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POTENTIAL EFFECTS OF MARINE DEBRIS ON BENTHIC COMMUNITIES

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Final Report

to

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ABSTRACT

Anthropogenic debris is entering the world's oceans from various sources. Although the impacts of debris at the surface and on beaches has received considerable attention, there is extremely little information available on the potential impacts to benthic organisms. This project was conducted to evaluate our current knowledge of benthic impacts and to propose future research programs to improve our understanding of potential effects. Information was obtained through a review of the available literature on marine debris and discussions with benthic ecologists. A case study approach was used to evaluate potential impacts to benthic resources in the North Pacific Ocean because more information on debris is available there than for most other regions.

Debris includes paper, metal, glass and cloth. Although plastics are a small percentage of total debris, they are the best studied because they are persistent and evident in marine environments. Debris can enter the oceans from landbased sources and from military, recreational or passenger ships. In the open ocean, however, the principal sources appear to be merchant shipping and commercial fishing ships. Although the greatest source of total debris may be merchant ships, derelict fishing gear seems to produce the greatest biological impacts. Debris found on beaches in the North Pacific is dominated by trawl webbing (by weight) and gillnet floats (by number). It is unknown what type of debris is most common on the sea floor. The principal concerns for producing benthic impacts are lost or abandoned crab pots and gill nets that may be suspended vertically from the ocean bottom because they may continue to "ghost-fish" for an extended time after being lost.

There is little information on the fate and impacts of benthic debris. It is clear that crab pots and gill nets do continue to fish. Gill nets will ball up and become fouled with algae that makes them visible. They will then be less effective for fishing but may catch some fish for several years. The principal impact appears to be on non-commercial species. Crab pots also may fish for several years although new regulations require biodegradable panels that allow organisms to escape. Organic debris probably provides additional food for benthic organisms and metal may provide hard substrate for attachment of benthic species. Thus, all impacts of debris are not necessarily negative.

Several international conventions as well as federal laws in the United States regulate discharge of wastes in the oceans. Enforcement of these regulations at sea is extremely difficult, however. The most successful methods for decreasing input of debris probably involves educational programs for fishermen as well as recreational sailors. Merchant shipping and military vessels have space on board to store debris and can establish procedures on ship to reduce their inputs.

A number of research projects are proposed to determine the quantity and type of debris on the sea floor and the potential impacts on benthic organisms. Two types of projects are particularly important: (1) monitoring programs to quantify the types of debris on the bottom, and (2) long-term observational projects to determine the interactions between various types of debris and benthic organisms.

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I. INTRODUCTION

Large quantities of non-biodegradable debris, including waste matter discharged from ships, refuse from land and lost or discarded fishing gear, is intentionally or unintentionally deposited in the sea. Since such disposal has been perceived as an environmental problem only recently, characterization of its impacts has hardly begun. Several recent symposia and papers have addressed some aspects of the situation (Shomura and Yoshida 1985; Coe 1986; Laist 1987; Pruter 1987). Almost all of this attention, however, focused on debris that floats at the sea surface and remains visible. There is much less information on debris that sinks to the sea bottom and becomes essentially invisible. Also, there has been less concern about benthic impacts of debris because there are fewer living resources on most of the sea bottom than near the surface. The purpose of this paper is to review the data that are available to characterize the nature, abundance, distribution and fate of benthic debris, and to assess its potential impacts. Some sources and fates of debris in the oceans are shown schematically in Figure 1.

Debris or litter on the sea surface began to attract scientific attention in the early 1970s (Carpenter and Smith 1972; Venrick et al. 1973). The National Academy of Sciences (NAS 1975) examined litter as a potential ocean pollutant, but rated its threat as minimal (except in inshore areas) and considered its primary impact to be aesthetic. Litter was defined as "solid materials of human origin which are discarded at sea or reach the sea through domestic and industrial outfalls. It may include plastics, paper, glass, metals, lumber and trees, and may vary in size from meters to microns in length or diameter."

Debris is attracting attention currently for several reasons. First, there is an increasing awareness of debris washed ashore on beaches (Merrell 1980, 1984). More importantly, there is concern about the entanglement of organisms (especially mammals and birds, but also fishes to a lesser extent) in floating debris. For example, Fowler (1982) calculated that mortality due to entanglement might account for the current decline in populations of Pribilof Island fur seals in the eastern Bering Sea. Potential impacts of debris have stimulated a growing body of literature in the 1980s (e.g., Shomura and Yoshida 1985). The problem seems most acute in, but is not limited to, the North Pacific. Organisms that may be affected include birds, mammals, turtles, fish and crustaceans worldwide. Coe (1986) reviewed impacts on northern and southern fur seals, Hawaiian monk seals, sea lions, whales, sea turtles and seabirds.

To date, however, there has been little more than anecdotal mention of the occurrence of debris on the sea floor. Jewett (1976) and Feder et al. (1978) described the anthropogenic materials in bottom trawls from the Gulf of Alaska and the eastern Bering Sea. Submersibles were used by Carr et al. (1985) and High (1985) to observe organisms captured in underwater "ghost nets" snagged on the bottom. Potential effects of derelict crab and lobster traps have also been

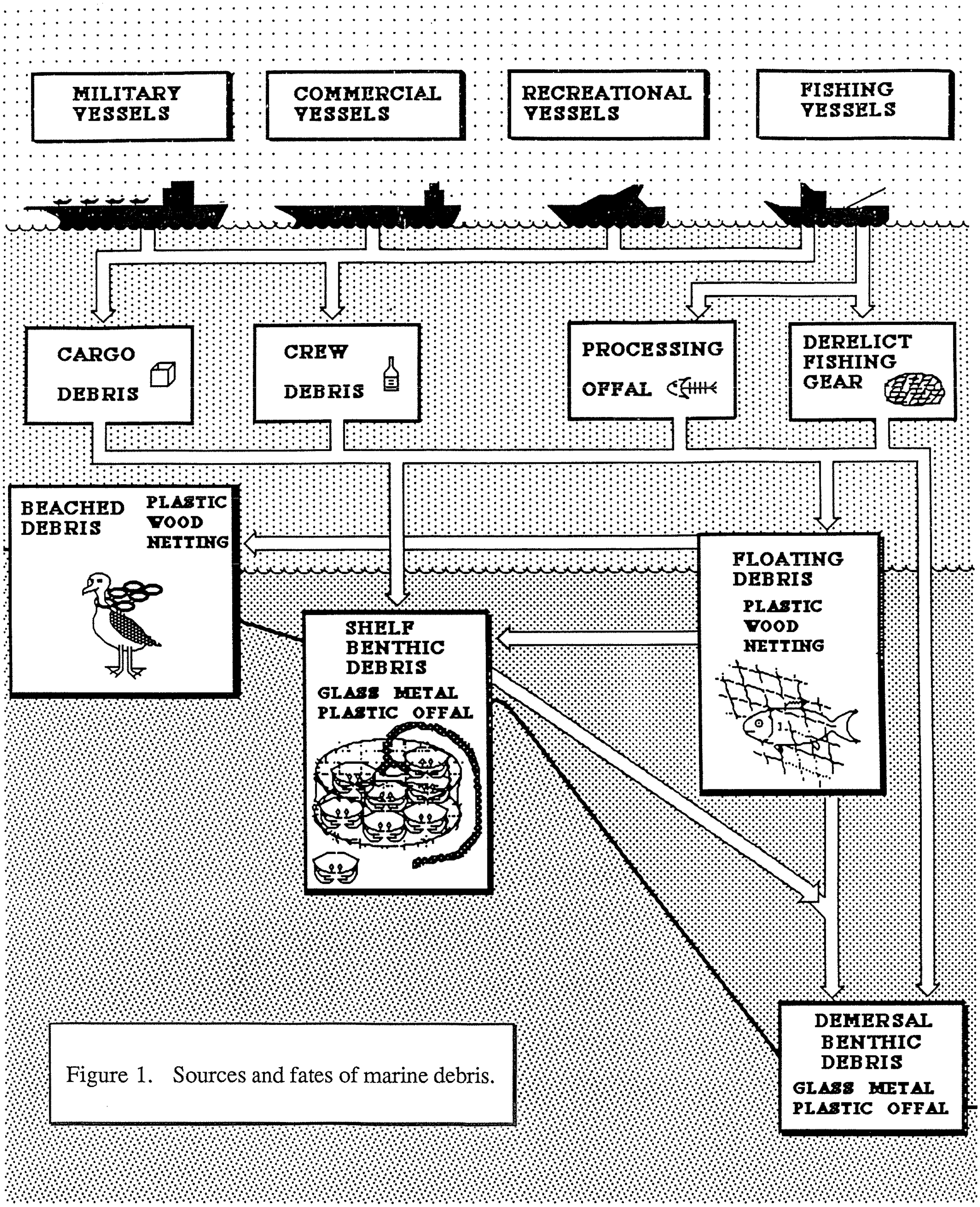

Figure 1. Sources and fates of marine debris.

mentioned (High 1985). There has been no systematic attempt, however, to characterize or quantify the types of debris that sink to the ocean floor, their distribution and magnitude, or their biological impacts.

Following this general introduction this paper provides an approach to identify questions and obtain data on benthic impacts of marine debris. This is followed by a brief overview of the present status of knowledge of the types and sources of debris reaching the oceans, including available estimates of annual tonnages of debris generated worldwide. To estimate the sources and magnitude of benthic debris generated, however, requires more detailed data. Therefore, the succeeding section uses a case study approach to examine data from the North Pacific Ocean and Bering Sea. This is the best known data set on the generation of marine debris for any region of the world ocean. These data primarily concern derelict fishing gear, the impacts of which may be significant in some cases. In the North Pacific and Bering Sea, the known impacts are almost entirely to organisms at the ocean's surface and have been adequately reviewed in existing literature. The next section of this paper discusses existing knowledge of benthic impacts in the case study region with supporting information from other regions. Closing sections review the legal framework surrounding debris and present conclusions and recommendations for future research.

II. APPROACH

A major task of this review is to develop a conceptual overview of the significant issues for evaluating impacts of benthic debris. A proposed framework for this process, broken into major tasks, is outlined in Table 1. The major questions to be addressed in each task and the associated subtasks are listed. Answers for most of these questions are currently unavailable because of a lack of appropriate data. This sequence therefore is presented to provide a format to characterize available information and to identify the additional data or research activities that are needed to fully evaluate the potential impacts to benthic communities.

III. SOURCES AND TYPES OF DEBRIS

In order to estimate the input of debris to the marine benthic environment it is necessary to know the sources and amounts of debris disposed of and observed in the ocean. The National Academy of Sciences (NAS 1975) estimated the percent composition, sources and annual global tonnage of debris (Tables 2 and 3).

Table 2 includes only debris generated by individuals (domestic mostly packaging), but Table 3 also includes commercial waste (such as cargo refuse and lost fishing gear). These estimates were based on few data and simple assumptions. Rates of debris generation on vessels were estimated

Table 1. Proposed framework for research on benthic impacts of marine debris.

I. Identify Sources and Magnitude of Debris Input to the Ocean
  A. Identify classes of debris
  B. Identify sources for each class of debris
  C. Estimate magnitude of input from each source
  D. Estimate spatial and temporal distribution of inputs

II. Distinguish Floating from Sinking Debris
  A. Identify materials that float and sink
  B. Identify sources of floating and sinking debris
  C. Identify processes that sort floating and sinking materials
  D. Estimate relative or absolute magnitude of sinking fraction
  E. Estimate spatial and temporal flux of sinking material

III. Characterize Possible Fates of Benthic Debris
  A. Burial, fragmentation, disintegration
  B. Time scales and regulating factors
  C. Differences by region and substrate

IV. Describe Benthic Communities Where Debris Comes to Rest
  A. Describe shelf, slope, rise, and abyssal habitats
    1. Substrate, currents, etc.
  B. Distinguish habitats by latitude and geographic area
  C. Distinguish classes of organisms
    1. By size, substrate, trophic status, distribution
  D. Derive spatial and temporal intersection of debris with organisms

V. Characterize Potential Impacts of Debris on Organisms
  A. Qualitatively identify potential harmful effects
    1. By type of debris, organism (e.g., entanglement, suffocation, poisoning, etc.)
  B. Qualitatively characterize most likely impacts
    1. By type of debris, organism, location
  C. Attempt to quantify impacts
    1. Especially commercial/sport resources

VI. Characterize Other Potential Impacts
  A. Navigation, fishing operations, diving
  B. By location, substrate, season, type of debris

VII. Identify Data Gaps and Research Needs
  A. Use "Known, Uncertain, Unknown" approach to classify data needs
  B. Identify most important and practicable research to meet needs

VIII. Identify Management Strategies to Reduce Benthic Impacts
  A. Describe current management and legal framework
  B. Describe current preventative measures
  C. Identify potential additional preventative measures

Table 2. Percent composition (by weight) of domestic debris originating from vessels and from land (NAS 1975).*

Material	% of debris from ships	% of debris from land
Paper	63.0	72.0
Metal	16.6	11.7
Glass	9.6	12.0
Cloth	9.6	1.8
Plastics	0.7	1.8
Rubber	0.5	0.7
Total	100.0	100.0

*Does not include food and vegetable wastes.

Table 3. Estimates of litter input to the ocean (NAS 1975).

Source	(Million tons/yr)
Passenger vessels	0.028
Merchant vessels	
Crew	0.110
Cargo	5.600
Recreational vessels	0.103
Commercial fishing vessels	
Crew	0.340
Gear	0.001
Military vessels	0.074
Oil drilling and platforms	0.004
Catastrophe	0.100
Total	6.360

to be 0.8 kg/person/day for crew-associated refuse and 285 metric tons/vessel/year (1718 kg/vessel/day) for cargo-associated refuse. Global annual inputs were obtained by multiplying these by the estimated average crew size (40) and volume of shipping traffic (9100 ships at sea at any time) taken from 1964 data. Although the debris flux was not characterized by geographic region, it was noted that 80% of observed shipping was concentrated in the Northern Hemisphere and within 400 km of land, and about one-third of the debris was of U.S. origin.

The estimates did not include several sources of debris that could be relevant to the present study: rapidly degradable materials such as vegetable and food wastes (estimated at an additional 0.95 kg/person/day on shipboard); shipwrecks; petroleum residues; materials placed to make artificial reefs; and materials such as dredge spoils or sewage sludge that are disposed as part of a regulated ocean dumping program. NAS (1975) also may have underestimated shore-based industrial inputs of litter to the ocean, which are now suspected to account for much of the volume of plastic spherules observed floating on the ocean surface (Wallace 1985; Pruter 1987). According to Bean (1987), the U.S. dumps about nine million tons of solid waste per year into the ocean, and it is believed that direct dumping represents only about 10% of the total pollutants loading to the ocean, the majority entering from landbased sources via rivers, estuaries and other avenues.

These estimates clearly indicate that merchant shipping is the dominant source of litter to the ocean, accounting for 90% of the estimated input. The next largest source, commercial fishing vessels, accounted for only 5% of estimated litter input to the world's oceans. Nearly all of the litter (98%) from merchant vessels was cargo-associated, but most debris from fishing vessels was calculated to come from crew garbage, rather than from lost cargo material or fishing gear.

The NAS (1975) estimates have been modified to estimate more recent flux of debris to the ocean. Horsman (1982) counted numbers of debris items discarded into the ocean. He observed that merchant shipping discards an average of 3.2-6.2 metal containers, 0.2-0.3 glass containers and 0.3 plastic containers per person daily. Multiplied by average crew size of 30 and the number of merchant ships at sea (71,000 in 1979), he calculated a global input of 6.8 million metal, 426,000 glass and 639,000 plastic containers discarded at sea each day. More recent estimates by Horsman (1985) are that globally 4.8 million metal, 300,000 glass and 450,000 plastic containers are dumped in the sea by ships every day. These materials were estimated to represent only 26%-30% of total refuse disposal, the rest being biodegradable material. The data are not available to convert these counts to masses that would be comparable to the NAS (1975) data. The more recent data are likely to represent higher inputs of refuse, however, because of the much higher volume of shipping traffic.

The procedure used by NAS (1975) and Horsman (1982, 1985) for estimating the amount of garbage dumped from vessels at sea was extended by Parker et al. (1987). Their data provide updated estimates of weights of debris generated at sea. For example, an estimate of the amount of solid waste generated by U.S. Naval vessels is presented in Table 4. This estimate is nearly 75% higher than the estimate by NAS (1975).

Some of the other estimates made by NAS (1975) now appear certain to have been too low. They estimated an annual global loss of only 1,350 tons of fishing gear. In contrast, Merrell (1980) estimated losses of 1,664 tons annually in Alaska waters alone and extrapolated this to 135,000 tons globally. Merrell (1984) estimated that 1,361 tons of debris were generated by the fishing industry in the Bering Sea alone in 1980, and that 145,000 net fragments were discarded. Horsman (1985) also estimated that commercial fishing vessels dispose of more than 23,000 tons of plastic packaging and 135,000 tons of plastic fishing gear every year. Coe (1986) used more

Table 4. Estimates of solid waste generated at sea by the U.S. Navy (from Parker et al. 1987).

Material	Waste generated kg/person/day
Garbage	0.55
Paper	0.40
Metal	0.24
Wood	0.12
Cloth	0.04
Ceramic/glass	0.01
Rubber	0.005
Plastics	0.005
Total	1.38

recent estimates of global numbers of fishing vessels (at least one million) and assumed no change in the per-vessel rate of plastic debris generation derived by NAS (1975), to calculate that generation of plastic waste has increased from 5.25 to 43.5 million pounds (2,386-19,772 metric tons) per year and the rate of loss of fishing gear from 2.98 to 24.7 million pounds (1,354-11,227 tons) per year, since the NAS report was issued.

Duerr (1980) estimated the input of garbage to U.S. coastal waters alone by recreational fishermen to be 34,000 tons per year, compared with the NAS (1975) global estimate of 103,000 tons per year.

These changes do not alter the basic finding (Table 3) that cargo associated garbage on merchant vessels is the largest source of debris to the ocean, However, very different results are obtained if the dominant types and sources of debris are inferred from observations at sea and on beaches. For example, the majority of debris observed at the sea surface and on beaches in the North Pacific region, including whole or fragmented lost or dumped gear as well as ordinary trash, is plastic (Wallace 1985) and appears to originate with the fishing industry (Merrell 1980). Plastic constituted 86% of all debris observed at sea in the North Pacific by Dahlberg and Day (1985), and similar observations are documented around the world (Pruter 1987). Studies on the biological impacts of marine debris also evaluate almost exclusively the effects of plastics. If the data in Tables 2-4 on actual inputs of material to the ocean are at all realistic, the observed abundance of plastics must reflect the buoyancy and durability of these materials. The abundance, distribution and effects of metal, paper, glass, etc., which are presumed to sink rapidly to the bottom, are unknown. Although this review emphasizes the impacts of plastics, impacts from other materials may be just as significant.

Pruter (1987) indicates that the data are not available to determine if the largest source of plastics to the ocean is shipping or landbased waste materials that are carried to sea by rivers. Except locally, most plastic debris is not generated by beachgoers (Neilson 1985). Sources of plastic certainly vary with the type of plastic. Coe (1986) and Laist (1987) classify plastics entering the ocean into four categories: (1) fishing gear, including webbing, twine, ropes, floats, hooks, traps and pots; (2) packaging such as strapping, padding, cases, bags, bottles and other containers; (3) raw plastic spherules, beads, etc.; and (4) convenience items including cups, plates, six-pack holders, etc. The first two categories are predominantly associated with vessels. Wallace (1985) reviewed arguments that land is the main source of small floating plastic pellets. Ship-generated plastic litter might be estimated to a first approximation from the findings of NAS (1975): 0.7% of 6.36 million tons, or 44,520 tons. This is clearly an underestimate.

It seems clear that landbased sources of benthic debris could account only for materials very close to shore. On most continental shelves and in the deep sea debris must originate from shipping. We consider the main sources to be merchant shipping and commercial fishing, although the principal source cannot be established without additional data.

IV. SOURCES AND SUPPLY OF BENTHIC DEBRIS: A NORTH PACIFIC CASE STUDY

To estimate the quantity of debris that may cause biological impacts to marine benthic communities, it is useful to consider specific data that are available on potential rates of input and standing stocks of debris in biologically sensitive areas. On the open continental shelves where major fishery grounds are located, it is uncertain if merchant or fishing vessels are more important sources of debris. In contrast to the data presented above (Section II), which emphasize merchant vessels as the principal source, the best data on the biological effects of debris released at sea is for debris from fishing vessel. The most extensive efforts to quantify the standing stock of debris at sea have focused on heavily-fished areas of the North Pacific Ocean and Bering Sea.

According to Merrell (1984), most of the debris found on Amchitka Island beaches (in the Aleutian Islands) originates with the fishing fleet. Seven types of items accounted for 86% of the total weight of litter found on Amchitka beaches in 1982, and six of those items were commercial fishing gear. The three most abundant items were trawl webbing, gill netting and strapping, with trawl webbing contributing 76% of the total weight of litter. Most of the known biological impacts in this region also involve fishery-related debris. It is uncertain whether this pattern indicates: (1) a predominance of fishing traffic and debris generation over merchant vessel sources, especially since fishing vessels would be more common closer to shore, or (2) segregation processes (such as flotation) that concentrate fishing debris where it is visible and has biological effects. Although there is limited information available, these data suggest that derelict fishing gear may be the most significant source of debris in this region.

The impact of derelict fishing gear on the benthos depends on the amount, location and characteristics of the gear lost; on whether and when the gear sinks to the bottom; and on what type of benthic environment it encounters, including the types of organisms that are present to be affected. There are no definitive data on the amounts and types of gear that reach the benthos in the North Pacific and Bering Sea. However, some of the data on surface debris presented in Shomura and Yoshida (1985) can be adapted to estimate the types and amounts of fishing gear debris that may sink to the bottom in certain areas of this region. The analysis does not include crew-associated trash, which NAS (1975) estimated to be the largest source of debris from fishing vessels (Table 3).

IV.A. Net Materials

The fates of lost fishing gear depends on several properties of the gear and the environment. The gear that we will consider is primarily webbing from fishing nets, for which there is information on incidence and impacts, and not the associated floats, leadlines, etc. There are no data on the proportion of lost gear that floats and sinks. Therefore, we cannot convert estimates of lost gear to estimates of sinking gear. Different types of nets use plastic materials with different specific gravities that determine if a lost net floats or sinks. The principal synthetic compounds used in the fishing industry are polyamide (nylon), polyester, polyethylene and polypropylene (Coe 1986). These (especially polyamide) replaced biodegradable fibers as the principal material in fishing nets between the end of WWII and the early 1960s. During this period fishing effort in the North Pacific increased and reached its peak in the mid-1970s (Fredin 1985; Pruter 1987).

The two major classes of fishing gear in use in the study area are subsurface trawls and surface nets such as gill nets (Uchida 1985). Trawl webbing is made of polyethylene (PE), which is positively buoyant (Coe 1986). Therefore, detached segments of trawl nets will rise to the surface. Ropes are made from polypropylene, which also floats. Gill nets are made of polyamide (PA), which is negatively buoyant, so segments of gill netting will sink. Polyamide may be used for the wings of some midwater trawls. Coe (1986) suggested that polyethylene (PE) in trawl nets could be replaced by the more expensive but negatively buoyant polyamide (PA). This would reduce the hazard to surface organisms but increase any potential hazard to benthic organisms.

The fate of netting material depends on how nets are used and their material. Nets are deployed at specific depths and are equipped with weights and/or floats to maintain them at the proper depth. Trawls are weighted and deployed in midwater or at the bottom and, when full, a trawl cod end is very heavy and will sink, even though the webbing itself is buoyant. (Cod ends full of pollock or rockfish float, at least temporarily, because of the expanded swim bladders of the fish). Gill nets are usually suspended at the surface by floats and do not accumulate the same load of fish as trawls per unit of material. Thus derelict surface gill nets probably reach the bottom only when they drift long enough to lose their floats and become burdened with fouling organisms, or if lost with a heavy load of fish during retrieval. Residence times of derelict gill nets at the surface are estimated at from 2 to 10 years (Wallace 1985). (Some gill nets are deployed near the bottom, however, see below). Thus it is not clear from consideration of netting material and deployment alone what is the major source of lost gear to the benthos.

IV.B. NET USAGE AND LOSS

Important factors governing the loss of different types of fishing gear are the relative amounts in use and their probability of loss. Uchida (1985) reviewed the types of nets used in North Pacific fisheries by area and estimated the total amounts of netting deployed each year. His data show that, in the North Pacific as a whole, gill nets far exceed all other types of nets in terms of km available on shipboard to be deployed: 170,000 km annually versus 2000 km of purse seine, 5500 km of trawl and 8900 km of miscellaneous net gear. The dominant use of gill nets in the North Pacific is by the Japanese coastal herring and sardine fisheries. However, if Asian coastal fisheries are eliminated, the ratio between gillnet and trawl net use remains very high (about 26,000 km to 200 km annually). Although absolute losses are not reported, gill nets are the type of gear that is most likely to become lost or damaged and discarded during fishing operations. Rates of loss are still considered low, however (NMFS 1986).

The amounts of gill net actually deployed are even more impressive. Table 5 compiles data on gill netting used per year. These estimates are derived by multiplying units of net deployed per day (measured in tans, 50 m in length for gill nets) by the length of the fishing season for several fisheries. The dominant gillnet fisheries are the Japanese high-seas mothership salmon driftnet fishery, the Japanese landbased salmon driftnet fishery, the Japanese coastal herring and sardine fisheries, and the Japanese, Taiwanese and Korean high seas squid fisheries. These fisheries occur predominantly in the open ocean rather than over the continental shelf; they have been excluded from the 200-mile EEZ's of the U.S. and U.S.S.R. since 1977 (Fredin 1985). The salmon fisheries are also excluded from areas east of 175°E longitude, and the mothership fishery is excluded from waters south of 56°N. The squid fishery takes place entirely south of 45°N (Chen 1985). The efforts expended today for salmon as shown in Table 5 are only 30-50% of the peak efforts expended by the Japanese mothership fleet in the 1950s and Japanese landbased fleet in the 1970s. The squid fishery expanded rapidly, however, and the combined gillnet fisheries of the North Pacific region are now considered the largest use of netting in the history of fishing (Coe 1986).

Table 5. Estimates of gill netting used in the North Pacific and Bering Sea.

Source	Fishery	Deployment km/yr
Pruter 1986	All	1,650,000 km/yr
U.S. Commerce 1984	All	24,750 km/day
Eisenbud 1984	All	28,800 km/day
Merrell 1984	Japanese salmon	2,580 km/day*
Fredin 1985	Japanese mothership	150,000 km/yr (at present) 450,000 km/yr (in 1956)
	Japanese landbased	150,000 km/yr (at present) 300,000 km/yr (in 1975)
Shima 1985	Japanese mothership	127,710 km/yr
	Japanese landbased	124,740 km/yr
	Japanese squid	967,100 km/yr
	Japanese marlin, etc.	189,720 km/yr
Gong 1985	Korean squid	359, 800 km/yr*

*Calculated

There are some estimates of loss rates that can be used to calculate the length of gill netting debris generated annually. Drift net losses are considered by some to be relatively rare and on the decrease; netting is expensive ($3,400-$4,400 per km) and discarding it at sea is prohibited by Japanese law (NMFS 1986). Japan, Korea, Taiwan and the USSR now expend considerable effort to incinerate or recycle gill netting debris rather than casting it over the side (Freeman 1987; NMFS 1986; Jones and Ferrero 1985). An annual average of 296 km of gill netting were estimated to be lost from Japanese salmon fisheries from 1978-1981, the only years for which data were available (Merrell 1984). Total annual net lengths deployed by these fisheries in 1980 was estimated to be in the range of 150,000 km per year. Approximately 1 km of net was lost per 500 km of net deployed, a loss rate of 0.2%.

In 1982, Japan reported a gillnet loss rate of 6 tans per 10,000 tans set, or 0.06% (NMFS 1986). From this figure, an annual loss of 1,122 tans (56.1 km) in the U.S. EEZ and 1620 tans (81 km) outside the EEZ was calculated. Eisenbud (1984) quoted figures of 18,000 (28,800 km) miles of total gill net deployed nightly by Japanese high sea salmon and squid fisheries, yielding a calculated loss of 10.8 miles (17.3 km) per night, or 1624 miles (2600 km) per 5-month fishing season. Estimates were also derived from these percentage loss rates and the estimate of total gillnet usage (Pruter 1986). These range from 990 km/yr (0.06% of 1.65 million km) to 3,300 km/yr (0.2%). These figures begin to approach the entire stock of trawl netting available in the region, 5500 km (Uchida 1985). Thus, there is a strong case that gill netting is the dominant source of fishery-associated debris in the region.

Although there is a much lower standing stock of trawl webbing than gill netting in use in the study area, trawls are used predominantly on the continental shelf where biological impacts are more likely. Trawls (especially bottom trawls) are highly susceptible to loss (Uchida 1985). There is no easy unit for expressing the exposure of trawls to loss that is equivalent to length of gill nets, because trawl effort is commonly expressed in units of time rather than distance and the conversion is complex. Low et al. (1985) reported total trawl effort in the region in terms of vessel-months, estimated rates of loss and discussed the difficulty of obtaining at-sea estimates of the frequency of lost trawl nets. Only about half of the foreign operations, which dominate the fishery, are observed by U.S. observers and they may not have monitored all instances of net damage or loss. A total of 65 nets or portions of nets were estimated to have been lost off Alaska in 1983, which experienced 2114 vessel-months of fishing effort. Most (45) of the estimated losses occurred in the process of transferring cod ends between processing vessels and catcher boats in joint-venture fisheries. This yields an approximate loss rate of 0.03 losses per vessel-month.

Low et al. (1985) emphasized that these data only estimated frequency of loss and did not indicate amounts of net material lost. They used these figures to back-calculate probable loss rates in the past, based on previous patterns of fishing effort. Present rates during trawling operations are inferred to be lower per vessel-month than at times in the past, because a greater portion of the current effort takes place in the Bering Sea where the bottom is relatively smooth and free of obstructions, as compared to the more rocky bottom of the Gulf of Alaska and Aleutians. Overall effort also is lower at present than during the mid-1970s. However, overall loss rates are estimated to be at an all-time high because of the predominance of losses during cod-end transfers in joint ventures.

There is no clear indication from these *a priori* considerations whether gill nets or trawls constitute the major source of debris that impacts benthos in the study area. Pertinent information for each is summarized in Table 6. Gill netting is used in far greater quantities than trawl webbing, but is often used away from the continental shelf so benthic impacts are expected to be less significant. There are no data on tracking of lost gill nets or netting fragments from which to determine how likely it is for netting lost on the high seas to drift over the shelf before sinking, but derelict gill nets have been found over the shelf (Anonymous 1973; DeGange and Newby 1980).

Table 6. Properites of gill and trawl nets relevant to benthic impacts.

Property		Gill nets	Trawl nets
Length deployed		1.65 million km/yr	?
Where deployed		Open ocean	Continental shelf
Loss rates		0.06-0.2% 990-3300 km/yr	0.03 per vessel-month 65 per year
Buoyancy	material deployed	negative positive	positive negative

There is also no index of the exposure of trawls to loss comparable to the length for gill nets. Distance or duration of tows times trawl size might be used, but numbers of cod end transfers could be the most important single factor in trawl losses. The fates of both types of nets after loss are almost unknown, especially the disintegration process that may free trawl fragments to float and gillnet fragments to sink. The proportions of netting fragments that originate from lost nets versus crew discards also are unknown.

IV.C. OBSERVATIONS OF DEBRIS IN THE STUDY AREA

An alternative method to estimate the incidence of sinking debris is to establish a conversion factor based on the incidence of floating debris and beach drift. Qualitative reports of these debris, including garbage and other materials in addition to fishing nets, are available worldwide and in the North Pacific (e.g., Anonymous 1983; Neilson 1985; Merrell 1985). Merrell (1980) estimated the total annual loss of plastic from fishing vessels in Alaskan waters at 1,664 metric tons. The dominant litter on Amchitka (Aleutian Islands) Alaska was trawl netting (by weight) and gillnet floats (by number), which underscores the importance of these sources of debris. Gillnet floats indicate the intensity of the gill netting fishing effort. However, there is a low incidence of gillnet material itself either because floatless nets ball up and rapidly sink or floats are lost from operational nets without the net being lost.

Merrell (1984) observed that decreasing trends in abundance of debris since 1972 corresponded well to decreases in fishing effort in the region. Foreign (mostly Soviet) trawlers decreased in number by 66% from 1972-1982, and trawl-web accumulation on Amchitka decreased 37% from 1976-1982. Japanese gillnet boats decreased 62% from 1956-1980 and the number of floats at Amchitka decreased from 126 to 59 km^{-1} from 1974-1982. No formal correlations were established and Merrell (1985) warned against drawing quantitative inferences from these data, which have high spatial variability.

Recent data on the incidence of floating debris in the North Pacific is compiled in Table 7. Sightings by Jones and Ferrero (1985) taken in 1984 were greatly affected by weather and sea state conditions. Eight sightings of trawl net fragments and 30 sightings of gillnet fragments were reported, along with one sighting of mixed gillnet and trawl net debris and five sightings of unidentified net debris. Most of these sightings were in the western Pacific and Bering Sea in areas of gillnet fishing. Gillnet fragments ranged from 0.5 m to 150 m in size. Jones and Ferrero (1985) also described eight records of discarding gill nets from vessels and three instances of recovery of lost or abandoned gill nets during the same period. The small number of sightings was attributed to poor spotting conditions and possibly to self-entanglement of nets that might accelerate sinking. No attempt was made to correlate sightings with possible frequency or amount of loss of net material.

Table 7. Observed surface debris in the North Pacific Ocean and Bering Sea.

Source	Debris	Location	Abundance*
Jones and Ferrero 1985	gill/trawl webbing	W Pacific/Bering	0.21/1000 km
Lenarz 1985	"	"	2.5-5 per 10,000 km^2
Laist 1987	gill netting	off NE Japan central N Pacific	1.976 per 1000 km 1.835 per 1000 km
Dahlberg and Day 1985	all (87%.plastic)	transect Alaska-Hawaii-Japan	0.28 per km^2 (north) 3.73 per km^2 (south)
Venrick et al. 1973	all	central N Pacific	4.24 per km^2
Morris 1980	all	Mediterranean	2000 per km^2
Fowler 1987	trawl webbing gill netting	W Pacific/Bering same	0.2-1.7 per 1000 km "up to 3 times higher"
Dahlberg and Day 1985	trawl webbing	central N Pacific	0.356 per 1000 km
Jones and Ferrero 1985	trawl webbing	Aleutians	1.349 per 1000 km

*Units are reported in either linear (km^{-1}) or areal (km^{-2}) measure.

Dahlberg and Day (1985) recorded all debris observed on transects between Alaska, Hawaii and Japan. Eighty-six percent of the 727 objects observed were plastic, and only three were net fragments. Objects were concentrated in a region of surface current convergence between 40° and 29°N.

The concentration of surface debris in regions of convergence resembles the pattern seen by other observers in the Pacific and the Atlantic (Wallace 1985). Again there was no correlation with type or magnitude of debris source that could be used to estimate the abundance of associated sinking material.

Another index of the abundance of debris might be obtained from reports of animal entanglements. The incidence of entanglement of Pacific northern fur seals (*Callorhinus ursinus*) in debris has most recently been reviewed by Fowler (1987). Approximately 0.04% of the fur seal population is sighted with entangled debris, a rate estimated to be two orders of magnitude larger than it was 40 years ago. About two-thirds of the entanglements involve trawl netting, and the remainder involve plastic packing bands and other miscellaneous debris. These are considered mainly floating rather than benthic debris. About 20% (4 of 20) of the trawl webbing fragments observed in the surveys described by Fowler (1987) had entangled seals. The rate of entanglement of seals in gillnet fragments was lower, even though the number of gillnet fragments observed in various surveys reviewed by Fowler (1987) was as much as three times that of trawl webbing fragments, and the gillnet fragments generally are very large. Fowler's (1987) examination of the evidence (and that of Lenarz 1985) is consistent with the hypothesis first advanced in 1982 that juvenile mortality caused by entanglement could account for the decline being observed in the Pribilof Island population of northern fur seals.

In the absence of any quantitative study of the fates of derelict nets and net fragments, there is currently no reliable way to quantify the incidence of debris with data on losses. The unknowns regarding persistence of netting at the surface, and about disintegration rates of nets, are too great to attempt to estimate the fraction of lost netting that sinks.

IV.D. Crab Pots

Loss of pots for Dungeness, king, or other crabs in this region may have serious impacts on benthic resources. In fact, there is more concern about the potential impacts of lost traps on high value commercial resources in this region than there is for any other type of debris. High (1985) estimated that hundreds of Dungeness crab pots are lost each year from Alaska to California and about 10% of king and tanner crab traps are lost each year. Estimates of the total standing stock of derelict crab traps now on the shelf range from over 30,000 in all Alaskan waters (High and Worlund 1979) to as many as 26,000 in the western Gulf of Alaska alone (Freeman 1987). King crab pots along the West Coast now are required to have a biodegradable panel to minimize their "ghost-fishing" life span (Freeman 1987), but some older derelict traps surely remain. Furthermore, the extent of compliance with biodegradable panel regulations is currently unknown although it is presumed to be quite low. Escape panels are also required in Dungeness crab pots in Alaska, Washington, Oregon and California (Pruter, personal communication). High (1985) speculated that the ghost-fishing life span of Dungeness crab pots might be 6 years or more.

IV.E. Incidence of Benthic Debris

Only a few records of occurrence of debris on the sea bottom are available anywhere in the world. Again, the North Pacific and Bering Sea region provide the best data. Jewett (1976) described objects taken in bottom trawls, average length about 6 km, on the eastern Gulf of Alaska shelf in 1975. Objects were found in 33 of 58 hauls (57%). Plastic items (e.g., trash bags, bait wrappers, packing straps) were most abundant but other materials (e.g., tar paper, bottles, steel cable, rubber gloves, a tire and two derelict snow-crab pots) were also collected. Feder et al. (1978) reported on debris found in bottom trawls on the southeastern Bering Sea shelf (in the area of most active fishing efforts). In 1975 records were kept only for 12 trawls in which debris were found; in 1976 records were kept of every trawl, and 43 of 106 trawls contained debris. Plastic and metal were taken most frequently (individual items were not characterized in the paper, nor were numbers of items per-trawl), followed by rope, glass, fishing gear, cloth, rubber, wood and paper. These data cannot be used to calculate the abundance of debris items per unit area without an actual count of items. However, a conservative estimate can be obtained by calculating only one item per haul. Average length of a trawl was 3.25 km with a width of 12.2 m. Thus, in the Bering Sea the incidence was 43 items per 4.2 km^2 or about 10 per km^2. Assuming the same trawl width in the Gulf of Alaska the figure obtained is about 33 items per 4.25 km^2 or 7.8 per km^2.

Most of this debris accumulated during the past 10-15 years, the period of extensive fishing effort in the Bering Sea and Gulf of Alaska (Fredin 1985). The data of Jewett (1976) and Feder et al. (1978) were taken at the peak of fishing effort before the imposition of reduced catch quotas in the U.S. EEZ, so debris would be expected to have accumulated since then at a slower rate. Nevertheless, accumulations today probably exceed those of a decade ago. Certain types of debris, such as tires and bottles do not disintegrate and accumulate indefinitely. Freeman (1987) claims that 50% of trawls contain trash in some areas of the West Coast. However, more recent and extensive data are needed to validate this estimate.

IV.F. SUMMARY

These reports indicate considerable uncertainty about the fates of various items and materials in the marine environment. The same items (e.g., trawl webbing, gill netting and packing straps) may be found on the surface, on beaches or at the bottom, and it is not obvious what processes control this distribution. Nets set or snagged on the bottom are obviously more likely to be found there, and nets found at the surface were probably lost there. However, the extent of sinking of nets (and other debris) lost or discarded at the surface is uncertain and may be the most important factor in determining the overall benthic debris budget.

This section considered what insights can be gleaned from a close study of one area of the ocean in which some detailed data are available on one type of debris, derelict fishing gear. Gill netting and trawl webbing appear to dominate this segment of the debris budget, in terms of both amounts of material lost and documented impacts. Which of these two has greater significance cannot be determined without further study.

Larger questions also remain about the role of fishing gear in the overall debris budget of this region and the ocean as a whole. The earlier estimates of NAS (1975) indicated that debris generated by cargo and crew of merchant ships, and crew of fishing vessels, far exceeded derelict fishing gear as a source of debris on a global scale. Nevertheless, fishing gear may be the most important source of debris in heavily fished areas such as the Bering Sea and North Pacific Ocean. It would be valuable to have estimates of other sources of debris in this region to determine if the apparently dominant role of fishing debris is caused by the magnitude of debris sources or (more likely) from the different fates of different types of debris. It might be possible to estimate the magnitude of other debris sources by applying existing data on rates of refuse generation (e.g., Parker et al. 1987) to data on numbers and sizes of merchant and fishing vessels. The emphasis on fishing gear in this region may be appropriate, even if it is only a small segment of the total debris input, because this material has produced a relatively high incidence of observed impacts.

V. FATES AND IMPACTS OF BENTHIC DEBRIS

There are extremely few data on the fates of fishing gear, or any other marine debris, after it leaves the surface. The major sinks for debris in the ocean are beaches and the sea bottom. On beaches burial, abrasion, microbial degradation and photooxidation continue to break down debris. On continental shelves, input of sediments and attachment of fouling organisms can bury or degrade many types of debris. On the deep sea bottom probably only burial is important, and steady state burial is a very slow process in the absence of undersea landslides, turbidity currents, etc. (Wallace 1985). Microbial action is very slow in the deep sea, and modern plastic netting materials are resistant to microbial decomposition.

Gill nets in particular have a high potential for self-entanglement that may affect their transport and effects on biota. Jones and Ferrero (1985) observed a gill net floating at the surface to be entangled into "green rope" by storm action. Large pieces of net and monofilament line have been observed to "ball up" to sizes up to 30 by 100 feet (Wallace 1985). They may snag on the bottom, but if floats are still attached they may also extend surfaceward and present a broad target for entanglement for months or years. Wallace (1985) projected a minimum 50-year life span for sunken nets on the ocean floor. However, that is undoubtedly a substantial overestimate of the functional life of the netting, especially in shallow water.

High (1985) observed impacts of underwater entrapment by sunken gill nets set on or near the bottom. These nets have a high loss rate because they are often set near wrecks or other underwater obstructions that attract fish. In experiments, the rate of escape by Pacific cod once netted was only 14%. Nets designed to fish slightly off the bottom and in the near-bottom water column did so only during slack tide, the rest of the time lying on the bottom. Derelict gill nets observed in shallow (<80 m) water in Puget Sound over the course of 6 years continued to capture birds and fish for 3 years and crabs for the duration of observation, with no apparent degradation of the net material. Some of the net material was rolled into piles or bundles by tidal currents, which reduced its capture of fish and birds. Capture was also reduced somewhat by rapid fouling of the nets by algae. Freeman (1987) reported additional observations by High indicating potential crab mortalities in the thousands from a single sunken derelict gill net in Puget Sound.

Similar observations were made on the Atlantic coast by Carr et al. (1985). Demersal gill nets are set in the Gulf of Maine in strings of 10 or more totaling about 1000 m in length, with five or six strings set together. These nets, whether active or lost, can conflict with recreational fishing and trawling. Experimental nets were set and observed by divers. Portions of these nets lost much of their vertical profile over periods of time varying from 2 days to as long as 1 or 2 months, because of twisting by currents and motions of ensnared fish, and because of entanglement with bottom obstructions. Algal fouling occurred but did not appear to affect entanglement. Some capture of fish (Atlantic cod, *Gadus morhua* and tautog, *Tautoga onitis*) was observed before entanglement of the net. Dives were also made in the submersible Johnson Sea-Link, in which 10 ghost gill nets were located over a total surveyed area of 100 acres of bottom that was mostly ledges with rocks and boulders. From the extent of fouling it was estimated that the nets were all more than 2 years old. Four nets that were tangled into large balls, and balled portions of two other nets, contained almost no entangled fish. Four nets that were stretched along the bottom with a profile usually reduced to <0.6 m, and stretched portions of the other two nets, contained entangled fish including (in a typical 90 m section) 12 dogfish, 1 wolffish, 1 sea raven and 1 lobster. Other nets also contained tautog, cunner, cod, flounder and skate. Benthic scavengers such as starfish and crabs were concentrated under all nets, suggesting a steady supply of food fallout from the nets. Although these observations are continuing, the main impact of ghost nets appeared to be on the non-commercial dogfish resource.

High (1976, 1985) and High and Worlund (1979) observed the behavior of derelict crab pots in Pacific waters. Dungeness crabs placed in normal crab pots were unable to escape 23 to 79% of the time, the higher rate being for legal size crabs. The mortality rate was 17% after 12 days and up to 25% after 74 days, and there were indications that dead crabs attracted more crabs to the pots. The duration of ghost-fishing is surely influenced by the amount of self-baiting that occurs after a trap is lost. Unfortunately, there are very few data to assess the extent and duration of self-baiting in these pots. High (1985) estimated the ghost-fishing life span of Dungeness crab pots as at least 6 years. The percentage of king crab failing to escape pots was lower, 8%-20%, and dead crabs did not act as bait for other king crabs. Some cod and halibut are expected to enter derelict pots since 6%-9% of pots retrieved in normal use contain these fish species. Survival of these species in crab pots may be as short as 24 hours (Freeman 1987). On the basis of the observations of Carr et al. (1985) and High (1985), crabs and other scavenging invertebrates may be the most vulnerable benthic species to derelict fishing gear (Coe 1986). Pecci at a1. (1978) studied ghost-fishing in lobster traps in the North Atlantic and found that some lobsters persisted in the traps for several months after being captured, although they were often injured or evenually died. Furthermore, it was noted that lobsters would enter the trap months after the initial bait had been eaten. It is unknown what stimulates this behavior. Smolowitz (1978) pointed out that the impact of ghost-fishing on different species will depend upon species specific behavior patterns that are currently unknown. Although estimates are available on the number of lost pots and the mortality of crabs in the pots, more information is required on the rate of attraction of crabs to derelict pots in order to estimate the absolute mortality of crabs from this source. Alaska law now requires a biodegradable panel in king crab pots which should reduce future losses (Coe 1986).

Other biological impacts of sunken fishing gear are mainly matters for speculation. Gear on the sea bottom is unlikely to entangle birds except in very shallow water. Diving birds (such as murres) can be entangled in drift or ghost nets to depths of several meters; 60%-80% of birds entangled in drift nets are diving birds (Wallace 1985). Sunken fishing gear has the potential to entangle other benthic feeders such as walruses and grey whales, sperm whales and beaked whales. However, there is no documentation of entanglement of such animals from benthic sources. The impacts of derelict hook-and-line fishing gear appear to be less extensive than those of netting and traps (Coe 1986). Observations of derelict halibut longlines by High (1985) showed that these pose little hazard, despite being lost in large quantities, because they do not attract fish once they lose their bait and tarnish, which happens within a few hours or days.

There are some types of benthic debris that may be beneficial. Organic enrichment of parts of the sea floor by the carcasses of midwater organisms in trawl cod ends, for example, is a nutrient source for benthic scavengers. There may be localized inputs of organic matter to the benthos due to entangled or captured fish, birds and mammals. Therefore, a major difference between gill and trawl nets may be the size of organic load they bring with them to the bottom. A lost gill net, even with many organisms entangled in it, is very likely to carry less of a load of fish than does the cod end of a trawl net. DeGange and Newby (1980) reported retrieving a section of gill net containing about 225 salmon and 115 seabirds. In contrast a single trawl cod end may contain up to 50-70 tons of fish.

Some materials are intentionally placed in marine environments to enhance fishery habitat. Debris such as derelict ships and junked cars is used in places to create artificial reefs that provide habitat on featureless bottoms. Most debris that settles to the seafloor will be beneficial to some species because it provides additional substrate for settlement. This is evident from observations of debris, even at the sea surface, that is covered with encrusting organisms. On hard bottom environments the increase in available space for settlement may be insignificant. In fact, these may represent less desirable locations for settlement because they are less stable than the natural substrate. However, in soft bottom environments the addition of debris that provides substrate for attachment will provide habitat for new species and increase the ecological diversity of the community. Although the original community will be altered, increased diversity is often considered to be a desirable ecological feature.

Lost fishing gear also can impact humans directly (Coe 1986). Although shipping is impacted primarily by surface debris, benthic debris can affect recreational and commercial bottomfishing, and submarines and submersibles. Wallace (1985) cites several incidents per year of encounters of British submarines with fishing nets in use. There may be simple ways to estimate such encounters through surveys of marinas, shipyards, etc. Sunken nets also are a potential hazard to SCUBA divers, who also are attracted to sunken wrecks (High 1985). No formal study has apparently been conducted of the frequency of encounters by divers and ships with floating or benthic debris, but such occurrences are commonly mentioned as potential hazards (Evans 1971; Wallace 1985).

There is little documentation of biological impacts of other types of benthic debris. Polystyrene and polyurethane are commonly found in floating forms and may be less significant to the benthos. Pruter (1987) cited three examples in the Severn estuary and Bristol channel, U.K., where polystyrene pellets were found in sediments near shore, or had been ingested by young flounders (Kartar et al. 1973; Morris and Hamilton 1974; Kartar and Abou-Seedo 1976). Ingestion of small particles of all types must be considered a potential hazard for bottomfish. Incidence of plastic or other small particles in open continental shelf locations would not be detected by trawling. Therefore, there are no data to indicate if this is a significant concern.

VI. LEGAL ASPECTS OF BENTHIC DEBRIS

The problem of debris in the ocean is best approached by preventative (educational or legal) rather than cleanup methods. Any legal remedy involves the tremendously difficult problem of enforcement, which requires at least identification of offenders if not witnessing of any violation. Furthermore, the legal regime is different in international waters than the U.S. 200-mile Exclusive Economic Zone (EEZ) and different for foreign fleets than for domestic.

In international waters three legal regimes are relevant to this problem (Lentz 1987): the Law of the Sea (LOS) Convention; the 1978 Protocol to the International Convention for the Prevention of Pollution from Ships (MARPOL); and the Convention on the Prevention of Pollution by Dumping of Wastes and Other Matter, also known as the London Dumping Convention (LDC). These treaties have both similarities and differences in jurisdictions and sanctions.

Article 5(1) of the LOS Convention prohibits discharge of any substances or energy that results or is likely to result in "such deleterious effects as harm to living resources and marine life," and other articles include vessels as pollutant sources subject to this restriction. Other provisions in the LOS Convention specify rules for cooperation between signatory states. One of these clauses requires coastal states to reimburse ship owners for fishing gear lost in the attempt to avoid damage to submarine cables or pipelines. The LOS Convention is structured to accomodate issue-specific international rules and standards such as those of MARPOL and LDC.

MARPOL is structured around the assumption that about one-third of marine pollution originates with vessels. Annex V of MARPOL specifically treats garbage pollution and prohibits "the disposal into the sea of all plastics, included but not limited to synthetic ropes, synthetic fishing nets and plastic garbage bags." Accidental losses, where adequate precautions have been taken to reduce such losses, are exempted. Annex V MARPOL was ratified by enough nations to bring it into force internationally on December 29, 1988. It requires stronger U.S. controls on discharge of ship-generated garbage beyond the three-mile territorial limit.

The LDC, written in 1972, is the only global agreement solely concerned with dumping in the sea. It defines categories of prohibited wastes, and includes plastics and other synthetic materials that may interfere with "legitimate uses" of the sea. However, the LDC has generally been applied to dumping of waste loaded from landbased sources for disposal at sea, rather than to ship-generated sources. Lentz (1987) noted that LDC and MARPOL appear to have some overlapping jurisdiction, but that LDC should be interpreted to include all non-accidental discharge of waste materials regardless of origin.

Lentz (1987) also discussed regional compacts such as the International Convention for the High Seas Fisheries of the North Pacific Ocean, between the U.S., Canada and Japan, as legal instruments for controlling waste disposal. This agreement (and the global Strategy for Fisheries

Management and Development of the Food and Agricultural Organization of the United Nations) could be interpreted as mandating optimal utilization of resources and so might be used to prohibit the unintentional catch and entanglement of birds, fish and mammals in the North Pacific that accompanies some disposal practices.

The complex situation regarding the jurisdiction of U.S. law over marine debris has been reviewed by Gosliner (1985) and Bean (1987). Five major legal instruments are targeted specifically at disposal of harmful substances in the ocean: the *Marine Fishery Conservation and Management Act* (MFCMA) of 1976, the *Marine Protection, Research, and Sanctuaries Act* (MPRSA) of 1972, the *Federal Water Pollution Control Act* (FWPCA), the *Resource Conservation and Recovery Act* (RCRA) of 1976, and the *Marine Plastic Pollution Research and Control Act* of 1987, which implements the provisions of MARPOL Annex V.

The MFCMA mandates the conservation and management of fisheries in U.S. waters. It requires foreign fishermen inside the 200-mile U.S. EEZ to have a permit that may be conditional on restrictions required for such conservation and management. The MFCMA specifically prohibits the intentional discarding of material (including fishing gear) that interferes with navigation, fisheries, or marine mammals by vessels in the U.S. EEZ. Accidental discharges must be reported immediately to the Coast Guard. These provisions do not apply to U.S. fishermen, however.

The MPRSA (which implements the London Dumping Convention in the U.S.) requires an EPA permit to transport any material for the purpose of dumping it in U.S. territorial waters (12 miles). Such permits are not available for material originating outside the U.S. However, wastes generated in the normal operation of fishing, cargo and recreational vessels (including fishing gear) are not prohibited because they are not transported for the purpose of dumping. It is unclear whether the provisions of the MPRSA can be extended to the full 200-mile width of the U.S. EEZ.

The FWPCA prohibits such discharges of hazardous "elements or compounds" within territorial waters and is usually applied to toxic chemicals. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) and the FWPCA authorizes cleanup of hazardous substances in the environment under certain conditions. Application of these two laws to the debris problem would rest on demonstrating that garbage, derelict fishing gear, etc., could be classified as hazardous substances presenting imminent danger to fish, shellfish, or wildlife. RCRA is easier to construe as applying to garbage and fishing gear, but it has not been. Such an application would require new EPA regulations and would need to be accompanied by potentially cumbersome record-keeping.

Landbased sources of plastic to the oceans include direct discharge from industry and discharge by consumers. The former source could be (but is not) regulated by the EPA under the Clean Water Act. The latter discharge, more diffuse and difficult to monitor, is most appropriately policed under state and local authority through such measures as product bans and re-use requirements.

Several wildlife protection laws also could be invoked as a way of attacking the debris problem. These laws include the Marine Mammal Protection Act (MMPA), the Fur Seal Act, the Endangered Species Act and the Migratory Bird Treaty Act. None of these are a preventative measure—they only impose penalties for "taking" a protected animal. The laws do not require intent in order to invoke sanctions against a take that is unpermitted, and they do support prior restraints against some activities if it can be shown that there is a reasonable certainty that such activities will result in an unpermitted take. Difficult enforcement problems face any attempt to apply such laws to the unintentional catch or entanglement of birds, fish, or mammals in discarded fishing gear or garbage, however.

Other procedures for attacking the debris problem include state laws applied to measures enforceable at dockside, such as requiring trash compacters or prohibiting some plastic products. The situation is made more difficult because two separate federal statutes provide for compensation of fishermen for lost or damaged gear. These statutes may be a disincentive for reducing gear disposal. Such claims, however, may provide a source of data on the incidence of gear loss.

VII. CONCLUSIONS AND RECOMMENDATIONS

It is clear from the above analysis that the available data are insufficient to define the impact of marine debris on benthic communities. Much of the required information could be obtained with survey or research projects if the potential threat to benthic communities was considered to be sufficiently great to merit that effort. Table 8 summarizes our current understanding of the benthic debris problem in terms of specific components and our extent of certainty and uncertainty regarding each of these issues.

There are some preliminary estimates of the amount of debris that enters the ocean on a global scale, but these estimates are outdated and cannot be converted directly for use in a localized area. This discrepancy is shown by estimates of fishing gear losses in a case study region in the North Pacific Ocean and Bering Sea. Estimates of local losses exceed the global estimates of NAS (1975). Data are not available to compare debris generated by other sources in this case study area to determine if other findings of NAS (1975) (e.g., that crew- and cargo-generated debris exceeds losses of fishing gear) were valid.

Within this case study area, observations of debris in the environment and of impacts on biological resources also are dominated by derelict fishing gear, especially by gill netting and by trawl webbing, the two predominant types of gear in use. Sightings and impacts are almost totally restricted to the surface environment and floating debris. This fact produces a tendency to discount the potential for benthic impacts to occur and for such impacts to be caused by debris other than fishing gear. The only data available on benthic impacts have come from experiments and

Table 8. Known, uncertain and unknown data on benthic impacts of marine debris.

Category	Known	Uncertain	Unknown
Source	Categories of sources	Relative magnitudes of sources (global) Importance of derelict fishing gear in N. Pacific	Absolute magnitudes of sources (global) Relative magnitudes of sources (local)
Fates	Composition of materials and products General buoyancy of materials and products	Residence times at surface; transport at surface Deterioration of materials and products at surface	Residence time at bottom; transport on bottom Deterioration of materials and products on bottom
Standing stocks		Debris found in trawls in certain areas	Actual debris/m^2 by type and location on bottom Changes over time
Impacts		General types of impacts Types of organisms impacted	Magnitudes of impacts Spatial distribution of impacts Duration of impacts Possible beneficial impacts Significance of impacts for population and yield
Responses	Education and prevention would be most effective	Possibility and effectiveness of enforcing existing laws and treaties Possibility and effectiveness of mandatory recycling or incineration Possibility and effectiveness of degradable materials	Possibility and effectiveness of tracing origin of debris

observations from submersibles that were specifically targeted on that subject. Even these data indicate only the character, not the magnitude, of impacts that occur or might occur.

Despite the scarcity of data, several authors have made tentative conclusions about the significance of marine debris as an environmental problem. According to Laist (1987), the hazard to marine life from plastics of all types is mostly mechanical rather than chemical toxicity. Laist

(1987) noted that the incidence of documented impacts is low, but also noted that "the absence of overwhelming direct physical evidence of the problem is not necessarily unexpected or reassuring." Alverson (1985) stated that despite the uncertainties around impacts of debris, "...there is adequate data on hand to suggest that the distribution, diversity and quantity of marine debris are increasing (in most areas) and that the consequences to marine life and human safety should not be taken lightly." Coe (1986) indicated that derelict fishing gear is not yet a significant pollutant, but that nevertheless actions to reduce losses would be worthwhile. He concluded that high seas gill nets were an "inconsequential addition" to the derelict gear entanglement problem, but that the coastal gill net and trap fisheries were the primary sources of derelict gear known to be affecting fish and invertebrates. To these we should add the apparent impact of trawls on fur seals.

Coe (1986) described the state of knowledge and significance of the problem of benthic impacts of marine debris as follows: "There is an absolute vacuum in the literature on the consequences of sunken fishing gear or any other items in the deep ocean. Fishing gear lost on the high seas or swept off of the continental shelves by currents probably becomes a permanent part of the benthic landscape. These ecosystems are poorly understood and the impacts of the large amounts of virtually indestructible synthetic materials that are being deposited there can only be speculated upon. A beginning must be made in the assessment of the actual response of the major benthic ecosystems to the continuing accumulation of plastic debris of all sorts." That assessment accurately describes the current situation. The research proposed below will help to obtain initial information to begin to understand potential impacts.

VII.A. RECOMMENDED RESEARCH

To better define the potential impacts of marine debris to benthic communities, research needs to be conducted to address the following three questions:

1. How much and what type of debris occurs on the sea floor?
2. What are the effects of different types of debris?
3. What is the significance of benthic impacts to benthic populations?

There are, in addition, research and educational activities that could reduce the potential impacts of benthic debris (by reducing inputs) even without increased understanding of those impacts. Specific research projects are described below.

<u>How much and what type of debris occurs on the sea floor?</u>

This is an essential component for defining the potential impact of anthropogenic materials in benthic communities but there are virtually no data available to evaluate this question. The most direct approach is to obtain survey data on the distribution and abundance of different types of debris. This could be done most efficiently by including it as part of ongoing surveys of fish abundance as has been done recently in the Eastern Bering Sea (June 1989). This type of survey should also be conducted in other regions. Data should be recorded in terms of types and quantity of debris per trawl so that total abundance on the sea floor can be calculated. In addition any organisms that are associated with these items when they come to the surface should be recorded. It may be difficult to interpret information on debris/organism associations because they may have been established or destroyed in the net. However, there are some relationships (e.g., octopi in tin cans, fouling organisms on various debris items) that can confidently be determined to have been established on the seafloor. There are other methods to obtain this type of information such as conducting seafloor surveys with submersibles or establishing a survey specifically to evaluate debris. However, these would be considerably more expensive than adding debris as an additional component to already planned fish surveys. Current estimates of the abundance of debris on the seafloor suggest that it is not a sufficient problem to merit that expense. There may be additional data available from fishermen, or benthic ecologists but it is likely to be anecdotal rather than quantitative. One exception, however, is that Paul Dinnel (Fisheries Research Institute, University of Washington, pers. comm.) has collected data on debris in benthic beam trawls from Puget Sound for several years, but these data would require more analysis before quantitative assessments could be reported.

<u>What are the effects of different types of debris?</u>

Because the potential impacts associated with benthic debris are so speculative it is desirable to obtain more reliable information by direct observation of debris on the bottom. These observations could be made from submersibles, by remote cameras or, at shallow depths, by SCUBA divers. The greatest significance of these observations would be to assemble data for the same set of debris over an extended time period. Observations should be made on the species and numbers of individuals associated with the debris at different times, the persistence of the association and any changes that occur to the debris. For example, one might imagine that bottles sitting on the bottom are quite persistent and barnacles that settle on the bottle will also persist. Ghost nets on the other hand may fish very efficiently initially but slowly close and settle to the bottom where they fish less efficiently. Thus, it is very important to establish what changes in the associations between organisms and debris occur with time. In terms of affecting commercially important populations, the most important types of debris are probably gill nets and crab pots.

Alternatively, one could select a location, monitor it regularly to determine how much and what types of debris enters and leaves the area and what interactions occur with biota in the area. Some of these observations have been made (High 1985, Carr et al. 1985) previously and should be continued and expanded to increase our understanding of debris-biota interactions.

Our review discounted any potential for significant benthic impacts of debris of terrestrial origin, except very close to shore. Terrestrial inputs could include organic loading such as garbage barges or sewage plant effluent or more persistent debris. In either case the effects to the benthos are not well established even in nearshore environments where impacts could be quite important for certain fisheries such as bivalve shellfish. A search should be made for evidence of such effects. Direct observations from submersibles would provide the best documentation of potential impacts.

Observations made at artificial reefs may provide information on colonization by invertebrates and fisheries utilization of these habitats. It must be remembered, however, that these structures are designed to provide beneficial habitat. Random introductions of debris on the seafloor will not necessarily produce the same effects.

A similar experimental approach could be made to evaluate the transport and fate of nets lost at sea. An experiment should be undertaken in which a gill net and a trawl net are deliberately abandoned and their fate monitored for up to several years. Such monitoring is possible with use of transponders and satellite tracking. Ideally data will include residence time at the surface, transport at the surface and in the water column, ghost-fishing capability in the water column and near the bottom, transport and/or burial on the bottom, and persistence of the net. An important parameter to be derived from these data is the percentage of floating debris that ultimately sinks. Obviously, to obtain reliable global estimates, a large number of nets would need to be monitored. However, if sufficient insight is gained on the transport and sinking of surface nets, it then may be possible to estimate the amount of net material that settles in the deep sea. To obtain experimental observations on a derelict net on the deep-sea floor will require the use of a remote-control time-lapse or robot camera.

Some of these observations should emphasize scavenging invertebrates, especially crustaceans, since it has been suggested that these organisms may be the most sensitive to impacts of debris. This examination should include effects of other types of debris besides derelict fishing gear, such as plastic items and cans and bottles. In addition it should attempt to evaluate the role of increased organic loading associated with derelict nets.

<u>What is the significance of benthic impacts to biological populations?</u>

Most impacts of benthic debris, unlike those of surface debris, are never detected by casual observers. Extending the submersible investigations of ghost-fishing by submerged derelict nets and crab traps will provide additional information on potential impacts to individual organisms. From a fisheries perspective, however, it is necessary to combine these observed impacts with estimates of standing stocks and effective lifetimes of debris, and with knowledge of fishery stocks. Then we can obtain estimates of potential fish and invertebrate mortalities analogous to those derived by Fowler (1985, 1987) and Lenarz (1985) for the northern fur seal. Economically, it is feasible to do this only for commercially important stocks and regions that are being studied to obtain fishery data. The comparison with data collected on the effects of benthic debris may allow meaningful evaluations of the overall impact of debris.

The case study approach provides a mechanism to focus on particular regions, species and types of debris. It is a valuable approach that should be continued for examining benthic impacts and is consistent with Coe's (1986) recommendation "to focus this type of research on one or several managed commercial species on the continental shelves such as king crab, Dungeness crab, lobster or halibut in order to have enough information to draw conclusions, or future directions." It would be premature, however, to attempt a global synthesis of benthic debris generation or impacts without more extensive and accurate supporting data. It will be important to broaden the perspective of future investigations to new study areas to include species that have no exact counterpart in the North Pacific (e.g., sea turtles (Carr 1986, 1987; Balzs 1985) and manatees (Wallace 1985)). One case study should be directed at a representative deep-sea environment, possibly involving actual experimental impacts.

There are other types of research that might help us to better evaluate the potential significance of benthic debris even though they do not specifically address that issue. For example, if we could better quantify the discharge of debris from different types of vessels we would have a better estimate of the input terms. Similarly any research concerning the persistence of nets in the water column will also provide information on the potential input of materials to the benthos. We are not endorsing these research subjects because they will not lead directly to increased understanding of benthic impacts. Nevertheless, if such data were available they might be valuable.

The most important activity for reducing impacts of debris to benthic organisms is to reduce the input terms. This can be done through a program of education without any additional information concerning the impacts of the debris. In our study area most derelict fishing gear observed in the past has been associated with foreign fisheries. However, U.S. citizens are taking a rapidly increasing proportion of the catch in the U.S. FCZ, and Japanese and Korean vessels are under increasing restrictions on the disposal of gear and other plastic. Thus, efforts to reduce debris generation in the future might be most effectively focused on U.S. fisheries. Alverson (1985) noted that most of the data analyzed so far related to foreign fisheries, but that much more data were potentially available from U.S. fisheries.

Management measures that could be applied to benthic debris problems coincide with those proposed for dealing with surface debris (Alverson 1985; Chapman 1985): education; identification of gear; acceleration of U.S. effort in the international arena, such as ratification of Annex V of MARPOL; mapping of snags that can imperil gear; development of degradable net and trap components and materials; and exploration of voluntary or mandatory alternatives to disposal such as recycling and incineration. Enforcement of any regulations regarding disposal remains at least as difficult a problem for benthic debris as for surface debris.

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