A REVIEW OF MARINE DEBRIS RESEARCH, EDUCATION, AND MITIGATION IN THE NORTH PACIFIC

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ABSTRACT

The earliest biological investigations and reports of the marine debris problem focused on North Pacific species, principally seabirds and marine mammals. In 1984, the Workshop on the Fate and Impact of Marine Debris in Honolulu brought together scientists and managers to evaluate information on this problem. Based on the recommendations of the workshop this paper reviews research and management activities and results since 1984 in the North Pacific. The Governments of the United States and Japan have been the primary participants in these activities. Both United States and Japanese programs include research and monitoring, mitigation technology, and education, as evidenced by the variety of papers being presented at this conference. The effective implementation of the requirements of MARPOL Annex V, especially in the fishing industries of the North Pacific, is a common goal of most Pacific Rim nations. The fishing industries themselves have made significant commitments to address their contribution to the marine debris problem in the North Pacific. The effects of these actions on the known impacts of persistent debris in the North Pacific have yet to be realized.

INTRODUCTION

The early focus of attention in the marine debris issue in the United States was the North Pacific Ocean and its shores. This was due in large part to the early documentation of the interactions of wildlife with fisheries-generated marine debris. Observations of northern fur seals entangled in debris were recorded as early as 1936 (Fiscus and Kozloff 1972). Records of Laysan albatross ingesting plastic debris date from the mid-1960's (Kenyon and Kridler 1969). In 1974, field biologists began keeping records of entanglement of highly endangered Hawaiian monk seals (Henderson 1985). Widespread ingestion of plastic particles by 37 species of North Pacific seabirds was reported in a study by Day (1980).

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

Starting in the early 1960's, large-scale industrial fisheries proliferated in the North Pacific and in the Bering Sea. Increasing use, loss, and discard of persistent plastic nets, packing straps, packaging, and other refuse from these vessels were evident in surveys of Alaskan beaches since 1972 (Merrell 1985). The general surface circulation patterns of the North Pacific suggest that floating debris may remain at sea for several years before being deposited on shore (Reed and Schumacher 1985). Accumulating evidence of increasing amounts of debris in the ocean combined with observations of its range of impacts on wildlife led to the convening of the first international scientific meeting on marine debris in late 1984.

The Workshop on the Fate and Impact of Marine Debris (FIMD), held in Hawaii in November 1984, was an opportunity for the scientific community to evaluate the state of knowledge about marine debris and to draw conclusions where appropriate (Shomura and Yoshida 1985). Based largely on data from the North Pacific, the working groups at the 1984 workshop concluded that persistent marine debris poses a long-term threat to certain species as well as to maritime and coastal commerce. Observations from other ocean areas suggested that similar problems could exist in all the world's ocean areas. These revelations fostered the initial concern about this new and apparently widespread form of marine and coastal pollution.

In response to the charge to participants, the 1984 workshop prepared a series of findings and recommendations that were to become the guidelines for marine debris action in the North Pacific as well as the world. The executive summary of the workshop report includes the following conclusory paragraph:

> "The Workshop considered the information presented during the technical sessions and concluded that there is ample evidence that debris of both terrestrial and shipborne origin are widespread in the marine environment. While such debris is known to interact with a wide variety of marine mammals, fishes, turtles, birds, and invertebrates, in most instances the consequences and quantitative impacts of this interaction do not appear to be well understood. However, substantial qualitative evidence indicates these interactions are contributing to increased mortality over that resulting from natural causes."

These findings prompted the workshop participants to make general recommendations for information collection to elucidate the sources, distribution, amounts, fates, and impacts of persistent marine debris. Studies of the biological impacts of entanglement and ingestion on North Pacific marine mammals, seabirds, and sea turtles were specifically identified. The development of sampling methodology for beach and sea surface debris--especially fishing gear--was recommended. In concluding that marine debris is a real problem for marine life and vessels, however poorly quantified, the workshop recommended education and mitigation efforts to be undertaken concurrently with the information collection activities. The mitigation efforts were to include regulation of the types of debris most hazardous to marine life, investigations of the use of biodegradable

materials, net recycling, and the promotion of beach surveys and cleanups. Education efforts were recommended to advise user and interest groups of the nature and scope of the marine debris problem. The target groups were to include fishing and plastics industries, merchant carriers, the military, appropriate international organizations, and the public.

The workshop recognized that many of its findings were based on information from the North Pacific Ocean and recommended that the severity of the marine debris problem in other ocean regions be investigated. It also recommended a start on the evaluation of economic impacts of debris by obtaining data on worldwide vessel disablement caused by interactions with marine debris. The need for international cooperation in the investigation and solution of marine debris problems was broadly recognized by the workshop.

With the 1984 FIMD workshop as a starting point, this paper attempts to summarize and review recent marine debris research and monitoring, mitigation, and education activities affecting the North Pacific Ocean. This review includes known United States and foreign activities, brief summaries of their results, and an evaluation of developments and continuing needs in each action area. It is likely that there have been foreign government or industry actions addressing marine debris in the North Pacific that are not reported here. Any such omissions are unintentional. Many of these actions may be reported elsewhere in Shomura and Godfrey (1990).

RESEARCH AND MONITORING ACTIVITIES

Research related to marine debris problems has encompassed biological investigations, measurement of the sources, amounts and distribution of debris, and research and development for technological solutions. Under this section, biological research and the monitoring of debris sources and amounts will be reviewed. Research related to technologies for solving marine debris problems will be reviewed in the Mitigation section below.

Biological Research

Northern Fur Seal Entanglement

The United States, Japan, and the Soviet Union have carried out research related to the entanglement of the northern fur seal, *Callorhinus ursinus*. Until 1985, these research activities were coordinated under the Interim Convention on Conservation of Pacific Fur Seals. Since that time, cooperative research has continued between the United States and Japan at the Pribilof Islands, with each nation also doing independent research.

The northern fur seal population breeding at St. Paul Island in the eastern Bering Sea has been the subject of continuing study of the role of entanglement in fur seal population dynamics. Against a background of a declining population, the hypothesis that entanglement is a principal contributor to that decline was evaluated (Fowler 1985). Research to

elucidate this relationship was primarily confined to the immediate vicinity of St. Paul Island during the summer breeding season.

Scientists from the United States and Japan continued cooperative studies on juvenile male fur seals in order to count and tag entangled seals. These studies (involving roundups) were necessary to simulate the juvenile male harvests which ended in 1984 but from which all previous entanglement rates had been calculated. A sample of nonentangled seals was tagged at the same time to allow for later evaluation of differential mortality based on resighting rates in future roundups. Roundups with tagging were conducted in 1985, 1986, and 1988. Resighting of these tagged seals provides data on the differential survival of entangled and nonentangled juvenile males. Roundups with removal of debris, starting in 1989, are expected to produce the tag resighting data necessary to estimate the changes in survival that may be possible through removal of debris for the period between weaning and the seals' first return to St. Paul Island.

Interpretation of the entanglement rates calculated from the roundups has been complicated by the possible differences in behavior of entangled and unentangled seals. Observations suggest that entangled seals may spend a larger proportion of their time away from the hauling grounds than their unencumbered counterparts. Studies in 1985 of entangled females with pups showed significantly longer feeding forays for entangled females and consequently less healthy pups. An experiment was conducted in 1988 using radio tags on entangled and unentangled juvenile males to measure differences in hauling behavior. Results will be useful in interpretation of prior years', roundup-based tag returns for calculating survival. These results are currently being analyzed with preliminary results presented by Fowler et al. (1990).

Without correcting for possible behavioral differences affecting the calculations, the entanglement rate for juvenile male fur seals has been near 0.4% from the late 1970's to the mid-1980's. Preliminary results for 1988 suggest that this rate may be decreasing due to less entanglement in waste trawl netting. Preliminary results and some interpretation of the tagging and differential mortality studies is presented in the Technical Session on Entanglement.

Both Japanese and United States scientists have carried out research on the behavior of fur seals leading to their entanglement. In 1986, an experiment in which fur seal pups were allowed to swim in a tank with various-sized pieces of netting showed that newly weaned pups were highly susceptible to entanglement in netting as small as 15 cm stretched mesh and that few were able to extricate themselves (Bengtson et al. 1988). Similar experiments in Japan with captive juvenile male fur seals showed that investigative behavior often led to entanglement, but many of these entanglements were temporary. In the Japanese experiments, the materials offered to the seals reflected the ranges of sizes found on naturally entangled, living seals. These experiments demonstrate the susceptibility of fur seals to entanglement in nets of various mesh sizes, and suggest that newly weaned pups may be at particular risk.

For most of the year, the northern fur seal population ranges across the entire subarctic Pacific. This makes coherent studies of at-sea entanglement arduous, expensive, and risky in terms of information return. Consequently, research on the entanglement of northern fur seals during their 9 months away from the Pribilof Islands has been minimal. At the Pribilof Islands, only the survivors are being investigated, giving a potentially biased view of the role of entanglement in population fluctuations. Research reviews and workshops in the United States to elucidate methods of inquiry that may be feasibly and economically applied to this question have been unsuccessful.

Recent data from the Pribilof Islands suggest that the fur seal population may have stabilized. Having been unable in the last 4 years to identify directly the role of entanglement in the fur seal population decline from the 1970's through the early 1980's, further entanglement research at the Pribilof Islands may be unproductive, although monitoring of entanglement rates as an index of hazardous debris changes should continue.

The question is certainly not closed. The impact of entanglement on 0- to 2-year-old fur seals while at sea remains one of the most serious marine debris issues. Resources permit only opportunistic gathering of data in the pelagic range of these animals. Reviews of remote sensing applications and other high technology approaches to this issue have shown them to be prohibitively risky or expensive. It is apparent that a complete, scientific assessment of the role of marine debris in population fluctuations of the northern fur seal will take many more years, if it can be done at all.

Northern Sea Lions

The northern sea lion, *Eumetopias jubatus*, population in the eastern Aleutian Islands has experienced a population decline of about 7% per year, similar to the northern fur seals at the Pribilof Islands. Unlike the northern fur seal, the northern sea lion population in the eastern Aleutians appears to have declined continuously since the 1960's. Concomitant decreases in other North Pacific population centers rule out emigration as an explanation. Entanglement in marine debris was hypothesized as a possible cause for this decline along with changes in prey availability, disease, direct killing by fishermen, and rookery/haul-out disturbances.

Since there were a few observations on record of entangled northern sea lions, surveys of the eastern Aleutian and Gulf of Alaska haul-out sites were conducted in June-July and November of 1985 (Loughlin et al. 1986). In the June-July survey, just over 30,000 sea lions were counted. Six were entangled and five more showed obvious signs of previous entanglement. The entanglement rate in this survey was 0.04% of the adult population. These data were judged inadequate to assess the magnitude of entanglement of sea lion pups because the survey took place before the pups had gone to sea for the first time.

The November survey was conducted to census fur seal and sea lion pups hauled out or stranded in the Aleutian Islands after weaning. This survey

covered nine known haul-out locations and possible stranding sites but found no entangled fur seal or sea lion pups.

These results did help to clarify the role of entanglement in the northern sea lion population decline by suggesting a very low entanglement rate and a possibly high level of escapement from entanglement, at least in adults. Just as with the northern fur seal, the question of what may be happening to newly weaned sea lion pups at sea remains unclear.

Hawaiian Monk Seals

Classified as an endangered species under the U.S. Endangered Species Act (ESA), the Hawaiian monk seal, *Monachus schauinslandi*, is afforded special attention to protect it from entanglement. Since 1982, field biologists have collected, catalogued, and destroyed potentially entangling debris found at known monk seal haul-out sites in the Northwestern Hawaiian Islands (NWHI). Wherever possible, seals are freed from debris. Through 1984, records showed 35 incidents of monk seal entanglement, including 8 with scars of previous entanglements (Henderson 1985). From 1985 to 1987, another 19 entanglements have been observed, 3 of which resulted in the death of the animal (Henderson 1988). These 19 incidents represent an increase in the observed rate of monk seal entanglement despite the fact that many haul-out beaches in the NWHI are cleaned at least once a year.

Further information on the effects of entanglement on the Hawaiian monk seal are presented in Henderson (1990).

Seabirds

While there are scattered reports of seabirds being entangled in a variety of materials, the more widespread problem for seabirds is the ingestion of debris, especially floating plastics. Research on marine debris/seabird interactions undertaken in the North Pacific since the 1984 workshop has focused exclusively on the ingestion problem. In 1986, three specific studies of the impacts of plastic ingestion on the seabirds of Hawaii were undertaken cooperatively by the U.S. National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service.

An evaluation of the incidence of ingested plastic in seabirds of the Hawaiian Islands was conducted between May 1986 and January 1987 (Sileo, Sievert, Samuel, and Fefer 1990). Prior to this study, only 2 of Hawaii's 22 species of seabirds had been thoroughly examined for ingested plastic. The study was able to examine 18 of Hawaii's 22 species, finding only 2 species with 0 plastic. The presence of plastic ranged from 0% in gray-backed and white terns and 1% in brown noddies to 94% in black-footed albatrosses. The data suggested that incidence of plastic in birds was related to the level of plastic in their immediate environment.

The other two studies of seabird ingestion of plastics involved the Laysan albatross population at Midway. Sampling of Laysan albatross chicks to determine diet, growth, and general health was initiated in 1987 to measure the relationship between plastic ingestion and growth, and plastic

ingestion and mortality. This study continued in 1989, as the variability in the amounts of plastic fed by parent albatrosses to their chicks has been higher than expected. Chicks in 1987 had on average nine times more plastic in their diet than did 1988 chicks. Preliminary indications are that plastic ingestion may not contribute in any obvious way to chick mortality; its impacts on growth, however, may be detectable (Sileo, Sievert, and Samuel 1990; Sileo, Sievert, Samuel, and Fefer 1990).

Papers presented at this conference indicate that several species of North Pacific shearwaters have been studied for plastic ingestion (Ogi 1990). Further, investigations of seabird ingestion are underway in the South Atlantic by Ryan, in the South Pacific by Gregory, and in the eastern tropical Pacific and the Antarctic by Ainley and others. As in the North Pacific studies, there is, as yet, little evidence of direct damage to most seabird species caused by the ingestion of plastic debris. This indication is by no means proven, although broad acceptance of such a finding may be forthcoming. The working group on ingestion of marine debris is expected to address this generalization and recommend definitive research actions.

Cetaceans

In the period between the 1984 workshop and the current conference, little progress has been made in distinguishing between evidence of cetacean entanglement in marine debris and cetacean entanglement in active fishing gear. In most cases, the animal is encumbered by some fragment of fishing gear or rope but is found stranded on shore or adrift at sea away from any direct source. There has been no accumulation of records since the 1984 workshop to indicate that North Pacific cetaceans are threatened by marine debris through entanglement. A direct review of this phenomenon using all available information has not been undertaken. The value of such a review should be discussed in the working group on entanglement.

The subject of ingestion of marine debris by odontocete cetaceans was reviewed by Walker and Coe from 1987 through 1988 and is reported in the Technical Session on Ingestion in these Proceedings. While Walker and Coe (1990) found virtually no ingestion of debris by free-ranging pelagic odontocetes, they describe several cases of severe trauma to captive dolphins due to plastic ingestion. This review also finds that Baird's beaked whale, *Berardius bairdi*, and the sperm whale, *Physeter macrocephalus*, which feed in the benthos, commonly ingest foreign materials that have sunk to the sea floor. This work also suggests that the filter-feeding mysticetes may be at much greater risk of ingesting debris than their toothed cousins. A review of current worldwide information on the ingestion of foreign materials by the mysticete whales and the impacts of ingestion seems justified, as does further investigation of the benthic-feeding odontocetes.

Sea Turtles

Balazs (1985) summarized the body of information on entanglement in and ingestion of marine debris by all species of sea turtles. While the North Pacific is home to at least four of the seven species of sea turtles,

all of which are protected under the ESA, the majority of research on the impacts of debris is being done in the southeastern United States. Because they are clearly vulnerable to entanglement (Balazs 1985), are relatively indiscriminate feeders (Lutz 1986), and are all endangered or threatened under ESA, sea turtles wherever they are found must be considered at serious risk from marine debris. Balazs and Choy (1990) provide an update on our knowledge about this problem for North Pacific sea turtles.

Research on the impacts of entanglement and ingestion on hatchling and juvenile sea turtles are being conducted by the Archie Carr Center for Sea Turtle Research at the University of Florida. This work is concentrating on the loggerhead turtle, *Caretta caretta*, in the Atlantic and will continue for at least 2 more years. The results of these studies regarding the role of convergence zones as debris sinks and sea turtle rearing areas may be generally applicable to other species of sea turtles, including those in the North Pacific.

Debris Sources and Amounts

The 1984 Hawaii workshop expressed concern about persistent debris at sea, on beaches, and on the sea floor. The principal focus of this concern was lost or discarded fishing gear, especially netting, traps, and ropes. These materials were judged to present the greatest hazard to marine life and ships through ghost fishing and entanglement. Since that time, research has been carried out to establish methods for surveying debris on beaches and at sea, systematic surveys have been conducted on beaches in Alaska, surveys of floating debris have been made from a number of vessels, a marine debris reference collection has been established, and trawl surveys of benthic debris have been completed.

Methods

A variety of approaches have been used to measure debris on beaches. Methods vary from geographic region to geographic region and from worker to worker. Most approaches have sound statistical underpinnings and reflect the experience and preferences of the survey initiator. Ribic and Bledsoe (1986) examined Alaskan beach survey data from Merrell (1980, 1985) and data from a number of sighting survey cruises in the North Pacific. They recommended methods for carrying out surveys of lost nets at sea and on beaches. Most of these recommendations focused on improving the ability to detect changes in debris density over time. From ship survey data for floating net sightings in the North Pacific and Bering Sea (Jones and Ferrero 1985), these workers calculated that net surveys in these regions would need to include at least 2,800 sampling units (1-h watches) in order to detect a reduction of 50% with 95% confidence. These surveys should be run annually and be designed to permit identification of, and stratification for, local concentrations of debris. This work also recommended that the suitability of aerial survey techniques for marine debris be evaluated.

Specific to entanglement problems in the North Pacific, the 1984 Hawaii workshop recognized the need for identifying the fishery of origin of nets and other fisheries materials found on animals and on the beaches.

In response to this need, the NMFS established a reference collection for fishing gear debris in the Alaska Fisheries Science Center in Seattle. Researchers with unidentified fisheries debris from the North Pacific may send a sample to the curator of this collection along with all pertinent information and receive an evaluation of its composition, the likely fishery of origin, and other pertinent information that may be available.

Debris Surveys

Since the work of Ribic and Bledsoe, there have been a large number of at-sea debris surveys, much of it from Japanese research and patrol vessels (Mio and Takehama 1988; Yagi and Nomura 1988). The surveys reported by Mio and Takehama involved 17 vessels covering 80,546 nmi in the North Pacific and recording 7,458 sightings, 1,584 of which were seaweed and 1,082 were wood, or 0.06 synthetic debris items of detectable size per track mile. Yagi and Nomura reported debris sighting data from vessels repeating a north-south transect from Japan to New Guinea from 1977 to 1986. This survey averaged 39 debris sightings annually in an average 4,000 km surveyed, or just under 0.01 items per track mile. An increasing trend in the number of plastic sheets and bags was identified in this series; however, no overall increase in plastic debris was obvious.

Cooperative research cruises each year since 1986 between the United States and the Republic of Korea and Taiwan have gathered data on the at-sea distribution of marine debris. These results are contained in the NMFS cruise reports (unpubl. data) but have not been consolidated or analyzed for time series or regional comparisons.

Some of the early research (Day 1980; Day et al. 1985) on ingestion of plastic particles by seabirds led to the speculation that a large amount of disintegrating plastic debris may be afloat in the convergence areas of the North Pacific. The density and characteristics of the microdebris were investigated by Day under contract to NMFS in 1987 and 1988. Samples were taken at 27 stations using neuston nets with mesh sizes in intervals down to 0.053 mm, and at 46 stations with mesh sizes in intervals down to 0.50 mm. In general, Day found areas of floating plastic particles all over the North Pacific, with the highest concentrations near Japan and just south of the Subarctic Front. The specific findings and interpretation of this work are reported in Day et al. (1990).

Ribic and Bledsoe (1986) concluded that "The usefulness of beach survey information is almost entirely dependent on the capability to infer ocean debris conditions from the beach information." The coordination of shipboard and beach surveys is essential if the utility of beach survey data is to be confirmed. Further, the lifetimes and dynamics of debris on beaches need to be understood if one is to conduct independent surveys over time in regions of interest. It may be necessary to remove or permanently mark debris to evaluate lifetime and movement as well as to ensure independence from survey to survey.

To date, there have been no coordinated ship/beach debris surveys to evaluate the relationship between amounts and types of floating and stranded

debris in any region of the North Pacific. Johnson and Merrell (1988) report on time series of beach debris surveys from selected beaches in Alaska, where they cleaned sections of beach and also tagged large debris items. From this work they have been able to estimate the rate of deposition of entangling materials on certain Alaska beaches. At Yakutat, the deposition rate of trawl nets was estimated at seven nets/km/year. As a result of his debris tagging work, Johnson discovered that large net debris may be buried, uncovered, and moved along the beach by severe winter storms Investigations into the dynamics of beached debris are continuing in Alaska and are further reported in Johnson (1990).

As part of the effort to protect Hawaiian monk seals from entanglement in debris, the research teams routinely survey, catalog, and remove nets, ropes, etc. from beaches in the NWHI. The net materials found in these surveys from 1982 to 1986 were reported by Henderson et al. (1987) and are updated by Henderson (1990). The collections through 1985 amounted to 632 nets or net fragments, 539 of which were poly, i.e., polypropylene or polyethylene, and 66 monofilament nylon. All of the monofilament net fragments were from gillnets and 54 of these were most likely from Asian squid and salmon driftnet fisheries. It was concluded that most of the poly nets and net fragments were from North Pacific midwater and bottom trawls. The fisheries of origin of this unexpectedly high proportion of trawl net materials on the beaches, and the ocean current systems that brought them to the NWHI, are yet to be established. Since the number of nets per kilometer of beach was quite high at several of the most important pupping beaches, and monk seals, unlike northern fur seals, entangle in a wide range of mesh sizes, the sources of poly fragments in the NWHI need to be understood and minimized.

Interest in the nature of accumulations of sinking debris on the Continental Shelf led to the enumeration of debris in bottom trawl surveys in the eastern Bering Sea in 1987 and off the U.S. west coast in 1988 (June 1990). These surveys were for groundfish abundance in areas of sand or mud bottom. The survey nets were set up to fish hard on the bottom, making it likely that debris in the upper few centimeters of the sediment would be scooped into the nets and be recorded. In general, the concentrations of sunken debris reflect the level of vessel activities in the areas. As one would expect, high traffic areas have greater debris densities than low traffic areas. Also, the types of debris found on the bottom generally reflect the surface activities.

In an attempt to elucidate the sources of net fragments in the North Pacific and the Bering Sea, a study of NMFS Foreign Fishery Observer Program data was conducted (Berger and Armistead 1987). The records from 1,068 observer cruises in 1982-84 in the U.S. exclusive economic zone (EEZ) provided data from every month of the year. The amounts of net discarded, lost, retrieved, or seen floating were recorded, as were net-mending activities and fishing operations. In 1982, 1983, and 1984, respectively, 14, 31, and 17% of the net pieces discarded were in the mesh size range to entangle fur seals. During this period, a total of 1,551 pieces of net were brought up in trawls and most were discarded back into the ocean. In 1983, foreign joint venture operations lost 70 trawl nets or large portions

of nets. In 1984, this number increased to 90 nets. Foreign fishing in the U.S. EEZ has been almost completely displaced since 1984, but it is not known if the loss and discard rate of nets and net fragments has changed. Under the U.S. domestic law implementing MARPOL Annex V, it is illegal to discard net fragments, and one would therefore expect the amount of net input into the U.S. EEZ in the North Pacific to decrease in the coming years.

Another applied study of the disposition of derelict fishing gear in the North Pacific was reported by Gerrodette et al. (1987). In this study, a series of monofilament drift gillnets were attached to satellite transmitters and set adrift to simulate lost sections of squid or salmon driftnet. The purpose of the study was to gather information on the size, shape, location, and length of time in the ocean. Four nets, 50, 100, 350, and 1,000 m long were released on 12 August 1986 in the vicinity of Hancock Seamounts, northwest of the Hawaiian Islands. The nets were tracked by satellite from 57 to 309 days. The 50- and 100-m nets collapsed within hours of being deployed. The 1,000-m net was reduced to approximately 15% of its original length after 9 days adrift. It appears that there is a positive correlation between the length of the drifting section of gillnet and its ghost fishing effectiveness. The complex tracks of the nets showed that prediction of the drift paths of derelict fishing gear requires a detailed knowledge of the local surface currents and wind conditions. Recent Japanese studies of drifting gillnet (Mio et al. 1990) confirm these general findings; however, the ghost fishing characteristics of a lost, full length, pelagic driftnet (approximately 5 km) have yet to be measured.

Lastly, voluntary public beach cleanups have been organized to the extent that a uniform method of data collection is being employed in the western United States and Hawaii (Center for Environmental Education 1988). The data from these annual cleanup programs may have some utility as indices of the long-term changes in the amounts and types of beach debris in various regions. The myriad promoters of this voluntary initiative are intent on the development of a worldwide International Beach Cleanup Day using the same data collection methods. Over a 10-year period, the success of the implementation of MARPOL Annex V may be seen in the data from these extensive but infrequent (once or twice per year) samplings. They should be broadly promoted.

MITIGATION

Under this section, the collection of activities whose objective was to lessen the input of persistent debris into the ocean, and especially the North Pacific, are summarized. These actions include technical assessments and developments of waste handling and disposal technologies, as well as legal and administrative efforts. Recent progress in both categories affects most ocean areas, including the North Pacific.

Legal and Administrative Actions

On 30 December 1988, the terms of optional Annex V of the International Convention for the Prevention of Pollution from Ships as modified by

the Protocol of 1978 (MARPOL 73/78) entitled "Regulation for the Prevention of Pollution by Garbage from Ships" entered into force for 35 nations representing slightly over 50% of the world's registered shipping tonnage. The MARPOL Annex V prohibits the discharge of plastic from ships into the ocean and sets distance-from-shore limitations for the discharge of other types of ship's garbage. Table 1 summarizes the discharge requirements of Annex V. Ships are defined under MARPOL 73/78 as all surface and subsurface craft as well as all fixed and floating platforms regardless of size. Annex V also identifies five special areas in which all discharge of garbage is prohibited. There are no special areas in the Pacific Ocean.

The principal North Pacific coastal nations that have ratified, and are implementing, MARPOL Annex V are North Korea, Japan, the U.S.S.R., and the United States. The domestic implementing legislation for Annex V differs somewhat between nations but, typically, flag vessels of signatory nations must meet the discharge requirements worldwide. All vessels within the EEZ's of signatory nations must meet the discharge requirements.

The Japanese showed concern over the trashing of the Pacific as early as 1970, when they enacted Domestic Law 136, "Law Relating to the Prevention of Marine Pollution and Maritime Disaster," which prohibits discharge of nets or net fragments and promotes onboard incineration. At the urging of the Fur Seal Commission in 1983, Japan joined the United States and the U.S.S.R. in a campaign to protect fur seals from entanglement by stopping the dumping of fishing gear and by cutting plastic strapping bands before discard. In June 1987, the Fisheries Agency, the Government of Japan (formerly the Fisheries Agency of Japan) established the Fishing Ground Preservation Division to carry out a broad range of projects related to the marine debris problem and its solutions. This program sponsors the research on the types and distribution of marine debris in the North Pacific reported above, and promotes a broad range of recycling, cleanups, and public education efforts, principally through prefectural governments and regional fishing organizations. Japanese domestic regulations implementing MARPOL Annex V were set in place in March 1988.

In response to the northern fur seal entanglement problem and the 1984 FIMD workshop, the United States set up the Marine Entanglement Research Program in the National Oceanic and Atmospheric Administration (NOAA). This program is charged with formulation and execution of research, mitigation, and education activities to address the marine debris problem in U.S. waters.

At the request of 30 U.S. Senators, and under the direction of the White House Domestic Policy Council (DPC), NOAA convened the Interagency Task Force on Persistent Marine Debris, which included the Departments of Defense, the Interior, Transportation, and Agriculture as well as the Environmental Protection Agency (EPA), the Office of Domestic Policy, the Marine Mammal Commission, the Office of Management and Budget, and the Office of the President. The Task Force reviewed the problem and produced a set of recommendations for United States actions. The DPC approved and published the Task Force Report in May 1988 (NOAA 1988). As implemented, these recommendations will have far-reaching impacts on the control of persistent marine debris in the North Pacific.

Table 1.--Summary of at-sea garbage disposal regulations. Source: Guidelines for the implementation of Annex V of MARPOL 73/78 (IMO 1988). (Note: The Baltic Sea special area disposal regulations took effect on 1 October 1989.)

Types of refuse disposed	All ships except platforms[a]		Offshore platforms[a]
	Outside special areas	Special areas[b]	
Plastics, including synthetic ropes and fishing nets and plastic garbage bags	Disposal prohibited	Disposal prohibited	Disposal prohibited
Floating dunnage, lining, and packing materials	Disposal permitted >25 nmi offshore	do	Do.
Paper, rags, glass, metal, bottles, crockery, and similar refuse	Disposal permitted >12 nmi offshore	do	Do.
All other garbage including paper, rags, and glass, comminuted or ground[c]	Disposal permitted >3 nmi offshore	do	Do.
Food waste not comminuted or ground	Disposal permitted >12 nmi offshore	Disposal permitted >12 nmi offshore	Do.
Food waste comminuted or ground	Disposal permitted >3 nmi offshore	Disposal permitted >12 nmi offshore	Disposal permitted >12 nmi offshore
Mixed refuse types	(d)	(d)	(d)

[a]Offshore platforms and associated ships include all fixed or floating platforms engaged in exploration or exploitation of seabed mineral resources, and all ships alongside or within 500 m of such platforms.

[b]Garbage disposal regulations for special areas shall take effect in accordance with Annex V 5(4)(b).

[c]Comminuted or ground refuse must be able to pass through a screen with mesh size no larger than 25 mm.

[d]When garbage is mixed with other harmful substances having different disposal or discharge requirements, the most stringent disposal requirements shall apply.

A wide range of activities have been undertaken in international organizations and commissions that recognize and address the marine debris issue. The broadest possible recognition of persistent marine debris as a legitimate marine pollutant has been a goal of the United States. As a result of actions by the United States, Japan, and others, the marine debris problem has appeared on the agendas of the International North Pacific Fisheries Commission, the International Fur Seal Commission, the Intergovernmental Oceanographic Commission, the Commission for the Conservation of Antarctic Marine Living Resources, the Food and Agriculture Organization, the United Nations Environmental Program, and, of course, the International Maritime Organization (IMO). One of the principal products of these international actions is the publication of guidelines by IMO (1988). The main objectives of these guidelines are:

- to assist governments in developing and enacting domestic laws which give force to, and implement, Annex V;
- to assist vessel operators in complying with requirements set forth in Annex V and domestic laws; and,
- to assist port and terminal operators in assessing the need for, and providing, adequate reception facilities for garbage generated on different types of ships.

All maritime nations are encouraged to ratify and implement Annex V, using the guidelines to help standardize international practice.

The provision of adequate port reception facilities to receive ships' garbage has been a significant concern expressed by port and terminal operators in the United States. Two projects were undertaken at North Pacific ports to evaluate this issue: one in the west coast fishing and logging port of Newport, Oregon, and one involving Unalaska/Dutch Harbor and Kodiak, Alaska. The Newport Marine Refuse Disposal Project found that community and port user involvement in, and ownership of, the local marine refuse problem led to a high level of usage of port reception facilities. Further, efficient waste management practice in the port was maintained by integrating the garbage reception system with recycling and reuse programs in the community and with waste oil reception sites. The lessons from the Newport Project are reported by Recht (1988). Currently, under a grant from NMFS the Pacific States Marine Fisheries Commission is conducting a program to assist eight west coast ports in their development and provision of adequate garbage reception facilities.

The results of the Unalaska/Dutch Harbor and Kodiak evaluations of port garbage handling problems were released in October 1989. Results suggest that the waste disposal facilities of these remote, highly vessel-dependent ports may be strained by the addition of vessel garbage. This is particularly true for Dutch Harbor, where the landfill life may be shortened significantly. These problems are complicated by the need to handle and dispose of waste oil, hazardous wastes, and garbage requiring special handling for pest control. Preliminary suggestions for solutions involve recycling, incineration, and regional consolidation of certain high-capital

waste handling facilities. The experiences gained in this project and the Newport Project are generally applicable to ports all across the Pacific Rim.

The State of Washington has developed and published a Marine Plastic Debris Action Plan as a guide for state agencies in addressing the marine debris problem (Washington State Department of Natural Resources 1988). This plan is an excellent model for coastal states seeking guidance on organizing to deal with marine debris issues. California and Alaska are in the process of developing state policy and action plans.

The principal maritime nations of the North Pacific that have not ratified Annex V are Canada, Mexico, the People's Republic of China, the Republic of Korea, and Taiwan. Domestic laws of these nations addressing garbage discharge from ships have not been reviewed for this paper. It is known that the Canada Shipping Act provides the Canadian Government with the authority necessary to establish garbage regulations more stringent than Annex V. The Government of Canada is currently reviewing options for marine debris programs and controls. The Republic of Korea has developed a guide for the conservation of marine mammals and salmonids in the North Pacific which requires fishing vessels to retain, and return for shore disposal, all plastics and waste fishing gear, and to maintain a record of these actions. Legislative and policy actions on marine debris in other North Pacific countries have not been widely reported.

Mitigation Technology and Procedures

In general, efforts to develop or improve technology and procedures to reduce, control, or eliminate marine debris and solid waste have been carried out by private industry, by governments, and by independent organizations. This work covers shipboard-specific waste handling procedures and equipment, fishing gear technologies, incineration, recycling, and degradable materials. Little of the research and development in these areas has been specific to the North Pacific or to the marine debris problem. However, these developments are germane to controlling marine debris input to the North Pacific and are briefly discussed in this section.

Shipboard Waste Handling

Since the 1984 FIMD workshop no primary technology has emerged to control either ship-generated or land-source debris entering the oceans. The variety of applications and needs has operated to broaden, rather than narrow, the technical and procedural options open to all who must dispose of wastes. While regulatory systems seem to have progressively restricted disposal options on land, most regulators are allowing vessel operators to choose methods most suited to their circumstances. Absent any substantive reasons to the contrary, preserving all technical options that allow disposers to meet the requirements of the law should result in higher levels of compliance.

In 1986, NMFS contracted for a review of shipboard waste handling options. The report (Parker et al. 1987) produced a table showing the

applicability of various waste disposal methods for various types of ships. Limited data on waste generation rates, ship configurations, and procedure capacities required some assumptions to be used in developing the table. The most general findings in this study were that:

- controlled incineration could be used aboard all but the smallest vessels;
- in using compactors, all but ships with very high crew complements (military vessels) should be able to store their compacted wastes on board;
- storage of uncompacted wastes on board is limited to fishing boats, research vessels, and others where the vessels are large relative to crew size; and
- waste generation rates on most vessels are too low to make recycling an economically attractive approach.

Alig et al. (1990) and Martinez (1990) review the more recent developments in shipboard waste handling technology and procedures.

The entry into force of Annex V has resulted in increased use of, and experimentation with, burn barrels for disposing of plastics and other garbage aboard ships with small crews, especially fishing boats in the North Pacific. The NMFS commissioned a study of the design and use of burn barrels to provide information on their technical feasibility, safety, and environmental considerations (SCS Engineers, Inc. 1989a). The work concludes that burn barrels are currently legal outside 12 nmi, may be regulated by coastal states inside 12 nmi, are not yet regulated by the EPA, are capable of reducing certain types of garbage to ash, and, under certain conditions, can be operated safely (Chang 1990). Operating and safety guidelines for the use of burn barrels aboard ships were prepared (SCS Engineers, Inc. 1989b). However, neither NMFS nor the contractor for these studies advocates the use of burn barrels.

Degradable Plastics

Since the 1984 FIMD workshop, the replacement of disposable plastics and fishing gear with degradable plastics has been widely discussed. This has been characterized as a potential solution for ghost-fishing problems caused by lost and discarded fishing gear, as well as a potential solution for litter and landfill capacity problems. Substantive research and development work on these types of plastics has been renewed after some initial work in the early 1970's. Most of this work is being done within the plastics industry and is proprietary. The American Society for Testing and Materials has formed a technical committee to define and develop standards for degradable plastics. In the mean time, there have been many commercial claims of product performance and applications for degradable polymers. Whether these products or future products will play a substantial role in controlling future plastic waste impacts on the environment remains to be seen.

The single recent study of the degradation properties of certain polymer types in marine and terrestrial settings was carried out by Andrady (1990). There has been no applied research on the use of degradable polymer products in the fishing industry. The primary work has been in the applications of natural fiber connectors or linkages in traps and pots to reduce their ghost-fishing life. Some coastal states around the North Pacific require natural fiber lacings or hangings in side panels or tunnels of crab, lobster, and fish traps. Ideally, these rot out shortly after the device is lost, rendering the trap harmless. A recently realized drawback to these approaches is that most natural fiber twines on the market are now fortified with some percentage of polymer fibers and do not rot as quickly or completely as expected (W. G. Gordon, New Jersey Marine Science Consortium, Sandy Hook: Executive Office, Building 22, Fort Hancock, New Jersey 07732, pers. commun. February 1988).

Fishing Gear Marking

Ghost fishing and entanglement are a widely recognized result of the loss and discard of fishing gear and gear fragments. The MARPOL Annex V explicitly excludes the accidental loss of fishing gear from its plastics discharge prohibition. This is sensible because, as a rule, fishermen balance the cost of replacing gear and the associated lost fishing opportunities against the expected value of their catch. Under most circumstances, this equation limits the risk of gear loss to economically acceptable levels. However, as long as fishing is a legitimate activity, some gear will continue to be lost. The wildlife and vessel hazards presented by this continuing accumulation will remain after all other plastic debris is controlled.

It has been suggested that the control of loss, discard, and abandonment of fishing gear could be improved through the use of marking systems. Nonremovable marks presumably could allow derelict gear to be traced back to its owner so punitive action could be considered. Thus, marking systems might add to fishermen's incentive to avoid loss, cease discard, and put more effort into recovery. The practical application of such marking systems would require a complex administration and a near-foolproof technology to succeed.

Under a grant from NMFS, a review of potential fishing gear tagging methods was conducted. The materials used in commercial fishing gear, their manufacturing and assembly techniques, and their working parameters were reviewed. Marking techniques considered were in the following categories: external tags, implants of various types, color codes, chemical codes, and bonded sheaths. This study (Northwest Marine Technology, Inc. 1989) concluded that it is technically feasible to mark fishing gear and that the optimum system will depend on the gear type. It points out that no matter what type of system is employed, extensive record keeping would be required if vessel-of-origin information is to be retained. This study did not evaluate the socioeconomic or political suitability of application of these techniques for any specific fishery or region.

It remains to be seen whether future improvements in fishing technology and procedures will actually reduce gear losses and increase

recovery rates or merely enable greater risks to be taken. This issue will be given increased attention in the United States in coming years.

The Marine Plastic Pollution Research and Control Act of 1987 required NMFS to report on the utility of using bounty systems and incentive systems to control the loss and discard of fishing gear in the ocean. To address this question, NMFS funded a workshop on these subjects in February 1988 in Portland, Oregon. The workshop concluded that artificial mechanisms to control fishermen's compliance with the regulations implementing MARPOL Annex V would be premature (Alaska Sea Grant 1988). It was recommended that education programs be continued and that such consideration wait until the required reports of compliance are made by the U.S. Coast Guard. If compliance levels are unacceptable then regulatory mechanisms should be explored in consultation with the fishing industry.

Recycling

Efforts to recycle postconsumer plastics have met with a wide variety of successes in recent years. In general, the controlling factors in the economic viability of plastic recycling appear to be the volume, supply, and purity of feedstocks. With few exceptions, subsidies have been necessary to entice recyclers into the mixed, postconsumer plastics arena. The municipal waste streams of urban areas are rich in plastics but require labor-intensive sorting. Technology for automated, mixed-waste sorting is under development, but separating polymer types may not be feasible. In response to this realization, a number of processes and products for recycled mixed plastics have been and are being developed. Current product examples include substitutes for outdoor lumber, watering troughs for farms, and fillers for pillows, padding, and insulation.

Plastics recycling in Japan dates back to 1964. Nylon six gillnets have been actively recycled by melt reprocessing since 1974 (Matsunaga 1988). Products from the recycled nylon six gillnets include automotive and appliance parts, telephones, heels for shoes, golf tees, light structural reinforcements, and plastic reinforced glass products. In recent years, nylon 6 has been largely replaced by nylon 66 in North Pacific fisheries because it is thinner and stronger. Nylon 66 cannot be recycled because of its heterogeneous properties, and Japanese net recycling capacity exceeds the supply of nylon 6 (Matsunaga 1988). Fishing gear recycling is currently unprofitable and must be subsidized by Federal and local governments (Nakamura 1988). Research programs in the Fisheries Agency, the Government of Japan are exploring new processes for recycling fishing gear (Takehama 1988). Aizawa and Satou (1990) report on the disposition and recycling of plastic products including nets.

It is noteworthy that in both Japan and the United States there appears to be a considerable demand for used fishing nets for less demanding fishery applications as well as for nonfishery uses. These uses include shellfish culture, seaweed drying, garden uses, erosion control. sports goals and backstops, and decorations. It is encouraging that domestic demand may absorb at least some of the nonrecyclable gear while recycling and other disposal alternatives are developed. Ports accepting

waste fishing gear under Annex V requirements should explore ways to encourage this demand.

MARINE DEBRIS EDUCATION

Recognizing that littering is chronic in developed and developing nations; that dumping at sea is a time-honored disposal method; that cheap, persistent plastics have changed the nature of the litter problem; and that terrestrial and marine enforcement capabilities are limited at best, realistic progress in the minimization of input of persistent wastes into the marine environment can only be brought about through gross changes in public attitudes and behavior. Education and example are repeatedly identified as the processes for effecting such changes.

Recognition of the ocean and coastlines as valuable national resources is particularly strong among the North Pacific Rim nations. Each of the cultures around the Pacific embodies an ocean ethos, the foundations of which lie in their maritime heritage. This heritage is based on resource utilization, trade, and transportation. A growing appreciation of the relationships between ocean (and environmental) health, productivity, and human use patterns appears to be making these cultural sentiments vulnerable to change. Education programs addressing the marine debris problem are intentionally or unintentionally using the broad appeal of the ocean and coasts to take advantage of this vulnerability. By moving a society's ocean ethos towards the belief that a clean ocean has value, individuals in that society will be less inclined to act counter to that belief.

The maritime heritage, hence the ocean ethos, varies widely among the cultures and subcultures around the North Pacific. To have a lasting effect on the attitudes and behaviors of a subculture (such as regional, ethnic, or industrial), education must be either so general that it does not seriously conflict with the world view or highly specific to that subculture's interests and vulnerabilities. In some cases, an education approach may fit both criteria. Marine debris education programs around the North Pacific have been combinations of both approaches.

Concern over entanglement of northern fur seals and ghost fishing by derelict gillnets in the North Pacific dictated that the first marine debris education program be focused on the fishing industries. In 1983, the North Pacific Fur Seal Commission funded the preparation and distribution of a poster requesting fishermen of Canada, Japan, the U.S.S.R., and the United States to control their discharge of net fragments and packing bands to reduce seal entanglement. Starting in 1985 in the United States, NMFS developed information, documents, and other educational materials for distribution to the fishing fleets of the Pacific Rim nations. Seminars and printed materials were given to every fishing association and fisheries management entity on the U.S. west coast. Formal presentations were made, and printed matter was distributed in Japan, the Republic of Korea, and Taiwan in 1986. Fishing industry associations independently and in conjunction with NMFS carried out marine debris awareness activities and developed and distributed information. The fishing industry sponsored a coast-wide meeting on the marine debris issue for fishermen in Newport, Oregon in July 1986.

The Newport meeting was followed by an international, industry-sponsored North Pacific Rim Fishermen's Conference on Marine Debris in Kailua-Kona, Hawaii, in October 1987. Sponsorship and participation in this conference came from fishing industry groups and associations from Canada, the Republic of China, Japan, the Republic of Korea, and the United States. The conference recommended a set of marine debris research priorities and adopted a resolution declaring the fishing industries' commitment to controlling their part of the marine debris problem. A group of fishing industry associations on the U.S. west coast used this resolution to develop an engraved plaque entitled "Fishermen's pledge for a clean ocean." The proceedings of this conference (Alverson and June 1988) are a valuable source of information about North Pacific marine debris programs and actions.

In response to all manner of inquiry from the public, NOAA established a west coast Marine Debris Information Office in San Francisco in late 1988. This office distributes 16 separate packages of general marine debris information depending on the nature of the request received. Requests for information may be mailed to:

Center for Marine Conservation
Marine Debris Information Office, NOAA
312 Sutter Street, Suite 606
San Francisco, CA 94108 U.S.A.

The broadest possible audience has been sought through the production of a variety of posters, brochures, and videotapes. An award winning 7 1/2-m video called "Trashing the oceans" was produced in 1987 and has been shown all over the world. This production is suitable for general audiences and is available from NOAA or the Marine Debris Information Offices. The NOAA, the Society of the Plastics Industry, and the Center for Marine Conservation (CMC) worked together to develop and distribute brochures and public service advertisements through marine trade journals and magazines nationwide (Bruner 1990; Debenham 1990).

Judie Neilson first organized large-scale, public, voluntary beach cleanups focusing on the persistent waste problem in Oregon in 1984 (Neilson 1985). The idea has caught on in every coastal state in the United States as well as in Japan. In 1988 in the United States, 47,500 volunteers cleaned 5,630 km (3,500 mi) of shoreline, removing almost 1,000 tons of trash. These data were collected by the volunteers and assembled, analyzed, and reported by CMC with support from Federal and private sources (CMC 1989). The results of the cleanups have been widely reported in local and national media, used in congressional testimony, and incorporated into ever-broadening education programs.

In an attempt to ensure the widest possible understanding of the requirements of MARPOL Annex V and to build the basis for compliance, NMFS has contracted for the development and implementation of a shipping and cruise lines industry education program (Wallace 1990). This activity is directed at all vessels and vessel operators plying U.S. waters, regardless of nationality. Products from this work will include model shipboard waste

management plans, summaries of the U.S. regulations implementing MARPOL Annex V, and packets of information on the impacts of marine debris. Delivery of these materials will be through corporate offices, union offices, and associations of shipowners and officers.

Programs initiated by the Fisheries Agency, the Government of Japan in recent years have included fishing industry and public education components (Yagi and Otsuka 1990). Voluntary beach cleanups have been organized in the coastal prefectures. Seabed cleanups involving fishermen and divers are being carried out in ports and high-use coastal areas. In 1986, 3,959 km^2 in 25 separate areas were cleaned. Several general video presentations on the marine debris problem, on cleanups, and on the national marine debris program have been produced for wide national and international distribution.

The Republic of Korea has developed an education program and a set of regulations to control the discharge of waste fishing gear from its fishing vessels (Lim 1988). Each year, vessel captains are required to attend a training session by the National Fisheries Research and Development Agency which includes marine debris education. The admiral of the Korean Deep Sea Fisheries Association is charged with educating Korean fishermen against discharging entangling materials. The full extent of Korean and other Pacific Rim countries' marine debris education activities, apart from fishing industry actions, is unknown.

Finally, in an effort to raise the world level of understanding and appreciation of all facets of the marine debris problem, the NMFS initiated and acted as principal sponsor for the Second International Conference on Marine Debris.

CONCLUSIONS

The recommendations from the 1984 FIMD workshop have not been fully met. Research on the impacts of marine debris on wildlife has not established a clear understanding of the role of entanglement and ingestion in the population fluctuations of any marine species. Efforts to measure the sources and amounts of persistent debris have been greater in the North Pacific than in any other ocean area, but a full understanding of the dynamics of input, output, and circulation remains well in the future.

However, since the FIMD workshop, mitigation and education efforts have enjoyed the highest priorities. By international standards, legal and administrative actions to address the marine debris problem have progressed rapidly. The entry into force of MARPOL Annex V marks the primary international step in controlling ship-generated debris. Technological solutions for solid waste in the oceans and on land are now receiving major attention from government and industry sectors around the Pacific Rim. Education programs continue to expand, reaching people all over the world, even though the high level of international cooperation recommended by the FIMD workshop has not been achieved. As domestic policy and problems are addressed, the opportunity for, and suitability of, international action will increase.

Research

The research community addressing persistent waste pollution of the oceans is in a period of transition. Researchers, particularly biologists, initially noted the effects of marine debris as an oddity, not necessarily associated with their primary research. Since the FIMD workshop and the entry into force of MARPOL Annex V, the study and understanding of this type of pollution has become a legitimate, although minor, activity purposely incorporated into marine research agendas. As this evolution proceeds, definitions of terms are accepted, methods of inquiry are shared and generalized, new disciplines are involved, the literature is established, and the underpinnings of a new subdiscipline are solidified. The next 5 years will undoubtedly see the recognition of a marine faction of the solid waste research community including biologists, chemists, oceanographers, engineers, economists, lawyers, and possibly an institution or two. The work of this community is likely to be more applied than basic, as the immediate problems of solid waste management at sea and along the coasts must be solved to comply with current and future statutes. This emphasis will likely result in the diversion of limited resources from research on the biological impacts of marine debris.

While North Pacific species (northern fur seal, Hawaiian monk seal, Laysan albatross) have been the most intensively studied, inability to field pelagic research programs continues to prevent full elucidation of the role of debris in population changes. Increased knowledge of the behavioral and physical mechanisms of impact and the materials involved has strengthened the deductive evaluations of effects on populations, particularly for northern fur seals. Should international field research programs be developed for North Pacific high seas driftnet fisheries, information may become available to assess further the impacts of marine debris on fur seals. The experiments necessary to finally assess the physical impact of plastic ingestion on seabirds and sea turtles should be undertaken immediately. Studies on the possible toxic effects of plastic ingestion should also be initiated.

Specific regional studies of the direct and indirect costs to coastal communities resulting from debris are overdue. Collection of information on the incidence of vessel damage caused by persistent marine debris has been sporadic and mostly anecdotal. There have been few recent studies of the impacts of ghost fishing on target or nontarget species, on fisheries production, or on profitability. These types of information are essential for evaluating the range of economic impacts of debris and for crafting appropriate solutions. Clear, broadly applicable models for evaluating the economic impacts of accumulating marine debris would be valuable tools used worldwide.

Mitigation

Marine debris mitigation is proceeding apace. Laws are being passed, attitudes are changing, and industries are getting the message. The relationship between marine debris and the overall solid waste crisis is the real key here. The marine problem will not be completely solved until the

land-based disposal problem is solved. Broad public concern for the ocean and coastal environment has allowed a start to be made; there can be no turning back. The timetable for control depends on the rate of development and implementation of rational solid waste disposal practice. For the near future, two areas of emphasis are evident. First, the remaining North Pacific Rim nations must accede to MARPOL and ratify Annex V. Second, the focus for the next several years must be on technology, policy, processes, regulation, enforcement, and education to fully implement MARPOL Annex V. On land, appropriate combinations of source reduction, recycling, incineration, substitution, and use of landfills must be sought. Within 2 to 5 years, control of persistent waste discharge into the ocean could be fully institutionalized around the North Pacific Rim. This endeavor assumes increased international cooperation in the provision of port reception facilities, in enforcement, and in promoting responsible waste management by all maritime nations.

Education

At least in the United States, the power of ocean issues to stir public action has been increasing for several decades. The marine debris issue has become a major rallying point for advocates and educators alike, catalyzing public awareness and action on an array of environmental issues. A high level of volunteerism is being achieved in public and industry education programs. Apparently, the United States and much of the developed world are ready to accept the responsibility for solving the marine debris problem. It is an issue whose time has come, one that may open the way for increased public insistence on, and acceptance of, a more responsible environmental policy.

Each nation must develop and effectively distribute information on its laws and regulations to implement MARPOL Annex V or its national equivalent. Timely, informed assistance in this implementation phase is critical to the long-term public acceptance of these requirements. All vessel operators and ports need this assistance. It should be noted that widely publicized examples of enforcement actions can be highly educational.

For the immediate future, existing education materials should be translated and adjusted as necessary for broad international use. The beach cleanup programs should be expanded to include all coastal nations. The cleanup data should be reported as widely as possible. Outlets for marine debris education materials should be established and publicized by all national and international agencies having environmental or maritime responsibilities. These are all low-cost, highly credible activities that should appeal to most governments and organizations. After all, who is willing to say, "I support marine debris?"

Finally, the Third International Conference on Marine Debris should be held in 1994 or 1995 to document world progress on this issue.

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