupka et al. 2008).

Level A stranding reports were not designed to elucidate cause-specific mortality trends. The degree of confirmed biometric data included in our study is associated with varying levels of uncertainty. The inability to distinguish between cases associated with low, moderate, or high levels of effort across time and space prevents us from making strong conclusions about these data. When considering the large amount of funding given to stranding networks, the need for refinement and standardization of data collection is recommended to reduce biases. Studies such as ours would benefit from stranding networks organizing the data to account for annual effort and consistent reporting templates for data to minimize uncertainty.

As revealed in other studies, an apparent increase in strandings and subsequent reporting may be directly linked to increased observational effort, and not an accurate representation of a true increase in strandings (Berrow & Rogan 1997, Evans et al. 2005, Danil et al. 2010). In order to make any definitive, conclusive statements in regards to Level A stranding data, we must have a better measurement of effort. Supplementary reports produced from post-mortem examinations are of great value when attempting to identify cause-specific trends. However, necropsies were performed in only 26% of the cases in the present study, despite the Endangered Species Act (ESA) listing. We recognize that this can prove to be very difficult in view of the vast size of Alaska and the small human population in many parts of the state, and appreciate the role limited funding may play.

For the purpose of conservation efforts and the desire to utilize stranding data to inform management of SSL, we have a few specific recommendations. We stress the need for increased stakeholders in western Alaska. This would allow for minimization of bias when analyzing temporal and spatial trends in SSL strandings. The western SSL stock that inhabits waters west of Samalga Pass (~170°W) is in a state of decline, and reasons for this are not clear (Fritz et al. 2013). Annual field efforts should prioritize the collection and analysis of stranded SSL across their geographic range. Due to the limited human population west of Samalga Pass, and stranding response in that area, it is unlikely that stranding data will be informative to management plans without increased surveillance efforts. In contrast, stranding effort in the NW Region is more uniformly distributed and likely representative of the eastern SSL stock population distribution. Our study has highlighted the need to support marine mammal stranding monitoring and

surveillance programs, improve and standardize data collection and reporting processes, and increase the amount of post-mortem examinations. With improved surveillance and quality of stranding data, researchers can better understand both short- and long-term factors affecting SSL mortality.

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