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# A Decade of Change in Nets and Plastic Litter From Fisheries Off Alaska

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**Ten 1 km beaches on Amchitka Island, Alaska, were surveyed once annually in 1972–1974 and in 1982 to determine weights and numbers of fish-net fragments and other plastic litter items. Most litter was from Japanese and Soviet fishing vessels. Litter rapidly increased during 1972–74 (from 122 to 345 kg km$^{-1}$ of beach) but decreased 26% by 1982 to 255 kg km$^{-1}$. There was a 37% reduction in weight of trawl web on Amchitka beaches, and the number of gill-net floats declined 47%. The decrease in litter between 1974 and 1982, attributed to fewer trawlers and gill-netters fishing off Alaska, shows that marine litter could be rapidly reduced if disposal of litter at sea were restricted.**

Plastic litter discarded at sea entangles and kills marine mammals, birds and fish, disables ships, and aesthetically degrades beaches. In a comprehensive assessment of global marine litter, the United States National Academy of Sciences (1975) estimated that $6.4 \times 10^6$ t of litter, concentrated unevenly in the Northern Hemisphere, is discarded annually into the world's oceans. Surprisingly, there have been few studies to determine the quantities, sources and rates of accumulation and disappearance of litter. Most studies of plastic litter pollution have been limited to short-term observations from ships of floating debris (Venrick *et al.*, 1973; Colton *et al.*, 1974; Wong *et al.*, 1974; Shaw & Mapes, 1979; Morris, 1980; Dixon & Dixon, 1983) or one-time beach surveys of stranded litter (Scott, 1972; Winston, 1982; Shiber, 1982; Gregory, 1983).

This paper compares surveys of plastic litter accumulations on beaches at Amchitka Island, Alaska, in 1982 with surveys that I made on the same island 8–10 yr earlier (Merrell, 1980) and discusses the relationship between this litter and its main source, commercial fisheries.

Amchitka Island, one of the western Aleutian Islands, is far from populated areas: about 2400 km west of Anchorage, Alaska, and 1100 km east of the nearest Asian mainland. Surface currents in both the northern

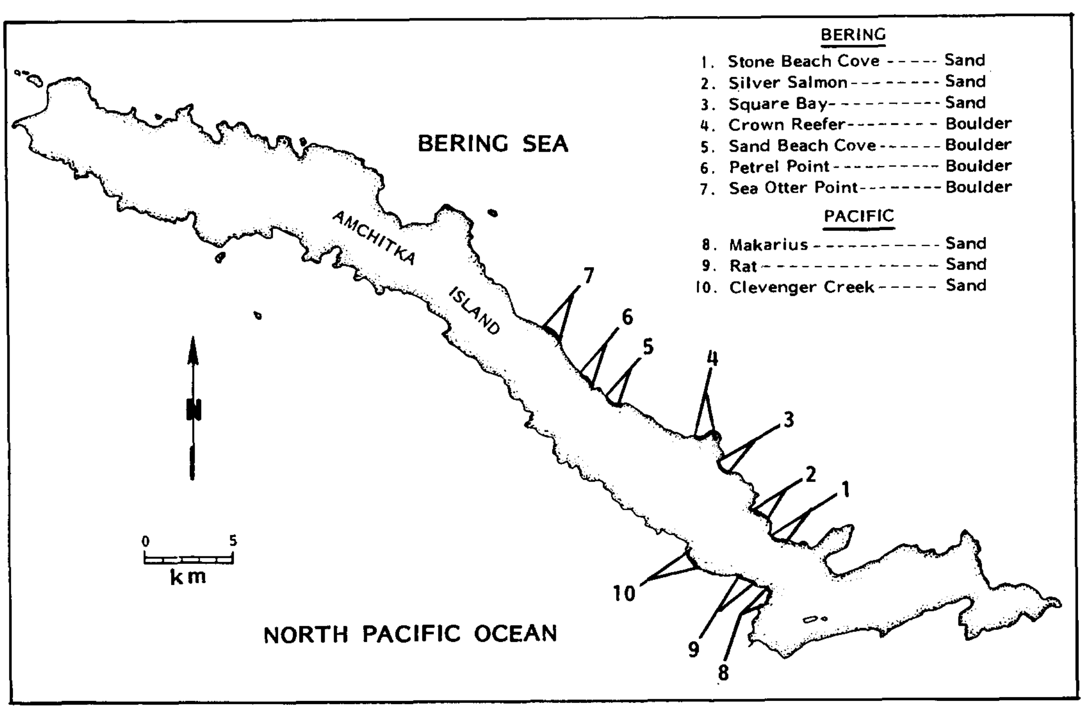


**Fig. 1** Locations of beaches surveyed for plastic litter on Amchitka Island.

North Pacific Ocean and the Bering Sea (see McAlister & Favorite, 1977) transport litter discarded at sea to Amchitka Island; thus, accumulations of litter on Amchitka beaches provide a measure of litter from a large, sparsely populated area.

Most litter on Amchitka beaches is from Japanese and Soviet fishing vessels (Feder *et al.*, 1978; Merrell, 1980). In the early 1970s, I estimated that their fleets discarded or lost 1664 t of plastic litter annually (Merrell, 1980) and found that accumulation of litter on Amchitka beaches was increasing at an alarming rate: within the period 1972–74, the weight of litter increased 2.8 times from 122 kg $km^{-1}$ to 345 kg $km^{-1}$ of beach, and the number of items increased 2.6 times from 193 items $km^{-1}$ to 499 items $km^{-1}$. To determine whether this dramatic increase in beach litter was continuing and whether the composition of litter had changed since 1974, I resurveyed the same beaches in 1982. Between 1972 and 1982, areas open to fishing off Alaska were reduced, and the number of vessels declined, so I expected less litter on Amchitka Island in 1982 than in 1974.

## Methods

Ten beaches, each 1 km long, were surveyed once annually from 1972 to 1974 and in 1982. Three of the ten beaches were on the Pacific (south-western) shore, and seven were on the Bering Sea (north-eastern) shore of the Island. Six beaches were sand, and four were primarily boulders (Fig. 1). Data for all 10 beaches were combined because accumulations of litter were not consistently different for sand or boulder beaches or for Bering Sea or North Pacific exposure (Merrell, 1980).

I used the same methods in 1982 as in the 1972–74 surveys. To minimize sampling variability, I made all the surveys. One observer can easily survey an entire beach from the edge of the water to the lower edge of terrestrial vegetation because the tidal range at Amchitka Island is slight (about 2 m annual maximum), and beaches have a moderate to steep gradient. I recorded all plastic litter items visible from walking height, i.e. anything larger than about 5 mm.

Small fragments of trawl web were weighed on a hand-held spring scale; weights of large wads too heavy to lift were estimated. Representative examples of other litter items were weighed to obtain an average weight, and total weight of that item was estimated by multiplying the mean weight by the frequency of occurrence on all the beaches. Lengths of each piece of each size of synthetic-fibre rope were estimated, and the total weight determined by multiplying the estimated length by the weight per unit length given in a rope specification chart (Wall Rope Works–New Bedford Cordage Co., Beverly, New Jersey, USA). For litter partially buried in kelp, driftwood, sand or cobbles, I estimated the weight of only the visible portion; therefore, only part of total litter present was included in the surveys. Types of litter on the same beach were similar in all years, but quantities of each type varied widely between beaches (Merrell, 1980).

## Changes in Litter Composition Since 1974

With minor exceptions, the proportions of different litter items were the same in 1982 as in 1972–74. Hundreds of kinds of plastic items were found, but only

**TABLE 1**

Weight and number per kilometre of 23 most common items of plastic litter on ten 1 km beaches on Amchitka Island 1972–74 and 1982 (* indicates commercial fishing gear)

| Item | Kilograms per kilometre | | | | Number per kilometre | | | |
|---|---|---|---|---|---|---|---|---|
| | 1972 | 1973 | 1974 | 1982 | 1972 | 1973 | 1974 | 1982 |
| *Trawl web | 103.87 | 122.15 | 271.75 | 171.27 | 12.3 | 16.7 | 23.7 | 34.0 |
| *Trawl floats | 4.70 | 10.09 | 18.25 | 19.55 | 1.7 | 5.2 | 5.0 | 5.4 |
| *Rope† | 6.21 | 13.20 | 36.08 | 14.30 | 10.1 | 20.0 | 25.9 | 24.5 |
| *Inflatable buoys | — | — | — | 5.94 | — | — | — | 2.0 |
| Beverage crates | 0.19 | 0.96 | 1.91 | 3.40 | 0.1 | 0.5 | 1.0 | 1.7 |
| *Gill-net floats | 3.15 | 4.44 | 6.03 | 2.82 | 65.6 | 92.5 | 125.6 | 58.7 |
| *Bulk liquid containers | 0.53 | 0.92 | 3.21 | 2.10 | 1.2 | 1.9 | 5.4 | 1.5 |
| Bottles | 0.77 | 1.30 | 2.47 | 1.90 | 12.6 | 23.1 | 45.3 | 38.0 |
| Plastic fragments | 0.12 | 0.23 | 0.57 | 1.09 | 33.5 | 64.0 | 137.4 | 305.0 |
| *Fish baskets | 1.08 | 2.14 | 3.03 | 1.08 | 1.0 | 1.2 | 1.7 | 1.0 |
| *Polyvinyl sponge floats | 0.16 | 0.18 | 0.54 | 0.40 | 2.3 | 2.6 | 8.0 | 1.6 |
| Sandals | 0.36 | 0.22 | 0.31 | 0.30 | 3.0 | 1.8 | 2.6 | 2.5 |
| Pails | 0.20 | 0.22 | 0.44 | 0.23 | 1.1 | 1.3 | 2.6 | 1.0 |
| *Crab bait containers | 0.01 | 0.04 | 0.12 | 0.23 | 0.1 | 0.5 | 1.6 | 1.2 |
| Lids and tops | 0.07 | 0.07 | 0.14 | 0.18 | 11.9 | 13.0 | 25.0 | 33.2 |
| *Chemical ampules | 0.04 | 0.04 | 0.13 | 0.14 | 3.0 | 2.9 | 9.0 | 9.9 |
| Cups and bowls | 0.09 | 0.08 | 0.12 | 0.11 | 2.1 | 1.9 | 2.9 | 2.7 |
| *Strapping | 0.05 | 0.05 | 0.11 | 0.092 | 30.1 | 32.0 | 70.7 | 57.6 |
| *Outboard oil containers | 0.035 | 0.06 | 0.12 | 0.035 | 0.6 | 1.1 | 2.0 | 0.6 |
| Six-pack yokes | 0.003 | 0.006 | 0.01 | 0.023 | 0.6 | 1.1 | 2.0 | 4.5 |
| Cigarette lighters | 0 | 0 | 0 | 0.022 | 0 | 0 | 0 | 1.1 |
| Cap visors | 0.003 | 0.005 | 0.018 | 0.013 | 0.1 | 0.2 | 0.7 | 0.5 |
| Shotgun cases | 0.002 | 0.002 | 0.003 | 0.007 | 0.2 | 0.2 | 0.3 | 0.7 |
| Total | 121.64 | 156.42 | 345.42 | 255.23 | 193.2 | 283.1 | 498.4 | 588.9 |
| Total excluding plastic fragments | 121.52 | 156.19 | 344.85 | 254.14 | 159.7 | 219.1 | 361.0 | 283.9 |

†Length per kilometre: 1972, 255 m; 1973, 501 m; 1974, 802 m; 1982, 565 m.

23 items were found five or more times during 1982 surveys (Table 1). Twelve items were used in commercial fishing; most of the other items were probably garbage discarded from fishing vessels. Garbage from vessels is a world-wide pollution problem (Horsman, 1982) that has not been effectively resolved despite efforts to regulate garbage disposal at sea (International Maritime Organization, 1983; Gill, 1982).

## Relationship Between Beach Litter and Commercial Fishing

Although there clearly is a relationship between litter on the beaches of Amchitka Island and its fishery sources, data from my annual surveys can be used to draw only general inferences because information is lacking on time elapsed between litter discard and stranding, quantity of litter lost or discarded in any year, fishing effort, and influence of winds and currents on distribution of litter.

Principal fisheries in the Bering Sea and northern North Pacific Ocean are a Japanese gill-net fishery for salmon (*Oncorhynchus* spp.) and trawl fisheries for Pacific ocean perch *(Sebastes alutus)*, walleye pollock *(Theragra chalcogramma)*, Pacific cod *(Gadus macrocephalus)*, and several species of flatfish (Merrell, 1977; Forrester *et al.*, 1978).

As a result of extension in 1976 of the United States fishery jurisdiction from 19 km (12 miles) offshore to 322 km (200 miles), the number of foreign trawlers off Alaska declined 66% from 706 trawlers in 1972 (the year with the maximum number) to 232 trawlers in 1982 (Fig. 2) (J. C. Hammond, pers. comm.). The reduction in number of trawlers was primarily a result of fewer Soviet vessels—from a peak of 377 in 1972 to six in 1982.

The trawl fishery is the source of enormous quantities of trawl web on Amchitka beaches. The decline in the number of foreign trawlers off Alaska since 1976 coincided with a 37% reduction in trawl-web accumulations on the sample areas of Amchitka beaches, from 272 kg $km^{-1}$ in 1976 to 171 kg $km^{-1}$ in 1982 (Fig. 2; Table 1).

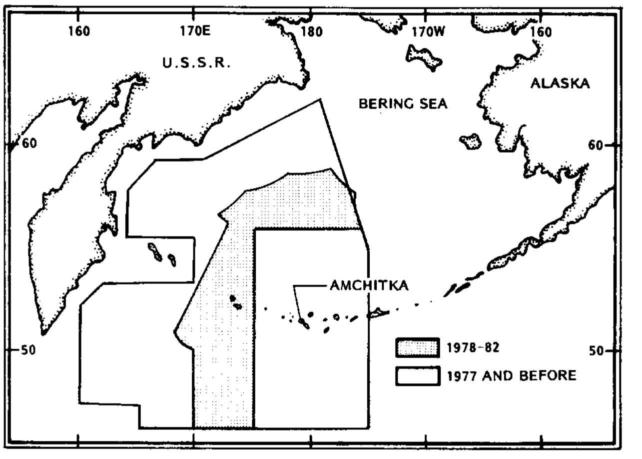


**Fig. 3** Areas where Japanese gill-netters fished in 1952–77 and 1978–82.

The number of high seas gill-netters has also been greatly reduced since my 1972–74 surveys because of negotiations between Japan and the USSR and between Japan, the United States, and Canada. In 1977, the USSR established a 322 km (200 miles) fishery conservation zone off its coast and thus closed a large area to Japanese gill-netting (Fig. 3). Also, under terms of the International Convention for the High Seas Fisheries of the North Pacific Ocean, the Japanese gillnet fishery was barred from another large area centred on the western Aleutians between 175°E and 175°W longitude and 56°–46°N latitude. In addition to area closures, the number of Japanese salmon gill-net boats was reduced 62% from a maximum of 447 boats in 1956 to 172 boats in 1980 (Fredin *et al.*, 1977; M. Dahlberg, pers. comm.).

The Japanese gill-net fishery is the source of gill-net floats, the most numerous item in all years. The dramatic decline in the number of gill-net floats on Amchitka between 1974 and 1982, from 126 floats $km^{-1}$ of beach to 59 floats $km^{-1}$ of beach, is the result of fewer gill-nets being fished (Fig. 4) and elimination of gill-netting from the Amchitka area (Fig. 3).

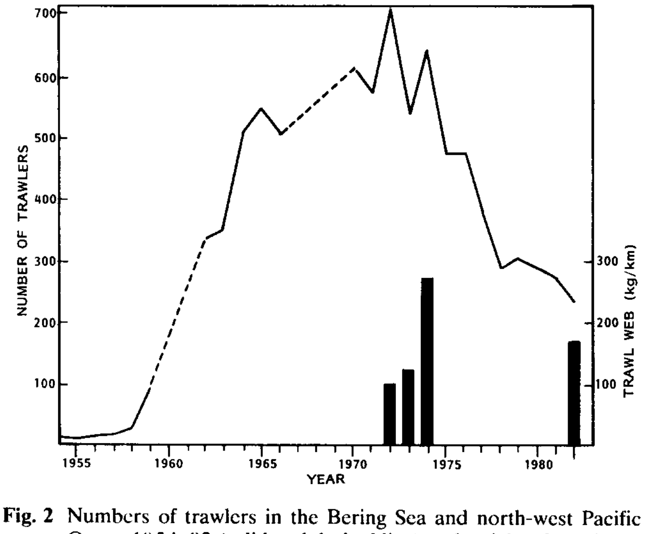


**Fig. 2** Numbers of trawlers in the Bering Sea and north-west Pacific Ocean 1954–82 (solid and dashed line) and weight of trawl web on Amchitka Island beaches (bars). Dashed lines are extrapolated for years with no Soviet trawl data. Source of data: 1954–59, Forrester *et al.* (1978); 1962–66, Chitwood (1969); 1970–82, J. C. Hammond (pers. comm.).

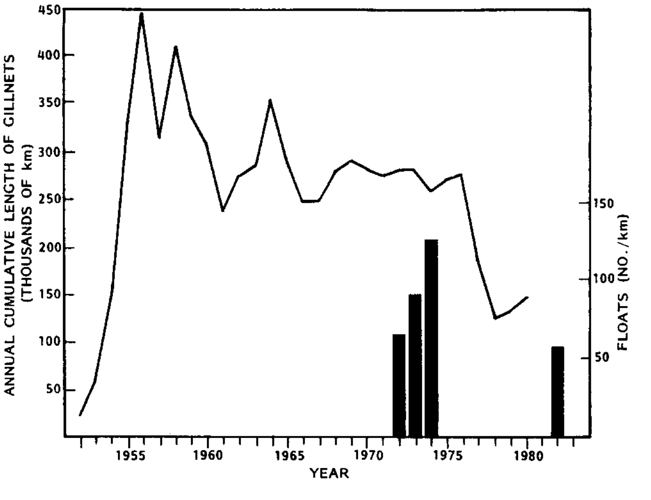


**Fig. 4** Cumulative length (days×kilometres) of Japanese gill-nets fished each year (line) and number of floats on Amchitka Island beaches 1972–74 and 1982 (bars). Sources of data: 1952–77, Fredin *et al.* (1977); 1978–80, M. Dahlberg (pers. comm.).

## Disappearance of Litter Items

Most litter, once stranded, stays ashore and is not redistributed: marked gill-net floats remained where first stranded (Merrell, 1980), and some distinctive items present in 1974 were in the same place in 1982. Although the total weight of plastic litter declined from 345 kg $km^{-1}$ to 255 kg $km^{-1}$ between 1974 and 1982, the number of items increased from 498 items $km^{-1}$ to 589 items $km^{-1}$ (Table 1). Hard items, weathered and battered by surf, disintegrate; thus, the number of fragments increased despite a reduction in strandings of whole items. If plastic fragments are eliminated from the analyses, decreases in both weight and number of plastic items are similar between 1974 and 1982: a 26% decline in weight and 21% decline in numbers.

In 1982, six of the seven litter items that made up 86% of the total weight of litter were commercial fishing gear (Table 1). The exceptions (Japanese beer and soft-drink crates) were probably discarded from fishing vessels. The weight of rope, trawl web, gill-net floats and bulk liquid containers decreased between 1974 and 1982, but weight of trawl floats, inflatable buoys and crates increased. To explain this inconsistency, I considered each item individually because different factors influence their disappearance rates.

*Trawl web*

Between 1974 and 1982, the number of trawl web fragments increased, but the average weight decreased more than 50%, from 11.5 to 5 kg per fragment. Apparently, fewer large fragments of damaged web were discarded recently than in earlier years. Trawl web, unlike hard plastics, resists weathering and abrasion and is eventually buried in sand and under boulders (Figs. 5 and 6). Some large fragments of web present during the 1972–74 surveys, but not found in 1982, had probably become completely or partially buried, also contributing to the reduced average weight of fragments found in 1982.

*Trawl floats*

These thick plastic spheres, averaging about 30 cm in diameter, are virtually indestructible and resist burial or being blown inland (Fig. 7). The total weight of trawl floats increased only slightly between 1974 and 1982 because, unlike most other litter in 1974, they were collected by workmen to make flower pots (Merrell, 1980). Thus, the number of trawl floats coming ashore was underestimated in my 1974 survey. Between 1974 and 1982, Amchitka Island was mostly uninhabited, so the slight increase in number of trawl floats in 1982 reflects an 8-yr accumulation and is consistent with the reduction in trawl fishing (Table 1).

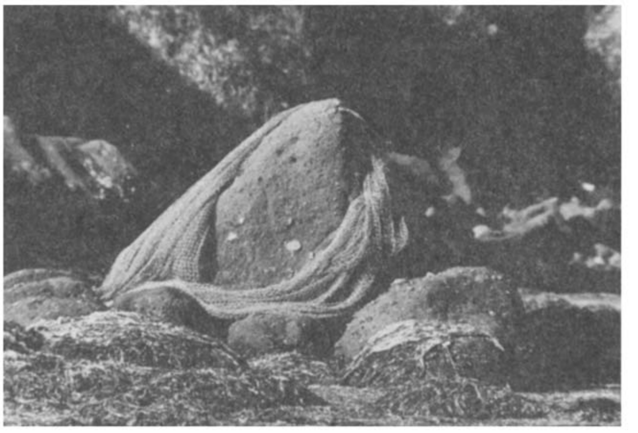

**Fig. 6** Large trawl web fragment draped over and between boulders.

**Fig. 7** Trawl float.

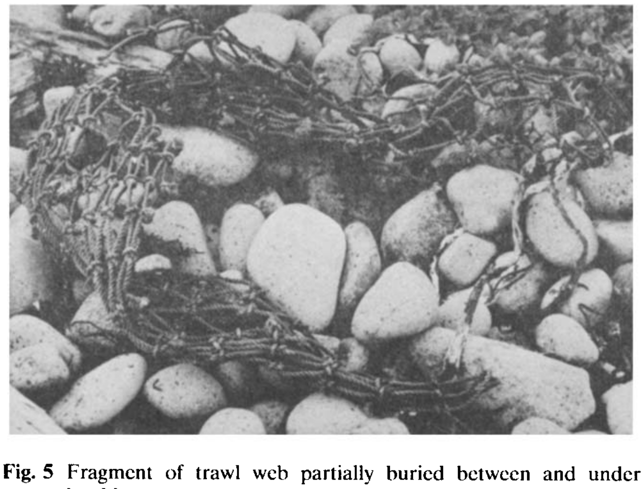

**Fig. 5** Fragment of trawl web partially buried between and under boulders.

*Synthetic-fibre rope*

Most rope was probably from trawl fisheries, although some was attached to inflatable buoys from the United States king crab *(Paralithodes kamschatica)* fishery. Between 1974 and 1982, the weight of rope on beaches decreased 60% (from 36 to 14 kg $km^{-1}$), and cumulative length of rope decreased 30% (from 802 to 565 m); however, the number of pieces remained almost the same (Table 1). An explanation is not apparent for the slight change in number of pieces despite the reduction in weight and length.

*Inflatable buoys*

All the inflatable buoys were from United States crab pots, as evidenced by State of Alaska registration numbers marked on them (Figs 8 and 9). Like trawl floats, they are prized by collectors, so my 1972–74

**Fig. 8** Inflatable buoy from US king crab fishery.

**Fig. 9** Inflatable buoy from the US king crab fishery and partially buried trawl web fragment.

surveys did not reflect their actual abundance (Merrell, 1980). Inflatable buoys are nearly indestructible and resist burial or being blown inland; therefore, those found in 1982 (2 buoys $km^{-1}$) represent the accumulation since 1974.

*Beer and soft-drink crates*

All crates were Japanese (Fig. 10), and their numbers almost doubled between 1974 and 1982 (from 1 to 1.7 crates $km^{-1}$). Crates are resistant to breaking, burial, or being blown inland; thus, the number of crates in 1982 is an 8-year accumulation.

*Gill-net floats*

Gill-net floats disappear rapidly from beaches by being blown inland, buried in sand, broken by storm battering, or gnawed by rats (Fig. 11). During an experiment in 1973 with marked floats, 41% disappeared within a year (Merrell, 1980). Despite their rapid disappearance, gill-net floats were the most numerous litter item in all years. Although gill-net fishing has decreased since 1974, more than 2.5 million floats are still used each year: in 1982, 172 boats each fished 15 km of net $day^{-1}$ with 15 000 floats per net. Data on lost nets are available only for 1978–81, when an average of 296 km of net, with approximately 295 000 floats, were lost (M. Dahlberg, pers. comm.). Only a few lost nets are recovered for salvage or disposal ashore.


**Fig. 10** Japanese beer crate and fish sorting basket.

**Fig. 11** Japanese gill-net float gnawed by rat.

*Strapping*

These strong 12–15 mm wide bands (Fig. 12) are used as strapping for bundles and crates. In 1982, they were the second most abundant item on Amchitka beaches. They are blown inland or buried because of their small

**Fig. 12** Strap on Japanese box.

size and light weight and, therefore, disappear rapidly from beaches. There were 21% fewer straps on Amchitka beaches in 1982 than in 1974.

## Environmental Significance of Litter

Aside from the offensive sight of plastic refuse littering wilderness beaches, the most serious environmental effect is entanglement of marine mammals, birds and fish in derelict fishing gear (Merrell, 1980). Entangled fur seals have been observed in both Northern and Southern Hemispheres. Entangled cape fur seals *(Arctocephalus pusillus)* have been noted since 1972 in southern Africa breeding colonies (Shaughnessy, 1980), and northern fur seals *(Callorhinus ursinus)* encumbered with net fragments and strapping have been noted on the Pribilof Islands since the early 1960s (Fowler, 1982). However, it was not until Fowler (1982) estimated that as many as 50 000 northern fur seals become entangled and die annually that the extent of the problem was recognized.

Three of the most abundant plastic litter items from commercial fisheries are implicated in fur seal entanglements: trawl web, gill-nets and strapping. Trawl web is of greatest concern because it makes up 76% of the weight of litter on Amchitka beaches (Table 1) and is the primary cause of fur seal mortalities by entanglement (Fowler, 1982).

**Fig. 13** Uncut strap.

**Fig. 14** Fur seal with uncut strap around shoulders, St Paul Island, Pribilof Islands.

Fish and seabirds are probably more frequently entangled in gill-nets than mammals. Derelict gill-nets several kilometres long and loaded with birds and fish have been reported at sea (Anon., 1983), and the few gill-net fragments I found on Amchitka usually contained skeletal parts of birds and fish. Very few fur seals have been observed entangled in gill-nets on the Pribilof Islands (Fowler, 1982).

Strapping is a cause of seal entanglements: Fowler (1982) reports strapping on about one-third of the entangled northern fur seals on the Pribilof Islands. Uncut strapping forms a continuous loop (Fig. 13); seals put their head through the loop and then cannot remove the strapping (Fig. 14). In 1982, most straps on Amchitka beaches were cut (35 uncut and 589 cut).

## Solutions to Control Litter

Educational programmes to discourage discard of litter at sea are unlikely to be effective—disposal of litter at sea is cheap, easy, and most vessels do not have facilities for storing litter. The International Maritime Organization is trying to reduce marine litter through the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978. But Annex V of this Convention, which deals with plastic pollution, is optional, and only 16 nations have accepted it. The merchant fleets of these 16 nations constitute about 35% of the gross tonnage of the world. The most effective solution to litter pollution by fisheries is unilateral action by nations that require fishing permits in their waters. Fishing vessels should be required to retain litter aboard for incineration or disposal ashore as a condition for permission to fish.

The dramatic decline in beach litter on Amchitka Island after curtailment of fishing in the North Pacific Ocean and Bering Sea shows that litter could be rapidly reduced if disposal of litter at sea were restricted.

My 1982 survey was made possible by the US Coast Guard and the National Marine Fisheries Service Marine Mammal Laboratory, which provided air transport to Amchitka Island, and the US Department of Energy, which provided accommodations and vehicle transport to beaches on the island.

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BASELINE

# Trace Metals and Chlorinated Hydrocarbons in Ross Seals from Antarctica

During the 1981/82 relief voyage to Antarctica of the South African supply ship, *S A Agulhas*, samples of tissue were taken from Ross seals, *Ommatophoca rossi*, to be analysed for trace metals and chlorinated hydrocarbons. The specimens had been collected as part of a detailed study of this species by the Mammal Research Institute (University of Pretoria). The Ross seal is restricted to the heavy consolidated pack-ice off the Antarctic coastline (Laws & Hofman, 1979) and is therefore well isolated from anthropogenic sources of pollution.

Trace metals and chlorinated hydrocarbons have not been measured previously in Ross seals. Some results have been reported for Leopard, Crabeater and Weddell seals from Antarctica (Sladen *et al.*, 1966; Brewerton, 1969; Risebrough *et al.*, 1976). Levels in other species of seal, world-wide, have been relatively well documented. Risebrough (1978) provides a review.

Seals were taken in the pack-ice of Queen Maud Land from an area extending between about 4 degrees east and 4 degrees west of the Greenwich meridian (Fig. 1). Consistently the tip of the liver and a portion of blubber from the mid-ventral region were excised from each specimen upon the ice. The samples were wrapped in aluminium foil and stored at about −20 °C pending analysis.

A portion of each liver sample was digested in a mixture of nitric and perchloric acid and analysed for a range of trace metals using conventional atomic absorption techniques. Further portions of liver were digested in a sulphuric acid–potassium permanganate solution and analysed for mercury using the cold vapour technique of Hatch & Ott (1968).

Chlorinated hydrocarbons were extracted from the blubber samples with hexane. The extract was 'cleaned up' using a modification of the Holden and Marsden (1969) method. Measurements were made with a gas-liquid chromatograph fitted with an electron capture detector.

Details of these methods are given by Watling (1981).

The trace metal concentrations in liver (Table 1) showed a fair degree of scatter for each metal, but in all cases this was considered to be within the bounds of normal sampling and analytical variation. There were no obvious relationships between metal concentrations and the sex or size (age) of the animals, although a scarcity of males (only 15% of the total) and tendency for the animals to be of similar size restricted this type of appraisal. A comparison of the results with those reported for other species of seal (Fig. 2) showed that the Ross seal livers contained considerably lower concentrations of mercury and lead than those reported for seals from more polluted localities. However, copper, cadmium and zinc concentrations were higher in the Ross seal livers. This was especially true of cadmium for which a considerable increase was evident. The remoteness of the Antarctic pack-ice from anthropogenic sources of metal pollution suggests that this is a natural phenomenon.

Ross seals are believed to feed primarily on squid and to a lesser extent on fish and krill (Laws & Hofman, 1979). Squid have been shown to have markedly high hepatic concentrations of copper, cadmium and zinc (Martin & Flegal, 1975; Hamanaka *et al.*, 1982) and it is suggested that these cephalopods are the probable source of the metals. This assumed relationship between diet and high metal concentrations must remain speculative until corroborative evidence is obtained, particularly as these metals are not generally considered to be biomagnified (Swartz & Lee, 1980).