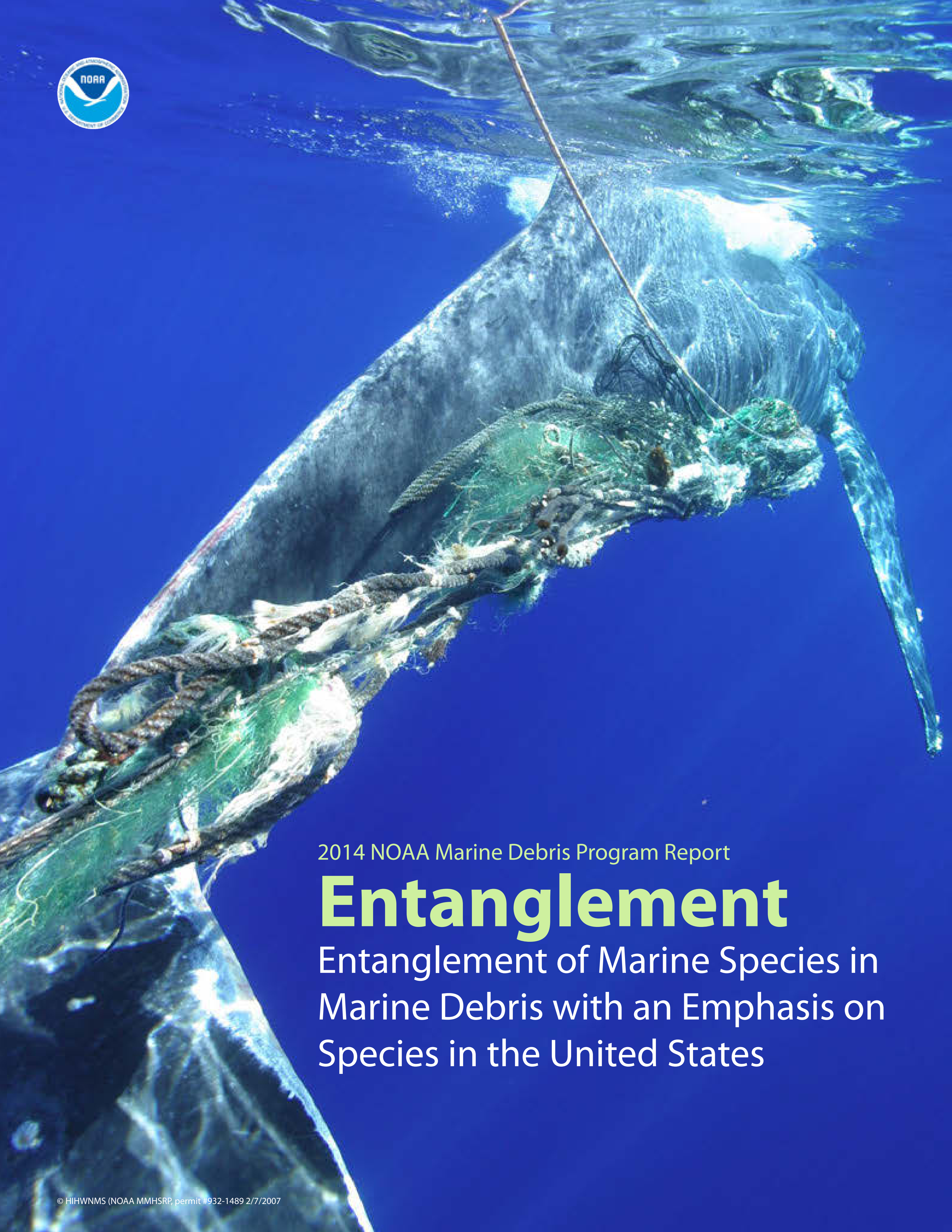


2014 NOAA Marine Debris Program Report

Entanglement

Entanglement of Marine Species in Marine Debris with an Emphasis on Species in the United States

© HIHWNMS (NOAA MMHSRP, permit #932-1489 2/7/2007

April 2014

National Oceanic and Atmospheric Administration
National Ocean Service

National Centers for Coastal Ocean Science – Center for Coastal Environmental Health and Biomolecular Research
219 Fort Johnson Road
Charleston, South Carolina 29412

Office of Response and Restoration
NOAA Marine Debris Program
1305 East-West Hwy, SSMC4, Room 10239
Silver Spring, Maryland 20910

Cover photo courtesy of Hawaiian Islands Humpback Whale National Marine Sanctuary (NOAA MMHSRP) taken under permit #932-1489) 2/7/2007.

For citation purposes, please use:
National Oceanic and Atmospheric Administration Marine Debris Program. 2014 Report on the Entanglement of Marine Species in Marine Debris with an Emphasis on Species in the United States. Silver Spring, MD. 28 pp

For more information, please contact:
NOAA Marine Debris Program
Office of Response and Restoration
National Ocean Service
1305 East West Highway
Silver Spring, Maryland 20910
301-713-2989
www.MarineDebris.noaa.gov

Acknowledgements

The National Oceanic and Atmospheric Administration (NOAA) Marine Debris Program would like to acknowledge Wayne McFee for conducting this research, and Jason Paul Landrum and Courtney Arthur for providing guidance and support throughout this process. Special thanks go to Jeff Hyland (National Centers for Coastal Ocean Science – Center for Coastal Environmental Health and Biomolecular Research) and David Laist (Marine Mammal Commission) for reviewing this paper and providing helpful comments. An additional thank you goes to John Hayes (NOAA National Ocean Service, National Centers for Coastal Ocean Science) for a copy/edit review of this report and Asma Mahdi for design and layout. Funding for this project was provided by the NOAA Marine Debris Program.

TABLE OF CONTENTS

Synthesis of Literature

EXECUTIVE SUMMARY

Entanglement of marine species in marine debris is a global problem affecting at least 200 species. Based on the literature reviewed in the United States alone, at least 115 species of marine mammals, sea turtles, sea birds, fish, and invertebrates are affected. This review of the literature focused primarily on marine debris entanglement specific to the U.S., incorporating over 170 reports dating as far back as 1928. Most reports of entanglement in marine debris involved pinnipeds, particularly northern fur seals (*Callorhinus ursinus*) and Hawaiian monk seals (*Monachus schauinslandi*), as well as sea turtles. Inconsistencies in defining and distinguishing marine debris from actively fished gear significantly limits assessments of marine debris entanglement rates. Further, marine species databases rarely list marine debris data as a separate field, they are not easily searchable and would be more effective if centralized into one database. While entanglement in marine debris is a source of morbidity and mortality for individuals of many species, the impacts of greatest concern are those that affect whole populations of organisms, particularly small populations that are threatened or endangered. For at least some endangered species, such as Hawaiian monk seals, available data suggest that entanglement in marine debris can produce significant adverse effects at the population level, and can contribute to declines in the total numbers of these already endangered animals. For other species, with seemingly large populations or those populations that are difficult to count, population-level effects are more uncertain. However, despite the difficulties in detecting population-level effects, marine debris clearly poses a threat to animal welfare for those individuals that become entangled. Future work should: 1) collect information on the various sources (*e.g.*, ocean-based v. land-based debris) and types (*e.g.*, fishing gear (active v. derelict) v. boating gear) of marine debris that negatively affect organisms, especially those animals that are critically endangered, 2) assess the relative impacts of marine debris amid other potential factors stressing these organisms/populations, such as changing weather patterns linked to climate change, climatological events (*e.g.*, El Niño/La Niña Southern Oscillation), losses in food availability, and disease, and 3) accurately assess the proximate mechanisms driving the observed spatial and temporal patterns of entanglement of organisms in marine debris, such as existing overlap in animal active habitat with areas of higher debris concentrations (*i.e.*, oceanic convergence zones), and increases in the relative contribution of land-based and ocean-based debris with growing human population and activity along coastlines. These patterns are not well established and require further attention. Understanding the sources and types of marine debris that affects organisms as well as the patterns of impact in a natural setting will be crucial to guide appropriate mitigation policies and practices.

Some of the major findings from this review of the literature include:

- 44 sea bird species, 9 cetacean species, 11 pinniped species, 31 invertebrate species/taxa, 6 sea turtle species reported entangled in marine debris in the United States.
- Entanglement rates varied across different species/taxa, but rates seemed to be greater in areas of overlap between high population densities and either human fishing intensity or areas of high debris accumulation (*e.g.*, convergence zones). Often, the source of fishing gear remnants or other marine debris is unknown.
- Some of the highest known marine debris entanglement rates occur with Hawaiian monk seals (0.7% as of 2004) where population numbers are taken into consideration.
- For several species of marine mammals, juveniles and sub-adults have been found to be more susceptible to becoming entangled in debris when compared to more agile, developed adults.
- Overall, the reported entanglement rates of certain species should be used with caution since these rates can be biased based on the sampling method and the difficulty in distinguishing between actively fished gear and marine debris.
- Thus, there is a real need for records of wildlife entanglement to distinguish between entanglements in marine debris as opposed to entanglements in actively fished gear.
- In certain regions in the U.S. and likely elsewhere in the world, numerous species are underrepresented in the literature, implying that reported marine debris entanglement rates are inherently conservative.

Please report stranded or entangled marine mammals and sea turtles by calling the stranding network member for your area (U.S. only). Hotline numbers are listed online at http://www.nmfs.noaa.gov/pr/health/stranding.htm.

BACKGROUND

Marine debris entanglement is a global problem that affects a large number of marine species. Most research articles documenting the entanglement of marine species in the United States are limited to certain geographic areas and species. Prior to the 1950s much of the fishing gear and land-based disposables were made of biodegradeable products such as hemp rope or paper bags (Laist *et al.* 1999; Gregory 2009). These products broke down quickly in the marine environment. As plastic and synthetic materials became more popular for fishing activities and land-based use, lost or abandoned fishing gear and non-disposable items made of synthetic material became entanglement threats for many marine species, including marine mammals, sea birds, sea turtles, fish, crustaceans, and even corals.

Entanglement can cause decreased swimming ability, disruption in feeding, life-threatening injuries, and death. Laist (1997) provided a global review of marine debris entanglements and found entanglement records for 136 marine species worldwide, including 86% (6 of 7) of all sea turtle species, 16% (51 of 312) of all seabird species, and 28% (32 of 115) of all marine mammal species. Additional species have been identified since that review. For example, Baulch and Perry (2012) identified 15 cetacean species with entanglement records compared to 11 identified by Laist (1997). This review documents 111 species in U.S. waters alone.

From the literature reviewed, Alaska and northwest Pacific region, California, Hawaii, Florida, and the northeast Atlantic region all contained common reports on entanglement of marine species in debris. Species such as the northern fur seal (*Callorhinus ursinus*) inhabit waters where marine debris may be more concentrated and thus increase the potential entanglement rate of these animals in marine debris. Examples are the Subtropical Convergence Zone north of Hawaii in the North Pacific Subtropical Gyre (Howell *et al.* 2012), which is crossed twice each year by migrating humpback whales (*Megaptera novaengliae*) and includes the pelagic range of juvenile fur seals, and the Northwest Hawaiian Islands, where drifting debris accumulates on coral reefs inhabited by Hawaiian monk seals (*Monachus schauinslandi*).

While land-based pollution is considered to be a significant source of marine debris, the discard and loss of synthetic material and plastics by the maritime industry is also a significant concern. To address the latter concern, the International Convention for the Prevention of Pollution from Ships (formally adopted in 1973 and updated in 1978 as MARPOL 73/78), Annex V to MARPOL was adopted in 1985 and entered into force in 1988 to reduce waste disposal from ships and prohibit the dumping of plastics into the ocean (Henderson 2001). The overall effectiveness of Annex V is debatable, as marine species continue to become entangled in marine debris. Initially, potential impacts on northern fur seal populations brought the problem to the forefront of international discourse. During the early 1980s, the scientific community was concerned over the precipitous decline in the northern fur seal population in the Pacific. Entanglement in derelict fishing gear was considered a major factor in their decline (Fowler 1985) and numerous papers were presented at the Workshop on the Fate and Impact of Marine Debris (Shomura and Yoshida 1985). After Annex V, entanglement of fur seals declined and remained relatively consistent through 2005 (Williams *et al.* 2004), though it is unclear if Annex V implementation was the cause of this decline. However, as the human population and the numbers of ships continue to increase along the U.S. coast, the threat of increased marine debris from both marine and land-based operations appears to be getting worse.

Other significant actions were taken during the 1980s to address the problem of marine debris and its effects on marine species, including: the creation of the Marine Entanglement Research Program (now the Marine Debris Program at the National Oceanic and Atmospheric Administration (NOAA)), the Marine Plastics Pollution Research and Control Act of 1987, a U.S. Navy waste disposal program, marine debris workshops and meetings, and beach sweeps (Laist *et al.* 1999; Laist and Liffman 2000). More recently, the Keep America Beautiful Initiative in the United States, the resolutions by the U.N. General Assembly, the outcomes of the Rio+20 Conference (SCBD 2012), the development of the Honolulu Strategy (UNEP 2011), and the Global Partnership on Marine Litter (UNEP 2013) have highlighted the seriousness of the problem both in the U.S. and abroad.

This report presents a synthesis of the literature of entanglement of marine species in debris in the United States. A bibliography is attached for reference. Every attempt was made to distinguish between entanglement in active gear and entanglement in marine debris, though for some species, reports do not distinguish between the two types of gear and will eventually require further attention in future assessments.

PINNIPEDS

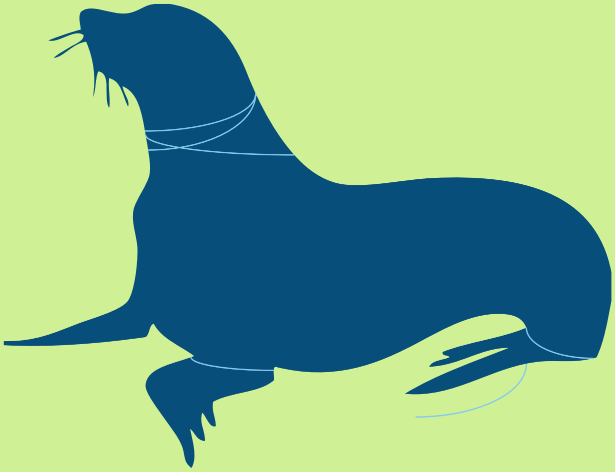
Literature on 11 species of pinnipeds in U.S. waters were reviewed, including: the northern fur seal (*Callorhinus ursinus*), Hawaiian monk seal (*Monachus schauinslandi*), California sea lion (*Zalophus californianus*), northern elephant seal (*Mirounga angustirostris*), Pacific harbor seal (*Phoca vitulina richardsi*), Atlantic harbor seal (*Phoca v. vitulina*), Steller sea lion (*Eumetopias jubatus*), Guadalupe fur seal (*Arctocephalus townsendi*), harp seal (*Phoca groenlandica*), gray seal (*Halichoerus grypus*), and hooded seal (*Cystophora cristata*). The pinniped with the most references to marine debris entanglement was the northern fur seal (n=26), followed by the Hawaiian monk seal (n=11), and the California sea lion and northern elephant seal (n=7 each). All of the literature pertaining to entanglement of pinnipeds in marine debris occurred from research conducted in Alaska, Hawaii, or California, with the exception of two studies from Cape Cod, MA on the east coast of the U.S. Pinnipeds were generally observed to be entangled around the head and appendages in net fragments, monofilament line, packing straps, rope, and rubber products. While entanglement can affect all age classes, juveniles and subadults appeared to be the most susceptible (Goldstein *et al.* 1999; Hanni and Pyle 2000). In a study from the southeast Farallon Islands from 1976–1998, Hanni and Pyle (2000) noted that of 914 entangled pinnipeds across five different species, sea lions (otariids) were most commonly entangled in fishing debris, but seals (phocids) were more commonly entangled in land-based debris. California sea lions appear to have the highest incidence of entanglement (Goldstein *et al.* 1999; Hanni and Pyle 2000; Dau *et al.* 2009; Stevenson 2011), although Guadalupe fur seals, which are relatively rare in U.S. waters, had a much higher entanglement rate than California sea lions (15.4% and 3.8%, respectively) (Goldstein *et al.* 1999). This may be explained by better record keeping, along with an increase in the California sea lion population (Goldstein *et al.* 1999). Neck constrictions were prevalent in all species but most common in California sea lions and Steller sea lions. Hanni and Pyle (2000) reported neck constrictions of California sea lions in 70% of the entanglements with monofilament fishing nets and line being the most common source (13%).

At least six studies reveal that entanglement from marine debris was less frequent than entanglements from active fishing gear (Stewart and Yochem 1985, 1987, 1990; Hanni and Pyle 2000; Swails 2005; Raum-Suryan *et al.* 2009). Marine debris entanglements ranged from 27% to 50% of the total entanglements in those studies. Nevertheless, the overall entanglement rates described in those reports are provided to indicate the general scale and trend of occurrence. California sea lion entanglement rates observed on beaches in the California Channel Islands increased from 0.08% in 1983–84 to 0.12% in 1988–89 with a high of 0.16% from 1985–88 (Stewart and Yochem 1987, 1990). These observations were based on beach counts and may not reflect all entanglements, and may indicate a significant number of entanglements with active gear. Another source of information on entanglement rates comes from rescue centers. Goldstein *et al.* (1999) reported that from 1986–1998, 2.7% of California sea lions brought into a California marine mammal rescue center for rehabilitation showed signs of entanglement in marine debris. Over 90% of these were either yearlings or subadults, with the highest number recorded. While this may seem like an increase in entanglements over the 15-year period, this number is likely due to sampling methods. The Stewart and Yochem studies were confined to islands in the Southern California Bight, while Goldstein *et al.* reported on live stranded animals from coastal central California. Coastal central California entanglements peaked in 1992, potentially due to an El Niño (Goldstein *et al.* 1999). Monofilament line and packing straps were the most prevalent debris type.

Entanglement rates for Steller sea lions may be increasing in Alaska. In 1986, Loughlin *et al.* (1986) reported an entanglement rate of 0.07%, but between 2000–2007 Raum-Suryan *et al.* (2009), reported a rate of 0.26%. The latter study also found that of 386 entangled animals, 49% were entangled around the neck and 54% of these involved packing straps, 30% rubber bands, 7% each of net and rope, and 2% in monofilament line (Jensen *et al.* 2009). Calkins (1985) noted that most individuals affected were 2–3 yr-old juveniles entangled in packing straps and net fragments.

Prior to 1983, northern elephant seal entanglement rates were estimated at approximately 0.08% (Stewart and Yochem 1985), but increased somewhat to 0.15% in

> **“U.S. Pinnipeds were generally observed to be entangled around the head and appendages in net fragments, monofilament line, packing straps, rope, and rubber products. While entanglement can affect all age classes, juveniles and subadults appeared to be the most susceptible.”**



1983–84 and 0.16% between 1984 and 1986 in the Southern California Bight (Stewart and Yochem 1987). Goldstein *et al.* (1999) reported an entanglement rate of 0.4% among rescued elephant seals from 1986–1998, all of which were pups. However, Hanni and Pyle (2000) reported a negative trend in entanglements on the Southeast Farallon Island, CA from 1976–1998. Of the 68 animals entangled there, 59% were entangled in marine debris other than nets and monofilament line. Most of these entanglements were packing straps (22%). Stevenson (2011) reported 22 northern elephant seals entangled in packing straps from 2001–2005 in central California and the U.S. Pacific Northwest coast.

Prior to 1983, Pacific harbor seal entanglement rates were estimated to be approximately 0.08% (Stewart and Yochem 1985). This rate varied from 1983–1989 between a low of 0% in 1983 to 0.06% from 1984--1986. Packing straps and other debris accounted for most of the entanglements (Stewart and Yochem 1987). Goldstein *et al.* (1999) reported an entanglement rate among rescued harbor seals of 0.28%, most of which (66.7%) were pups. The incidence of entanglement was considerably lower on the Southeast Farallon Island, with only three entangled harbor seals documented from 1976–1998 (Hanni and Pyle 2000).

Guadalupe fur seals were the least reported of the pinniped species by number, apparently because of their lower numbers in U.S. waters and secluded habitat. Hanni *et al.* (1997) reported three of the 14 (21.4%) animals observed in California between 1988 and 1995 with evidence of entanglement; one with polyfilament line around the neck, one with net markings, and one with hook and line. Entanglement in debris was evident with 15.4% of the Guadalupe fur seals taken for rehabilitation from 1986–1998 (Goldstein *et al.* 1999). All of the interactions involved pups.

Only two studies were found that document entanglements among eastern U.S. pinnipeds. Swails (2005) conducted a study in Cape Cod, MA from 1999–2004 and Bogomolni *et al.* (2010) conducted one on Cape Cod from 2000–2006. Both studies found a high incidence of debris entanglement for gray seals (33.3% in Swails and 37.9% in Bogomolni et al.), and significantly lower rates among harbor seals (7.4%), harp seals (1.9%), and hooded seals (0.0%) (Swails 2005). Most of those entanglements, however, were believed to be from active fishing gear, and not necessarily caused by marine debris; an important distinguishing factor when determining management decisions.

Figure 1. *Packing band debris entangled around the neck of a sub-adult Steller sea lion in Alaska.*

Credit: © AK Dept. Fish & Game, taken under federal permit #14325

Northern Fur Seal

The first reported entanglement of a northern fur seal was reported in 1923 (Jensen *et al.* 2009). In the late 1800s and early 1900s their numbers declined significantly due to uncontrolled at-sea harvests of an estimated 300,000 individuals. To prevent the decline, the harvesting nations (Canada, Japan, the Soviet Union, and the United States) signed a treaty in 1911 agreeing to ban at-sea harvests, which were non-selective for sex, in lieu of annual on-land harvest of juvenile males at the species rookeries to be managed cooperatively by the four harvesting nations. The new system stopped the decline, and the northern fur seal population subsequently increased to approximately 2 million seals by the 1940s (French and Reed 1990). Beginning in 1956, the harvest was expanded to include juvenile females based on a theory that the action would increase the fitness of surviving females, and after a brief decline in abundance, the population would stabilize and pup production would increase, thereby increasing the harvest potential. The population subsequently began declining as expected, but the decline did not stabilize, which then ended this practice in 1968 (French and Reed 1990).

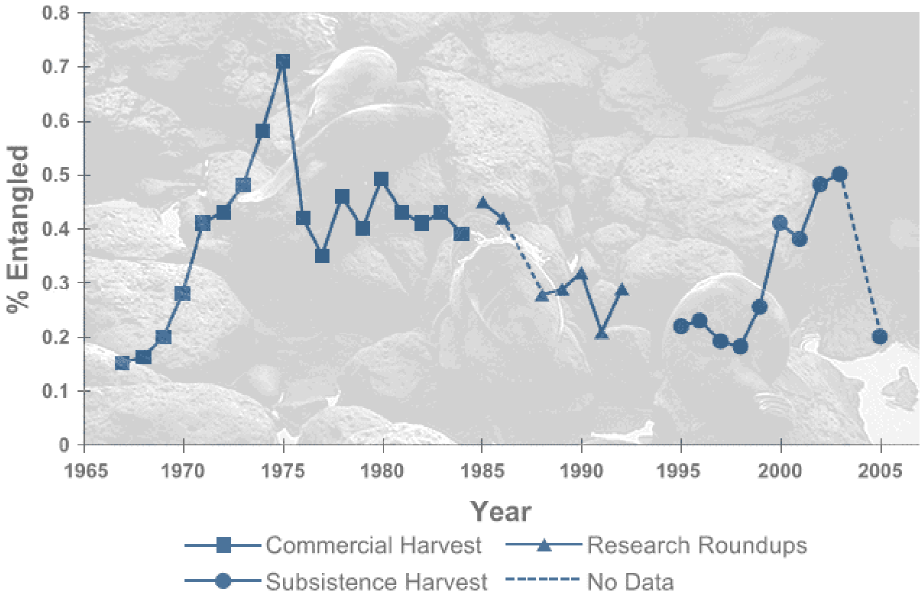


Figure 2. *The graph shows the percentage of entangled northern fur seals observed in surveys conducted on the Pribilof Islands during the commercial fur seal harvest (1967–84), during research "roundups" (1985–92), and during the subsistence harvest (1995–2005). Source: Zavadil, P.A., A.D. Lestenkof,K. Holser, A. Malavansky and B.W. Robson. 2007. Northern Fur Seal Entanglement Studies on the Pribilof Islands in 2005.*

The population continued its decline through the 1970s prompting numerous investigations that implicated entanglement in marine debris as a significant contributing factor (Fowler 1985; Swartzman *et al.* 1990; Laist 1997; Fowler 2000). However, hypotheses suggesting that marine debris has a large impact on the size of the fur seal population of the Pribilof Islands (in the Bering Sea, off the coast of Alaska) have been challenged because of either low sample size or insufficient observations; more specifically due to few observations of entangled seals on land and unverified large numbers of entangled seals at sea (Trites *et al.* 1992). By 1976, an estimated 40,000–50,000 fur seals per year were estimated to be killed by strapping bands from bait boxes and netting, and the population was declining at a rate of 4–6% per year (Fowler 1982; Laist 1997; Derraik 2002) and continued declining into the 1980s (Fowler 2000). When French and Reed (1990) used a model to include subadult male entanglement rates and mortality combined with adult female harvest and entanglement mortality, the decline due to entanglement in marine debris was estimated to be 1% per year, slower than in the 1970s. They proposed that a 20% reduction in entanglement mortality rates would sufficiently stop this decline. During the 1990s, the Pribilof Islands population remained stable (Laist 1997) and was estimated to be 1,002,516 in 1996 (NMFS 1998). These estimates are based on the estimated number of pups born in the rookeries multiplied by expansion factors from life table analyses (Lander 1981; NMFS 1998). However, the population declined to an estimated 721,935 by 2006 (NMFS 2007) and to 611,617 by 2011 (Allen and Angliss 2012). With entanglement rates staying constant (see below) from the 1990s, it is likely that factors other than marine debris, such as climate change, prey availability, El Niño events, and migration of adult females to a rapidly expanding rookery on Bogoslof Island along the Aleutian Island chain may have caused a recent decline in the Pribilof Islands population (NMFS 2007). However, entanglement rates may be considered conservative since monitoring of at-sea entanglements are not figured into the data.

The majority of entanglements appear to involve strapping bands from bait boxes used by fishermen and trawl net debris <150g (Fowler *et al.* 1990); trawl nets were estimated to make up between 49–72% of all entanglements (Scordino 1985; Fowler 1987; Baba 1995; Kiyota and Baba 2001). In a one-year study of fur seal entanglement, 70% of entangled animals (primarily subadult males) were able to shed the debris (Scordino 1985), though larger fragments of net may prevent seals from returning to land or result in their death (Fowler *et al.* 1990). In 1988, a 50% reduction in trawl net entanglements occurred, possibly due to mariner education and less discarded or lost gear (Fowler *et al.* 1990), or the institution of MARPOL Annex V (Ribic *et al.* 1994). It is difficult to ascertain which measure had a greater effect on the reduction, but both may have played a significant role. Entanglements in packing straps decreased from 48–55% in the 1970s to 16–26% in the early 1980s (Scordino 1985) and remained around 14% until 1993 (Baba 1995).

Juvenile fur seals are the most affected by entanglement in debris, possibly because their playful nature and curiosity attracts them to floating nets (Yoshida and Baba 1985; Laist 1997; Fowler 2000). Fowler (1985, 1987) estimated that juvenile entanglement mortality during their first two years at sea could be as high as 15%. Entanglement rates with juveniles were similar or lower in the 1990s

(Jensen *et al.* 1998). Females were entangled less often, at about half the entanglement rate of males (Delong *et al.* 1990). Although, there is evidence to suggest that entanglement of females affects reproductive success (Scordino 1985; Fowler 1987). Entanglement rates for females ranged from 0.06% in 1985 to 0.23% in 1986 (Delong *et al.* 1990) and 0.013% from 1991–1999 (Kiyota and Baba 2001), much lower than the average 0.4% for juvenile males (Delong *et al.* 1990; NMFS 2007). Behavioral traits between sex and age may account for differences in entanglement rates, as juveniles tend to be more curious with objects in their environment (Kiyota and Baba 2001).

Entanglement rates of northern fur seals (as measured by the proportion of animals seen entangled on rookeries) have been recorded since the late 1960s and are some of the highest of any pinniped species (Antonelis *et al.* 2006). Entanglement rates on the Pribilof Islands steadily increased from the late 1960s (low of 0.15%) through 1975 (high of 0.71%), when the popularity of synthetics in fishing gear expanded (Fowler 1985). Entanglement rates since 1975 have hovered around 0.4% with the exception of 2002–2003, when the rates increased to about 0.5% (see Figure 2; Fowler 1985; Scordino 1985; Baba *et al.* 1990; Delong *et al.* 1990; Fowler *et al.* 1990; French and Reed 1990; Baba 1995; NMFS 2007; Williams *et al.* 2004).

The decline of fur seal entanglement rates could be due to many factors, including changes in fishing practices in seal habitat (Laist 1997; Kiyota and Baba 2001). This raises concern that the data presented may include entanglements that occurred in actively-fished gear. Although, many of the papers do specify net fragments, which can be considered marine debris along with packing straps and other debris. Nevertheless, other debris besides netting is described and probably constitutes a smaller but still significant amount of entanglement debris.

Hawaiian Monk Seal

The endangered Hawaiian monk seal is a tropical seal found only the Hawaiian Archipelago; most monk seals now occur in the remote Northwestern Hawaiian Islands (NWHI). The seal population is estimated to be 1,212 (Carretta *et al.* 2013) and has been declining since the 1950s (Lowry *et al.* 2011). Among the major threats to the species is entanglement in marine debris (Henderson 2001; Boland *et al.* 2003). The monk seal was hunted to near extinction in the 1800s and early 1900s. Although the species likely recovered to some extent during the first half of the 1900s, between the mid-1950s—when the first seal counts were made—and the mid-1990s, the population had declined to one-third of its size due at least in part to entanglement in trawl nets and other debris that drift into the NWHI from other areas (*e.g.*, Alaska, Russia, Japan) and accumulates along the beaches and in lagoon reefs of atolls (Donohue et al., 2001). In 2000, President Clinton imposed an order to designate a reserve within 50 nautical miles of the NWHI

Figure 3. *A Hawaiian monk seal lays along the shoreline with a fishing net entangled around its neck.*

Credit: NOAA Fisheries, Pacific Islands Fisheries Science Center, taken under Marine Mammal Permit #10137 (Ilana Nimz photographer)

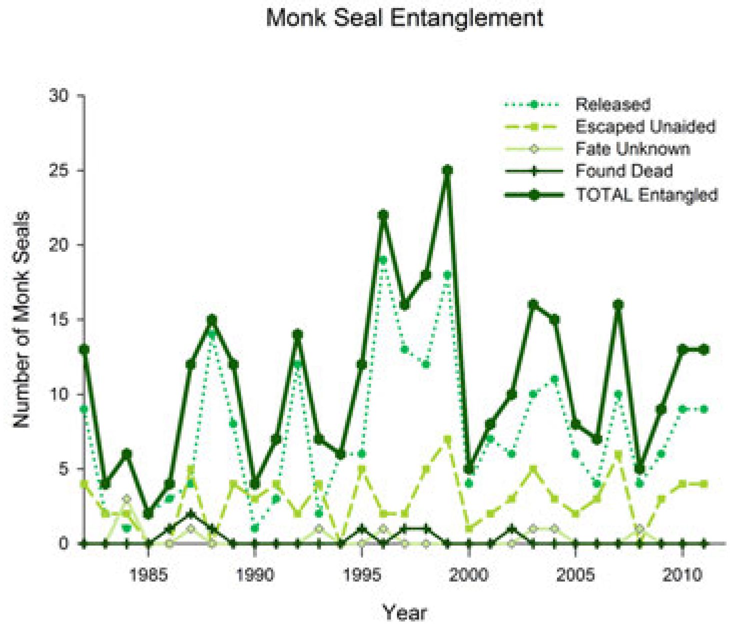


Figure 4. *Number of entangled Hawaiian monk seals observed from 1992 through 2011. Data provided by the National Marine Fisheries Service, Pacific Islands Fisheries Science Center (MMC 2012).*

to restrict fishing. Therefore, nearly none of the entanglements in this area involve gear that is fished in the NWHI. Since then, substantial efforts have been made to remove net debris from NWHI lagoons and Islands. In 2002, this habitat was designated as a National Marine Sanctuary (Marine Mammal Commission 2003) and was designated as the Papahanaumokuakea Marine National Monument in 2006 by President Bush. In the 1990s, entanglements averaged 15 individuals per year and 25 were recorded entangled in 1999. These entanglements declined from 2000–2002 (5, 8, 10, respectively) (MMC 2003), possibly due to clean up efforts. From 2003 to 2011, the number of entangled monk seals has fluctuated between 5 and 16 per year (MMC 2012).

Marine debris entanglements of monk seals were first described in 1969, with other reports occurring in Balazs (1979) and Andre and Ittner (1980). Monk seals are commonly entangled in trawl net fragments, packing straps, and monofilament line. For example, of 35 monk seals documented as entangled (n=27 seals) or having entanglement scars (n=8 seals) between 1974 and 1984, 49% (n=17 seals) were able to free themselves (Henderson 1985). From 1985–1988, 34 entanglements were recorded mainly in monofilament lines, nets, and packing straps. Most entanglements, like most monk seals, are found in the NWHI at the six major monk seal breeding colonies. Entanglement rates can vary significantly between years and at different breeding colonies. Based on estimates of monk seal abundance and observed entanglements at different breeding colonies, among those that have experienced some of the highest entanglement rates are colonies at Kure Atoll in 1988 (71.5%; 5 of 7 seals), Laysan Island in 1988 (2.1%; 7 of 331 seals), and Lisianski Island in 1992 (3.7%; 8 of 217 seals) (MMC 1994). Most of those seals were either disentangled by field crews, or were able to free themselves. Between 1982 and 2011, 311 monk seals were documented as being entangled in marine debris (Figure 4; MMC 2012).

Overall marine debris entanglement rates for the entire population from 1982 to 2005 have been summarized by Donohue and Foley (2007) (Figure 4). However, these entanglement rates are based on the number of entanglements divided by the product of the number of annual observation days and the mean of the annual beach counts, a method of calculation that is different than reported by the MMC (2012), where the total population estimate is considered based on the NMFS Stock Assessment Reports. The entanglement rate increased from 0.06% to 0.48% from 1985 to 1988 (Henderson 1990) and did not decrease after MARPOL Annex V, except for a decrease in 1990 to 0.10% (Henderson 2001). In fact, the entanglement rate climbed to 0.70% by 2004 (Donohue and Foley 2007; USEPA 2011). This elevated rate was attributed to an El Niño event that concentrated marine debris in monk seal habitat (Donohue and Foley 2007). Entanglement rates for Hawaiian monk seals are variable and cyclical, corresponding to El Niño effects when the Southern Tropical Convergence Zone (STCZ) moves southward toward the range of the Hawaiian monk seal (Donohue and Foley 2007). The southward movement of the STCZ also generally results in higher observed entanglement rates.

CETACEANS

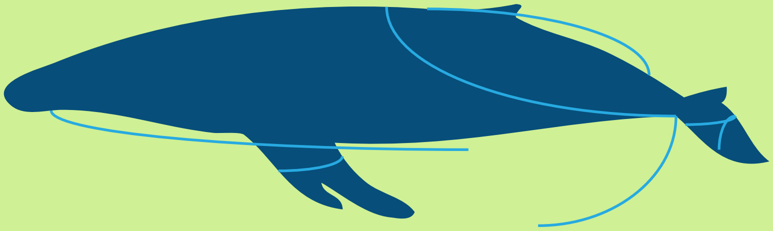
Cetaceans (whales and dolphins) are affected by marine debris entanglement all over the world. Recorded entanglement events have been documented for at least 60% (6 of 10 species) of the baleen whales (mysticetes) and 8% (5 of 65 species) of the toothed whales (odontocetes) (Laist 1997, 1999). While fishing gear, likely including at least some abandoned, lost or otherwise discarded fishing gear (ALDFG), constitutes the vast majority of baleen whale entanglements, a broader array of ALDFG appears to pose entanglement risks for bottlenose dolphins and perhaps other odontocetes. Thus, most entanglement records pertain to incidental or by-catch in actively fished gear, instead of entanglement in marine debris (Laist 1997; Baulch and Perry 2012; Butterworth 2012).

Worldwide, Baulch and Perry (2012) list 15 species of cetaceans involved in entanglement in marine debris, which is 4 more species than listed by Laist (1997). In the United States, the literature presented 8 species of mysticetes and one odontocete species as entangled in fishing operations or marine debris. Most individuals are entangled in actively fished gear, either through chance encounters with lines or nets, or from attempting depredation. Some, however, also become entangled in lost or otherwise abandoned gear they may encounter while swimming or feeding. The nine cetacean species documented in this review to be impacted by debris appears to be a conservative estimate of the total number of cetaceans that are potentially entangled in marine debris in the U.S. As Simmonds (2012) acknowledges in a similar review, many institutions that record cetacean strandings and sightings rarely publish reports on single animals that may be affected. For example, Sadove and Morreale (1990) reported on 4 species of mysticetes and 13 species of odontocetes entangled in netting, trap line, or longline in the New York Bight, but the report does not specify which species were entangled in active fishing operations and which were indeed marine debris.

Baleen whales with entanglement reports, include: the humpback whale (*Megaptera novaeangliae*), the North Atlantic right whale (*Eubalaena glacialis*), the minke whale (*Balaenoptera acutorostrata*), the gray whale (*Eschrichtius robustus*), and the bowhead whale (*Balaena mysticetus*). However, the only baleen whales for which entanglement records have clearly been attributed to marine debris as opposed to active gear are humpback, right, minke, gray, and bowheads (Laist 1997, Baulch and Perry 2012). The only odontocete species where marine debris entanglement was evident were the sperm whale (*Physeter macrocephalus*), the bottlenose dolphin (*Tursiops truncatus*), the harbor porpoise (*Phocoena phocoena*), and the Dalls porpoise (*Phocoenoides dalli*).

Common sources of entanglements for baleen whales included line and net fragments attached through the mouth or around the tail and flippers. Most reports of entanglements of baleen whales did not specify marine debris as the source, but Baulch and Perry (2012) and Macfadyen *et al.* (2009) tried to exclude reports that contained entanglement in active fishing gear and concentrated on ALDFG. Bottlenose dolphins were the most commonly entangled odontocete, with most entanglements involving monofilament line, net fragments, and rope attached commonly to the appendages. Anecdotal reports from stranding networks also mention entanglements in packing straps and rubber gaskets.

Entanglement rates in marine debris were nearly impossible to decipher because of the high incidence of reports that did not distinguish between ALDFG, active fishing gear, and marine debris in their analyses. However, Baulch and Perry (2012) reported that entanglement of cetaceans in marine debris has increased dramatically in recent decades, but data to document the extent of increase are generally insufficient to accurately quantify recent trends.



"Common sources of entanglements for baleen whales included line and net fragments attached through the mouth or around the tail and flippers."

Humpback Whales

Reports of entangled humpback whales in the U.S. (n=18) constituted the vast majority of papers on baleen whale entanglement. However, most of these reports did not distinguish between entanglements in marine debris and active fishing gear, and most were from annual Stock Assessment Reports on mortality of baleen whales from the National Marine Fisheries Service (NMFS). All but three reports (Jensen *et al.* 2009; Neilson *et al.* 2009; Lyman 2012) described humpback whales from the eastern U.S. and Gulf of Maine. Four of the reports described entanglements based solely on scarring with no indication of what type of material inflicted these wounds, which would provide information on the source of the debris (Robbins and Mattila 2001, 2004; Neilson *et al.* 2009; Robbins 2012). A vast majority of these reports, however, likely involve interactions with active gear rather than debris.

Nearly all (98%) of the marine debris entanglements of cetaceans were with ALDFG as opposed to land-based marine debris, mostly pot trap lines and nets worldwide (Baulch and Perry 2012), and this seemed to be the case with humpback whales. Wiley *et al.* (1995) reported that as much as 25% of the stranded humpback whales observed between 1985 and 1992 from Virginia to North Carolina could be attributed to entanglement, and that annual mortality rate may be 4.8% when added to natural mortality of Gulf of Maine humpbacks (Volgenau *et al.* 1995).

The difficulty in describing annual mortality rates caused by marine debris for baleen whales is evident as gleaned from reports such as Johnson *et al.* (2005) and Jensen *et al.* (2009), where 73% and 76%, respectively, of fishing gear attached to humpbacks was from a known fishery and likely being actively fished. The remaining entanglement proportions (*i.e.*, 27% and 24%) were from unknown sources that could have included marine debris. Either way, the case can be made that humpbacks are vulnerable to entanglement in debris, though entanglement in marine debris appears to be considerably less than entanglement in fishery operations. Keeping this bias in mind, the following entanglement rates include both presumed actively fished entanglements and sources that are unknown (presumably including at least some marine debris).

The data extrapolated from Johnson *et al.* (2005) from 1993–2002 provide an annual entanglement-caused mortality rate of three

Figure 5. *(Right). NOAA's Marine Mammal Health and Stranding Response Program from the Hawaiian Islands Humpback Whale National Marine Sanctuary respond to and aid an entangled humpback whale.*

Credit: Courtesy of HIHWNMS (NOAA MMHSRP Permit #932-1489) - 2/28/05

Credit: Courtesy of HIHWNMS (NOAA MMHSRP Permit #932-1489) - 2/28/05

Figure 6. *(Left) A humpback whale entangled in fishing gear swims near the ocean's surface.*

humpback whales per year along the U.S. East Coast. Most of these entanglements were around the tail and mouth, with pot gear and net representing the most common gear types. Entanglement data for the U.S. East Coast and Canadian Provinces were described in NMFS reports from 2000 to 2010 (Cole *et al.* 2006; Nelson *et al.* 2007; Glass *et al.* 2008, 2009, 2010; Henry *et al.* 2011, 2012), with each publication covering five years, although these years overlapped (*e.g.*, 2000–2004; 2001–2005, etc.). Data from 2000–2004 (Cole *et al.* 2006) and 2005–2009 (Henry *et al.* 2011) were used to extrapolate entanglement rates for those periods. The entanglement rate appears to be increasing, since rates increased from 14.4 animals per year (2000–2004) to 18.8 animals per year (2005–2009).

In Alaska, extrapolating data from Jensen *et al.* (2009), an entanglement rate of 8.8% per year was found between 1997 and 2007. Only 24% of the entanglements were from unknown sources, possibly including marine debris, and the rest clearly were from active fishing operations mainly involving pot gear and nets. Similarly, Neilson *et al.* (2009) describe most of the entanglements (77%) from pot gear and nets, and the remaining unknown. Entanglements were suggested to be increasing over time (Neilson *et al.* 2009).

The lone report from Hawaii described entanglements found in the Hawaiian Islands Humpback Whale National Marine Sanctuary but included some animals that likely became entangled in their northern feeding grounds and carried those lines to their winter calving grounds in Hawaii. For example, 10 animals with gear observed in Hawaii have also been sighted with gear in Alaska, with one animal traveling over 2,450 nautical miles with gear attached (Lyman 2012). This report also noted that humpbacks are frequently entangled in fishing pot gear, monofilament (net or line is not described), moorings, longline, and marine debris (Figure 5 & 6; Lyman 2012).

Only 8% of the affected animals were found entangled in marine debris as opposed to entangled in actively fished gear, and these incidents have increased over time. Additionally, as mentioned previously, four studies described reports of observed whales with scars on their tails, indicating past entanglement events (Robbins and Mattila 2001, 2004; Neilson *et al.* 2009; Robbins 2012). Yearlings and juveniles appear to have the highest incidence of entanglement (Robbins and Mattila 2001; Robbins 2012), although adults have more scars (Neilson *et al.* 2009). From 1997–2010, the acquisition of new entanglement scars varied from year-to-year between 6% and 26% (Robbins 2012). Robbins and Mattila (2001) noted that between 48–68% of animals have had a past entanglement and 17% showed new entanglement scars after one year of observation (Robbins 2012). It is evident, therefore, that a significant number of animals are becoming entangled, but are able to shed their burden of lines and netting. The disentanglement rate of fishing gear from whales is low and likely not a strong mitigating measure to eliminate the impacts of marine debris and ALDFG.

North Atlantic Right Whale

Numerous studies have been completed on mortality of this critically endangered baleen whale. With approximately 450 individuals in the population (Waring *et al.* 2013), analysis of mortality is critically important. As with humpback whales, the problem with entanglement records for this species is they are largely assumed to involve active fishing gear and entanglements in marine debris appear to be relatively infrequent. Most of the literature reviewed (n=15) documents whales that have become entangled in pot lines, non-mobile gear, lines, and nets.

Recently, Knowlton *et al.* (2012) conducted a 30-year (1980–2009) comprehensive review of entanglement rates using photographs of right whales. In the report, 626 individuals were observed and 82.9% showed entanglement, and 80% of those observations involve entanglement in non-mobile pot gear and nets. The other 20% constituted entanglement from unknown sources, but mainly from rope. The overall entanglement rate was 25.9% for the 30-year period, with the highest rate coming in 1983 with 50%. A seven-year pattern of high entanglement rate exists but is not explained by the authors. If we consider that 20% of the entanglements that came from unknown sources are marine debris, the best estimate for a marine debris entanglement rate over the 30-year period would be 4.2%. Caution should be noted here in that this estimate likely contains cases where entanglements occurred in active gear, and future efforts should take care in trying to separate whale entanglement via actively fished gear and via marine debris. Despite the limited capacity to assess the difference in these entanglement rates, this study suggests that right whales are indeed likely being impacted by marine debris, suggesting that further action is required to assess the extent of entanglement of these whales in marine debris and to promote action to eliminate this impact on these animals.

Bottlenose Dolphin

The bottlenose dolphin is one of the most studied cetacean species because of its near-shore habitat of coastal oceans, bays, sounds, and rivers. However, few reports exist that document the entanglement of these animals in marine debris. This review provides one of the first compilation of reports documenting marine debris entanglement of this species. Many reports of individual animals entangled in fishing gear and marine debris are found in unpublished, "gray" literature from various research institutions and academia, as well as media reports. The reports described here (n=12) are all from the east coast of the U.S. and Gulf of Mexico, specifically Virginia, South Carolina, and Florida.

Anecdotal evidence has shown that bottlenose dolphins can become entangled in various forms of marine debris, including: net fragments, monofilament line, rubber gaskets, rope, clothing, and other forms of debris. Mann *et al.* (1995) described a dolphin calf entangled in monofilament line that eventually was shed after weeks of observation. Wells *et al.* (1998) observed two of 11 dolphins recovered dead in Sarasota, FL from 1993–1996 entangled in monofilament line. Many individuals bare scars from past entanglements as evidenced by Wells and Scott (1994), where 11% of dolphins handled during live capture-release studies from 1975–1990 showed past entanglement from fishery gear or marine debris. The resident population in Sarasota and their interactions with fishing gear and humans have been studied for decades. In a study from 2000–2007, Powell and Wells (2011) determined that nearly 2% of this small population died in 2006 due to entanglement or ingestion of recreational fishing gear, a level that may not be sustainable. Depredation of caught fish or bait from recreational fishing lines was thought to be the major cause of these deaths and, while not directly marine debris, it could expose these animals to discarded fishing line. By 2007, 14% of the population was observed either entangled in recreational fishing gear or exhibiting depredation behaviors (Powell and Wells 2011), a trend that has increased over time. Wells *et al.* (2008) concluded that eight of the 12 entanglements recorded from 1988–2007 involved debris, including seven that were caught in discarded monofilament line and one in a man's bathing suit. Thirty-eight other dolphins showed evidence of scarring from past entanglements.

In part due to the entanglement in monofilament line described above, a Florida Entanglement Working Group was established in 2003 (Bassos-Hull and Powell 2012). This group reports on entanglements in dolphins, manatees, and sea turtles on an annual basis. From 1997–2009, 132 bottlenose dolphins were reported entangled or with ingested fishery-related gear and other types of debris statewide (Bassos-Hull and Powell 2012). Of these, 73.5% were from hook and line or monofilament line, while 6% from other types of material. While Bassos-Hull and Powell (2012) and Bassos-Hull (2013) do not specify marine debris as the source of those entanglements, they do report entanglement "hot spots," including the Indian River Lagoon of the east coast of Florida, the central west coast (Sarasota–Tampa), the southwest coast, and the Florida Keys.

In the Indian River Lagoon, monofilament line appears to be the most common source of bottlenose dolphin entanglements (Lelis 2012; Stolen *et al.* 2013). From 1997–2009, 2.7% of all stranded dolphins were entangled in monofilament line caught largely on the dorsal fin and other appendages. If you exclude the number of animals observed where interactions with active gear could not be determined, then 6.1% of these animals were entangled in ALDFG monofilament line.

In South Carolina , entanglements in marine debris include monofilament line, rope, and past net entanglement observed in the stranding record. Marine debris such as rope fragments and packing straps have been photographed on free-swimming dolphins (W. McFee, unpublished data, NOAA) (Fig. 4). McFee and Hopkins-Murphy (2002) observed an overall entanglement rate of 10.8% (or 1.8/yr) in marine debris from 1992–1996, primarily from monofilament line and rope fragments, excluding those cases where the source could not be determined. That rate increased over the next seven years (1997-2003) to 12.3% (or 2.1/ yr) (McFee *et al.* 2006). This rate was greatly influenced by the high number of entanglements in 1997–1998. From 2004–2012, the entanglement rate has decreased, providing an overall entanglement rate since 1992 of 8.8% (1.7/ yr) (Fig. 5; W. McFee, unpublished data, NOAA).

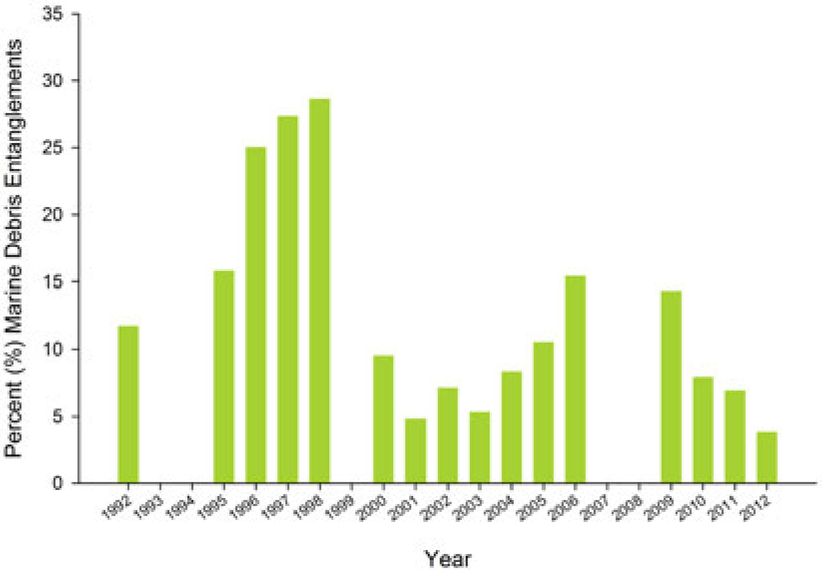


Figure 7. *Percentages of bottlenose dolphins stranded in South Carolina that were found entangled in active fishing gear and marine debris. Source: McFee and Hopkins-Murphy 2002; McFee et al. 2006; McFee, unpublished data.*

OTHER MARINE MAMMALS

As with other marine species, environmental factors and changing fishing practices and gear affect annual entanglement rates. Increased entanglement in monofilament line in Sarasota, FL was suggested to be caused by harmful algal blooms, with reductions in available prey species causing dolphins to change their foraging strategies in ways that increased their exposure to human activities and debris (Powell and Wells 2011). An increase in marine debris entanglements in South Carolina from 1996–1998 was unexplained, but also occurred in El Niño Southern Oscillation years. New fishing gear that ends up as debris also can be detrimental. Barco *et al.* (2010) identified Spectra® twine as a source of lines entangling a dolphin in Virginia and causing lacerations that were more severe than typical monofilament line of the same diameter. This line had encrusting algae on it, which suggests it may have been ALDFG; it apparently was causing more drag, facilitating deep cuts in the flukes.

The Secretariat of the Convention on Biological Diversity (SCBD) (2012) reported 52 marine mammal species with entanglement records worldwide. Many of these species occur in the United States. Other marine mammals that have been found in the literature with entanglement records in U.S. waters are the Florida manatee (*Trichechus manatus latirostris*) (O'Shea *et al.* 1985; Beck and Barros 1991; Nill 1998; Spellman 1999; Bassos-Hull and Powell 2012; Bassos-Hull 2013) and sea otter (*Enhydra lutris*) (Degange and Newby 1980; Moore *et al.* 2009).

While human-related manatee deaths are generally associated with watercraft mortality, there are reports of this species being entangled and killed in debris from monofilament line and rope. The best source of information comes from the Florida Wildlife Commission website, though it is difficult to parse out marine debris entanglement from this dataset. From 2003 to 2007, 29 salvaged manatee carcasses were found entangled in marine debris consisting of monofilament line, nets, and rope, representing 0.6% of the total (1,805) dead manatees collected over this period (FWC Florida Manatee Stock Assessment Report, 2009). During the same period, ~25% of animals that were successfully rescued were entangled in marine debris. This was far more than the 2.7% that were entangled and rescued from 2007 to 2011 (FWC Florida Manatee Stock Assessment Report, 2013). Beck and Barros (1991) reported 2.5% mortality from entanglement between 1974 and 1985. From 1983 to 1999, 29.5% of rescued manatees were entangled in monofilament lines, nets, and packing straps (Spellman 1999). Over 49% of these animals were adult females. Some of these animals required surgical amputation of forelimbs or had lost forelimbs due to entanglement. Furthermore, given that Florida manatee populations are quite low (~3,800) (FWC FWRI Manatee Synoptic Aerial Surveys 2009), future efforts should identify the types and sources of debris leading to manatee deaths and act to prevent these mortality events.

Table 1. Factors complicating the analysis of marine entanglement (adapted from Laist 1997 and Gregory 2009).

Detection and Discovery	**Sampling and Reporting Biases**
• Isolate incidents over a wide area	• Limited at-sea sampling • Few long-term surveys
• Often difficult to detect entangled animals at sea when they surface; easier on stranded animals	• Inconsistent sampling methods Strandings are an unknown portion of total mortality;
• Detection at sea difficult if floating below surface or concealed in matted debris • Some dead animals are held underwater by debris anchored on the sea floor	• Shore counts of live entangled animals are biased toward survivors with minor amounts of debris and less serious injuries
• Entangled dead animals may disappear quickly through sinking or predation.	• Limited efforts and ability to distinguish entanglements caused by active gear vs. marine debris

SEA BIRDS

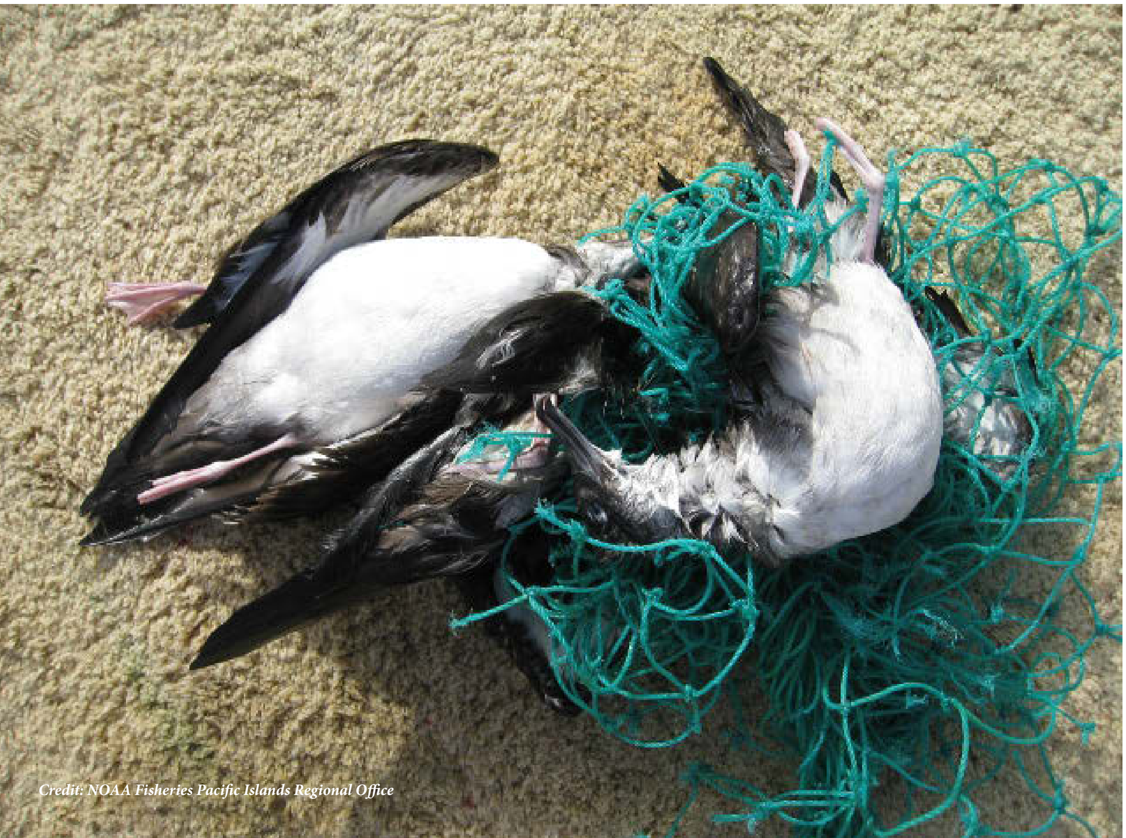
Worldwide it is estimated that at least 67 species of sea birds are entangled in or ingest plastic (SCBD 2012). Laist (1997) lists 138 species worldwide with entanglement or ingestion records, with 19 species of sea birds specifically entangled in marine debris found in the United States. Moore *et al.* (2009) lists some of the same species but provides an additional 22 species, and Harris *et al.* (2006) lists three other species, bringing a minimum estimate of sea birds entangled to 44 species in the Continental U.S. and Hawaii. Moore *et al.* (2009) point out that inconsistencies in distinguishing between entanglement in actively fished gear and marine debris make it difficult to assess the effect of marine debris on sea birds. Nevertheless, from 2001–2005, entanglement rates ranged from 0.2% to 1.2% for all sea birds observed by beach monitoring programs in California, Oregon, and Washington. A majority of entanglements involved fishing gear such as monofilament line and hooks, but 8.3% of the entanglements were from non-fishery-related items. Common murres and western gulls were the most common species found entangled.

In a review of bird and pinniped entanglements in five rehabilitation facilities throughout California from 2001–2006, Dau *et al.* (2009) found entanglements to be the cause of 31.1% of rescued brown pelicans (*Pelecanus occidentalis*) and 11.1% of rescued gulls (*Larus spp.*). The area of greatest entanglement for brown pelicans was Monterey Bay (59.6%; 180/302), and for gulls was Los Angeles and Orange Counties (16.1%; 92/572). The majority of these entanglements were fishery related including monofilament line and hook.

Sea birds have also been found dead in derelict fishing nets (Figure 8 – below). Diving birds appear to be susceptible to entanglement in nets while pursuing fish underwater (Good *et al.* 2007; Gilardi *et al.* 2010). Good *et al.* (2007) described seven species of sea birds, mainly cormorants, dead in derelict fishing nets in the Northwest Straits and Puget Sound. Brandt's cormorant, the common loon, and western grebe were identified as species of special concern for derelict net entanglements in Washington (Good *et al.* 2007; Gilardi *et al.* 2010). Degange and Newby (1980) also documented 99 sea birds (five species) entangled in a single derelict high-seas salmon drift net in 1978. Harris *et al.* (2006) surveyed beaches in Cape Cod, MA and found 6.7% of dead beach-cast sea birds were entangled in hook, monofilament line, or nets. However, they go on to report that 2.2% were also entangled in marine debris in 2003–2004.

Besides the risk of entanglement from derelict nets and fishing gear, sea birds are also susceptible to entanglement from plastics and other synthetic materials that they may gather for making nests (Fig. 8) (Votier *et al.* 2011; Butterworth 2012). Podolsky and Kress (1989) observed cormorants in Maine making nests from plastic marine debris including net fragments and fishing line. In their opinion the biggest threat of entanglement was to the chicks, though no entanglements were observed.

Many coastal states have undertaken certain efforts to reduce entanglement rates through marine debris clean-up measures and installed fishing line recycle centers at boat landings in part due to entanglement of sea birds and other marine species. One such program is the California Lost Fishing Gear Recycling Project administered by the University of California–Davis Wildlife Health Center that began in 2005. Research on alternative materials for non-consumables has also been done, including a study on a biodegradable material for six pack rings (Thompson and Cote 1997). This study in Maine used Triton cardboard six pack holders on ducks and determined that not only did the ducks easily shed them but also the material degraded within 30–60 days.



Credit: NOAA Fisheries Pacific Islands Regional Office

Figure 8. *A dead shearwater seabird entangled in a derelict fishing net.*

SEA TURTLES

In an initial review of entanglement cases of sea turtles in marine debris worldwide, Balazs (1985) found no cases before 1950 and 95% of the cases occurred after 1970. The absence of entanglement records prior to 1950 could be from the low use of synthetic materials in fishing practices and land-based products, as mentioned with northern fur seals, and through lack of awareness of the problem. For the latter, the Sea Turtle Stranding and Salvage Network did not begin until 1980 and since then has been instrumental in exposing the problem. All seven species of sea turtle have been reported entangled in marine debris globally (SCBD 2012). Six of the seven species occur in U.S. waters where reports have documented entanglements: green (*Chelonia mydas*), loggerhead (*Caretta caretta*), hawksbill (*Eretmochelys imbricata*), Kemp's Ridley (*Lepidochelys kempi*), Olive Ridley (*Lepidochelys olivacea*), and leatherback (*Dermochelys coriacea*). The behavior of sea turtles makes them particularly vulnerable to entanglement. For example, young sea turtles tend to seek shelter under floating objects to avoid predation (Carr 1987; Stevenson 2011). These areas are also a source of food, as small marine animals also congregate here. Unfortunately, sea turtles tend to align themselves with oceanic fronts, convergences, rip, and driftlines where marine debris often occurs (Balazs 1985; Carr 1987). As such, sea turtles are susceptible to entanglement in all forms of marine debris that can form loops and openings that could catch on and appendages (Fig. 7).

Balazs (1985) lists 52 cases in U.S. waters between 1973 and 1984. Most of the reports were of green turtles from Hawaii (46%), with other species, including green, from Florida and Texas, and single reports from New York, Rhode Island, and California. From 1980–1992, Teas and Witzell (1995) reported 52 sea turtle entanglements per year from stranding network beach observations combining data from the Gulf of Mexico, southeast U.S., northeast U.S., and U.S. Caribbean. Of these, 54.7% were entangled in fishing gear including monofilament line, rope, and net while 6.8% were entangled in other marine debris including burlap bags, six pack rings, onion bags, packing straps, steel cables, plastic bags, rubber gloves, beach bottles, and other debris; much of which likely originated from the shrimping fishery (Miller et al., 1995). Most of the entangled sea turtles were loggerheads. In Texas and the northern Gulf of Mexico, 3.5% to 7.5% of the sea turtles observed stranded in the late 1980s were entangled in marine debris (Plotkin and Amos 1990; Duronslet *et al.* 1991). Most of these were Kemp's Ridley turtles, with hawksbill turtles showing a propensity for entanglement in plastic bags (Plotkin and Amos 1990). Leatherbacks have been commonly entangled in monofilament line (Innis *et al.* 2010), presumably from active fishing gear as suggested from studies in the New York Bight (Sadove and Morreale 1990; Gerle and DiGiovanni 1998). A similar rate of 6% entanglement in marine debris of stranded turtles was observed in Florida from 1989–1994 (Bjorndal and Bolten 1995). A study involving observations of more than 1,500 free-swimming sea turtles worldwide (Bjorndal and Bolton 1995) reported the percentage of entanglements of all sea turtles as 5%, similar to the above rates during the same time period.

More recently, the Florida Entanglement Working Group reported 1,217 sea turtles that were entangled or had ingested marine debris from 1997–2009 (Bassos-Hull and Powell 2012). This number does not parse out the percentage of sea turtles just entangled and includes entanglements in active fishing gear, such as crab pot lines. However, 13.4% of those entangled or that had ingested marine debris were categorized as "other" types of debris.

Credit: David Burdick/Marine Photobank

Figure 9. *Biologists work to free a green sea turtle entangled in a discarded fishing net in the Tumon Bay Preserve in Guam.*

OTHER MARINE SPECIES

There is reference to numerous reports worldwide of other marine species becoming "entangled" in marine debris, including: fish, invertebrates, and corals. It appears that most of the reports on fish species (66 from SCBD 2012) and most of the crustaceans may be victims of "ghost fishing," where nets continue to "fish" if lost at sea. In the case of corals, nets or lines that snag on the colony can eventually cause destruction when wave action pulls the debris back and forth (Donohue *et al.* 2001; Yoshikawa and Asoh 2004). Benthic invertebrates such as crabs and starfish may become entangled after walking through netting, lost traps, or debris that has settled to the sea floor, possibly scavenging those animals that have already become entangled (Good *et al.* 2007).

The earliest report of any fish found entangled in marine debris was from Gudger (1928) of a mackerel (Scomber scombrus) caught off Block Island near Connecticut, which was wrapped with a rubber band. Gudger and Hoffman (1931) also reported a shortfin mako (*Isurus oxyrhincus*) found dead with a rubber car tire around its neck in Cuba. Another shortfin mako in California was reported by Wegner and Cartamil (2012) entangled in a natural fiber rope resulting in scoliosis, abrasions, and undernourishment. Bird (1978) reported entanglement of three species of sharks by packing straps and a salmon shark (*Lamna ditropis*) was found in gillnet fragments in the North Pacific (Jones and Ferrero 1985). In a study from 1998–2005, smalltooth sawfish (*Pristis pectinata*) were found entangled in PVC pipe, monofilament line, elastic bands, and netting in Florida (Seitz and Poulakis 2006). The long snout with exposed teeth of this species could make it vulnerable to any debris that could easily attach to the teeth. Wallace (1985) notes manta rays (*Manta spp.*) being entangled in monofilament line, potentially because of the wing-like body and trailing spine that could easily catch on floating debris. Monofilament line was also observed encircling a blacknose shark in North Carolina causing a deformation of the spine (Schwartz 1984). Laist (1997) also lists an unidentified skate and dogfish (*Squalus acanthius*) as entangled in gillnet in Cape Cod Bay. Undoubtedly, sharks are entangled in marine debris more often than is reported in the literature. However, given the huge numbers of unentangled fish that are caught, entanglement of fish in debris other than ALDFG is likely insignificant.


Credit: Elaine Blum

Figure 10. *A dead tiger shark (and other fish) entangled in derelict nets in Florida.*

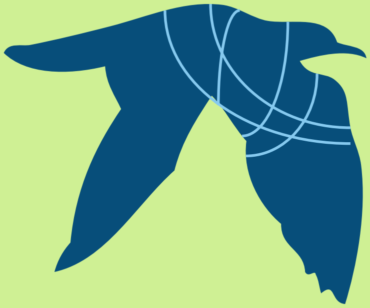
Invertebrates are not well represented in the literature as entangled in marine debris, and often there is only a slight mention of the impact to these species (Stevenson 2011; SCBD 2012). However, the problem of entanglement in debris appears to be far greater than what is reported based on a few studies. Laist (1997) lists four species of crustaceans (three crab, one lobster) entangled in lost gillnets mostly from the North Pacific. Chiappone *et al.* (2002) detailed the effect of marine debris on sessile invertebrates in the Florida Keys. Taxa included were gorgonians, fire coral, sponges, and zoanthids. Nearly 68% of the entanglements of these species were due to monofilament line and hooks. In Hawaii, 14 species of invertebrates were affected by net entanglement (Donohue *et al.* 2001). These taxa include sipunculids, arthropods, echinoderm, and platyhelminths. Good *et al.* (2007) recorded 27 species of invertebrates entangled in netting in Puget Sound. Likewise in Puget Sound, Gilardi *et al.* (2010) recorded 10 species of invertebrates entangled in experimental nets. Both sources expressed concern over the number of Dungeness crabs (*Cancer magister*) entangled, as this species is of commercial interest.

CONCLUSIONS

The impacts from entanglement of marine species in marine debris are clearly profound, and in many cases entanglements appear to be increasing despite efforts over four decades to reduce the threat. This review reported entanglement in marine debris in the U.S. of 44 species of sea birds, 13 species of cetaceans, 11 species of pinnipeds, 31 species/taxa of invertebrates, 6 species of sea turtles, and a few fish species. Many of the fish species were excluded due to reports of "ghost fishing," and a more comprehensive review of this work is available in another topic paper (Ghost fishing Topic Paper). The majority of cases revolve around entanglement in fishing gear and ALDFG and to a lesser degree other plastic debris.

Available entanglement rates are at best minimum estimates, and the methods to derive these estimates are at times quite different depending on the source of the data (*e.g.*, rates based on strandings vs. rescue/rehabilitation records vs. observations of live animals seen carrying debris). For instance, entanglement-related mortality rates of Hawaiian monk seals have partially accounted for at-sea entanglement deaths (Henderson 2001; Boland and Donohue 2003), but entanglement rates for northern fur seals have not considered this source of mortality. Further, the extent to which entanglements actually hinder a population is still not understood for most species. As stated previously, there is some evidence to suggest that a decline in the northern fur seal population was due in part to entanglement in marine debris (Fowler 2000). For other pinniped species such as the Hawaiian monk seal, entanglement in marine debris is a clear contributor to its ongoing decline and appears to be more important for some breeding groups than others. Entanglement rates in marine debris for pinnipeds and sea turtles appear to be more accurate than for cetaceans; for sea birds, data and rates appear to more intermediate. Impact estimates may be inferred by observing seals at known rookeries (Henderson 2001; Donohue and Foley 2007; NMFS 2007) or well-known resident populations, such as the bottlenose dolphin population in Sarasota Bay, Florida. As mentioned previously, without an accurate assessment of at-sea mortality caused by entanglement in debris, it is difficult to generate overall entanglement-related mortality rates. For other marine species, such as cetaceans, entanglement rates in marine debris are lacking mainly because of the limited efforts to distinguish entanglement in active fishing gear vs. marine debris and because most data are from stranding records represent an unknown proportion of entangled animals or total annual mortality. Minimum estimates of population size are given in NMFS Stock Assessment Reports based on aerial and ship-board surveys, but some of these surveys are outdated. Entanglement rates for other cetaceans, such as the bottlenose dolphin, also rely on stranded animals and observations of live free-swimming entangled animals to obtain an incidence of entanglement. Strandings provide a minimum estimate of entanglement incidents, as not all dead animals at-sea make it to shore, and not all live entangled animals are observed. Further, assigning individual entangled cetaceans to a discrete population is often difficult since many species have complex population structures.

From reports in the United States, at least 115 marine species are impacted by entanglement, including mammals, turtles, birds, fish and crabs. World wide, the number tops 200.



We may never know the true extent to which marine debris entanglements affect most populations of marine species. For some species with low population levels such as the Hawaiian monk seal, development of minimum entanglement estimates are possible; however, for all marine species, the principal difficulty lies in the limited ability to detect entangled animals at sea, especially pelagic deep diving species of cetaceans that spend little time at the surface. Therefore, the best available data for most species are from strandings of dead animals for cetaceans and sea turtles, counts and sightings of live entangled pinnipeds and sea birds at rookeries, and counts of dead animals in ghost gillnets and traps for fish and crustacean species. In the same context, the number of animals that survive entanglements in marine debris is largely unknown, but may have significant effects even for survivors. That is, some animals sustain debilitating injuries, such as lost limbs or deep cuts that can reduce their ability to swim, feed, and reproduce. The extent to which such injuries might affect populations as a whole is not known. There is evidence to suggest that many individuals shed their entangling debris, but even then, the lingering effects of entanglement can incur life-long physical problems that may shorten life spans. For endangered species this could be as harmful as mortality itself. This makes understanding the real effects of entanglement at a population level more difficult. In other words, just because we see individuals free-swimming with entanglement scars, doesn't mean that the individuals are returning to normalcy without a negative effect on the population as a whole. Both mortality and morbidity should be included in the data when describing the effects of entanglement rates on populations.

The type of marine debris causing entanglement varied at times among species. Fur seals were generally entangled in net fragments, but Steller sea lions showed a propensity of entanglement in packing straps. Dolphins, sea turtles, and sea birds were commonly entangled in monofilament line. Large baleen whales were entangled in nondescript lines, making it difficult to ascertain if the entangling fishing gear was active or derelict fishing gear. Regardless, fishing gear composed of rope or netting is assumed to be the most common source.

A few species are susceptible to marine debris in areas where their habitat overlaps with high concentrations of marine debris, such as the North Pacific Gyre and the northern fur seal and the NWHI and Hawaiian monk seals. Macfadyen *et al.* (2009)

and others provide good detail of these convergence zones in the Pacific and Atlantic Oceans. These zones also may affect humpback whales and sea turtles.

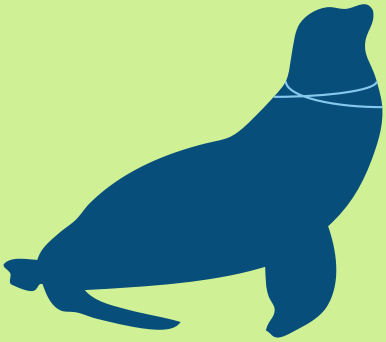
While in some regions of the world it may appear that land-based and surface water debris is declining (Gregory 2009), natural disasters such as hurricanes and tsunamis have potentially added to the amount of entangling debris in the marine environment (SCBD 2012). Further, as the coastal population continues to grow, particularly in the southeastern U.S., the potential for increased levels of land-based marine debris could occur. Numerous local, state, regional, and national programs for the removal of marine debris have occurred and continue to be implemented, yet entanglement of marine species in marine debris is still a significant threat to many species. For some endangered species, like the Hawaiian monk seal and northern fur seal, this threat could tip the balance of survival of the species.

Laist (1997) and Laist *et al.* (1999) suggested numerous ways to address the problem of entanglement in marine debris. These suggestions included: documenting and monitoring entanglement rates; disentangle individuals entangled; recover gear that is lost or abandoned, encourage fishermen to report lost or abandoned gear; keep marine debris on board if brought up during fishing operations; incentives for fishermen to report and return marine debris; provide reception facilities at port; and develop new technology for fishing gear, such as float releases to aid in its retrieval if gear is lost, and degradable fishing gear when applicable. Since this report over 15 years ago, the suggestions by other authors have changed very little. Macfadyen *et al.* (2009) detail numerous ways of preventing ALDFG, including: gear marking; on-board technology to detect ALDFG, such as GPS or sea bed mapping technology; inspection of gear by port authorities; onshore collection/reception; payment incentives for old/retrieved gear; reduction in fishing effort; spatial management; biodegradable nets and pots and other technology, like adding barium sulfate to nets to reflect sound, better reporting of lost gear such as modeled by the California Lost Fishing Gear Recovery Project and the SeaDoc Society; gear recovery; awareness programs; and dedicated efforts to remove derelict fishing gear from areas of accumulation . While these mitigation efforts address fishing gear, they do not necessarily address all sources of marine debris, such as land-based plastics. A workshop to address the ability to distinguish between active fishing gear and ALDFG on entangled animals is highly recommended, and has been discussed recently as a research priority, especially for cetaceans (IWC 2013).

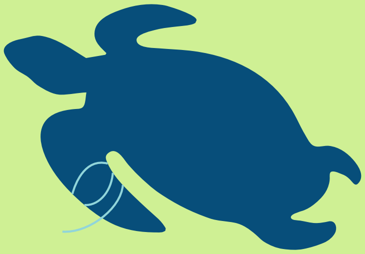
The SCBD (2012) addressed strategies to mitigate the impacts of marine debris, not only for ALDFG, but also for marine debris in general. They outline numerous institutional strategies at global, regional, and national levels. While they emphasize that many waste management and recycling efforts have been unsuccessful, there have been cases of successful implementation of mitigation measures. One of these, "reuse and reduce," includes: reducing the amount of plastics in packaging, eco-labels for consumers to make better decisions on use and disposal practices, green procurement, biodegradable products, and voluntary actions at the corporate and local level to develop such programs. As with Laist (1997) and Macfadyen *et al.* (2009), the SCBD (2012) recognized the value of incentives for collection and recycling, as numerous countries, including the U.S., are very successful of this reduction in waste. Building awareness within the community and among businesses has also been shown to create a positive initiative (Laist *et al.* 1999).

It was obvious from the reviewed literature that there are many gaps and difficulties in assessing entanglement in marine debris. Laist (1997) outlined factors that complicate this process (Table 1). For the current review, the most striking difficulty came from the inconsistency of determining what is marine debris and what is not. The SCBD (2012) defines marine debris as "any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment." This includes ALDFG. Some studies specifically list ALDFG as marine debris, while others do not distinguish between ALDFG and active gear, especially with North Atlantic right whale and other baleen whale studies. Thus, entanglement rates in marine debris may be inflated if one considers all entanglements, including those in active fishing gear, to be caused by marine debris. Similarly, the term "ghost fishing" is used to describe gear that is lost or discarded that continues to catch target and non-target species. There is a need to clearly define the terms above to adequately describe the rate of entanglement for many species.

It also became apparent that the reporting of marine debris in the literature is not as



Most entanglement reports in the United States involve northern fur seals, Hawaiian monk seals, and sea turtles.



extensive as it could be and, thus, estimates of entanglement in marine debris are likely underestimated. Many institutions fail to publish these accounts because, many times, they are only of single individuals (Simmonds 2012).

Stranding programs also do not have clear protocols for distinguishing marine debris from active fishing gear and recording incidents of entanglement in debris vs active fishing gear separately. Numerous reports of marine debris entanglement involving odd items or particularly well-documented cases can be found in local media reports or newspaper articles. For instance, a bottlenose dolphin was disentangled from a rubber gasket that was around its neck in 2008 (http://savannahnow.com/mary-landers/2008-07-02/dolphin-freed-trashy-noose#.Uop_xfmsi-0) and another was found entangled in a pair of swimming trunks (http://www.brookfieldzoo.org/pgpages/pagegen.273.aspx). Further, many institutions hold large, underused data sets that include information on anthropogenic sources of entanglement and mortality, but these data sets may not classify or report entanglement events linked directly to marine debris. For instance, the U.S. National Marine Mammal Stranding Database administered by NOAA/NMFS contains basic information regarding every marine mammal that strands in the U.S. This database has a place to specify whether the animal was involved with human interaction or not, but only allows the person entering data to choose from boat strike, fishery interaction, shot, or other form of human interaction. If fishery interaction is checked, the data entry person can choose whether gear was present or not. However, there is no category for marine debris and thus trying to determine if the entanglement was truly from marine debris is difficult and not easily searchable. It is likely that many other federal wildlife databases are similar and do not specify marine debris in their outputs. There is a need across all government agencies that input wildlife data to include marine debris as an entanglement source. It may be helpful to create a centralized database where marine debris entanglement reports could be sent, even if the report involved a single animal, and be easily searched.

Finally, there are likely other species from other regions of the U.S. that suffer injury or death from being entangled in marine debris, but are not widely recognized or reported. Most of the literature describes entanglement of marine species from Alaska, California, Puget Sound, Florida, and in the case of baleen whales, the New England region, though this may simply reflect an absence of occurrence. The Mid-Atlantic and Gulf of Mexico regions of the U.S. are lacking in reports of marine debris entanglement. Similarly, reports of marine debris entanglement on sea birds and sea turtles are limited to a few papers, and reports on polar bears and walruses are non-existent, possibly due to an arctic habitat that is virtually devoid of commercial fishing and is an area of low sources of marine debris.

CITED REFERENCES

Afelin, C. and B. Puleloa. 1982. Marine turtles. SEAN Bull. 7(1):13.

Allen, B.M. and R.P. Angliss. 2012. Northern fur seal eastern Pacific Stock - Stock Assessment Report. NOAA *Technical Memorandum* AFSC 245. pp. 23–31.

Allsopp, M., Walters, A., Santillo, D. and P. Johnston. 2006. Plastic debris in the world's oceans. edited by Greenpeace: Greenpeace.

Andre, J. B., and R. Ittner. 1980. Hawaiian monk seal entangled in fishing net. *Elepaio* 41(6):51.

Anonymous. 1981. Marine turtles. SEAN Bulletin 6(3): 22.

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

Baba, N., Kiyota, M. and K. Yoshida. 1990. Distribution of marine debris and northern fur seals in the eastern Bering Sea. In: R.S. Shomura and M.L. Godfrey (eds.), Proceedings of the Second International Conference on Marine Debris, 2–7 April, 1989, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS SWFSC 154*. pp. 419–430.

Baba, N. 1995. Characteristics of northern fur seals *Callorhinus ursinus* entangled in marine debris in the western North Pacific Ocean and Okhotsk Sea from 1971 to 1987 and 1993. In: J.C. Clary (ed.) Poster abstracts and manuscripts from the Third International Conference on Marine Debris, May 8–13, 1994. *NOAA Technical Memorandum NMFS-AFSC 51*. pp. 85–89.

Balazs, G.H. 1978. A hawksbill turtle: in Kaneohe. Bay, Oahu. *Elepaio* 38(11):128–129.

Balazs, G.H. 1979. Synthetic debris observed on a Hawaiian monk seal. *Elapaio* 40(3):43–44.

Balazs, G.H. 1980. Synopsis of biological data on the green turtle in the Hawaiian Islands. *NOAA Technical MemorandumNMFS-SWFC-7*. 141 p.

Balazs, G.H. 1982a. Driftnets catch leatherback turtles. *Oryx* 16(5): 428–30.

Balazs, G.H. 1982b. Hawaii's fishermen help sea turtles. *Hawaii Fisheries News* 7(11): 8–9.

Balazs, G.H. 1983. Recovery records of adult green turtles observed or originally tagged at French Frigate Shoals, Northwestern Hawaiian Islands. *NOAA Technical Memorandum NMFS-SWFC-36*. 42 p.

Balazs, G.H. 1985. Impact of ocean debris on marine turtles: entanglement and ingestion. Paper presented at the Proceedings of the workshop on the fate and impact of marine debris, Honolulu, HI, November 27–29, 1984.

Barco, S.G., D'Eri, L.R., Woodward, B.L., Winn, J.P. and D.S. Rotstein. 2010. Spectra® fishing twine entanglement of a bottlenose dolphin: a case study and experimental modeling. *Marine Pollution Bulletin* 60: 1477–81.

Bassos-Hull, K. and J. Powell. 2012. Entanglement hot-spots along the Florida coastline: a need for outreach and action. *Nicks n Notches*. Sarasota Dolphin Research Program and Chicago Zoological Society. January 2012, p. 11.

Bassos-Hull, K. 2013. Florida Entanglement Working Group: tracking impacts of entanglement on marine wildlife and promoting entanglement prevention initiatives. *Nicks n Notches*. Sarasota Dolphin Research Program and Chicago Zoological Society. January 2013. pp. 8–9.

Baulch, S. and C. Perry. 2012. A sea of plastic: evaluating the impacts of marine debris on cetaceans. Marine Mammal Commission Report SC/64/E10. 24 pp.

Beck, C.A. and N.B. Barros. 1991. The impact of debris on the Florida manatee. *Marine Pollution Bulletin* 22: 508–10.

Bird, P.M. 1978. Tissue regeneration in three carcharhinid sharks encircled by embedded straps. Copeia 2: 345–349.

Bjorndal, K.A. and A.B. Bolten. 1995. Effects of marine debris on sea turtles. In: J.C. Clary (ed.) Poster abstracts and manuscripts from the Third International Conference on Marine Debris, May 8–13, 1994. *NOAA Technical Memorandum NMFS-AFSC 51*. pp. 29–30.

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

Boland, R.C. and M. J. Donohue. 2003. Marine debris accumulation in the nearshore marine habitat of the endangered Hawaiian monk seal, *Monachus schauinslandi* 1999–2001. *Marine Pollution Bulletin* 46: 1385–1394.

Bradenton Times. 2010. Dolphin calf freed of plastic entanglement in Sarasota Bay. Staff report, The Bradenton Times. March 2, 2010.

Bradford, A., Weller, D., Ivaschenko, Y., Burdin, A. and R. Brownell Jr. 2009. Anthropogenic scarring of Western gray whales (*Eschrichtius robustus*). Publications, agencies, and, staff of the U.S. Department of Commerce. Paper 16.

Broadrick, T. 1982. Marine turtles. SEAN Bull. 7(6):18.

Butterworth A., Clegg, I and C. Bass. 2012. Untangled - Marine Debris: a global picture of the impact on animal welfare and of animal-focused solutions. London: World Society for the Protection of Animals. 75 pp.

Calkins, D.G. 1985. Steller sea lion entanglement in marine debris. In: R.S. Shomura and H.O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26–29 November 1984, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-54*.

Carr, A. 1987. Impact of nondegradable marine debris on the ecology and survival outlook of sea turtles. *Marine Pollution Bulletin* 18, Supplement B (6// 1987): 352–56.

Carretta, J.V., E. Oleson, D.W. Weller, A.R. Lang, K.A. Forney, J. Baker, B. Hanson, K. Martien, M.M. Muto, M.S. Lowry, J. Barlow, D. Lynch, L.

Carswell, R. L. Brownell Jr., D. K. Mattila, and M.C. Hill. 2013. U.S. Pacific Marine Mammal Stock Assessments: 2012. *NOAA Technical Memorandum, NMFS-SWFSC-504*. 378 p.

Carswell, B., K. McElwee, and S. Morison (eds.). 2011. Technical Proceedings of the Fifth International Marine Debris Conference. March 20–25, 2011. *NOAA Technical Memorandum NOS-OR&R-38*.

Cassoff, R.M., Moore, K.M., McLellan, W.A., Barco, S.G., Rotstein, D.S. and M.J. Moore. 2011. Lethal entanglement in baleen whales. *Diseases of Aquatic Organisms* 96: 175–185.

Chiappone, M., White, A., Swanson, D.W. and S.L. Miller. 2002. Occurrence and biological impacts of fishing gear and other marine debris in the

Florida Keys. *Marine Pollution Bulletin* 44: 507–604.

Clapham, P.J., Young, S.B. and R.L. Brownell. 1999. Baleen whales: conservation issues and the status of the most endangered populations. *Mammal Review* 29: 37–62.

Clary, J.C. (ed.). 1995. Poster abstracts and manuscripts from the Third International Conference on Marine Debris, May 8–13, 1994, Miami, Florida. *NOAA Technical Memorandum NMFS-AFSC-51*. 108 pp.

Cole, T.; Hartley, D; Garron, M. 2006. Mortality and Serious Injury Determinations for Baleen Whale Stocks Along the Eastern Seaboard of the United States, 2000–2004. *U.S. Dep. Commer., Northeast Fish. Sci. Cent. Ref. Doc.* 06-04; 18 p.

Conant, S. 1984. Man-made debris and marine wildlife in the northwestern Hawaiian Islands. Elepaio 44: 87–88.

Dau, B.K., Gilardi, K.V.K., Gulland, F.M., Higgins, A., Holcomb, J.B., St. Leger, J. and M.H. Ziccardi. 2009. Fishing gear-related injury in California marine wildlife. *Journal of Wildlife Diseases* 45: 355–62.

DeGange, A.R., and T.C. Newby. 1980. Mortality of seabirds and fish in a lost salmon driftnet. *Marine Pollution Bulletin* 11:322–323.

DeGange, A.R. and R.H. Day. 1991. Mortality of seabirds in the Japanese land-based gillnet fishery for salmon. *The Condor* 93: 251–58.

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

Derraik, J.G.B. 2002. The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin* 44: 842–852.

Donohue, M.J., Boland, R.C., Sramek, C.M. and G.A. Antonelis. 2001. Derelict fishing gear in the Northwestern Hawaiian Islands: diving surveys and debris removal in 1999 confirm threat to coral reef ecosystems. *Marine Pollution Bulletin* 42: 1301–1312.

Donohue, M.J. and D.G. Foley. 2007. Remote sensing reveals links among the endangered Hawaiian monk seal, marine debris, and El Niño. *Marine Mammal Science* 23: 468–473.

Duronslet, M.J., D.B. Revera, and K.M. Stanley. 1991. Man-Made Marine Debris and Sea Turtle Strandings on Beaches of the Upper Texas and South-Western Louisiana Coasts, June 1987 through September 1989. *NOAA Technical Memorandum NMFS-SEFC-279*. 47 pp.

Feldkamp, S.D., Costa, D.P. and G.K. DeKrey.1989. Energetic and behavioral effects of net entanglement on juvenile northern fur seals (*Callorhinus ursinus*). *Fishery Bulletin* 87: 85–94.

Fletcher, E. 1982. Marine turtles. SEAN Bull. 7(5):15.

Fowler, C.W. 1982. Interactions of northern fur seals and commercial fisheries: In Transactions of the 47th North American Wildlife and Natural Resources Conference. Washington, D.C. Wildlife Management lnstitute. 278–292.

Fowler, C.W. 1985. An evaluation of the role of entanglement in the population dynamics of northern fur seals on the Pribilof Islands. In: R.S. Shomura and H.O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26–29 November 1984, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-54*.

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

Fowler, C.W., Merrick, R. and J.D. Baker. 1990. Studies of the population level effects of entanglement on northern fur seals. In: Proceedings of the Second International Conference on Marine Debris, April 2–7, 1989, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-154*.

Fowler, C.W., R. Ream, B. Robson, and M. Kiyota. 1992. Entanglement studies, St. Paul Island, 1991 juvenile male northern fur seals. Seattle. U.S. Department of Commerce, Alaska Fisheries Science Center. AFSC Processed Report 92-07:45.

Fowler, C.W. 2000. Ecological effects of marine debris: the example of northern fur seals, p. 40–58. In: Proceedings of the International Conference on Derelict Fishing Gear and the Ocean Environment, 6–11 August 2000, Honolulu, HI. U.S. Dep. Commer., NOAA.

French, D.P. and M. Reed. 1990. Potential impact of entanglement in marine debris on the population dynamics of the northern fur seal, *Callorhinus ursinus*. In: Proceedings of the Second International Conference on Marine Debris, April 2–7, 1989, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-154*.

FWC FWRI. 2009. Manatee Synoptic Surveys. St. Petersburg, FL, USA. Accessed April 30, 2014. Available from http://www.fws.gov/northflorida/Manatee/SARS/20091230_rpt_Final_Florida_Manatee_SAR.pdf

FWC FWRI. 2013. Manatee Synoptic Surveys. St. Petersburg, FL, USA. Accessed April 30, 2014. Available from http://www.fws.gov/northflorida/Manatee/SARS/20130328_FR1149-Draft_Revised_Manatee_SAR_FL_Stock.pdf

Gerle, E., and R. DiGiovanni. 1998. An Evaluation of Human Impacts and Natural Versus Human Induced Mortality in Sea Turtles in the New York Bight. In: *NOAA Technical Memorandum NMFS SEFSC 415*.

Gilardi, K.V.K., Carlson-Bremer, D., June, J.A., Antonelis, K., Broadhurst, G. and T. Cowan. 2010. Marine species mortality in derelict fishing nets in Puget Sound, Wa and the cost/benefits of derelict net removal. *Marine Pollution Bulletin* 60: 376–382.

Glass A.H., Cole, T.V.N., Garron, M., Merrick, R.L. and R.M Pace III. 2008. Mortality and serious injury determinations for baleen whale stocks along the United States eastern seaboard and adjacent Canadian Maritimes, 2002–2006. U.S. Dept Commer, Northeast Fish Sci Cent Ref Doc. 08-04; 18 p.

Glass A.H., Cole, T.V.N. and M. Garron. 2009. Mortality and serious injury determinations for baleen whale stocks along the United States eastern seaboard and adjacent Canadian maritimes, 2003–2007 (2nd Edition). U.S. Dept Commer, Northeast Fish Sci Cent Ref Doc. 09-04; 19 p.

Glass A.H., Cole, T.V.N. and M. Garron. 2010. Mortality and serious injury determinations for baleen whale stocks along the United States eastern seaboard and Canadian Eastern seaboards, 2004–2008. *NOAA Technical Memorandum NMFS-NE-214*. 19 pp.

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

Good, T.P., June, J.A., Etnier, M. and G. Broadhurst. 2007. Quntifying the impact of derelict fishing gear on the marine fauna of Puget Sound and the Northwest Straits. *Proceedings of the ICES Annual Science Conference 2007*. ICES CM 2007/Q:09. 28 pp.

Gregory, M.R. 2009. Environmental implications of plastic debris in marine settings - entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions of The Royal Society B* 364: 2013–2025.

Gudger, E.W. 1928. A mackerel (*Scombrus scombrus*) with a rubber band rove through its body. *American Museum Novitates* 310: 1-6.

Gudger, E.W. and W.H. Hoffmann. 1933. A shark encircled with a rubber automobile tire. Scientific Monthly 33: 275–277.

Hammett, Y.C. 2013. Manatee entanglement is not unusual. *Tampa Tribune*. May 15, 2013.

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

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

Harris, R.J., Tseng, F.S., Pokras, M.A., Suedmeyer, B.A, Bogart, J.S.H., Prescott, R.L. and S.H. Newman. 2006. Beached bird surveys in Massachusetts: the Seabird Ecological Assessment Network (Seanet). *Marine Ornithology* 34: 115–122.

Haubold, E.M., Deutsch, C. and C. Fonnesbeck. 2006. Final biological status reviewof the Florida manatee (*Trichechus manatus latirostris*). Status assessment by the 2005–2006 Florida Manatee Biological review Panel. Florida Fish and Wildlife Conservation Commission, St. Petersburg, Florida. 36 pp.

Henderson, J.R. 1984. Encounters of Hawaiian monk seals with fishing gear at Lisianski Island, 1982. *Marine Fisheries Review* 46(3):59–61.

Henderson, J.R. 1985. A review of Hawaiian monk seal entanglements in marine debris. In: Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26–29 November 1984, Honolulu, Hawaii. *NOAA Technical Memorandum. NMFS-SWFSC-54*. pp. 326–335.

Henderson, J.R. 1990. Recent entanglements of Hawaiian monk seals in marine debris. In: Proceedings of the Second International Conference on Marine Debris. 1990. April 2–7, 1989, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-154*. pp. 540–553.

Henderson, J.R. 2001. A pre- and post-Marpol Annex V summary of Hawaiian monk seal entanglements and marine debris accumulation in the northwestern Hawaiian Islands, 1982–1998. *Marine Pollution Bulletin* 42: 584–589.

Henry A.G, Cole, T.V.N., Garron, M. and L. Hall. 2011. Mortality and serious injury determinations for baleen whale stocks along the Gulf of Mexico, United States and Canadian eastern seaboards, 2005–2009. U.S. Dept. Commer, Northeast Fish Sci Cent Ref Doc. 11-18; 24 p.

Henry A.G, Cole, T.V.N., Garron, M., Hall, L., Ledwell, W., and A. Reid. 2012. Mortality and serious injury determinations for baleen whale stocks along the Gulf of Mexico, United States east coast and Atlantic Canadian Provinces, 2006–2010. U.S. Dept. Commer, Northeast Fish Sci. Cent Ref Doc. 12-11; 24 p.

Hildebrand, H.H. 1980. Report on the incidental capture, harassment and mortality of sea turtles in Texas. SWFC, NMFS, Contract No. NA80-GG-A-00160, 33 p.

Hiruki, L.M., Gilmartin, W.G., Becker, B.L. and I. Stirling. 1993. Wounding in Hawaiian monk seals (*Monachus schauinslandi*). *Canadian Journal of Zoology/Revue Canadienne de Zoologie* 71: 458–468.

Hofman, R.J. 1995. The changing focus of marine mammal conservation. Trends in Ecology & Evolution 10: 462–465.

Howorth, P.C. 1994. Entanglement of marine mammals in synthetic debris. In: W.L. Halvorson and G.J. Maender (eds.), The Fourth California Islands Symposium: update on the status of resources. pp. 111–121.

Innis, C., Merigo, C., Dodge, K., Tlusty, M., Dodge, M., Sharp, B., Myers, A., McIntosh, A., Wunn, D., Perkins, C., Herdt, T.H., Norton, T. and M. Lutcavage. 2010. Health evaluation of leatherback turtles (*Dermochelys coriacea*) during direct capture and fisheries gear disentanglement. *Chelonian Conservation and Biology* 9:205–222.

International Whaling Comission (IWC), 2013. Report of the 2013 IWC Scientific Committee workshop on Marine Debris; *SC/65a/Rep06*. https://events.iwc.int/index.php/scientific/SC65a/paper/viewFile/277/267/SC-65a-Rep06.

Jensen, A., Williams, M., Jemison, L. and K. Raum-Suryan. 2009. Somebody untangle me! Taking a closer look at marine mammal entanglement in marine debris. Alaska Sea Grant Report volume 09-01, no. 2009-01-01. pp. 63–69.

Johanos, T.C. and T.J. Ragen. 1999. The Hawaiian monk seal in the northwestern Hawaiian Islands, 1996. *NOAA Technical Memorandum NMFS-SWFSC-259*. 132 pp.

Johnson, A., Salvador, G., Kenney, J., Robbins, J., Kraus, S., Landry, S. and P. Clapham. 2005. Fishing gear involved in entanglements of right and humpback whales. *Marine Mammal Science* 21: 635–645.

Johnson, S. W. and T. R. Merrell. 1988. Entanglement Debris on Alaskan Beaches, 1986. *NOAA Technical Memorandum NMFS-F/NWC-126.*

Johnson, Scott W. and J.H. Eiler. 1999. Fate of radio-tagged trawl web on an Alaskan beach. *Marine Pollution Bulletin* 38: 136–141.

Jones, L.L. and R.C. Ferrero. 1985. Observations of net debris and associated entanglements in the North Pacific Ocean and Bering Sea, 1978–84. In: Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. *NOAA Technical Memorandum. NMFS-SWFSC-54*. pp. 183–196.

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

Knowlton, A.R. and S.D. Kraus. 2001. Mortality and serious injury of northern right whales (*Eubalaena glacialis*) in the western North Atlantic Ocean. J*ournal of Cetacean Research and Management* Special Issue 2: 193–208.

Knowlton, A.R., Hamilton, P.K., Marx, M.K., Pettis, H.M. and S.D. Kraus. 2012. Monitoring North Atlantic right whale (*Eubalaena glacialis*) entanglement rates: a 30 yr. retrospective. *Marine Ecology Progress Series* 466: 293–302.

Kraus, S.D. 1990. Rates and potential causes of mortality in North Atlantic right whales (*Eubalaena glacialis*). *Marine Mammal Science* 6: 278–291.

Kraus, S.D. 2002. Birth, death and taxis: North Atlantic right whales in the twenty-first century. Ph.D., University of New Hampshire. Laist, D.W. 1987. Overview of the biological effects of lost and discarded plastic debris in the marine environment. Marine Pollution Bulletin 18, no. 6, Supplement B (6// 1987): 319–26.

Laist, D.W. 1996. Marine debris entanglement and ghost fishing: a cryptic and significant type of bycatch? In Proceedings of the Solving Bycatch Workshop: Considerations for Today and Tomorrow. Seattle, WA: Alaska Sea Grant College Program, Fairbanks, AK (USA).

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. Chap. 10 In *Marine Debris*, J.M Coe and D.B Rogers (eds.). Springer Series on Environmental Management, 99–139: Springer New York.

Laist, D.W., Coe, J.M. and K.J. O'Hara. 1999. Marine debris pollution. In *Conservation and Management of Marine Mammals*. J.R. Twiss Jr. and R.R. Reeves (eds.). Smithsonian Institution Press, Washington DC. pp. 342–363.

Laist, D.W. and M. Liffmann. 2000. Impacts of marine debris: reasearch and management needs. *Issue Papers of the International Marine Debris*

Conference, Aug. 6–11, 2000. Homolulu, Hawaii. pp. 16–29.

Lambertsen, R.H., Rasmussen, K.J., Lancaster, W.C. and R.J. Hintz. 2005. Functional morphology of the mouth of the bowhead whale and its implications for conservation. *Journal of Mammology* 86: 342–352.

Lander, R.H. 1981. A life table and biomass estimate for Alaskan fur seals. *Fish. Res.* (Amst.) 1:55–70.

Lelis, L. 2012. Entangled bottlenose dolphin rescued near New Smyrna Beach. Orlando Sentinel. January 11, 2012.

Loughlin, T.R., Gearin, P.J., DeLong, R.L. and R.L. Merrick. 1986. Assessment of net entanglement on northern sea lions in the Aleutian Islands: 25 June–15 July 1985. NWAFC Processed Review 86-02. 50 pp.

Lowry, L.F., D.W. Laist, W.G. Gilmartin, and G.A. Antonelis. 2011. Recovery of the Hawaiian monk seal: a review of conservation efforts 1977–2010 and thoughts for the future. *Aquatic Mammals* 37(2): 397–419. 10.1578/AM.37.3.2011.397

Lyman, E. 2012. 2011–2012 season summary onlarge whale entanglement threat and reports received around the main Hawaiian Islands. Report to the Hawaiian Islands Humpback WhaleNational Marine Sanctuary. 12 pp.

Macfadyen, G., Huntington, T. and R. Cappell. 2009. Abandoned, lost or otherwise discarded fishing gear. Rome, Italy: UNEP FAO.

Mann, J., Smolker, R.A. and B.B. Smuts. 1995. Responses to calf entanglement in free-ranging bottlenose dolphins. *Marine Mammal Science* 11: 100–106.

Marine Mammal Commission. 1994. Annual report of the Marine Mammal Commission for 1993. Species of special concern: Hawaiian monk seal. pp. 27–35.

Marine Mammal Commission. 2003. Annual report for 2002. Species of special concern: Hawaiian monk seal. pp. 79–95.

Marine Mammal Commission. 2012. Annual report to Congress 2010–1011. Species of special concern: Hawaiian monk seal, pp. 110–124.

McFee, W.E. and S.R. Hopkins-Murphy. 2002. Bottlenose dolphin (*Tursiops truncatus*) strandings in South Carolina, 1992–1996. *Fishery Bulletin* 100:258–265.

McFee, W.E., Hopkins-Murphy, S.R. and L. H. Schwacke. 2006. Trends in bottlenose dolphin (*Tursiops truncatus*) strandings in South Carolina, USA, 1997–2003. *Journal of Cetacean Research and Management* 8:195–201.

McIntosh, N., Simonds, K., Donohue, M., Brammer, C., Mason, S., and S. Carbajal (eds.). 2000. Proceedings of the International Marine Debris Conference on Derelict Fishing Gear and the Ocean Environment. Honolulu, Hawaii. 429 pp.

Miller, J.E., Waker, S.W. and Echols, D. L. June 1995. Marine Debris Point Source Investigations 1994–1995 Padre Island National Seashore. Resource Management Division, Padre Island National Seashore. Corpus Christi, TX 41.

Mooney, J. and J. Naughton. 1981. Marine turtles. SEAN Bull. 6(6):10.

Moore, E., Lyday, S., Roletto, J., Litle, K., Parrish, J.K., Nevins, H., Harvey, J., *et al.* 2009. Entanglements of marine mammals and seabirds in central California and the north-west coast of the United States 2001–2005. *Marine Pollution Bulletin* 58: 1045–1051.

Moore, M., Andrews, R., Austin, T., Bailey, J., Costidis, A., George, C., Jackson, K., *et al.* 2013. Rope trauma, sedation, disentanglement, and monitoring tag- associated lesions in a terminally entangled North Atlantic Right Whale (*Eubalaena glacialis*). *Marine Mammal Science* 29: E98-E113.

National Marine Fisheries Service (NMFS). 1998. Pinniped Stock Assessment Report. National Marine Fisheries Service. pp. 15–21.

National Marine Fisheries Service (NMFS). 2007. Conservation plan for the Eastern Pacific stock of northern fur seal (*Callorhinus ursinus*). National Marine Fisheries Service, Juneau, Alaska.

Neilson, J.L., Straley, J.M., Gabriele, C.M. and S. Hills. 2009. Non-lethal entanglement of humpback whales (*Megaptera novaeangliae*) in fishing gear in northern southeast Alaska. *Journal of Biogeography* 36: 452–464.

Nelson, M., Garron, M., Merrick, R.L., Pace, R.M. III and T.V.N. Cole. 2007. Mortality and serious injury determinations for baleen whale stocks along the United States eastern seaboard and adjacent Canadian Maritimes, 2001–2005. U.S. Dep. Commer., *Northeast Fish. Sci. Cent. Ref. Doc.* 07-05; 18 p.

Nill, E.K. 1998. The Florida manatee (*Trichechus manatus latirostris*) entanglement report 1998. Final report to the US Fish and Wildlife Service. 23 pp.

O'Shea T.J., C.A. Beck, R.K. Bonde, H.I. Kochman, and D.K. Odell. 1985. An analysis of manatee mortality patterns in Florida, 1976-81. *Journal of Wildlife Management* 49(1):1–11.

Panel, UNEP Scientific and Technical Advisory (UNEP). 2011. Marine debris as a global environmental problem: introducing a solutions based framework focused on plastic. B.E. LaBelle, R. Thompson, H. Bouwman and L. Neretin (eds.).

Phillips, R.A., Ridley, C., Reid, K., Pugh, P.J.A., Tuck, G.N. and N. Harrison. 2010. Ingestion of fishing gear and entanglements of seabirds: monitoring and implications for management. *Biological Conservation* 143: 501–512.

Philo, L.M., George, J.C. and T.F. Albert. 1992. Rope entanglement of bowhead whales (*Balaena mysticetus*). *Marine Mammal Science* 8: 306–311.

Plotkin, P. and A.F. Amos. 1990. Effects of anthropogenic debris on sea turtles in the northwestern Gulf of Mexico. In: *NOAA Technical Memorandum NMFS-SWFSC-154*. pp. 736–744.

Podolsky, R.H. and S.W. Kress. 1989. Plastic debris incorporated into double-crested cormorant nests in the Gulf of Maine. *Journal of Field Ornithology* 60: 248–250.

Powell, J.R. and R.S. Wells. 2011. Recreational fishing depredationand associated behaviors involving common bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *Marine Mammal Science* 27: 111–129.

Raum-Suryan, K.L., Jemison, L.A. and K.W. Pitcher. 2009. Entanglement of Steller sea lions (*Eumetopias jubatus*) in marine debris: identifying causes and finding solutions. *Marine Pollution Bulletin* 58: 1487–1495.

Raum-Suryan, K.L., Jemison, L.A. and K.W. Pitcher. 2009. Lose the loop: entanglements of Steller sea lions (*Eumetopias jubatus*) in marine debris (Poster). 18th Biennial Conference on the Biology and Conservation of Marine Mammals, Quebec City, Canada, October 2009.

Ribic, C.A., Dixon, T.R. and I. Vining. 1992. Marine debris survey manual. National Marine Fisheries Service's Marine Entanglement Research Program (MERP), 94 pp.

Ribic, C.A., Johnson, S.W. and C.A. Cole. 1994. Distribution, type, accumulation, and source of marine debris in the United States, 1989–93. Environmental Protection Agency, 48 pp.

Robbins, J. and D.K. Mattila. 2001. Monitoring entanglements of humpback whales (*Megaptera novaeangliae*) in the Gulf of Maine on the basis of caudal peduncle scarring. 2001. In: *53rd Scientific Committee Meeting of the International Whaling Commission*. Hammersmith, London.

Robbins, J. and D.K. Mattila. 2004. Estimating humpback whale (*Megaptera novaeangliae*) entanglement rates on the basis of scar evidence. Report to the Northeast Fisheries Science Center, National Marine Fisheries Service, Woods Hole, MA. 43EANF030121. 16 pp.

Robbins, J. 2012. Scar-based inference into Gulf of Maine humpback whale entanglement. 2010. Report to the Northeast Fisheries Science Center, National Marine Fisheries Service EA133F09CN0253. 27 pp.

Ryan, P.G., Moore, C.J., Van Franeker, J.A. and C.L. Moloney. 2009. Monitoring the abundance of plastic debris in the marine environment. *Philosophical Transactions of The Royal Society B* 364: 1999–2012.

Sadove, S.S. and H. Smith. 1981. Marine turtles. SEAN Bull. 6(7):15.

Sadove, S.S. and S.J. Morreale. 1990. Marine mammal and sea turtle encounters with marine debris in the New York Bight and the northeast Atlantic. In: Proceedings of the Second International Conference on Marine Debris." 1990. April 2–7, 1989, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-154*. pp. 562–570.

Saez, L., Lawson, D., DeAngelis, M., Petras, E., Wilkin, S. and C. Fahy. 2013. Understanding the co-occurrence of large whales and commercial fixed gear fisheries off the west coast of the United States. *NOAA Technical Memorandum NMFS-SWR-044*. 102 pp.

Schwartz, F.J. 1984. A blacknose shark from North Carolina deformed by encircling monofilament line. *Florida Science* 47: 62–64.

Scordino, J. 1985. Studies on fur seal entanglement, 1981–84, St. Paul Island, Alaska. In: Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26–29 November 1984, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-54*.

Secretariat of the Convention on Biological Diversity (SCBD) and the Scientific and Technical Advisery Panel-GEF. 2012. Impacts of marine debris on biodiversity: current status and potential solutions. Montreal. Technical Series No. 67. 61 pp.

Seitz, J.C. and G.R. Poulakis. 2006. Anthropogenic effects on the smalltooth sawfish (*Pristis pectinata*) in the United States. *Marine Pollution Bulletin* 52: 1533–1540.

Shomura, R.S. and H.O. Yoshida. 1985. Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26–29 November 1984, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-54*.

Shomura, R.S. and M.L. Godfrey. 1990. Proceedings of the Second International Conference on Marine Debris. April 2–7, 1989, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-154*.

Simmonds, M.P. 2012. Cetaceans and marine debris: the great unknown. *Journal of Marine Biology*.

Spellman, A.C. 1999. Manatee entanglements in fishing gear and debris.Abstract. Thirteenth Annual Conference on the Biology of Marine Mammals. Maui, Hawaii. November 28–December 3, 1999.

Stevenson, C. 2011. Plastic debris in the California marine ecosystem: a summary of current research, solution strategies and data gaps. edited by CA Ocean Protection Council and Ocean Science Trust: Ocean Science Trust.

Stewart, B.S. and P.K.Yochem. 1985. Entnaglements of pinnipeds in net and line fragments and other debris in the southern California Bight. In: R. S. Shomura and H.O. Yoshida (eds.), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26–29 November 1984, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-54*.

Stewart, B.S., and P.K. Yochem.1987. Entanglement of pinnipeds in synthetic debris and fishing net and line fragments of San Nicolas and San Miguel Islands, California, 1978–1986. *Marine Pollution Bulletin* 18: 336–339.

Stewart, B.S. and P.K. Yochem. 1990. Pinniped entanglement in synthetic debris in the Southern California Bight. Proceedings of the Second International Conference on Marine Debris, April 2–7, 1989, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-154*.

Stolen, M., Noke-Durden, W. and T. Mazza. 2013. Effects of fishing gear on bottlenose dolphins (*Tursiops truncatus*) in the Indian River Lagoon system, Florida. *Marine Mammal Science* 29: 356–364.

Swails, K.S. 2005. Patterns of seal strandings and human interactions in Cape Cod, Massachusettes. Thesis. Master of Environmental Management, Duke University. 24 pp.

Swartzman, G.L., Ribic, C.A. and C.P. Huang. 1990. Simulating the role of entanglement in northern fur seal, *Callorhinus ursinus*, population dynamics. In: Proceedings of the Second International Conference on Marine Debris, April 2–7, 1989, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-154*.

Teas, W.G. and W.N. Witzell. 1995. Impacts of anthropogenic debris on marine turtles in the western North Atlantic Ocean. In: J.C. Clary (ed.), Poster abstract and manuscripts from the Third International Conference on Marine Debris, May 8–13, 1994, Miami, Florida. *NOAA Technical Memorandum NMFS-AFSC 51*. pp. 93–95.

Thompson, M.E. and W.A. Cote. 1997. Potential effects of discarded Triton paperboard six-pack carriers on fish and wildlife. *Marine Pollution Bulletin* 34: 135–137.

Thompson, R.C., La Belle, B.E., Bouwman, H. and L. Neretin. 2011. Marine debris: defining a global environmental challenge. In: *A STAP ADVISORY DOCUMENT*: UNEP, GEF.

Trites, A.W. 1992. Northern Fur Seals: Why have they declined? *Aquatic Mammals* 18(1): 3–18.

Timmers, M., Donohue, C. and M. Kistner. 2005. Marine debris of the northwestern Hawaiian Islands: ghost net identification. edited by Sea Grant.
United Nations Environment Programme (UNEP). 2011. The Honolulu Strategy: a global framework for prevention and management of marine debris. Accessed on January 8, 2014 from: http://5imdc.files.wordpress.com/2011/03/honolulustrategy.pdf
UNEP. 2013. Global Partnership on Marine Litter: draft framework document/operational guidelines. Accessed on January 8, 2014 from: http://www.gpa.unep.org/index.php/global-partnership-on-nutrient-management/publications-and-resources/global-partnership-on-marine-litter-gpml/170-draft-framework-document-for-gpml/file

U.S. Environmental Protection Agency (USEPA). 2011. Marine debris in the North Pacific: a summary of existing information and identification of data gaps. EPA-909-R-006. 20 pp.

U.S. Fish and Wildlife Service. 2011. New death report - manatees. found at: http://www.fws.gov/northflorida/Manatee/Rescue-Rehab/Manatee_R3_Program_Reports.html

Van Der Hoop, J.M., Moore, M.J., Barco, S.G., Cole, T.V.N, Daoust, PY., Henry, A.G., McAlpine, D.F., *et al.* 2013. Assessment of management to mitigate anthropogenic effects on large whales. *Conservation Biology* 27: 121–133.

Van Der Hoop, J.M., Moore, M., Fahlman, A., Bocconelli, A., George, C., Jackson, K., Miller, C., Morin, D., Pitchford, T., Rowles, T., Smith, J. and B. Zoodsma. Behavioral impacts of disentanglement of a right whale under sedation and the energetic cost of entanglement. *Marine Mammal Science* DOI:10.1111/mms.12042.

Volgenau, L., Kraus, S.D. and J. Lien. 1995. The impact of entanglements on two substocks of the Western North Atlantic humpback whale, *Megaptera novaeangliae*. *Canadian Journal of Zoology* 73: 1689–1698.

Votier, S.C., Archibald, K., Morgan, G. and L. Morgan. 2011. The use of plastic debris as nesting material by a colonial seabird and associated entanglement mortality. *Marine Pollution Bulletin* 62: 168–172.

Wallace, N. 1985. Debris entanglement in the marine environment: a review. *Proc. of the Ninth Ann. Work. on Sea Turtle Cons. and Bio., SA.*

Waring, G.T., Josephson, E., Maze-Foley, K. and P. Rosel. 2013. US Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2012. Draft - *NOAA Technical Memorandum NMFS-NEFSC.*

Wegner, N.C. and D.P. Cartamil. 2012. Effects of prolonged entanglement in discarded fishing gear with substantive biofouling on the health and behavior of an adult shortfin mako shark, Isurus oxyrinchus. *Marine Pollution Bulletin* 64: 391–394.

Wells, R.S. and M.D. Scott. 1994. Incidence of gear entanglement for resident inshore bottlenose dolphins near Sarasota, Florida. In: W.F. Perrin, G.P. Donovan and J. Barlow (eds.). *Gillnets and Cetaceans.* p. 629.

Wells, R.S., Hofmann, S. and T.L. Moors. 1998. Entanglement and mortality of bottlenose dolphins (*Tursiops truncatus*) in recreational fishing gear in Florida. *Fishery Bulletin* 96: 647–650.

Wells, R.S., Allen, J.B., Hofmann, S., Bassos-Hull, K., Fauquier, D.A., Barros, N.B., Delynn, R.E., Sutton, G., Socha, V. and M. D. Scott. 2008. Consequences of injuries on survival and reproduction of common bottlenose dolphins (*Tursiops truncatus*) along the west coast of Florida. *Marine Mammal Science* 24:774–794.

Wiley, D.N., Asmutis, R.A., Pitchford, T.D. and D.P. Gannon. 1995. Stranding and mortality of humpback whales (*Megaptera novaeangliae*) in the mid-Atlantic and Southeast United States, 1985–1992. *Fishery Bulletin* 93: 196–205.

Williams, M.T., Rodrigues, R., Williams, B.Q., MacLean, S.A., Zavadil, P.A. and A.D. Lestenkof. 2004. Trends in northern fur seal entanglement in marine debris on the Pribilof Islands, Alaska from 1995–2003. LGL Report P631, prepared for the National Oceanic and Atmospheric Administration Prescott Stranding Grant Program.

Williams, M. and E. Ammann. 2009. Marine debris in Alaska: Coordinating our efforts. Alaska Sea Grant College Program, University of Alaska Fairbanks.

Wolf, R. 1982. Marine turtles. SEAN Bull 7(5):15.

Yoshida, K. and N. Baba. 1985. The problem of fur seal entanglement in marine debris. In: R.S. Shomura and K. Yoshida (eds.), Proceedings of the Workshop on the Fate and Impact of Marine Debris., 26–29 November 1984, Honolulu, Hawaii. *NOAA Technical Memorandum NMFS-SWFSC-54*. pp.448–452.

Yoshikawa, T. and K. Asoh. 2004. Entanglement of monofilament fishing lines and coral death. *Biological Conservation* 117: 557–560.

APPENDIX

Table 1. *Entanglements of invertebrates in marine debris in the U.S.*

Common Name	*Reference*
American Lobster	Laist 1997
Brown box crab	Good *et al.* 2007
Butter clam	Good *et al.* 2007
Dungeness crab	Good *et al.* 2007, Gilardi *et al.* 2010
Fire coral	Chiappone *et al.* 2002
Giant barnacle	Laist 1997, Good *et al.* 2007
Giant Pacfic chiton	Good *et al.* 2007
Golfball crab	Good *et al.* 2007, Gilardi *et al.* 2010
Gorgonians	Chiappone *et al.* 2002
Granular claw crab	Good *et al.* 2007
Green sea urchin	Good *et al.* 2007, Gilardi *et al.* 2010
Heart crab	Good *et al.* 2007
Helmet crab	Good *et al.* 2007
Hermit crab	Gilardi *et al.* 2010
Kelp crab	Laist 1997, Good *et al.* 2007
Leafy hornmouth	Good *et al.* 2007
Longhorn decorator crab	Good *et al.* 2007, Gilardi *et al.* 2010
Lyre crab	Good *et al.* 2007
Northern cancer crab	Laist 1997
Northern kelp crab	Good *et al.* 2007, Gilardi *et al.* 2010
Nuttall's cockle	Good *et al.* 2007
Oregon triton	Good *et al.* 2007
Pacific littleneck clam	Good *et al.* 2007
Pacific octopus	Good *et al.* 2007
Puget sound king crab	Good *et al.* 2007, Gilardi *et al.* 2010
Red fur crab	Good *et al.* 2007
Red rock crab	Laist 1997, Good *et al.* 2007, Gilardi *et al.* 2010
Red sea urchin	Gilardi *et al.* 2010
Smooth pink scallop	Good *et al.* 2007
Spiny pink star	Good *et al.* 2007
Sponges	Chiappone *et al.* 2002
Sunflower star	Good *et al.* 2007
Tanner crab	Good *et al.* 2007
Zoanthids	Chiappone *et al.* 2002

Table 2. *Entanglements of sea birds in marine debris in the U.S.*

Common Name	*Reference*
American coot	Moore *et al.* 2009
Auklet	Jones and Ferrero 1985, Laist 1997
Black skimmer	Laist 1997
Black-crowned night heron	Moore *et al.* 2009
Black-footed albatross	Laist 1997, Moore *et al.* 2009
Brandt's cormorant	Good *et al.* 2007, Moore *et al.* 2009
Brown pelican	Laist 1997, Moore *et al.* 2009
California gull	Moore *et al.* 2009
Caspian tern	Moore *et al.* 2009
Clark's grebe	Moore *et al.* 2009
Common eider	Moore *et al.* 2009
Common loon	Good *et al.* 2007, Moore *et al.* 2009
Common merganser	Good *et al.* 2007, Moore *et al.* 2009
Common murre	Jones and Ferrero 1985, Laist 1997
Double crested cormorant	Good *et al.* 2007, Moore *et al.* 2009
Glaucus winged gull	Moore *et al.* 2009
Great black-backed winged gull	Laist 1997
Great blue heron	Moore *et al.* 2009
Great egret	Moore *et al.* 2009
Herman's gull	Moore *et al.* 2009
Herring gull	Harris *et al.* 2006
Horned puffin	Jones and Ferrero 1985, Laist 1997
Larus spp. Gulls	Good *et al.* 2007, Moore *et al.* 2009
Laughing gull	Laist 1997
Laysan albatross	Degange and Newby 1980, Laist 1997
Lesser scaup	Moore *et al.* 2009
Masked booby	Conant 1984, Laist 1997
Nothern fulmar	Degange and Newby 1980, Laist 1997, Moore *et al.* 2009
Pacific loon	Moore *et al.* 2009
Pelagic cormorant	Good *et al.* 2007, Moore *et al.* 2009
Pied bill grebe	Moore *et al.* 2009
Ringed billed gull	Moore *et al.* 2009
Rock dove	Moore *et al.* 2009
Ruddy turnstone	Laist 1997
Scoty tern	Laist 1997
Short-tailed shearwater	Degange and Newby 1980, Laist 1997, Moore *et al.* 2009
Snowy egert	Moore *et al.* 2009
Sooty sherwater	Laist 1997, Moore *et al.* 2009
Surf scoter	Moore *et al.* 2009
Tufted puffin	Degange and Newby 1980, Jones and Ferrero 1985, Laist 1997
West x Glaucus winged gull hybrid	Moore *et al.* 2009
Western grebe	Laist 1997, Good *et al.* 2007, Moore *et al.* 2009
Western gull	Laist 1997, Moore *et al.* 2009
White pelican	Laist 1997, Moore *et al.* 2009
White winged scoter	Harris *et al.* 2006

Table 3. *Entanglements of marine mammals in marine debris in the U.S.*

Common Name	*Reference*
Atlantic harbor seal	Good *et al.* 2007
Bottlenose dolphin	Wells and Scott 1994, Mann *et al.* 1995, Wells *et al.* 1998, McFee and Hopkins-Murphy 2002, McFee *et al.* 2007, Barco *et al.* 2010, Powell and Wells 2011, Bassos-Hull and Powell 2012, Lelis, 2012, Bassos-Hull 2013, Stolen *et al.* 2013
Bowhead whale	Philo *et al.* 1992
California sea lion	Laist 1997, Good *et al.* 2007, Gilardi *et al.* 2010
Dall's porpoise	Degange and Newby 1980
Eastern gray whale	Laist 1997
Florida manatee	O'Shea *et al.* 1985, Beck and Barros 1991, Nill 1998, Spellman 1999, Bassos-Hull and Powell 2012, Butterworth 2012, Bassos-Hull 2013
Gray seal	Good *et al.* 2007
Guadalupe fur seal	Good *et al.* 2007
Harbor porpoise	Laist 1997
Harp seal	Laist 1997, Good *et al.* 2007
Hawaiian monk seal	Good *et al.* 2007
Hooded seal	Good *et al.* 2007, Gilardi *et al.* 2010
Humpback whale	Good *et al.* 2007
Minke whale	Good *et al.* 2007, Gilardi *et al.* 2010
North Atlantic right whale	Good *et al.* 2007
Northern elephant seal	Good *et al.* 2007, Gilardi *et al.* 2010
Northern fur seal	Fowler 1982, 1985, 1987, Laist 1997, Good *et al.* 2007
Pacific harbor seal	Good *et al.* 2007
Sea otter	Degange and Newby 1980, Moore *et al.* 2009
Sperm whale	Moore *et al.* 2009
Steller sea lion	Good *et al.* 2007, Gilardi *et al.* 2010

Table 4. *Entanglements of sea turtles and other species in marine debris in the U.S.*

Common Name	*Reference*
Blacknose shark	Schwartz 1984
Dogfish	Laist 1997
Green sea turtle	Balazs 1980, 1982b, 1985, Hildebrand 1980, Anon 1981, Mooney and Knaughton 1981, Henderson 1984, Plotkin and Amos 1990, Sadove and Morreale 1990, Teas and Witzell 1995, Gerle and DiGiovanni 1998
Hawkbill sea turtle	Balazs 1978,1985, Hildebrand 1980, Broadrick 1982, Fletcher 1982, Wolf 1982, Plotkin and Amos 1990, Teas and Witzell 1995
Kemp's ridley sea turtle	Plotkin and Amos 1990, Sadove and Morreale 1990, Duronslet *et al.* 1991, Teas and Witzell 1995, Gerle and DiGiovanni 1998
Leatherback sea turtle	Sadove and Smith 1981, Plotkin and Amos 1990, Sadove and Morreale 1990, Teas and Witzell 1995, Gerle and DiGiovanni 1998
Loggerhead sea turtle	Balazs 1985, Plotkin and Amos 1990, Sadove and Morreale 1990, Bjorndal and Bolten 1995, Teas and Witzell 1995, Gerle and DiGiovanni 1998
Mackerel	Gudger 1928
Manta ray	Wallace 1985
Olive ridley sea turtle	Balazs 1982a,b, Afelin and Puleloa 1992, Teas and Witzell 1995
Salmon shark	Jones and Ferrero 1985
Shortfin mako shark	Gudger and Hoffman 1931, Wegner and Cartamil 2012
Skate, unidentified	Laist 1997
Smalltooth sawfish	Seitz and Poulakis 2006

Penny Pritzker
United States Secretary of Commerce

Dr. Kathryn D. Sullivan
Under Secretary of Commerce for Oceans and Atmosphere

Dr. Holly A. Bamford
Assistant Administrator, National Ocean Service