

## A Decade of Live California Sea Lion (*Zalophus californianus*) Strandings Along the Central California Coast: Causes and Trends, 1991-2000

Denise J. Greig,<sup>1</sup> Frances M. D. Gulland,<sup>1</sup> and Christine Kreuder<sup>2</sup>

<sup>1</sup>The Marine Mammal Center, Marin Headlands, 1065 Fort Cronkhite, Sausalito, CA 94965, USA

<sup>2</sup>The Wildlife Health Center, School of Veterinary Medicine, University of California, Davis, CA 95616, USA

### Abstract

Stranded marine mammals offer a unique sample of relatively inaccessible wild animals that are more likely to represent the diseased segment of the population and are easy to examine thoroughly. Examination of these animals, therefore, offers a method to detect novel diseases in free-living aquatic mammals. Diseases in marine mammals may reflect environmental changes such as ocean pollution, prey shifts, and global warming. To detect spatial and temporal trends in prevalence of such diseases, we reviewed records for 3,707 California sea lions (*Zalophus californianus*) that stranded live between 1991 and 2000 along the central California coast. Reasons for stranding were determined from a combination of clinical examinations, hematology and serum biochemistry, radiography, gross necropsy, histopathology, microbiology, and biotoxin assays. Over the ten years, 74% of sea lions stranded in Santa Cruz, Monterey and San Luis Obispo Counties, and 83% of these were admitted between May and October each year. Malnutrition was the most common reason for stranding (32%), followed by leptospirosis (27%), trauma (18%), domoic acid intoxication (9%), and cancer (3%). Strandings caused by malnutrition were greatest during the El Niño events of 1992, 1993, and 1998, while strandings caused by leptospirosis accounted for over 60% of strandings in 1991, 1995, and 1999. Although domoic acid was first reported in California sea lions in 1998, there was a small stranding event in 1992 that, based on clinical examinations and histopathology, was probably also caused by domoic acid. The observed prevalence of cancer among stranded animals remained constant over the past ten years at 3%.

**Key Words:** California sea lion, *Zalophus californianus*, cancer, domoic acid, leptospirosis, El Niño, malnutrition, mortality, strandings, California

### Introduction

Marine mammal strandings have been documented for hundreds of years (De, 1997). Data from stranded animals have been used to assess species range, morphology, and taxonomy (Lucas & Hooker, 2000), to identify human interactions with marine mammals (Berrow & Rogan, 1997; Goldstein et al., 1999), and to detect spatial and temporal patterns of mortality (Kreuder et al., 2003; Silva & Sequeira, 2003). Frequencies of strandings have been correlated with natural environmental perturbations such as storm surges and El Niño events (Dunlap, 1995; Greig et al., 2001), and longitudinal stranding data have been used, in conjunction with natural mortality data, to estimate additional mortality during a marine mammal die-off (Eguchi, 2002; McLellan et al., 2002).

Data from stranded animals provide insights into disease processes contributing to marine mammal mortality. Stranded animals are not a random sample of the free-living population because they are more likely than other animals to be unhealthy, and detection rate is dependent on human effort and accessibility to stranded animals, which vary greatly; however, because diseases occur at higher prevalences in stranded animals, these animals provide an opportunity to identify novel diseases in marine mammals that are otherwise relatively inaccessible (Gulland, 1999). Thus, diseases previously unknown in marine mammals, such as domoic acid toxicosis, herpesviruses, Q fever, and coccidioidomycosis, all have been discovered among stranded animals (Fauquier et al., 1996; Lapointe et al., 1999; Lipscomb et al., 2000; Scholin et al., 2000). Furthermore, longitudinal stranding data may reveal spatial and temporal trends in commonly observed causes of stranding and, thus, provide insight into predisposing factors for morbidity and mortality.

Previous surveys of stranded pinnipeds admitted for rehabilitation to The Marine Mammal

Center (TMMC) in Sausalito, California, from 1975-1990 identified the major causes of strandings as malnutrition, renal disease, and pneumonia (Dierauf, 1983; Gage et al., 1993; Gerber et al., 1993). Goldstein et al. (1999) found that 7.5% of 6,196 pinnipeds admitted to TMMC between 1986 and 1998 had human-related injuries, of which 66% were gunshot injuries primarily in California sea lions.

This paper examines the causes of stranding for California sea lions along the California coast from the border of San Luis Obispo/Santa Barbara

Counties (35° 00' 20" N, 120° 37' 24" W) to the Oregon state border (41° 59' 54" N, 124° 12' 42" W) between 1991 and 2000 (Figure 1). The objectives were to document spatial and temporal patterns in causes of stranding and to assess trends in disease frequency among stranded California sea lions.

### Materials and Methods

This study focused on live strandings because dead stranded animals rarely were examined adequately or were too decomposed to determine

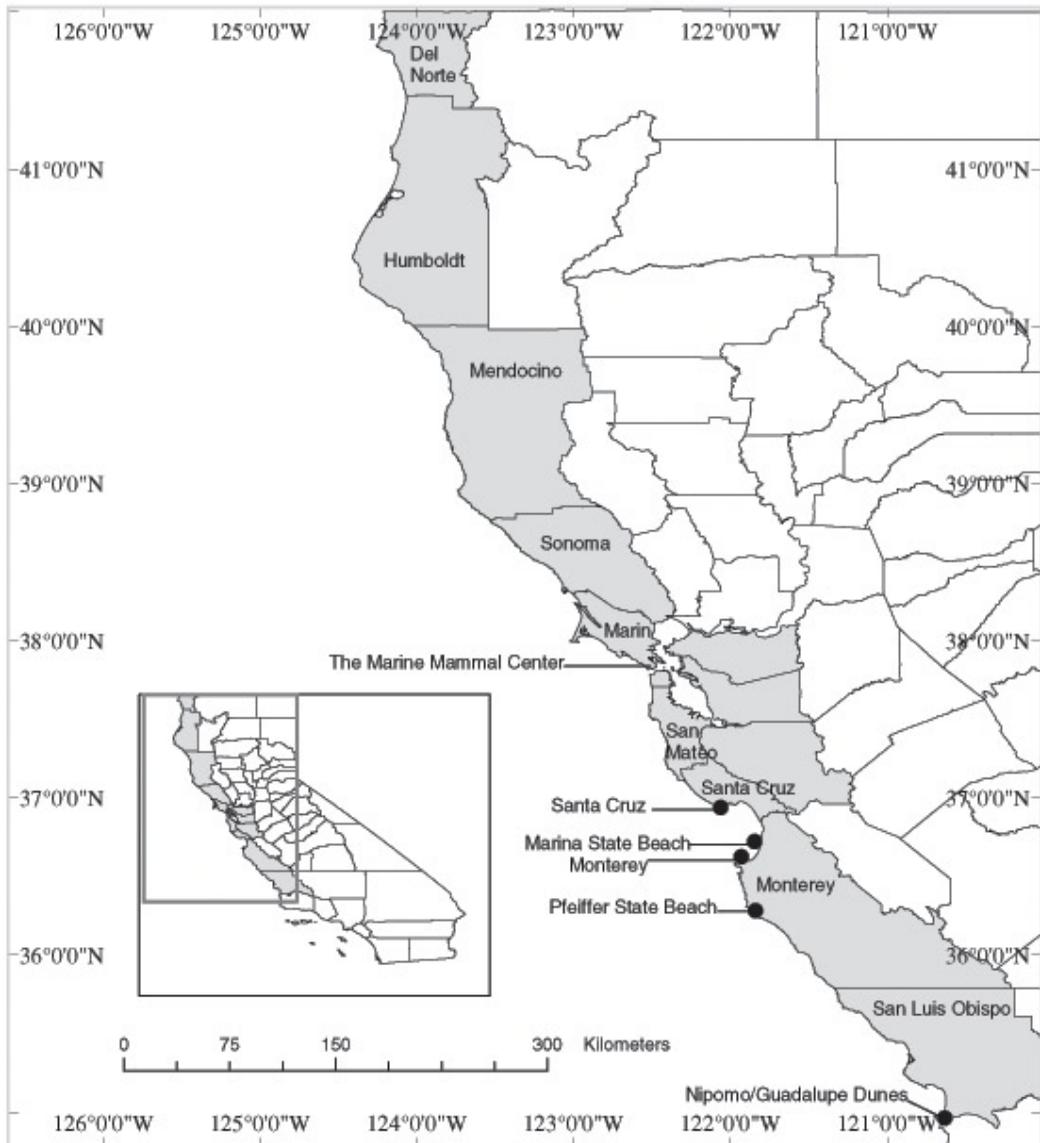


Figure 1. Map of study area

cause of stranding. Medical records were reviewed for 3,707 California sea lions that stranded along the central California coast from 1 January 1991 through 31 December 2000 and were admitted to TMMC for rehabilitation. Date and location of stranding, sex, and age class were recorded, and a reason for stranding was assigned to each animal. Sex determination was based on observed genital morphology, and age class was determined using a combination of standard body length, tooth size, and stage of sagittal crest development. Age classes were defined as follows: pup (0-1 year), yearling (1-2 years), juvenile male (2-4 years), subadult male (4-8 years), juvenile or subadult female (2-5 years), adult male (8+ years), and adult female (5+ years). To compare standard body length with tooth age, age was determined by counting dental growth layers on the cut surface of the upper left canine for 344 animals. Teeth were prepared according to the methods outlined in Evans & Robertson (2001), with the exception that teeth were cut using a diamond blade isomet saw and were etched in acid for approximately 20 minutes. For statistical analysis, age classes were collapsed to three age classes: yearling (pup and yearling), subadult (juvenile and subadult), and adult.

#### *Stranding Causes*

Cause of stranding was determined from a combination of results from clinical examinations, hematology and serum biochemistry parameters, radiographs, gross necropsy, histopathologic examination of tissues, fecal sedimentation for parasites, bacterial culture, and biotoxin assays (Goldstein et al., 1999; Gulland et al., 1996a, 1996b; Gulland et al., 1997; Gulland et al., 2002). Causes of stranding were categorized as malnutrition, leptospirosis, trauma, domoic acid, cancer, miscellaneous, behavioral, or unknown.

Animals were placed into the malnutrition category if they were a yearling and weighed less than 25 kg or, if during rehabilitation, their total mass increased by 25% of their body weight at admission in less than a month and no other disease process was detected that could explain stranding. Animals were placed into the leptospirosis category if serum chemistry results were indicative of leptospirosis (blood urea nitrogen > 100 mg/dl, creatinine > 2 mg/dl, sodium > 155 meq/L and phosphorus > calcium) or if gross necropsy (swollen kidneys with loss of renule differentiation and pale tan renule cortices) and histopathology (interstitial nephritis) revealed renal disease consistent with leptospirosis (Gulland et al., 1996b; Colagross-Schouten et al., 2002).

Sea lions in the domoic acid category exhibited clinical symptoms of exposure to the neurotoxin domoic acid (ataxia, seizures, disorientation;

Gulland et al., 2002), had neuronal necrosis or hippocampal atrophy on histopathology, or had domoic acid in body fluids and in most cases stranded during a known, domoic acid producing, algal bloom (Scholin et al., 2000). Animals with clinical signs similar to those described above that stranded before 1998 were categorized as "suspected" domoic acid cases because the presence of the neurotoxin was not confirmed in any cases before 1998 (Scholin et al., 2000). The domoic acid toxicity and suspect domoic acid toxicity categories were combined for data analysis. Only animals with extensive and fatal metastatic carcinoma were included in the cancer category (Gulland et al., 1996a). Mild, nonfatal, non-invasive benign tumors were not considered causes of stranding.

The behavioral category consisted of animals that were not sick or injured, but were admitted for rehabilitation because they were either out of their usual habitat (on highways, in areas with people and dogs), nuisance animals (approaching people, begging for food), newborn pups abandoned by their mothers, or picked up illegally by a member of the public. The unknown category consisted mostly of animals that were admitted mildly underweight and lethargic, and had no characteristic clinical signs or abnormal hematology or serum chemistry. Most animals improved with supportive treatment and were released without a definitive diagnosis being made, while some animals died prior to receiving a diagnosis and necropsy results were inconclusive.

#### *Statistical Analyses*

Growth characteristics were assessed using a von Bertalanffy growth model fitted to the standard body length at age data:  $y = L*(1 - e^{-k*(x-t_0)})$ . The model was fitted using *SigmaPlot Version 8.0* and incorporated the nonlinear least squares Marquardt-Levenberg parameter estimation algorithm. The distribution of specific causes of stranding by sex and year were evaluated by the two-sided chi-square test of independence (*SPSS Version 11.0*, SPSS Inc., Chicago, Illinois). Geographic clustering was evaluated for strandings caused by leptospirosis, domoic acid, and cancer. The spatial scan statistic with the Bernoulli model (Kulldorf & Nagarwalla, 1995) was used to test whether cases with these causes of stranding were randomly distributed along TMMC's response area. Stranding locations for these causes of stranding were compared to locations for sea lions with all the other stranding causes. Geographical clusters identified through spatial analysis were used to define an additional variable for logistic regression analysis. A logistic regression model was used to identify risk factors for animals stranding because of leptospirosis (*SPSS Version 11.0*). The dependent

variable was the cause of stranding (leptospirosis versus all other causes of stranding). Covariates were sex, age class, season (January-June or July-December), and geographical cluster.

### Results

Over the decade of study (1991-2000), 3,707 California sea lions live stranded in the study area. The annual number of live California sea lion strandings along the central California coast has increased since 1975 (Figure 2). Greater numbers of strandings occurred during the El Niño events of 1983/1984, 1991/1992, and 1997/1998. The sex ratios of stranded animals changed over the years: from 1975 through 1991, only 29% of sea lions were female, while from 1992 through 2000, 70% of stranded sea lions were female.

Strandings from the study period (1991-2000) represented 77% of the total strandings from 1975-2000. During this ten-year period, 74% of California sea lion strandings came from Santa Cruz, Monterey, and San Luis Obispo Counties (Figure 3), and 83% of California sea lions were admitted between the months of May and October (Figure 4). Of the stranded sea lions, 41% were female and 59% were male. Fifteen percent were

adults, 37% were subadults, and 48% were yearlings. Standard body lengths ranged from 91-217 cm for female sea lions and 90-300 cm for male sea lions (Figure 5). There was a significant relationship between standard body length and tooth age for both males ( $r^2 = 0.842$ ,  $p < 0.0001$ ) and females ( $r^2 = 0.650$ ,  $p < 0.0001$ ).

Malnutrition (32%,  $n = 1174$ ), leptospirosis (27%,  $n = 1011$ ), and trauma (18%,  $n = 652$ ), were the most common causes for stranding, while domoic acid intoxication (9%,  $n = 328$ ), cancer (3%,  $n = 99$ ), behavioral (1%,  $n = 25$ ), and unknown (2%,  $n = 61$ ) causes were less common (Table 1). Strandings caused by miscellaneous diseases accounted for 10% ( $n = 357$ ) of strandings. The greatest numbers of sea lions stranded in 1998 ( $n = 740$ ) when there was an El Niño event and a domoic acid producing algal bloom (Gulland, 2000).

#### Malnutrition

Prevalence of malnutrition was highest during 1992, 1993, and 1998 ( $p < 0.001$ ) when El Niño conditions prevailed in California (Table 1). Yearlings made up 84% (993 out of 1,173) of the animals in this category, which contained greater numbers of male than female sea lions ( $p < 0.001$ , Table 2).

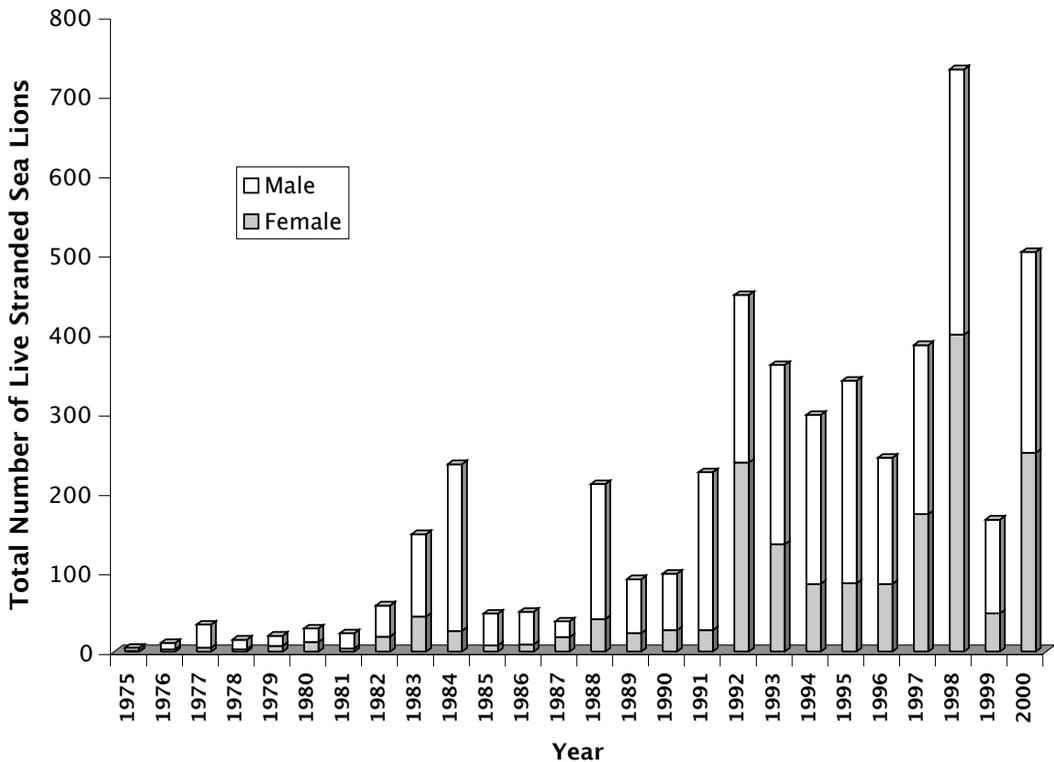


Figure 2. Live California sea lion strandings by sex and by year, 1975-2000

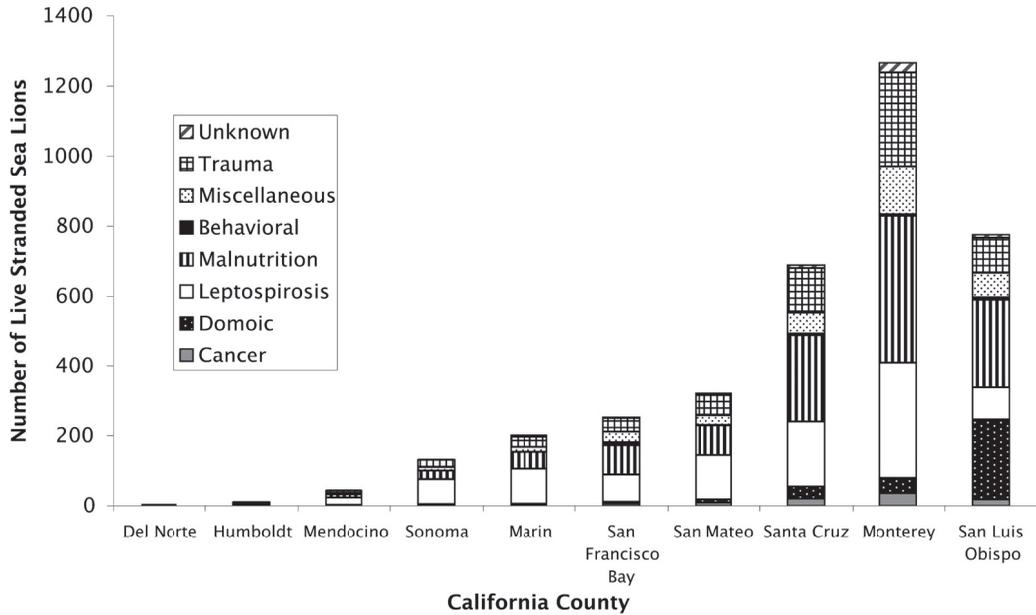


Figure 3. Causes of live California sea lion strandings by county, 1991-2000

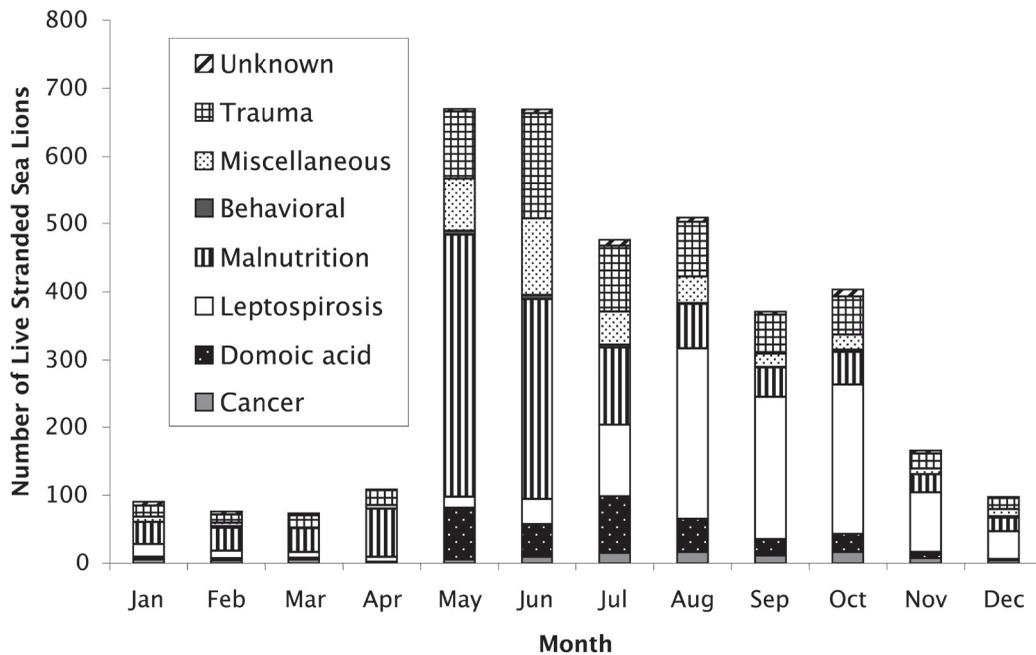
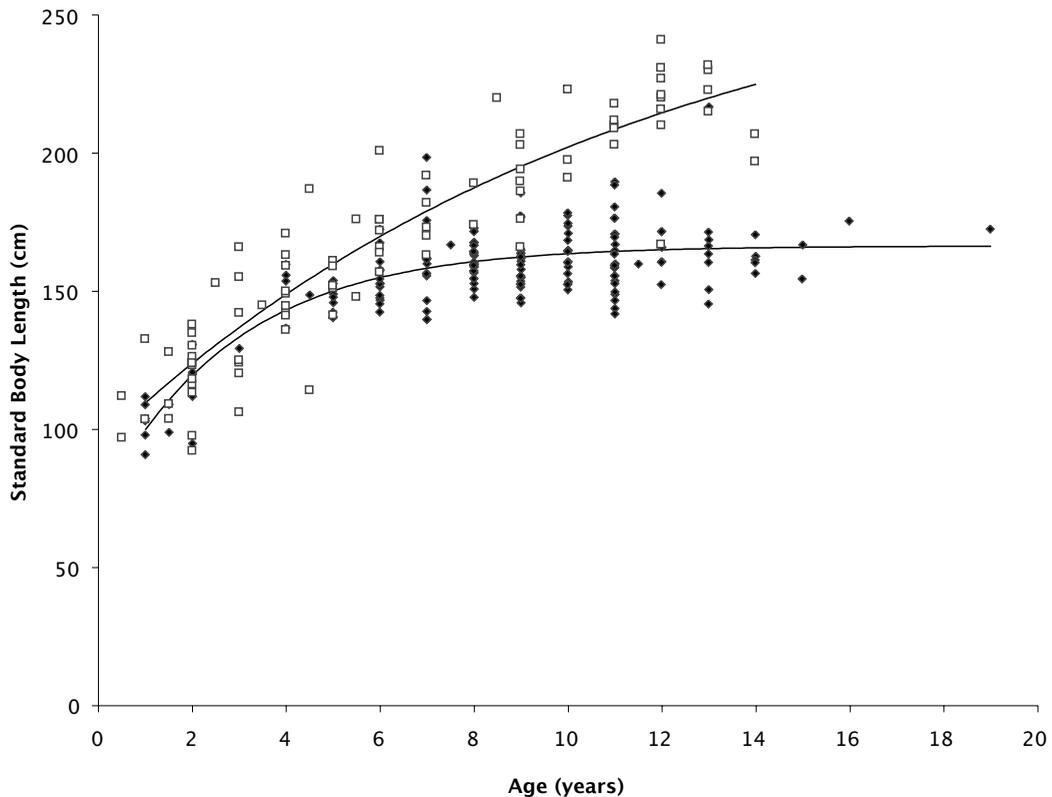


Figure 4. Causes of live California sea lion strandings by month, 1991-2000

Fifty-three percent of the sea lions in this category were admitted in May and June (Figure 4). Malnourished animals had a number of secondary disease conditions, including heavy parasite burdens, abscesses, nonspecific respiratory symptoms,

ocular lesions, skin ulcers typical of San Miguel sea lion virus (calicivirus) infection, and pox lesions (Gulland et al., 2001). Prevalence of parasites in these animals was high. By July each year, prevalence of *Parafilaroides decorus* (based on necropsy



**Figure 5.** Relationship between standard body length and tooth age for 173 female and 90 male California sea lions; squares are males, diamonds are females, and the lines are the von Bertalanffy growth curves. For the female growth curve,  $r^2=0.65$ ,  $k=0.3523$ ,  $t_0=-1.5988$ ,  $L=166.4139$ . For the male growth curve,  $r^2=0.84$ ,  $k=0.0882$ ,  $t_0=-4.6688$ ,  $L=278.6571$ .

**Table 1.** Number of live stranded California sea lions by year and cause of stranding, 1991-2000

	Cancer	Domoic acid	Leptospirosis	Malnutrition	Behavioral	Miscellaneous	Trauma	Unknown	Total
1991	7	10	154	19	4	6	21	4	225
1992	8	25	14	202	1	50	142	7	449
1993	14	6	21	218	0	25	68	9	361
1994	11	0	122	66	3	31	59	6	298
1995	7	1	222	45	1	19	41	2	338
1996	8	2	32	83	2	42	71	4	244
1997	13	4	106	116	0	62	75	10	386
1998	10	86	57	378	8	75	114	12	740
1999	8	6	105	10	1	10	21	0	161
2000	13	188	178	37	5	37	40	7	505
Total	99	328	1,011	1,174	25	357	652	61	3,707

examination or fecal sedimentation) was 94% among yearlings, but these lungworms were not usually associated with significant pneumonia.

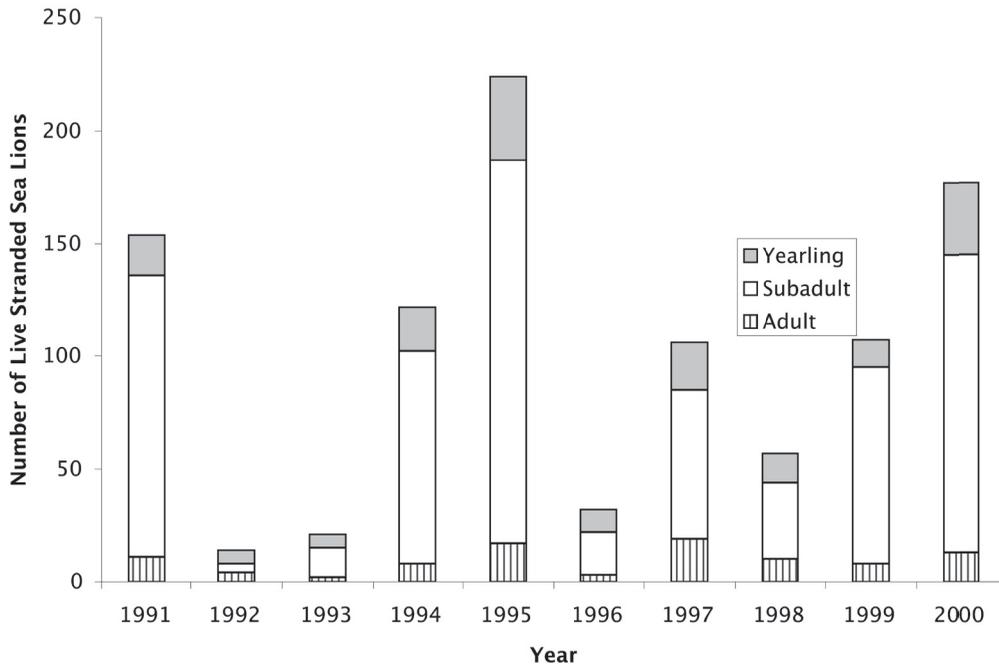
#### *Leptospirosis*

Strandings due to leptospirosis differed significantly by year ( $p < 0.001$ ) and were most

common in 1991, 1995, and 2000 (Figure 6). Leptospirosis was responsible for over 60% of all sea lion strandings in 1991, 1995, and 1999 (Table 1). The prevalence of leptospirosis overall was greater among males than females ( $p < 0.001$ ; Table 2). Leptospirosis occurred frequently during 1991, 1994, 1995, 1999, and 2000 ( $p <$

**Table 2.** Number of live stranded California sea lions by age class, sex, and cause of stranding, 1991-2000 ( $n = 3,692$  because 15 animals were omitted from the data set: 6 of unknown age class and 9 of unknown sex)

Cause	Adult			Subadult			Yearling			Grand Total
	Female	Male	Total	Female	Male	Total	Female	Male	Total	
Cancer	62	26	88	4	5	9	1	1	2	99
Domoic acid	243	10	253	15	38	53	14	7	21	327
Leptospirosis	62	33	95	88	653	741	66	108	174	1,010
Malnutrition	5	0	5	52	123	175	489	504	993	1,173
Behavioral	1	1	2	1	8	9	2	7	9	20
Miscellaneous	24	6	30	28	78	106	119	102	221	357
Trauma	36	41	77	43	211	254	135	182	317	648
Unknown	16	2	18	5	19	24	6	10	16	58
Total	449	119	568	236	1,135	1,371	832	921	1,753	3,692

**Figure 6.** Age class of live California sea lions stranding with leptospirosis by year, 1991-2000

0.001), and during those years, 70% of affected animals were subadult males (Table 2). Eighty-six percent of the animals in this category were admitted between July and November (Figure 4). A geographic cluster of leptospirosis cases was detected from the city of Santa Cruz north along the coast to the Oregon border (Figure 1). The cluster was centered at 41.7401° N, 124.1856° W with a radius of 563.17 km ( $p = 0.001$ ). Forty percent (516 of 1,279) of strandings within this cluster were due to leptospirosis, while 20% (495 of 2,425) of strandings outside of the cluster were

caused by leptospirosis. Logistic regression analysis revealed that age, sex, stranding location, and season were significantly associated with stranding due to leptospirosis (Table 3). Leptospirosis cases were three times more likely to strand in the spatial cluster from Santa Cruz to Oregon than elsewhere in TMMC's response range, and were 8.2 times more likely to strand between June and December. Leptospirosis cases also were 4.5 times more likely to be subadult than yearling and 1.6 times more likely to be male than female. The logistic regression model for leptospirosis

**Table 3.** Risk factors for California sea lions live stranding with leptospirosis: significant variables in the leptospirosis logistic regression model and the odds ratios

Variables	Odds ratio	95% CI for odds ratio		<i>p</i> -value	
		Lower	Upper		
Spatial cluster	South of Monterey Bay	1.000			
	Monterey Bay	1.815	1.371	2.403	0.000
	Santa Cruz North	2.983	2.251	3.954	0.000
Age class	Yearling	1.000			
	Subadult	4.459	3.592	5.537	0.000
	Adult	1.248	0.924	1.686	0.149
Sex	Female	1.000			
	Male	1.619	1.304	2.011	0.000
Season	January-June	1.000			
	July-December	8.173	6.436	10.377	0.000

exhibited a fair fit overall (Hosmer and Lemeshow Chi-square 11.390,  $p = 0.181$ )

#### Trauma

Trauma cases exhibited wide variation in stranding by year. Years of highest prevalence were 1992 at 32% and 1996 at 29% ( $p < 0.001$ ). The greatest numbers of strandings due to trauma occurred in 1992 and 1998. Most trauma cases were due to gunshots (48%,  $n = 311$ ), while entanglement in fishing line and other debris (17%,  $n = 109$ ), shark bites (7%,  $n = 44$ ), and propeller wounds (1%,  $n = 7$ ) were less common. Trauma from unknown causes (26%,  $n = 172$ ) included fractures, blunt trauma, hind-end paralysis, and blindness of unknown etiology, as well as stingray spines and tar. Human-caused injuries (including gunshots, fishing entanglements, and propeller wounds) accounted for 67% ( $n = 436$ ) of all trauma cases. Some cases classified as trauma from unknown causes may have been human caused, but cases were not classified as such unless definitive evidence (i.e., a bullet, actual presence of debris entangling the animal) was found. As there were such a variety of causes of trauma, spatial analysis to investigate risk factors was not performed as different types of trauma would be expected to be associated with different risk factors.

#### Miscellaneous

The miscellaneous category encompassed all other disease-related strandings, including peritonitis, abscesses, pneumonia, pleuritis, generalized septicemias, cystitis, central nervous system infections with bacteria and protozoa, *Coccidioides immitis* infection, intussusception/volvulus, endocarditis, renal failure, hemoperitoneum, pericarditis, prolapsed uterine, and congenital defects (Table 4). Peritonitis was the most common cause of stranding, accounting for 38% of strandings in the

miscellaneous category (Table 4). Peritonitis was particularly prevalent in 1992 and 1998, accounting for more than 5% of stranded animals in both years.

#### Domoic Acid

The greatest numbers of sea lions stranding with domoic acid intoxication occurred in 1998 and 2000. In 2000, 37% of sea lions stranded because of domoic acid toxicosis (Table 1). In August and September 1992, 21 animals stranded in San Luis Obispo County, six years prior to the first documented case of domoic acid toxicosis in marine mammals. The clinical signs exhibited by these animals (seizures and ataxia) and the spatial and temporal clustering of their strandings suggests that this was a domoic acid event. Similarly, in 1991, three adult females stranded seizing on one day in San Luis Obispo County, suggesting another domoic acid related event. A geographic cluster of domoic acid cases was identified from Nipomo/Guadalupe Dunes to Pfeiffer State Beach (Figure 1). The cluster was centered at 35.1062° N, 120.6318° W with a radius of 184.72 km ( $p = 0.001$ ). Thirty percent (235 of 795) of the strandings in this cluster were caused by domoic acid, while only 3% (93 of 2,909) of strandings were caused by domoic acid outside of this spatial area.

#### Cancer

Cancer prevalence averaged 3% of stranded animals per year (SD  $\pm 1\%$ ). Cancer was advanced by the time it caused stranding, and 84.5% of cancer cases were adults. Most sea lions were young adults rather than aged adults: among a subsample of animals aged using their teeth, age range for females with cancer was 4.5 to 19 years (mean = 9.3, SD = 2.6,  $n = 60$ ) and for males it was 4 to 13 years (mean = 9.9, SD = 2.8,  $n = 21$ )

**Table 4.** Causes of live California sea lion strandings by age within the miscellaneous category

Cause	Adult	Subadult	Yearling	Total
Peritonitis	8	26	100	134
Abscess	2	31	57	90
Pneumonia	7	19	17	43
Pleuritis	2	14	14	30
Bacteremia	1	6	17	24
Cystitis	2	2	3	7
Central nervous system infection	0	1	5	6
<i>Coccidioides immitis</i>	1	3	2	6
Intussusception/volvulus	1	1	4	6
Endocarditis	3	0	0	3
Renal failure/disease	1	1	1	3
Hemoperitoneum	0	1	0	1
Pericarditis	0	0	1	1
Prolapsed uterus	1	0	0	1
Congenital defects	1	1	0	2
Total	30	106	221	357

years. Sixty-six percent of animals with cancer were female and 34% were male. Sea lions with cancer were admitted in all months of the year, but 57% were admitted between July and October and comprised greater than 3% of total strandings from October to March. A geographic cluster of animals stranding with cancer was detected along Monterey between Pfeiffer State Beach and Marina State Beach (Figure 1). The cluster was centered at 36.2809° N, 121.8609° W with a radius of 35.7 km ( $p = 0.002$ ). Ten percent of the strandings in this cluster (21 of 214) were caused by cancer, while only 2% of strandings (78 out of 3,463) were caused by cancer outside of this spatial area.

#### *Behavioral and Unknown*

Behavioral abnormalities or interactions with humans accounted for 0.7% of stranded sea lions, and the cause of stranding for 1.5% of stranded sea lions remained unknown.

### Discussion

There has been an increase in the annual numbers of sea lions stranded in central California over the past 25 years. The increase in strandings mirrors the increase in the population of California sea lions off California (Forney et al., 2000), but it is probably also a function of growth in public awareness of strandings and the development of an organized stranding network. Directed carcass recovery attempts can be used to estimate mortality rates (Melin, 2002), but data from the California stranding network is opportunistic and effort varies with weather, season, and the number of people on the beach. Over the decade of this

study, urbanization of the California coastline has increased public contact with stranded marine mammals, which likely increased the search effort between 1975 and 2000. The greater number of strandings in the three southern counties is likely a function of their proximity to the California sea lion breeding grounds on the Channel Islands. This proximity also explains the high number of yearlings in May and June, corresponding to time of weaning and the first attempts by these animals to forage. Animals in the behavior category were probably clinically healthy animals that were not truly stranded and reflect increasing contact between the public and pinnipeds as the California coastline becomes increasingly urbanized.

Although most stranded sea lions are not in prime body condition because most diseases result in weight loss (with the exception of acute ones such as domoic acid intoxication and trauma), malnutrition without other disease was the major cause of stranding in this study. The increase in prevalence of malnourished sea lions, especially yearlings, during El Niño years is consistent with the reported effects of El Niño on the sea lion population in the Channel Islands: reduced prey resulted in nursing females spending more time at sea and decreased growth rates among pups (Ono et al., 1987).

Forty percent of strandings were disease-related and leptospirosis accounted for the greatest proportion of these diseases. Gerber et al. (1993) reported a 32% prevalence of renal disease among California sea lions stranded between 1984 and 1990, suggesting the prevalence of this disease has not increased between the two decades of study. The cyclical nature of the number of animals stranded with leptospirosis observed in this and previous studies may be due to changes

in herd immunity among the sea lion population or to temporal or seasonal patterns of transmission (Gulland et al., 1996b). In most mammals, leptospirosis is transmitted by oral ingestion of contaminated urine or water (Leighton & Kuiken, 2001). Although the route of *Leptospira* sp. transmission in sea lions has not been determined, if urine is important, spatial differences in stranding patterns of sea lions with leptospirosis may be due to differences in persistence of urine in the environment—for example, urine persisting on rocky haul-out areas longer than on sandy rookeries.

The number of sea lions stranding due to human interactions was consistent with that reported by Goldstein et al. (1999) for an overlapping period from 1986-1998. A higher prevalence of human interactions during 1992 and 1998 may be a consequence of malnourished animals during El Niño years having a greater tendency to approach people for food or to linger in areas frequented by humans due to overall weakness resulting from malnutrition.

Peritonitis, which is relatively common in stranded sea lions, was most often a result of perforated duodenal ulcers. The cause of these ulcers is unclear, but in the past, gastric ulcers in sea lions have been associated with anisakid infections, stress, and uremia (Gulland et al., 1996b; Lauckner, 1985). The higher prevalence of these peritonitis cases in years with high numbers of malnourished animals suggests that malnutrition may play a role in the pathogenesis of ulcer perforations. Perforated gastric ulcers have been documented in emaciated California sea lions (Ridgway et al., 1975), but further work is needed to determine the mechanism involved in perforation by these duodenal ulcers. The complex of pneumonia, pleuritis, and septicemia was also common, and most likely it is a consequence of mixed bacterial infections secondary to a variety of conditions. A range of bacteria have been isolated from stranded California sea lions (Thornton et al., 1998), and these may infect traumatic wounds or invade lesions resulting from parasitic infections. *Parafilaroides decorus* infection is common in juvenile California sea lions (Lauckner, 1985), and heavy infections may result in bacterial microabscesses in the lungs that can rupture causing pleuritis.

Strandings from domoic acid toxicity appear to have increased dramatically over the ten years of this study. Although first documented in marine mammals in 1998 (Scholin et al., 2000), the clinical signs in animals stranded in 1991 and 1992 suggest that sea lions were affected before this date. On the time scale of this study, the severity of the domoic acid events seems to be increasing. The increase in the number of domoic acid

strandings confounds analysis of some of the other causes of stranding—for example, minimizing the leptospirosis prevalence in 2000. This emphasizes the importance of examining patterns in the total numbers of animals stranding, as well as in disease prevalence.

The prevalence of malignant, metastatic carcinoma has not changed over the decade of this study. As this disease is chronic and progressive, and sea lions have an annual migration pattern, stranding date and location are unlikely to be associated with the time and place where the tumor first developed. Thus, the observed pattern in stranding location is unlikely to give insight into the factors involved in the etiology of this fatal disease. The biological significance of the spatial cluster near Monterey is unclear, but it may represent an easy place for sick animals to come ashore. Alternatively, there could be a genetic component to both the etiology of this cancer and sea lion movement patterns.

Facilities to treat stranded marine mammals are developing worldwide and offer increased opportunities to learn about the health of wild populations. Percentages of stranded animals with certain diseases may or may not mirror disease prevalence in the wild population. In addition, because stranded animals are reported by the public, their spatial distribution likely reflects areas of the coast with greatest human habitation. Despite these biases, long-term analysis of stranding patterns can reveal disease trends among the stranded population and can help elucidate factors contributing to marine mammal strandings.

#### Acknowledgments

We thank past and present staff and volunteers for their years of hard work that made this study possible, especially Matt Roosevelt and Catherine Gunther-Murphy for help evaluating sea lion charts; Marty Haulena, Debbie Fauquier, and Becky Duerr for performing necropsies and collecting California sea lion teeth; and Kelly Robertson and Kerri Danil from Southwest Fisheries Science Center, La Jolla, for aging those teeth. Thanks also to Wade Smith for assistance in fitting the growth curves. We thank the Arthur and Elena Court Nature Watch Conservancy and the John H. Prescott Marine Mammal Rescue Assistance Grant Program for financial support. The work described in this paper was conducted under a Letter of Authorization from the National Marine Fisheries Service's Marine Mammal Health and Stranding Program.

## Literature Cited

- Berrow, S. D., & Rogan, E. (1997). Review of cetaceans stranded on the Irish coast, 1901-95. *Mammal Review*, 27, 51-76.
- Colagross-Schouten, A. M., Mazet, J. A. K., Gulland, F. M. D., Miller, M. A., & Hietala, S. (2002). Diagnosis and seroprevalence of leptospirosis in California sea lions from coastal California. *Journal of Wildlife Diseases*, 38, 7-17.
- De, S. W. M. A. (1997). Five centuries of sperm whale strandings along the Flemish coast. *Bulletin de L'Institut Royal des Sciences Naturelles de Belgique Biologie*, 67, 11-14.
- Dierauf, L. A. (1983). A survey of live pinnipeds stranded along the northern California coast. *California Veterinarian*, 6, 22-26.
- Dunlap, W. S. (1995). *The influence of El Niños on pinniped strandings along the California coast 1982-1992*. M.S. thesis, University of San Diego, San Diego, CA.
- Eguchi, T. (2002). A method for calculating the effect of a die-off from stranding data. *Marine Mammal Science*, 18, 698-709.
- Evans, K., & Robertson, K. (2001). A note on the preparation of sperm whale (*Physeter macrocephalus*) teeth for age determination. *Journal of Cetacean Research & Management*, 3, 101-107.
- Fauquier, D. A., Gulland, F. M., Trupkiewicz, J. G., Spraker, T. R., & Lowenstine, L. J. (1996). Coccidiodomycosis in free-living California sea lions (*Zalophus californianus*) in central California. *Journal of Wildlife Diseases*, 32, 707-710.
- Forney, K. A., Barlow, J., Muto, M. M., Lowry, M., Baker, J., Cameron, G., Mobley, J., Stinchcomb, G., & Carretta, J. V. (2000). *U.S. Pacific marine mammal stock assessment: 2000* (NOAA Technical Memorandum, TM-NMFS-SWFSC-300).
- Gage, L. J., Gerber, J. A., Smith, D. S., & Morgan, L. E. (1993). Rehabilitation and treatment success of California sea lions (*Zalophus californianus*) and northern fur seals (*Callorhinus ursinus*) stranded along the central and northern California coast, 1984-1990. *Journal of Zoo & Wildlife Medicine*, 24, 41-47.
- Gerber, J. A., Roletto, J., Morgan, L. E., Smith, D. M., & Gage, L. J. (1993). Findings in pinnipeds stranded along the central and northern California coast, 1984-1990. *Journal of Wildlife Diseases*, 29, 423-433.
- 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, A. B., Secchi, E. R., Zerbini, A. N., & Dalla, R. L. (2001). Stranding events of southern right whales, *Eubalaena australis*, in southern Brazil. *Journal of Cetacean Research & Management*, Special Issue, 157-160.
- Gulland, F. M. D. (1999). Stranded seals: Important sentinels. *Journal of the American Veterinary Medicine Association*, 214, 1191-1192.
- Gulland, F. M. D. (2000). *Domoic acid toxicity in California sea lions (Zalophus californianus) stranded along the central California coast, May-October 1998* (NOAA Technical Memorandum, NMFS-OPR).
- Gulland, F. M. D., Haulena, M., & Dierauf, L. (2001). Seals and sea lions. In *CRC handbook of marine mammal medicine* (2nd ed.) (pp. 907-926). Boca Raton, FL: CRC Press.
- Gulland, F. M., Trupkiewicz, J. G., Spraker, T. R., & Lowenstine, L. J. (1996a). Metastatic carcinoma of probable transitional cell origin in 66 free-living California sea lions (*Zalophus californianus*), 1979 to 1994. *Journal of Wildlife Diseases*, 32, 250-258. [Published erratum appears in *Journal of Wildlife Diseases*, 1996, 32(3), 564.]
- Gulland, F. M., Lowenstine, L. J., Lapointe, J. M., Spraker, T., & King, D. P. (1997). Herpesvirus infection in stranded Pacific harbor seals of coastal California. *Journal of Wildlife Diseases*, 33, 450-458.
- Gulland, F. M., Koski, M., Lowenstine, L. J., Colagross, A., Morgan, L., & Spraker, T. (1996b). Leptospirosis in California sea lions (*Zalophus californianus*) stranded along the central California coast, 1981-1994. *Journal of Wildlife Diseases*, 32, 572-580.
- Gulland, F. M. D., Haulena, M., Fauquier, D., Langlois, G., Lander, M. E., Zabka, T., & Duerr, R. (2002). Domoic acid toxicity in Californian sea lions (*Zalophus californianus*): Clinical signs, treatment and survival. *Veterinary Record*, 150, 475-480.
- 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. K. (2003). Patterns of mortality in southern sea otters (*Enhydra lutris nereis*) from 1998-2001. *Journal of Wildlife Diseases*, 39, 495-509.
- Kulldorf, M., & Nagarwalla, N. (1995). Spatial disease clusters: Detection and inference. *Statistics in Medicine*, 14, 799-810.
- Lapointe, J. M., Gulland, F. M. D., Haines, D. M., Barr, B. C., & Duignan, P. J. (1999). Placentitis due to *Coxiella burnetti* in a Pacific harbor seal (*Phoca vitulina richardsi*). *Journal of Veterinary Diagnostic Investigations*, 11, 541-543.
- Lauckner, G. (1985). Diseases of mammalia: Pinnipedia. In *Diseases of marine animals IV* (pp. 683-794). Hamburg, Germany: Biologische Anstalt Helgoland.
- Leighton, F. A., & Kuiken, T. (2001). Leptospirosis. In E. S. Williams & I. K. Barker (Eds.), *Infectious diseases of wild mammals* (pp. 498-501). Ames: Iowa State University Press.
- Lipscomb, T. P., Scott, D. P., Garber, R. L., Krafft, A. E., Tsai, M. M., Lichy, J. H., Taubenberger, J. K., Schulman, F. Y., & Gulland, F. M. D. (2000). Common metastatic carcinoma of California sea lions (*Zalophus californianus*): Evidence of genital origin and association with

- novel gammaherpesvirus. *Veterinary Pathology*, 37, 609-617.
- Lucas, Z. N., & Hooker, S. K. (2000). Cetacean strandings on Sable Island, Nova Scotia, 1970-1998. *Canadian Field-Naturalist*, 114, 45-61.
- McLellan, W. A., Friedlaender, A. S., Mead, J. G., Potter, C. W., & Pabst, D. A. (2002). Analysing 25 years of bottlenose dolphin (*Tursiops truncatus*) strandings along the Atlantic coast of the USA: Do historic records support the coastal migratory stock hypothesis? *Journal of Cetacean Research & Management*, 4, 297-304.
- Melin, S. R. (2002). *The foraging ecology and reproduction of the California sea lion* (*Zalophus californianus californianus*). Ph.D. dissertation, University of Minnesota, Minneapolis.
- Ono, K. A., Boness, D. J., & Oftedal, O. T. (1987). The effect of a natural environmental disturbance on maternal investment and pup behavior in the California sea lion. *Behavioral Ecology and Sociobiology*, 21, 109-118.
- Ridgway, S., Geraci, J., & Medway, W. (1975). Diseases of pinnipeds. *Rapports et Procès-Verbaux Des Réunions. Conseil International Pour L'exploration De La Mer*, 169, 327-337.
- Scholin, C. A., Gulland, F., Doucette, G. J., Benson, S., Busman, M., Chavez, F. P., Cordaro, J., DeLong, R., De Vogelaere, A., Harvey, J., Haulena, M., Lefebvre, K., Lipscomb, T., Loscutoff, S., Lowenstine, L. J., Marin, R., Miller, P. E., McLellan, W. A., Moeller, P. D. R., Powell, C. L., Rowles, T., Silvagni, P., Silver, M., Spraker, T., Trainer, V., & Van Dolah, F. M. (2000). Mortality of sea lions along the central California coast linked to a toxic diatom bloom. *Nature (London)*, 403, 80-84.
- Silva, M. A., & Sequeira, M. (2003). Patterns in the mortality of common dolphins (*Delphinus delphis*) on the Portuguese coast, using stranding records, 1975-1998. *Aquatic Mammals*, 19(1), 88-98.
- Thornton, S. M., Nolan, S., & Gulland, F. M. D. (1998). Bacterial isolates from California sea lions (*Zalophus californianus*), harbor seals (*Phoca vitulina*), and northern elephant seals (*Mirounga angustirostris*) admitted to a rehabilitation center along the central California coast, 1994-1995. *Journal of Zoo and Wildlife Medicine*, 29, 171-176.