DISTRIBUTION, ABUNDANCE, AND SOURCE OF ENTANGLEMENT DEBRIS AND OTHER PLASTICS ON ALASKAN BEACHES, 1982-88

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ABSTRACT

Sixty kilometers of outer coast beaches at 25 locations in Alaska were surveyed from 1982 to 1988 to determine distribution, composition, quantity, deposition, and source of plastic debris washed ashore. Approximately 67% of all plastic debris found was fishing gear (e.g., net fragments, rope, floats) and 33% was packaging material (e.g., plastic bags, bottles). Debris found which could entangle marine mammals, seabirds, and fish included trawl web, rope, packing straps, and monofilament gillnet. Monofilament gillnet was not abundant (usually <5 pieces/km) on beaches, but trawl web was found on beaches throughout Alaska and exceeded 10 fragments/km at more than 50% of the locations sampled. Foreign fisheries were the source of most (98%) of the monofilament gillnet washed ashore; the source of trawl web is shifting from foreign to domestic fisheries.

Trends in composition and abundance of plastic debris were monitored at three sites: Amchitka Island, Middleton Island, and Yakutat. Amchitka Island had similar quantities (~300 items/km) of total plastics in 1982 and 1987, although the amount of trawl web at this site continued to increase. Quantities of plastic debris on Middleton Island remained similar from 1984 to 1987 (average 860 items/km), with the exception of an approximate 33% decline in 1985 from the 4-year average. Near Yakutat, the quantity of trawl web deposited ashore increased from 8.8 to 10.1 fragments/km/year from 1985 to 1988. Continuing the surveys of these benchmark beaches will help determine whether recent mitigating legislation is effective in reducing the disposal of entanglement debris and other plastics at sea.

INTRODUCTION

Marine pollution has become a major environmental concern in the 1980's. One form of marine pollution that has attained international attention is plastic debris discarded or lost in the world's oceans.

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Plastics are of particular concern because they persist in the environment for years, endangering marine animals and man. Seabirds and sea turtles can ingest pieces of plastic that block their digestive tracts (Balazs 1985; Day et al. 1985); seabirds, fish, and invertebrates can become entrapped in derelict gillnets (DeGange and Newby 1980; High 1985); marine mammals can become entangled in fragments of trawl web, packing straps, and rope (Fowler 1987; Stewart and Yochem 1987); and ships can be disabled from plastic debris which fouls props or cooling intakes (Wallace 1985).

Most plastics are lightweight, float at or near the ocean surface, and often wash ashore. Plastic debris is common on Alaskan beaches because of the loss or discard of fishing gear (e.g., trawl web, rope, and floats) and other plastic debris from large commercial fishing fleets operating in the North Pacific Ocean and Bering Sea (Merrell 1985; Uchida 1985). Plastic debris washed ashore represents, to some degree, the types and quantities lost or discarded at sea. Beach surveys may be the best method of evaluating whether recent mitigating legislation (MARPOL Annex V) to reduce the input of plastics into the sea is effective.

The National Marine Fisheries Service (NMFS) has conducted beach surveys for plastic debris on Alaskan beaches periodically since 1972. The objective of this paper is to examine recent trends in the distribution, composition, quantity, deposition, and source of plastic debris on Alaskan beaches based on surveys from 1982 to 1988; the emphasis was on entanglement debris (trawl web, gillnet, rope, and packaging straps) at study sites that were repetitively sampled since 1982. The occurrence of trawl web is discussed in detail because it is one of the most abundant entanglement debris items found on Alaskan beaches (Merrell and Johnson 1987; Johnson and Merrell 1988), and it is the principal item entangling northern fur seals, *Callorhinus ursinus*, on the Pribilof Islands (Fowler 1987). Additional information on past NMFS studies can be obtained from Merrell (1980, 1984, and 1985).

METHODS

Approximately 60 km of outer coast beaches at 25 locations in Alaska have been surveyed for plastic debris since 1982 (Fig. 1). Locations of beaches surveyed at least twice as benchmarks include: Amchitka Island in the Aleutians; Middleton Island in the central Gulf of Alaska; and beaches near Yakutat in the eastern Gulf of Alaska (Fig. 1).

Beaches were surveyed primarily during summer (June-September) in all locations with the exception of those near Yakutat. Ten beaches on Amchitka Island were surveyed once in September 1982 and again in September 1987; three beaches on Middleton Island were surveyed once in either July or early August 1984 through 1987; and eight beaches near Yakutat were surveyed once in September 1985, four times in 1986 and 1987 (January, April, July, September), and twice in 1988 (March and September). Five of the eight Yakutat beaches were surveyed once in September 1984.

Survey methods were similar for all beaches (Merrell 1985). Most beaches were 1 km in length. The survey area for each beach included the

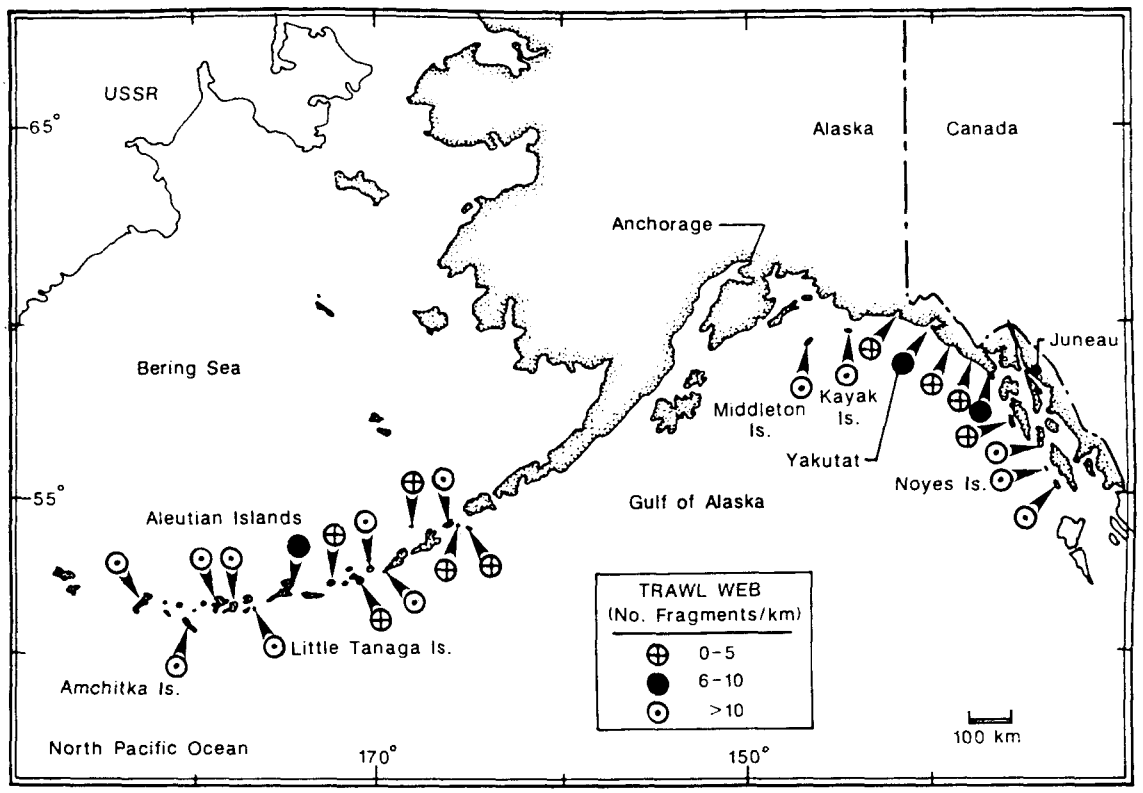

Figure 1.--Locations of beaches surveyed for plastic debris and quantity of trawl web fragments (number per kilometer) found in Alaska, 1982-88.

intertidal zone between the water's edge and the seaward limit of terrestrial vegetation at the upper limit of normal high tide. All plastic debris visible from walking height was counted (i.e., pieces ≥5 mm, and trawl web and monofilament gillnet fragments with five or more complete meshes). Rope of any diameter was counted if it was ≥1 m in length. We did not count pieces (e.g., gillnet floats and plastic bottles) if they were less than one-half their original size. We either weighed or estimated the weight of trawl web fragments depending on size and location: whether they were loose on the beach, buried, or snarled on drift logs. Stretch mesh was measured (knot to knot inside measure) for one representative mesh of each net fragment sampled. We did not search for debris within piles of drift logs or seaweed.

Beginning in 1985, all trawl web fragments at Yakutat were tagged with a small metal tag or removed and discarded inland from the beach. Trawl web fragments that were tagged and remained onshore could therefore be distinguished from new (not tagged) fragments, making it possible to determine deposition by season and year. At Middleton and Amchitka Islands, trawl web and gillnet fragments were painted with orange dye so that they could be identified in future surveys.

To determine trends in accumulation of all types of plastic debris, a 1-km beach on Middleton Island was cleared of all surface debris annually from 1984 to 1987. Debris was moved to terrestrial areas above the high-tide zone. Debris too large to move, partially buried, or snarled on drift logs was marked with paint, flagging, or tags for identification in future surveys.

The only major change in the sampling procedure was made in 1986 and 1987 when all beaches were subdivided into ten 100-m increments, thereby providing ten different data sets for each 1-km beach. This change was designed to improve the statistical precision of debris estimates (Ribic and Bledsoe 1986).

Differences in quantities of entanglement debris items on Amchitka Island were tested by paired t-tests, where observations in 1982 and 1987 were paired for each of ten 1-km beaches. Differences in quantities of individual debris items between Amchitka and Middleton Islands in 1987 were tested by t-tests. The association between quantity of trawl web and total plastic debris found on Alaskan beaches was determined by linear correlation.

RESULTS

Derelict trawl web was found on sampled beaches throughout Alaska (Fig. 1). At over 50% of the locations sampled, trawl web exceeded 10 fragments/km of beach. Locations with the highest quantities of trawl web included Little Tanaga Island in the Aleutians (216 fragments/km), Kayak Island in the central Gulf of Alaska (92 fragments/km), Amchitka Island (55 fragments/km), and Noyes Island in southeast Alaska (53 fragments/km) (Fig. 1).

Trawl web was significantly correlated ($P < 0.05$; $r = 0.37$) with the quantity of total plastic debris (all types) found per kilometer of beach. Thus, beaches that accumulated many fragments of trawl web generally also accumulated numerous other plastics. Locations with the highest quantities of total plastics included Noyes Island (1,330/km), Kayak Island (1,142/km), and Middleton Island (988/km) (Fig. 1).

Composition of total plastic debris (based on number of individual items) on Amchitka Island beaches was similar in 1982 and 1987. Likewise, composition of plastic debris on Middleton Island was similar in all years (1984-87). At both locations in 1987, nearly two-thirds of all items found were derelict fishing gear (Table 1).

Quantities of entanglement debris changed on Amchitka Island from 1982 to 1987, but only rope increased significantly ($P < 0.05$) (Fig. 2). Trawl web, strapping, gillnet, and gillnet floats (possible indicator of quantity of gillnet lost), either increased or decreased, but not significantly (Fig. 2). Because some items increased and some decreased, total plastics were similar in 1982 and 1987 (~300 items/km).

Table 1.--Percent composition of derelict fishing gear based on number of plastic debris items found on Amchitka and Middleton Islands, Alaska, 1987.

Debris items	Percent of total			
	Amchitka		Middleton	
Derelict fishing gear	68		62	
Rope		31%		7%
Trawl web		26%		4%
Floats		20%		82%
Straps		16%		3%
Gillnet		1%		1%
Miscellaneous		6%		3%
Packaging material	28		35	
Personal effects	2		2	
Miscellaneous	2		1	

The number of trawl web fragments found on Amchitka Island beaches has steadily increased since 1972 (Fig. 3); the average weight of individual fragments, however, has decreased from 11 kg in 1974 to 4 kg in 1987. The frequency of occurrence of different trawl web mesh sizes measured on Amchitka Island was similar in 1982 and 1987 (Fig. 4). In both years, the most common mesh size was 101-150 mm; approximately one-third of the fragments had mesh sizes >150 mm.

Quantities of entanglement debris remained relatively stable on Middleton Island from 1984 through 1987 (Fig. 5). During these 4 years, trawl web averaged 24 fragments/km of beach; rope, 51 pieces/km; straps, 16/km; and gillnet fragments, 4/km. Gillnet floats increased 58% from 287/km in 1984 to 454/km in 1987. Total plastics found on Middleton Island were similar in 1984, 1986, and 1987. In 1985, however, there was a 33% decline in total plastics from the 4-year average of 860 items/km (Fig. 5). Differences in quantities of debris by location were evident between Middleton and Amchitka Islands in 1987 (Table 2). Significantly ($P < 0.05$) more trawl web was found on Amchitka than on Middleton Island, whereas significantly ($P < 0.001$) more gillnet floats and total plastics were found on Middleton Island. Although not significant, twice as much gillnet was found on Middleton Island as on Amchitka Island.

A 1-km beach on Middleton Island, cleared of all plastic debris annually from 1984 to 1987, accumulated debris quickly, sometimes within 1 year (Fig. 6). Trawl web, gillnet, and rope, cleared from this beach in 1986, accumulated to previous or higher quantities by 1987. Entanglement debris accumulated in a similar proportion each year; rope was the most abundant, usually followed by trawl web, gillnet, and closed straps (Fig. 6).

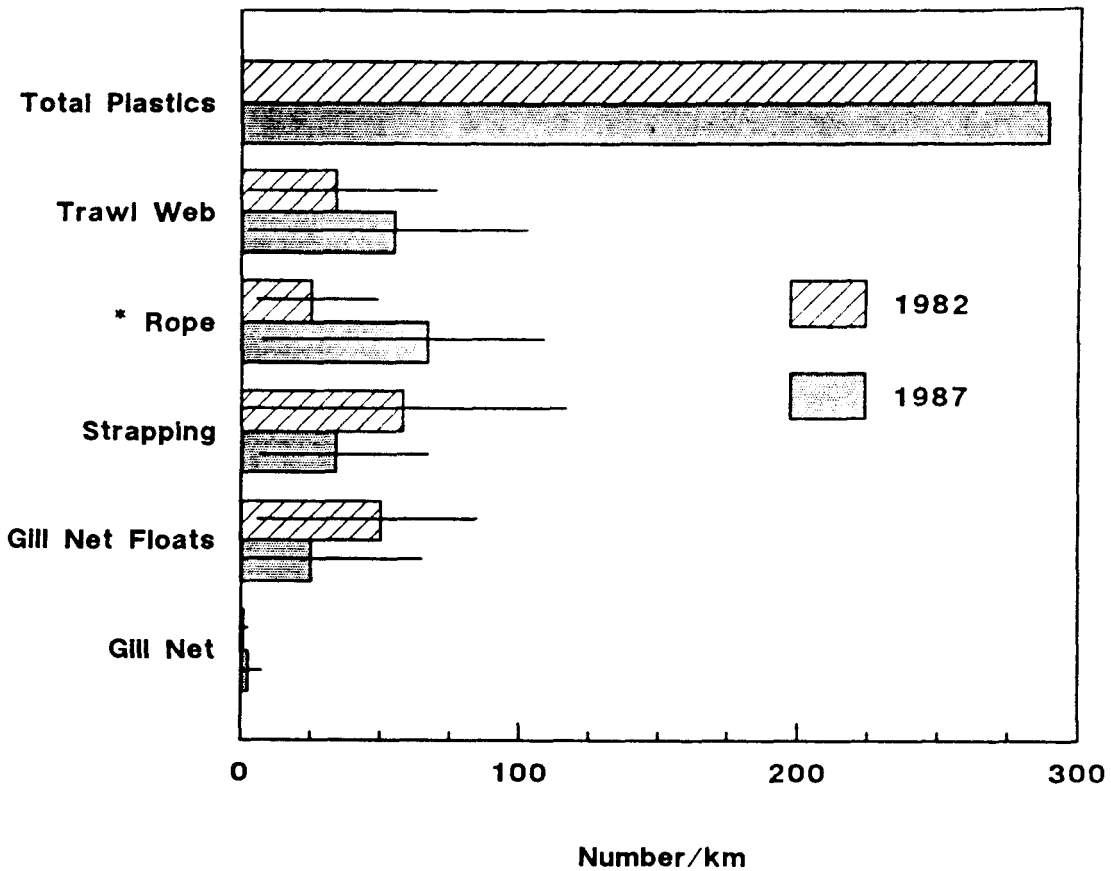

Figure 2.--Quantities (mean ±SD) of entanglement debris and total plastics found on Amchitka Island, Alaska, in 1982 and 1987. Data based on ten 1-km beaches. Asterisk denotes significant difference between years $P < 0.05$.

Total deposition of trawl web at Yakutat was similar from 1985 to 1988 (range 8.8 to 10.1 fragments/km/year) (Table 3). More fragments, however, washed ashore during the fall-winter months (Oct.-Apr.) than the spring-summer months (May-Sept.). Of the beach locations examined more than once, deposition of trawl web was greatest on Amchitka Island, followed by Middleton Island and Yakutat. Some locations, such as Little Tanaga Island, Kayak Island, and Noyes Island, accumulated more trawl web than the above or adjacent locations, probably because of their favorable orientation to major ocean currents, prevailing storm winds, or increased fishing effort and loss of gear in nearby waters.

At present, the source of trawl web washed ashore is shifting from foreign vessels to domestic vessels as U.S. trawl fisheries replace foreign trawl fisheries in the North Pacific Ocean and Bering Sea in the latter 1980's (Cotter et al. 1988) (Fig. 7). Most (98%) monofilament gillnet washed ashore, however, is from foreign high seas fisheries (Fig. 7) because monofilament nylon gillnets, with the exception of a small herring fishery, are banned in Alaska (Uchida 1985). The most common (42%) mesh size of gillnet washed ashore was 110 mm stretch mesh (Table 4). Based on mesh

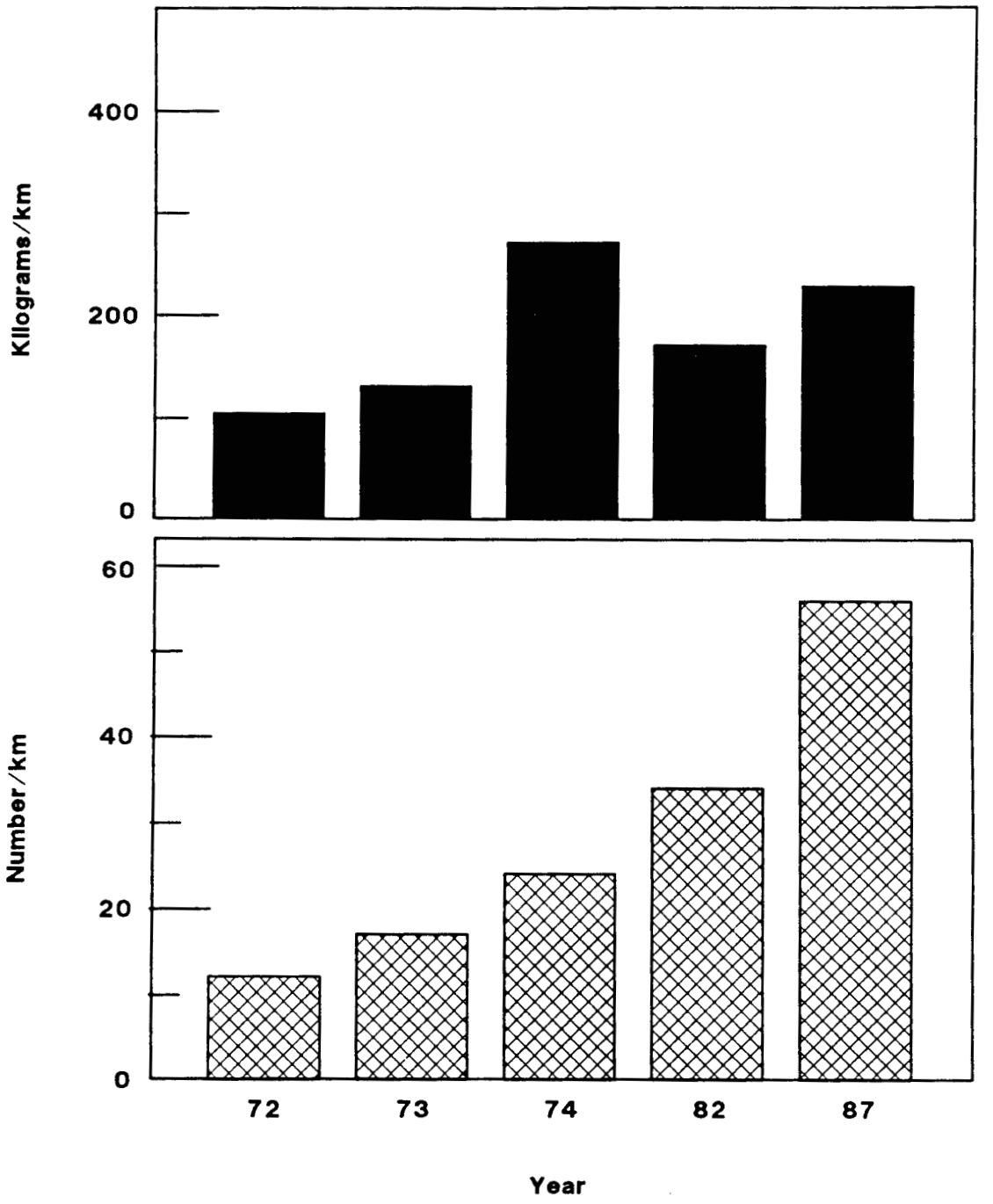

Figure 3.--Number and weight of trawl web fragments found on Amchitka Island, Alaska, from 1972 to 1987. Ten 1-km beaches surveyed in each year. Data for 1972-74 from Merrell (1985).

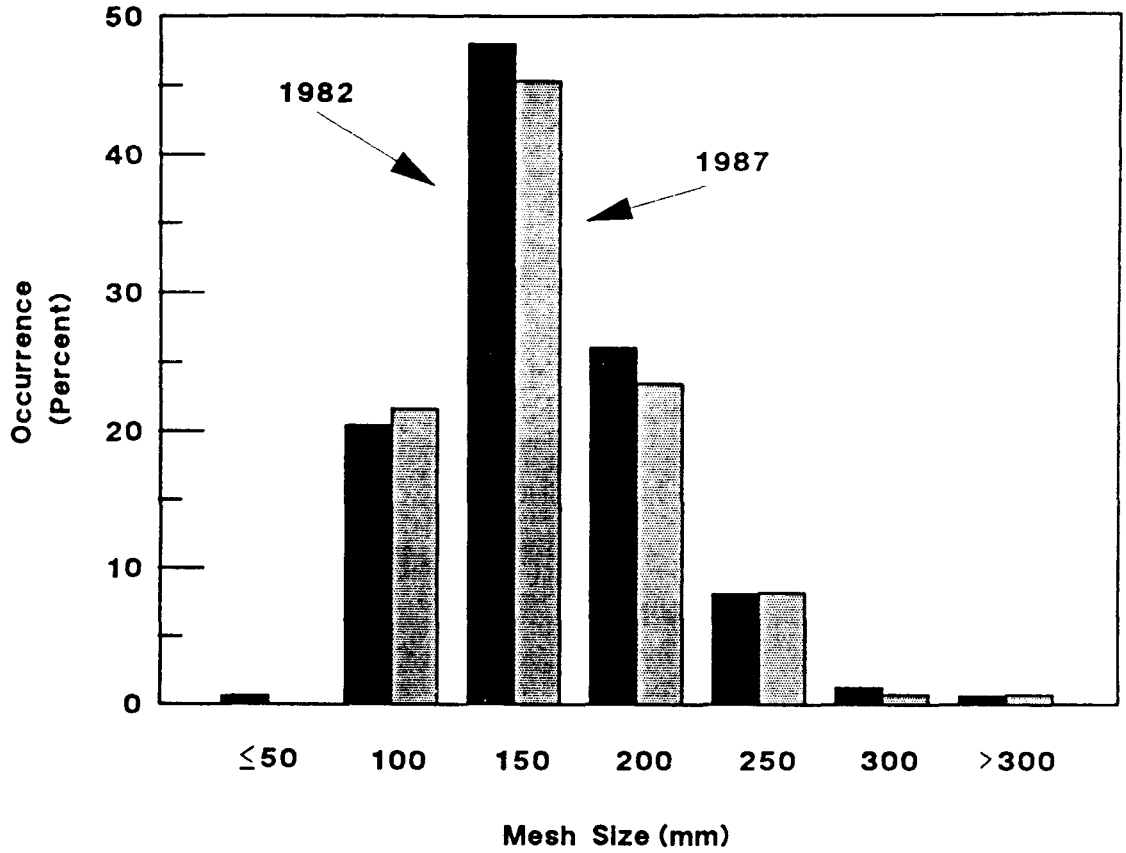

Figure 4.--Percent occurrence of different mesh sizes of trawl web fragments found on Amchitka Island, Alaska, in 1982 (n = 333) and 1987 (n = 282). The X-axis label is upper limit of interval.

size, likely sources of foreign gillnet are high sea fisheries (Japan, Taiwan, Korea) for squid and salmon (Merrell 1985; Uchida 1985).

DISCUSSION

The widespread distribution and continual accumulation of plastic debris on outer coast beaches of Alaska are indicative of the vast quantities of debris lost or discarded into the North Pacific Ocean and Bering Sea. Annually, an estimated 1,664 metric tons of plastic debris are lost or discarded from fishing vessels in Alaskan waters (Merrell 1980). Although large quantities of plastic debris were found on many Alaskan beaches, it was not evenly distributed. Some beaches with large quantities of trawl web (>10 fragments/km) and other plastic debris were adjacent to locations with small quantities of debris (Fig. 1). Accumulation of debris on beaches depends upon the orientation of the beach to major ocean currents and prevailing winds. Even within a given location, debris abundance can differ dramatically; the windward side of Middleton Island, for example, had 15 times the amount of debris found on the leeward side of the island (Johnson and Merrell 1988). Thus, when interpreting results

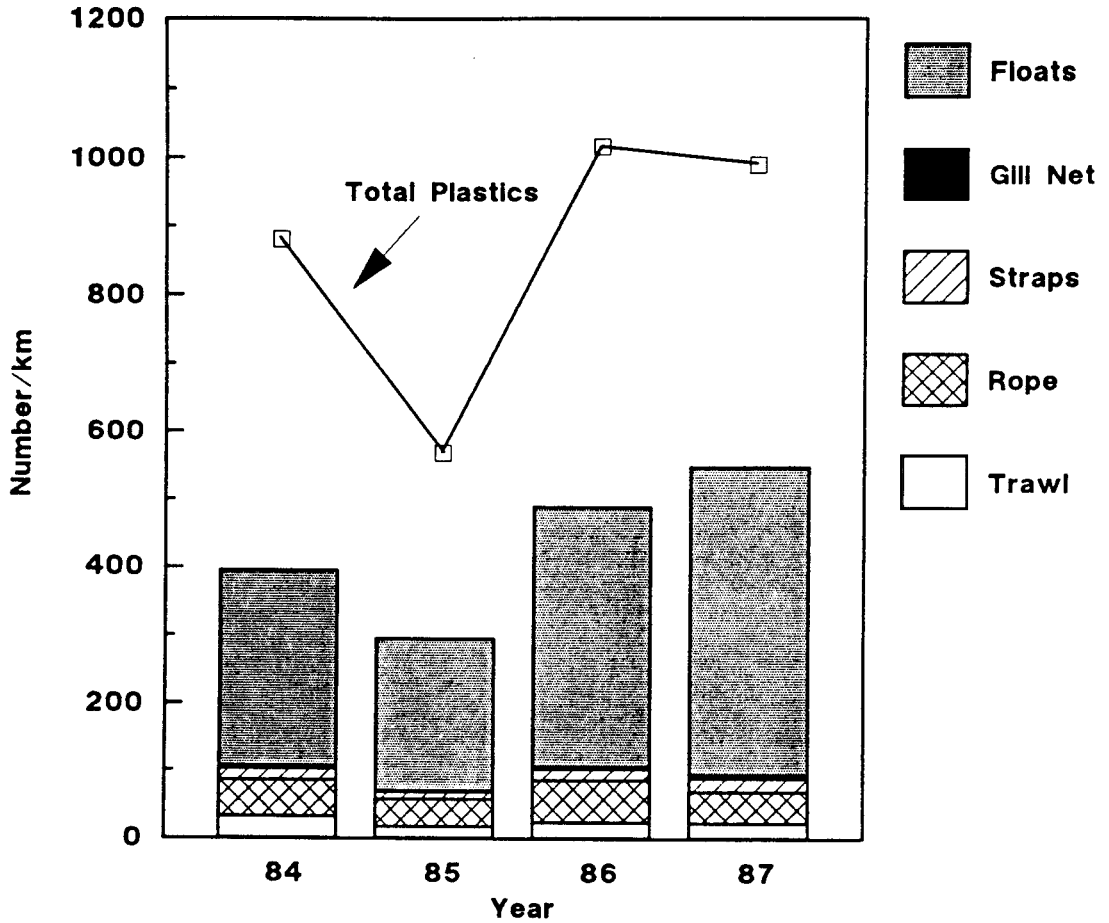

Figure 5.--Quantities of entanglement debris and total plastics found on Middleton Island, Alaska, from 1984 to 1987. Data based on two 1-km beaches.

Table 2.--Quantities of entanglement debris and total plastics found on Amchitka and Middleton Island beaches, Alaska, 1987 (* $P < 0.05$; ** $P < 0.001$); n = number of 100-m sections.

	Number per 100 m	
Debris type	Amchitka n = 50	Middleton n = 18
Fishing gear		
Trawl web	5.5*	2.2
Rope	6.7	4.1
Strap	3.4	1.7
Gillnet	0.2	0.4
Gillnet floats	2.5	43.8**
Total plastics	31.0	95.0**

Table 3.--Deposition of trawl web on eight 1-km sections of beach at Yakutat, Alaska, from 1985 to 1988.

	Number of trawl web fragments deposited ashore								
	1985-1986			1986-1987			1987-1988		
Beach	Oct.-Apr.	May-Sept.	Total	Oct.-Apr.	May-Sept.	Total	Oct.-Mar.	Apr.-Sept.	Total
1	8	3	11	4	2	6	7	2	9
2	4	0	4	6	1	7	6	6	12
3	3	4	7	8	2	10	7	3	10
4	12	7	19	16	0	16	7	10	17
5	12	2	14	9	0	9	8	3	11
6	0	2	2	3	1	4	2	2	4
7	1	0	1	4	0	4	2	4	6
8	10	2	12	18	1	19	7	5	12
Total	50	20	70	68	7	75	46	35	81
Mean per kilometer per year			8.8			9.4			10.1

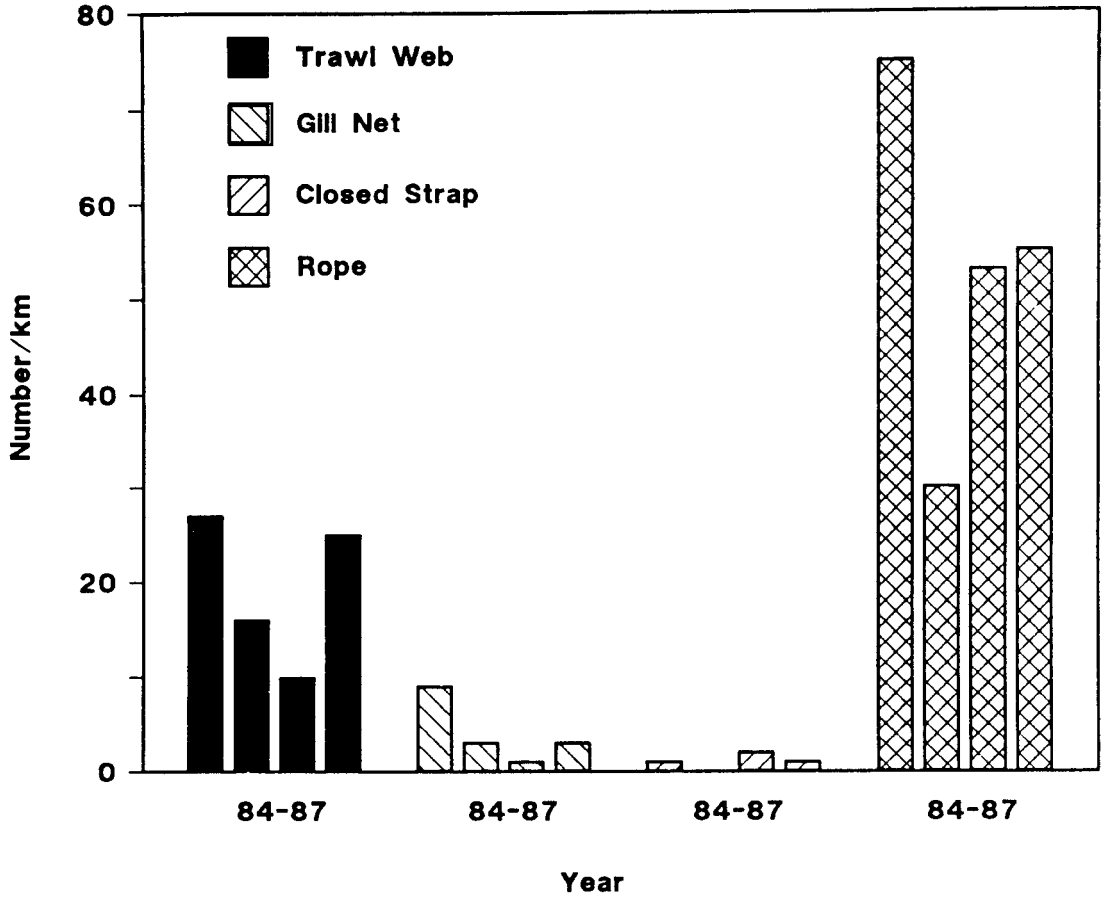

Figure 6.--Accumulation of entanglement debris on a 1-km beach on Middleton Island, Alaska, that was cleared of all debris annually from 1984 to 1987.

of surveys, knowledge of local ocean currents and prevailing winds is necessary.

Composition of plastic debris was nearly identical on Amchitka and Middleton Islands. In both locations in 1987, over 60% of the debris found on beaches was fishing gear. This does not seem unusual, considering that 5,500 km of trawl net and 170,000 km of gillnet are available to various fisheries in the North Pacific (Uchida 1985). Of the three benchmark locations, debris washing ashore on remote Amchitka and Middleton Islands is probably most representative of the types and quantities lost or discarded at sea.

With the exception of rope, which increased significantly, quantities of entanglement debris did not change significantly on Amchitka Island from 1982 to 1987. Trawl web fragments, however, did increase from 34 to 55 fragments/km, continuing the upward trend of earlier years. The average weight of a fragment of trawl web found on Amchitka Island in 1987 was 4 kg, and some of the fragments were rectangular in shape, indicating they

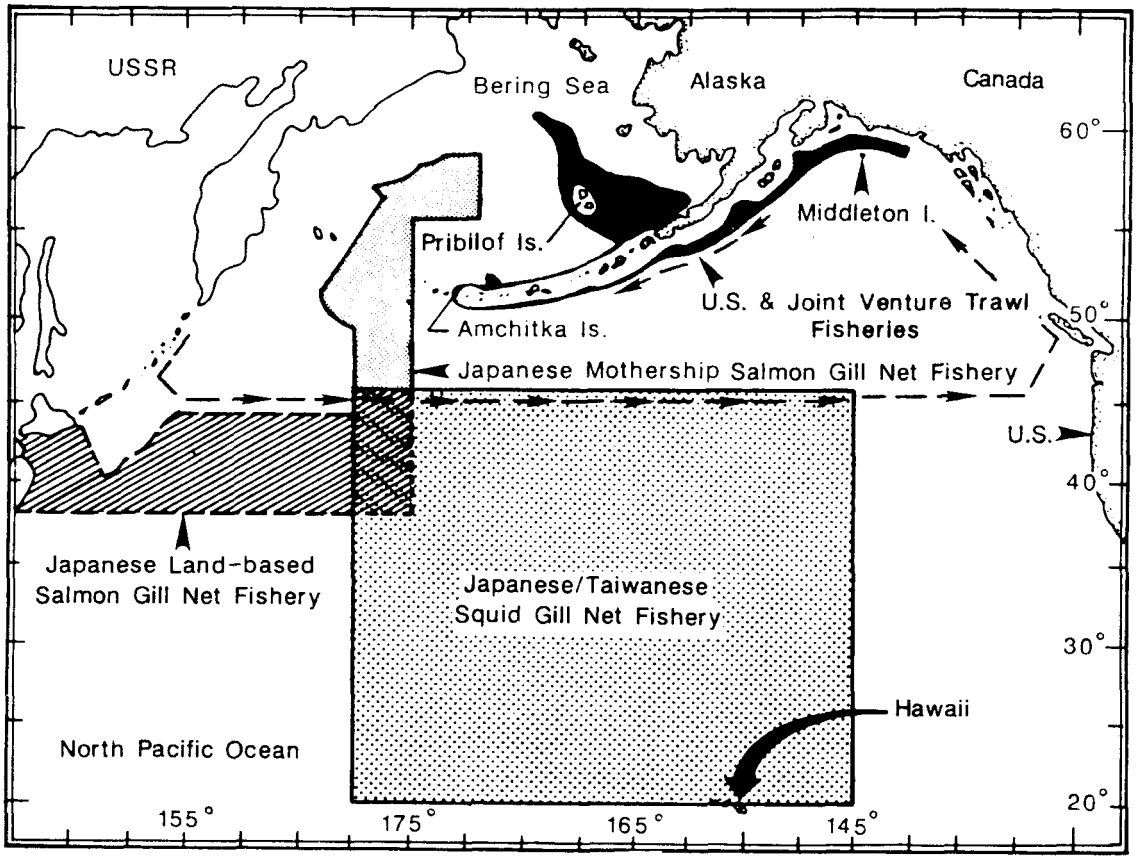

Figure 7.--Major trawl and gillnet fisheries in the North Pacific Ocean and Bering Sea. Adapted from Low et al. (1985) and Merrell (1985). Broken arrows indicate major ocean currents (Reed and Schumacher 1985).

may have been patches discarded overboard from commercial trawlers from net-mending operations. Berger and Armistead (1987) estimated that from 1982 to 1984, over 2,700 pieces of trawl web were discarded overboard into Alaskan waters from net-mending operations.

Although the number of trawl web fragments that washed ashore continued to increase on Amchitka Island, the frequency of occurrence of different mesh sizes remained stable. Approximately one-third of the fragments in both 1982 and 1987 had mesh sizes >150 mm. These are the mesh sizes most likely to entangle northern fur seals (Scordino 1985; Fowler 1987). Similar occurrences of mesh sizes have been reported for other beach locations in Alaska (Johnson 1989). Therefore, assuming trawl web washed ashore is representative of that which is floating at sea, approximately one-third of the derelict trawl web at sea could entangle fur seals.

On Middleton Island, quantities of entanglement debris remained relatively stable from 1984 through 1987, and were generally lower than quantities found on Amchitka Island. More rope and strapping and significantly

Table 4.--Mesh sizes of gillnet fragments found on Alaskan beachesfrom 1982 to 1988, and probable fishery sources (Chen 1985; Gong 1985; Uchida 1985; United States-Taiwan Bilateral Meeting 1988).

Mesh size (mm)	Number of fragments: Amchitka Island	Middleton Island	Yakutat	Total	Fishery[a]
55	0	1	0	1	Herring--US
95	0	1	0	1	Squid--T,K
100	0	1	0	1	Squid--T,K
105	0	1	0	1	Squid--T,K
110	0	20	7	27	Squid--T,K; Salmon--JL
115	8	7	4	19	Squid--T,K,J; Salmon--JL
120	1	4	9	14	Squid--T,J; Salmon--JM
130	0	0	1	1	Salmon--JM
Total	9	35	21	65	

[a]US = United States, T = Taiwan, K = Korea, J = Japan, JL = Japanese land-based, JM = Japanese mothership.

more trawl web were observed on Amchitka Island than on Middleton Island in 1987, probably because of the proximity of Amchitka Island to concentrated trawl fisheries in the North Pacific Ocean and Bering Sea (Fig. 7). Gillnet fragments and floats, however, were more abundant on Middleton Island than on Amchitka Island, even though Amchitka Island is closer to gillnet fisheries in the North Pacific Ocean and Bering Sea (Fig. 7). This may be due to the eastern direction (towards North America) of the subarctic ocean current (Reed and Schumacher 1985), which may transport debris from the high-seas squid and Japanese land-based salmon fisheries (Merrell 1985) into the Gulf of Alaska and favor deposition on Middleton Island.

The quantity of debris washed ashore is affected by frequency and intensity of storms, changes in ocean currents, winds, fishing effort, and areas fished. At Amchitka Island, total plastics remained at about 300 items/km in both 1982 and 1987. At Middleton Island, however, there was a 33% reduction in total plastics in 1985, possibly the result of a change in ocean currents or an unseasonable storm which may have redistributed debris from the beach. By 1986 and in 1987, debris had accumulated on beaches on Middleton Island to quantities near those observed in 1984 (~900 items/km). A decline in quantity of debris on beaches near Yakutat was also reported in 1985 (Merrell and Johnson 1987), supporting the concept that there may have been a change in ocean conditions affecting the accumulation of debris on beaches throughout Alaska. Thus, when monitoring trends in abundance, it is best to sample each beach location at the same time each year in

order to document the variability between years due to changes in ocean conditions or fishing effort.

Of the entanglement debris washed ashore, the reason for the scarcity of gillnet is still unclear. Gillnet is perhaps the most likely of all gear types to be lost (Uchida 1985) but it is one of the least abundant entanglement debris items found on Alaskan beaches. Approximately 1,609,000 km (1 million mi) of gillnet are fished each year in the North Pacific Ocean, of which an estimated 965 km (600 mi) are lost or abandoned each year (Eisenbud 1985). A possible explanation for the lack of gillnets on Alaskan beaches is that they may sink to the ocean bottom from the weight of marine growths (e.g., algae, barnacles) and the carcasses of marine mammals, seabirds, and fish. In some cases, gillnets may drift at mid-depths, get stranded farther offshore in intertidal areas, and never reach the beach. Because derelict gillnets tend to collapse and "roll up" relatively quickly (Gerrodette et al. 1987), they may form a better substrate for marine growths and thereby attract fish and other predators which may get entangled, ultimately causing the net to sink. Trawl web, on the other hand, usually does not "roll up" like gillnet and does not appear to form a suitable substrate for collecting marine growths. This may explain why more trawl web washes ashore than gillnet.

The short period of time (sometimes within 1 year) in which plastic debris accumulated on a beach on Middleton Island that had been cleared of all debris suggests that a substantial amount of debris is probably adrift at sea. Johnson and Merrell (1988) reported a 40% accrual of new debris (previously unseen) on an Alaskan beach in just a 4-month period. The rapid accumulation and, often times, disappearance of debris on beaches are largely controlled by storms. Storms are primarily responsible for depositing debris ashore and removing or redistributing debris already stranded; some of the debris is washed inland to terrestrial areas or buried by sand (Johnson 1989).

Frequent sampling and tagging of trawl web fragments at Yakutat indicates that most fragments are washed ashore in the fall-winter months due to storms. Shiber (1982) also reported an increased deposition of plastic debris in winter on beaches in the Mediterranean Sea. The increase in deposition of trawl web at Yakutat from 8.8 fragments/km in 1985-86 to 10.1 fragments/km in 1987-88, is consistent with the increase in trawl web observed on beaches at Amchitka Island from 1982 to 1988. The reason for the increased deposition of trawl web on Alaskan beaches is unclear; although the number of fragments has increased, the areas fished and the total number of vessels (~300) operating off Alaska have remained relatively steady since 1978 (Low et al. 1985).

Monitoring plastic debris and derelict fishing gear on beaches in Alaska and in other locations may be the best method of evaluating whether the input of plastics into the sea is decreasing because of compliance with MARPOL Annex V. Monitoring plastic debris abundance at sea by aircraft and ship surveys may work, but isn't feasible considering the cost and the immense areas to be covered.

At present, beach surveys are an effective method to determine types, sources, and composition of plastic debris that washes ashore. Trends in abundance of plastic debris may be more difficult to determine because of the variability in the accumulation of debris in different locations and years. Therefore, a better understanding is needed of the interrelationship of ocean currents, storms, and drift patterns, and their effects on the distribution of plastic debris in the North Pacific. In addition, information is needed on the length of time plastic debris remains at sea once it is lost or discarded. Some answers may be gained by releasing marked floats at specific locations in the North Pacific Ocean and Bering Sea and following their recovery.

Regardless of limitations of beach surveys, by establishing benchmarks and continuing to sample at these locations at least once a year at approximately the same time, a trend should become evident as to whether quantities of debris are increasing, decreasing, or remaining the same. Alaskan beaches, specifically Amchitka and Middleton Islands, will serve as long-term benchmarks to monitor plastic pollution because: 1) they are remote from urban sources of pollution, 2) they continually accumulate debris, and 3) a data base of several years already exists.

In summary, plastic debris is found on many outer coast beaches throughout Alaska and most is composed of fishing gear. Rope and trawl web are the two most abundant entanglement debris items found; they continue to wash ashore in some locations in an increasing number. Monitoring debris on beaches in Alaska and elsewhere in the coastal United States for the next several years may help to determine if mitigating legislation is reducing the entry of entanglement debris and other plastics into the ocean.

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