North Pacific Fur Seal Commission. (1985). Proceedings of the Tokyo Meeting April 15–18, 1985, Tokyo, Japan. National Oceanic and Atmospheric Administration. Washington, D.C.
Provincetown Center for Coastal Studies. (1984). Report to the National Marine Fisheries Service, The Release of a Humpback Whale, IB-1, from Entanglement. Provincetown, Massachusetts.
Scordino, J. (1985). Studies of fur seal entanglement, 1981–84. St. Paul Island, Alaska. In *Proceedings of the Workshop on the Fate and Impact of Marine Debris*, 27–29 November 1984, Honolulu, Hawaii (R. S. Shomura & H. O. Yoshida, eds), pp. 278–290. US Dep. Commer. NOAA Tech. Memo., NMFS. NOA-TM-NMFS-SWFC-54.
Shaughnessy, P. D. (1980). Entanglement of cape fur seals with man-made objects. *Mar. Pollut. Bull.* **11**, 332–336.
Shomura, R. S. & Matsumoto, W. S. (1982). Structured Flotsam as Fish Aggregating Devices. US Dep. Commer. NOAA Tech. Memo., NMFS. NOAA-TM-NMFS-SWFC-22.
Stewart, B. S. & Yochem, P. K. (1987). Entanglement of pinnipeds in plastic debris and fishing net fragments in the Southern California Bight, 1978–1986. *Mar. Pollut. Bull.* **18**, 00–00.
Sturkie, P. D. (ed.) (1965). *Avian Physiology.* Cornell University Press, Ithaca, New York.
Uchida, R. N. (1985). The types and amounts of fish net deployed in the North Pacific. In *Proceedings of the Workshop on the Fate and Impact of Marine Debris*, 27–29 November 1984, Honolulu, Hawaii (R. S. Shomura & H. O. Yoshida, eds), pp. 37–108. US Dep. Commer. NOAA Tech. Memo., NMFS. NOAA-TM-NMFS-SWFC-54.
US Department of Commerce. (1980). Final Environmental Impact Statement on the Interim Convention on Conservation of North Pacific Fur Seals. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Washington, D.C.
US Department of Commerce. (1981). Final Environmental Impact Statement on the Incidental Take of Dall Porpoise in the Japanese Salmon Fishery. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Washington, D.C.
US Department of Commerce. (1985). Environmental Impact Statement on the Interim Convention on Conservation of North Pacific Fur Seals. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Washington, D.C.
Yoshida, K. & Baba, N. (1985). A Survey of Drifting Stray Fishing Net Fragments in the Northern Sea of Japan (Western Pacific Ocean). Document Submitted to 28th Meeting of the Standing Scientific Committee of the North Pacific Fur Seal Commission. Tokyo, Japan. April 3–12, 1985.
Yoshida, K., Baba, N., Nakajima, M., Fujimaki, Y., Furuta, A., Nomura, S. & Takahashi, K. (1985). Fur Seal Entanglement Survey Report Test Study at a Breeding Facility, 1983. Document submitted to the 28th Meeting of the Standing Scientific Committee of the North Pacific Fur Seal Commission. Tokyo, Japan. April 4–12, 1985.

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Marine Debris and Northern Fur Seals: a Case Study

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Since the early 1930s small numbers of northern fur seals (*Callorhinus ursinus*) have been observed with various objects caught around their necks, shoulders and, less frequently, their flippers. The incidence of such entanglement increased following the mid-1960s when fishing effort in the North Pacific and Bering Sea increased and when plastic materials began to be used extensively in making trawl netting and packing bands. The current incidence of entanglement observed among subadult males on St. Paul Island (of the Pribilof Islands) is about 0.4%, a level at least two orders of magnitude greater than observed in the 1940s. Almost all entangling materials observed on subadult males ashore weigh less than 0.4 kg and are predominantly fragments of trawl netting and plastic packing bands. Most of the trawl netting debris found at sea or on beaches in the Bering Sea area consists of fragments larger than those found on the seals that return to the Pribilof Islands. During pelagic surveys, trawl netting debris is sighted at the rate of 0.2–3.1 fragments per 1,000 km. Between 10 and 17% of these fragments have been observed to contain entangled seals. Seals appear to become entangled after approaching and investigating debris. Entanglement involves both sexes and appears predominantly to involve young animals, which are occasionally observed entangled as groups in large debris. Entanglement in debris results in increased energy expenditures, especially while dragging large fragments of net at sea. Compared to non-entangled seals, entangled seals spend more time at sea, whether foraging, travelling, or both. Changes in pup numbers born and unexpected mortality in the first several years of life exhibit a relationship with entanglement to provide a correlative explanation for recent population dynamics. These factors collectively suggest that mortality of fur seals due to entanglement in marine debris contributes significantly to declining trends of the population on the Pribilof Islands.

Since the 1930s northern fur seals (*Callorhinus ursinus*) of the Pacific Ocean have been observed caught (usually tangled around their necks and shoulders) in various objects (Scheffer, 1950). Just after the Second World War, seals were observed caught in rubber rings thought to be of military origin. At that time less than 0.004% of the commercially harvested subadult males were observed to be entangled (10 animals of 320,728 harvested). Since then the incidence of entanglement among young males taken in the commercial harvest has increased, especially in the late 1960s when commercial fishing effort increased and synthetic materials became important in the construction of nets (Fig. 1). During the last 10 years, about 0.4% of young males observed ashore at St. Paul Island have been entangled in debris.

Concern about the potential effects of entanglement on individual animals and on the population has resulted in a number of studies. The data from early work concerning this problem are presented and summarized by Fiscus & Kozloff (1972), Sanger (1974), and Scordino & Fisher (1983). Data from recent land-based studies and a summary of historical pelagic observations are presented in Scordino *et al.* (in prep.). The results of recent pelagic surveys are presented by Dahlberg & Day (1985), Jones & Ferrero (1985), Yoshida & Baba (1985a, b) and Baba *et al.* (1986). Recent analyses and interpretations of these data are presented in Fowler (1982, 1985a, b), Swartzman (1984), and Lenarz (1985). The most recent land-based studies are summarized in Bengtson *et al.* (in prep.) and DeLong *et al.* (in prep.).

Observations on Land

Data on the number of entangled northern fur seals observed in the commercial harvest on the Pribilof Islands have been collected for over 20 years (Scordino & Fisher, 1983; Scordino *et al.*, in prep.). The weights, kinds, and mesh sizes of debris from entangled animals were recorded in 1973 and every year since 1981 (Table 1). Debris of the same types observed on northern fur seals also accumulates on island beaches of the North Pacific. This debris has been studied by Merrell (1980, 1985), Fowler (1982), and Fowler *et al.* (1985). Between 60 and 80% of fragments of fishing nets found on beaches are larger (by weight) than those found on the northern fur seals that return to the Pribilof Islands (Fig. 2).

The stretched mesh size of trawl netting debris that is found on entangled juvenile male fur seals taken in the harvest varies but is most often 20–25 cm (Fig. 3). Similarly, most packing bands found on animals are 15–25 cm when stretched and measured from one end of the loop to the other (Fig. 4). The stretched mesh size of trawl net fragments found on beaches is generally smaller than those found on seals (Fig. 3) whereas closed loop packing bands are generally larger on beaches than on seals (Fig. 4). The cranial circumference of newly weaned pups measures approximately 30 cm, making them vulnerable to entanglement in netting debris of smaller meshes (i.e. as small as 15 cm stretched mesh). This has been verified experimentally (Fig. 5).

Two-thirds of the debris observed on seals ashore consists of trawl net fragments; the remaining debris on these animals is mostly packing bands and other miscellaneous objects associated for the most part with the fishing industry (Table 1). The mesh sizes and twine sizes of the net fragments most often seen on seals are characteristic of the 'wings' of trawl nets. The flexible nature of the twine of these fragments may contribute to the problem, allowing seals easily to insert their heads into a mesh. Seals have been observed entangled in debris of various colours but selectivity has not been demonstrated.

Young animals (between birth and 2–3 years old) appear to be most susceptible to entanglement. Surveys conducted on St. Paul Island between 11 September and 16 October (DeLong *et al.*, in prep.), showed that the incidence of entanglement among pups increased as soon as they began entering the water at the end of the breeding season. Small groups (2–12 animals) of young pups have been observed entangled together in the same fragment of netting (Fowler, 1984; DeLong *et al.*, in prep.); this occurrence has never been observed among adult fur seals. As will be seen below, statistical analysis of the entanglement data in conjunction with population data produce the most consistent results when entanglement-related mortality is assumed to exert its primary effect on animals less than 2–3 years old. The occurrence of entanglement among older age-classes (of both sexes) is thought to be less than among the young males but potentially significant (Bigg, 1979; DeLong *et al.*, in prep.).

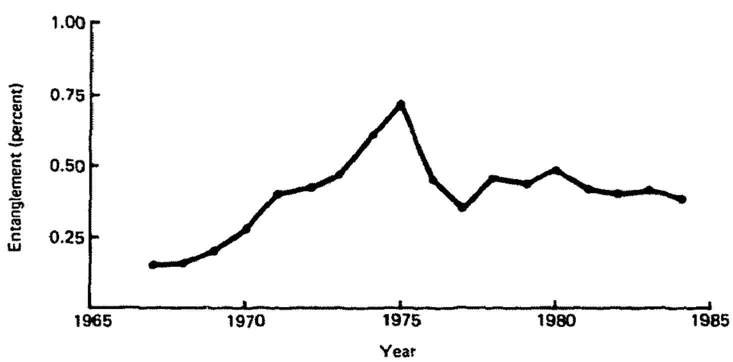

Fig. 1 The entanglement rate observed in the harvest and research drives of subadult male fur seals for St. Paul Island, Alaska, 1960–85.

TABLE 1

Types of entangling debris observed on northern fur seals during the harvest (1981–1984) or entanglement research roundups and surveys (1985)* on St. Paul Island, Alaska, 1981–1985. (From Bengtson *et al.*, in prep.)

Type of debris	Number of seals 1981	1982	1983	1984	1985	Total
Trawl net fragment:						
mesh size over 20 cm	45	52	52	37	34	220
mesh size under 20 cm	4	5	6	3	2	20
undetermined mesh size	19	5	21	10	17	72
Monofilament gill-net fragment	0	3	2	4	2	11
Cord used in net construction/repair	3	4	2	2	5	16
Plastic packing band	20	26	18	20	8	92
String	5	3	2	4	0	14
Rope or line	1	2	2	5	7	17
Rubber band	3	0	1	0	0	4
Plastic ring	1	0	1	1	0	3
Plastic gasket	0	0	2	0	0	2
Monofilament line	0	1	0	0	0	1
Plastic six-pack holder	0	1	0	0	0	1
Plastic packing web	0	0	1	0	0	1
Plastic object	0	0	0	1	0	1
Lawn chair material	1	0	0	0	0	1
Cloth sack band	0	0	1	0	0	1
Metal headlight ring	0	0	1	0	0	1
Plastic line with handle	0	0	0	0	1	1
	102	102	112	87	76*	479

*Includes a number of animals sighted independent of roundups and therefore not to be used for calculating proportion entangled.

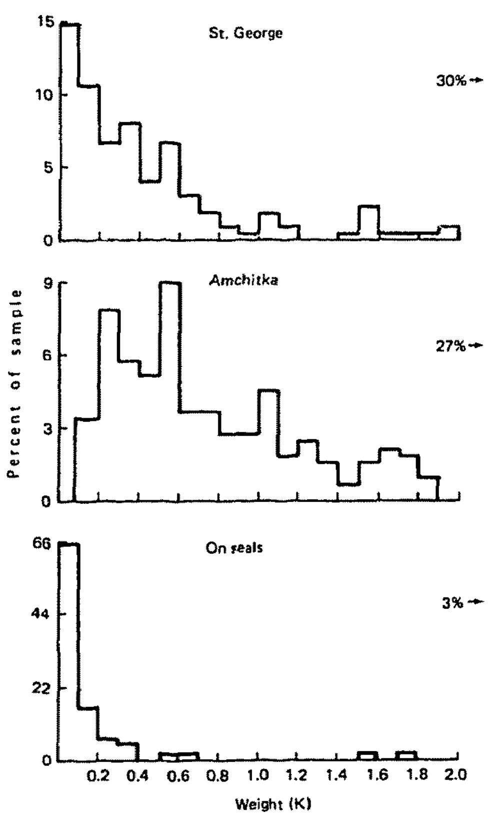

Fig. 2 Size-frequency distribution of net fragments (based on weight of debris shaken free of sand and water but still damp) collected on two islands (St. George and Amchitka) in the vicinity of the Bering Sea and on fur seals taken in the harvest on St. Paul Island. The portion of the sample that would occur off the graphs at these scales is indicated by the arrows.

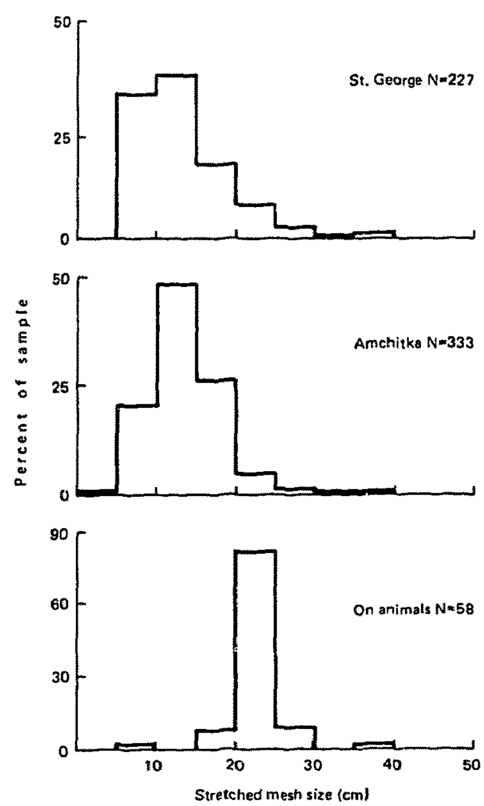

Fig. 3 Frequency distributions of mesh sizes of net fragments found on two islands (St. George and Amchitka) in the vicinity of the Bering Sea and on animals taken in the harvest on St. Paul Island.

Observations at Sea

A number of surveys to examine the density and distribution of debris at sea were conducted by Japanese and US scientists in 1984 and 1985 (Table 2). Thirty pieces of trawl netting and 33 pieces of gill netting were sighted during these surveys. All six studies used basically the same methodology for sighting debris from aboard vessels. During these surveys debris was sighted at the rate of 0.657 pieces of trawl netting per 1000 km in the western Pacific (Yoshida & Baba, 1985b) and up to 3.13 pieces per 1000 km in the eastern Bering Sea (Yoshida & Baba, 1985a; Baba *et al.*, 1986). Dahlberg & Day (1985) reported encountering trawl debris at the rate of 0.356 pieces per 1000 km in the central North Pacific between Kodiak Island and Hawaii, and data from Ignell (1985) indicate an encounter rate of 0.23 pieces per 1000 km. Jones & Ferrero (1985) reported encounter rates of 1.349 pieces per 1000 km in the Aleutian Islands area of the North Pacific. The mean encounter rate for all studies (from Table 2) is 1.2 pieces of trawl net per 1000 km.

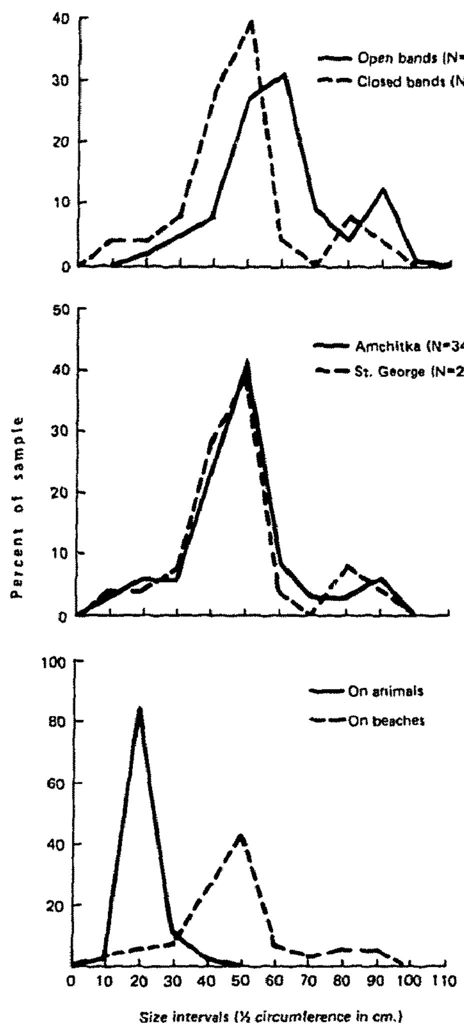

Fig. 4 Size-frequency distributions of plastic banding materials found on two islands (St. George and Amchitka) in the vicinity of the Bering Sea and on entangled animals taken in the harvest on St. Paul Island. Top panel: comparison of the sizes of open (cut so as to be a simple band, but measured to reflect ½ their length) and closed (i.e. stretched loops measured from one end to the other or ½ circumference) pieces on St. George Island. Middle panel: comparison of sizes of closed loops for two islands. Bottom panel: comparison of sizes of closed loop materials on both islands with those found on entangled animals.

Figure 6 shows the distribution of netting debris that was sighted between 1978 and 1986 as available in records maintained by the National Marine Fisheries Service. These sightings include data from the surveys summarized in Table 2 (simple symbols) as well as from more recent surveys from which analyses have not been completed (symbols with bars). Data plotted in this figure do not include netting that contained entangled animals (which is shown in Fig. 7). The relative concentration of trawl webbing (compared to gill netting) is greater in the eastern Bering Sea than in the central Pacific.

The available data suggest that there is a greater concentration of trawl debris in the areas of concentrated fishing effort and in areas where oceanographic conditions tend to concentrate floating debris. The highest observed encounter rates were from the eastern Bering Sea, an area exposed to a large number of trawl-days fished (Fredin, 1985). Dahlberg & Day (1985) noted that the increased concentrations of debris they observed in the central part of the North Pacific was to be expected as a result of oceanographic and atmospheric dynamics associated with the North Pacific gyre. The highest observed rates of encounter for gill nets seems to correspond with areas of gillnet fishing.

By way of comparison with the distribution of debris, the historical (1967–1985) data on entangled seals observed away from the breeding rookeries are presented in Table 3 and are shown in Fig. 7. These data primarily represent opportunistic sightings that have been made incidental to fishery observer programmes, and include the four entangled seals seen in the surveys summarized in Table 2. Three of the seals in Table 3

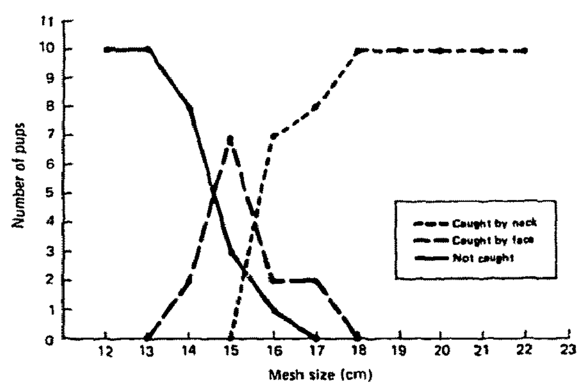

Fig. 5 Results of entanglement experiments on captive, nearly-weaned pups. Net fragments of the mesh size (stretched mesh) indicated were experimentally presented to pups (from Bengtson *et al.*, in prep.). At smaller (13–15 cm) mesh sizes, animals were caught by the face, whereas larger (15–18 cm) mesh entangled seals around the neck.

TABLE 2

Summary of results from pelagic surveys in the North Pacific Ocean and Bering Sea of derelict nets and net fragments.

Distance km	Number of pieces Trawl net	Gill net	Entangled seals	Oceanic Region	Reference
2224	3	9	0	Western and Northern North Pacific	Jones & Ferrero (1985)
3456	6	2	0	Western Pacific	Yoshida & Baba (1985a)
9121	5	10	2	Eastern Bering Sea	Yoshida & Baba (1985b)
2809	1	3*	0	Central Pacific	Dahlberg & Day (1985)
4366	1	8	1	Central Pacific	Ignell (1985)
2930	14	1	1	Eastern Bering Sea and Aleutian Islands	Baba *et al.* (1986)
24906	30	33	4		

*Based on original data supplied by R. Day (pers. comm.)

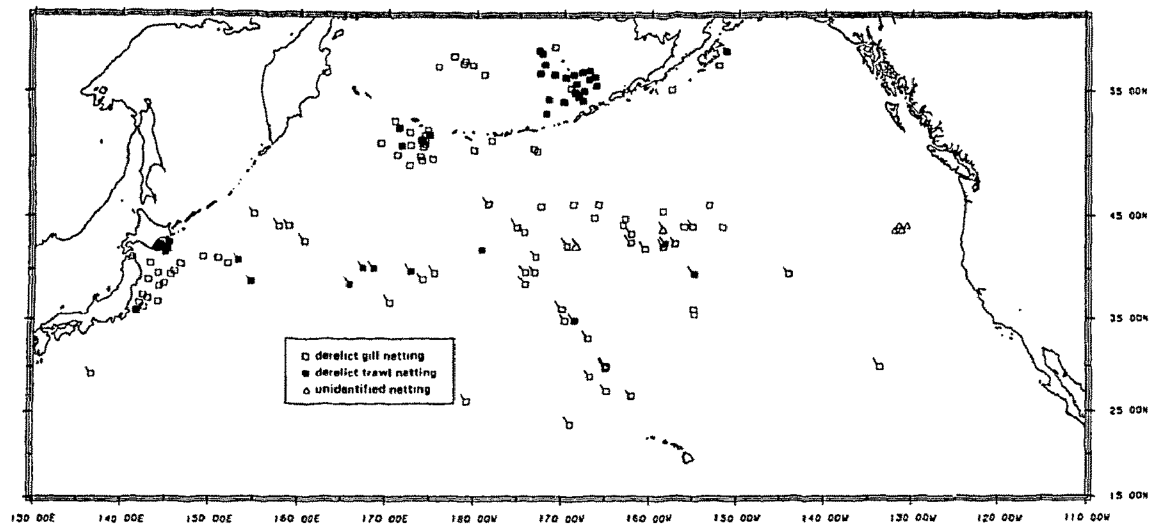

Fig. 6 The recorded occurrence of netting debris in the North Pacific Ocean. Simple symbols are for data from the surveys summarized in Table 2. (For details on cruise tracks see references cited in Table 2.)

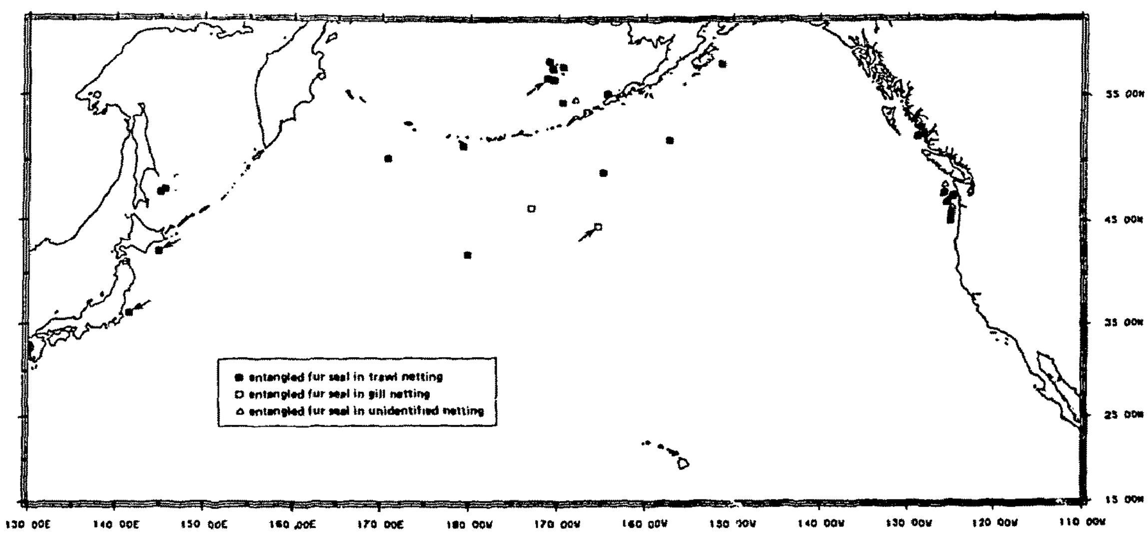

Fig. 7 Occurrence of entangled fur seals recorded in the North Pacific Ocean away from rookery areas. The four seals sighted during surveys (Table 2) are identified with arrows (from Scordino *et al.*, in prep.; the references for Table 2; and records at the National Marine Mammal Laboratory).

TABLE 3
Summary of data on entangled seals sighted* in areas other than on rookeries and haulout areas (based on data presented in Scordino *et al.*, in press, and records on file with the National Marine Mammal Laboratory).

Date	Sex	Debris size	Debris type	Animal's condition
15 Mar. 67	Male	≥ 0.5 kg	Trawl	Dead
Dec. 67	Female	–	–	Alive
30 Jan. 68	Female	–	–	Alive
21 Feb. 70	Female	≥ 0.5 kg	Trawl	Dead
29 Apr. 70	–	≥ 0.5 kg	Trawl	Alive
31 Dec. 70	–	–	Trawl	Alive
4 Aug. 71	–	< 0.5 kg	Trawl	–
13 July 78	–	–	Gill net	–
9 July 80	–	–	Trawl?	–
8 Dec. 80	Male	–	Trawl	Dead
20 June 81	–	≥ 0.5 kg	Trawl	Two alive
28 Feb. 82	–	≥ 0.5 kg	Trawl	Dead
Mar. 82	Female	–	Trawl	Dead
7 Apr. 82	Female	< 0.5 kg	Trawl	Dead
10 May 82	–	≥ 0.5 kg	Trawl	Dead
19 June 82	–	< 0.5 kg	Gill net	–†
7 July 82	Male	–	Trawl	–†
2 Aug. 82	Female	–	Trawl	Dead
22 Sept. 82	–	≥ 0.5 kg	Trawl	Dead
18 Nov. 82	–	≥ 0.5 kg	Trawl	Three alive
5 Dec. 83	Female	≥ 0.5 kg	Trawl	–
29 Feb. 84	Male	< 0.5 kg	Trawl	–
26 July 84	–	< 0.5 kg	Trawl	Alive
19 Sept. 84	–	–	–	Dead
22 Dec. 84	–	≥ 0.5 kg	–	Alive
19 July 85	Male	≥ 0.5 kg	Trawl	Dead†
26 Aug. 85	Male	≥ 0.5 kg	Gill net	Dead†
13 May 86	–	≥ 0.5 kg	Trawl	Dead

*These sightings fall into various categories. Some were obtained during pelagic research (some pertaining to fur seals and some to other species). Some are the result of records kept on strandings observed along the coast of the eastern Pacific. Others are incidental sightings made near the Pribilofs but not on land or at rookery areas.
†These animals are represented also in Table 2.

were reported by Jones & Ferrero (1985) as sighted under conditions for which there was no measure of the distance covered. These data included four pieces of trawl net and 20 pieces of gill net and the three entangled seals (two of which were entangled in one piece of trawl net). Combining the Jones & Ferrero (1985) observations with data in Table 2, we see that six seals have been observed in 34 pieces of trawl webbing debris (17.6%). If we restrict the calculation to the more controlled conditions of active pelagic surveys (Table 2), then three seals have been observed in 30 pieces of trawl webbing (10%).

Entangled seals and debris have been found over widespread and overlapping areas (Figs. 6, 7). These areas represent a large part of the distribution of the northern fur seal. More study is needed in the eastern part of the North Pacific, roughly the Gulf of Alaska and waters to the south. This area has not been covered by surveys such as those shown in Table 2, but it includes an eastern extension of the zone of concentrated debris noted by Dahlberg & Day (1985). Northern fur seals pass through this area during migration, and other parts of this region of the North Pacific are also used presumably for foraging (especially by young animals). See Kajimura (1984) for a treatment of the general distribution of northern fur seals.

The debris seen at sea, whether on entangled fur seals or simply floating, generally consists of pieces larger than those observed on entangled animals on land (more than 4 m^2, or 0.5 kg). Thirteen of the 18 entangled seals observed at sea (for which there are data on the size of entangling debris) were found in pieces larger than 0.5 kg (Table 3). Of 11 pieces of debris sighted at sea during surveys by Yoshida & Baba (1985a, b) 8 were over 0.5 kg. Eight of 13 trawl net fragments for which Baba *et al.* (1986) report weights were over 0.5 kg. Jones & Ferrero (1985) suggest that the predominant sighting of large pieces at sea may result merely from large pieces having a greater probability of being sighted. Such may be the case for both seals and human observers. Well over half of the trawl debris sighted on land weighs more than 0.5 kg (Fig. 2).

The incidence of fur seals entangled in derelict fragments of gill nets appears to be low (about 2% of all entangled seals seen on land) but may not be negligible (Table 1). At least three of 24 entangled animals seen at sea (12.5%; Table 3) were entangled in gillnetting (as distinct from those in trawl netting). One of these, a dead male fur seal reported by Ignell (1985), was entangled in a large (40 m×9 m) piece of gill net. In the pelagic surveys from the central and western Pacific, gill-net fragments were sighted in higher frequencies than trawl net material. For example, Jones & Ferrero (1985) reported 20 gillnet fragments and 4 trawl net fragments in the western and northern Pacific and southwestern Bering Sea. It seems likely that some fur seals become entangled in gillnetting, the pieces of which are generally very large, and then cannot return to the Pribilof Islands. This possibility is supported by the lower proportion of seals observed entangled in gill-net fragments on land (2%) than at sea (12.5%). Entanglement in derelict gill nets, therefore, needs further investigation.

Although the ease of collecting information for the male portion of the population (especially juvenile males from the harvest and on hauling grounds) has led to a male bias in the data for entanglement in fur seals (e.g. Table 1), entanglement does involve animals of both sexes. Of 13 animals observed entangled away from the primary breeding areas and for which the sex of the animal was recorded (Table 3), 7 were identified as females. Studies using captive animals (Yoshida *et al.*, 1985) also indicate that both males and females become entangled. Entangled pups of both sexes are observed on the Pribilof Islands, and surveys of rookeries have shown that entanglement of older animals also involves females as well as males (DeLong *et al.*, in prep.).

The Effects of Entanglement on Seals

Entanglement in trawl netting debris increases the drag on an animal as it swims through water, thus increasing the energy required to move about and capture prey. Feldkamp (1985) has shown that, at normal swimming speeds, the energy requirement for a California sea lion (the size of an average adult female fur seal) entangled in a piece of net of about 400 g was about four times that of the same sea lion when not entangled by debris. On St. Paul Island in 1985, field studies were conducted on female fur seals entangled in

100 g pieces of trawl netting. Of 17 females observed in this study, 9 failed to return to their pups after making four or fewer trips; those that did return spent about twice as much time at sea (DeLong *et al.*, in prep.) as did non-entangled (i.e. control) females.

Many entangled seals observed over the years have had lacerations and infections caused by the entangling debris, usually on the neck (Scordino & Fisher, 1983). Occasionally, entangled animals (tagged for identification) with severe lacerations have been observed a year later without debris, apparently healthy (Scordino, 1985). Some survive with the same severe lacerations for over a year. However, a proportion of these animals die from causes associated with entanglement. Thirteen of 22 entangled seals observed away from rookery and haulout areas were dead (Table 3). Entangled pups observed in larger pieces of debris during surveys conducted in 1985 were often dead and decomposing (DeLong *et al.*, in prep.); and if alive, they appeared to be exhausted. Mortality probably results from starvation (from the inability to capture prey), strangulation, infection, severed carotid arteries, drowning, increased vulnerability to predation, or combined effects.

Entanglement-caused mortality may be a principal cause contributing to the current decline in the fur seal population on the Pribilof Islands (Fowler, 1985a, b). Figure 8 shows the estimated number of pups born annually during 1950–1985. The solid line represents this data smoothed by a running mean of three years (to reduce normal interannual variability). The annual percentage changes in the smoothed data are correlated (Fig. 9) with the entanglement rates (Fig. 1) observed 6 years earlier. Six years is the approximate age of recruitment to the breeding female population (York, 1983). Note that as the entanglement rate rose to its peak in 1974 and 1975 (Fig. 1) the rate of decline in fur seal pup numbers increased to its highest value in the late 1970s (Fig. 8). Following 1980 the rate of decline is somewhat less, corresponding to entanglement rates which returned to about 0.4% (Fig. 1). The intercept of the regression line relating these two variables (Fig. 9) indicates that the rate of increase in population numbers expected at the entanglement rate of zero is the same as that observed in the early 1920s when the population was last observed at current levels (Fowler, 1985a).

Prior to 1965, before the entanglement rates began to rise (Fig. 1), the survival of 0- to 2-year old male pups at sea was correlated directly with pup survival on land (Lander, 1981). Since 1965, however, the survival of pups at sea has declined relative to survival on land (Fowler, 1985a). Figure 10 illustrates the correlation between observed annual entanglement rates (Fig. 1) and this deviation of observed at-sea survival from that predicted using observed on-land survival and the regression of pre-1965 data. The data shown (Fig. 10) represent the period 1967 to 1981, and the survival data are lagged by 2 years to coincide with the applicable rate of entanglement. This relationship suggests that at zero entanglement there would be essentially no extra mortality (the intercept of Fig. 10); in other words, mortality during the first 2 years of life would be expected to be that predicted for current population levels if there were no entanglement. The slopes and intercepts of these two correlations, therefore, are consistent with the hypothesis that entanglement-caused juvenile mortality is the major factor contributing to current declining population trends. Furthermore, estimates of mortality caused by entanglement (e.g., Fowler, 1985a) are consistent with the rate of decline observed in the population as determined from simulation models (Swartzman, 1984). Scordino (1985) reported data showing that 25% of juvenile male seals entangled in small debris (tagged and released) returned to St. Paul Island the following year. A comparable rate of return reported by Griben (1979) for the general population of young males was 59%, which is statistically significantly different from Scordino's estimate ($p<0.05$). Scordino's and Griben's data can be used to estimate the annual survival of animals in small debris as 0.42 (=0.25/0.59). Using other methods and data from the harvest, Fowler (1985a) estimated the annual survival of similarly entangled animals to be about 0.46 ($p<0.05$). Both the 0.42 rate from the Scordino/Griben data and the 0.46 rate from Fowler (1985a) lead to the conclusion that a significantly higher mortality occurs among animals entangled in small debris (~ 400 g or less, Fig. 2). After applying

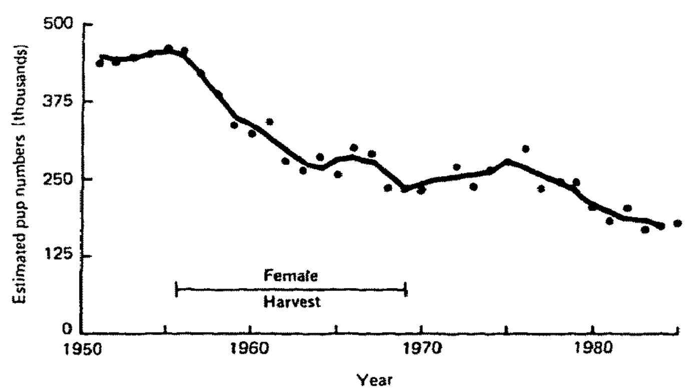

Fig. 8 The estimated numbers of fur seal pups born on St. Paul Island, Alaska, 1951–1985 (from NMFS files). The solid line is from a running mean of three.

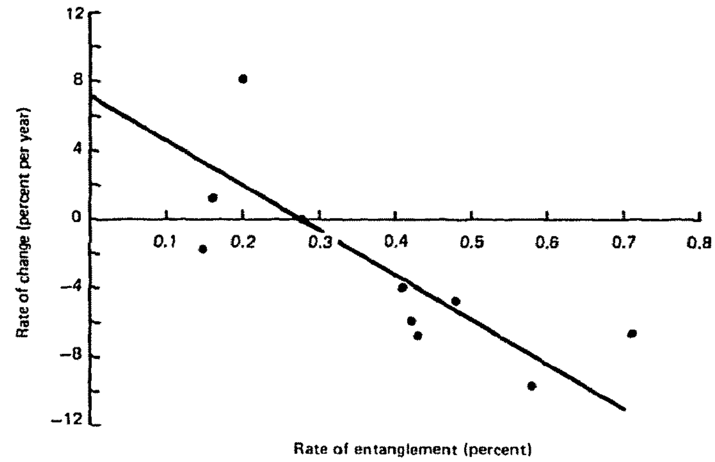

Fig. 9 The correlation between the rate of change in estimated numbers of fur seal pups (as determined from a running mean of three for 1972–1984) and the percent of juvenile males observed entangled 6 years earlier (1967–1977, R=0.77).

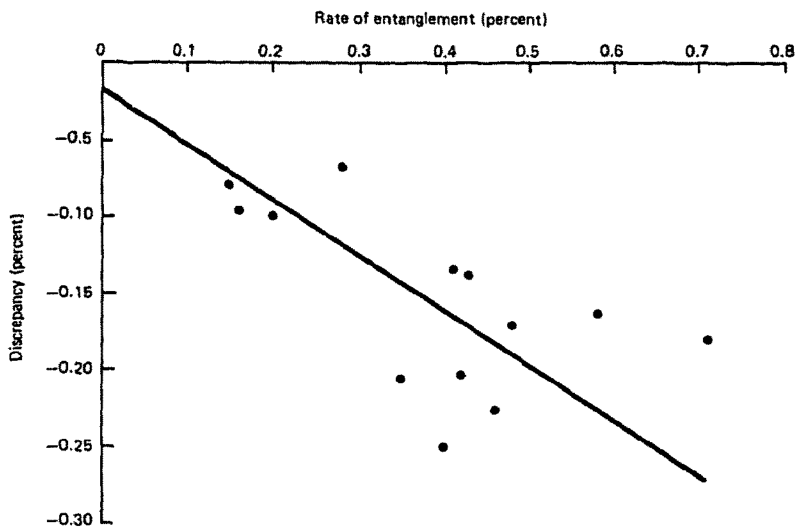

Fig. 10 The correlation of the discrepancy between predicted (from a previous correlation with pup survival on land) and observed survival rates of juvenile male fur seals (1966–1978) and percent of juvenile males observed entangled 1 year later (1967–1979) (for details concerning this analysis, see Fowler, 1985a, R=0.60).

correction factors for the size composition of debris, it was estimated that about 15% of young fur seals from the Pribilof Islands suffer from debris-related mortality (Fowler, 1985a). Fowler (1985a, b) also noted other factors indicating that the decline is due to entanglement-caused mortality, including a correlation between the rates of change in adult male numbers and observed entanglement rates (from the commercial harvest).

Discussion

During their autumn through spring migration most northern fur seal females and juveniles travel from the Pribilof Islands to as far south as southern California (Kajimura, 1984), a roundtrip distance of more than 8000 km. About one-half of the waters traversed in this migration are in the northern part of the range where significant numbers of trawl net fragments occur, as based on surveys mentioned earlier and the distribution of fishing effort. Data indicate that the bulk of groundfish trawl fishing is in the Bering Sea and Gulf of Alaska with about 80% of the Bering Sea effort in the eastern Bering Sea (Fredin, 1985). Since the population of fur seals on San Miguel Island does not exhibit entanglement rates comparable to those seen on the Pribilof Islands (NMFS data) and presumably does not migrate as far north as the seals from the Pribilof Islands, trawl material is presumably less abundant in the southern half of the species' range.

The average seal from the Pribilof Islands is estimated to travel well over 8000 km per year in the areas thought to contain significant numbers of trawl net fragments [illegible]ing the distances travelled between foraging [illegible] during migration, and during time spent at the [illegible] foraging areas. If we assume 1. that the encou[illegible] trawl debris in the ocean is comparable to that [illegible]erved during surveys (0.66–3.13 pieces per 1000 km), and 2. that seals will detect and thereby encounter debris at the same rate observed from ships, then the average female or juvenile seal in the eastern North Pacific is expected to encounter 3–25 pieces of trawl debris in the average year (with the encounter rates of the eastern Bering Sea and Gulf of Alaska being toward the higher end of the range). Of these pieces, over 30% are expected to be of a mesh size in which young seals can become entangled (fragments above 15 cm, Fig. 3).

The populations of northern fur seals of the western Pacific (breeding on the Commander Islands, Robben Island, and the Kuril Islands) are relatively stable or declining only very slowly in comparison to that of the Pribilof Islands. Although the sample sizes are small, the lower rate of encounter for debris in the western Pacific (0.657 pieces per 1000 km) compared to the eastern Bering Sea (1.736–3.13 per 1000 km) may result in less entanglement-related mortality and less of an effect on the population. Such differences would be anticipated on the basis of the distribution of fishing effort which shows a concentration in the eastern Bering Sea (Fredin, 1985).

Close comparison of Soviet data on fur seal entanglement in the western North Pacific to the data reported here for the eastern North Pacific would be of significant scientific value. Unfortunately, the methods used by the Soviets to determine entanglement rates are different from the methods used to produce the rates determined for fur seals of the Pribilof Islands. The Soviet data include all seals observed entangled and hence are higher than the rates reported for the Pribilof Islands (which include only those observed entangled among those killed or counted). Assuming that the methods are the same for all islands of the western Pacific, however, the highest rates are those reported for Robben Island, where a decline has been in progress since the mid-1960s. Thus on both sides of the Pacific, growing or stable populations (i.e. those in San Miguel and the Commander Islands) are associated with lower observed entanglement rates than those observed for declining populations (Robben Island and the Pribilof Islands).

Fur seals are attracted to objects in the water and often insert their heads through holes. Fiscus & Kajimura (1965, 1967) report pelagic observations of seals on floating kelp mats, logs, and other objects. Research with captive animals (Yoshida *et al.*, 1985) has demonstrated their tendency to swim toward plastic packing bands and net fragments and insert their heads. This behaviour appears to be similar to that observed for pups which play with objects such as kelp in near-shore waters. As seen in studies with captive animals, some entangled seals are occasionally able to free themselves while others are not. Although there seems to be deceptively little debris in the pelagic environment (in terms of density), synthetic fishing debris does evidently pose a hazard to northern fur seals. Evidence for this is seen in the degree to which mortality attributable to entanglement correlatively accounts for current declining trends (e.g., Figs. 9, 10; Fowler, 1985a). Only a fraction (less than 5%) of the contacts between animals and debris at the rates mentioned above need result in entanglement and death to contribute significantly to or cause the decline. Further evidence of the hazard is provided by the animals observed entangled (both dead and alive) at sea. Most of those caught in large debris apparently find it impossible to swim effectively and cannot return to the breeding islands. Although at present we do not know the rate of entanglement among juvenile animals at sea, the reasons for concern are obvious.

Solutions to the problem of ocean debris and its effect on northern fur seals and other species of marine life (Shomura & Yoshida, 1985) are elusive and many of those that have been suggested are difficult to implement. Educational programmes are currently being used to inform fishermen of the hazards debris poses to wildlife. Fishermen may quickly appreciate these hazards because fishing vessels are occasionally disabled when netting debris fouls their propellors. Removal of debris from beaches may be possible in some areas, but it is not clear whether such cleanup efforts would have an impact on the oceanic distribution of debris over large geographic scales. The development and use of degradable materials in fishing nets have begun and may provide a reasonable approach to reduce the hazard of debris at sea.

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Baba, N., Yoshida, K., Onoda, M., Nagai, N. & Toishi, S. (1986). Research on ocean current and drifting stray fishing gear and net fragments in the area southwest of the Pribilof Islands and the southern coast of the Aleutian Islands, July–Aug. 1985. Report of the Far Seas Fisheries Research Laboratory, Shimizu, Japan.

Bengtson, J. L., Fowler, C. W., Kajimura, H., Merrick, R., Nomura, S. & Yoshida, K. (in prep.). Fur seal entanglement studies: Juvenile males and newly-weaned pups, St. Paul Island, Alaska. In *Fur Seal Investigations, 1985.* (P. Kozloff, ed.) US Dep. Commer., NOAA Tech. Memo. Seattle, WA.

Bigg, M. A. (1979). Incidence of adult northern fur seals entangled in debris on St. Paul Island, 1978. Pacific Biological Station, Nanaimo, British Columbia, V9R SK6, Canada.

Dahlberg, M. L. & Day, R. H. (1985). Observations of manmade objects on the surface of the North Pacific Ocean. In *Proceedings of the Workshop on the Fate and Impact of Marine Debris,* 26–29 November 1984, Honolulu, Hawaii (R. W. Shomura & H. O. Yoshida, eds), pp. 198–212. US Dep. Commer. NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-54.

DeLong, R. L., Dawson, P. & Gearin, P. J. (in prep.). Incidence and impact of entanglement in netting debris on northern fur seal pups and adult females, St. Paul Island, Alaska. In *Fur Seal Investigations, 1985*. (P. Kozloff, ed.). US Dep. Commer., NOAA Tech. Memo.
Feldkamp, S. (1985). The effects of net entanglement on the drag and power output of a California sea lion, *Zalophus californianus*. *Fish. Bull.* 83, 692–695.
Fiscus, C. H. & Kajimura, H. (1965). Pelagic fur seal investigations, 1964. US Dep. Inter., US Fish Wildl. Serv., Spec. Sci. Rep. Fish. No. 522.
Fiscus, C. H. & Kajimura, H. (1967). Pelagic fur seal investigations, 1965. US Dep. Inter., US Fish. Wildl. Serv., Spec. Sci. Rep. Fish. No. 537.
Fiscus, C. H. & Kozloff, P. (1972). Fur seals and fish netting. In *Fur Seal Investigations, 1971*. Unpubl. rep. Natl. Mar. Mammal Lab., Northwest Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98115.
Fowler, C. W. (1982). Interactions of northern fur seals and commercial fisheries. *Trans. N. Am. Wildl. Nat. Resour. Conf.* 47, 278–292.
Fowler, C. W. (1984) Entanglement in fishing debris as a contributing factor in the decline of northern fur seals on the Pribilof Islands. Natl. Mar. Mammal Lab., Northwest Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98115.
Fowler, C. W. (1985a). An evaluation of the role of entanglement in the population dynamics of northern fur seals on the Pribilof Islands. In *Proceedings of the Workshop on the Fate and Impact of Marine Debris*, 16–29 November 1984, Honolulu, Hawaii (R. S. Shomura & H. O. Yoshida, eds), pp. 291–307. US Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFC-54.
Fowler, C. W. (1985b). Status Review: Northern Fur Seals (*Callorhinus ursinus*) of the Pribilof Islands, Alaska. Natl. Mar. Mammal. Lab., Northwest Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98115.
Fowler, C. W., Scordino, J., Merrell, T. R. & Kozloff, P. (1985). Entanglement of fur seals from the Pribilof Islands. In *Fur Seal Investigations, 1982* (P. Kozloff, ed.), pp. 22–33. US Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-71.
Fredin, R. A. (1985). Fishing effort by net fisheries in the North Pacific Ocean and Bering Sea since the 1950's. In *Proceedings of the Workshop on the Fate and Impact of Marine Debris*, 16–29 November 1984, Honolulu, Hawaii (R. S. Shomura & H. O. Yoshida, eds), pp. 218–251. US Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFC-54.
Griben, M. R. (1979). A study of the intermixture of subadult male fur seals *Callorhinus ursinus* (Linnaeus, 1785) between the Pribilof Islands of St. George and St. Paul, Alaska. M.Sci. Thesis, Univ. Washington, Seattle.
Ignell, S. E. (1985). Results of the 1985 research on the high-seas squid driftnet fisheries of the North Pacific Ocean. Document submitted to the International North Pacific Fisheries Commission, Tokyo, Japan, November 1985.
Jones, L. & Ferrero, R. C. (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 (R. S. Shomura & H. O. Yoshida, eds), pp. 183–196. US Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-SWFC-54.
Kajimura, H. (1984). Opportunistic feeding of the northern fur seal, *Callorhinus ursinus*, in the eastern North Pacific Ocean and eastern Bering Sea. US Dep. Commer., NOAA Tech. Rep. NMFS SSRF-779.
Lander, R. (1981). A life table and biomass estimate for Alaskan fur seals. *Fish. Res.* 1, 55–70.
Lenarz, W. (1985). Theoretical first approximations of densities of discarded webbing in the eastern North Pacific Ocean and Bering Sea. In *Proceedings of the Workshop on the Fate and Impact of Marine Debris*, 26–29 November 1984, Honolulu, Hawaii (R. S. Shomura & H. O. Yoshida, eds), pp. 213–219. US Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFC-54.
Merrell, T. R. (1980). Accumulation of plastic litter on beaches of Amchitka Island, Alaska. *Mar. Environ. Res.* 3, 171–184.
Merrell, T. R. (1985). Fish nets and other plastic litter on Alaska beaches. In *Proceedings of the Workshop on the Fate and Impact of Marine Debris*, 26–29 November 1984, Honolulu, Hawaii (R. S. Shomura & H. O. Yoshida, eds), pp. 160–182. US Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFC-54.
Sanger, G. A. (1974). On the effect of fish net scraps and other oceanic debris in northern fur seals. Background paper submitted to the 17th Annual Meeting of the Standing Scientific Committee of the North Pacific Fur Seal Commission.
Scheffer, V. B. (1950). Experiments in the marking of seals and sea-lions. US Dep. of Int. Spec. Sci. Rep. Wildl. No. 4.
Scordino, J. (1985). Studies on fur seal entanglement, 1981–1984, St. Paul Island, Alaska. In *Proceedings of the Workshop on the Fate and Impact of Marine Debris*, 26–29 November 1984, Honolulu, Hawaii (R. S. Shomura & H. O. Yoshida, eds), pp. 278–290. US Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFC-54.
Scordino, J., & Fisher, R. (1983). Investigations on fur seal entanglement in net fragments, plastic bands and other debris in 1981 and 1982, St. Paul Island, Alaska. (Background paper submitted to the 26th Annual Meeting of the Standing Scientific Committee of the North Pacific Fur Seal Commission. 28 March–8 April 1983, Washington D.C.).
Scordino, J., Kajimura. H., Baba, N. & Furuta, A. (in prep.). Fur seal entanglement studies in 1984, St. Paul Island, Alaska. In *Fur Seal Investigations, 1985*. (P. Kozloff, ed.) US Dep. Commer., NOAA Tech. Memo.
Shomura, R. S. & Yoshida, H. O. (eds) (1985). *Proceedings of the Workshop on the Fate and Impact of Marine Debris*, 26–29 November 1984, Honolulu, Hawaii. US Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFC-54.
Swartzman, G. L. (1984). Factors bearing on the present status and future of the eastern Bering Sea fur seal population with special emphasis on the effect of terminating the subadult male harvest on St. Paul Island. US Mar. Mammal Comm., Washington, D.C.
York, A. (1983). Average age at first reproduction of the northern fur seal (*Callorhinus ursinus*). *Can. J. Fish. Aquat. Sci.* 2, 121–127.
Yoshida, K. & Baba, N. (1985a). Results of the survey on drifting fishing gear or fish net pieces in the Bering Sea. Far Seas Fisheries Research Laboratory, Shimizu, 424, Japan.
Yoshida, K. & Baba, N. (1985b). A survey of drifting stray fishing net in the northern Sea of Japan (Western Pacific Ocean). Far Seas Fisheries Research Laboratory, Shimizu, 424, Japan.
Yoshida, K., Baba, N., Nakajima, M., Fujimaki, Y., Furuta, A., Nomura, S. & Takahashi, K. (1985). Fur seal entanglement survey report: Test study at a breeding facility, 1983. Far Seas Fisheries Research Laboratory, Shimizu, 424, Japan.