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A Pre- and Post-MARPOL Annex V Summary of Hawaiian Monk Seal Entanglements and Marine Debris Accumulation in the Northwestern Hawaiian Islands, 1982–1998

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Entanglements of Hawaiian monk seals, *Monachus schauinslandi*, were documented in the northwestern Hawaiian Islands (NWHI) from 1982 to 1998, and debris which presented a threat of entanglement was inventoried and removed from 1987 to 1996. A total of 173 entanglements was documented. The number of entanglements did not change after implementation of MARPOL Annex V in 1989. Pups and juvenile seals were more likely to become entangled than older seals, and became entangled primarily in nets, whereas entanglement of subadults and adults was more likely to involve line. The subpopulation of seals at Lisianski Island experienced the most entanglements, although Lisianski did not accumulate the most debris. Localized high entanglement rates may gravely affect individual monk seal subpopulations. Accumulation of debris has not diminished since implementation of Annex V, nor has occurrence of derelict drift nets abated since a 1989 moratorium. Debris washing ashore has likely been circulating in the North Pacific Ocean for some time. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: pinniped; Monachus; monk seal; marine debris; entanglement; MARPOL

Introduction

During the past 35 years, durable and resilient plastic materials have replaced natural fibers in the maritime industry. Polypropylene and nylon nets have replaced antiquated and once prevalent tarred cotton and linen webbing, and various plastic lines are now used in place of manila or other natural fibers such as hemp (Pruter, 1987). The use of plastics has resulted in large amounts of persistent marine debris drifting in the world's oceans and washing ashore. This debris is aesthetically offensive, presents a hazard to vessels, and may entangle or be ingested by wildlife (Laist, 1987).

General concern over the impact of this pollution was addressed in a separate Annex, Annex V, of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78). Annex V of MARPOL is intended to reduce solid waste pollution from ships, in part by prohibiting ocean dumping of plastics. Annex V was formally adopted in 1988, came into effect in 1989, and has been ratified by more than 70 nations. For some marine mammal populations (e.g., northern fur seal, *Callorhinus ursinus*) the rate of entanglement has decreased since Annex V was passed (Fowler *et al.*, 1994).

The impacts of marine debris on wildlife are well-documented. Laist (1996) estimated that 267 marine species have ingested and/or become entangled in marine debris. Pinnipeds may be particularly susceptible to entanglement: Fowler (1988) stated that 16 of the 33 extant species of pinnipeds were documented as having become entangled. By 1996, the number of entangled pinniped species had grown to 19 (Laist, 1996).

Hawaiian monk seals were first observed entangled by marine debris in 1969, with several reports following (Balazs, 1979; Andre and Ittner, 1980; Kenyon, 1980; Henderson, 1984). Henderson (1990) summarized data on all observed entanglements of Hawaiian monk seals through 1988, and concluded that (1) pups were the most susceptible to entanglement; (2) the rate of entanglement was increasing, and; (3) Lisianski Island represented the site with the highest rate of entanglement.

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Types of debris found to entangle Hawaiian monk seals were listed in Henderson (1985, 1990), but no overall summary has been published. Data have not been published regarding beach debris from the northwestern Hawaiian Islands (NWHI). This report summarizes all entanglements of Hawaiian monk seals from 1982 to 1998, and documents types of potentially entangling debris removed from NWHI beaches from 1987 to 1996.

Study Site

The endangered Hawaiian monk seal, *M. schauinslandi*, is the only marine mammal endemic to the Hawaiian Archipelago. The primary haulout and breeding sites are within the remote NWHI, which extend approximately 2100 km northwest of Kauai. Five locations comprise the major breeding sites: Kure Atoll, Pearl and Hermes Reef, Lisianski Island, Laysan Island, and French Frigate Shoals. Migration among sites is not common – approximately 90% of a population using a haulout site was born at that island (Ragen and Lavigne, 1999). The distance to which seals travel offshore to forage is not well-known, although individuals have been documented travelling between French Frigate Shoals and nearby St. Rogatien Bank and Necker Island, distances of 110 and 165 km, respectively.

Methods

From 1982 to 1998 biologists from the National Marine Fisheries (NMFS) Honolulu Laboratory maintained field camps at most major breeding sites. Field methods are detailed by Johanos and Ragen (1999). The length of annual field visits varied by both location and year, ranging from several days to six months during March–August. Camps were established annually at Kure Atoll, Laysan Island, and French Frigate Shoals; no camps were established at Pearl and Hermes Reef in 1994 or at Lisianski Island in 1989 and 1994. While monitoring seal populations, field staff recorded life-threatening incidents, including occurrences of entanglement or scarring from entangling debris, and whenever possible released entangled animals. A seal was considered entangled if any part of its body was encircled by debris. Seals resting or asleep on debris were not considered entangled unless their head or body was inside a loop and field personnel thought the animal would not be able to free itself. The entangling item was categorized as net, line, ring, strap, or other/unknown. Seals entangled by an aggregate of net and line were considered entangled in 'net/line'. Seals with entanglement scars were assumed to have become entangled at the island where first observed, and the type of entangling item was considered unknown.

Based on animal size, all entangled seals were assigned to one of four age classes: Pups – less than one year (includes nursing and weaned pups); juveniles – 1–3 years; subadults – 4–6 years; adults – 7 years and older. Juveniles and subadults were sometimes combined into a single category, 'immatures'.

The number of entanglements observed may be influenced by both the amount of field effort (observation time) and the size of the seal population, both of which have varied during the 15-yr duration of this study. To obtain an entanglement index corrected for potential biases, annual entanglement rates were determined by dividing the number of entanglements by a product of the number of field days and the mean annual beach counts of seals (including pups) for the five major breeding locations. Entanglements which were observed independent of NMFS effort (i.e. observed by non-NMFS personnel such as US Coast Guard or US Fish and Wildlife Service) were excluded from data used to determine entanglement rates. Non-NMFS observations, however, were used in analyses of total entanglements, entanglement locations, size classes of entangled seals, and the types of debris items involved.

Seals with embedded fishhooks were not included in these data. These seals were assumed to have encountered an active fishery, and the hookings were therefore not considered to represent encounters with passive debris.

Debris considered to present a threat of marine mammal entanglement was removed from beaches. Commencing in 1987, characteristics of such debris items were documented prior to being destroyed. Beach debris removed included: all nets or fragments of webbing; lines and packing straps at least 1 m long or forming a loop; items forming a ring or other opening of at least 10 cm diameter. The latter category ('rings') included plastic or rubber rings of unknown provenance, as well as cones used in traps of the hagfish fishery. All rope, string, and line were combined into the single category 'line'. Nets were considered to be drift-nets if the mesh consisted of monofilament material. All other nets were assigned as trawl nets, a category that therefore may contain some fragments of purse seines or other similar gear. Aggregates comprising several types of debris were considered to be a single item, and were assigned to the debris type constituting most of the mass of the aggregate. Items not considered an entanglement threat (e.g. bottles, plastic items, and fishing floats) were neither included in the inventory nor removed.

Results

Entanglements

A total of 173 entanglements was documented during 1982–1998 (Fig. 1): 159 described by NMFS biologists, and an additional 14 observed by non-NMFS personnel. The number of annual entanglements has varied greatly during the 17-yr interval, with a documented high of 22 incidents in 1996.

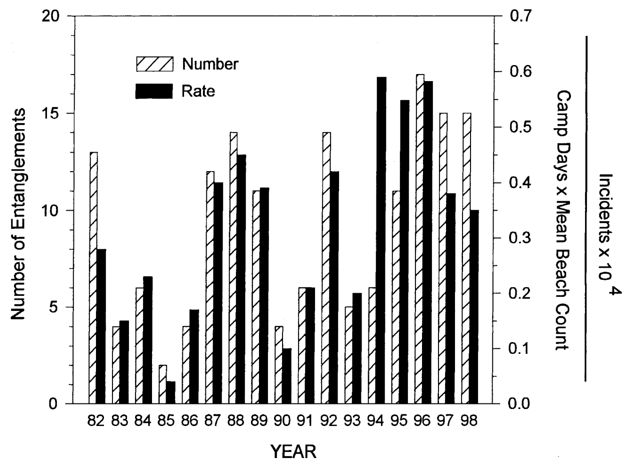

Fig. 1 Number and rate of Hawaiian monk seal entanglements, 1982–1998.

The entanglement data were allocated according to years pre-MARPOL (1982–1988) and post-MARPOL (1989–1998). Data from 1989 and 1994 were excluded because of incomplete observation effort. A Mann Whitney test was conducted to compare the ranks of number of entanglements between the two groups. The results do not reject the null hypothesis of no difference before and after MARPOL ($R1 = 69.5$, $R2 = 50.5$, $U = 14.5$).

The entanglement rate (entanglements corrected for beach count and observation effort) dropped after 1996 (Fig. 1).

The highest number of entanglements has been documented at Lisianski Island, although the seal subpopulation at Lisianski is not the largest (Fig. 2) among the five major breeding sites. The number of entanglements at each site was compared using a Chi-Square analysis.

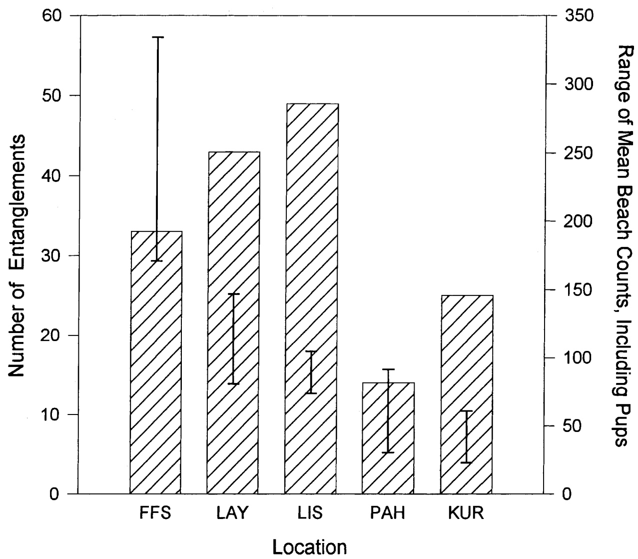

Fig. 2 Number of Hawaiian monk seal entanglements (columns) and range of beach counts (bars), 1982–1998; FFS – French Frigate Shoals, KUR – Kure Atoll, LAY – Laysan Island, Lis – Lisianski Island, PAH – Pearl and Hermes Reef.

The expected numbers of entanglements were calculated in the following way:

1. For each year (excluding 1989 and 1994), total the mean beach counts for all five sites, and calculate the proportion of the total contributed by each site.
2. For each site each year, the expected number of entanglements is the product of the total entanglements observed at all five sites and the proportion of total beach count.

The results ($X^2 = 63.47$, $df = 4$, $p < 0.0001$) indicate that the number of entanglements at each island is not proportional to the number of seals at the island: entanglements far exceed expectations at Lisianski, and are far less than expectations at French Frigate Shoals.

From 1982 to 1998 the percentage of each size class of seals entangled varied, with pups representing the highest percentage of all observed entanglements (Fig. 3), followed by immatures and adults. Together, pups and immature seals accounted for nearly 80% of all observed entanglements, but only 46% of the population. A Chi-Square analysis compared the number of observed entanglements at each site to the expected number. The expected number was derived by multiplying the entanglement total by the proportion of each size class of seals represented in the 1998 population from the five major breeding locations. Results showed a significant difference from the expected values ($X^2 = 100.51$, $df = 3$, $p \ll 0.0001$).

Few injuries or mortalities have been observed to result from entanglement. Of the 173 incidents, 28 seals incurred injuries from entanglement, including 7 seals found dead. At least 158 entangled seals are known to have survived having been entangled, including 118 that were disentangled by field personnel, and 40 that escaped unaided from debris. The fates of eight entangled seals are not known: they could not be captured and

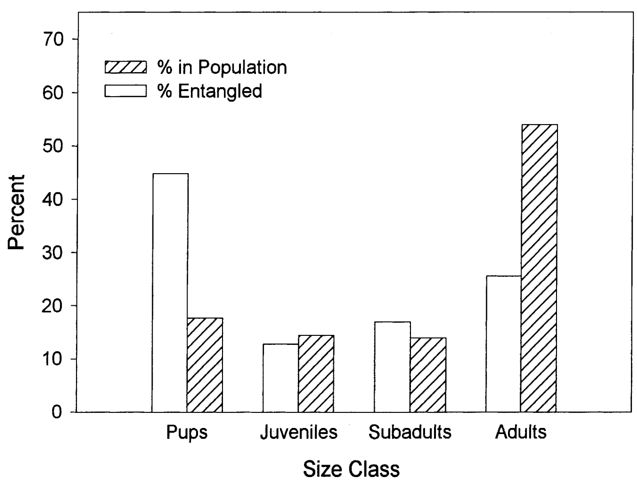

Fig. 3 Percent of each size class of Hawaiian monk seals entangled in marine debris, 1982–1998, compared to each class's representation in the 1998 population.

disentangled, and were never observed after they were seen entangled.

Entangling debris

Seals were observed entangled in nets or fragments of net ($n = 56$), line ($n = 48$), net/line combination ($n = 16$), packing bands ($n = 13$), plastic rings ($n = 15$), and other/unknown debris ($n = 25$) (Fig. 4). Among size classes, pups and juveniles were most likely to become entangled in nets, other/unknown items, and rings. Older seals were most often found entangled in lines and nets.

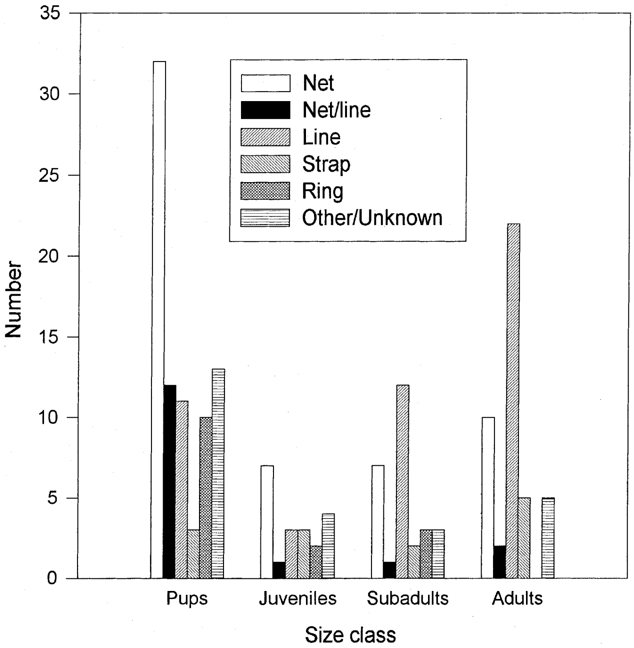

Fig. 4 Number of Hawaiian monk seals observed entangled in each type of debris item in the NWHI, 1982–1998.

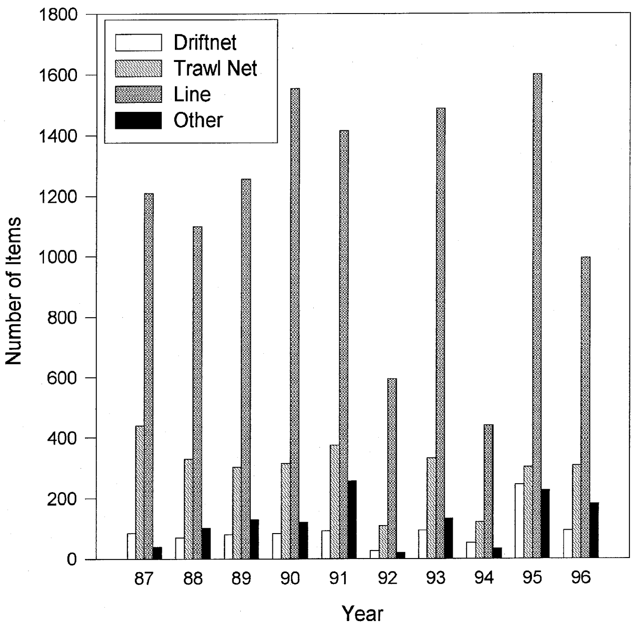

Fig. 5 Debris items inventoried on NWHI beaches, 1987–1996.

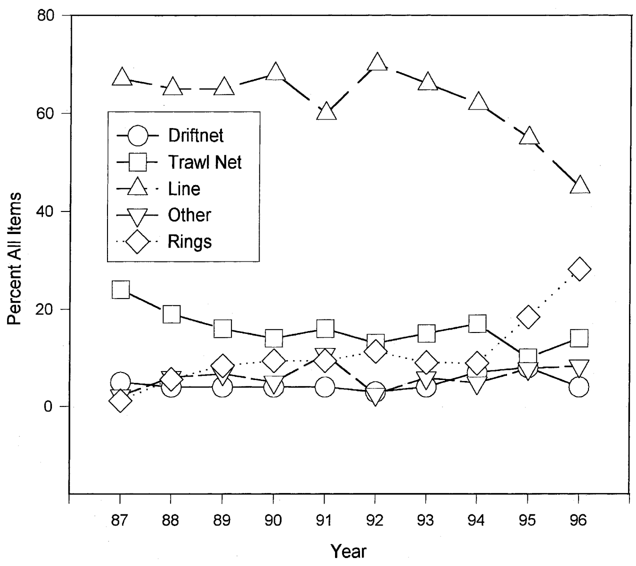

Fig. 6 Percent occurrence of entangling items on NWHI beaches, 1987–1996.

TABLE 1

Year	KUR	PAH	LIS	LAY	FFS	Total
1987	659	323	275	353	186	1796
1988	822	260	[a]	581	36	1699
1989	815	234	[a]	649	228	1926
1990	418	262	714	758	122	2274
1991	278	572	279	1175	112	2416
1992	15	[a]	[a]	620	215	850
1993	875	310[b]	711	359	7	2262
1994	40	[a]	[a]	598	72	710
1995	312	678	1199	582	144	2915
1996	844	241	515	586	12	2198
Total	5078	2880	3693	6261	1134	19 046

[a] No data.
[b] Partial data.

Beach debris

Over 19 000 debris items were destroyed during 1987–1996 (Fig. 5) after documentation of relevant information. The relatively low number of items documented in 1992 and 1994 was a result of reduced field effort in those years – debris was not collected from two breeding sites. Lines were the most prevalent debris item, with fragments of trawl net being the second most prevalent (Fig. 6). Drift nets and other items comprised a smaller proportion. Historically, the most potentially entangling items have been removed from Laysan Island (Table 1).

Discussion

Hawaiian monk seals continue to become entangled in marine debris, despite seasonal cleaning of hazardous items from their haulout beaches. Entanglement rates showed considerable variation during the 17-yr observation period, but rates during 1994–1996 were consistently the highest since observations commenced in

1982. The large number of entanglements observed in 1996 may have resulted from increased observation effort, since the effort-corrected rate remained comparable to the preceding two years.

The seals' haulout beaches are cleaned annually by field personnel and remain relatively free of entangling debris for the duration of field effort. Thus, entangled seals which are observed have either encountered marine debris floating away from shore, or, particularly if they are observed early in the field season, are likely to have become entangled in beach debris that washed ashore during the 6–9 months when field personnel were absent. Moreover, field biologists use natural or applied markings to identify most animals on each island, and recognizable seals which were observed unencumbered often appeared on cleaned beaches bearing entangling items, presumably having acquired the debris at sea.

It is unclear why pups and immature seals are more susceptible to entanglement in nets, while older seals become entangled predominantly in line. Recently weaned pups remain relatively close to the islands of their birth (Henderson and Johanos, 1988), so it is possible that nets present more of a hazard on nearshore reefs, whereas lines are encountered at more distant locations by older seals.

The highest rate of entanglement continues to occur at Lisianski Island, although beach debris data do not indicate that Lisianski has consistently accumulated higher amounts of potentially entangling debris. Henderson (1990) suggested that high entanglement rates at Lisianski Island result from the windward location of pupping areas, exposing young seals to more debris than their counterparts at other islands.

Johnson (1994) conducted beach surveys in Alaska which documented reduced deposition of trawl webbing since implementation of MARPOL V. The amount of entangling debris washing ashore in the NWHI, however, has shown no sign of diminishing, despite implementation of MARPOL Annex V in 1989. Most of the entangling items we documented (i.e. nets and lines) were clearly from the fishing or other maritime industries. Vessels may be continuing to dump debris despite MARPOL regulations, or lose fishing gear during normal operations.

Significant amounts of 'pre-MARPOL' debris may continue to circulate in the North Pacific Ocean, posing an ongoing threat. Kubota (1994) simulated the effects of Stokes drift, Ekman drift, and geostrophic currents on theoretical debris items placed throughout the North Pacific. The resulting movement predicted all debris becoming situated in a narrow band running approximately ENE–WSW, crossing the NWHI in the vicinity of Laysan and Lisianski Islands. Theoretical debris items placed across the North Pacific Ocean at 45°N were predicted to concentrate, forming an area of high debris density at 27°N, 170°W, approximately 220 km NE of Laysan Island. Matsumura and Nasu (1996), summarizing six years of surveys documenting drifting debris, confirmed that the Pacific region north and north-east of Hawaii showed relatively high densities of fishing gear and nets. No trawl fisheries operate near Hawaii or the NWHI, so it is probable that trawl webbing found in the NWHI originates in the North Pacific, Gulf of Alaska, or the Bering Sea.

It is noteworthy that the relative amount of high seas drift net found on beaches has not diminished despite international implementation of a moratorium at the end of 1992. Unless unauthorized drift net operations are continuing, the nets which are washing ashore now were lost prior to 1993, and have remained in circulation in the North Pacific.

Some changes in the type of entangling debris washing ashore are evident. The relative amount of plastic rings increased during 1994–1996, with a commensurate drop in the relative amount of line. Subsequent years of monitoring will determine if this is a significant trend. One source of the increased number of rings is the hagfish fishery, which occurs primarily in temperate nearshore waters on both sides of the Pacific Ocean. Black plastic cones which constitute the ends of this fishery's tubular traps have been found in increasing numbers, although no seals have been observed entangled in them. The source of other rings is unknown.

The Hawaiian monk seal population is estimated to be 1450 (Ragen and Lavigne, 1999). The 173 entanglements over 17 years therefore represent an annual entanglement rate of 0.70%, a higher rate than has been observed in other pinnipeds. Fowler (1987) reported a rate of 0.4% for immature male northern fur seals; Stewart and Yochem (1990) reported rates from 0.08% to 0.16% for California sea lions and northern elephant seals; Arnould and Croxall (1995) estimate 0.3% entanglement among Antarctic fur seals at Bird Island, South Georgia. Although the number of observed deaths has been low, it is likely that unobserved mortality caused by debris occurs, as is the case of Northern fur seals (Fowler *et al.*, 1994). An unknown number of animals may become entangled either at sea in debris too large for the animal to carry back to land, or on offshore reefs in nets which are fouled on the coral. The high entanglement rates observed for Hawaiian monk seals suggest that marine debris is a source of mortality for the Hawaiian monk seal population.

Moreover, entanglement may significantly impact individual subpopulations of Hawaiian monk seals. Because each islands subpopulation is relatively discrete, with restricted movement among islands, local effects of entanglement could be severe. For example, the entire subpopulation at Lisianski Island was estimated in 1997 to have comprised 188 seals (Nevins *et al.*, 1997). In the 17 years summarized by this report, entanglements at Lisianski have annually averaged 2.9 seals, or 1.5% of the 1997 subpopulation.

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