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Evidence of anthropogenic trauma in marine mammals stranded along the central California coast, 2003–2015

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Abstract

A total of 11,162 stranded marine mammals was admitted to a rehabilitation center on the central California coast between

January 2003 and September 2015. Six hundred seventeen animals (6%) had evidence of anthropogenic trauma (AT). California sea lions comprised the majority (83%) of AT cases, particularly by entanglement in marine debris (*n* = 277) and gunshot injuries (*n* = 165). Guadalupe fur seals had the highest prevalence of entanglement in marine debris. Cetaceans were primarily affected by boat collisions (*n* = 19). The highest numbers of overall strandings were recorded in 2009 (*n* = 1,690) and 2015 (*n* = 1,666); 2009 also had the highest total number (*n* = 137) and prevalence (8%) of AT cases. Prevalence of fishing tackle cases increased compared to similar data from 1986 to 1998 while prevalence of gunshot cases decreased, and other causes remained static. Cases of fisheries interactions were further examined and characterized, and when direct fisheries interactions were separated from other causes of AT, fisheries interactions accounted for 50% (*n* = 310) of all AT cases during the study period. Direct fisheries interactions were the most common type of AT observed among stranded marine mammals in central California. Tracking AT trends is important to further understand possible causes and inform mitigation efforts.
Key words: anthropogenic trauma, cetaceans, marine debris, pinnipeds, fisheries interactions.

Anthropogenic trauma (AT), defined as injury attributed to humans, including both intentional injury as well as unintentional interaction between an animal and human-produced gear and debris, has been documented as a significant source of morbidity and mortality for marine mammals (Harcourt 1994, Wells and Scott 1997, D'Agrosa *et al*. 2000, Knowlton *et al.* 2003, Read *et al.* 2006). In the United States, The Marine Mammal Protection Act of 1972 made it illegal to harass or harm marine mammals, but even with enforcement, intentional human trauma occurs. Injuries due to gunshot wounds have been noted in many marine mammal mortality surveys, although few shootings are witnessed (Gerber *et al*. 1993, Greig *et al*. 2005). As human populations continue to expand in coastal areas, and marine mammal populations such as the California sea lion (*Zalophus californianus*) increase, human-marine mammal conflicts are expected to continue.

Marine debris, including fishery-related and ocean trash, poses a direct threat to marine mammals through entanglement and ingestion (Johnson *et al.* 2005, Moore *et al.* 2009). Marine debris causes chronic morbidity, and is often progressive and fatal (Stewart and Yochem 1987, Jacobsen *et al.* 2010). Along the California coast, entanglements in marine debris have been documented to affect wild pinniped populations since the 1970s, and prevalence has been static to increasing (Stewart and Yochem 1987, Hanni and Pyle 2000). Stranding data can be a useful source of information about anthropogenic trauma, though there are caveats with using these data to estimate population-level rates, as strandings data favor sick or injured animals, and an unknown portion of affected animals never wash ashore (Simeone *et al.* 2015).

A retrospective study of stranding data from 1986 to1998 documented evidence of marine mammal-anthropogenic trauma among stranded animals along the central California coast (Goldstein *et al.* 1999). The purpose of the current study is to analyze numbers of stranded marine mammals with evidence of AT from 2003 to 2015, and to determine whether these cases are changing over time. This study compared these recent data to the older data set to determine if overall trends in total numbers and prevalence of AT changed over time. We expected the number of AT cases to be correlated with the number of stranded animals, and we further hypothesized that AT would vary by species, season, stranding location, age class, and sex, due to differences in life history characteristics and distribution of different taxa.

Materials and Methods

Pinnipeds and cetaceans that strand along the central California coast between 40.0006°N, −124.0205°W and 34.9742°N, −120.6482°W, are assessed by The Marine Mammal Center (TMMC), a rehabilitation hospital in Sausalito, California. Live animals are transported to the facility for rehabilitation, or relocated after providing medical care. Data from stranded animals with evidence of AT were obtained from TMMC medical records from January 2003 to September 2015. This timeframe was selected to include the same number of months as Goldstein *et al.* (1999), which reviewed cases from January 1986 to September 1998, in order to accurately compare the data sets. Recorded information for all animals included: species, date and location of stranding, sex, age, standard length, type of interaction, evidence of interaction, location of injury, and final disposition. Clinical examination of every live animal was performed, including hematology and serum biochemistry, physical examination, and evaluation of wounds or injuries. In cases where an injury caused by marine debris was found, the object was removed, and wounds were treated. In cases of suspected gunshot wounds, radiographs were taken to determine the location, type, and size of the ammunition. If animals were found dead or died during treatment, necropsies were performed and the presence of wounds, marine debris, or lead fragments was recorded. When possible, items were recovered, typed and measured. Sex of animals was determined based on external genital appearance, and age class assigned based on length, pelage, or tooth development as previously described (Riedman 1990).

Stranding location was pooled because of high variability in stranding numbers between counties. Counties within the response range were categorized into larger groups: north (Mendocino, Sonoma, Sacramento, Marin, San Francisco, Alameda, and San Mateo counties), central (Santa Cruz and Monterey counties) and south (San Luis Obispo and Santa Barbara counties). Santa Barbara county standings were only included from 2013 to 2015 based on stranding response capabilities. Stranding month was also pooled for analysis by season: winter (December, January, February), spring (March, April, May), summer (June, July, August), and fall (September, October, November). "Cases" refer to animals with AT, while "strandings" refers to all stranded animals.

For the first analysis, four categories of AT were established according to the type of injuries most commonly found in the recorded data, and following the criteria used by Goldstein *et al.* (1999): marine debris, gunshot, fishing tackle, and boat collision. Cases of AT were grouped into these four categories consistent with Goldstein *et al*. (1999). Marine debris included any active or discarded fishing netting, fishing line, plastic strapping, plastic bags, ropes, and rubber o-rings. Gunshot included all cases where lead fragments were found. When ammunition was recovered, it was typed, and measured, then classified as shot from 9-2 gauge, BB, buck shot from 4-000 gauge, or fragments if size could not be determined. Fishing tackle included the presence of any hook, lure, or pots.

Boat collision trauma was considered when characteristic propeller injuries were noted, or blunt force trauma associated with an anatomic location and to a degree of severity consistent with vessel strike were found, as described in Moore *et al.* (2013). Animals were assigned to more than one category if affected by more than one type of AT as reported in Goldstein *et al*. (1999) (*e.g*., if an animal had both fishing tackle and line present).

An additional analysis was made using a different categorization to separate direct fisheries interaction from other kinds of marine debris entanglement not directly related, or without sufficient evidence of being related to fisheries. Two categories were established for this additional categorization: Fisheries-related trauma and marine debris entanglement (nonfisheries-related). Fisheries-related trauma included the presence of any kind of fishing line, net, hook, lure or pots. Marine debris entanglement (nonfisheries-related) included any entanglements or wounds caused by materials other than fisheries-related gear such as, packing straps, rubber o-rings or other trash. This category also included cases with entanglement scars, where the materials causing the scar were not found with the animal, and there was not sufficient evidence to associate them with fisheries.

Statistical analyses were performed using SAS/STAT 14.1. Correlation was used to determine whether total numbers of AT cases per year were related to total numbers of strandings per year. One-way analysis of variance (ANOVA) or Wilcoxon tests were used to determine whether both total numbers of AT cases and prevalence varied by categorical data (*i.e*., species, sex, age class, location, marine debris type), with Tukey’s *post hoc* tests to determine differences between individual categories. Only pinnipeds were analyzed in the comparison with Goldstein *et al*. 1999, because that study did not include cetacean data. Either Student's *t*- or Wilcoxon tests were used to compare current stranding data for both total numbers of AT cases and prevalence with data reported in Goldstein *et al.* (1999). All data were tested for normality and equal variance, and values of $P < 0.05$ were considered significant.

Results

A total of 11,162 stranded animals was recorded from January 2003 to September 2015. Ten thousand, eight hundred and thirty-eight were pinnipeds (97%) and 324 were cetaceans (3%). Evidence of AT was found in 617 animals (5.5% total prevalence) (Table 1).

The total number of all AT cases during this time period was correlated with overall strandings ($r^2 = 0.62$, $F_{1,11} = 18.0$, $P = 0.001$). However, when analyzed separately, the number of pinniped AT cases was correlated with higher overall pinniped strandings ($r^2 = 0.54$, $F_{1,11} = 12.8$, $P = 0.004$), but this was not found with cetaceans ($r^2 = 0.24$, $F_{1,11} = 3.5$, $P = 0.08$). The largest overall number of stranded animals ($n = 1,690$) occurred in 2009, which also had the largest number of AT cases ($n = 137$). The smallest overall number of stranded animals was recorded in 2012 (n=523), and 2006 had the smallest number of AT cases ($n = 14$) (Fig. 1).

Additionally, AT cases varied by season. Amongst all pinnipeds, there was a difference between the total number of AT cases by season ($\chi^2 = 10.4$, df = 4, $P = 0.016$), with summer having more cases than both winter and fall (Wilcoxon, $P < 0.05$) (Fig. 2). Percent AT varied by season in pinnipeds (ANOVA, $F_{3,155}$

= 5.2, *P* = 0.008), with summer months having higher prevalence than both spring and winter (Tukey's, $P < 0.05$) but not fall (Tukey's, $P = 0.11$). Similarly, in cetaceans total numbers of AT cases varied by season ($\chi^2 = 9.82$, df = 4, $P = 0.022$), and both spring and summer months showed higher numbers of cases than both winter and fall (Wilcoxon, $P < 0.05$). Prevalence of AT cases in stranded cetaceans also varied by season (ANOVA, $F_{3,155} = 9.9$, $P = 0.003$), with spring months having higher prevalence than all other seasons (Tukey's, $P < 0.05$).

Differences in stranding location were detected for pinniped AT cases (ANOVA, $F_{2,6} = 4.9$, $P = 0.05$), with central counties having the highest total number of AT cases (Tukey's, $P < 0.05$)(Fig. 3). However, central counties also had the greatest number of pinniped strandings overall and the prevalence did not vary between the counties ($P = 0.19$). For stranded cetaceans, there were no statistically significant differences between stranding locations (ANOVA, $F_{2,6} = 4.6$, $P = 0.06$), but northern counties had higher total numbers of AT cases. Cetacean prevalence also did not vary by location ($P = 0.68$).

Across taxa, there were more California sea lion strandings due to AT than any other species, representing 83% of all AT cases. The main trauma category affecting pinnipeds was marine debris (54% of all AT cases; Table 2), while cetaceans were most frequently affected by boat collision injuries (3% of all AT cases; Table 3).

A total of 511 California sea lions was affected by AT. Male California sea lions ($n = 325$) were more frequently affected than females ($n = 177$) ($t = 2.47$, df = 22, $P = 0.02$). California sea lions also varied by age class ($r^2 = 0.43$, $F_{4,66} = 4.38$, $P = 0.009$), with yearlings and juveniles comprising more

AT cases than other age classes (Tukey's, $P < 0.05$). The most frequently encountered category of AT for California sea lions was marine debris ($n = 277$), followed by gunshot ($n = 165$), fishing tackle ($n = 158$), and boat collision ($n = 4$) (Table 1).

Forty-two cases of AT were recorded for northern elephant seals (*Mirounga angustirostris*), 12 for harbor seals (*Phoca vitulina*), 10 for Guadalupe fur seals (*Arctocephalus philippii townsendi*), five for northern fur seals (*Callorhinus ursinus*), and one Steller sea lion (*Eumetopias jubatus*) (Table 1).

A total of 35 cetaceans was affected by AT in the years reported. Mysticete species (*Megaptera novaeangliae*, *Eschrichtius robustus*, *Balaenoptera musculus*, *Balaenoptera physalus,* and *Balaenoptera acutorostrata*) were found to be more frequently affected by AT ($n = 22$) than odontocetes species (*Phocoena phocoena*, *Physeter macrocephalus*, *Delphinus delphis, Delphinus capensis*, *Stenella longirostris*, and *Orcinus orca*) ($n = 13$), while the distribution of overall stranded cetaceans during the study period was the opposite (mysticetes comprising 16% of all stranding cases, odontocetes comprising 84%; Table 1). Twenty-one of the affected animals were females and 14 were males. The most affected age classes were adults ($n = 18$) and juveniles ($n = 10$). Adult females were the most affected group overall ($n = 11$). Boat collision was the most frequent cause of AT in cetaceans, representing 54% of the AT cases for cetaceans, followed by marine debris (34%), while fishing tackle represented only 9% and gunshot cases were not observed in this group (Table 3).

Marine Debris

Marine debris entanglement was the most common type of AT found in pinnipeds ($n = 331$), representing 54% of all AT cases and 3% of all pinniped strandings (Table 2). Marine debris injuries were recorded in 12 cetaceans, representing 2% of all AT cases. Odontocetes comprised more cases (75% of cetacean marine debris cases) than mysticetes (25%). Prevalence is reported in Table 1.

Of the 331 pinnipeds affected by entanglement in marine debris, 55% were males, 39% were females, and 6% were of unknown sex. By age class, the greatest percentage of entanglement in marine debris was documented in yearlings (40%), followed by juveniles (19%), and pups (17%). In cetaceans, cases were equally frequent in males and females, and 50% of the cases were adults. The most common material that caused entanglement was fishing line (n = 124) mainly clear line, ranging from 0.25 to 0.9 cm in diameter; and green or clear monofilament gill netting (n = 105), which typically ranged from 9–11 cm^2 mesh size with an 80–100 lb strength. The lesions caused by marine debris entanglement were often located around the neck, head, and flippers/fins.

The largest number of pinniped marine debris injury cases was recorded in 2009 (n = 94), followed by 2014 (n = 36) and 2015 (n = 36) (Table 2), while 2014 had the highest number of marine cases for cetaceans (n = 5) (Table 3). Cases of pinniped marine debris entanglement were noted throughout the year, but were more frequently recorded during the months of July (n = 60), June (n = 56), and May (n = 55) across all years examined, even though prevalence did not change seasonally (Fig. 2). April, June, August, and September each had two cases of cetacean marine debris, representing 67% of all marine debris cases recorded in cetaceans during the study period.

Most marine debris cases in pinnipeds originated from

Monterey County (n = 123; 37% of all marine debris cases recorded in pinnipeds), Santa Cruz County (n = 67), and San Luis Obispo County (n = 67) (Fig. 3). San Francisco County (n = 4; 33% of all marine debris cases recorded in cetaceans) and San Mateo County (n = 3) registered the highest frequencies for this category in cetaceans.

Gunshot

Gunshot was the second most common type of AT recorded, with a total of 169 cases noted throughout the study period. California sea lions comprised 98% (n = 165) of these cases (Table 2). No gunshot cases were recorded in cetaceans. Prevalence is reported in Table 1.

Gunshot injuries were found along the entire body, but frequently encountered in the head or neck. Cases were more frequently recorded in males (70%) than in females (30%). Of all age classes, adults comprised the highest proportion of gunshot wounds, followed by juveniles and yearlings. A higher proportion of juvenile and yearlings presenting gunshot wounds were male compared to female (85%), however, more adult females were affected than adult males. The highest number of gunshot injuries was recorded in 2003 (n = 29) followed by 2004 (n = 27) (Table 2). Among all years, September (n = 25), July (n = 24), and August (n = 23), had the highest frequency of these injuries (Fig. 2). Monterey County had the highest number of gunshot cases (n = 43), as well as the highest number of total strandings (Fig. 3).

Fishing Tackle

California sea lions made up 94% of fishing tackle cases in pinnipeds (n = 158) (Table 1). Males were more frequently found to have fishing tackle present (58%) than females (37%); and yearlings were the most affected age class. Fishing tackle affected three cetaceans; one adult female humpback whale, one male juvenile gray whale, and one adult male killer whale.

Fishing tackle AT cases occurred most commonly during the months of July (*n* = 60), June (*n* = 40), and May (*n* = 20) across all years (Fig. 2). The most frequently encountered hooks were the sabiki (*n* = 37) and the octopus hook (*n* = 27). All recorded cetacean cases involved crab pot entanglements. Santa Cruz county had the largest number of fishing tackle cases (*n* = 60) (Fig. 3).

Boat Collision

Boat collisions were reported more frequently in cetaceans than pinnipeds (Table 1). Boat collision was recorded in 19 cetaceans, accounting for 54% of all cetacean AT cases. These injuries were recorded in 17 mysticetes and two odontocetes. Nine of these animals were adults, four were juveniles and four were calves. All the pinnipeds affected by boat collisions (*n* = 10) were young: three were juveniles, three were yearlings and four were pups. The majority of affected pinnipeds were male (80%). Cases were most frequently noted during the months of May (*n* = 7), June and July (*n* = 5), followed by April and October (*n* = 4) (Fig.2). The largest number of cases was reported in Marin County (*n* = 9) (Fig. 3).

Comparing Retrospective and Current Anthropogenic Trauma Data

Total numbers of stranded pinnipeds increased during the time period reported in this study when compared to Goldstein *et al.* (1999) ($F_{1,76}$ = 4.6, P = 0.035) (Fig. 4). This is likely due to population growth and to anomalous years with highly increased numbers of stranded California sea lions within the last 5 yr (Melin *et al*. 2010). Within California sea lions, which accounted for most AT cases, total numbers of AT due to marine debris increased in recent years ($F_{1,24}$ = 5.26, P = 0.031). Similarly, total numbers of AT due to fishing tackle, such as hooks, increased (χ^2 = 5.46, df = 1, P = 0.019). However, there was no change in the total number of gunshot (P = 0.11) or boat collision (P = 0.72) cases (Fig. 4). Because the number of strandings was different between the two time periods, and AT was associated with numbers of strandings, the following comparisons use prevalence (proportion of AT to strandings) to standardize data between the two time periods. No changes were seen in the prevalence of boat strike (P = 0.66) or marine debris (P = 0.94) cases in California sea lions, however prevalence of fishing tackle entanglements marginally increased (χ^2 = 3.1, df = 1, P = 0.079) with a mean of 0.7% in Goldstein *et al.* 1999 and 0.15% during the time period reported in this study. Prevalence of gunshots in California sea lions did decrease when compared to Goldstein *et al.* 1999 (χ^2 = 12.7, df = 1, P = 0.0004). Total elephant seal strandings did not change when compared to Goldstein *et al.* 1999, however, cases of AT due to marine debris did increase (χ^2 = 6.69, df = 1, P = 0.0097). Both total Guadalupe fur seal strandings ($F_{1,24}$ = 4.56, P = 0.043) and total marine debris AT cases ($F_{1,24}$ = 6.31, P = 0.019) increased when compared to Goldstein *et al.* (1999). No other significant changes were seen in other pinniped species between each time period. Cetaceans were not assessed in the Goldstein *et al.* data set.

Distinguishing Direct Fisheries Interactions

Within pinnipeds, which represented the majority of AT cases, direct fisheries interactions were significantly higher than AT from nonfishing-related materials (t = 2.94, P = 0.042).

Three hundred pinnipeds had entanglements or wounds caused by materials that were directly related to fisheries (Table 4). The most common materials causing these injuries were fishing line and fishing nets. Ninety-eight cases of marine debris injuries in pinnipeds were caused by nonfishing-related materials (Table 4). Amongst all pinnipeds, there was a difference between the total number of direct fisheries interactions cases by season ($\chi^2 = 5.85$, df = 4, $P = 0.021$), with summer having more cases than all other seasons (Wilcoxon, $P < 0.05$). In contrast, there was no effect of season on nonfishing-related materials ($P = 0.42$). Differences in stranding location were detected for direct fisheries interactions ($\chi^2 = 7.8$, df = 4, $P = 0.02$), with central counties having the highest total number of direct fisheries interactions (Tukey's, $P < 0.05$). Differences in stranding location were also detected for AT due to nonfishing-related materials interactions ($\chi^2 = 6.19$, df = 4, $P = 0.045$), with central and southern counties having higher numbers than northern counties (Tukey's, $P < 0.05$). California sea lions, which represented the majority of pinniped AT cases, had over four times more direct fisheries interactions than nonfisheries interactions (Table 4). In contrast, elephant seals had more nonfisheries interactions (Table 4). Out of 35 total AT cases, direct fisheries interactions occurred in 10 cetaceans, while marine debris unrelated to fisheries caused injuries in five cetaceans (Table 4).

Discussion

The natural history of the marine mammal species along the California coast likely explains many of the stranding patterns noted. California sea lions comprised the majority of overall cases due to their local abundance (more than 130,000 animals along the California coast), and the proximity of their primary rookeries to the southern end of the rescue range (Lowry and Maravilla-Chavez 2005). Although several cetacean species are residents of coastal California, cetaceans cases in general are likely underrepresented due to the fact that they are more likely to die at sea than pinnipeds, who routinely haul out on land.

Total strandings, as well as total AT cases, peaked in 2009 and 2015. In 2009, this was attributable to an anomalous oceanographic event characterized by the strongest negative upwelling observed in four decades and uncharacteristically warm sea surface temperatures. The timing of the event coincided with reduced availability of typical prey of California sea lions, as well as high pup and yearling mortality due to starvation (Melin *et al*. 2010). Previous studies have also found a higher number of strandings associated with AT and fisheries interactions occur during El Niño events, potentially due to the fact that young animals learning to forage may be less successful during El Niño conditions, and there may be an increase in competition for resources between marine life and fishermen, or a physical overlap in fishing ranges (Greig *et al.* 2005, Keledjian and Mesnick 2013). This trend was noted during 2009, but not in 2015. This may be due in part to the partial data set through September of 2015, but total strandings were similar to 2009, and AT cases did not rise above the annual mean. The lack of increase in AT cases is likely explained by the fact that the majority of strandings in 2015 were prematurely weaned California sea lion pups, that typically would not have had time to attempt to forage prior to their rescue.

The counties with the highest numbers of both AT cases and overall strandings were Monterey, Santa Cruz, and San Luis Obispo. This may reflect higher effort because of their proximity to TMMC rescue facilities in both Monterey and San Luis Obispo. Monterey Bay is often used as a feeding area, especially by California sea lions during the high productivity season, increasing the abundance of animals near those areas (Melin *et al.* 2010). These are also highly populated areas with high human usage of the coast for different activities such as fishing, tourism, and recreational activities, which may increase the possibility for AT in these areas.

In the California sea lion data set, males were more frequently affected by AT than females, mirroring findings in similar marine mammal studies (Goldstein *et al.* 1999, Mawson and Coughran 1999). Adult male sea lions have higher mortality rates than adult females (Hernández-Camacho *et al*. 2008). Adult males are not restricted to breeding rookery islands, and travel more often than females, often hauling out in coastal areas where they may be more exposed to sources of AT. However, younger animals were more affected than older animals in this study, especially by marine debris entanglement. This may be due to lack of experience, limited foraging abilities, and curiosity, facilitating entanglement in fishing nets, lines, and tackle (Zavala-González and Mellink 1997). In contrast, among cetaceans, adult females comprised the largest number of AT cases. This may be due in part to the natural history of cetacean species that inhabit the California coast, but it is difficult to interpret these data due to the small number of cetacean AT cases.

Cases of AT peaked during summer, which may be related to higher abundance of animals in the area at this time of year.

During the summer months there is higher ocean productivity due to upwelling generated by the California current, which brings an influx of animals to the area to feed near the coast, and the summer is also the peak weaning and reproductive season for California sea lions, which is a time when young animals are more vulnerable to AT and stranding (Melin *et al.* 2010).

AT cases ranged from 3% to 8% of total strandings each year, with a mean of 5%, slightly lower than the 8% mean reported previously (Goldstein *et al.* 1999). Small differences in record keeping, such as classification of gear, make direct comparison of the two data sets challenging, but trends in total trauma cases have been largely static. Gunshot cases comprised nearly 5% of all pinniped cases between 1986 and 1998, and dropped to 2% of all cases in this study between 2003 and 2015. Although Goldstein *et al.* (1999) reported individual years with high totals of gunshot cases, overall there were no significant annual differences in the numbers of gunshot cases reported in this study. Most importantly, however, prevalence of gunshot cases has decreased. Marine debris and fishing tackle entanglements have both replaced gunshot wounds as the most frequently encountered type of AT. The percentage of marine debris cases significantly increased for three pinniped species, comprising 2% of all pinniped strandings between 1986 and 1998, and rising to 3% between 2003 and 2015.

When analyzing the categorized data to better understand the trends of direct interactions with fisheries, half of the overall AT cases in this study can be directly related to some sort of fisheries interactions, especially with fishing lines and nets. The highest incidence of these interactions noted during the summer months in this study can also be related to the temporality of these fishing activities, since the majority of these fisheries are open during the summer season (Goldstein *et al*. 1999).

Roughly 17% of entanglements and injuries were caused by ocean trash (nonfishing-related marine debris). This differentiation was not made in the previous data set. Therefore, we were unable to determine if this category increased over time. However, over the past 30 yr, the use and disposal of plastics and other synthetic materials has expanded at a rapid pace (Derraik 2002). Without waste management improvements, the amount of plastic entering the ocean is expected to increase by an order of magnitude by 2025 (Jambeck *et al.* 2015). Reports of encounters between marine organisms and debris have increased in frequency, both for numbers of species and numbers of individuals affected (Laist 1997, Gall and Thompson 2015).

California sea lions comprised the greatest number of cases in both fisheries-related injuries and nonfisheries-related marine debris. As described previously this is a result of California sea lions being the most abundant species in the area, and sea lions have been reported to have high rates of interactions with fisheries worldwide (Szteren and Paez 2003, Page *et al*. 2004). Guadalupe fur seals had the highest prevalence for both debris categories. This is of particular concern because of the current population status of the species. Direct fisheries interactions and ocean trash appear to be significant threats for this species based on this study.

Boat collision was the primary source of AT for cetaceans (54%), while minor for pinnipeds (2%). This may reflect sampling bias in the stranding record if pinnipeds killed by boats are less likely to be recovered. Boat collision has been documented as an important cause of mortality in cetaceans, especially in large whales, and it is considered a significant threat for the viability of some species such as the north Atlantic right whale (*Eubalaena glacialis)* (Van Waerebeek *et al.* 2007, Berman-Kowalewski *et al.* 2010). The Pacific coast of the United States is considered a hotspot for boat collision incidents due to its high volume of vessel traffic (Jensen and Silber 2003).

The prevalence of AT cases noted in the rehabilitation population in this study (6% of all strandings) may be higher than the actual prevalence among wild populations, because marine mammals admitted to rehabilitation facilities are typically either sick or injured. Additionally, animals with some traumatic injuries may be more likely to stay close to or on the coast where they can be noted by the public and reported for rescue. However, studies of wild marine mammals have noted similar prevalence among wild animals. The prevalence of marine debris cases (3%) was similar to that previously reported in wild New Zealand fur seals (*Arctocephalus forsteri*) (2.8%) and higher than what was reported in wild pinnipeds on the Channel Islands in California (0.16%), at Marion Island, Southern Ocean (0.24%), and for Hawaiian monk seals (*Neomonachus schauinslandi*) (0.7%) (Stewart and Yochem 1987, Henderson 2001, Hofmeyr *et al.* 2002, Boren *et al.* 2006). Entanglements are often chronic in nature, and entangled animals are highly visible for assessment in the wild.

Alternatively, some trauma categories may be underestimated. Gunshot wounds are more likely to be immediately fatal compared to marine debris entanglements, and therefore less likely to be encountered on the beach. Cetacean trauma was also likely underestimated because cases of live entanglement or nonfatal boat-strike were not included in the stranded animal data set. Continued research is necessary to better understand the relationship between human actions and marine mammals in the wild.

Anthropogenic trauma is a threat in particular to marine mammals worldwide, but the rates noted in this study are unlikely to significantly impact population sizes for most of the species studied. For Guadalupe fur seals, a threatened and reproductively isolated species, this study's findings are concerning that total strandings and entanglement in marine debris increased compared to the previous data set. Fisheries interactions are recognized as a main potential threat to this population (Aurioles-Gamboa 2015). Monitoring trends in AT is also important for recovering populations, such as the recently delisted Eastern Distinct Population Segment of Steller sea lions, for whom AT remains a threat to recovery (NMFS 2008). Increasing human and marine mammal populations are likely to shift the frequency of interactions between these two groups. In addition, entanglement in and ingestion of marine debris has the potential to significantly affect endangered marine mammal species that have much smaller population sizes. Debris entanglement and fisheries bycatch are listed as primary threats to the endangered Hawaiian monk seal, Mediterranean monk seal (*Monachus monachus*), and vaquita *(Phocoena sinus*) (Reeves *et al.* 2003, Kovacs *et al.* 2012). For these small populations, AT has the potential to greatly affect species recovery.

The majority of the cases in this study were rescued following a report of injury. In some cases, however, proactive attempts to address entanglements are made, due to their prolonged morbidity and eventual progression to conditions such as tracheal perforation and death. Wild entangled animals are often robust and difficult to approach, even with a severe entanglement. Novel techniques are being developed to address the challenges encountered when attempting to disentangle marine mammals from marine debris. Remote sedation using drug combinations that preserve the respiratory drive can increase the safety of immobilization of animals near and in the water (Melin *et al.* 2013, Frankfurter *et al.* 2016). Utilization of tracking equipment such as an acoustic dart and hydrophone allow teams to track darted animals until they become sedated and can be safely recovered and disentangled (Frankfurter *et al.* 2016). Once disentangled, these animals retain scar tissue for life, and they are useful to educate the public on the threat of marine debris to wild marine mammals.

Marine mammals affected by AT are highly visible sentinels of the impacts humans have had on the marine ecosystem (Bossart 2011). Anthropogenic trauma remains a significant cause of morbidity and mortality in stranded marine mammals along the central California coast. Intervention at the local, state, and federal level is needed to enforce legislation protecting marine mammals from directed harm. Novel ideas are needed to address the growing issue of marine debris, or entanglement in and ingestion of ocean trash will continue to harm pinnipeds and cetaceans, and numerous other taxa.

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Figure 1. Total strandings (black) and anthropogenic trauma cases (gray) admitted to The Marine Mammal Center between 2003 and September 2015. Prevalence of anthropogenic trauma cases (%) is indicated for each year. AT = anthropogenic trauma. Total number of strandings correlated to AT cases (r^2 = 0.62, $F_{1,11}$ = 18.0, P = 0.001).

Figure 2. Monthly anthropogenic trauma cases by trauma type for all species admitted to The Marine Mammal Center between 2003 and September 2015.

Figure 3. Anthropogenic trauma cases by county for all species admitted to The Marine Mammal Center between 2003 and September 2015. Counties range from northern (left) to southern (right).

Figure 4. Anthropogenic trauma cases comparing data from 1986–1998 (Goldstein *et al.* 1999, left, dark gray columns) and 2003–2015 (present study, right, light gray columns) and changes in prevalence. Note that 1998 and 2015 data only go through

September.

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Table 1. Total strandings and anthropogenic trauma cases by type of trauma and species of marine mammal admitted to The Marine Mammal Center between January 2003 and September 2015. Prevalence is listed in parentheses beside each number.

	Total admitted	Total anthropogenic trauma	Marine debris	Gunshot	Fishing tackle	Boat collision
All	11,162	617 (5.5)	343 (3.1)	169 (1.5)	171 (1.5)	29 (0.3)
Pinnipeds	10,838	582 (5.4)	331 (3.1)	169 (1.6)	168 (1.6)	10 (0.1)
California sea lion	7,675	511 (6.7)	277 (3.6)	165 (2.1)	158 (2.1)	4 (0.1)
Elephant seal	1,831	42 (2.3)	35 (1.9)	0 (0)	4 (0.2)	2 (0.1)
Harbor seal	1,071	12 (1.1)	4 (0.4)	2 (0.2)	4 (0.4)	4 (0.4)
Guadalupe fur seal	76	10 (13.2)	10 (13.2)	0 (0)	0 (0)	0 (0)
Northern fur seal	165	6 (3.6)	5 (3.0)	1 (0.6)	2(1.2)	0 (0)
Steller sea lion	20	1 (5.0)	0 (0)	1 (5.0)	0 (0)	0 (0)
Cetaceans	324	35 (10.8)	12 (3.7)	0 (0)	3 (0.9)	19 (5.9)
Mysticetes	271	22 (42.3)	3 (5.8)	0 (0)	2 (3.8)	17 (32.7)
Odontocetes	52	13 (4.8)	9 (3.3)	0 (0)	1 (0.4)	2 (0.7)

Table 2. Total strandings and anthropogenic trauma cases (AT) recorded annually in pinnipeds admitted to The Marine Mammal Center between January 2003 and September 2015.

		California sea lion					Northern elephant seal				Pacific harbor seal					Guadalupe fur seals		Steller sea lion		Northern fur seal			
Year	Total admitted	Total AT	Gunshot	Debris	Fishing tackle	Boat collision	Total AT	Debris	Fishing tackle	Boat collision	Total AT	Gunshot	Debris	Fishing tackle	Boat collision	Total AT	Debris	Total AT	Gunshot	Total AT	Gunshot	Debris	Fishing tackle
2003	808	51	29	16	16	–	4	3	1	–	3	–	1	2	–	2	2	–	–	–	–	–	–
2004	661	46	26	14	6	–	3	3	–	–	–	1	1	–	1	–	–	–	–	–	–	–	–
2005	659	23	12	8	4	1	7	6	1	–	–	–	–	–	–	–	–	–	–	2	–	2	1
2006	532	11	4	5	2	1	1	1	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–
2007	665	33	11	16	8	1	1	–	–	–	–	–	–	–	–	1	1	–	–	2	1	1	1
2008	747	33	9	18	12	–	1	–	–	–	1	–	–	–	1	1	1	–	–	–	–	–	–
2009	1,660	129	20	87	78	–	4	4	–	–	1	–	1	1	–	2	2	–	–	–	–	–	–
2010	961	36	9	24	11	–	2	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2011	519	24	10	10	–	–	2	2	–	–	–	–	–	–	–	2	2	–	–	–	–	–	–
2012	503	15	7	8	1	–	1	1	–	–	3	1	1	1	1	1	1	–	–	–	–	1	–
2013	500	18	4	12	1	1	8	7	–	1	1	–	–	–	–	–	–	–	–	–	–	–	–
2014	987	42	13	24	8	–	7	7	1	–	–	–	–	–		–	–	1	1	–	–	–	–
2015	1,636	50	11	35	11	–	1	–	–	1	1	–	–	–	1	1	1	–	–	–	–	–	–
Totals	10,838	511	165	277	158	4	42	35	4	2	12	2	4	4	4	10	10	1	1	6	1	5	2

Table 3. Total strandings and anthropogenic trauma cases (AT) recorded annually in cetaceans examined by The Marine Mammal Center between January 2003 and September 2015.

Year	Total admitted	Mysticetes				Odontocetes			
		Total AT	Debris	Fishing tackle	Boat collision	Total AT	Debris	Fishing tackle	Boat collision
2003	9	1	—	—	1	—	—	—	—
2004	22	—	—	—	—	2	1	—	1
2005	18	1	—	1	—	1	1	—	—
2006	9	1	—	—	1	—	—	—	—
2007	29	5	—	—	5	—	—	—	—
2008	41	—	—	—	—	1	1	—	—
2009	30	1	—	—	1	—	—	—	—
2010	25	5	1	—	4	—	—	—	—
2011	18	2	—	—	2	—	—	—	—
2012	20	1	—	—	1	—	—	—	—
2013	37	2	—	1	1	4	3	—	—
2014	36	2	2	—	—	3	3	—	—
2015	30	1	—	—	1	2	—	1	1
Totals	324	22	3	2	17	13	9	1	2

Table 4. Comparison of fisheries and nonfisheries-related anthropogenic trauma in stranded pinnipeds and cetaceans admitted to The Marine Mammal Center between January 2003 and September 2015. Prevalence is listed in parentheses beside each number.

Anthropogenic trauma cases	Pinnipeds	Cetaceans
Fisheries interactions	300 (2.8)	10 (3.1)
Fishing line	124 (1.1)	0 (0)
Netting	105 (1.0)	7 (2.2)
Lure and hooks	59 (0.5)	0 (0)
Crab pots	8 (0.1)	3 (0.9)
Unspecified entanglement	4 (0)	0 (0)
Nonfishing-related marine debris	98 (0.9)	5 1.5)
Packing strap	27 (0.2)	0 (0)
Entanglement scar	19 (0.2)	3 (0.9)
Other (nonfishing-related)	52 (0.5)	2 (0.6)
Gunshot	169 (1.6)	0 (0)
Boat collision	10 (0.1)	19 (5.9)

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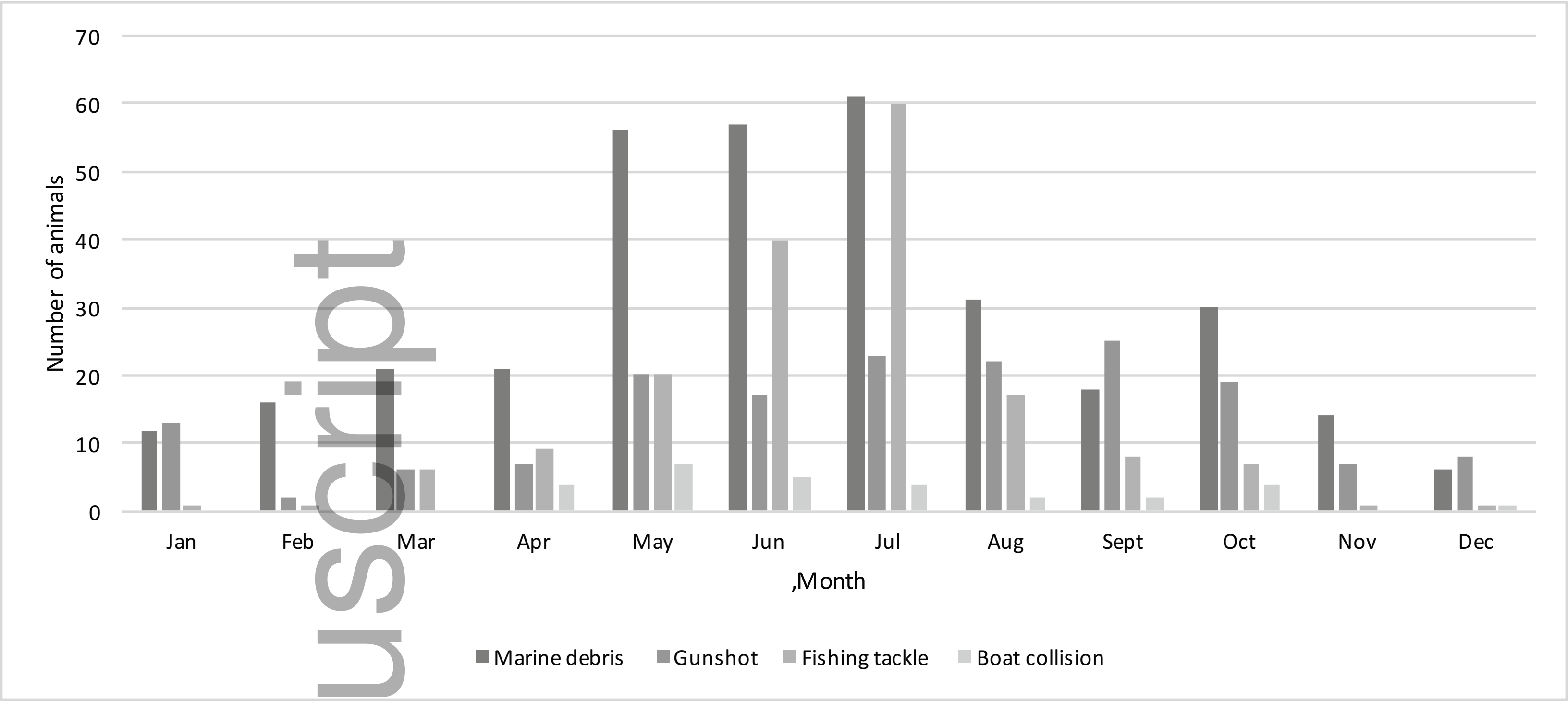

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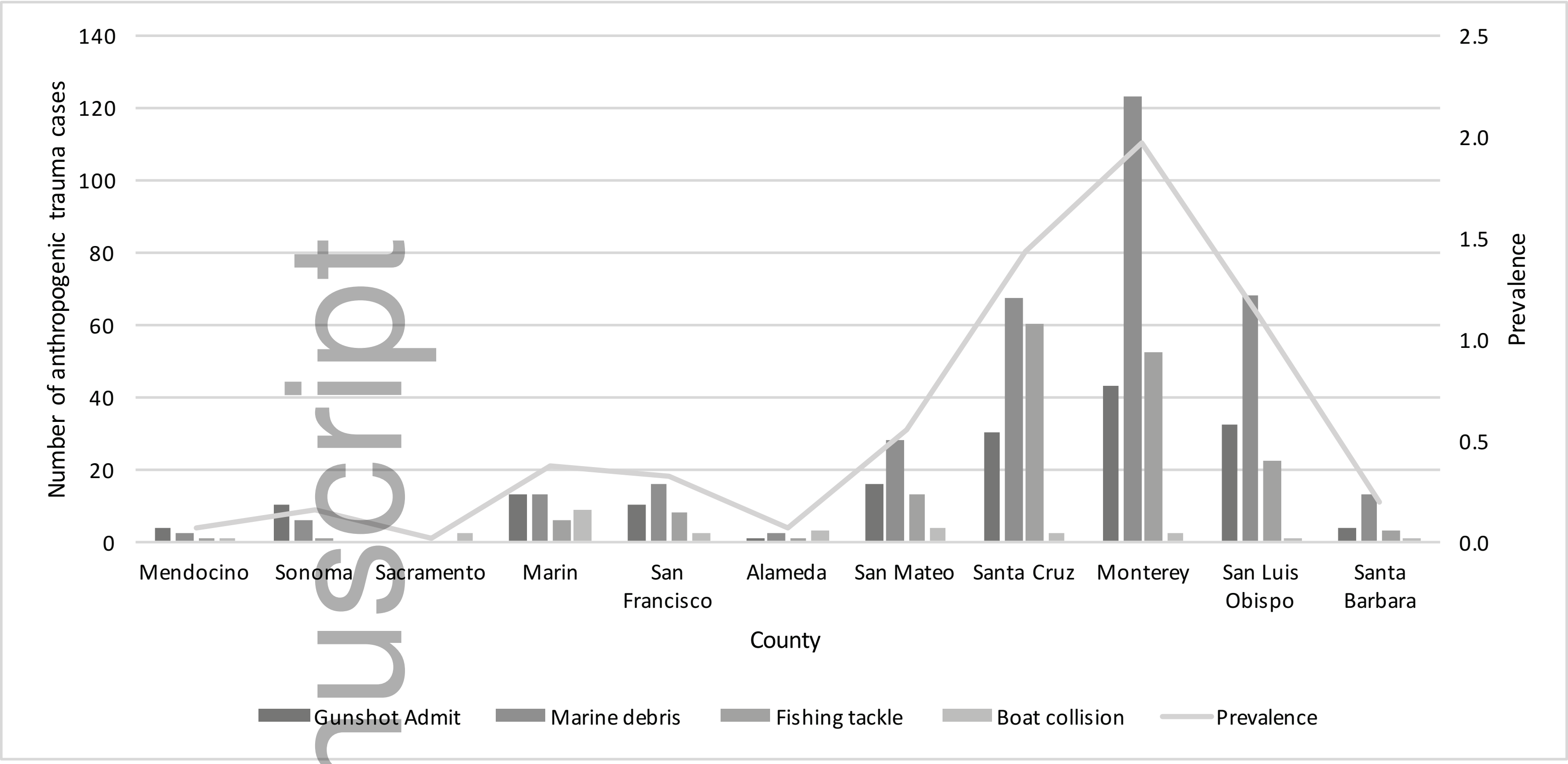

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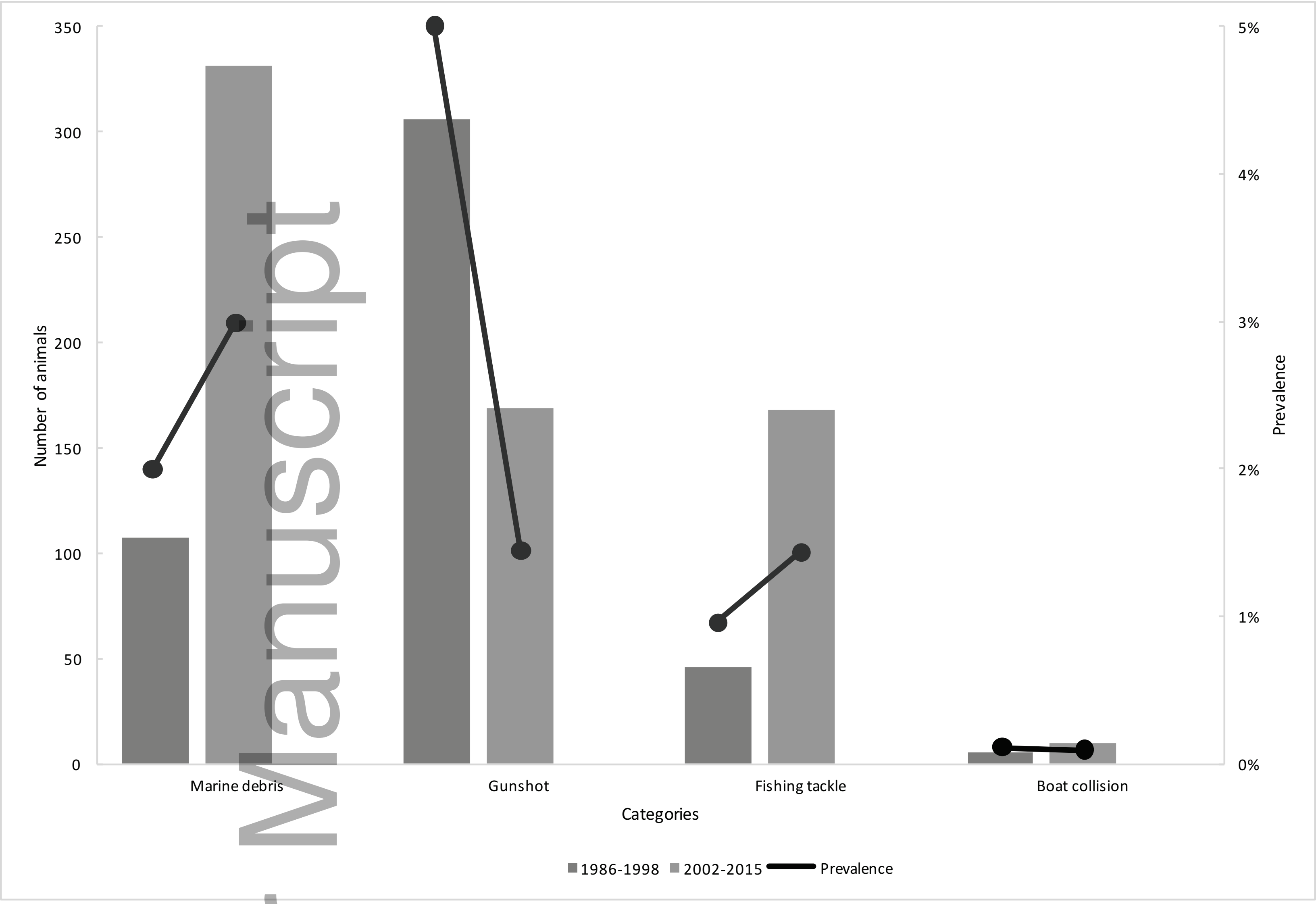

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