Marine Pollution Bulletin 149 (2019) 110557

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Entangled seabird and marine mammal reports from citizen science surveys from coastal California (1997–2017)

Erica L. Donnelly-Greenan[a,b,*], Hannahrose M. Nevins[a,b,1], James T. Harvey[a]

[a] Moss Landing Marine Laboratories, 8272 Moss Landing Road, Moss Landing, CA 95039, USA
[b] California Department of Fish and Wildlife Office of Spill Prevention and Response, Marine Wildlife Veterinary Care and Research Center, 1451 Shaffer Road, Santa Cruz, CA 95060, USA

ARTICLE INFO

Keywords:
Entanglement
Entangled
Seabirds
Marine mammals
Beach survey

ABSTRACT

Marine fauna in the California Current System is susceptible to entanglement in anthropogenic debris. We examined beach survey data from six California counties to describe trends of entangled marine birds and mammals (1997–2017). Surveyors reported 357 cases of entanglements among 65,604 carcasses. Monterey County had the greatest average entanglement rate (0.007) of surveyed counties, however, was not statistically different from Santa Cruz ($p > 0.05$). Twenty-six seabird species (97%) and three marine mammal species (3%), and three non-marine birds were affected. Numerically, Common Murre (23%), Brandt's Cormorant (13%), Western Gull (9.6%), Sooty Shearwater (8%) and Brown Pelican (7%) were the most affected due to abundance, but their entanglement rates were not statistically different ($p > 0.05$). The most *vulnerable* species were those frequently documented as entanglement despite low deposition numbers (*Merganser* spp. 25%). Entangling material consisted primarily of monofilament line (some hooks/lures), but other entanglement items were reported.

1. Introduction

Marine wildlife is susceptible to entanglement in marine debris that enters the marine environment from land-based (beaches, waterways, and runoff), ship-based (recreational and commercial vessels), and catastrophic sources (hurricanes, typhoons, tsunamis). Entanglements of live and deceased seabirds, marine mammals, sea turtles, and fish have been documented as early as the 1970s, and has continued the following few decades (Stewart and Yochem, 1987; Laist, 1997; Moore et al., 2009; Barcenas-De la Cruz et al., 2017; Staffieri et al., 2018; Ryan, 2018; Carretta et al., 2019). If anthropogenic caused entanglements are not removed (by natural breakage or by human intervention), they can result in bodily harm, severe injury, and possibly death to the individual (Barcenas-De la Cruz et al., 2017).

Marine fauna often encounters marine debris in coastal waters of the California Current System, including one of the largest federally protected marine areas, The Monterey Bay National Marine Sanctuary (MBNMS; 36°48′N 122°30′W/36.8°N 122.5°W; Rosevelt et al., 2013). Specifically, fishing gear – including monofilament line, hooks, and weights - are a chronic source of entanglement mortality for seabirds and marine mammals in California (Julian and Beeson, 1998; Moore et al., 2009). Moore et al. (2009) reported 31 impacted sea bird species and nine marine mammal species (including entanglement rates) based on multiple citizen science (including Coastal Ocean Mammal and Bird Education and Research Surveys; BeachCOMBERS) and land-based survey programs between 2001 and 2005, but more recent reports from the California coast are lacking. It is necessary to routinely document incidence and rates of entanglements of marine debris on wildlife in an effort to inform policies directed towards reducing marine debris and for recommendations for future mitigation.

Here, we examined a 20-year data set from BeachCOMBERS, a citizen science program, to examine trends in species impacted by entanglements. Since its inception in 1997, the BeachCOMBERS program has coordinated > 200 volunteers to monitor human and natural impacts to coastal wildlife by documenting the deposition on beaches of marine birds, mammals, and sea turtles from Santa Cruz County south to Los Angeles County. This long-term monitoring program has successfully informed resource managers about wildlife impacts from oil spills, starvation, fishery interactions, harmful algal blooms, and plastic ingestion (Jessup et al., 2009; Nevins et al., 2011; Donnelly-Greenan et al., 2014; Henkel et al., 2014; Gibble et al., 2018).

* Corresponding author at: Moss Landing Marine Laboratories, 8272 Moss Landing Road, Moss Landing, CA 95039, USA.
E-mail addresses: edonnelly@mlml.calstate.edu (E.L. Donnelly-Greenan), hnevins@abcbirds.org (H.M. Nevins), jharvey@mlml.calstate.edu (J.T. Harvey).
[1] Present AddressAmerican Bird Conservancy, 190 Benito Ave., Santa Cruz, CA 95062, USA.

https://doi.org/10.1016/j.marpolbul.2019.110557
Received 24 May 2019; Received in revised form 27 August 2019; Accepted 28 August 2019

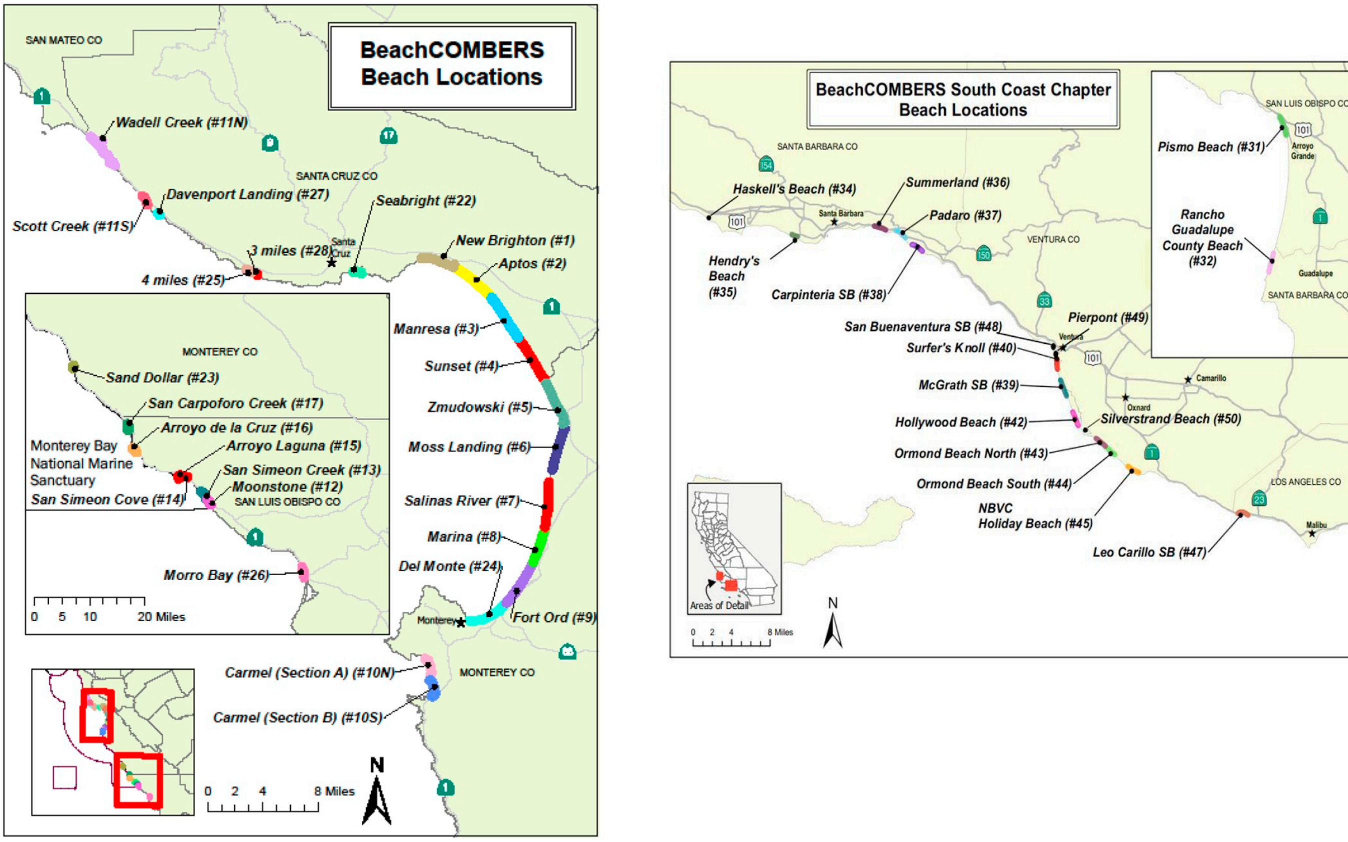

Fig. 1. Left to Right: BeachCOMBER survey beaches within northern chapter (upper inset), central chapter (lower inset), and southern chapter (far right).

2. Methods

2.1. Survey methodology and geographic location

BeachCOMBERS surveys sandy beaches (accessible by road or a trail and generally < 2 km from vehicular access) in a strip transect, where beach-cast carcasses within the strip are recorded as two surveyors zig-zag the beach. The protocol was developed from a pilot study in 1996 and a review of previous beach surveys to determine the proper number, distribution, and frequency of surveys and effort necessary to detect changes in beach-cast organisms (Simons Jr., 1985; Jameson, 1986; Stenzel et al., 1988; Bodkin and Jameson, 1991; Roletto and Grella, 1995; Benson, 2000). The survey effort was centered on the wrack line of the previous high tide, although the entire beach is surveyed in a zigzag fashion to ensure that most carcasses were located (Nevins et al., 2011). These surveys serve as an estimate of deposition rather than a total census because not all carcasses will be detected by the observers (i.e. buried, missed) and the number of animals detected will increase with effort, experience, beach type, and frequency of surveys (Byrd et al., 2009; Nevins et al., 2011).

During the first week of every month, volunteers collected standardized data on all dead marine bird, mammal, and sea turtles along coastal California (Fig. 1). If a carcass was encountered, it was: (1) identified to family or species (when possible), (2) recorded as new versus old deposition, (3) examined for carcass condition (including entanglement), (4) marked to avoid recounting, and (5) occasionally collected for further examination by affiliated biologists (detailed sampling protocol[2]). Standardized survey effort allowed for comparison of relative changes in the deposition rate of marine birds and marine mammals, and provided a monthly index of ecosystem health (Nevins et al., 2011).

We summarized entanglement records for the North (Santa Cruz and Monterey in the Monterey Bay National Marine Sanctuary; 36°48′N 122°30′W/36.8°N 122.5°W), Central (San Luis Obispo; 35° 34′N 121°6′W/35°7′N 120°38′W), and Southern (Santa Barbara, Ventura, and Los Angeles; 34° 57′N 120°39′W/34°2′N 118° 54′W) chapters of the BeachCOMBERS program (1997–2017), and report entanglement rates, species affected, type of entanglement gear, time (month, year) and location by county. Initially, the BeachCOMBERS program surveyed ten beaches in Santa Cruz and Monterey Counties (1997–1998). The program quickly expanded to 11 beaches (1999), 17 beaches including San Luis Obispo County (mid-2001–2002), to 30 beaches by 2009, and to 31 beaches in 2013 (Fig. 1). In early 2013, the Southern Chapter was established adding 14 beaches (5 in Santa Barbara, 7 in Ventura, and 1 in Los Angeles) and an additional 4 (2 in Santa Barbara and 2 in Ventura) in 2017. At this time, not all survey areas are comparable due to this variation in survey effort (years, km surveyed), therefore only the Santa Cruz and Monterey average entanglement rates were statistically compared.

2.2. Statistical analyses

Statistical analyses were run in R64 software. Yearly entanglement rates were square-root transformed and a Shapiro-Wilk test ensured normality of the transformed data. An unpaired two sample *t*-test compared the difference in average entanglement rates between comparable counties. A Kruskal-Wallis test tested for significant differences among the entanglement rates of the five most impacted species. The alpha level 0.05 was set for all statistical analyses.

[2] https://www.mlml.calstate.edu/beachcombers/wp-content/uploads/sites/35/2017/10/BC-Protocol-2018.pdf.

3. Results

3.1. Entanglement by taxa and demographics

Entanglement reports were tallied by year (1997–2017) and species from monthly surveys by BeachCOMBERS. From the 20-year data set, 65,604 carcasses were reported of which there were 357 entanglements affecting 26 seabird species (n = 345 or 97% of entanglement cases were birds), three marine mammal species (n = 9, 3% of entanglements), and three non-marine birds (1 Rock Dove, 1 American Crow, 1 unidentified bird). There were no reports of entangled sea turtles in this data set. From here thereafter, we discuss entangled marine birds and mammals only (n = 354), which are the focus of the BeachCOMBERS surveys (Table 1).

Annually, surveyors report 9 to 31 entanglements per year. In early years (1997–1998), entanglements were relatively high compared to survey effort (47 km). The most reported entanglements occurred in 2015 (n = 31) followed by 1997 (n = 30) when Common Murres (COMU) were the primary species affected (Table 1). Numerically, five abundant species were most affected during the 20-year time span (Table 1): Common Murre (23.8% of entangled carcasses, n = 15,499 reports), Brandt's Cormorant (13.3%, n = 6160 reports), Western Gull (9.6%, n = 2244 reports), Sooty Shearwater (7.9%, n = 3066 reports), and Brown Pelican (6.8%, n = 1219 reports). For one species the pattern was reverse; Northern Fulmar which is numerically abundant (7925 reports) comprised a small amount of the total entanglement cases (1%). Among the five most impacted species, no significant difference was found among the rates of entanglement (Chi square = 2.60, p = 0.63, df = 4). Combined, Alcids (24.6%), gulls (18.9%), and cormorants (18.4%) were the taxa most affected comprising 61.3% of total entanglements.

The most vulnerable species were those which surveyors reported more frequently documented entanglement as the cause of death, despite low numbers overall, such as Merganser spp. (25% of 8 reports) and Long-beaked Common Dolphin (14% of 7 reports). Elegant Tern, Willet and Black-footed Albatross also fit in this category of species vulnerable to entanglement, but overall low reported cases (i.e., < 25; Table 1, Fig. 4).

Whereas the majority of impacted individuals were of unknown age and sex (90.9%), a greater portion was categorized as adult (37.1%) compared with immature (21.0%). In examining the five most impacted species separately (n = 216), adults of Brandt's Cormorant (25 of 31), Brown Pelican (10 of 17), and Common Murre (38 of 55) were entangled more often than immatures; whereas immature Western Gull were entangled more frequently than adults (17 of 24). Additionally, one Brown Pelican, seven Common Murres, and two Western Gulls were identified as hatch-year birds. For Sooty Shearwater, age and sex cannot be determined by plumage, and requires internal examination, therefore, all individuals were reported as unknown for both classifications.

3.2. Entanglement by category

Monofilament line was the primary source of entanglement (n = 278, 78%), of which 90 cases included the presence of a hook or lure (Fig. 2). Fourteen entanglement cases (4%) were categorized as suspected commercial fishing interaction that involved net (gill, herring, unspecified monofilament net), salmon gear, or an indication of likely fishery interaction (a Common Dolphin was reported with a missing tail fluke caused by a clean cut[3]). Seventeen cases (4.8%) involved entanglement in various forms of plastic (ring, bands, string, swim googles), 10 of which included balloons and/or balloon strings, and 1 murre with a piece of plastic protruding from its abdomen. Other cases (2.0%) included an unspecified cormorant caught in a bait box; three gulls entangled in twine together; three others, a Brandt's Cormorant, Double-crested Cormorant, and Common Murre, appeared to have choked and suffocated on a fish prey item. It was uncertain if fishing interaction or other entanglements also were part of the record for the choking cases, but shore-casting fishers operate in the area. At least one Godwit, reported outside of the monthly survey window, was found with gear attributed to this fishery.

3.3. Entanglement by time, and survey county

Between 1997 and 2017, entangled individuals comprised 1.7% of all reported carcasses (Table 2). Based on the total number of carcasses reported for each county, the greatest numbers of entanglements were reported on Monterey County beaches (0.6%) with an average entanglement rate of 0.007 carcasses per year (1997–2017). In Santa Cruz County, 0.5% of reported carcasses were entangled at an average rate of 0.006, which was not significantly different than Monterey (P = 0.23, $t = -1.21$, df = 40). San Luis Obispo and Ventura counties were not surveyed as consistently throughout the 20-year span, however, both counties reported 0.3% of total carcasses reported as entangled with a 0.005 and 0.003 average annual entanglement rates, respectively (Table 2). No entanglements were reported on survey beaches in Santa Barbara or Los Angeles counties. By month, the greatest percent entangled of total carcasses were reported in July (0.8%), followed by April–June and August (0.7%), September–October (0.6%), and November–January (0.3%).

4. Discussion

Our results indicate that entanglement in marine debris continues to impact marine wildlife within California coastal waters, including the MBNMS. During twenty years of the survey program, BeachCOMBERS documented 353 cases of entanglements out of 65,604 total carcasses affecting 26 seabird species, three marine mammal species, and no sea turtles (Table 1; Figs. 3, 4). BeachCOMBERS has documented few stranding records of deceased sea turtles (3 over the 20 yr survey period), therefore, it is not unexpected that we report a lack of entangled sea turtles. Entanglement in active fishing gear (bycatch rates) continues to threaten all sea turtle species in the Pacific Ocean (Julian and Beeson, 1998; Carretta et al., 2019).

We did not find a consistent pattern in the rate of entanglement relative to the number of carcasses reported. Among seabird groups, nearshore species (pelicans, gulls) were more susceptible to entanglement in marine debris than others (1–2% of documented records). Our results indicate that entanglement is chronic among diving birds (i.e. alcids, cormorants) and surface-feeding seabirds (i.e. gulls, tubenoses) with > 61% cases represented by five species. Battisti et al. (2019a) created a global 'black-list' of seabirds and shorebirds interactions with anthropogenic litter which reported 151 seabird species (58.5%) of 206 reported interacted with entanglement. Similarly, they reported elevated percentages of reported entanglements (for orders with > 10 species) among Pelecaniformes (84.6% including pelicans and cormorants), Charadriiformes (63.6% including murres and gulls), and Procellariiformes (33.3% including shearwaters), however Anseriformes (66.7%) were also greatly represented (Battisti et al., 2019a).

Mergansers, primarily piscivorous estuarine ducks, were not prevalent our records (n = 8), however when they were present they were likely entangled (67%) perhaps due to foraging in close proximity to near-shore fishing activities. The primary source of entanglements was from monofilament line with and without hooks/lures – which are either ingested, or wrapped around the birds' bodies, wings, or legs, impairing mobility and perhaps ultimately leading to starvation or drowning (Figs. 2, 3). Recreational line and hook's small, linear shape

[3] Other small cetacean fishery interactions have been reported through the Stranding Network through Moss Landing Marine Laboratories; however, they were not within the BeachCOMBERs survey window and are not included in our data.

Table 1
Entanglements by year and species from monthly Beach COMBER surveys, 1997–2017.

Family/species	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total # entangled	Total reported	% ratio of all entangled	% entangled of total reported
Alcids	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Murre, Common (*Uria aalge*)	14	3	2	3	7	5	2	7	4	–	5	2	5	–	5	2	2	1	6	1	8	84	15499	23.73	0.54
Auklet, Rhinoceros (*Cerorhinca monocerata*)	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	642	0.28	0.16
Guillemot, Pigeon (*Cepphus columba*)	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1	–	–	2	444	0.56	0.45
Cormorants	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Cormorant, Brandt's (*Phalacrocorax penicillatus*)	3	–	–	1	2	–	2	2	2	1	1	3	10	3	2	1	2	2	5	3	2	47	6160	13.28	0.76
Cormorant, Double-crested (*Phalacrocorax auritus*)	–	1	–	–	–	–	–	–	1	1	–	–	–	–	1	–	–	–	–	–	–	4	164	1.13	2.44
Cormorant, Pelagic (*Phalacrocorax pelagicus*)	1	–	–	–	–	–	–	–	1	–	–	–	–	–	2	–	–	1	–	–	–	5	343	1.41	1.46
Cormorant, Unidentified	–	1	–	–	–	1	–	1	–	3	2	–	–	–	–	–	–	–	–	–	1	9	674	2.54	1.34
Pelicans	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pelican, Brown (*Pelecanus occidentalis*)	–	–	–	–	5	2	1	–	–	–	1	–	1	–	2	2	1	2	4	2	1	24	1219	6.78	1.97
Sea Ducks	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Scoter, Surf (*Melanitta perspicillata*)	–	1	–	–	–	–	–	–	–	–	1	–	–	–	–	2	–	–	3	–	–	7	1118	1.98	0.63
Scoter, unidentified	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	192	0.28	0.52
Merganser, Red-breasted (*Mergus serrator*)	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	6	0.28	16.67
Merganser, Common (*Mergus merganser*)	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	2	0.28	50.00
Shorebirds	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Willet (*Tringa semipalmata*)	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	24	0.56	8.33
Shorebird, unidentified	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	2	153	0.56	1.31
Grebes	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Grebe, Western (*Aechmophorus occidentalis*)	–	1	–	–	1	–	2	1	1	–	–	3	–	1	1	–	2	–	1	1	–	15	1977	4.24	0.76
Grebe, *Aechmophorus* spp.	–	–	–	2	–	–	1	–	–	–	3	–	–	–	–	1	–	–	1	–	1	9	1818	2.54	0.50
Grebe, Clarks (*Aechmophorus clarkii*)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1	396	0.28	0.25
Grebe, unidentified	1	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	2	631	0.56	0.32
Larids	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gull, California (*Larus californicus*)	–	–	–	–	–	2	1	–	–	1	2	–	–	3	–	–	–	1	–	–	1	11	1130	3.11	0.97
Gull, Heermann's (*Larus heermanni*)	–	–	–	1	2	–	–	2	–	1	1	–	–	–	–	–	–	–	–	–	–	7	356	1.98	1.97
Gull, Glaucous-winged (*Larus glaucescens*)	1	–	–	–	–	–	–	–	–	–	–	1	1	–	1	–	–	–	1	–	–	5	236	1.41	2.12

(continued on next page)

Table 1 (*continued*)

Family/species	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total # entangled	Total reported	% ratio of all entangled	% entangled of total reported
Gull, Ring-billed (*Larus delawarensis*)	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**	**72**	**0.28**	**1.39**
Gull, Thayer's (*Larus thayeri*)	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	**1**	**31**	**0.28**	**3.23**
Gull, Western (*Larus occidentalis*)	2	1	1	–	2	2	3	–	2	3	3	1	3	2	1	–	–	2	4	–	2	**34**	**2244**	**9.60**	**1.52**
Gull, unidentified	–	1	–	–	–	3	1	–	1	–	1	1	2	3	1	1	1	–	1	2	–	**19**	**2807**	**5.37**	**0.68**
Tern, Elegant (*Thalasseus elegans*)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	**1**	**25**	**0.28**	**4.00**
Loons	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Loon, Common (*Gavia immer*)	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	**1**	**271**	**0.28**	**0.37**
Loon, Pacific (*Gavia pacifica*)	–	–	1	–	1	–	2	–	1	–	–	–	3	–	–	–	–	–	–	–	–	**8**	**966**	**2.26**	**0.83**
Loon, unidentified	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**	**170**	**0.28**	**0.59**
Procellariids	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Albatross, Black-footed (*Phoebastria nigripes*)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–	**2**	**24**	**0.56**	**8.30**
Fulmar, Northern (*Fulmarus glacialis*)	–	1	–	–	–	–	1	–	1	–	1	–	–	–	–	–	–	–	–	–	–	**4**	**7925**	**1.13**	**0.05**
Shearwater, Black-vented (*Puffinus opisthomelas*)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	**1**	**50**	**0.28**	**2.00**
Shearwater, Sooty (*Ardenna grisea*)	5	2	1	2	5	1	–	2	–	1	–	–	1	1	1	2	2	1	1	–	–	**28**	**3086**	**7.91**	**0.91**
Shearwater unidentified	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	3	**5**	**120**	**1.41**	**4.17**
Marine Mammals	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
CA Sea Lion (*Zalophus californianus*)	–	–	–	–	–	–	–	–	–	–	4	2	–	–	–	–	–	–	1	–	–	**7**	**3388**	**1.98**	**0.21**
Harbor Seal (*Phoca vitulina*)	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**1**	**586**	**0.28**	**0.17**
Long-beaked Common Dolphin (*Delphinus capensis*)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	**1**	**7**	**0.28**	**14.29**
Total	**30**	**13**	**5**	**11**	**26**	**17**	**17**	**16**	**14**	**12**	**27**	**14**	**26**	**13**	**19**	**11**	**11**	**12**	**31**	**9**	**19**	**354**	**29810**	**100**	

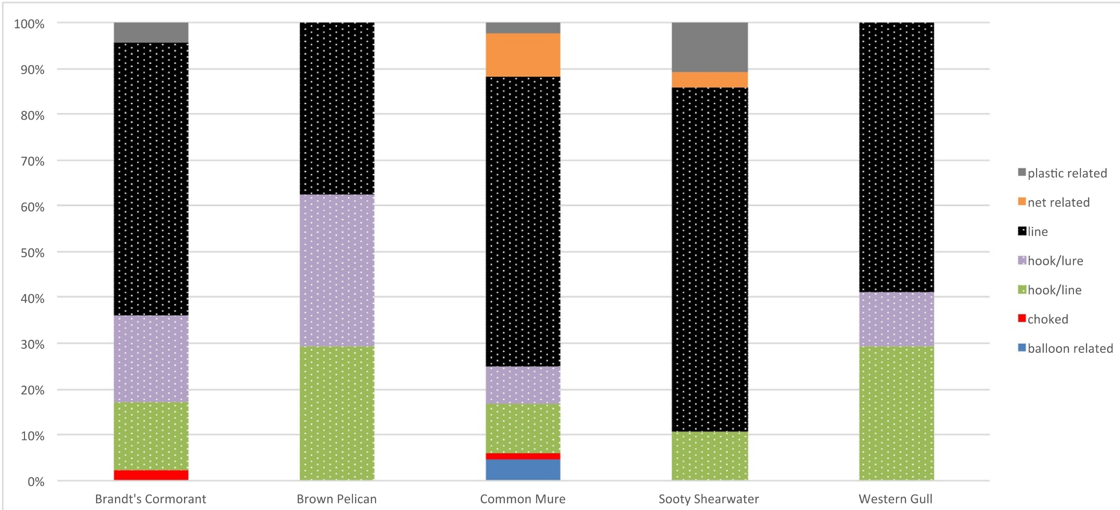

Fig. 2. Primary entanglement categories for five most reported entangled species from BeachCOMBERS surveys (1997–2017). Stippled areas represent entanglement due to recreational fishing activity.

Table 2

Counts, percentages, and rates of entangled seabird and marine mammal carcasses by beach survey year and county: Santa Cruz (SC), Monterey (MTY), San Luis Obispo (SLO), and Ventura (VEN). Differences in the average entanglement rates between SC and MTY were not significant ($p > 0.05$). Shaded county values are not comparable to SC and MTY due to varying effort or added survey areas were established later in the program.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total #	% ratio of all entangled	% entangled of total reported	$\bar{x}$ entanglement rate
SC	6	4	1	3	4	2	8	4	3	7	6	4	8	1	5	3	3	0	1	2	6	**81**	**70.3**	**0.6**	**0.006**
MTY	24	10	4	8	21	14	8	11	11	3	19	9	18	12	13	8	5	9	25	5	11	**248**	**22.9**	**0.5**	**0.007**
SLO	-	-	-	-	1	1	1	1	0	2	2	0	0	0	1	0	0	1	1	1	1	13	**3.7**	**0.3**	**0.005**
VEN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	2	4	1	1	**11**	**3.1**	**0.3**	**0.003**
Total #	**30**	**14**	**5**	**11**	**26**	**17**	**17**	**16**	**14**	**12**	**27**	**13**	**26**	**13**	**19**	**11**	**11**	**12**	**31**	**9**	**19**	**353**	**-**	**1.7**	**-**

and cryptic coloration make this type of marine litter less obvious and difficult to recover, sample, and remove once it has been lost in the environment (Battisti et al., 2019b). Presumably birds were caught in gear while actively feeding or got caught in derelict fishing gear during swimming; our methods did not distinguish these types or among the source of injury. The species most affected (Common Murres, Western Gulls) were numerically dominate in the sample and these results are similar to those reported by Moore et al. (2009), however, we report greater numbers of Brandt's Cormorants and Sooty Shearwaters that have become entangled more frequently in the extended California data set. In particular, Common Murres are resident diving alcids that have been greatly impacted in Central California and elsewhere by gill net fisheries (Piatt et al., 1982; Julian and Beeson, 1998; Forney et al., 2001) and by recreational fishing activities (this study, Moore et al., 2009). Legislative restrictions on gill net activities in the late 1990s reduced commercial fishery impacts on Common Murre, and populations slowly recovered, although other anthropogenic impacts (oil spills) have impacted recovery rates (McChesney et al., 1998). We reported 12 incidences of net related entanglements, however only six were reported as confirmed gill nets through sample collection or photograph (three murres in 1997, one in 1998, one in 2002, and one Common Loon in 1998). One loon was reported in 2007 on a Santa Cruz county beach after the legislative restriction on gill net activity.

Seasonal and temporal patterns in entanglements were evident for Common Murres and Sooty Shearwaters. Common Murre entanglements were the greatest in late spring (April–June) and again in late summer through early fall (August–October). These patterns align with the breeding months in central California (≥April) when murres are returning to breeding colonies and post-chick rearing (late summer–-early fall) when birds were dispersing from colonies (McChesney et al., 2008). Common Murre breeding colonies are slightly north (Devil's Slide Rock, Marin County) and south (Big Sur, Monterey County) of where beaches were surveyed (McChesney et al., 2008). Sooty Shearwaters are present in MBNMS throughout the summer (late spring–early fall; April–September) after migration from the southern hemisphere (Briggs and Chu, 1986). Increases in murre and shearwater deposition during summer are reflected yearly in survey abundance data; thus, entanglement patterns for these species align with shearwater summer migration patterns and occurrence in coastal waters of MBNMS. Conversely, Brandt's Cormorant and Western Gull are residents of MBNMS (Baltz and Morejohn, 1977) are found entangled throughout the year without strong seasonal patterns.

Our yearly number of entanglements is likely a low estimate of overall impacts. Reports of live entanglements in conjunction with beach-cast data present a better understanding of particular species impacted by entanglements. For example, whereas gulls tend to be represented in both beach-cast and live entanglement data (this study, Dau et al., 2009, Moore et al., 2009) this is not the case for all species. Our data reflects a limited number of entangled marine mammals and Brown Pelicans that are often reported as live entangled to rescue and rehabilitation centers. The centers regularly admit entangled wildlife patients and also receive reports of large, entangled cetaceans, requiring special response teams. These large cetaceans entanglements are not reflected in our beach survey data, however entanglements have been well documented for Mysticetes and Odontocetes globally (Poeta et al., 2017). While our records reflect seven entangled California Sea lions, one Harbor Seal, and one Long-beaked Common Dolphin, The Marine Mammal Center (stationed along the coast of California) reported an intake of 277 entangled pinnipeds between 2003 and 2015, where the threatened Guadalupe fur seal had the greatest prevalence as opposed Northern fur seals that were the most globally cited pinniped species (Barcenas-De la Cruz et al., 2017; Poeta et al., 2017). Similarly, Barcenas-De la Cruz et al. (2017), reported clear monofilament line or netting as the primary source of entanglement (wrapped around the

Fig. 3. Entangled Common Murres: entanglement in fishing line impairing the functionality of its mandible (top left), entanglement in monofilament net (top middle), a zoomed in view of bird entanglement in monofilament net (top right), and an entanglement in a plastic ring (bottom) reported from BeachCOMBERS surveys (Photos: Hannah Nevins, Karin Forney, Scott Benson and BeachCOMBER volunteers).

Fig. 4. (Left) A Black-footed Albatross was found entangled in discarded balloons and strings on Marina State Beach in June 2013 (Photo: Chris Miller and Patty Brown). (Right) Black-footed and other albatrosses may be attracted to balloons and plastic objects at sea because of color and physical structure, thus increasing chances of becoming entangled (Photo: Rich Stallcup).

neck, head, and flippers) with the greatest number of reports in the late spring–summer (May–July) in Monterey (37%) followed by Santa Cruz and San Luis Obispo (Barcenas-De la Cruz et al., 2017). Dau et al. (2009) reported 2.9% prevalence (n = 4398) of fishing gear related injuries among emitted pinnipeds (2001–2006), but they were less likely to be affected by fishing gear than other rehabilitation-admitted species such as Brown Pelicans and Gulls. Pinnipeds large body size relative to seabirds could decrease the likelihood of their live rescue or morbidity from fishing gear injuries (Dau et al., 2009).

In the survey data, beach-cast Brown Pelicans represented 6.7% of reported entangled species (2% of all reported pelican carcasses n = 1219) suggesting an increased vulnerability for entanglement compared to other reported species. Many entanglement cases for this species are from live birds, which are subsequently treated at wildlife rehabilitation centers and released (Dau et al., 2009). In 2001, numerous pelicans were repeatedly entangled at fishing piers throughout the MBNMS (Nevins personal comm. with Native Animal Rescue), however, few (n = 5) were reported dead by BeachCOMBERS that year. Furthermore, Dau et al. (2009) reported 31.1% prevalence of fishing gear related injuries in rescued pelicans from the entire California coast between 2001 and 2006 (n = 1894), with seasonal fluctuations peaking in the summer and fall during an increase in recreational fishing activity. Thus, BeachCOMBERS records are only representative of a proportion of the total entangled individuals found on survey beaches and are strictly limited to those found dead. Entangled Brown Pelicans, pinnipeds, and likely some gull species are underrepresented in our beach-cast data whereas others, such as Common Murres, Cormorants, and Shearwaters are well represented. Improved data integration among survey programs and rescue/rehabilitation groups in California, as previously suggested by Moore et al. (2009), would provide a more accurate depiction of species impacted by entanglements. As public data, including BeachCOMBERS, becomes integrated in to public data portals such as CeNCOOS,[4] precise tallies of entangled wildlife, (live and deceased) is a likely reality in the near future.

The majority of entanglements were reported in Monterey county, which may be a result of increased recreational fishing activities in those areas or a factor of carcass retention on particular beaches. Throughout MBNMS, public piers (approximately five total, two in Monterey county) are accessible for recreational fishing activities. In California, public piers do not require fishing licenses, thus making them attractive for recreational use but potential wildlife entanglement zones, particularly for more opportunistic sea lions, pelicans, and gulls that attempt to steal bait or catch fish from lines. These species also rest or haul-out on wharves and piers, increasing the chance of direct interactions. In some years, shared prey, such as Anchovy schools, move inshore and fishing activities and birds overlap greatly, such years can be catastrophic and often lead to the closing of pier due to record numbers of interactions (e.g. Santa Cruz closure in August of 2008 in response to outcry from public regarding entangled pelicans with injuries).

While it is difficult to determine whether carcasses were entangled during active foraging vs. derelict fishing gear encountered in habitat and foraging areas (Laist, 1997; Moore et al., 2009) and public piers are in close proximity to survey beaches in all four counties (≥ 3 in Santa Cruz and San Luis Obispo and ≥ 2 in Ventura). Carcass deposition and retention on survey beaches is of importance could be impacted by a variety of oceanographic climatic factors, and the influence of such factors on carcass deposition (such as wind, tide height, wave height) are variable among years (Cruickshank, 2015). Two beaches in Monterey County (Marine State Beach and Zmudowski State Beach) averaged the greatest deposition numbers within the MBNMS survey area (Cruickshank, 2015), which likely influenced the retention of entangled carcasses.

We report the majority of entanglement items were from recreational fishing activities and entanglement rates were greatest during summer (July–August). Based on these results, we suggest efforts to target educational outreach for California recreational fishers prior to summer months would be beneficial in reducing marine bird and mammal entanglements in tangent with policies that aim to reduce anthropogenic waste at the source. California ocean literacy organizations (Seabird Protection Network, Surfrider Foundation, Save Our Shores, etc.) have made great strides in bringing awareness of ocean issues to the consciousness of citizens, galvanizing community-supported action such as beach clean-ups, marine debris awareness, and prevention campaigns. Given the importance of the California coastal waters, oceanic, and estuarine habitat to marine wildlife, continued efforts to promote reduction and proper waste disposal are essential. Efforts that target responsible fishing practices and how to avoid accidental interaction with seabirds and marine mammals would beneficial, particularly in popular recreational fishing areas.

Acknowledgements

This work was funded by the Monterey Bay Sanctuary Foundation, Moss Landing Marine Laboratories, and U.S. Fish and Wildlife Service. We are grateful to all the BeachCOMBERS volunteers for their tireless effort to collect data on a monthly basis. We thank the staff and volunteers of the Monterey Bay National Marine Sanctuary, Marine Wildlife Veterinary Care and Research Center, California Department of Fish and Wildlife in Santa Cruz, Moss Landing Marine Laboratories, and Oikonos Ecosystem Knowledge for the years of support and participation with the program.

[4] https://www.cencoos.org/data/access.

References

Baltz, D.M., Morejohn, G.V., 1977. Food habits and niche overlap of seabirds Wintering in Monterey Bay, California. Auk 94 (3), 526–543.
Barcenas-De la Cruz, D., DeRango, E., Johnson, S.P., Simeone, C., 2017. Evidence of anthropogenic trauma in marine mammals stranded along the central California coast, 2003-2015. Mar. Mamm. Sci. 34 (2), 330–346.
Battisti, C., Staffieri, E., Poeta, G., Sorace, A., Luiselli, L., Amori, G., 2019a. Interactions between anthropogenic litter and birds: a global review with a 'black-list' of species. Mar. Pollut. Bull. 138, 93–114.
Battisti, C., Kroha, S., Kozhuharova, E., De Michelis, S., Fanelli, G., Poeta, G., Pietrelli, L., Cerfolli, F., 2019b. Fishing lines and fish hooks as neglected marine litter: first data on chemical composition, densities, and biological entrapment from a Mediterranean beach. Environ. Sci. Pollut. Res. 26, 1000–1007.
Benson, S.R., 2000. Seabirds within Monterey Bay – observations of the quick and the dead. In: Carless, J. (Ed.), Ecosystem Observations for the Monterey Bay National Marine Sanctuary 1999. National Oceanic and Atmospheric Administration, Monterey Bay National Marine Sanctuary, Monterey, CA (20 pp).
Bodkin, J.L., Jameson, R.J., 1991. Patterns of seabird and marine mammal carcass deposition along the central California coast, 1980-1986. Can. J. Zool. 69, 1149–1155.
Briggs, K., Chu, E., 1986. Sooty shearwaters off California: distribution, abundance and habitat use. Condor 88 (3), 355–364. https://doi.org/10.2307/1368883.
Byrd, G.V., Reynolds, J.H., Flint, P.L., 2009. Persistence rates and detection probabilities of bird carcasses on beaches of Unalaska Island, Alaska, following the wreck of the M/V Selendang Ayu. Mar. Ornithol. 37, 197–204.
Carretta, J.V., Moore, J.E., Forney, K.A., 2019. Estimates of marine mammal, sea turtle, and seabird bycatch from the California large-mesh drift gillnet fishery: 1990-2017. In: U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-619.
Cruickshank, M., 2015. Predicting Stranding Patterns of Live Oiled Seabirds, Carcass Deposition, and Carcass Retention in Monterey Bay. Master's Theses. 4579 12 pp.. https://scholarworks.sjsu.edu/etd_theses/4579.
Dau, B.K., Gilardi, K.V.K., Gulland, F.M., Higgins, A., Holcomb, J.B., Leger, J.S., Ziccardi, M.H., 2009. Fishing gear–related injury in California marine wildlife. J. Wildl. Dis. 45 (2), 355–362.
Donnelly-Greenan, E.L., Harvey, J.T., Nevins, H.M., Hester, M.M., Walker, W.A., 2014. Prey and plastic ingestion of Pacific Northern Fulmars (*Fulmarus glacialis rogersii*) from Monterey Bay, California. Mar. Pollut. Bull. 85 (1), 214–224.
Forney, K.A., Benson, S.R., Cameron, G.A., 2001. Central California gillnet effort and bycatch of sensitive species. In: Proceedings of the Seabird Bycatch: Trends, Roadblocks, and Solutions, University of Alaska Sea Grant, AK-SG-01-01.
Gibble, C., Duerr, R., Bodenstein, B., Lindquist, K., Lindsey, J., Beck, J., Henkel, L., Roletto, J., Harvey, J., Kudela, R., 2018. Investigation of a largescale common Murre (*Uria aalge*) mortality event in California, USA, in 2015. J. Wildl. Dis. 54 (3), 569–574.
Henkel, L.A., Nevins, H., Martin, M., Sugarman, S., Harvey, J.T., Ziccardi, M.H., 2014. Chronic oiling of marine birds in California by natural petroleum seeps, shipwrecks, and other sources. Mar. Pollut. Bull. 79 (1–2), 155–163.
Jameson, G.L., 1986. Trial systematic salvage of beach-cast sea otter (*Enhydra lutris*) carcasses in the central and southern portion of the sea otter range in California. In: Final Report to the Marin Mammal Commission, MM2629849-8, (60 pp).
Jessup, D.A., Miller, M.A., Ryan, J.P., Nevins, H.M., Kerkering, H.A., Mekebri, A., Crane, D.B., Johnson, T.A., Kudela, R.M., 2009. Mass stranding of marine birds caused by a surfactant-producing red tide. PLoS One 4 (2), e4550. https://doi.org/10.1371/journal.pone.0004550.
Julian, F., Beeson, M., 1998. Estimates of marine mammal, turtle, and seabird mortality for two California gillnet fisheries: 1990-1995. Fish. Bull. 96 (2), 271–284.
Laist, D.W., 1997. Impacts of marine debris: Entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe, J.M., Rogers, D.B. (Eds.), Marine Debris: Sources, Impacts, and Solutions. Springer-Verlag, New York, pp. 99–140.
McChesney, G.J., Carter, H.R., Parker, M.W., Takekawa, J.E., Yee, J.L., 1998. Population trends and subcolony use of common Murres and Brandt's cormorants at point Reyes headlands, California, 1979-1997. In: Unpubl. final report. U.S. Geological Survey, Biological Resources Division, Western Ecological Research Center, Dixon, CA (Department of Wildlife, Humboldt State University, Arcata, CA; and U.S. Fish and Wildlife Service, San Francisco National Wildlife Refuge Complex, Newark, CA. 103pp.).
McChesney, G.J., Lontoh, D.N., Rhoades, S.J., Borg, K.A., Donnelly, E.L., Gilmour, M.E., Kappes, P.J., Eigner, L.E., Golightly, R.T., 2008. Restoration of Common Murre Colonies in Central California: Annual Report. Unpubl. Final Report. U.S. Fish and Wildlife Service, San Francisco Bay National Wildlife Refuge Complex, Newark, CA (87 pp).
Moore, E., Lyday, S., Roletto, J., Litle, K., Parrish, J.K., Nevins, H., Harvey, J., Mortenson, J., Greig, D., Hermance, A., Lee, D., Adams, D., Allen, S., Kell, S., Piazza, M., 2009. Entanglements of marine mammals and seabirds in central California and the northwest coast of the United States 2001–2005. Mar. Pollut. Bull. 58 (7), 1045–1051.
Nevins, H.M., Benson, S.R., Phillips, E.M., de Marignac, J., DeVogelaere, A.P., Ames, J.A., Harvey, J.T., 2011. Coastal Ocean Mammal and Bird Education and Research Surveys (Beach COMBERS), Beachcomber 1997–2007 Ten Years of Monitoring Beached

Marine Birds and Mammals in the Monterey Bay National Marine Sanctuary. Marine Sanctuaries Conservation Series ONMS-11-02 U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD (63pp).
Piatt, J.F., Nettleship, D.N., Threlfall, W., 1982. Net-mortality of common Murres and Atlantic puffins in Newfoundland, 1951-81. In: Publication of an Organization Other than the U.S. Geological Survey. Pacific Seabird Group, pp. 196–207.
Poeta, G., Staffieri, E., Acosta, A.T., Battisti, C., 2017. Ecological effects of anthropogenic litter on marine mammals: a global review with a "black-list" of impacted taxa. Hystrix, the Italian Journal of Mammalogy 28 (2), 253–264.
Roletto, J., Grella, L., 1995. Beach Watch Annual Report. Unpublished Report. Available from:. GFNMS, Fort Mason, San Francisco, CA (16 pp).
Rosevelt, C., Los Huertos, M., Garza, C., Nevins, H.M., 2013. Marine debris in central California: quantifying type and abundance of beach litter in Monterey Bay, CA. Mar. Pollut. Bull. 71, 299–306.
Ryan, P.G., 2018. Entanglement of birds in plastics and other synthetic materials. Mar. Pollut. Bull. 135, 159–164.
Simons Jr., M.M., 1985. Beached bird survey project of the Atlantic and Gulf coasts: December 1, 1975 to November 30, 1983. American Birds 39 (3), 358–362.
Staffieri, E., de Lucia, G.A., Camedda, A., Poeta, G., Battisti, C., 2018. Pressure and impact of anthropogenic litter on marine and estuarine reptiles: an updated blacklist highlighting gaps of evidence. Environ. Sci. Pollut. Res. 26, 1238–1249.
Stenzel, L.E., Page, G.W., Carter, H.R., Ainley, D.G., 1988. Seabird mortality in California as witnessed through 14 years of beached bird censuses. In: Point Reyes Bird Observatory Report for the Gulf of the Farallones Nation Marine Sanctuary, (175 pp).
Stewart, B.S., Yochem, P.K., 1987. Entanglement of pinnipeds in synthetic debris and fishing net and line fragments at San Nicolas and San Miguel Islands, California, 1978-1986. Mar. Pollut. Bull. 18 (6), 336–339.