NOAA Technical Memorandum NMFS

JULY 1985

PROCEEDINGS OF THE WORKSHOP ON THE FATE AND IMPACT OF MARINE DEBRIS
27-29 November 1984, Honolulu, Hawaii

Richard S. Shomura
Howard O. Yoshida
(Editors)

NOAA-TM-NMFS-SWFC-54

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Center

NOAA Technical Memorandum NMFS

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Richard S. Shomura and Howard O. Yoshida (Editors)
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Sponsors: **Fish and Wildlife Service**
Marine Mammal Commission
National Marine Fisheries Service
North Pacific Fishery Management Council
Pacific Fishery Management Council
Pacific Sea Grant College Programs
Western Pacific Fishery Management Council

NOAA-TM-NMFS-SWFC-54

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary
National Oceanic and Atmospheric Administration
Anthony J. Calio, Deputy Administrator
National Marine Fisheries Service
William G. Gordon, Assistant Administrator for Fisheries

PREFACE

The events leading to the organization of the Workshop on the Fate and Impact of Marine Debris are described in the Executive Summary. In addition to the Executive Summary, the proceedings of the workshop contains an introduction, the full text of the papers presented at the three technical sessions, abstracts of oral presentations, an abstract of a poster session, and reports of the four Working Groups. All technical papers were reviewed by one or two referees. Although some papers report research in progress, the completeness of the records related to marine debris is enhanced by their inclusion.

In the Appendices are listed the steering group, the agenda of the workshop, a list of participants, a list of titles of background and working papers, and a bibliography on entanglement.

As Chairman of the Steering Group of the Workshop on the Fate and Impact of Marine Debris, the senior editor had the pleasure of working with individuals representing a wide spectrum of the scientific community: Officials of state and federal agencies, officials of the Marine Mammal Commission, Executive Directors of the North Pacific, Pacific and Western Pacific Fishery Management Councils, representatives of several conservation groups, and officials of fisheries agencies of the Governments of Japan, Republic of Korea, and Republic of China (Taiwan). The success of the workshop was ensured by the willingness of individuals to contribute and participate in the various sessions.

Suzanne Montgomery of Washington Communications Service, 150 N. Muhlenberg Street, Woodstock, Virginia, prepared the Executive Summary.

Special thanks are extended to the University of Hawaii Sea Grant College Program for their assistance in handling the logistics of the workshop and aiding in the preparation of the proceedings for publication.

Pacific Sea Grant College Programs contributing funds for the workshop included the University of Hawaii (NOAA Grant No. NA81AA-D-00070), the University of Alaska (NOAA Grant No. NA82AA-D-00044C), the University of California (NOAA Grant No. NA80AA-D-00120), and the University of Washington (NOAA Grant No. NA84AA-D-00011). This proceedings is also a Hawaii Sea Grant College Program cooperative report, UNIHI-SEAGRANT-CR-85-04.

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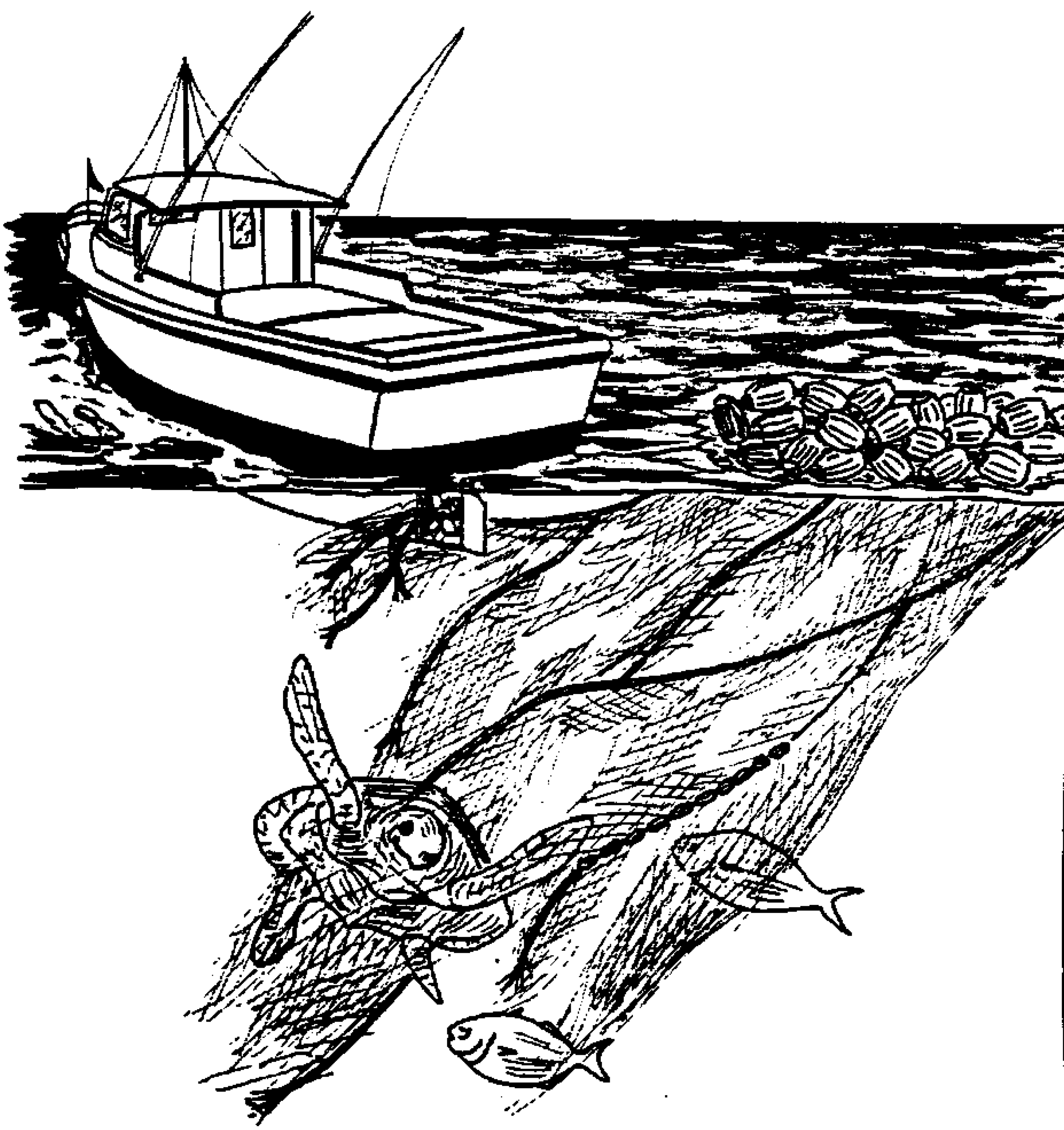
EXECUTIVE SUMMARY



EXECUTIVE SUMMARY

I. INTRODUCTION

For the past decade, concern has been growing among scientists, fishermen, conservationists, and others over the markedly increased volume of marine debris apparent in the world's oceans. This form of marine pollution may be a particularly serious problem in the North Pacific Ocean, where an abundance of lost or discarded fishing gear and other nonfisheries-generated material, including cargo nets and plastic packing bands, may be contributing to the mortality of several marine species. These include marine mammals, notably northern fur seals and Hawaiian monk seals, marine turtles, seabirds, and fishes--organisms which may become entangled with or ingest man-made debris. This debris may also pose a potential threat to human safety as a result of fouling vessel propulsion systems.

Many of those concerned have pointed out the need for a more precise definition of the problem. In 1982 the Marine Mammal Commission asked the National Marine Fisheries Service (NMFS) to organize a workshop to address the marine debris issue and provided initial planning funds for that purpose. In December 1983 the Southwest Fisheries Center Honolulu Laboratory, NMFS, established a Steering Group to organize an international workshop to address the scientific and technical aspects of the marine debris problem and its impact on marine resources. The Workshop on the Fate and Impact of Marine Debris took place 26-29 November 1984 at the Ala Moana Americana Hotel in Honolulu, Hawaii.

Objectives.--The objectives of the Workshop, as defined by the Steering Group were to: (1) review the state of knowledge on the fate and impact of marine debris to determine the extent of the problem; (2) identify and make recommendations on possible mitigating actions; and (3) identify and make recommendations on future research needs. The Steering Group recognized that active fishing operations, such as the high seas gill net fisheries in the North Pacific, may also pose a serious threat to marine species, but determined that this problem was beyond the scope of the planned Workshop. Thus, the Honolulu Workshop was limited to consideration of marine debris and its impact on marine species.

Workshop Organization.--To lay the groundwork for subsequent discussion, the Workshop was opened with a review of the existing conventions, laws, and regulations that could provide a legal framework for dealing with the problem of marine debris. Background and experience papers on three aspects of the problem were presented in the technical sessions that followed. The session topics were: the source and quantification of marine debris; the impact of debris on marine resources; and the fate of marine debris in the world's oceans. Because of the broad public interest in the topic, particularly as regards the entanglement issue, a fourth, general session was held to focus on identification of management needs.

Upon completion of the technical sessions, participants met in four separate Working Groups to discuss the results of the technical sessions and to formulate recommendations on needed actions. At a final plenary session, Working Group chairmen summarized the results of these deliberations for consideration by the Workshop participants as a whole.

Sponsors and Participants.--Sponsors of the Workshop included: the U.S. Fish and Wildlife Service, the Marine Mammal Commission, the NMFS, the North Pacific Fishery Management Council, the Pacific Fishery Management Council, the Pacific Sea Grant College Programs, and the Western Pacific Regional Fishery Management Council.

Participants included representatives of these groups along with scientists from various disciplines, administrative and management personnel from Federal and State offices, and representatives of the fishing industry, the academic community, conservation groups, and aquaria. Although participants were primarily from the United States, scientists from the Republic of Korea, Japan, the Republic of China (Taiwan), New Zealand, Canada, the Federal Republic of Germany, and the United Kingdom were also present.

II. BACKGROUND

The tendency of marine mammals and other marine species to become entangled in pieces of fishing or cargo nets, packing bands, and other debris lost or discarded at sea has been recognized for many years. In the mid-1960's, the North Pacific Fur Seal Commission noted the increasing number of northern fur seals in the harvest that were becoming entangled in material lost or discarded by fishermen and the merchant fleet. Over the past decade, the four nations party to this convention--Canada, Japan, the United States, and the Soviet Union--have attempted to check this problem through an educational program directed at the fishing operations in the North Pacific Ocean.

Over this same period, it has become apparent that the problems of entanglement are not limited to northern fur seals, but also involved other marine mammals species, including the endangered Hawaiian monk seal, sea lions, harbor seals, and northern elephant seals. Other incidents involving entanglement of seabirds, marine turtles, and fish have also been recorded.

Simultaneously, it has been found that some species, including endangered species of sea turtles and many species of marine birds, are ingesting ocean debris, such as plastic bags, small plastic pellets (believed to be the raw form of material used in molding plastic products), and other man-made materials.

While many of the incidents of entanglement and ingestion of marine debris have been observed in the North Pacific Basin, data from other areas of the world show that the problem is global.

In most instances, the extent of entanglement in and ingestion of materials by marine species is not known; nor is it clear what impact this interaction between marine animals and man-made debris may be having on individual animals or populations as a whole. There is reason to believe, however, that entanglement of northern fur seals in net fragments, lines, packing bands, and other debris may be a significant mortality factor.

Based on data analysis carried out in preparation for the April 1982 meeting of the North Pacific Fur Seal Commission, a preliminary estimate of the annual mortality rate due to entanglement at that time was that it was more than 5% of the population as a whole. Subsequent analyses indicate that mortality from entanglement may exceed the original estimate and probably has its greatest effect on young animals.

There are also questions about the sources of such debris and what ultimately happens to it once it enters the marine system. However, it is increasingly apparent that marine mammals, seabirds, turtles, and fish are becoming entangled in or are ingesting man-made debris lost or discarded in the oceans.

III. SUMMARY OF TECHNICAL SESSIONS

The Workshop program included 29 invited background and working papers presented during 3 technical sessions. The technical sessions focused on: Source and quantification of marine debris, chaired by Dayton L. Alverson; impacts of debris on resources, chaired by Douglas G. Chapman; and fate of marine debris, chaired by James D. Schumacher. A summary of the technical sessions follows.

Session I. Source and Quantification of Marine Debris

The purposes of this session were to describe sources of marine debris and, to the extent possible, indicate the quantity that may exist in the North Pacific Ocean. The widespread occurrence of debris was well documented by various papers presented during all three technical sessions of the Workshop. However, it was clear that accurate estimates of the volume of debris both entering and leaving the North Pacific Ocean annually are lacking.

The nature and magnitude of the major fisheries in the North Pacific that could be contributing significantly to marine debris were described by several participants. The high seas gill net fisheries offer a substantial potential for generating debris due to the large quantity of gear used. Uchida reported that 170,000 km of gill nets are used by 15 fisheries annually. The Japanese coastal sardine and herring fisheries represent 72% of this activity. The trend in use of high seas gill nets is not clear, but it appears the reduction in Japanese high seas effort since 1958 (Fredin) is compensated for by the increased Taiwanese squid effort since 1970 (Chen).

The trawl fishery is the other major activity in the North Pacific Ocean with a potential for generating netting debris. While not as large as the high seas gill net fishery in terms of miles of netting in the water, the trawl fishery is a significant effort in the area. Since about 1962, the total trawling effort by all countries has been relatively stable at between 2,000 and 2,500 vessel months per year (Low et al.). This view was generally corroborated by Fredin.

Another significant source of debris was suggested in the presentation by Neilson. Both from land-based and water-related activities, the general population contributes a variety of debris in the form of polystyrene, strapping bands, rope, packaging materials of many types, plastic bags and sheets, and plastic food utensils.

The quantity of debris in the North Pacific was addressed by four papers covering various aspects and geographic areas. Merrell and Neilson described types and quantities of debris found on beaches in Oregon, southwest Alaska, and Amchitka Island in the Aleutians. Merrell reported that trawl netting constituted 67 to 85% of the debris by weight on the beaches studied in Alaska. Neilson reported that a synoptic survey of Oregon beaches yielded 26 tons of material in about 3 h. It was primarily polystyrene, plastic food utensils, bags or sheets of plastic, and plastic bottles. Fishing materials represented a relatively small part of the total.

Dahlberg and Jones reported results of debris observations on the open ocean. From a survey between Hawaii and Kodiak, Alaska, Dahlberg noted geographic areas of concentration, due presumably to the action of ocean currents. The types of material were similar to those reported by Neilson in Oregon. Both Dahlberg and Jones noted that the amount of debris sighted was low, but a paper by Lenarz indicates that the observed densities are not inconsistent with mortality rates estimated for northern fur seals.

Session II. Impact of Debris on Resources

The aim of this session was to present the results of observations of marine debris impacting marine organisms or man, largely at the individual level. A review of the literature by Wallace included some unpublished results of research on debris entanglement and debris ingestion. Also noted were some impacts on humans, including entanglement during underwater activities and in vessel propellers.

Incidences of entanglement have been monitored most extensively for northern fur seals, primarily as part of the subadult male harvest. Since the late 1960's, a record of such observed entanglement has been made for St. Paul Island in the Pribilofs. More intensive studies have been made in recent years. The results, while suggestive, provided only an indirect explanation of the recently observed decline (about 6.5% per year) in fur seal populations in the Pribilof Islands. As part of this work, Fowler developed models which indirectly related the population decline to entanglement, but more recently and more directly, in a paper presented in this session, showed correlations between observed entanglement on land and changes in the number of pups born.

Since Steller sea lions feed also in an area used by fur seals, it is not surprising that these animals are also observed entangled in netting and plastic packing bands. Calkins reported on such incidents and also on beach surveys that attempted to determine the proportion of marine debris on beaches that has potential for entangling animals. Similar observations were reported on by Stewart and Yochem with respect to several species of pinnipeds in the Southern California Bight. In general, rates of entanglement in this area were much lower than for the northern species discussed above.

There are scattered incidences of monk seal entanglement, some in published reports but many in unpublished reports and field notes. Such reports have been collected and were summarized for the years 1976 to 1984 in a paper presented by Henderson.

Three papers reported on entanglement or ingestion of marine litter, primarily plastic bags and pellets. One reported on such incidents in New Zealand, one on marine birds around the world, and one on marine turtles. While the fact of such plastic ingestion is clear, the actual impact on the individual animals is much less clear.

In separate papers, High and Carr reported on directed and incidental observations of various types of lost gear, e.g., crab pots, longline, and gill nets, that have continued to "fish" for periods of several years after becoming derelict. These studies demonstrate that such "ghost" gear will have continuing impact on the resources being targeted by the fishery, but until more is known on the amount and longevity of such lost gear, it is not possible to quantify the impact at the population level.

Session III. Fate of Marine Debris

The goal of this session was to review the state of knowledge on the fate of marine debris in the North Pacific Ocean, including the Bering Sea. Two papers were presented on forcing mechanisms for and behavior of the general circulation, followed by two presentations that viewed the question of fate of marine debris from model perspectives.

From presentations by Seckel and Reed, it is evident that our understanding and description of general circulation have advanced significantly, due particularly to the wealth of direct current measurements made during the past decade. The lack of knowledge of debris behavior with time and the natural variability of the upper ocean, however, preclude prediction of debris transport on an individual item basis. Concentrations of debris, however, were suggested to be most likely in either the Subarctic Convergence Zone or on the west coast of North America from about lat. 40° to 50°N.

Presentations by Galt and Gerrodette focused on model approaches to the problem of debris. Galt indicated processes whereby debris would most likely be concentrated and regions where such processes are active. The Subarctic Convergence was again noted as a region of reduced spreading tendency. Observations presented by Dahlberg indicated higher concentrations of debris actually existed here. Gerrodette presented a conceptual model, based on population dynamics, which considered marine debris as a group of various species whose birth and death rates are poorly quantified. Critical for this approach is information on how much debris exists and where and when it entered the marine environment. This model was a useful framework for Working Group III discussions about possible mitigating actions and for identification of needs for future research.

IV. SUMMARY OF WORKING GROUP MEETINGS

The reports of the four Working Groups reflect the perspectives from which each approached the issue of marine debris in the world's oceans--its origins, its impact on marine species, its fate in the marine environment, and tools for addressing and managing the problem. Full reports of the three technical Working Groups and the Working Group on Management Needs are included in the proceedings of the Workshop. The Working Group reports are summarized here.

As became apparent during the final plenary session of the Workshop, a number of common conclusions and similar recommendations emerged from the individual Working Groups. For example, the groups agreed on the need for: extensive efforts to educate the public on the marine debris problem; quantitative data to assess the impact of debris on marine resources; and increased information to determine the sources and distribution of debris.

Working Group participants agreed that despite insufficient data, available evidence shows that marine debris now threatens a number of marine species, including marine mammals, seabirds, marine turtles, and fish, and presents a hazard to vessel operations. Clearly, the problem is not limited to any group or groups of animals, but can affect commercially valuable species and endangered and threatened species, as well as human safety at sea.

At the same time, the groups recognized that marine debris may have positive benefits for both marine species and man, such as a tendency to concentrate finfish, which should be investigated.

It was also recognized that entanglement of nontarget marine animals in actively fishing gear may pose as great or a greater problem than interactions with marine debris, and it was agreed that this issue should be addressed in another forum.

While the precise impacts on marine populations as a whole are not known, the Working Groups agreed that it was clear that marine debris negatively affects certain marine species on an individual level. These include the northern fur seal, which is experiencing a population decline, and the endangered Hawaiian monk seal. Marine debris also impacts other species, including certain seabirds, turtles, and fish resources. Thus, the Working Groups placed major emphasis on the need for studies to assess the impact of marine debris on marine resources. Such studies should be undertaken in concert with efforts to educate user groups and the public on the marine debris problem and to obtain additional information on its source and extent.

From the common threads woven throughout the four Working Group reports, it was clear that education may be the most effective first step in addressing the marine debris problem. Information programs explaining the problem should be developed for user and interest groups, including the fishing industry, the plastics manufacturing industry, the public, merchant carriers, the military, and appropriate international groups. Such efforts could lead to a reduction in the discard of material from both shipboard and land-based sources and could spur development of relatively simple techniques to reduce the impact of such debris.

The Working Groups recommended that programs be implemented to apprise involved industries and the public of the extent and impacts of marine debris and the means by which these problems might be mitigated. For example, the fishing industry should be advised that wanton discard of unwanted gear and net fragments may endanger not only marine mammals, birds, and turtles, but can impact fish resources through "ghost-fishing" (the tendency of some discarded fishing gear to continue to take fish) and imperil their vessels by fouling propulsion systems.

To mitigate debris problems, crews of merchant vessels should be informed that a step as simple as cutting plastic cargo bands before discarding could eliminate entanglement of marine animals. The plastics manufacturing industry should be advised that disposal of plastic pellets in their factory effluents is jeopardizing certain species of marine birds and turtles. Manufacturers of fishing nets and other gear should be advised of simple measures that could reduce the potential adverse effects of such material on marine species. For example, plastic packing bands could be stamped with instructions that they be cut before they are discarded.

The Working Groups also agreed that the general public should be made aware of the marine debris problem and its help solicited in increasing efforts to clean up beaches and areas where debris may concentrate.

At the same time, the Working Groups agreed that a mechanism is needed to improve the exchange of ideas, data, and techniques on the marine debris problem. It was specifically recommended by one group that the NMFS designate a person of appropriate stature as program coordinator for the marine debris problem. The Working Groups concluded that exchange of such information would be facilitated through a more precise definition of common terms and the assembly of a catalog or reference collection to aid in identification of net fragments and other forms of commonly found debris.

International cooperation was considered essential in addressing the marine debris issue. Working Group I identified possible sources of additional information and expertise that might contribute to an increased understanding of the problem. These sources include the International North Pacific Fisheries Commission data on net design and usage in the northeast Pacific region; available data on U.S. fishing activities in the eastern portion of the North Pacific; and historical observations of entanglement, particularly involving northern fur seals.

The Working Groups also agreed on the need to obtain more information from foreign fisheries operating in the U.S. Exclusive Economic Zone and from fishing activities elsewhere in the world, both to pinpoint origins of marine debris and to determine the extent of the problem. For example, it was recommended that information on fouling of fishing and recreation vessels, as well as other waterborne traffic, should be collected in order to assess the full scope of impacts on marine debris.

Workshop participants identified several steps that could be taken to help determine the origin of marine debris, such as a requirement that all fishing nets be marked for identification, both to determine the origin of the derelict net and the area where it was lost. It was suggested that ocean-going vessels be used as "platforms of opportunity" to help assess the quantity and distribution of debris and that fishing and merchant vessels should be asked to contribute data on rate and location of gear loss so that the fate of such debris could be determined.

The Working Groups also recommended that efforts be initiated to investigate means of regulating sizes and types of mesh used in those sections of nets likely to be lost or replaced at sea. It was proposed that fishermen be required to install biodegradable (e.g., vegetable fiber) material in critical portions of nets and on fishing pots. Accidental loss of nets might be reduced through development of charts to identify areas where snags are known to exist.

It was also considered important to conduct experiments to study the fate of lost fishing nets, including where the nets go, how they are broken down by natural forces, and how long they may pose a hazard to marine life and humans.

Workshop participants noted that, while several species and types of marine animals are impacted by marine debris, it is not possible to make generalizations about the problem. Available information suggests that the northern fur seal is the species most seriously affected by marine debris, but because of limited data, precise estimates of entanglement-caused mortality rates have not been produced. Additional research is needed to gain a better understanding of the effects of debris on northern fur seal population dynamics. At the same time, it will be necessary to address other potential causes of the ongoing decline in the northern fur seal population.

It was concluded that further information is needed to confirm the level of northern fur seal mortality resulting from entanglement; to determine if northern fur seals become entangled in netting of all sizes in proportion to its frequency; to compare the distribution of netting at sea and on beaches; and to measure the drag effect on seals entangled in debris and the impact on the animals' ability to forage. Five specific research projects were recommended to obtain information in these areas: radio-tagging experiments to track entangled seals; placement of marked debris near rookery islands to determine its fate; additional beach surveys to document quantity and types of debris; sampling programs to determine distribution of debris at sea; and comparison on impacts on northern fur seals with those on other pinnipeds.

Workshop discussions suggested that the marine debris problem today may parallel the pesticide problem as it emerged in the 1960's. Just as raptors were the early indicators of widespread pollution by pesticides, northern fur seals may represent the "tip of the iceberg" as regards marine debris. That is, marine debris may be a generic and widespread problem, and investigations of its impact on other species may indicate similar patterns and effects. It was felt that, if additional research on northern fur seals leads to a recognition of a widespread problem, scientists and managers would be in a better position to manage marine resources in general.

V. CONCLUSIONS AND RECOMMENDATIONS

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.

As a means of addressing the uncertainties surrounding this problem while mitigating the known impacts, the Workshop agreed to the following recommendations:

Education.--Efforts should be undertaken to advise user and interest groups of the nature and scope of the marine debris problem. Such groups should include the fishing and plastics manufacturing industries, merchant carriers, the military, appropriate international groups, and the public.

Collection of information.--Studies should be undertaken to:

* Assess the impact of marine debris on marine resources, including fish species, northern fur seals, Hawaiian monk seals, seabirds, and marine turtles.
* Determine the sources and distribution of debris, possibly through development of a sampling methodology.
* Determine the fate of lost gear and debris once it is deposited in the marine environment.
* Develop a means of identifying derelict gear through creation of a reference collection.
* Obtain worldwide data on vessel disablement as a result of interactions with marine debris.

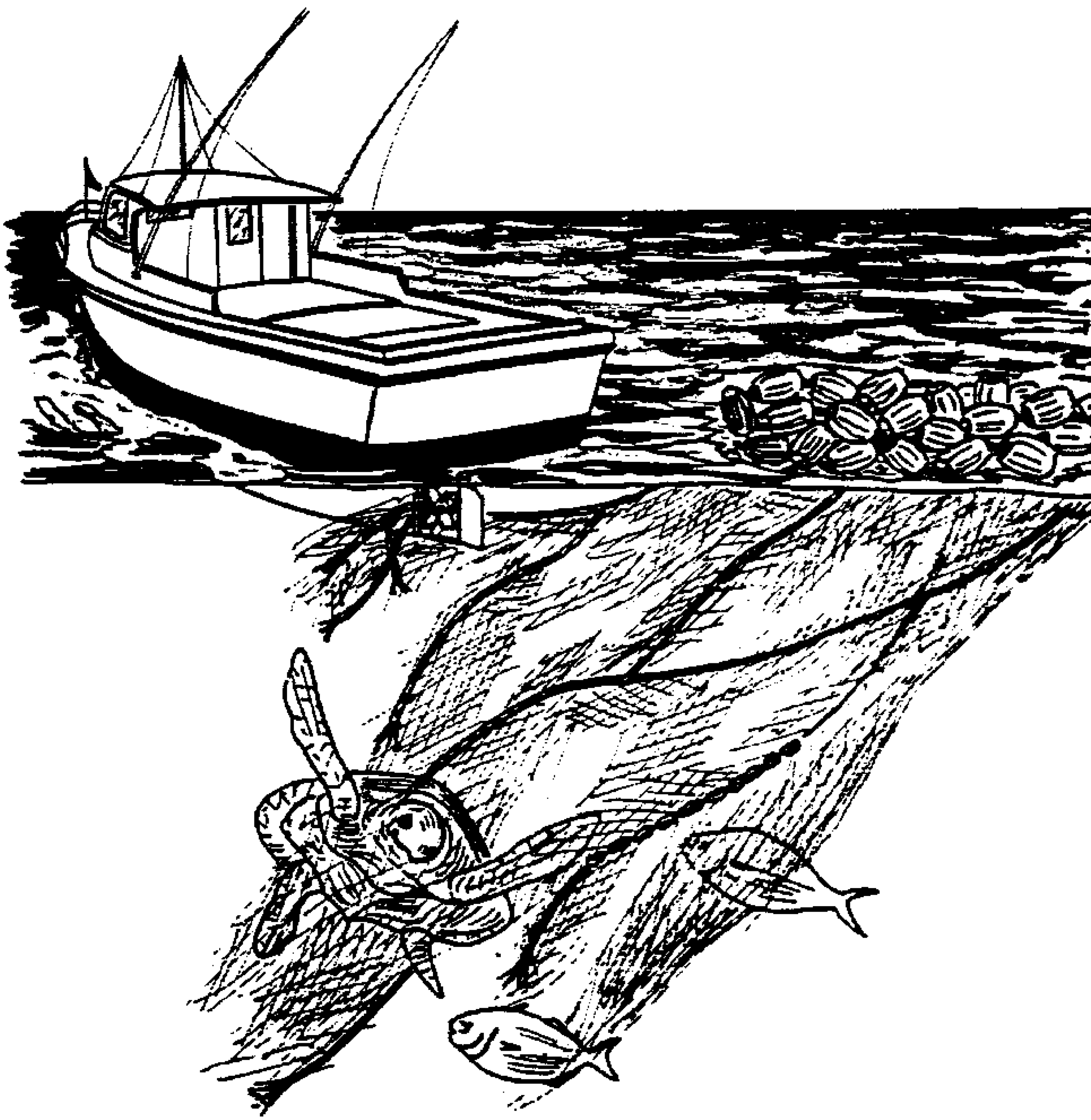
Additional efforts should be undertaken to: Develop alternative methods for both fishing and nonfishing activities to replace those methods that contribute significantly to the marine debris problem; identify and publicize geographic areas where fishing gear is likely to be snagged and lost; determine the impact of debris on the seafloor; obtain data on gear loss of high seas gill net fisheries; establish the severity of the debris problem in areas other than the North Pacific; examine possible positive benefits of debris; determine impacts of ingestion of debris by seabirds and turtles and other marine organisms; and expand existing stranding networks for marine mammals, birds, and turtles, and incorporate examinations for evidence of interactions with debris.

Mitigation.--Two major efforts are recommended:

* Regulate disposal of material that can result in high negative impact on resources; and
* Investigate use of biodegradable materials in gear construction and the recycling of net materials.

Additionally, it is recommended that efforts be made to regulate use of gear that has a major impact on resources and to encourage surveys and clean up of beaches where interactions between marine species and debris is likely to occur.

INTRODUCTION



LEGAL AUTHORITIES PERTINENT TO ENTANGLEMENT BY MARINE DEBRIS

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ABSTRACT

A variety of statutes and treaties are potentially applicable to marine debris, although no law specifically addresses this problem. These laws may be separated into four categories: pollution control laws such as the London Dumping Convention or the Ocean Dumping Act, wildlife laws such as the Endangered Species Act or the Marine Mammal Protection Act, fisheries laws such as the Magnuson Fishery Conservation and Management Act, and pollution abatement laws such as the Superfund Legislation. All of these authorities are analyzed and the enforcement difficulties are considered. Alternative enforcement mechanisms are examined, including gear marking, a bounty system on discarded fishing gear, and an expanded observer program. Where possible, the statutes are examined to determine what types of research would be most useful in filling the information gaps which inhibit effective utilization or enforcement.

ISSUE

The Marine Mammal Commission (Commission), in a letter dated 18 November 1983, requested that the National Oceanic and Atmospheric Administration (NOAA) identify and evaluate all domestic and international authorities which may be useful in preventing the dumping of fishing gear and other debris which may be responsible for the entanglement of marine mammals. The Commission further requested that any authority be identified which might be used to facilitate the recovery of gear fragments and other discarded material already in the sea. In making its request, the Commission voiced its concern for the seriousness of the entanglement problem, particularly with respect to the North Pacific fur seal and the Hawaiian monk seal.

SUMMARY AND CONCLUSION

Although the extent of the entanglement problem is unknown, it has been hypothesized that the numbers of fish, marine mammals, and seabirds killed or injured by discarded fishing gear and other debris are substantial. Several pollution control statutes and treaties which prohibit or limit the dumping of debris into the oceans may be useful in curbing the

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In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

disposal of net fragments and other material. Wildlife statues currently prohibit the unpermitted taking of numerous species and may be useful in reducing the entanglement of birds, fish, marine mammals, and sea turtles.

The Magnuson Fishery Conservation and Management Act (Magnuson Act), which regulates fishing within 200 miles of the United States, may also be used to prohibit the disposal of fishing gear at sea and the entanglement of wildlife. However, for any of these laws to be enforceable the originator of the debris must be identified. Since the disposal of debris generally occurs in remote locations, identification of violators is usually difficult. Alternative methods of enforcement, including more extensive marking of gear, the institution of a bounty on net fragments, or the expansion of the observer network should be investigated.

Even if no additional fishing debris is ever lost or disposed of, that currently in the oceans may continue to present a hazard to fish, wildlife, and navigation. Fishing nets are highly persistent and may remain suspended in the water column indefinitely. Provisions of the Federal Water Pollution Control Act and the Comprehensive Environmental Response, Compensation, and Liability Act arguably provide authority for the clean up of debris within the 200-mile, U.S exclusive economic zone (EEZ).

BACKGROUND

Recently a marked decline in the fur seal populations of the Pribilof and other North Pacific islands has been observed. In 1980, the species population was estimated to be 1.74 million seals. Current estimates place the population at about 1.2 million seals (North Pacific Fur Seal Commission 1984). The decline estimates for the Pribilof Island population is between 5 and 8% per year.

Although it is known that fur seals do become entangled in fishing gear and other debris, mortality rates of entangled seals are unknown. However, it is likely that many of the seals which become entangled in discarded fishing gear or other debris cannot free themselves and ultimately die from strangulation, starvation, or infection. Fowler (1982) has hypothesized that 5% or more of the fur seal population may die annually from entanglement and that this mortality may be a primary cause of the observed decline in fur seal numbers.

In addition to seals, other marine mammals, including whales, may be prone to entanglement. Sea turtles have also been cited as potential entanglement victims. The mortality of seabirds due to entanglement in fishing gear has been estimated to be several hundred thousand per year.

Lost or discarded fishing gear also continues to capture fish as it drifts at sea. This untended activity is referred to as ghost fishing and affects commercial and unexploited species of fishes as well as marine mammals, birds, and turtles. Concern has also been expressed that drifting gear poses a safety threat to vessels. Some entanglement of vessel propulsion systems has been reported.

DISCUSSION

Statutes and Treaties

Most statutes and treaties that are pertinent to the problem of the disposal of fishing gear at sea and the resultant entanglement take one of two tacks. The London Dumping Convention (Convention), the MARPOL Protocol, the Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA), the Federal Water Pollution Control Act (FWPCA), and the Resources Conservation and Recovery Act of 1976 (RCRA) seek to prevent the disposal of harmful substances in the oceans. Wildlife statutes, such as the Marine Mammal Protection Act (MMPA), the Fur Seal Act, the Endangered Species Act (ESA), and the Migratory Bird Treat Act (MBTA) generally prohibit, with certain exceptions, the capturing or killing of species subject to their provisions. This second category of laws does not prevent the discard of debris, except as may be specifically prohibited by regulation if a take is reasonably certain to result. Rather, it imposes sanctions only after a protected animal is actually ensnared.

A third type of statute, which contains components of each of those previously mentioned, is the Magnuson Act. This statute requires the conservation and management of United States fisheries. Regulations issued pursuant to the Magnuson Act specify when and how fish may be taken. Regulations currently prohibit foreign fishing interests from intentionally discarding fishing gear.

Lastly, there are laws which provide mechanisms to abate existing pollution problems. Provisions of the FWPCA and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) authorize the clean up of certain substances. These statutes and treaties are discussed individually and in detail below.

Pollution Control Laws

Pollution control laws regulate what substances may legally be released into the oceans and specify the circumstances under which those releases may be made. The Federal statutes which address ocean dumping are administered primarily by the Environmental Protection Agency (EPA). The focus of much of EPA's authority is the control of hazardous substances, particularly toxic chemicals. Therefore, EPA regulations are often designed to address those materials rather than the persistent objects which may be responsible for entanglements. If the various definitions of hazardous substances contained in pollution control statutes can be construed to include discarded fishing gear, clean up authority may exist. Statutes which authorize the clean up of hazardous wastes are discussed in a later section.

Convention on the prevention of marine pollution by dumping of wastes and other matter (London Dumping Convention), 26 U.S.T. §2403.--The Convention to which the United States is a party, prohibits the dumping of certain wastes or other matter at sea. "Dumping" under the Convention includes "any deliberate disposal at sea of wastes or other matter from vessels..." but does not include "the disposal at sea of wastes or other matter incidental to, or derived from, the normal operations of vessels..."

unless the vessel is operating for the purpose of disposing or treating such matter (Art. III, §1). Under this definition, some of the debris responsible for entanglements may be covered by the Convention, but other debris may not be.

Clearly, debris that is generated on land and taken to sea for the express purpose of dumping is within the coverage of the Convention. However, dumping, for the purposes of the Convention, only includes deliberate disposal. Any accidental loss of debris is not governed. More important in the context of entanglements is the exception for the disposal of matter incidental to the normal operation of vessels. Net discards which are generated in the course of fishing operations may be considered to fit that exception. The countervailing argument to this interpretation is that while the generation of net fragments may be incidental to fishing operations, the intentional disposal of this debris does not constitute the normal operation of a fishing vessel.

The Convention requires the issuance of a permit before most materials can be dumped, but prohibits, except in emergency situations, the dumping of wastes or other matter listed in Annex I to the Convention. Included in Annex I are "persistent plastics and other persistent synthetic materials, for example, netting and ropes, which may float or remain in suspension in the sea in such a manner as to interfere materially with fishing, navigation or other legitimate uses of the sea" (Annex I, §4).

Generally, the types of materials involved in entanglements are included in Annex I. If one assumes that the disposal of this debris constitutes dumping under the Convention's definition, the applicability of the Convention hinges upon how one defines the phrase "legitimate uses of the sea." A strong argument can be made that the utilization of the oceans to ensure healthy populations of marine mammals and other marine fauna is a legitimate use of the sea which is materially interfered with when casting off netting and other debris.

As discussed below, the MPRSA, which implements the Convention, when strictly construed, may not prohibit the domestic dumping of refuse, but may merely prohibit transport for the purpose of dumping. Nevertheless, regulations issued pursuant to the MPRSA seem to implement the strictures of the Convention.

Applicability of the Convention to the disposal of fishing gear may prove helpful in alleviating the entanglement problem. Japan ratified the treaty in 1980, joining other sizable fishing nations such as the U.S.S.R., People's Republic of China, the United States, Canada, and Poland as contracting parties. Among the principal exploiters of the North Pacific fisheries only the Republic of Korea has not joined the Convention. Even though the Convention addresses the problem on an international scale, it is not a panacea. Since the generation of a significant portion of the entangling debris takes place at sea, enforcement is difficult, if not impossible. It is not known precisely how other party nations have implemented the Convention domestically. A research effort is being undertaken to ascertain the specific foreign laws that may be applicable to the entanglement problem.

Protocol of 1978 relating to the International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL Protocol).--The MARPOL Protocol seeks to counter most forms of pollution generated by ships, including that from oil, toxic substances, sewage, and garbage. The MARPOL Protocol, unlike the Convention, covers the accidental disposal of matter incidental to normal vessel operations. One important exception to the applicability of the MARPOL Protocol, however, is provided by its definition of "discharge." This term does not include "dumping within the meaning of the [Convention]." Therefore, if it is determined that a category of debris falls within the parameters of the Convention, its discard is not governed by the MARPOL Protocol.

Annex V to the MARPOL Protocol, one of three optional annexes and not yet in force, regulates the disposal of garbage at sea from ships. In general, the disposal of "all plastics, including but not limited to synthetic ropes, synthetic fishing nets, and plastic garbage bags is prohibited." An exception is made though, for the "the accidental loss of synthetic fishing nets or synthetic material incidental to the repair of such nets, provided that all reasonable precautions have been taken to prevent such loss." Although these accidental losses of nets are exempted from the general prohibitions of Annex V, its applicability to much of the debris that is responsible for entanglements is clearer than that of the Convention.

Entered into force in October 1983, the MARPOL Protocol consists of far fewer parties than the Convention. Of the major North Pacific fishing nations, Japan, People's Republic of China, the U.S.S.R., and the United States have ratified or acceded to the MARPOL Protocol. Japan is the only one of these nations to adopt the optional annexes (including Annex V), but acceded to the MARPOL Protocol with a reservation. The optional annexes are not now in force. They shall enter into force only after they have been adopted by at least 15 nations whose fleets jointly constitute 50% of the gross tonnage of the world's shipping.

As with similar attempts to prohibit the dumping of inert substances in the oceans, the MARPOL Protocol would be virtually unenforceable. To be covered, not only would net fragments have to be identifiable to a particular vessel, but it would have to show that the loss of the gear was not accidental or that reasonable precautions to prevent the loss were not taken.

The Act to Prevent Pollution from Ships (Act) (33 U.S.C. §1901), domestically implements the MARPOL Protocol. Under the Act it is a violation for any vessel, while in the navigable waters of the United States, and for a United States vessel anywhere, to act in violation of the MARPOL Protocol or regulations issued pursuant to the Act (33 U.S.C. §1907). Since the United States has not yet adopted optional Annex V, its prohibitions are not included in the Act.

Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA) (33 U.S.C. §1401).--The MPRSA, which implements the Convention, primarily addresses ocean dumping by regulating the domestic transportation of wastes or other debris for the purposes of dumping and by prohibiting the act of dumping within the U.S. territorial sea and contiguous zone (out to 12 miles) if the material has been transported from outside the United States. The usefulness of this statute to address entanglement problems resulting from foreign fishing is limited, however, since most foreign fishing operations occur beyond the contiguous zone.

The MPRSA provides that except in those instances in which a permit has been issued, no person shall transport from the United States, and no vessel registered in the United States shall transport from any location, any material for the purpose of dumping it into ocean waters (33 U.S.C. §1411(a)). In taking this tack, the U.S. Congress failed to prohibit explicitly the dumping of debris but clearly prohibited transportation for this purpose. Net fragments are, in general, not purposefully transported for disposal. The intent to dispose of fishing gear usually does not develop until it breaks at sea, after it has already been transported. Thus, the MPRSA appears, on its face, to be inapplicable to gear discarded from domestic fishing vessels or to debris from other vessel classes.

The legislative history, however, expresses a congressional intent to prohibit the actual dumping of debris, not merely its transportation for the purpose of dumping. The purpose of the legislation, as explained in the Senate report accompanying the 1972 MPRSA, was to ban "the transportation for dumping <u>and</u> <u>dumping</u> beyond the territorial jurisdiction of the United States of...waste material unless authorized by a permit" (emphasis added) (S. Rept. 451, 92d Cong., 2d Sess., reprinted in [1972] U.S. Code Cong. & Ad. News 4234, 4234). Elsewhere in the U.S. Senate report, however, the purpose of the Act was declared "to be the regulation of the transportation of material for dumping into the oceans..." (<u>Id</u>. at 4243).

The seeming inconsistency among the statutory language and the two expressions of legislative intent is clarified in the section by section analysis of the Senate report. That analysis provides that the prohibition of certain actions under the Act "on the jurisdictional basis of regulating transportation is an appropriate assertion of sovereignty of the United States without breaching the inherent issues of international maritime law" (<u>Id</u>. at 4245). Although the high seas are open to all nations and no nation may validly subject any part of them to their sovereignty, the right to regulate commerce proceeding from the ports of a country including that engaged in by foreign vessels, is well recognized in international law. Thus, Congress concluded that "[a]sserting jurisdiction to regulate transportation by persons subject to the jurisdiction of the United States for the purpose of dumping in the oceans (whether they be high seas or not) attains the same objective as a direct prohibition of dumping without doing violence to principles of international law" (<u>Id</u>. at 4246).

That Congress intended to prohibit the dumping of material as well as transportation for the purpose of dumping is also enunciated in the legislative history of the 1974 amendments to the MPRSA. The Senate report set out the purpose of the amendments: "to make [the MPRSA] fully consonant with the treaty responsibilities of the United States under the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter" (S. Rept. 726, 93d Cong., 2d Sess., reprinted in U.S. Code Cong. & Ad. News 2792, 2792). This treaty, discussed in greater detail above, requires its signatories to prohibit the "dumping" of certain, designated materials, including synthetic nets and ropes, not merely the transportation for the purpose of dumping.

Congress has made it clear that its purpose in enacting the MPRSA and amendments was to prohibit the dumping of waste materials in the oceans, absent the necessary permit. In fact, such a prohibition is mandated by U.S. treaty obligations pursuant to the Convention. However, the drafters chose to sidestep the potential international ramifications of placing a blanket restriction on dumping in the high seas. Rather, Congress saw fit to invoke its power under the Commerce Clause (U.S. Const. Art. I, §8, Cl. 3) and address the problem of marine pollution by restricting the transportation of wastes for the purpose of dumping. Most likely, Congress never envisioned a situation where material could be dumped at sea without being transported for that purpose. Lumsdaine (1976), in discussing the coverage of the MPRSA, states that the Act should be broadly interpreted to include this apparent omission.

Broadly construing the requirement of the Act that the transporting be purposeful may remedy also this apparent omission. When they head to sea, fishermen know that gear will occasionally be lost or broken. If they intentionally dispose of broken nets and the like, it is conceivable that the purposefulness of the transporting may be inferred. In the absence of a statutory construction to cover the act of dumping rather than transportation for that purpose, the material purportedly responsible for numerous entanglements is not subject to regulation under the MPRSA.

Assuming that the MPRSA prohibition section is interpreted as being applicable only to the transportation of material for the purpose of dumping and not the act of dumping, the prohibitions of the Convention may have been elsewhere incorporated into the Act. Although the strictures of the Convention which prohibit the dumping of persistent synthetic materials at sea are absent from the prohibition section of the MPRSA, they have been incorporated into the dumping permit section. The statute (33 U.S.C. §1412(a)) reads:

> "The Administrator [of EPA] shall establish and apply criteria for reviewing and evaluating such permit applications.... To the extent that he may do so without relaxing the requirements of this subchapter, the Administrator, in establishing or revising such criteria, shall apply the standards and criteria binding upon the United States under the Convention, including its Annexes."

The EPA general counsel's office has interpreted the inclusion of the Convention criteria in this section as limiting them to permit review. Others have suggested that mention of the standards and criteria of the Convention has the effect of incorporating the totality of its provisions into the MPRSA. When viewed in the context of EPA's own regulations, the latter is probably the better interpretation.

The purpose and scope of EPA regulations which implement the MPRSA, as stated at 40 C.F.R. §220.1, include the establishment of "procedures and criteria for the issuance of permits by the EPA pursuant to section 102 of the Act." However, the same section of the regulations reiterates the prohibitions section of the Act, bringing them within the scope of the permit regulations. In discussing the relationship between the MPRSA and international agreements, the regulations (40 C.F.R. §220.1(b)) state:

"In accordance with section 102(a) of the Act, the regulations and criteria included in this Subchapter...apply the standards and criteria binding upon the United States under the [Convention] to the extent that application of such standards and criteria do not relax the requirements of the Act."

Since the prohibitions of the MPRSA have been incorporated into the aforementioned subchapter, the standards of the Convention, including those regarding dumping without a permit, are probably applicable to the extent that they parallel or strengthen the Act. Section 108 of the MPRSA authorized the Administrator of EPA to issue such a regulation.[1]

If it is determined that the MPRSA is applicable to the discard of gear by domestic fishermen anywhere and foreign fishermen within the 12-nmi contiguous zone, any such discard would require a dumping permit. Among those substances for which permits will not be approved are "persistent inert synthetic or natural materials which may float or remain in suspension in the ocean in such a manner that they may interfere materially with fishing, navigation, or other legitimate uses of the ocean" (40 C.F.R. §227.5). So interpreted, these regulations, in line with the restrictions contained in Annex I of the Convention, would prohibit dumping of synthetic net fragments or similar material.

The MPRSA was enacted before the establishment of the United States' 200-mile EEZ. At the time of passage, the MPRSA prohibited dumping of material transported from outside the United States into waters then subject to U.S. jurisdiction, 12 miles from shore. In light of statements in the legislative history which express an intent to prohibit dumping within all coastal waters under U.S. jurisdiction, it seems consistent with the purposes of the MPRSA to extend its prohibitions and permit requirements to the bounds of the EEZ. An extension of MPRSA jurisdiction would have little effect on the activities of foreign fishermen, since they are already prohibited from discarding gear into the EEZ by the Magnuson Act, infra.

In summary, the MPRSA may be disparately interpreted. A blanket prohibition on the dumping of nondegradable fishing debris may be read into its prohibition section, particularly when viewed in light of statements in the legislative history. Even if the prohibition section is construed as applicable only to the transportation for the purpose of dumping, the prohibitions on dumping inert materials contained in the Convention may have been incorporated into the MPRSA via its permit section and the EPA regulations.

Federal Water Pollution Control Act (FWPCA) (33 U.S.C. §1251).--Section 311(b)(1) of the FWPCA (33 U.S.C. §1321(b)(1)) establishes the United States policy that

[1]Section 108 (33 U.S.C. §1418) provides that, "in carrying out the responsibilities and authority conferred by this subchapter, the Administrator [of EPA], the Secretary [of the Army], and the Secretary of the department in which the Coast Guard is operating are authorized to issue such regulations as they deem appropriate."

"there should be no discharges of oil or hazardous substances into or upon the navigable waters of the United States, adjoining shorelines, or into or upon waters of the contiguous zone, or in connection with activities under the Outer Continental Shelf Lands Act or the Deepwater Port Act of 1974, or which may affect natural resources belonging to, appertaining to, or under the exclusive management authority of the United States (including resources under the Fishery Conservation and Management Act of 1976)."

The definition of "discharge" given in section 311(a)(2) of the FWPCA (33 U.S.C. §1321(a)(2)) includes all dumping and other types of disposal that would apply to the act of discarding net fragments and other, related refuse. However, the definition of "hazardous substances" must be stretched if net fragments and other entangling debris are to be included within the coverage of this Act (33 U.S.C. §1321(b)(2)).

"'Hazardous substances', which are designated by the Environmental Protection Agency, are those elements or compounds which, when discharged in any quantity...present an imminent and substantial danger to the public health or welfare, including, but not limited to, fish, shellfish, wildlife, shorelines and beaches."

If the entanglement problem is of the suspected magnitude, there is little question that the disposal of netting and plastics presents an imminent and substantial danger to fish and wildlife. What is problematical in applying the FWPCA to the entanglement situation is whether the debris in question can be classified as either an element or a compound. The List of Hazardous Substances found at 40 C.F.R. Table 116.4A and prepared pursuant to Section 311 of the FWPCA, enumerates over 300 substances. All of these substances are toxic chemicals. Although it is conceivable that a creative interpretation of the hazardous substances definition could be used to include netting and debris, the toxicity of the chemicals currently designated as being hazardous evidences a narrower interpretation of this phrase by the EPA, the agency responsible for the enforcement of the Act.

Resources Conservation and Recovery Act of 1976 (RCRA) (42 U.S.C. §6901).--The RCRA regulates the disposal of solid wastes to promote the protection of health and the environment. Solid wastes controlled by this statute include discarded solid or liquid material from industrial, commercial, mining, and agricultural operations. Discarded fishing gear probably is a solid waste under RCRA since it is generated in the course of commercial activities.

Some solid wastes are further classified as "hazardous wastes" if they "pose a substantial present or potential hazard to human health or the environment where improperly treated, stored, transported, or disposed of..." because of their "quantity, concentration, or physical, chemical, or infectious characteristics" (42 U.S.C. §6903(5)). The EPA is required to promulgate a list of hazardous wastes taking into account the substances' toxicity, persistence, and degradability in nature, potential for accumulation in tissue, and other related factors such as flammability, corrosiveness, and other hazardous characteristics" (42 U.S.C. §6921). A list of designated hazardous wastes appears at 50 C.F.R. §261.30 *et seq*. Similar to the FWPCA list of hazardous substances, this list is dominated by toxic chemicals. Other hazardous wastes may be designated under 50 C.F.R. §261.20 et seq. if they exhibit ignitability, corrosivity, reactivity, or toxicity. Net fragments exhibit none of these characteristics. Similar to most other pollution control statutes, the existing regulatory scheme is primarily designed to control toxic and reactive chemicals, not inert substances such as lost or discarded fishing gear or other debris.

Changes in the EPA regulations may be appropriate to accommodate the listing of net fragments and other synthetic materials. Under RCRA these materials may fit the definition of a hazardous waste because of their quantity, concentration and physical properties. Although no materials have been designated by EPA as hazardous wastes based upon their persistence or slow rate of degradation, these are considerations expressly enumerated in the Act.

Designation of some fishing gear as hazardous substances may be helpful in curtailing entanglements. Generators of hazardous wastes must keep accurate records which identify the quantities of hazardous waste generated and the disposition of those wastes. However, other requirements under RCRA for handling hazardous wastes may prove to be overly burdensome and inappropriate to the control of fishing debris. Records must be kept of all hazardous wastes transported, including their sources and delivery points. Facilities which store, treat, or dispose of hazardous wastes must be licensed and keep records of the dispositions of those wastes.

Whether fishing debris is characterized as hazardous waste or not, some potential benefits of RCRA may apply to the entanglement situation. The Act (42 U.S.C. §6973(a)) provides that:

> "Upon receipt of evidence that the handling, storage, treatment, transportation or disposal of any solid waste or hazardous waste may present an imminent and substantial endangerment to health or the environment, the Administrator [of EPA] may bring suit on behalf of the United States...to immediately restrain any person contributing to such [activities]...."

Fines may be levied upon violators who fail to comply with these restraints. Since net fragments and other fishing debris are solid wastes (and potentially hazardous wastes) and their disposal would likely result in the endangerment of the environment, injunctive relief may be applicable to the discard of these materials. To seek an injunction, however, the prospective violator must be identifiable.

Wildlife Laws

Wildlife statutes prohibit the taking of designated species absent a permit. A "take" is variously defined in the statutes, but always includes the killing of the protected animal. Takes can also be caused indirectly, through habitat destruction (Palila v. Hawaii Department of Land and Natural Resources, 639 F.2d 495 (9th Cir. 1981)). It is unlikely that takings by entanglements in gear that has been intentionally discarded would ever be authorized in a permit issued by a wildlife agency since such a take would be avoidable in most instances.

In general, no violation of these laws occurs until an animal is in fact taken. The mere discard of debris does not, except in extreme circumstances, constitute a violation of wildlife law. Without some mechanism for identifying the owners of gear responsible for entanglement, enforcement of these provisions is virtually impossible.

If it can be shown with reasonable certainty that an action is likely to result in a take, that action can be prohibited irrespective of whether it actually results in a taking. Under this interpretation, the Fish and Wildlife Service has prohibited waterborne activities in designated manatee protection areas (50 C.F.R. §17.100). Similarly, the discarding of marine debris could be regulated under wildlife statutes if areas can be identified in which the discard is reasonably certain to take protected species.

Marine Mammal Protection Act (MMPA) (16 U.S.C. §1361).--Section 102 of the MMPA, 16 U.S.C. §1372, sets out prohibitions on the taking of marine mammals. It is generally unlawful for any person or vessel subject to the jurisdiction of the United States to take any marine mammal on the high seas or within areas subject to the jurisdiction of the United States. Included in the definition of a "take" is the capture or killing of marine mammals. Permits for the taking of marine mammals may be issued under a variety of circumstances, including those takings which are incidental to commercial fishing operations. Disposal of netting or other gear at sea, however, is not integral to commercial fishing, and it is highly unlikely that an incidental taking permit would ever be issued which would encompass such conduct.

Incidental taking permits may not be issued under any circumstances for species which have been designated as depleted. Among marine mammals designated as being depleted are those species listed as endangered or threatened under the ESA. Since the Hawaiian monk seal and several species of great whales which inhabit North Pacific waters have been listed as endangered under the ESA, the narrower bases for issuing permits for depleted marine mammals is particularly germane to this discussion.

The North Pacific fur seal is currently excluded from management under the MMPA when the substantive terms of the MMPA contravene the Interim Convention for the Conservation of the North Pacific Fur Seal, 8 U.S.T. §2283, or the Fur Seal Act (International Fund for Animal Welfare v. Baldrige, No. 84-1838 (D.D.C. 28 June 1984)). However, should the parties to the fur seal convention let that agreement lapse, it is probable that management of the fur seal would come under the aegis of the MMPA.

A petition to list the fur seal as a threatened species under the ESA is now under consideration. If management were pursuant to the MMPA and the fur seal were listed under the ESA, the greater protection given a depleted species under the MMPA would apply. Takings would only be allowed for scientific research, and no incidental taking would be permissible.

The extent of whale entanglement is unknown, but that it is possible has been demonstrated in the North Atlantic. Thirty-five humpback whales became entangled in nets of the capelin fishery in the Labrador Sea during 1982. Of these, all but four were released alive (International Wildlife 1984).

Fur Seal Act (16 U.S.C. §1151).--The Fur Seal Act makes it unlawful for any person or vessel subject to the jurisdiction of the United States to engage in the taking of fur seals in the North Pacific Ocean except as provided for in the act or its regulations. The primary exceptions to the taking prohibition is the controlled commercial harvest conducted pursuant to the Fur Seal Treaty and the provision for subsistence taking by Indians, Aleuts, and Eskimos. Any capture or killing of a North Pacific fur seal by entanglement in fishing gear or other debris is likely to be a violation of the Fur Seal Act.

Endangered Species Act (ESA) (16 U.S.C. §1531).--Under the ESA it is generally unlawful for any person subject to the jurisdiction of the United States to take any endangered species within the territorial sea of the United States or on the high seas. A similar prohibition on the taking of threatened species is contained in 50 C.F.R. §227.71. More extensive than its definition under the MMPA, the term "take," when used in the context of the ESA, includes killing, trapping, harming, or capturing.

Under certain circumstances it is permissible to take endangered or threatened wildlife. The 1982 amendments to the ESA incorporated procedures whereby the incidental take of endangered species may be allowed (16 U.S.C. §1539(a)(1)(B)). It is possible that an incidental take permit could be issued to cover entanglement in accidentally lost fishing gear. However, this exception is probably not applicable to entanglement in debris that has been intentionally disposed of since an allowable taking must be incidental to an otherwise lawful activity. If disposal of nets at sea is considered to be a violation of one or more of the aforementioned pollution control laws, a permit could not be issued.

Two further limitations on the use of ESA incidental taking permits should be noted. As currently written, the ESA provides for the issuance of such permits only for takes which occur within a state or the territorial sea of the United States. (These permits may be issued only for takes which are otherwise prohibited by 16 U.S.C. §1538(a)(1)(B).) Permits which allow for incidental takes by entanglement or other means could not be issued for takes which occur beyond the territorial sea. Second, permits could not be issued for the incidental take of endangered or threatened marine mammals. Under 16 U.S.C. §1543 any more restrictive, conflicting provision of the MMPA takes precedence over the ESA. Since all listed marine mammals are deemed to be depleted under the MMPA, only permits for scientific research may be issued for those species.

Similar to incidental take permits, the incidental taking of threatened species pursuant to 50 C.F.R. §117.72(e) is probably inapplicable to entanglements resulting from discarded gear. Incidental taking of threatened species is allowable only during fishing or scientific research activities. The prohibited disposal of gear cannot rightly be considered a fishing activity.

As previously mentioned, some whale species and the Hawaiian monk seal, all of which are endangered, may be susceptible to entanglement. Although primarily tropical, some species of endangered or threatened sea turtles may also be subject to entanglement. Not presently on the endangered and threatened species list, the North Pacific fur seal is under consideration for listing as a threatened species.

Migratory Bird Treaty Act (MBTA) (16 U.S.C. §701).--The United States has entered into four separate treaties (with Canada, Mexico, Japan, and the U.S.S.R.) to protect migratory bird species.[2] The MBTA provides the domestic framework for satisfying the international obligations of the United States derived from these treaties. Among the protections afforded by the MBTA is a prohibition on the unpermitted capture or killing of migratory birds.

In applying the MBTA to the case of an unintentional poisoning of American widgeons, the court in United States v. Corbin Farm Service (444 F. Supp. 510, 529 (D. Calif. 1978)), held that "it is clear that Congress intended to make the unlawful killing of even one bird an offense." The court determined that no showing of intent was required to obtain a conviction for the killings: "the guilty act alone [was] sufficient to make out the crime" (Id. at 536). Even though the accused committed no willful violation, they were "in a position to prevent [the killings] with no more care than society might reasonably expect and no more exertion than it might reasonably exact from one who assumed his responsibilities" (Id. at 535-536, citing Morissette v. United States, 342 U.S. 246, 256). The court also noted that "penalties commonly are relatively small, and conviction does no grave damage to an offender's reputation" (Id. at 536).

Parallel to the situation in Corbin Farm, entanglement of migratory birds should be actionable without a showing of intent. The potential penalties in the two instances are identical and to refrain from the discard of fishing gear is in no way an onerous or unreasonable burden.

The list of migratory birds enumerated at 50 C.F.R. §10.13 includes several species that may be subject to entanglement. Examples of susceptible species are: several duck species, most shorebirds, grebes, gulls, jaegers, cormorants, murres, pelicans, and terns.

Ostensibly applicable to the problem of seabird entanglement, the MBTA may be limited in scope. A 1980 Department of Interior solicitor's opinion concludes that the taking prohibitions of the MBTA do not apply to U.S. citizens in foreign countries. A subsequent solicitor's opinion addresses the extraterritorial applicability of the MBTA in the fishing context.

> "[E]ven if the incidental take of migratory birds by...Japanese fishermen constituted a violation of the Japanese Treaty and the MBTA, prosecutions by the United States could be brought only if the violations occurred in the U.S. territorial waters."

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[2]Convention for the Protection of Migratory Birds, 16 August 1916, United States-Canada, 39 Statute 1702; Convention for the Protection of Migratory Birds and Game Mammals, 7 February 1936, United States-Mexico, 50 Statute 1311; Convention for the Protection of Migratory Birds and Birds in Danger of Extinction, and Their Environment, with Annex, 14 March 1972, United States-Japan, 25 U.S.T. 3329; Convention Concerning the Conservation of Migratory Birds and Their Environment, 19 November 1976, United States-U.S.S.R., 29 U.S.T. 4647.

In the solicitor's view, the MBTA prohibitions apply to foreigners only within the U.S. 3-mile limit. If this is the case, prosecutions under the MBTA would not be suitable mechanism for preventing the majority of bird entanglements by foreign fishermen.[3]

In light of United States v. Mitchell (553 F. 2d 996 (5th Cir. 1977)), it is nearly certain that the MBTA taking sanctions are inapplicable within foreign jurisdictions. Applicability of the MBTA to takings by U.S. citizens on the high seas, however, is more likely. To limit the statute's applicability to U.S. territory would leave open a large immunity for violations by U.S. citizens on the high seas. Therefore, the MBTA may be useful in deterring some entanglements caused by domestic fishermen.

Fisheries Law

Fishery Conservation and Management Act (Magnuson Act) (16 U.S.C. §1801).--Primary among the purposes of the Magnuson Act is the conservation and management of the fishery resources found off the coasts of the United States. As one means of fulfilling that purpose, Congress has restricted foreign fishing within the 200-mile EEZ. Foreign fishermen are required to obtain permits before fishing in the EEZ. Permits issued under the Magnuson Act may contain appropriate conditions or restrictions which are related to fishery conservation and management. One restriction placed upon foreign fishing, codified at 50 C.F.R. §611.16, directly addresses the disposal of fishing gear:

> "Except in cases of emergency...or as specifically authorized...no fishing vessel may intentionally place into the fishery conservation zone [200-mile limit] any article, including abandoned fishing gear, which may:
>
> "(1) Interfere with fishing or obstruct fishing gear or vessels; or
>
> "(2) Cause damage to any fishery resource or marine mammal."

Furthermore, vessels which encounter any abandoned article are required to report the nature and location of the article immediately to the Coast Guard.

Although the foreign fishing regulations specifically prohibit the intentional disposal of gear, no counterpart regulations exist for domestic fishermen. The Magnuson Act provides for the development of fishery management plans (FMP's) which affect foreign and domestic fishing. All FMP's shall contain conservation and management measures which are appropriate to the fishery being regulated. It is not clear whether conservation and

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[3]A contrasting view was expressed in a 1975 solicitor's opinion dealing with the applicability of the 1972 Migratory Bird Treaty with Japan to gill net fishing operations. Citing a section of the treaty which obligates the parties to prevent damage to birds from pollution of the seas, the opinion concludes that this focus "would appear to negate any intent to ignore activities on the high seas."

management measures may be included in an FMP if their purpose is solely to provide protection to marine mammals or birds. However, entanglements of wildlife are only one aspect of the problem created by the disposal at sea of fishing gear. There is little doubt that the dumping of gear and debris may be regulated under the Magnuson Act if the prohibition is directed towards alleviating the problems of ghost fishing or vessel entanglement.

Currently, a proposal to amend all existing FMP's to prohibit the disposal of gear at sea by domestic and foreign fishermen is under consideration by the National Marine Fisheries Service.

Pollution Abatement

Fishing gear and other debris which are currently adrift in the oceans may continue indefinitely to present a hazard to fish, wildlife, and navigation owing to their inert nature. Two statutes administered by the EPA could make funds available for the clean up of debris if the problem were shown to be severe enough. Similar to other statutes which control pollutants, these laws principally are tailored to the recovery of hazardous substances, particularly toxic wastes. However, a literal reading of the statutes indicates that the clean up of discarded fishing gear or other debris may be funded under these acts.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (42 U.S.C. §9601).--Pursuant to CERCLA (42 U.S.C. §9604(a)) authority is given for the clean up of certain hazardous waste sites:

> "Whenever (A) any hazardous substance is released or there is a substantial threat of such a release into the environment, or (B) there is a release or substantial threat of a release into the environment of any pollutant or contaminant which may present an imminent and substantial danger to the public health or welfare, the President is authorized to act, consistent with the national contingency plan, to remove...such hazardous substance, pollutant, or contaminant...."

Clean up of these sites may be accomplished using monies of the CERCLA trust fund, in some instances, even when the violator is not identifiable.

A "hazardous substance" for the purposes of CERCLA includes any hazardous waste identified under RCRA, those hazardous substances listed under the FWPCA, or any other substance designated pursuant to CERCLA. As discussed previously, it is conceivable that net fragments may fit the criteria for designation as hazardous under RCRA or the FWPCA, although they are not currently listed. Under CERCLA, EPA may designate as hazardous those substances which, "when released into the environment may present substantial danger to the public health or welfare or the environment..." (42 U.S.C. §9602(a)). What constitutes the public welfare is not delineated under CERCLA. Guidance regarding the meaning of this phrase may be gleaned from the FWPCA. In that act, the "public health or welfare of the United States" includes, but is not limited to, "fish, shellfish, and wildlife and the shorelines and beaches..." (33 U.S.C. §1321(d)). If this standard is applicable to CERCLA, it is clear that the public welfare would be imperiled by entanglement of fish or wildlife, and that EPA could designate net fragments as a hazardous substance.

If discarded fishing gear were to be designated as hazardous, the fact that it had been released into the environment would allow the President to provide remedial actions. For the purposes of CERCLA, "environment" includes the territorial seas, the contiguous zone, and the 200-mile EEZ.

"Pollutant or contaminant" is defined in 42 U.S.C. §9604(b). The phrase includes, but is not limited to any "substance..., which after release into the environment and upon exposure, ingestion, inhalation, or assimilation into any organism either directly from the environment or indirectly by ingestion through food chains, will or may reasonably be anticipated to cause death, disease, behavior abnormalities, cancer...or physical deformations, in such organisms...." Although fishing debris may cause the death of organisms, it is not the result of ingestion, inhalation, assimilation, or mere exposure. However, the definition of pollutant or contaminant is not necessarily limited to substances which are harmful to organisms in one of these four ways. The EPA could, if it thought the situation severe enough, probably designate net fragments and other debris as pollutants or contaminants. If the debris were determined to be a pollutant or contaminant, the disposal must present an imminent or substantial danger to the public health or welfare. Assuming that the FWPCA definition of public welfare is applicable to CERCLA, such a danger is probably engendered by fishing debris.

The final requirement under CERCLA which limits the authority to clean up hazardous substances, pollutants, or contaminants is that the actions must be consistent with the national contingency plan (NCP). The NCP sets up a system whereby priorities for taking remedial actions for releases are set. Among the criteria to be considered in ranking releases based upon the relative risk or danger to public health or welfare of the environment are: the population at risk, the hazard potential of the substances, the potential for contamination of drinking water supplies, the potential for the destruction of sensitive ecosystems, and other appropriate factors (42 U.S.C. §9605). A detailed description of the hazardous waste site ranking system appears at 40 C.F.R. part 300, Appendix A. At present, 538 sites have been listed and ranked.

For the clean up of discarded fishing gear to be effectuated using the funds available under CERCLA, it must be shown that the scope of the entanglement problem is extensive enough to warrant a priority ranking. To accomplish this, the identification of a site where the problem is particularly acute is probably necessary. It is unlikely that any single release would be significant in itself. To be a problem worthy of CERCLA clean up attention, an area of limited size where debris is particularly concentrated or harmful to the environment would probably have to be identified. It should be noted, however, that CERCLA (42 U.S.C. §9604(d)(4)) provides that:

> "Where two or more noncontiguous facilities are reasonably related on the basis of geography, or on the basis of the threat, or potential threat to the public health or welfare or the environment, the President may, in his discretion, treat these related facilities as one for the purposes of this section."

Although clean up may be effectuated without determining the generator of the wastes, a system for identifying the sources of discarded gear may prove helpful in the context of CERCLA. If the polluters were known, funding for the clean up could be recovered from them. In that event, adherence to the priority system for hazardous waste sites would be less strict. Additionally, CERCLA allows for the assessment of damages against the generator for injury to, destruction of, or loss of natural resources resulting from the release of a hazardous substance.

Federal Water Pollution Control Act (FWPCA) (33 U.S.C. §1251).--In addition to possible clean up under CERCLA, clean up is also possible under the FWPCA if net fragments are determined to be hazardous substances for its purposes. If a substance is discharged upon the waters of the United States, including those of the EEZ, "the President is authorized to act to remove or arrange for [its] removal...unless he determines such removal will be done properly by the owner or operator of the vessel..." (33 U.S.C. §1321(c)(1)). Since most often the owner or operator of the vessel is unknown, the Government could undertake the clean up of fishing debris.

Enforcement Considerations

Existing Legislation

Typically, pollution and wildlife laws are ineffectual with regard to entanglements. Even though thousands of illegal takes may occur annually, it is virtually impossible to identify the offenders. Net fragments may remain suspended in ocean waters indefinitely, entangling fish and wildlife for years, allowing violations to be far removed temporally and spatially from the take.

Pollution control laws are likewise generally unenforceable. Assuming that the disposal of net fragments is a violation of these laws, the incidents take place in distant and diverse areas at sea and mostly out of the view of observers. Even if the origin of a net fragment is determined, it would still be difficult to prove that it was dumped and not merely lost in the course of fishing activities. A similar problem exists in enforcing the regulations issued under the Magnuson Act. To be a violation, gear must have been intentionally discarded.

A further impediment to markedly reducing entanglements is worthy of note. The statutes considered herein, even if functioning at peak efficiency, are applicable only to those persons and vessels subject to United States jurisdiction. There is no unilateral action that the United States can take which would address the disposal of gear by foreigners outside the 200-mile limit.

Alternative Enforcement Mechanisms

Without a workable enforcement scheme, existing mechanisms for controlling the disposal of gear or entanglements are mere paper tigers. Four alternative enforcement schemes are presented below.

Gear marking.--It has been suggested that a more extensive marking of fishing gear be required. In this way violators will be much more readily identifiable. The cost involved in such a program may be prohibitive, though, since markings would have to be detailed enough to distinguish a large number of fishermen and numerous enough to allow identification of small net fragments.

Another consideration to be weighed before instituting a marking system, is what type of activity is the regulation seeking to preclude. Although it is true that all lost gear is equally liable to ensnare fish or wildlife, is it reasonable to punish those who accidentally lose or break equipment? If the purpose behind a marking system is to prosecute those who intentionally dispose of gear, a showing of that intention is required in addition to merely identifying the origin of the gear. Marking alone will not provide such a showing. If marking is to be used to identify all persons unlucky enough to have entangled a protected animal in lost gear, close scrutiny should be given to the reasonableness of requiring fishermen to recover any portion of accidentally lost gear.

Bounty system.--Another proposed mechanism to alleviate the entanglement problem is the institution of a bounty system for lost, abandoned, or discarded fishing gear. Theoretically, fishermen would be paid for turning in pieces of nets that they may otherwise discard at sea. A bounty, however, would only be effective against entanglement in gear that is intentionally discarded or recoverable when lost. It is not known what percentage of entanglements occur in these categories of fragments.

Economic factors must be well evaluated in designing a bounty system. The reward for turning in used nets would have to be high enough to provide an incentive for turning in gear that would otherwise be discarded at sea, but low enough to make the program affordable. Checks would also have to be designed which would foil those who may seek a reward for turning in old, retired nets that may already have been disposed of properly. Reports indicate that trawlers often recover fragments in their nets. A bounty system may be useful in encouraging these fishermen to bring in this debris rather than rereleasing it into the ocean waters.

There exists a persistent rumor that Korea has implemented a bounty system on nets. When asked about this, a Korean fisheries official was unaware of the existence of any such system. If a Korean bounty program does exist it may be helpful as a model for the design of a United States system.

Expanded observer network.--At present, observers are only placed on foreign fishing vessels. Even though the Magnuson Act prohibits the discard of gear by foreign fishermen, some violations probably occur. Stricter enforcement of existing regulations may alleviate some entanglements. The observer network could also be expanded to include domestic fishing vessels. Although the authority for placing observers on domestic vessels is uncertain, the decision in Balelo v. Baldrige 724 F. 2d 753 (9th Cir. 1984) would seem to permit it.

Citizen suits and rewards.--Enforcement of most of the statutes that may be applicable to the entanglement situations is difficult at best. Those responsible for enforcement often cannot cover the expansive area over which violations might occur. In some instances agencies utilize identifiable. The cost involved in such a program may be prohibitive, though, since markings would have to be detailed enough to distinguish a large number of fishermen and numerous enough to allow identification of small net fragments.

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Citizen suits and rewards.--Enforcement of most of the statutes that may be applicable to the entanglement situations is difficult at best. Those responsible for enforcement often cannot cover the expansive area over which violations might occur. In some instances agencies utilize these limited resources to counter more immediate threats to human health and welfare. Two ways of increasing the enforcement effort regarding these laws are by allowing citizens to commence legal actions or by providing an incentive to those who provide information that is used in enforcement actions.

Citizen suits are provided for by the MPRSA (33 U.S.C. §1415(g)). Under that section, attorney's fees may be awarded in appropriate cases. One such case where a citizen plaintiff prevailed and was awarded fees is Save One Sound Fisheries v. Calloway (429 F. supp. 1136 (D.R.I. 1977)). The court there states, "[t]he possibility of such fees serves as an incentive for private parties to enforce provisions of the various statutes deemed too important to be left to the limited enforcement resources of the Justice Department" (Id. at 1139). Citizen enforcement is generally difficult, however, in view of the problems in gathering evidence and successfully prosecuting this type of lawsuit.

Providing rewards to those who furnish information which leads to successful prosecutions is another way of obtaining public participation in enforcement. The U.S. House of Representatives version of the MPRSA provided that a portion of a levied fine would be paid to any individual who provided information leading to the conviction. The Senate apparently did not approve of the notion of federally subsidized informants and did not adopt the provision (Weinstein-Bacal 1978).

It should be noted that the effectiveness of rewards for information is doubtful. The ESA allows for such rewards but that provision is seldom, if ever, invoked.

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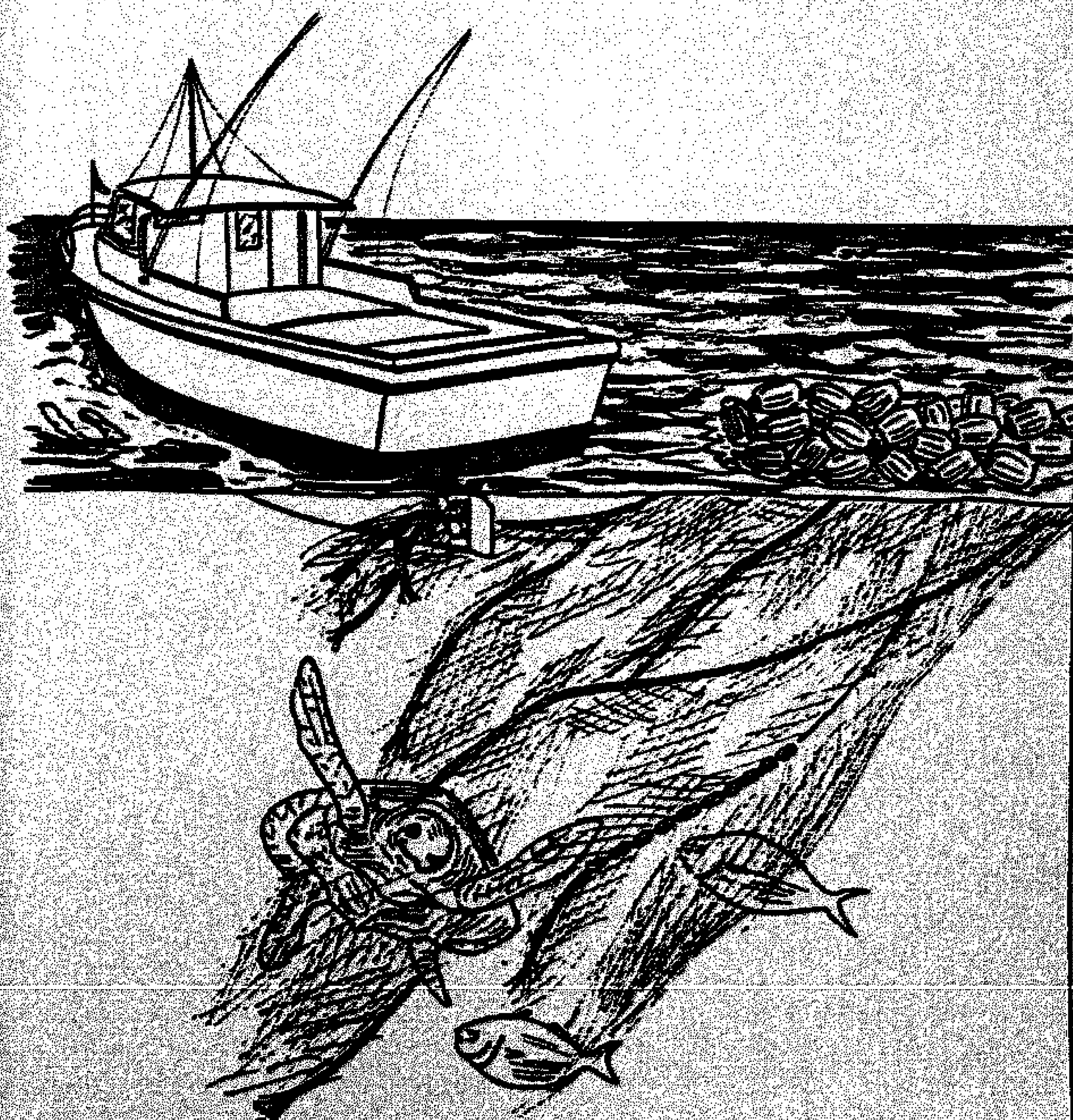
SESSION I

SOURCE AND QUANTIFICATION OF MARINE DEBRIS



THE TYPES AND ESTIMATED AMOUNTS OF FISH NET DEPLOYED IN THE NORTH PACIFIC

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ABSTRACT

This report reviews the major net fisheries of the North Pacific and provides crude estimates of the amount of net gear available to the various coastal and high seas fisheries. Specifications of gill nets, purse seines, trawls, set nets, haul seines, and lift nets, when available, are provided, together with the number of units of nets and vessels operating in the fisheries. First-cut estimates indicate that there are about 170,000 km of gill net, 2,000 km of purse seine, 5,500 km of trawl net, and 8,900 km of miscellaneous net gear available to the various North Pacific net fisheries.

INTRODUCTION

The modern fishing industry has developed primarily as a result of three technological revolutions--mechanization, echo sounding, and development of synthetic fibers (Kristjonsson 1959).

The advent of synthetic fibers brought about a major revolution in the fishing industry. Nylon, the first of the synthetic fibers to be developed, had wide applications in fishing nets. Made from polyhexamethylene adipamide, nylon, and other amides such as perlon and rilsan all possessed excellent characteristics for constructing the ideal fish net (Arzano 1959; Lonsdale 1959).

Nets made from nylon and all other synthetic fibers, eventually lose strength in use; however, they do not rot. It is this nondegradable quality that makes nylon nets so highly attractive to the fishing industry as well as a menace when they become a component of the marine debris.

This report reviews the major net fisheries of the North Pacific (Fig. 1) and makes an attempt at providing some measure of the amount of netting used in coastal and high seas fisheries. It is by no means an exhaustive review and excludes many of the minor net fisheries operating along coastal areas of North Pacific rim countries. Reviews of the net fisheries are gear-oriented; however, because there are many areas of overlap in gear types for any given species, the net gear that contributes most heavily to

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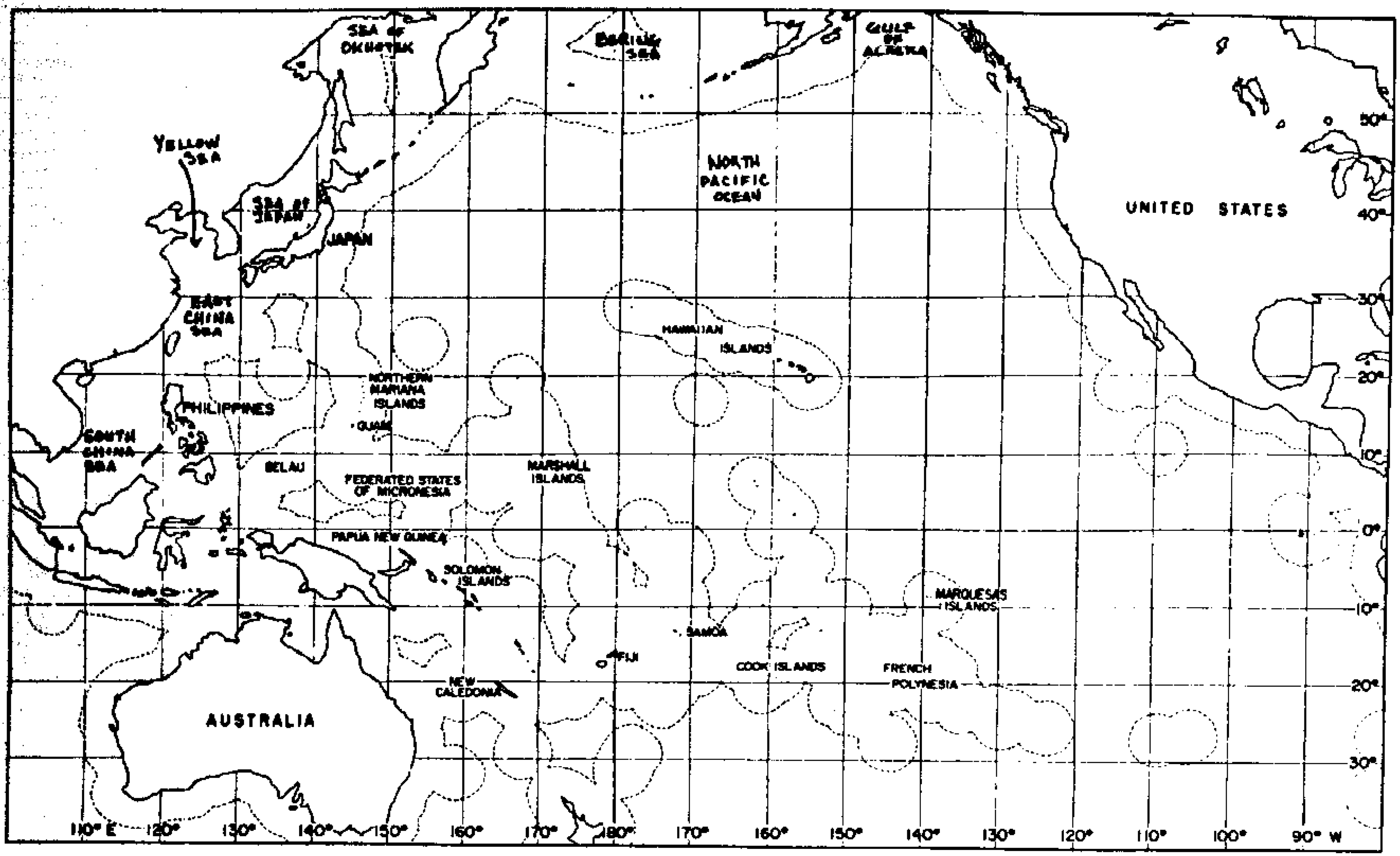

Figure 1.--The North Pacific Ocean.

harvesting the species will be the one emphasized. When available, the gear specifications, as well as the number of vessels operating, and the number of units fished per vessel are provided. Scientific names of species mentioned in this report are given in tables either in the text or appendix.

Although this report describes "typical" gear, it should be obvious to the reader that fishing gear, like fishing methods, are different throughout the world. Differences in the gear used, even for catching the same species and in the same fisheries, exist because fishermen tend to adapt or modify gear based on their experience, knowledge of the fish's habitat and behavior patterns, and cultural practices.

NET CHARACTERISTICS

Netting, which is basically constructed of yarns or threads to form meshes, can be fabricated by machine or by hand in any size desirable, in whatever type and size of twine, and can be either knotted or knotless.

Before synthetic fibers came into general use, most twine used to fabricate webbing came from natural fibers such as cotton, linen, hemp, manila, and sisal. Synthetic fibers first appeared in Japanese gill nets and in portions of surrounding nets in 1949 with the introduction of nylon webbing. In 1951, vinylon (polyvinyl alcohol) was used in surround nets and later vinylidene was used in large set nets (Japan Chemical Fibres Association (JCFA) 1971). The production of synthetic fiber fishing nets increased annually, and by 1956 it surpassed production of nets made of natural fibers. By 1957, synthetic fiber nets accounted for 70% of the production, and by 1964, 100% of all netting material made in Japan.

Additional synthetic fibers such as vinyl chloride, polyethylene, polyester, and polypropylene were introduced subsequently for fishing nets that required specific properties. The downward trend in the production of natural fiber nets and the upward trend in the production of synthetic fiber nets in Japan in 1960-68 are illustrated in Table 1; the percentage of the various types of nets made of the different synthetic materials is given in Table 2.

Table 1.--Fishing net production in Japan (Japan Chemical Fibres Association 1971). (Source: Ministry of International Trade and Industry, Japan.)

Year	Grand total	Natural fiber nets total	Synthetic fiber nets total	Breakdown by fiber						
				Polyamide	Polyvinyl alcohol	Vinylidene	Polyvinyl chloride	Polyester	Poly-ethylene	Poly-propylene
1960	10,596	2,344	8,252	3,639	3,194	709	528	93	99	
1961	11,295	2,006	9,289	4,134	3,567	715	409	167	297	
1962	11,732	1,346	10,386	4,726	4,040	509	364	187	560	
1963	12,965	1,061	11,904	6,976	2,320	689	448	416	967	88
1964	14,015	746	13,269	6,874	2,939	845	310	559	1,556	186
1965	16,236	567	15,669	8,944	3,345	827	279	482	1,715	77
1966	17,773	400	15,373	9,566	3,514	844	205	581	2,591	72
1967	18,765	381	18,384	10,283	2,933	869	183	407	3,569	150
1968	18,983	366	18,647	9,414	3,667	1,098	87	587	3,507	287

Table 2. --Utilization ratio of synthetic materials for fishing nets in Japan (%) (Japan Chemical Fibres Association 1971).

	Set nets	Purse seines	Trawl	Gill nets	Lift nets	Laver nets	Culture nets	Other nets	Total
Polyamide	4	27	7	43	--	4	2	13	100
Polyvinyl alcohol	12	17	8	5	5	35	9	9	100
Vinylidene	80	3	5	5	--	--	5	2	100
Polyvinylchloride	69	5	4	--	--	--	9	13	100
Polyester	20	72	4	2	--	--	1	1	100
Polyethylene	10	10	46	2	6	9	7	10	100
Polypropylene	--	--	--	92	--	--	7	1	100

Synthetic materials used for net making are selected for certain characteristics. For example, polyamide is ideal for salmon and trout gill nets and sardine and tuna purse seines, whereas polyvinyl alcohol webbing is used for horse mackerel, mackerel, and tuna purse seines.

Not all nets are pure, that is, the webbing may be of mixed twine, for example, fibers of nylon may be mixed with polyvinyl chloride. There are more than 10 different mixtures which may consist of up to four different synthetic materials.

The size of netting yarn follows the internationally accepted tex system, which is the weight in grams of 1,000 m of single yarn (von Brandt and Klust 1971). For heavy twisted yarn and for all plaited yarns, the Rtex[1] number is used. This is defined as the weight in grams of 1,000 m of total netting yarn. Fishermen in the United States, Canada, and Great Britain, however, have been reluctant to use this system. Instead, they rely on the number system which is a carryover from the old cotton twine designation (McNeely and Walsh 1980). Excellent detailed discussions on types and uses of twine and netting for commercial fishing, on methods used to manufacture netting, and on net design may be found in Nomura and Yamazaki (1975) and McNeely and Walsh (1980).

Yarns come in different degrees of twist: soft, medium, hard, and extra hard. For bottom trawls, medium-laid yarn is used. The netting yarn should combine high, wet-knot breaking strength at the smallest possible twine diameter, be highly resistant to abrasion, have relatively high extensibility under all fishing conditions, have good elasticity for withstanding the shock of a sudden heavy load, and have no knot slippage or knot inversion. Thus, plaited netting is highly preferred for bottom trawl (von Brandt and Klust 1971).

Nets always have some degree of hydraulic resistance, that is, during towing, dragging, pursing, and hauling, there is some friction of the

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

netting as it passes through water. Because the efficiency of the net as a fishing gear depends primarily on its shape in the water, clear knowledge and understanding of the net's resistance due to the use of the different fibers, twine size, mesh size, knot type, and angle of attack are required. The hydraulic resistance of the net is also directly proportional to the area of the net; thus, if the net area increases "n" times, so will the resistance (Nomura and Yamazaki 1975).

Deformation of the net, which can decrease its fishing efficiency, can occur even in weak current. Experiments in Japan have demonstrated that deformation of set nets can occur in currents as weak as 0.25 knot. As the current speed increases, the floats along the upper edge of the net are pulled downward into the water, and under strong currents the whole net is flattened and forced to the bottom. As net tension increases further, the whole net simply drifts away if not anchored properly (Nomura and Yamazaki 1975).

When a net is towed, for example, during trawling, it tends to take a form of minimum resistance, that is, the height at the head of the net decreases with increasing speed; however, after a certain ship speed, the net becomes stabilized at a constant height (Nomura and Yamazaki 1975).

In the sections that follow, a variety of gear is described. Some of the gear descriptions were obtained from the Food and Agriculture Organization of the United Nations (FAO) (1965). Explanations and definitions from the FAO catalogue are too detailed and lengthy to reproduce; therefore, only a few of the basic and important terms are defined here.

- Preservatives used are: 0 = none used; T = tarred; C = barked, cutched, or tanned; Cu = copper; and R = resin.
- Upper and lower edges refer to the number of meshes along the top and bottom of each panel, respectively.
- Depth is the number of meshes down the side of each panel.
- "Baiting rate" is a system of specifying the points, bars, and meshes cut.

Abbreviations used are:

Man.	manila	M.	medium
Sis.	sisal	S.	soft
Comb.	combination rope	Fm.	fathoms
S.W.R.	steel wire rope	g	grams
Gal.	galvanized	kg	kilograms
Swiv.	swivel	m	meters
Spher.	spherical	diam.	diameter
Lam. Ply.	laminated plywood	p.	point (side knot)
H.	hard lay (of twines or lines)	m.	mesh
		b.	bar

The following definitions are from Klust (1973), Nomura and Yamazaki (1975), and McNeely and Walsh (1980).

Breast line.--Vertical ropes which connect at each end to the footrope and headrope. Breast lines are attached to side panels of trawl gear and to the ends of purse seines and gill nets.

Bunt, sack, bag.--These terms refer to the heavy web section of purse seines into which fish are concentrated by sequentially strapping aboard sections of the bunt to dry up the fish before they are scooped aboard in a large scoop called a brail.

Cod end, bag, sack, fish bag.--These terms are used to describe the heavy mesh in the aftermost sections of trawl gear where fish accumulate during the fishing operation. Some larger vessels drag the entire cod end up an inclined ramp at the stern of the vessel, and smaller vessels are required to split the catch into smaller amounts that can be brought aboard in increments up to 3 tons per hoist.

Extensibility.--The complex physical properties of netting that undergo changes in dimension in the form of elongation or extension due to application of a tensile force. The complexity results from several factors which include but are not restricted to the amount of elongation immediately after applying a breaking load, reaction of the yarn to a gradually increasing load, reaction under sustained load over long durations, reaction of yarn to repeated loading and unloading, total or permanent elongation, and energy absorption.

Footrope, leadline, groundline.--A lower section of the net to which weights (lead or chains) are normally attached. The term "groundline" is sometimes also used in describing the low leg of bridles used to pull a trawl through the water. A footrope provides downward thrust to oppose upward thrust of the float line to facilitate opening of the net in fishing operations.

Hanging ratio.--Defined as L/W, i.e., the relationship between the length (L) of the rope along which the webbing (W) is hung and the stretched length of the webbing. For example, 628 m of stretched webbing hung on 440 m of rope will produce a hanging ratio of L/W = 440/628 = 0.71.

Hang-in.--An expression also quite commonly used and defined as (W-L)/W.

Headrope, float line, corkline.--These terms are used interchangeably to describe the top strength member rope and its floats which are normally attached to assist in vertical opening of the net.

Intermediate.--Intermediate sections of the net are found only in trawl gear in the after-section of the net and are used to connect the main body meshes to meshes of the fish bag.

Main body or body.--Refers to the great bulk of netting used to fill in the basic design of the net, exclusive of peripheral parts such as riblines, headrope, footrope, breastlines, selvage strips, intermediate sections, and fish bag.

Net.--Any completed assembly of netting or sections of netting having a prescribed shape useful to perform a desired function, e.g., tennis net, safety net, basketball hoop net, and fishing net.

Netting, webbing, web.--These three terms are used interchangeably to describe the basic material from which nets are made.

Panel.--A single section of netting cut to a prescribed shape and size that is joined to other panels in the construction of a completed net.

Riblines.--Strength member ropes attached to outer seams of trawl gear. Whenever netting attached to riblines is hung in (unit length of netting attached to less than one unit length of ribline), it becomes a load-bearing member during fishing operations and assists in opening the net to its desired shape. Whenever netting is hung to riblines with identical unit lengths, the riblines serve only to limit the extent of damage whenever a net is torn and to assist in bringing aboard large catches of fish after the net has been collapsed during retrieval.

Selvage (selfage) edges and selvage strips.--The machine-made or man-made, double twine edges along a length of netting or along the edges of panels of netting. Selvage strips are narrow sections of netting fabricated of much heavier twine than main body netting and have a width of 2 or 3, up to 50 meshes. Selvage strips are commonly made utilizing larger mesh size in addition to larger twine size. Their main function is to more equally distribute load among strength-bearing members such as headropes, footropes, breastlines, and riblines, to main body meshes.

Splitting strap.--Heavy ropes which are permanently threaded through a maximum of seven steel rings placed around the cod end to allow pinching off a part (one-half to 3 tons) of the catch. Splitting straps are utilized by small vessels to bring aboard small sections of large catches.

NET CLASSIFICATION

The following brief descriptions of the various types of net gear used in fishing were adapted from Nomura and Yamazaki (1975).

I. Gill Nets

A. Surface gill net.--Buoyed to float on the surface.

1. Fixed surface gill net.--One or both ends of the net are anchored; used in shallow inlets or narrow waterways where fish such as sardine migrate.

2. Drift surface gill net.--Net drifts with current; used mainly in open offshore waters; for night sets, lights are attached to ends of nets; used in the salmon gill net fishery.

B. Midwater gill net.--Nets are suspended in midwater by long float lines.

1. Fixed midwater gill net.--Construction same as fixed surface gill nets; fishing depth is adjusted by use of long float line; ends of net anchored.

2. Drift midwater gill net.--Same as drift surface gill net; fishing depth adjusted with long float line; used to capture sardine, mackerel, and saury.

C. Bottom gill net.--Nets set near or on bottom; used for catching cod, flounder, shark, mackerel, sea bream, shrimp, and crab.

1. Fixed bottom gill net.--Set on or near the bottom with anchors; effective fishing depth to 200 m.

2. Drift bottom gill net.--Net allowed to drift freely over sea bottom.

D. Encircling gill net.--Gill net, which is set inside a large encircling net to first encircle the fish school; the inner net gills the fish, used to catch young yellowtail.

E. Sweeping gill net.--A net in which one end is anchored and the other other end is towed in a circle to bring the net in contact with fish.

F. Entangling net.

1. Single entangling net.--Single net with or without leadline used to entangle fish; used for king crab and tuna.

2. Trammel net.--A net composed of a panel of small meshed webbing sandwiched between two outer panels of large-meshed webbing; used to entangle or trap fish in a loop of webbing.

II. Haul Nets

A. Beach seine.--A bag-shaped net with long wings; usually used along shoreline and pulled by hand toward the beach.

B. Boat drag seine.

1. Upper-layer drag net.--This net is a long, conical bag with wings.

2. Danish seine.--A net in which one end is first attached to a buoy underwater before setting; remainder of tow rope, net, and opposite side tow rope is then payed out as boat travels a triangular course to return to the buoy; buoy is retrieved and the two ropes are hauled by the boat thus bringing the wings closer together and driving the fish into the net mouth.

3. Trawl net.--Conical net pulled by one or two boats for set periods of time.

a. Bottom trawl.--Hauled on or just off the bottom.

(1) Beam trawl.--Uses beam or other devices to spread net mouth; examples are dredge and coral net.

(2) Otter trawl.--Uses otter boards or "doors" to spread net mouth; examples are bottom fish trawl and shrimp trawl.

(3) Two-boat trawl.--Uses two boats to spread net mouth; examples are bull trawl and paranzella net.

b. Midwater trawl.--Hauled in midlayers; mouth held open either by otter boards or by two boats.

III. Push Net

Triangular, bag-shaped net two sides of which are fixed to scissorlike crossed bamboo sticks; net is pushed forward in shallow water by hand or boat.

IV. Lift Net

Operation of net involves raising or hauling a submerged net upward out of the water; net can be a small hand-operated net, hoop net, blanket net, or a large mechanical lift net.

A. Floating lift net.

1. Stick-held lift net.--Net is set deep beneath the water surface and is allowed to flow freely from the boat; hauling lines are attached to keep the net from drifting away; submerged net is lifted upward when fish schools aggregate over net; used to catch saury, mackerel, and horse mackerel with the aid of light attraction.

2. One-boat lift net.--Small scooping net is used.

3. Eight-angle net.--Net is a lift net operated by two boats.

B. Bottom lift net.--Net is submerged and rests on bottom.

1. Four-angle dip net.

2. Three-boat lift net.

3. Four-boat lift net.

4. Eight-boat lift net.

V. Surrounding Net

Net used to encircle fish schools from the side as well as the bottom; net is rectangular or has a bag with wings thus resembling a haul seine.

A. Surrounding net with pocket.--A semisurrounding net; bag net (better referred to as a lift net) is used together with a pair of wing nets; used at night with lights to attract fish schools.

B. Surrounding net without pocket.

1. Surrounding net with purse line.--Net is set around a fish school and the purse line quickly pulled in to close off the bottom of the net.

a. One-boat purse seine.--Net is set after skiff holding one end of the net is launched; boat then pays out net to surround fish school; the seiner then retrieves purse line and bridle from the skiff and the net bottom is closed; net is hauled with a power block; example: tuna purse seine.

b. Two-boat purse seine.--The purse line or wire rope is attached to the sinkers, similar to the one-boat seine; net operated by two boats; two-boat seine differs from one-boat seine in twine size, mesh size, length, width, and length-width ratio.

2. Surrounding net without purse line.--Lampara-type net; has neither rings nor purse line along the bottom.

VI. Cover Net

A. Cast net.--Conical net thrown by hand so that it opens nearly flat as it falls on the water surface; net sinks rapidly due to weights attached to edge of net.

B. Lantern net.--Net is fabricated to cover a wooden, lantern-shaped frame; operates by covering fish; hand hauled.

VII. Trap Net

Fish are caught in collecting units from which escape is prevented by labyrinths and retarding devices such as gorges and funnels.

A. Large-scale trap net.

1. Large stationary net without traps.

a. Large stationary triangular net.--Gear consists of a leader net and main net.

b. Large stationary oblong or octagonal net.--Main net is 400 m long and 100 m wide; leader net is nearly 4,000 m long.

2. Stationary net with trap.--Net has three parts--bag net (or main net with bag), barrier net (or playground net), and leader net.

a. Stationary net with one trap.--Main net is 200 m long; used to catch yellowtail, horse mackerel, squid, and some pelagic species.

b. Stationary net with two traps.

B. Medium stationary trap net.

1. Sardine stationary net.--Bag net does not reach to bottom; has leader net and big playground net with bottom sloped upward.

2. Herring stationary net.--Net is box-type bag net.

3. Salmon stationary net.--A surface or bottom trap net used on grounds with swift currents.

C. Small-scale stationary trap net.--A pound net with main net, leader, and conical bag net.

D. Guiding barrier.--Screen labyrinth net; gear consists of a fence (or fences) which guides the fish to one or more retaining chambers.

E. Portable trap and stow net.

1. Covered pots and fyke net.--This gear can be used singly or arranged in systems with wings and leaders; net has basketlike or cagelike appearance; made of wood, netting, wire, or plastic.

2. Stow net.--Net is fixed on stakes or anchored with mouth kept open by frame; usually placed in strong river currents.

NET FISHERIES

The net is a relatively young invention and was probably introduced in hunting earlier than in fishing (von Brandt 1964). Although net fishing developed rapidly in some countries after its introduction, it was of secondary importance in others where fishing methods such as hook and line, traps, striking gear, shooting, and fish barriers were more highly developed (von Brandt 1964). But it seemed inevitable that net fishing would occupy a prominent part in the fisheries of many nations as net making technology was perfected by repeated trial and error over a long period. Even today, many nations have not acquired the knowledge and technical skills to make nets; however, this is no longer a problem since machine-made nets from major industrial and manufacturing nations can be delivered to the most remote places of the world.

Today, the net fisheries harvest a large number of species using a wide assortment of gear including gill nets, tangle nets, trawls, purse seines, set nets, lift nets, and haul seines. Excellent reviews of some of the major fisheries in the North Pacific may be found in a number of reports (Alverson et al. 1964; Chitwood 1969; Frey 1971; Takahashi 1972; Browning 1974; and Forrester et al. 1978, 1983).

In the sections that follow, some of the major net fisheries in the North Pacific are reviewed.

Gill Net Fisheries

In the chronology of net gear, the gill net evolved after the beach seine but well before the development of the purse seine (Browning 1974). In terms of tonnage of fish landed, however, the gill net has to rank behind the purse seine and the trawl.

Although resembling the beach seine, the gill net fishes on a different principle, that is, whereas a beach seine surrounds or closes off the path of a school of fish, the gill net is simply a wall of netting whose meshes either form a "noose" around the heads and bodies of fishes and molluscs that swim forward vigorously (von Brandt 1964; Browning 1974), or entangle legs and spines of crustaceans. Furthermore, the gill net is much more versatile because it can be fished at the surface, in midwater, or on the bottom and be anchored or set adrift.

Gill nets may be classified into several categories depending on geographic area. On the U.S. west coast and Alaska, gill nets may be classified into two broad categories--drift nets in their several forms and the set or anchored gill net (Browning 1974). In Japan, in addition to the two mentioned above, there is a third classification referred to as a "movable type" gill net in which the net is used to encircle or is set near fish schools and the fishermen actively drive or herd the school into the meshes of the net (Yamaha Motor Co. (Yamaha) 1979a).

There are a number of major and minor fisheries in the North Pacific in which fishing vessels use gill nets exclusively or in combination with other gear. These include fisheries for salmon, squid, tuna, barracuda, pomfret, saury, shark, white seabass, Pacific herring, yellowtail, mackerel, bonito, flyingfish, sardine, pollock, king crab, cod, bream, shrimp, and flatfish (Nomura and Yamazaki 1975).

A net much like the gill net is the trammel net. Trammel nets have two outer walls and an inner, longer sagging curtain. They are designed to prevent fish like halibut, which can swim powerfully in reverse, from freeing themselves from a standard gill net. A fish swimming into a trammel net entangles its head in the small mesh and drives the inner curtain through the outer wall. The mesh then collapses behind the fish, bagging it and blocking its escape (Pleschner 1983).

Because of the extra time and skill required in fishing with trammel nets, many halibut fishermen use a simpler suspended or "trammelized" gill net. This type of net is fabricated by taking a single-walled net and interweaving a vertical string or line at intervals to prevent the net from expanding to its full height. The added slack traps the fish in a bag of mesh. This adaptation to the gill net fishes cleaner and offers a little more protection from seal predation; however, it is not effective at catching large fish (Pleschner 1983).

Coastal Gill Net Fisheries

In Japanese net fisheries, although the number of boats that can be operated in fisheries such as small-scale trawling, purse seining, boat seining, and fixed net fishing is limited by a licensing system, the number of gill-netters is licensed only in certain prefectures; therefore, gill netting is a popular fishing method among coastal fisheries and provides support to many families that rely solely on income from fishing (Yamaha 1979a). In fact, of Japan's fleet of 328,000 fishing boats that are under 5 gross tons (GT), 38,000 or 12% use gill nets exclusively.

Fishing with gill nets is a relatively simple operation along the coasts of Japan. The small fishing boats operate close to shore and can set and retrieve nets with small crews (Yamaha 1979a). Major species taken include sardine, mackerel, horse mackerel, saury, skipjack tuna, yellowtail, bluefin tuna, swordfish, salmon, trout, cod, shark, sea bream, flatfish, octopus, squid, sea urchin, sea cucumber, shrimp, and crab.

In the coastal drift net fishery for salmon and trout along the northern half of Japan in the northwestern Pacific and in the Sea of Japan, 1,380 boats landed 34,218 metric tons (MT) to 73,769 MT of salmon in 1971-76, averaging 50,024 MT annually (International North Pacific Fisheries Commission (INPFC) 1979).

The type of gill net used in the coastal fisheries varies considerably, depending on the target species. The fishermen decide on the most appropriate design and construction of the net, taking into consideration the quality of the material, thickness of the thread, mesh size, knotting method, mesh depth, and color. They also must select an optimum hanging ratio of the netting to give the net flexibility and increased entangling efficiency (Yamaha 1979a). The hanging ratio is usually determined after taking into consideration the target species, bottom topography, tidal current, water depth, and the surplus buoyant force of the floats.

For sardine drift net, the mesh is 4.3 cm, the float line is 30-48 m with a 35-40% hang-in, and the leadline is about a meter longer than the float line. The boats in this fishery carry about 7-8 men and are about 20 GT. Each boat sets about 40 units of nets per set (Nomura and Yamazaki 1975).

The Spanish mackerel fishery uses a different net with a mesh size of 7.5 cm, a depth of 130 meshes, and a float line 26 m long. Because the net is intended to drift at the surface, the leadline, which is 25 m long, is without weights. The hang-in is 44.5% in the float line and 44.6% in the leadline (Nomura and Yamazaki 1975).

The gear used in the mackerel drift net fishery is similar to that used in the sardine drift net fishery except that the mesh size is 7.0-8.5 cm and depth varies widely from 200 to 500 mesh. The length per unit of net is 75 m and the hang-in is 30-40% (Nomura and Yamazaki 1975).

There is also a mackerel bottom gill net which has a mesh size of 7.6 cm, is 100-400 meshes deep, with a float line of 36.4 m and a leadline of 33.3 m. The hang-in is 30% (Nomura and Yamazaki 1975).

In the flyingfish drift net fishery, the gear is fabricated into three parts--the end net, the first leader net, and the second leader net. Thirty units of net are strung together to form a length of gill net stretching 1,047 m long (Nomura and Yamazaki 1975).

Still another gear used in the coastal fisheries is the shrimp bottom gill net (Nomura and Yamazaki 1975; Yamaha 1979a). Made of nylon webbing, the mesh is 6-10 cm and the net is 10-17 meshes deep with a 50-69% hang-in. Each unit is 2.5 m long.

For shark fishing, a bottom gill net with mesh sizes 17-25 cm is used, and because sharks are caught by trammeling, the hang-in is as large as 40%. The net is 18 meshes deep with a stretched length of 50.5 m hung on a float line of 37.9 m. The leadline is 30.3 m. The boats operating in this fishery are 7-10 GT with eight men aboard. Usually, each vessel sets 40-80 units of gill net per day.

The Soviet Union's coastal fisheries bordering the North Pacific involve traps, beach seines, and weirs to capture maturing salmon from schools that are migrating to the spawning grounds. The areas fished include the east and west coasts of Kamchatka, the northern part of the Okhotsk Sea, along the coastline bordering the Okhotsk Sea from Lisyansky Peninsula to the Amur area, Amur River basin north to the Iska River, coast of Primore, Sakhalin, Kuril Islands, and the Gulf of Anadyr (Fig. 2) (INPFC 1979).

Soviet fishermen use several different types of gill nets and tangle nets for fishing in the northwestern Pacific. In general, nets are 20-30 m long, but for certain types of fishing, e.g., deep bottom fishing, nets may be up to 1,000 m long. The depth of the net is dictated by the target species. Most set gill nets are 1.7-2.5 m deep; most drift nets are 6-15 m deep. Andreev (1966) described several nets used in the northwestern Pacific, as follows:

Shark anchored gill net.--The net is 25 m long and 25 meshes deep; hanging ratio is 0.50; mesh size is 80 mm; and twine size is 20/12.[2]

Walleye pollock gill net.--The net is 30 m long and 30 meshes deep; hanging ratio is 0.60; mesh size is 48 mm; and twine size is 18/3.

Crab anchored gill net.--The net is 46 m at the corkline and 42 m at the leadline; the depth is 6.5 meshes; hanging ratio is 0.42-0.46; and the twine size is 20.12. No mesh size is given.

Anchovy drift net.--The net is 45 m long and 200 meshes deep; hanging ratio is 0.60; mesh size is 14 mm; and the twine size is 130/6.

Pacific saury drift net.--The net is 36 m long and 5.1 m deep; hanging ratio is 0.60; mesh size is 16 mm; and twine size is 61/6.

Mackerel drift net.--The net is 30 m long and 6.4 m deep; hanging ratio is 0.60; the mesh size is 40 mm; twine size is 34/12.

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[2]The numerator is the size of the yarn with which the twine is constructed and the denominator is the number of yarns in the twine.

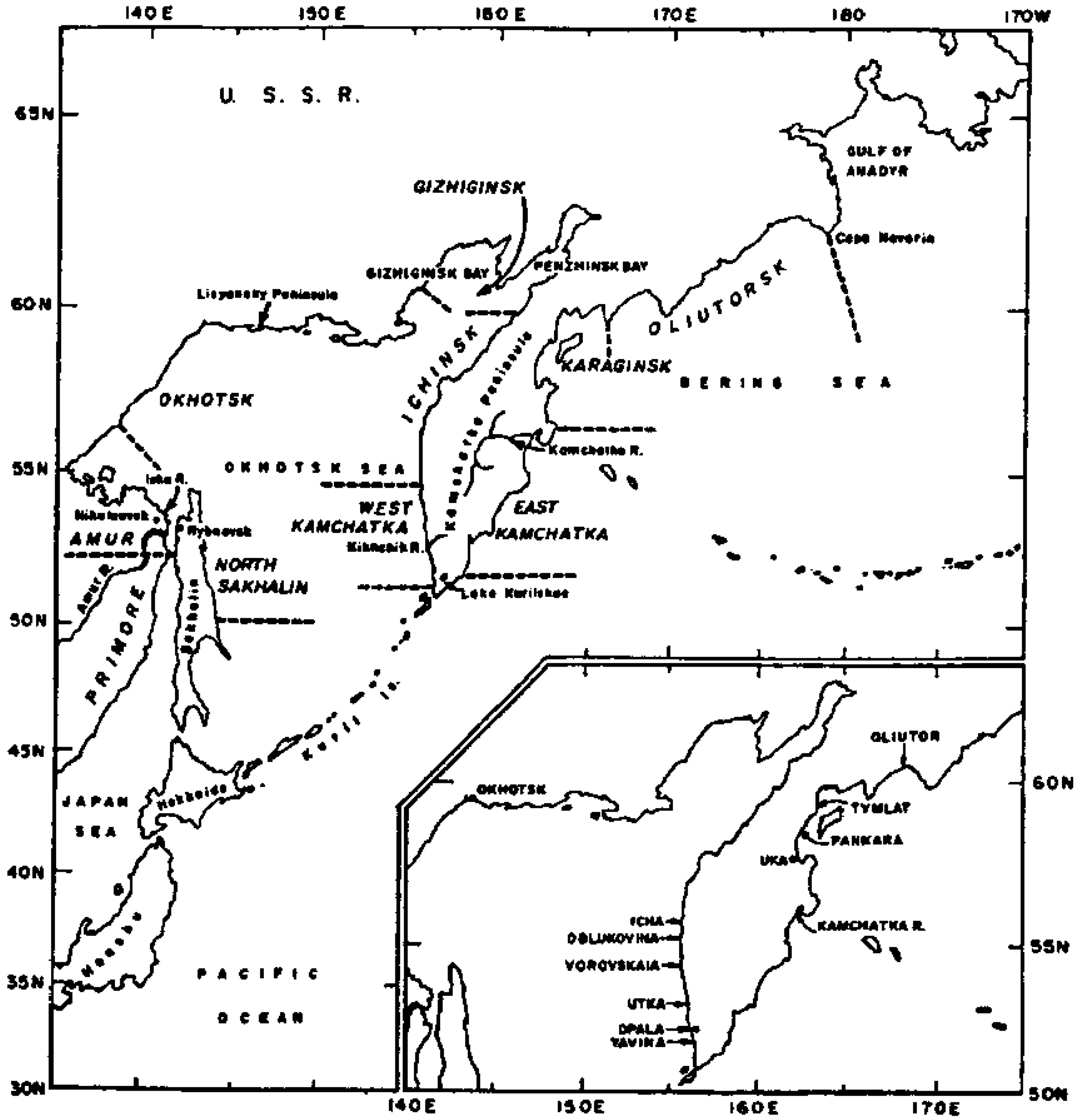

Figure 2.—Areas fished for salmon by Soviet fishermen (International North Pacific Fisheries Commission 1979).

<u>Salmon drift net</u>.—The net is 30 m long and 3.3 m deep; hanging ratio is 0.60; twine size is 34/12. No mesh size given.

<u>Herring drift net</u>.—The net is 30 m long and 6.0 to 15.2 m deep; hanging ratio is 0.60; twine size is from 34/6 to 61/6. No mesh size given.

Information is lacking on the number of units of gear used in the various Soviet fisheries.

Canadian and United States fishermen, including those in Alaska, fish for salmon in inshore waters. Salmon fishing with nets is prohibited at any distance from the outer coast with minor exceptions. Thus, except for salmon taken by trolling, the bulk of the Canadian and United States catch comes from purse seines and gill nets fished in inshore waters.

The Canadian gill net fishery for salmon in Georgia Strait is largest in the Fraser River area where fleet size reaches 800 vessels during the summer fisheries for sockeye and pink salmon, and during occasional fall openings for chum salmon (Argue et al. 1983). In the remainder of Georgia Strait, there are perhaps 3,000 gill net boats that fish at least once. The boats in this fishery are 10-15 m and carry nets with meshes of 130-149 mm for sockeye, pink, and coho salmon and 165-216 mm for chum and chinook salmon. Nets are restricted to a length range of 137 to 336 m and a depth of no more than 60 meshes. The number of days allowed for net fishing varies widely depending on location of the fishing grounds. In 1981, 2,508 gill-netters and combination gill net-troll boats fished for pink, chum, and sockeye salmon in British Columbia waters (Beacham 1984a, 1984b, 1984c).

A Canadian skiff gill net fishery also exists for high value roe herring (Ness 1977a; Forrester et al. 1983). In this fishery, gill nets now account for about half of the herring roe catch (Hourston and Haegele 1980). These gill nets are fished from aluminum skiffs especially developed for this fishery. In 1978-79, 1,300 gill-netters fished for herring roe.

In waters off the U.S. Pacific coast states, the gill net is the most important commercial salmon gear, accounting for roughly 50% of the landings from these states in 1975 (U.S. Department of Commerce 1978). Following gill nets in order of importance was the purse seine which accounted for 35% of the salmon landings, whereas lines produced just 14%. The remaining 1% of the catch came from haul seines, otter trawls, pound nets, floating traps, pots, dip nets, reef nets, and wheels. A summary of operating units for the U.S. Pacific coast fisheries in 1975 is shown in Table 3.

In the early years of the salmon fishery, linen gill nets were used; however, nylon webbing was introduced in the 1950's and replaced linen rapidly. Monofilament nylon webbing was used by a few fishermen in 1958 but was banned in Washington and Oregon in 1959 and in Alaska in 1960. The ban on monofilament gear, however, was not applied to Indian fisheries in Washington and in the Columbia River where existing fisheries commonly used monofilament gill nets. In 1965, a multiple strand monofilament gill net was introduced in Washington and is legal gear at the present time.

Although the U.S. commercial salmon fishery operates in the four Pacific coast states, only Alaska and Washington have large net fisheries. The regulations concerned with the Alaska salmon fishery are extremely complex and involve variations, by statistical districts, in fishing season, gear specifications, and type of gear allowed (Table 4).

In Washington, the commercial salmon fishery, which is carried out in Puget Sound, Grays Harbor, Willapa Bay, Columbia River, and offshore, depends primarily on purse seines and drift nets. In Puget Sound, drift nets may be 549 m long with stretched mesh varying from 114 to 210 mm, depending on area, season, and target species. Around San Juan Island, some reef nets are also used. The season extends from May to October. At Grays Harbor and Willapa Bay, drift nets allowed are 457 m long with a minimum mesh size 127 mm. The season here runs from July through November (INPFC 1979).

Table 3.--Summary of operating units, 1975 (U.S. Department of Commerce 1978).

ITEM	ALASKA	WASHINGTON	OREGON	CALIFORNIA	TOTAL, EXCLUSIVE OF DUPLICATION
			NUMBER		
FISHERMEN:					
ON VESSELS	8,946	5,227	2,858	8,912	22,741
ON BOATS AND SHORE:					
FULL-TIME	7,067	5,278	1,628	7,769	21,742
PART-TIME	-	339	18	-	357
TOTAL	16,013	10,844	4,504	16,681	44,840
VESSELS, MOTOR	2,432	2,390	1,300	2,325	7,031
GROSS TONNAGE	63,349	60,860	37,727	137,486	289,413
BOATS:					
MOTOR	4,195	4,505	1,571	2,832	12,972
OTHER	-	-	-	364	364
GEAR:					
HAUL SEINES, COMMON	9	85	5	11	110
PURSE SEINES:					
ANCHOVY	-	-	-	9	9
HERRING	-	31	-	-	31
MACKEREL	-	-	-	43	43
SALMON	1,014	348	-	-	1,231
TUNA	-	-	3	138	141
OTHER	-	-	-	204	204
LAMPARA NETS:					
MACKEREL	-	-	-	23	23
SQUID	-	-	-	28	28
TUNA	-	-	-	6	6
OTHER	-	-	-	57	57
BEAM TRAWLS, SHRIMP	27	7	-	3	37
OTTER TRAWLS:					
FISH	20	97	143	533	778
SHRIMP	87	48	184	51	322
OTHER	-	1	-	-	1
POUND NETS, FISH	2	1	-	-	3
FLOATING TRAPS	8	-	-	-	8
POTS AND TRAPS:					
CRAB:					
DUNGENESS	27,799	36,378	57,683	38,793	157,250
KING	51,791	-	-	-	51,791
OTHER	37,274	-	-	-	37,274
CRAWFISH	-	250	150	4,200	4,600
FISH	-	825	6,050	8,515	15,325
LOBSTER, SPINY	-	-	-	9,900	9,900
OCTOPUS	-	570	-	-	570
SHRIMP	3,775	2,650	-	148	6,573
GILL NETS:					
ANCHOR, SET, OR STAKE:					
SALMON	2,361	680	4	-	3,045
OTHER	23	-	29	324	376
DRIFT:					
BARRACUDA	-	-	-	78	78
SALMON	2,677	2,210	325	-	5,113
SEA BASS	-	-	-	58	58
SHAD	-	-	58	-	58
OTHER	-	5	17	648	670
TRAMMEL NETS	-	-	-	35	35
LINES:					
HAND AND TROLL, TUNA	-	-	7,710	-	7,710
HAND:					
ROCKFISH	-	154	-	30	184
TUNA:					
ALBACORE	-	222	-	1,178	1,200
YELLOWFIN	-	-	-	340	340
OTHER	-	-	-	16,384	16,384
TROLL:					
SALMON	7,078	13,681	13,014	13,695	45,409
TUNA	-	4,010	1,040	8,088	12,378
OTHER	-	123	-	12,762	12,885
LONG OR SET WITH HOOKS	10,883	1,019	225	1,640	13,632
DIP NETS:					
COMMON	-	188	5	120	313
DROP	-	20	-	-	20
BRAIL OR SCOOP NETS	-	-	-	73	73
REEF NET	-	78	-	-	78
HARPOONS:					
SWORDFISH	-	-	-	193	193
OTHER	-	-	-	3	3
WATER PUMP	-	-	4	-	4
DREDGES:					
CLAM	-	4	-	-	4
OYSTER:					
COMMON	-	46	4	-	50
SUCTION	-	2	-	-	2
SCALLOP, SEA	3	-	-	-	3
RAKES, OYSTER	-	-	-	46	46
SHOVELS	30	128	42	-	200
DIVING OUTFITS:					
ABALONE	-	-	-	288	288
OTHER	-	-	-	108	108

Note: Haul seines in Alaska have been included with purse seines. Nets or lines made up of small units for ease in handling, but fastened together in fishing, are counted as a single unit.

Table 4.--Net regulations in the Alaska salmon fishery, by type of gear and statistical districts (International North Pacific Fisheries Commission 1979).

District	Legal gear		Minimum stretch mesh (mm)	Beach seines, traditional and hand-hauled purse seines (m)
	Drift net (m)	Set gill net (m)		
Arctic-Yukon-Kuskokwim	91	183-274	203 (June) 152 (other months)	--
Bristol Bay	274	91	137	--
Alaska Peninsula-Aleutian Islands	--	366	133	183-457
Chignik	Banned	Banned	--	183-411
Kodiak	--	274	--	183-366
Cook Inlet	274	--	153 but 178 during Chinook run	165-457
Prince William Sound	274	--	--	229-274
Southeast Alaska	--	27-549	203 (<60 meshes deep) >203 (<40 meshes deep)	183-457

The commercial salmon fishery in Oregon consists only of the Columbia River gill net fishery, which is the same as that for Washington because of joint responsibility for management, and the ocean troll fishery. Drift nets are the only commercial gear allowed in the Columbia River fishery below the Bonneville Dam. Above it, set gill and dip nets are permitted in the exclusive Indian commercial fishery. Drift nets up to 457 m and set gill nets up to 91 m are legal gear. In February-March and in August, a 184-mm minimum mesh size is enforced to reduce the catch of steelhead trout. The mesh size is reduced to 114-mm mesh minimum in June-July only for sockeye throughout the Columbia River to protect the summer-run chinook salmon.

The Columbia River fishery has four seasons: winter (February-March), spring (April-May), summer (June-July), and fall (August-November) (INPFC 1979).

California, like Oregon, has banned gill net fishing for salmon and operates only an ocean troll fishery (INPFC 1979).

Other major gill net fisheries in waters of the Pacific coast states include those for herring. Exclusive gill net fishing for herring was not allowed in Alaska until 1976 where regulations adopted by the Alaska Board of Fisheries provided for 10 fishing areas in southeastern Alaska to be set aside for gill netting (Ness 1977a). Regulations for this fishery require a minimum mesh size of 5.4-cm stretch mesh. Nets can be no longer than 91 m and the maximum aggregate length allowed is 366 m per gear holder. The net is rigged with anchors and buoys and has an average fishing depth of 11 m. Although current regulations do not specify vessel type or size, the traditional boats are 5-9 m skiffs. The fishery operates only briefly (1 day) until the maximum catch quota is attained.

California also has a large coastal fishery for herring. Three gear types are involved in this fishery--purse seine, lampara, and gill net; however, the gill net is by far the most frequently used. Gill nets used in this fishery became more competitive when set or anchored nets were permitted in 1976-77. The result was that fishermen targeting primarily for herring roe shifted from round-haul nets to gill nets and this shift is continuing mainly because buyers prefer the larger fish and higher percentage of females in gill net catches.

In 1970-80, 363 vessels participated in the herring roe fishery, more than in any other commercial net fisheries in California. Of these, 306 were gill-netters.

Other gill net fisheries in California are for surface and bottom sea bass, bonito, and barracuda. Trammel nets are used for halibut and angel shark, and drift nets for thresher shark and swordfish. Average sets are about 20 to 30 pieces of net; each is 82.3 m long and 28 meshes deep. In 1975, there were 75 drift nets operating for barracuda, 56 units for sea bass, 35 units of trammel nets, and 648 units for a variety of other species.

High Seas Gill Net Fisheries

Two important high seas gill net fisheries exist in the North Pacific--one is for salmon, the other for squid.

The Japanese fishery for salmon in the North Pacific operates with mother ship fleets and land-based vessels. Mother ships are accompanied by catcher boats which fish with drift nets. Those vessels that are land-based work out of ports in northern Japan and use either drift nets or floating longlines.

The area of operation of the Japanese mother ship salmon fishery is shown in Figure 3. The number of mother ships and catcher boats that can operate in the salmon fishery is licensed by the Japanese Ministry of Agriculture and Forestry (JMAF). In 1969-78, these numbers varied from 11 to 40 mother ships and from 172 to 369 catcher boats (Table 5). Catcher boats, use monofilament gill nets with a minimum stretched mesh of 120 mm; however, more than 60% of the gill nets in use have a mesh size of 130 mm. Each catcher boat is allowed to set from 12 to 15 km of net at the maximum depending on the area being fished (INPFC 1979). Jones (1982) has estimated that annual fishing effort in the Japanese salmon mother ship fishery has

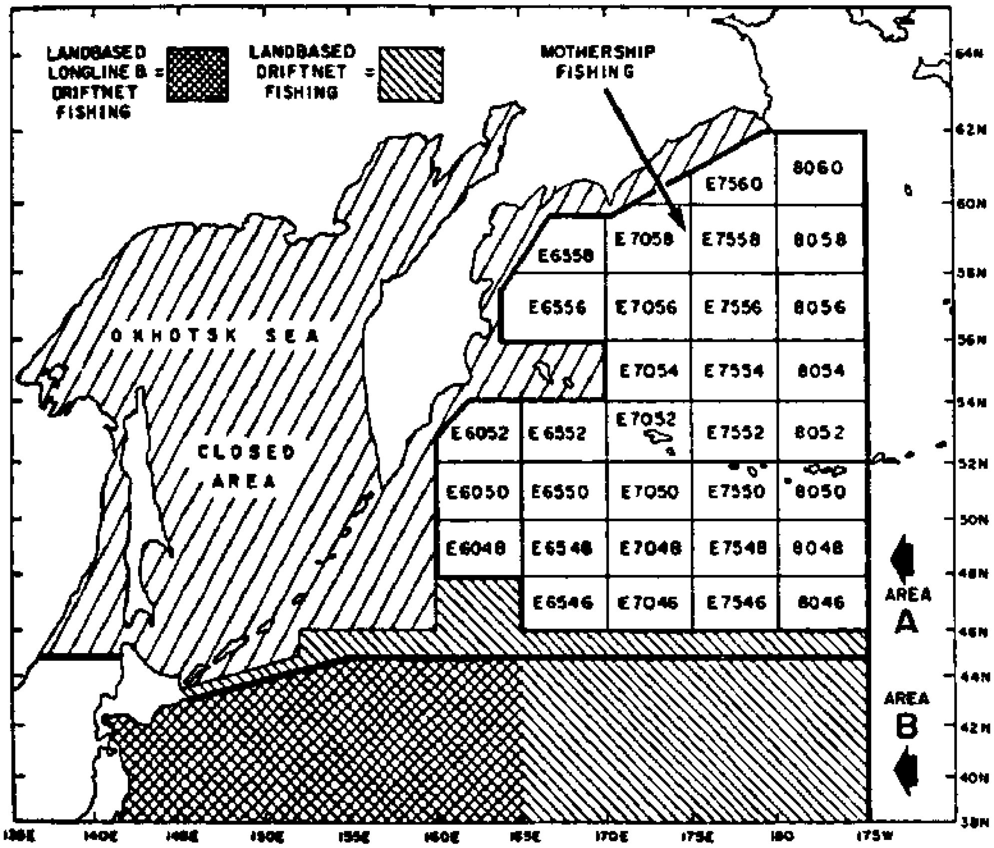

Figure 3.—Statistical areal divisions of the Japanese salmon fisheries, 1971 (International North Pacific Fisheries Commission 1971).

Table 5.—Changes in the Japanese salmon mother ship fishery during 1969-78 (effort in thousands of tans) (International North Pacific Fisheries Commission 1979).

Year	No. of mother ships	No. of catcher boats	Fishing effort[1]
1969	11	369	6,217
1970	11	369	6,028
1971	11	369	5,839
1972	10	332	5,917
1973	10	332	5,850
1974	10	332	5,433
1975	10	332	5,633
1976	10	332	5,811
1977	6	245	3,984
1978	4	172	2,721

[1]Cumulative quantity of gill net used, in thousands of tans.

fluctuated from 0.5 to 9.3 million tans (one tan is 50 m of gill net). The changes in fishing effort are related to quotas and restrictions imposed for available fishing grounds. Since 1978, effort has averaged about 3.0 million tans annually and has been concentrated in the grounds just south of the Aleutian Islands inside the United States fishery conservation zone.

In the land-based fishery, the JMAF has licensed about 325 vessels, which are required to land their catches at designated ports. These vessels use monofilament gill nets with a minimum stretched mesh of 110 mm although nets with 115 mm meshes are more commonly used. Each vessel is allowed to set a maximum of 12 or 15 km of nets (INPFC 1979). Specifications for a Japanese salmon gill net are shown in Table 6. The Japanese land-based salmon fishery operates just south of the area fished by the mother ship fleet and extends westward towards Japan. Effort in this fishery has been about 3.0 million tans annually, similar to that of the mother ship fleet.

Two fisheries that are offshoots of the high seas salmon fishery are the billfish drift net fishery (Suisan Sekai 1978) and the high seas squid fishery. Beginning full-scale operation around 1972, the billfish drift net fishery has about 395 vessels, a third of which fish with drift nets full time for billfish. The drift net used is usually 50 m long and 9 m deep. The remaining vessels in the fleet fish salmon drift nets part-time or engage in tuna longline during other times of the year.

The sudden surge of vessels entering this fishery was the result of the "oil shock" of 1973 and the Japanese Government's policy to reduce the salmon fishery fleet. Increased fuel and bait costs forced many vessels engaged in other fisheries to turn to the drift net fishery because of the advantage gained through low fuel consumption and elimination of bait costs.

The fishery now operates year round. Between July and October, billfish appear off Sanriku and after October, migrate southward, ending the Sanriku drift net fishery. Some vessels, however, continue pursuing the migrating fish and establish bases as far south as Nagasaki Prefecture in Kyushu. In addition to billfish, the drift net captures skipjack and yellowfin tunas, mahimahi, and sharks.

The fishery is not without problems. Conflicts have erupted between the drift net and skipjack tuna pole-and-line fishermen because of increased competition for the resource. Furthermore, cruising vessels have complained that occasionally they run into drift nets, resulting in propeller damage.

The Japanese squid fishery, which developed rapidly in 1978 in the northwestern Pacific, targets the red squid.[3] Most of the vessels participating are salmon drift-netters that shift to squid fishing after the close of the salmon season. This new fishery, however, like the billfish drift net fishery, met stiff opposition, mainly from the squid jigging boats. The result was that on 1 January, the JMAF restricted squid drift-netting

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[3]Court, W. G. 1979. Japan's squid fishing industry. Tokyo University of Fisheries, Tokyo, Japan, 34 p. (Mimeogr.)

Table 6.—Specifications for a Japanese salmon gill net (Food and Agriculture Organization of the United Nations 1965).

Data Sheet — **FAO No. 404**

NAME OF GEAR: Salmon Gillnet
TYPE: Driftnet
COUNTRY: Japan
LOCALITY: North Pacific Ocean
REFERENCE: K. Mori (1961)

Main species caught: Salmon and trout
Fishing conditions: Surface; in open ocean.

Vessels: Mothership based catcher boats
L. O. A.: 80 - 90 ft
Gross tonnage: 75 - 85
Horse power: 280 - 400
Crew: 20 - 22

WEBBING	A	B	C
Material	Amilan	Cremina	——→
Type of knot	[illegible]	——→	——→
Preservation	O	——→	——→
Colour			
Twine size Tex	410	see drawing	
Breaking strength kg.	16.5		
Stretched mesh mm.	121	121	121
Upper edge	820	——→	——→
Lower edge	820	——→	1
Depth	57	1 1/2	57
Baiting rate			
Take-up			
Selvedge			
Hanging	$\frac{a}{A}$ = 0.52		

LINES, ROPES	a a_1	b b_2	c	d φ
Material	Manila	——→	Cremina	Staple nylon
Preservation	O	——→	——→	——→
Circumference in.	1 1/4	1 1/2		
Diameter mm.	10	12	1790 tex	
Breaking strength kg. / lb.	600 / 1325	1015 / 2250	24 / 53	30 / 66
Twist	55 and 42	58 and 32		
Lay	S	——→		
Length m. / ft	51.4 / 168	50 / 164		1.21 / 4

FLOATS, SINKERS	1	2		
Number	66	62		
Material	Plastic	Lead		
Shape	Oval			
Diameter mm.				
Length mm.	200 x 60 x 38	30 x 20		
Static buoyancy kg	0.235			
Weight in air g.	61	75		
Weight submerged kg. / lb.				

to the area north of lat. 20°N and west of long. 170°E. Japan has a squid drift net fleet of 534 vessels.[4]

Of the 110 vessels in the Taiwan squid fishing fleet, about 30 operate in the central North Pacific during May-September. The western boundary of this fishery is long. 170°W. There is no eastern or northern boundary. After the completion of the May-September season, the vessels, together with others joining the fleet, move to the western North Pacific grounds located west of long. 170°W. In the Taiwan squid fishery, the jigging and gill-netting combination vessel of about 390 GT with a length of 47 m is most popular. Driven by a 850-hp engine, these vessels carry 16-18 men and have a carrying capacity of 280 MT. The vessels are capable of remaining at sea for up to 4 months. Each of the combination vessels is typically equipped with 250 to 500 shackles of gill nets with each shackle 50 m long. The depth of the net is 6.5 m; the webbing is of monofilament vinyl chloride fibers, usually green or light blue.

Taiwan gill nets, compared with Japanese nets, are relatively cheap and are not expected to provide service for more than two seasons. The meshes of Taiwan nets are smaller than those of Japanese nets, measuring 94 mm compared with 115-120 mm. Fishing about 400 shackles of gill nets per day, the Taiwan vessels usually begin setting by 1600 to 1700 and retrieving the nets at about 0100 to 0200.

Purse Seine Fisheries

The purse seine takes fish at or near the surface. It is widely used for capturing schooling fish such as sardine, horse mackerel, tuna, mackerel, salmon, anchovy, herring, menhaden, and bonito. Purse seines usually have large numbers of floats to provide the necessary buoyancy to keep the net afloat at all times when the rings are pursed during retrieval. To prevent the fish school from escaping from the lower end, the net must be fast sinking yet have webbing as thin as practicable. Consideration must also be given to properties of the webbing, that is, it should be able to withstand tension, impact, and friction during setting and retrieving. The type of net fabricated depends on the target species; for example, night fishing for horse mackerel and mackerel does not require a fast-sinking net, but the webbing should be stiff enough to overcome deformation by currents. In daytime sardine seining, the net should be fast sinking. For tuna seining where setting is done at high speed, the net should not only be fast sinking but also be strong enough to resist the impact of tuna rushing into it to avoid capture (Nomura and Yamazaki 1975). Specifications for various kinds of purse seines used throughout the world are given in Table 7.

The purse seine can be classified as a "surrounding net" with or without bag. A lampara net is an example of the former, whereas a ring net is typical of the latter. The actual function of the seine is to form a curtain or wall of netting when a school is surrounded. The seine is buoyed at the top, weighted on the bottom, and has either a large central bunt and

[4]Low, L.-L. 1982. Memorandum issued 13 December 1982, on "Taiwan squid fishery in the North Pacific." Natl. Mar. Fish. Serv. Northwest and Alaska, Seattle, WA 98115, 5 p.

Table 7.—Specifications for various purse seines used throughout the world (adapted from Nomura and Yamazaki 1975).

No.	Main species of fish	Country	Fishing area	Major part of net: Stretched mesh size (cm) l	Major part of net: Number of yarns (210 d) y	Length of net (m) L	Depth of net: Number of mesh in depth n	Depth of net: Depth (m)
1	Herring	Canada	British Columbia	3.5	15	440	2650	93
2	Herring	Iceland	Ic. Waters	3.1	9	400	3600	110
3	Herring	Iceland	Ic. Waters	3.1	9	445	2000	60
4	Herring & Mackerel	Norway	Bergen Coast	3.6	9	380	2660	96
5	Herring	Norway	Bergen Ct.	1.5	4	325	4000	60
6	Herring	U.K.	Irish Sea	4.8	9##	190	1000	48
7	Yellowfin Tuna	U.S.A.	California Waters	10.5	120##	780	750	80
8	Bluefin Tuna	Japan	Pacific Ocean	18.0	36#	1250	1500	270
9	Bluefin Tuna	Norway	Bergen Ct.	19.4	36	670	520	100
10	Horse mackerel & mackerel	Japan	East China Sea	3.75	12#	900	7500	280
11	Sardine	Japan	Pacific Ct.	4.0	12#	600	3500	140
12	Menhaden	U.S.A.	Atlantic Coast	3.75	9	600	3800	83
13	Salmon	Canada	Pacific Coast	9.0	45##	400	350	30
14	Cod	Norway	Bergen Ct.	7.0	21##	380	860	60

short wings, as in the lampara net, or has purse rings through which a pursing line passes to close off the bottom. The lampara-type net is used for horse mackerel, mackerel, anchovy, sardine, tuna, and bonito. Most present-day seines are made of nylon, vinylon, tetoron, and kyokurin (Nomura and Yamazaki 1975).

In purse seining, the fish school is first spotted and encircled with the net. After the net is set, the purse line that runs through rings on the bottom of the net is closed and the net is hauled with a power block. First to be retrieved is the lower part of the net with the rings. By hauling the net uniformly, the fish school is concentrated in the bunt, which is usually strengthened to withstand the strain. The fish school thus concentrated is then removed from the bunt in small portions with scoop nets (von Brandt 1964).

Fishing with purse seines can be classified into one-boat and two-boat operations. The advantages of a one-boat operation are that it is not labor intensive, the net can be shot in rough seas, capital investment is smaller, and operational expenses are less. Disadvantages are that the net cannot be set in shallow water, more time is needed for setting and hauling, and hauling is difficult in swift currents. In a two-boat operation, the seine can be set in shallow water, time of setting and hauling is reduced, and hauling in swift currents is relatively easy. The disadvantages are the need for larger crews, inability to operate in rough seas, and higher operational expenses (Yamaha 1984).

Net construction differs according to the species sought. In a one-boat operation to catch mackerel and large horse mackerel, nets are fabricated from webbing with No. 21 to 24 (yarn number) twine, stretched mesh size of 5–6 cm, and a buoyline varying anywhere from 495 to 975 m; the ratio of the bunt depth to the buoyline length is 0.08 to 0.15. For sardine and small horse mackerel, however, the net used has No. 18 to 24 twine and mesh size of 3.3 cm (Nomura and Yamazaki 1975), and the buoyline for a sardine purse seine used in the one-boat operation has a buoyline of 340–500 m with a ratio of bunt depth to buoyline length of 0.10 to 0.20.

In two-boat purse seining, the bunt has No. 18 to 21 twine and 5–6 cm mesh for catching mackerel and horse mackerel. Sardine seining requires a net with No. 6 twine and 1.7 cm mesh. Fishing in bays and inlets requires yet another net with No. 4 to 6 twine and 1.1 cm mesh. Tuna fishing requires a net with No. 60 to 80 twine and mesh size of 9 cm in the bunt (Nomura and Yamazaki 1975). For two-boat operations, the net is 580 to 1,000 m long at the buoyline; the ratio of the bunt depth to the buoyline length is 0.18 to 0.25. The two-boat sardine purse seine is 270–780 m at the buoyline with a ratio of bunt depth to buoyline depth being 0.20 to 0.30 (Nomura and Yamazaki 1975).

Coastal Purse Seine Fisheries

Data available on the Philippine purse seine fishery, which contributed about a third to the 1980 commercial fish production, indicate that there were 313 seiners operating in 1975; however, the number reached 413 seiners or about 17% of the commercial fishing fleet by 1980 (Encina 1982). The seines used are about 457–494 m long and 82 m deep. Fishing is done at night with lights to attract phototactic species. The most important commercial species taken include round scad, chub mackerel, yellowfin tuna, sardine, bigeye scad, herring, jack mackerel, saury, and anchovy (Bureau of Fisheries and Aquatic Resources (BFAR) 1975; Shomura et al. 1975). A fishing gear similar to the purse seine, called the ring net, is also used in the Philippines. This net combines the features of the round haul seine, which has the bunt in the center flanked by two wings, and the purse seine (Encina 1982; White and Yesaki 1982). This fishery had 158 units operating in 1980, and the principal species taken included round scad, bonito, skipjack tuna, frigate tuna, mackerel, and chub mackerel (BFAR 1975).

The surrounding net in Japan has overtaken the trawl as the single most important gear in terms of total catch. With the enactment of the 200-mile fishing zones, Japanese trawlers were forced to phase out operation in many traditional distant water fishing grounds and fish closer to their homeland, thus contributing to the relative increase in the surrounding net fishery from local waters (Yamaha 1984). In addition, technological advances in electronic fish finding equipment provided the surrounding net boats with a greater advantage, thus contributing immensely to their fishing efficiency, particularly in the sardine and anchovy fisheries.

The Japanese surrounding net fleet may be divided into three classes: large-scale boats of over 40 GT (constituting 76% of the fleet), medium-scale boats of 5-40 GT (making up 22%), and small-scale boats of <5 GT (accounting for 2%) (Yamaha 1984).

The surrounding net fishery is also divided into geographical regions in Japan. There are "northern surrounding net fisheries" which target members of the mackerel, sardine, and anchovy families in offshore waters of Hokkaido and northeastern Japan, the "west Japan surrounding net fisheries" which fish mainly for mackerel, horse mackerel, and sardine in the East China Sea, and the "pelagic surround net fisheries" for skipjack and other tunas in the western tropical Pacific.

The surrounding nets used in Japan are seines with or without pursing lines although the former type predominates. They are set by one or two boats, although recent trends have been to a one-boat operation. Sardine, horse mackerel, and mackerel make up 90% of the surrounding net fishery catch with smaller quantities of skipjack and other tunas, yellowtail, dorado, and Atka mackerel included in the remainder. In the small- and middle-scale surround net fisheries, boats in the 14.9 to 19.9 GT class are the most numerous. Net specifications for this fishery are shown in Table 8. A smaller seiner, for example, in the 8-9 GT class, will use a smaller net (Table 9).

Table 8.--Specifications: Purse seine fishing gear (Yamaha 1984).

Name	Sign	Material	No. of yarns	Mesh size	Depth	Length
Bunt	A	Nylon	2100. 18y.	23 mm	200	75 m
	B1	Nylon	2100. 12y.	23 mm	2,800	75 m
	B2	Nylon	2100. 12y.	23 mm	2,000	75 m
	B3	Nylon	2100. 12y.	23 mm	2,400	75 m
	B4	Nylon	2100. 12y.	23 mm	2,800	75 m
Body	C1	Nylon	2100. 12y.	23 mm	200	75 m
	C2	Nylon	2100. 12y.	23 mm	6,000	75 m
	C3	Nylon	2100. 12y.	23 mm	400 ~ 800	75 m
	D1	Nylon	2100. 9y.	23 mm	6,400	75 m
	D2	Nylon	2100. 9y.	23 mm	6,800	75 m
	E	Nylon	2100. 9y.	28 mm	400	75 m
	F1	Nylon	2100. 30y.	60 mm	200	75 m
	F2	Nylon	2100. 30y.	60 mm	100	75 m
Wing	C1	Nylon	2100. 12y.	23 mm	200	75 m
	D3	Nylon	2100. 9y.	23 mm	6,400	75 m
	D4	Nylon	2100. 9y.	23 mm	6,000	75 m
	F3	Nylon	2100. 30y.	60 mm	400	75 m
Selvedge	G	Nylon	2100. 60y.	34 mm	20	975 m
	H	Nylon	2100. 60y.	34 mm	20	975 m

(No. of meshes)

Table 9.--Net Specifications for small Japanese purse seiners (Yamaha 1984).

Fish sought	Material	Thickness	Mesh size (mm)
Horse mackerel and mackerel	Nylon	2100 9-12 y	28
Adult sardine	Nylon		16
Half-grown sardine	Nylon		12
Sardine fingerling	Nylon		9.7 or 10

In the two-boat operation where fishing is confined to daytime, the load of the net is shared by the two boats which are linked at the bow while traveling to the fishing grounds. Each seiner is equipped with its own pursing wire winch and a net hauler. Table 10 gives data on fishing grounds, boats, and nets used for various two-boat purse seine fisheries operating in the coastal waters of Japan. Detailed specifications for nets used in various one-boat and two-boat fisheries are given in Table 11.

Table 10.--Various two-boat purse seine fishing operations (Yamaha 1984).

Fishery	Sardine & horse mackeral purse seine	Luring-lamp type sardine & horse mackerel (purse seine	Gizzard shad purse seine	Hemisamph purse seine	Sardine purse seine	Sardine purse seine
Fishing ground	Kujukuri-hama Chiba Pref.	Kii channel Wakayama Pref.	Amakusa-nada Kumamoto	Shiranui-kai Kumamoto Pref.	Osaka Bay	Suruga Bay
Water depth	Under 50 m	40 ~ 80 m	40 ~ 60 m	30 ~ 40 mm	Under 60 m	200 ~ 300 m
Catch	Sardine, horse mackerel, gizzard shad, black porgy and grunt	Anchovy, horse mackerel, grunt, mackerl, mackerel scad and maruosoda (*Anxis tapeinosoma*)	Gizzard shad	Hemiramph	Anchovy, sardine, mackerel, barracuda, Umazura-hagi (*Navodon modestus*) and harvest fish	Sardine, horse mackerel and mackerel
Fishing season	All year round (peak – Sept. to Dec)	All year round (peak-Apr. to Jul.)	Oct. to Apr. (peak – Oct. to Dec.)	Nov. to May (peak – Dec. to Mar.)	Jun. to Nov.	Aug. to Nov.
Fishing boat (purse-seiner)	Under 5 tons	Under 5 tons	Under 5 tons	Under 5 tons	19.7 tons	19.9 tons
No. of crew	24 ~ 30	35 ~ 40	6 ~ 8	6 ~ 8	25	32
Net size (Buoy side tailored length)	300 ~ 350 m	Approx. 600 m	100 m	70 ~ 240 m	500 m	200 m
Net material	Nylon/Cremona	Cremona	Cremona	Cremona/Nylon	Nylon	Nylon
Mesh size	28 ~ 22 mm	Body 16 mm Wing 18 mm	38 mm	Body 22 ~ 20 mm Wing 19 ~ 18 mm	11 ~ 10.8 mm	Body 11.8 ~ 11 mm Wing 9.8 mm

Table 11.--Specifications for nets used in various one-boat and two-boat fisheries (Nomura and Yamazaki 1975).

Kinds of purse seine	Net: Name of parts	Net: Kinds of materials	Net: Number of yarns	Net: Mesh size	Buoy line: Length of net	Buoy line: Finished length	Buoy line: Shortening	Lead line: Length of net	Lead line: Finished length	Lead line: Shortening	Note
Two-boat type traditional purse seine	Bunt Wing	Kyokurin 〃	6~9 4	1.9 1.9	390m	312m	20%	390m	312m	20%	
One-boat horse mackerel	Bunt Wing	Vinylon 〃	18~24 12	5.4 6	1212	735	39	1363	818	40	Depth of net: 59 m Weight: 5,733 kg
– Ditto –	Bunt Wing	〃 〃	18~24 12~18	3.0 3.0	1027	690	33				Depth of net: 272 m Weight: 8,850 kg
One-boat large sardine	Bunt Wing	〃 〃	16 8	2.6 3.3	570	342	40	570	400	30	Center part: 8 yarns, 3.3 cm, 82 pieces
One-boat medium sardine	Bunt Wing	〃 〃	16 6	2.0 2.2	480	288	40	480	336	30	Center: 6 yar. 2.2 cm, 100 Mesh, 82 pieces
One-boat small sardine	Bunt Wing	〃 〃	12 4, 6	1.7 1.4	420	252	39	420	294	30	6, 1.6, 100, 30p 4, 1.5, 〃 20p 6, 2.0, 〃 24p
Two-boat horse mackerel	Bunt Wing	〃 〃	30 24	4.3 6.0	1090	586	46				Depth of net: 106 m Weight: 4,500 kg
– Ditto –	Bunt Wing	Kyokurin Nylon	18~21 9~12	3~3.8 6.0	1162	833	28	1182	994	16	Depth of net: 83 m Weight: 8,818 kg
Two-boat sardine	Bunt Wing	〃 〃	6 4	1.3 1.3	727	520	28	727	568	22	Depth of net: 112 m Weight: 2,430 kg
Two-boat anchovy	Bunt Wing	〃 〃	6 6	1.6 1.6	517	273	47				Depth of net: 111 m Weight: 2,370 kg
Two-boat tuna and bonito	Bunt Wing	〃 Vinylon	75 24~36	9.0 15~18	2503	1730	31	2503	1818	27	Depth: 272 m Weight – Nylon; 3,094 kg, Vinylon; 5,840 kg

In the northeastern Pacific, United States and Canadian fishermen use purse seines of various dimensions in fishing for salmon and herring. The specifications and construction diagrams of salmon and herring purse seines used by Canadian fishermen are given in Tables 12 and 13. In southeastern Alaska, U.S. salmon fishermen switch to purse seining during the offseason for salmon (Ness 1977b, 1977c).

For Canadian fishermen fishing in British Columbia, the maximum legal length of salmon purse seine is 402 m in all statistical areas except in the Strait of Juan de Fuca where purse seines may be up to 549 m. Purse seines with stretched meshes <90 mm are not permitted, and in some areas seines with stretched meshes of <102 mm are not allowed on or after 20 September. Canadian seiners fishing for pink, chum, and sockeye salmon numbered 532 vessels in 1980-81 (Beacham 1984a, 1984b, 1984c).

In the U.S. Pacific coast salmon fishery, three types of purse seines are commonly used:

Puget Sound seine.--A long, deep seine of standard construction but often differing in minor details according to fishermen preference and netmaker's specifications.

Jitney seine.--A short, shallow seine of Kodiak and other Alaska areas, tailored to regulations of the Alaska Department of Fish and Game.

Alaska limits purse seines to a maximum of 457 m with shorter maximums for some areas. In southeastern Alaska, the maximum permissible length is 457 m and the minimum is 274 m. Furthermore, no net may be <25.5 m or deeper than 35.7 m. This net is as representative as any in the salmon fishery in Alaska. In other areas of Alaska, different regulations apply. For example, in Prince William Sound, the minimum length allowable is 228.6 m whereas the maximum is 274 m. The minimum depth is 17.4 m, the maximum is 31.1 m. In the Kodiak area, purse seine lengths from 183 to 377 m are allowable but at least 91.4 must be 150 meshes deep with a minimum depth of 200 meshes.

Drum seine.--The Washington State and British Columbia drum seine is short (400 m), rather shallow (300 meshes). The seine is actually rectangular with corkline and leadline nearly equal instead of having a short leadline as in regular seines.

High Seas Purse Seine Fisheries

Purse seining for tuna began as far back as 1914 when nets fabricated primarily for capturing "whitefish" (barracuda, sea bass, and yellowtail) were first used. The subsequent development of a purse seine designed specifically for tuna and the tuna fishery as it is known today is well documented (Green et al. 1971).

The early tuna purse seines were fabricated of cotton netting but rapid deterioration of this material limited successful development of the tuna fishery. Two major technological developments--the nylon net and the power block--gave a tremendous boost to the fishery. These innovations also saved time and increased efficiency and fishing effort by allowing the

Table 12.--Specifications for a Canadian "swiftsure" salmon purse seine (Food and Agriculture Organization of the United Nations 1965).

Data Sheet — **FAO No. 312**

NAME OF GEAR:	"Swiftsure" Salmon Seine	Main species caught: Mature sockeye salmon	Vessels: Purse seiner
TYPE:	Purse Seine		L.O.A.: 50 to 90 ft
COUNTRY:	Canada	Fishing conditions: Offshore, in good weather, by day, using power block.	Gross tonnage: 40 to 80
LOCALITY:	Pacific Coast		Horse power: 200 to 500
REFERENCE:	P.J.G. Carrothers (1960)		Crew: 8

WEBBING		A 8	B 3	C 1	D 7	E 1	F 1	number of stripes
Material		Nylon	→	→	→	→	→	
Type of knot		Single (or double) - sheet bend						
Preservation		O or T	→	→	→	→	→	
Colour		Black	→	→	→	→	→	
Twine size	Tex	1,800	1,800	1,800	1,100	2,500	1,800	
Breaking strength	kg.	68	68	68	37	91	68	
	lb.	149	149	149	82	200	149	
Stretched mesh	mm.	75	75	90	90	125	90	
	in.	3	3	3 1/2	3 1/2	5	3 1/2	
Upper edge	m	38	38	750	750	780	62	
	fm	20	20	410	410	430	34	
Lower edge								
Depth (meshes)		100	100	25	100	50	25	
Setting rate		None						
Take-up								
Selvedge		Double twine on both sides						
Hanging		a/A = 15/20	C/A = 13½/20	c/B = 15/20	d/C = 285/410	e/E = 256½/410	e/F = 14/34	
		0.75	0.675	0.75	0.7	0.625	0.41	

LINES, ROPES		a	b	c	d	e	f	g	h	i
Material		Nylon	Polypropylene	Nylon	S.W.R.	Nylon	→	Staple Nylon		Nylon
Preservation		None	→	→	Galv.	None	→	→	→	→
Circumference	mm.	50	30	50	45	50		32		
	in.	2	1 1/8	2	1 3/4	2	→	1 1/4	→	
Diameter	mm.	16	10	16	14	16		11		
	in.	5/8	3/8	5/8	9/16	5/8	→	7/16	→	
Breaking strength	kg.	5,000	1,500	5,000	8,000	5,000		1,000		
	lb.	10,000	3,000	10,000	18,000	10,000	→	2,000	→	
Twist		Braid	→	→	Z	Braid	→	→		
Lay		H	→	→		H	→	M	→	
Length	m.	550	730	495	550	25½-28 ½	33-36½	75x4, 30	25x2, 10	
	fm.	300	400	270	300	14 - 16	18-20	75x2½	25x1 1/6	

FLOATS, SINKERS		(1) Floats	(2) Sinkers	(3) Purse Rings	(4) End Rings	(5) Seine Ring
Number		2,750	3,640	75	25	4
Material		Foam vinyl	Lead	Stainless steel	Brass	Monel
Shape		Cyl.	O	split	Torus	Torus
Diameter	mm.	127	35	19	12.7	19
	in.	5	1 3/8	3/4 steel	1/2 stk.	3/4 stk.
Length	mm.	121	35	102	76	10
	in.	4 3/4	1 3/8	4 wide	3 wide	4
Static buoyancy	kg.	1.05				
	lb.	2.3				
Weight in air	kg.	0.13	0.11			
	lb.	0.27	0.25			
Weight submerged	kg.		0.1			
	lb.		0.22			

Inshore nylon salmon seines are similar but not so deep.

Table 13.--Specifications for a Canadian winter herring purse seine (Food and Agriculture Organization of the United Nations 1965).

Data Sheet — FAO No. 301

NAME OF GEAR: Nylon Winter Herring Seine
TYPE: Purse Seine
COUNTRY: Canada
LOCALITY: Pacific Coast
REFERENCE: P.J.G. Carrothers (1960)

Main species caught: Mature Herring
Fishing conditions: Up to 100 miles from port in inshore waters (tides over two knots not fished). Spawning or feeding schools of fish are located by echo-sounders and at night are concentrated by mercury arc lights. The net is set around the school and hauled immediately, reaching to about 30 fm maximum from the surface.

Vessels: Wood or steel hull
L. O. A.: 60 - 90 ft
Gross tonnage: 80 - 200
Horse power: 200 - 500
Crew: 8 - 9

NETTING	A	B	C	D	E	F	G	H	I	
	1	4	6	1	11	1	1	1	1	No. of strips
Material	Nylon	→								
Type of knot	(knot symbol)	→								
Preservation	T	→								
Colour	Black	→								
Twine size Tex	1250	540	460	460	380	540	2200	1250	1250	
Breaking strength kg.	54	23	20	20	17	23	91	54	54	
Breaking strength lb.	120	51	45	45	38	50	200	120	120	
Stretched mesh mm.	38	28 1/2	28 1/2	28 1/2	35	28 1/2	127	89	89	
Stretched mesh in.	1 1/2	1 1/8	1 1/8	1 1/8	1 3/8	1 1/8	5	3 1/2	3 1/2	
Upper edge	670	73	73	625	625	700	700	68	77	strip length in m
	365	40	40	342	342	382	382	37	43	strip length in fm
Lower edge										
Depth	25	200	200	200	200	200	25	5	5	meshes per strip
Baiting rate	None									
Take-up	Selvedge twine(s) only									
Selvedge	Double selvedge on both sides of all strips									
Hanging	Directly to lines: 80% at bunt; 70% in body - leadline 2" shorter /10 fm									

LINES, ROPES	a_1	a	b	c	d	e	f	g	h	i	j
Material	Polydac	→	Polypropylene	Polydac	SWR	Polydac	→	Manila	→		
Preservation											
Circumference mm.	57	51	29	45	45	51	→	57	→	38	35
Circumference in.	2 1/4	2	1 1/8	1 3/4	1 3/4	2		2 1/4		1 1/2	1 3/8
Diameter mm.	19	16	9 1/2	14	14	16	→	19	→	13	12
Diameter in.	3/4	5/8	3/8	9/16	9/16	5/8		3/4		1/2	15/32
Breaking strength kg.	4150	3150	1350	2550	8200	3150	→	2450	→	1200	1020
Breaking strength lb.	9100	5900	3000	5600	18000	6900		5400		2650	2250
Twist	Z	Z	Braid	Z	Z	Z	→	Z	→		
Lay	M	M	S	M	S	M	→	S	→		
Length m.	110	440	585	530	640	51	44	57	50	4.50	2.30
Length fm.	60	240	320	290	350	28	24	31	27	2 1/2	1 1/4

FLOATS, SINKERS	(1) Floats	(2) Sinkers	(3) Purse Rings	(4)	(5)	(6) Gravel Rings
Number	2700	9200	82	2	2	38
Material	Foam plastic	Lead	Monel	→	Brass	→
Shape	Cylinder	O	Torus	→		
Diameter mm.	150	32	17 1/2	→		12 1/2
Diameter in.	6	1 1/4	11/16" Ø stock		5/8" Ø stock	1/2" Ø stock
Length mm.	95	16	100	→	100	75
Length in.	3 3/4	5/8" Ø	4		4	3
Static buoyancy kg.	1.6					
Static buoyancy lb.	3 1/2					
Weight in air kg.	0.16	0.11				
Weight in air lb.	0.36	0.25				
Weight submerged kg.		0.10				
Weight submerged lb.		0.23				

Floats, sinkers and purse line bridles are spaced uniformly along the seine.

seiners to set and retrieve the gear faster and to increase the number of sets possible in 1 day.

Purse seines and purse seiners have increased in size over the past two decades. During the early 1960's, a typical seine was 420 m long by seven strips deep (one strip = 100 meshes) (McNeely 1961). A net described by Coe and Vergne (1977) was 1,280 m long by 13 standard (10.8 cm mesh) strips deep. The maximum size net used in the newly developed purse seine fishery for skipjack tuna in New Zealand waters measured 1,682 m long and 263 m deep (Habib et al. 1980). The purse seines have also undergone modification by addition of a Medina panel which is a replacement webbing of 5.1 cm stretched mesh in the top strip of the net in the back-down area (Barham et al. 1977). This modification evolved as an effort by U.S. tuna fishermen to reduce mortality of porpoise which are caught in the tuna purse seine.

In the eastern Pacific tuna fishery, the number of boats in the international fleet operating each year from 1965 to 1982 ranged from 244 to 397. In 1982, of 262 tuna fishing boats participating, 220 boats or 84% were seiners (Inter-American Tropical Tuna Commission 1983). The number of tuna seiners in 1982, by size classes, is given in Table 14. Specifications of a U.S. tuna purse seine are given in Table 15.

Most Japanese tuna seiners operating in the western Pacific fishery for tuna are considerably smaller (250 to 500 GT) than the average United States seiner; however, there are a few United States type seiners in the 1,000 GT class. The purse seines used by Japanese vessels, however, are larger than those used by United States seiners in the eastern Pacific, varying from 1,025 to 2,400 m long and with depths of 110–350 m.[5] Some of the larger nets are used in two-boat seining.

Table 14.--The number of tuna seiners, by size class, fishing in the eastern tropical Pacific (Inter-American Tropical Tuna Commission 1983).

Class	Carrying capacity (short tons)	Number	Percent
1	<51	1	0.5
2	51–100	21	9.5
3	101–200	16	7.3
4	201–300	16	7.3
5	301–400	13	5.9
6	>401	153	69.5
Total		220	

[5]T. Otsu, trip to Japan report, 31 January to 22 February 1975. Available Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, P. O. Box 3830, Honolulu, HI 96812.

Table 15.--Specifications for a U.S. tuna purse seine (Food and Agriculture Organization of the United Nations 1965).

Data Sheet — FAO No. 310

NAME OF GEAR:	Tuna Purse Seine	Main species caught:	Tuna (yellowfin, skipjack)	Vessels	Purse Seiner
TYPE:	Purse Seine			L.O.A.:	115 to 150 ft
COUNTRY:	U.S.A.	Fishing conditions:	Off-shore, using power block	Gross tonnage:	125 to 700
LOCALITY:	California			Horse power:	600 to 2,000
REFERENCE:	R. L. McNeely, "Pacific Fisherman", June 1961.			Crew:	12 to 16

WEBBING	A_1 3 x 4	A_2 +3 x	B 3 x 4	C 4 x 1	D 3	E 4	F 2	(Number of strips)
Material	Nylon	→	→	→	→	→	→	
Type of knot	[illegible]	→	→	→	→	→	→	
Preservation	O	→	→	→	→	→	→	
Colour								
Twine size Tex	3,100	3,100	4,200	5,000	5,000	5,000	5,000	
Breaking strength kg. / lb.	170 / 375	170 / 375	212 / 468	250 / 555	250 / 555	250 / 555	250 / 555	
Stretched mesh mm. / in.	105 / 4 1/8	105 / 4 1/8	105 / 4 1/8	203 / 8	105 / 4 1/8	127 / 5	127 / 5	
Upper edge m. / fm.	165 / 90	210 / 115	46.5 / 25	210 / 115	77 / 42	210 / 115		
Lower edge							125	
Depth (meshes)	100	100	100	50	30	10½	15	
Baiting rate								
Take-up								
Selvedge	[illegible]							
Hanging	a/E = 90/100		c/C = 89/100					

LINES, ROPES	a	b	c	d	d_1	d_2	e	f	g	h	i	j
Material	Nylon	Polyethylene	Nylon	wire rope	wire rope	wire rope	chain	chain	chain	Polyethylene	Nylon	Nylon
Preservation												
Circumference mm. / in.												
Diameter mm. / in.	19 / 3/4	16 / 5/8	16 / 5/8	16 / 5/8	19 / 3/4	16 / 5/8	11 / 7/16	6 / 1/4	6 / 1/4	13 / 1/2	6 / 1/4	5,000 Tex
Breaking strength kg. / lb.												
Twist												
Lay												
Length m. / fm.	780 / 425	10 x 77 / 10 x 42	82 / 45	800	200 / 110	293 / 160	770 / 420	134 links	246 links	1,80 / 1		

FLOATS, SINKERS	(1) Floats	(2) Purse rings	(3) Links	(4) Rings	(5) Zipper rings	(6) End Brackets
Number	7,000	75	75	250	30	2
Material	Plastic	Galv. steel	Galv. iron			
Shape	cyl.	ring	link	ring	ring	triangle
Diameter mm. / in.	152 / 6	19 / 5/8	19 / 3/4	13 / 1/2		
Length mm. / in.	95 / 3 3/4	254 / 10	100 / 4	76 / 3		
Static buoyancy kg. / lb.	1.3 / 2.9					
Weight in air kg. / lb.						
Weight submerged kg. / lb.						

In the fishery for bluefin tuna off Japan, the Japanese seiner uses a net 1,250 m long, and the deepest part of the net is about 1,500 meshes deep, each mesh measuring 18 cm stretched for a total depth of about 270 m (Nomura and Yamazaki 1975).

Trawl Fisheries

The trawl fishes in midlayers down to the sea bottom or just off it for flatfish, shrimp, cod, haddock, rockfish, pollock, and other groundfish species. Basically, the trawl is a towed bag net, with a wide mouth at one end, which tapers to a narrow opening (cod end) that is tied shut during hauling. The funnellike shape of the net guides the fish towards the cod end.

The construction of a trawl net is extremely complex. It is fabricated from several panels cut according to a prescribed formula. Joining the resulting panels and ropes to form the net requires considerable knowledge of the dynamic forces imposed on parts of the net under operational conditions. Also, allowance must be made for unexpected extraordinary forces which may be exerted irregularly on the net.

The leading portion of a trawl net is called the wing, which leads backward to the body or belly (Lippa 1967). The belly then tapers off into an intermediate section and finally the cod end. The lower leading edge of the trawl mouth is hung to the footrope. The top edge of the trawl mouth is hung to the headrope as are the floats. The webbing can be either synthetic fiber or cotton. Mesh size of the webbing can vary widely from 80 to 240 mm; whereas the cod end can have meshes of 15 mm depending on the target species.

Several methods are used to keep the mouth of the trawl from collapsing during hauling. One is the use of a heavy horizontal beam. Beam trawls may be used with heavy "tickler chains," which are dragged along the sea floor in front of the net opening between the two guides on which the beam rests, to frighten fish. Being the original gear of the old steam trawlers, beam trawls are now used only on small vessels. The trawls can be towed in pairs, one on each side of the vessel; however, such operations can decrease stability unless the vessel is specifically designed for handling two trawls (Nomura and Yamazaki 1975).

Another method is to use two vessels. This method, called "bull trawling," uses a large net which can be hauled at great speeds. The most recent and widely used technique for spreading the trawl net employs large, flat boards or metal plates (otter boards) which can be rectangular or oval. The "doors," as they are commonly called, are attached to each side of the net (Nomura and Yamazaki 1975). The horizontal force provided by a pair of otter boards, which essentially act as "kites," keeps the mouth open as the net is towed through the water. Vertical forces are supplied by floats attached to the headrope and by weights attached either directly to the footrope as in the bottom trawl or on the lower spreading wires joining the footrope to the doors as in the pelagic trawl. The doors contribute significantly to the sinking forces in both types of trawl (Kerr 1972). The depth of tow can be regulated also by the amount of warp paid out and by adjusting vessel speed.

For the pelagic and semipelagic trawl, one of the basic requisites is the use of high-tenacity synthetic twines. Netting yarns, in addition to having high wet-knot breaking strength, should have particularly high extension and elasticity to equalize differences in load distribution in the fore net, thereby reducing the danger of shock loads bursting the net in heavy seas (von Brandt and Klust 1971).

The semipelagic trawl was fabricated to overcome problems in getting the mouth opening of the net to sweep the water column for fish that concentrate just off the bottom and outside the normal range of bottom trawls which have low vertical openings. Although vertical openings of these trawls can be stretched by various means, such modifications to the net usually produce a reduction in the horizontal width. New construction methods using four and six seams have produced nets of high vertical and wide horizontal openings which are considered best for bottom trawling.

There are some important differences between midwater and bottom trawling (Kutakov et al. 1971). These are:

- Because midwater trawling is aimed trawling, searches are made for schools of fish with hydroacoustic instruments. Upon detection, the vessel determines the school's depth and maneuvers into position before shooting the net and dragging through the school.
- Because midwater trawls fish in the water column between the seabed and sea surface, fish are able to dodge the oncoming net; therefore, midwater trawl nets are constructed symmetrically, that is, their top and bottom panels are equal. There is no overhang as in the bottom trawl or reverse overhang which exists in some trawls where the footrope moves ahead of the headrope.
- The mouth area and the towing speed of a midwater trawl considerably exceed those of a bottom trawl. The increased resistance of the net being hauled through the water column, however, requires increased power of the main engine.

The length of time that a trawl is towed is dictated by the catch rates prevailing. At the end of the tow, the net is hauled aboard and the cod end emptied of fish. Demersal trawls, which are designed and used primarily to scrape the sea floor, are particularly subject to damage and frequently to complete loss.

Coast Trawl Fisheries

In Japan, coastal small-scale trawls in use can be classified into four types, as follows:

- Trawl without beam.--Simplest of the trawls, this type consists of a net without an opening apparatus at the mouth. These trawls are either towed with one or two boats or are fastened to outstretched poles at the bow and stern of a vessel which makes use of tidal currents or wind power to get the fish into the net.

- Beam trawl.--This type of trawl has a beam of bamboo, wood, FRP, or metal to spread and hold the net mouth open.

- Dredge net.--The net has a wood or steel frame with claws made of steel or other types of metal. This dredge digs into and scrapes the sea floor as the net is towed and is used mainly for shellfish.

- Otter trawl.--The most highly developed among the trawls (Yamaha (1982b).

These various types of coastal small-scale trawls can be hauled either by side trawling or stern trawling; the latter is considered more efficient but requires a net hauler.

Except for the dredge, the other trawls are hauled either near the sea bottom or in midwater, depending on the conditions of the fishing grounds and the target species. The Japanese also engage in another type of fishing where the net is hauled near the surface layers, but this type is usually referred to as boat seining and thus is distinguished from trawling.

Concentrating on flatfish, cod, and hairtail as the major target species, the small-scale otter trawl fishery is a good representative of a coastal trawl fishery in Japan. In such small-scale trawl fisheries, the fishing gear and methods vary according to the species sought. For example, a vessel may fish with a small-mesh (20-mm stretch mesh) trawl throughout the year for various miscellaneous species but switch in winter-spring to a chain net (20-mm stretch mesh) for flatfish or in spring and autumn to a large-mesh (80-90 mm stretch mesh) net for sea bream and skipjack tuna (Yamaha 1982a).

The small-scale otter trawl has the following specifications (Table 16).

Table 16.--Specifications for a Japanese small-scale otter trawl (Yamaha 1982a).

	No of threads thickness	Mesh stretched (mm)	No. of meshes		No. of sheets
			Width	Length	
Wing net	12	28	100	100	2
Wing net	12	28	100	100	2
Wing net	12	28	100	100	2
Ceiling net	12	23	200-100	200	1
Belly net	12	28	100	300	2
Side belly net	12	28	100	300	2
Bag net	12	20	100	100	1
Fish catching section	12	20	100	200	2
Patch	12	20	100	200	2

- Towing wire rope is 8-9 mm diameter, and its length is three to four times the water depth.
- Otter boards made of wood or resin with sizes not to exceed 60 x 125 cm.
- Wing net, ceiling net, belly net, and bag net of nylon, 12 ply.
- Float of foam plastic.
- Sinker of iron or ceramic.

The boats operating in this type of fishery are usually constructed of FRP, with hull weight of 4.4 tons and a full load displacement of 9.54 tons. Overall dimensions are 14.04 m long, 32.60 m wide, and 1.63 m deep at midship.

A fishery that operates net gear in coastal shallow water and in bays is the dredge-net fishery which catches not only shellfish as was done in years past but nowadays also targets crustaceans and demersal fish. Because Japanese fishery statistics combine dredge-net catches with beam trawl catches, it is not possible to determine exactly what species are taken by this fishery; however, based on combined beam trawl-dredge net catches, the species include horse mackerel, mackerel, flatfish, cod, Atka mackerel, thornyhead, sailfin sandfish, drum, croaker, lizardfish, purple pike conger, cutlassfish, ray, sea bream, sea bass, sand lance, shrimp, crab, squid, octopus, ark shell, and sea slug (Yamaha 1983b).

Dredge nets vary widely. If the vessel is targeting demersal fish or crustaceans, the iron frame with dredge teeth is fabricated so that it slides over the sea floor on a pair of runners; special weights are added to the runner when fishing for shellfish. The total weight of the dredge net depends on the engine horsepower and towing capacity of the boat.

There is no standard shape or size or opening on these dredge nets. The usual size of the iron-frame assembly is 250-300 cm wide and 20-30 cm high, overall, when it is fitted with a fish or shrimp dredge net; however, it is 30-40 cm high when fitted with a shellfish dredge net. The dredge net is fabricated of polyethylene netting; mesh size varies according to the target species. For shellfish, the mesh is 60 mm; for demersal fish and shrimp, the meshes are 35-43 mm and 28 mm, respectively.

Along the British Columbia coastline, trawlers catch some 30 species of commercially important bottom fish including sole, cod, lingcod, rock-fish, and shrimp (Lippa 1967).

Most of the Canadian trawlers are purse-seine vessels like those of the United States Pacific coast. These trawlers are stout, beamy, have a broad undercut stern, and have a wheelhouse and galley located forward (Lippa 1967). Deck space is aft and quite ample. Powered by diesels of 60-300 hp, the vessels are between 9 and 30 m long and between 5 and 100 GT, although the typical vessel is closer to 25-49 GT.

The fleet is made up of (1) year-round trawlers (fishing more than 8 months per year), (2) seasonal trawlers (4-8 months per year), and (3) part-time or incidental trawlers (<4 months per year). Vessels are classified either as single-gear trawlers, which tow from a single point (usually starboard) on the vessel, and double-gear trawlers, which tow from two points on the vessel. Many vessels use a reel on which the trawl net is wound.

There are two types of trawl nets used in the Canadian fishery; the box trawl (or western or Pacific trawl) and the flat trawl (or eastern or Atlantic trawl) (Lippa 1967). Usually, vessels up to 49 GT use the former; larger vessels use the latter. Specifications of a Canadian midwater trawl are presented in Table 17.

High Seas Trawl Fisheries

The high seas trawl fisheries in the North Pacific, perhaps the largest fishery in terms of the number of vessels involved and the number of species harvested, include fishing vessels from Japan, the U.S.S.R., Republic of Korea, Taiwan, Canada, United States, and the Polish People's Republic. The species targeted by this fleet are shown in Table 18. In the Bering Sea, pollock constituted 80% and flatfish 11% of the catch. The bulk of the catch was taken by Japanese vessels and Soviet vessels took most of the remainder. Small amounts of pollock were also taken by the Republic of Korea (Forrester et al. 1983).

Canadian and United States vessels fished mainly for Pacific halibut in the Bering Sea region and small amounts of herring were also taken by United States vessels (Forrester et al. 1983). This situation, however, changed in 1984 (D. L. Alverson, pers. commun, 26 November 1984).

In addition to groundfish, there are directed fisheries for herring conducted mainly by the Soviets, and for shrimp and small amounts of squid by the Japanese (Forrester et al. 1983).

The number of Canadian, Japanese, and United States vessels fishing in the Bering Sea region in 1954-70 and Japanese vessels fishing in the same region in 1971-76 is shown in Table 19. The number of Canadian and United States vessels operating in 1971-76 and the number of Soviet vessels operating in the Bering Sea are not available.

In the contiguous states and British Columbia, the major species taken are hake (35%), Pacific ocean perch and other rockfish (22%), flatfish (including Pacific halibut) (12%), pollock (11%), and sablefish (8%). Soviet vessels caught 47% of the groundfish, mostly Pacific hake, and Japan accounted for 26%, the United States 15%, Canada 6%, and the Republic of Korea 2%. The Polish People's Republic also caught hake in 1975-76, averaging 35,000 MT per year. The number of Canadian, Japanese, and United States vessels fishing in the northeast Pacific region in 1963-76 is given in Table 20.

Operations of the foreign trawl fisheries in the eastern Bering Sea, Aleutian Islands region, Gulf of Alaska, and off the coasts of Washington, Oregon, and California have been reported in detail by Pruter (1976), Forrester et al. (1978), Bakkala et al. (1979), French et al. (1981), Nelson et al. (1981), and Wall et al. (1981).

Table 17.--Specifications for a Canadian herring midwater trawl (Food and Agriculture Organization of the United Nations 1965).

Data Sheet

FAO No. 123

NAME OF GEAR: Canadian Midwater Trawl
TYPE: One-boat midwater Trawl
COUNTRY: Canada
LOCALITY: British Columbian Waters
REFERENCE: Bulletin No. 104 by W.E. Barraclough and W.W. Johnson of the Fisheries Research Board of Canada - Biological Station - Nanaimo, B.C. (1961)

Main species caught: Herring
Fishing conditions: Fished at depths of 15 - 35 fm (27 - 64 m)

Vessels: Canadian Fishing Boats
L.O.A.: 60 - 75 ft (18 - 23 m)
Gross tonnage: 40 - 50
Horse power: 150 - 175
Crew:

WEBBING	A	B	C	D	E	F	G	H	I	J
Material	Nylon	→	→	→	→	→	→	→	→	→
Type of knot	[illegible]	→	→	→	→	→	→	→	→	→
Preservation	Can be dyed	→	→	→	→	→	→	→	→	→
Colour	As desired		→	→	→	→	→	→	→	→
Twine size Tex	690	→	→	→	450	→	→	→	→	→
Breaking strength kg.	19.9	→	→	→	14	→	→	→	→	→
Breaking strength lb.	44				31					
Stretched mesh mm.	127	→	114	89	32	→	→	→	→	→
Stretched mesh in.	5		4 1/2	3 1/2	1 1/4					
Upper edge	1	300	275	212	200	178	156	134	448	448
Lower edge	75	234	175	78	178	156	134	112	448	448
Depth	75	50	75	100	100	100	100	100	100	100
Baiting rate inner/outer	b / P	1 p 4 b	→	→	4 p 1 b	→	→	→	P	→
Take-up		B/C = 6/7	C/D = 5/6	D/E = 2/5						
Selfedge										
Hanging	a/B = 4.90/19.00	a₁/A = 9.05/9.53	b/net = 52/4.5							
	0.26	0.95	1.15							

LINES, ROPES	a	a₁	b	c	d	e	f
Material	Comb.	→	Br·Nyl	→	SWR	→	→
Preservation					Gal	→	→
Circumference mm.	44	→	25	→	29	→	41
Circumference in.	1 3/4		1		1 1/8		15/8
Diameter mm.	14	→	8	→	10	→	13
Diameter in.	9/16		5/16		3/8		1/2
Breaking strength kg.	1224	→	680	→	3003	→	7000
Breaking strength lb.	2700		1500		7840		16,500
Construction	6S	→	Br	→	9 x 16 S	→	6 x 19 S
Lay							
Length m.	4.90	9.05	52	0.90	54.90	56.70	18.30
Length ft	16	29 3/4	170	3	180	186	60

FLOATS, SINKERS	(1) Floats	(2) Boards	(3) Depressors	
Number	11	2	2	
Material		3/8" lam ply	3/4" steel plate	
Shape				
Diameter mm.	203			
Diameter in.	8			
Length mm.				
Length in.				
Static buoyancy kg.				
Static buoyancy lb.				
Weight in air kg.		61		
Weight in air lb.		135		
Weight submerged kg.				
Weight submerged lb.				

Headline 75 1/2 ft (29 3/4' + 16 + 29 3/4')

Footrope and winglines 23 m (9.05 + 4.90 + 9.05)

Table 18.--List of scientific and common names of fish species taken in the Alaska groundfish (Forrester et al. 1978).

Scientific name	English common name (INPFC preference first)	Japanese common or standard name
Sharks		
Galeorhinus zyopterus	soupfin shark	—
Squalus acanthias	Pacific dogfish	abura tsunozame
Herrings		
Clupea harengus pallasi	Pacific herring, herring	nishin
Codfishes		
Merluccius productus	Pacific hake	heiku, merurusa
Microgadus proximus	tomcod	—
Theragra chalcogramma	Pacific pollock, walleye pollock, whiting, pollock	suketo dara
Gadus macrocephalus	Pacific cod, true cod	ma dara, tara
Rockfishes		
Scorpaenidae	rockfishes	menuke rui
Sebastes alutus	Pacific ocean perch	arasuka menuke
Sebastes brevispinis	silvergray rockfish	gin menuke, kuro menuke
Sebastes flavidus	yellowtail rockfish	kin menuke, kiobire menuke
Sebastes goodei	chilipepper	—
Sebastes miniatus	vermilion rockfish	shu menuke
Sebastes paucispinis	speckled rockfish	bara menuke, bokachio
Sebastes pinniger	canary rockfish	orenji menuke
Sebastes ruberrimus	yelloweye rockfish	kojin menuke
Greenlings		
Ophiodon elongatus	lingcod	kin mutsu
Sablefishes		
Anoplopoma fimbria	blackcod, sablefish	gin dara, hokyuo mutsu
Flatfishes		
Hippoglossoides elassodon	flathead sole	uma garei, shiro garei
Hippoglossoides robustus	flathead sole	doro garei, shiro garei
Hippoglossus stenolepis	Pacific halibut, halibut	ohyo
Lepidopsetta bilineata	rock sole	shumusu garei, asaba garei
Limanda aspera	yellowfin sole	kogane garei, rosuke garei
Atheresthes evermanni	northern arrowtooth flounder	abura garei
Atheresthes stomias	turbot, arrowtooth flounder	abura garei
Eopsetta jordani	petrale sole	petoral nameta, tsubame garei
Microstomus pacificus	Dover sole	nameta garei, baba garei amerika nameta
Parophrys vetulus	English sole, lemon sole	igirisu garei
Shrimps		
Pandalus borealis	pink shrimp	hokkoku aka ebi
Pandalus goniurus	pink shrimp	benisuji ebi
Pandalus jordani	pink shrimp	—
Pandalus platyceros	prawn	—

Table 19.--Number of vessels, by type and by country, fishing for groundfish, shrimp, and herring in the Bering Sea region, 1954-76 (adapted from Forrester et al. 1978, 1983). Source: Fisheries Research Board of Canada; Fisheries Agency of Japan; Northwest and Alaska Fisheries Center, National Marine Fisheries Service, U.S. Department of Commerce; and International Pacific Halibut Commission.

	Gill net			Longline			Trawl			
Year	Canada	Japan	United States	Canada	Japan	United States	Canada	Japan[1]	Japan[2]	United States
1954	--	--	--	--	--	2	--	11	--	--
1955	--	--	--	--	--	1	--	9	--	--
1956	--	--	--	2	--	3	--	13	--	--
1957	--	--	--	--	--	1	--	13	--	--
1958	--	--	--	14	3	7	--	29	--	--
1959	--	--	--	20	6	19	--	64	--	--
1960	--	3	--	31	29	35	--	165	--	--
1961	--	[3]138	--	27	[3]138	34	--	243	54	--
1962	--	[3]67	--	33	[3]67	43	--	225	70	--
1963	--	112	--	53	115	52	--	148	93	--
1964	--	97	--	32	30	36	--	194	103	--
1965	--	68	--	15	10	19	--	149	126	--
1966	--	55	--	11	9	4	--	129	172	--
1967	--	53	--	19	7	17	--	198	173	--
1968	--	88	--	17	10	11	--	175	184	--
1969	--	64	--	16	10	7	--	186	182	--
1970	--	12	--	13	9	6	--	193	182	--
1971	--	6	--	--	13	--	--	182	182	--
1972	--	28	--	--	19	--	--	222	182	--
1973	--	14	--	--	22	--	--	154	182	--
1974	--	11	--	--	20	--	--	177	182	--
1975	--	6	--	--	23	--	--	154	182	--
1976	--	10	--	--	23	--	--	139	182	--

[1]Mother ship type groundfish fishery, North Pacific trawl fishery, and North Pacific longline-gill net fishery; includes Danish seine, pair trawl, side trawl, and stern trawl.

[2]Number of vessels licensed in the land-based trawl fishery; includes Danish seine and stern trawl. These vessels operated in the Okhotsk Sea and waters adjacent to the Kurile Islands as well as in the Bering Sea. Data are not available on the number of vessels operating in the Bering Sea region.

[3]Some vessels operated both gill nets and longlines. A detailed breakdown by gear type is not available.

Table 20.--Number of vessels, by type and by country, fishing for groundfish, shrimp, and herring in the Northeast Pacific region, 1963-76 (adapted from Forrester et al. 1978, 1983). Source: Fisheries Research Board of Canada; Fisheries Agency of Japan; International Pacific Halibut Commission; Northwest and Alaska Fisheries Center, National Marine Fisheries Service, U.S. Department of Commerce; Pacific Biological Station, B.C.

	Type of vessel												
	Gill net			Longline			Purse seine			Trawl[1]			Pots[2]
Year	Canada[3]	Japan	United States	Canada[3]	Japan	United States[4]	Canada	Japan	United States	Canada[3]	Japan	United States	United States
1963	--	3	--	236	--	342	113	--	19	77	4	268	18
1964	--	--	--	207	--	227	115	--	24	82	7	265	18
1965	--	--	--	189	--	237	132	--	28	74	13	264	22
1966	--	--	--	212	--	298	144	--	30	79	25	272	15
1967	--	--	--	151	6	286	74	--	25	81	26	312	20
1968	--	--	--	145	21	194	17	--	20	75	28	288	30
1969	4	--	--	144	26	221	19	--	43	73	33	287	9
1970	11	--	--	167	28	233	34	--	77	64	31	338	24
1971	72	--	--	154	23	111	135	--	46	64	31	314	29
1972	54	--	1	165	34	242	104	--	[5]12	56	66	[5]306	[5]39
1973	266	--	14	144	24	211	161	--	[5]27	62	31	403	[5]30
1974	1,002	--	12	76	22	165	247	--	[5]13	68	31	434	[5]39
1975	1,255	--	16	163	23	194	214	--	130	76	29	350	[5]32
1976[6]	1,068	--	105	160	22	616	188	--	173	87	25	532	85

[1]Includes Danish seine, side trawl, and stern trawl.

[2]Shrimp fishing.

[3]No data are available on the number of vessels that fished for shrimp. Data regarding the number of vessels fishing for herring were available only for the herring fishing season (approximately 1 May to 30 April of the following year); therefore, the gill net and purse seine data given here for calendar years actually are for fishing seasons, e.g., data for 1969 are for the period 4 May 1969 through 2 May 1970. No record was kept of the number of vessels that fished for herring with gill nets prior to 1969. Some vessels that trawled for groundfish also fished for herring. Vessels fishing with longlines took halibut; no data are available on number of longline, handline, or troll vessels that fished for species other than halibut.

[4]Includes about 25 vessels which fished only for species other than halibut in 1971 and 1972, an unknown number in 1973, 11 in 1974, 5 in 1975, and 415 in 1976.

[5]Number of Alaska based vessels unknown.

[6]An additional 543 United States vessels were engaged in the northeast Pacific fisheries using other gear or unclassified gear.

The Japanese fishery for groundfish in the Bering Sea developed over many years of fishing and in recent years had four principal components: the mother ship fishery, the North Pacific trawl fishery, the North Pacific longline-gill net fishery, and the land-based trawl fishery (Bakkala et al. 1979). These fisheries contributed 64, 31, 0.3, and 5%, respectively, to the Japanese catch from the Bering Sea in 1971-76.

Mother ship fishery.--This fishery consists of freezing fleets, meal and minced fish fleets, and longline-gill net fleets. Catcher boats are pair trawlers, Danish seiners, stern trawlers, and longline gill-netters; pair trawlers are the mainstay of the fleet. The number of mother ship fleets and the number of catcher boats attached to them are given in Table 21 for 1952-76. Characteristics of catcher boats and trawl gear are given in Table 22.

Table 21.--Fleet of the Japanese mother ship fishery, 1952-76 (International North Pacific Fisheries Commission 1979).[1]

Year	Number of mother ships	Number of fishing vessels[2]
1952	3	57
1953	3	105
1954	7	205
1955	14	406
1956	16	506
1957	16	461
1958	16	460
1959	16	460
1960	12	410
1961	12	410
1962	11	369
1963	11	366
1964	11	379
1965	11	369
1966	11	369
1967	11	369
1968	11	369
1969	11	369
1970	11	369
1971	11	369
1972	10	332
1973	10	332
1974	10	332
1975	10	332
1976	10	332

[1]Source: Fisheries Agency of Japan.
[2]Includes scouting boats.

Table 22.--Range in size of fishing vessels and gear in the Japanese mother ship and North Pacific trawl fisheries based on a sample of the fleets in 1976 (Bakkala et al. 1979). Source: Fisheries Agency of Japan 1976. Vessel and gear specifications of the Japanese fisheries in the North Pacific in 1976. Unpubl. manuscr., 2 p. Fisheries Agency of Japan, Kasumigaseki Chiyoda-ko, Tokyo, Japan.

Fishery	Target species	Vessels			Gear			
		Type	Gross tons	Horsepower	Headrope length (m)	Ground rope length (m)	Cod end mesh size (m)	Otter board size (m)
Mother ship	Pollock	Danish seine	96-125	450-1,450	90-130	100-143	7.5-9.0	--
		Pair trawl	115-214	650-1,400	57-130	70-160	8.0-9.0	--
		Stern trawl	299-349	1,200-1,900	48-52	57-63	8.0-8.5	1.9 x 3.2-3.0 x 4.8
	Yellowfin sole	Pair trawl	214	1,400	127	160	9.0	--
		Stern trawl	314	1,200	36	48	9.0	1.8 x 2.8
North Pacific trawl	Pollock	Stern trawl	2,455-5,470	3,500-5,700	64-80	65-111	9.0-10.0	2.4 x 3.8-3.2 x 5.0
	Yellowfin sole	Stern trawl	349-3,500	1,600-4,000	52-74	60-89	9.0-13.0	2.0 x 3.1-2.4 x 3.8
	Rockfish	Stern trawl	349-3,914	1,420-4,400	40-74	51-89	8.0-13.0	2.0 x 3.2-2.7 x 3.6

<u>North Pacific trawl fishery</u>.--This fishery consists of factory stern trawlers, which are usually larger than 500 GT and operate independently; these vessels fish and process their catch. Products, which consist of minced fish, frozen fish, and fish meal, are transferred to refrigerated transport vessels which carry them to Japan. Size of vessels and gear characteristics are given in Table 22. The main target of these trawlers is pollock in the eastern Bering Sea; Pacific cod and flounders are also caught in the trawl. In the Aleutian Islands region, target species are Pacific ocean perch and other rockfish, and smaller amounts of pollock and various groundfish constitute the remainder of the catch. There were 35-37 vessels licensed to operate in this fishery in recent years (Table 23).

<u>Land-based trawl fishery</u>.--The vessels in this fishery are essentially independent trawlers and are prohibited by Japanese regulations from transshipping their catch to cargo vessels. All vessels return to Japan after catching a full load. The target species are mainly flounder, pollock, and rattails. The gear used was mainly Danish seines; however, in recent years, the stern trawl has dominated. In 1969-76, 182 vessels operated in this fishery; however, the number declined to 143 in 1977 and to 75 in 1978 (Table 23). The catches include chiefly flounder, Pacific ocean perch, and black cod (Forrester et al. 1978).

The Soviet trawl fishery harvests a substantial part of its total catch from the Bering Sea and off the United States Pacific coast. Fishing off Alaska initially in 1959, the Soviet fleet expanded into the Gulf of Alaska and along the Aleutian Islands then moved into waters along the Alaska coastline. By 1966, they had fleets fishing off Oregon and Washington and subsequently expanded farther into waters off British Columbia and California (Pruter 1976). The Soviets are now engaged in joint venture operations (D. L. Alverson, pers. commun., 26 November 1984).

Like the Japanese, the Soviets employ the mother ships and independent factory trawlers that catch and process their own catches (Bakkala et al. 1979). This fleet concept is carried one step further in the Soviet operation, that is, the support vessels include base ships to carry administrators, staff, and to provide logistic support; factory ships to process catches; refrigerator transports to replenish stores and receive, freeze, and transport catches to port; oil tankers, passenger ships, tugs, patrol vessels, and at times hospital ships. The number of side and factory stern trawlers operating in waters off Washington, Oregon, and California in 1966-77, and off Alaska in 1963-74 is given in Tables 24 and 25, respectively. The basic types of Soviet trawlers used in the groundfish fisheries off Alaska are given in Table 26. The size of BMRT's (large freezer trawlers) and the dimensions of their trawls used to harvest walleye pollock and Atka mackerel are given in Table 27.

Trawlers of the Republic of Korea first entered the fisheries for Alaskan groundfish in 1967. Korean stern trawlers, similar in size and design to Japanese ones, target on pollock. Vessel size and fishing gear dimensions, shown in Table 28, are probably representative of the Korean trawl fleet operating in the North Pacific trawl fishery (Bakkala et al. 1979).

Table 23.--The number of fleets in the Japanese mother ship fishery and the number of vessels in the Japanese North Pacific trawl fishery, North Pacific longline-gill net fishery, and land-based trawl fishery, 1954-78 (Nelson et al. 1981). Source: Pereyra, W. T., J. E. Reeves, and R. G. Bakkala (principal investigators). 1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1976. Processed rep. 619 p. Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd., E., Seattle, WA 98112; Sasaki, R. 1977. Outline of the Japanese groundfish fishery in the Bering Sea, 1976 (November 1975-October 1976). Unpubl. manuscr., 11 p., Fisheries Agency of Japan, Far Seas Fish. Res. Lab., Shimizu 424, Japan; National Marine Fisheries Service data on file at Law Enforcement Division, Alaska Regional Office, Natl. Mar. Fish. Serv., NOAA, P. O. Box 1668, Juneau, AK 99802.

	Mother ship fleets				Independent vessels		
Year	Freezing fleet	Meal and minced fleet	Longline gill net fleet	Total	North Pacific trawl fishery	North Pacific longline gill net fishery	Land-based trawl fishery
1954	2	--	--	2	2	--	--
1955	2	--	--	2	3	--	--
1956	4	--	--	4	1	--	--
1957	4	--	--	4	--	--	--
1958	2	1	1	4	--	--	--
1959	4	1	1	6	2	--	--
1960	4	5	4	13	--	--	--
1961	13	5	14	32	3	--	54
1962	11	5	5	21	2	--	70
1963	10	2	5	17	2	--	93
1964	6	4	2	12	2	--	103
1965	6	4	2	12	2	--	126
1966	8	4	1	13	2	--	172
1967	7	5	2	14	42	22	173
1968	6	5	1	12	42	22	184
1969	5	5	1	11	42	21	182
1970	3	6	1	10	42	22	182
1971	5	6	1	12	42	22	182
1972	4	6	--	10	68	33	182
1973	4	6	--	10	42	26	182
1974	4	6	--	10	42	30	182
1975	3	5	--	8	35	27	182
1976	3	5	--	8	57	32	182
1977	1	5	--	6	51	23	143
1978	1	5	--	6	54	22	75

Table 24.--Number and equivalent gross registered tonnage of different Soviet catcher vessels sighted off Washington, Oregon, and California, 1966-75. Sightings were by National Marine Fisheries Service personnel and do not include repeated sightings of the same vessels (Pruter 1976).

Year	Side trawlers				Factory stern trawlers			Equivalent gross tons, all classes
	SRT	SRTR	SRTM	Total	BMRT	RTM	Total	
1966	149	9	13	171	39	--	39	177,000
1967	--	--	--	[1]126	48	--	48	?
1968	24	--	14	38	56	--	56	194,000
1969	12	--	6	18	44	--	44	147,000
1970	--	--	8	8	55	--	55	180,000
1971	--	--	6	6	64	--	64	207,000
1972	2	--	3	5	42	2	44	141,000
1973	12	--	8	20	51	11	62	200,000
1974	--	--	--	--	78	16	94	290,000
1975	--	--	--	--	82	15	97	300,000

[1]Not differentiated by class in 1967.

Table 25.--Number and equivalent gross registered tonnage of different Soviet catcher vessels sighted off Alaska, 1963-74. Sightings were made by National Marine Fisheries Service personnel and do not include repeated sightings of the same vessels. Observations not extensive enough to provide comparative numbers in 1959-62 and unavailable for 1975 (Pruter 1976).

Year	Side trawlers					Factory stern trawlers			Equivalent gross tons, all classes
	SRT	SRTR	SRTM	SRTK	Total	BMRT	RTM	Total	
1963	155	7	--	--	162	10	1	11	79,000
1964	237	9	12	--	258	28	1	29	167,000
1965	330	11	25	--	366	36	3	39	233,000
1966	248	9	44	--	301	42	4	46	245,000
1967	191	7	66	--	264	53	4	57	279,000
1968	97	5	90	--	192	71	3	74	324,000
1969	66	9	127	--	202	79	6	85	377,000
1970	65	11	144	--	220	97	6	103	447,000
1971	92	7	102	2	203	102	5	107	438,000
1972	111	6	161	7	285	100	11	111	497,000
1973	25	7	155	9	196	105	15	120	498,000
1974	25	7	174	8	214	117	14	131	546,000

Table 26.--Basic types of fishing vessels employed by the U.S.S.R. in groundfish fisheries off Alaska (Pruter 1976).

Vessel type	Gross tons	Length (m)	No. in crew	Descriptive remarks
SRT	265-335	38	22-26	Small side trawler of older type
SRTR	505-630	52	26-28	Medium side trawler--usually transships catch to factory ship but may operate independently and process and freeze own catch.
SRTM	700	54	30	Large side trawler-frequently operates independent of factory ships and processes and freezes own catch.
SRTK	775	--	--	New class of trawler equipped with stern ramp for more efficient trawling.
BMRT	3,170	85	90	Factory trawler which normally processes and freezes own catch.
RTM	2,657	82	--	Newer type of factory trawler having increased deck area aft for more efficient handling of gear and catch.

Table 27.--Size of Soviet (BMRT) factory stern trawlers and trawl dimensions used by fishing walleye pollock and Atka mackerel as shown by data of United States observers in 1976 and 1977 (Bakkala et al. 1979).

	Range in vessel size			Typical gear dimensions			
Target species	Length (m)	Gross tons	Horsepower	Head rope length (m)	Ground rope length (m)	Cod end mesh size (cm)	Otter boards
Walleye pollack	78-87	2,657-3,837	2,000-2,320	77.4	77.4	3.0-6.0	Round to oval, variable in size 1,600-1,800 kg.
Atka mackerel	78-87	2,581-3,510	2,000	31.0	44.0	3.0-5.0	Round to oval, 1,200 kg.

Table 28.--Vessel size and fishing gear dimensions of three Republic of Korea independent stern trawlers boarded by U.S. observers in 1977 (Bakkala et al. 1979).

Vessel	Vessels data				Gear					
	Length (m)	Gross tons	Horse power	No. in crew	Headrope length (m)	Ground rope length (m)	Vertical opening (m)	Cod end mesh size (cm)	Otter board size (m)
<u>Salvia</u>	84	2,285	3,200	58	59	78	6	10	2.5x3.8
<u>Shin An Ho</u>	106	5,680	6,000	157	80	75	7	10	3.0x5.0
<u>Heung Yang Ho</u>	104	5,377	5,800	92	74	105	38	10	3.0x4.8

Taiwan trawlers, which first entered the groundfish fishery in 1974 and have numbered only one or two independent stern trawlers, target walleye pollock and flounder (Bakkala et al. 1979). The vessels are from 900 to 1,900 GT and can produce only frozen fish products (Nelson et al. 1981).

The size and type of trawls used by the foreign fleet in the eastern Bering Sea, Aleutian Islands region, and the Gulf of Alaska vary considerably; the specifications of the trawl net and otter boards are summarized in Tables 29 and 30.

Canadian trawlers participating in the fishery for groundfish in the North Pacific average 60 GT and range between 3 and 265 GT. In 1968-70, the fleet consisted of 65-73 vessels of which roughly 60% fish at least 6 months of the year (Table 31). The vessels are essentially the U.S. Pacific coast seiner type crewed by 2-5 men. Catches are hauled aboard the vessels by means of winches, booms, and net reels. Details of the types of net and otter boards used are given in Table 31 (Forester et al. 1978).

United States trawlers in the North Pacific groundfish fishery are essentially similar to the Canadian vessels and totaled 225 in 1970. Table 32 shows the number of trawlers operating in the fishery in 1969-70, by tonnage class and the most common types of trawl gear used (Forrester et al. 1978). The number of U.S. trawlers has increased in recent years (D. L. Alverson, pers. commun., 26 November 1984).

Miscellaneous Net Fisheries

There are a number of other miscellaneous fisheries which rely on nets although the intensity with which this gear is employed is not as great as that in the major net fisheries. Included are the set net, haul seine, and lift net fisheries.

The set net is actually a passive gear which is set in coastal waters to guide migrating fish, or those swept by currents, to follow a "lead" into one or more enclosures from which they have difficulty escaping. The haul seine, which includes the beach seine and boat seine, is set in the

Table 29.--General description of the gear used in the foreign mother ship, stern trawl, and longline fisheries during 1977-78 in the eastern Bering Sea and Aleutian Islands region. Ranges in gear dimensions were taken from U.S. observer data (Nelson et al. 1981).

Nation and vessel type	Gear type	Headrope (m)	Ground rope (m)	Cod end mesh (mm)	Otter board: Dimensions	Otter board: Shape
Japan						
Mother ship	Danish seine	120-130	130-140	90	Not applicable	Not applicable.
	Pair trawl	130-155	155-175	90	Not applicable	Not applicable.
	Otter trawl	47-54	57-65	90-100	2.2 m x 3.4 m	Rectangular
Independent stern trawl						
Large trawlers	Otter trawl	42-100	51-122	90-110	2.6 m x 4.3 m to 3.3 m x 5.8 m	Rectangular.
Small trawlers	Otter trawl	45-56	45-65	90-110	2.2 m x 3.4 m	Rectangular.
U.S.S.R.						
Independent stern trawl	Otter trawl (bottom)	30-50	44-65	100-120	5.5-6.0 m^2	Disc.
	Otter trawl (pelagic)	77	77	100-120	5.5-6.0 m^2	Disc.
Republic of Korea						
Independent stern trawl	Otter trawl	65-80	75-100	90-100	2.8 m x 4.7 m	Rectangular.

Nation and vessel type	[1]Hachi length (m)	No. of hachi/ set	No. of hooks/ hachi	Gangion length (m)	Bait
Japan longliner	70-100	390-420	35-50	1.0-1.5	Frozen squid or pollock.

[1]A hachi is a unit of length in the Japanese longline fishery used to describe a unit of gear containing a number of baited hooks which are attached to the groundline by gangions. The term "skate" is used in North American longline fisheries.

Table 30.--Summary of gear dimensions used by foreign vessels fishing in the Gulf of Alaska, 1977-78 (U.S. observer data) (Wall et al. 1981).

Nation and vessel type	Head rope (m)	Ground rope (m)	Cod end mesh size (mm)	Otter board		Material
				Size	Shape	
Trawlers						
Japan						
Large surimi vessels	50-58.6	59-64.8	90-100	2.2x4.4 to 2.7x3.6	Rectangular	Iron or steel.
Large freezer trawlers	50-58.6	59-64.8	90-100	2.7x4.4 to 2.7x3.6	Rectangular	Iron or steel.
Small freezer trawlers	22-74.2	21-88.8	90-120	1.9x3.8 to 2.4x3.0	Rectangular	Steel or wood and steel.
U.S.S.R.						
Large freezer trawlers Pelagic trawl	77.4	77.4	60-120	5.5-6 m^2	Concave circular, elliptical, or	Steel.
Bottom trawl	30-50	24-48.8	60-120	5.5-6 m^2	rectangular	Steel.
Republic of Korea	60-80	81-103	90-105	1.5x2.5 to 3.0x5.0	Rectangular	Steel.
Poland	121.8	121.8	100	2x4	Rectangular	Steel.

Longline vessels	Hachi (m)	No. hachi per set	No. hooks per hachi	Gangion (m)	Bait
Japan	75-100	390-420	36-58	1. 0-1.7	Squid and pollock.

Table 31.--Size distribution (gross tons) of vessels engaged in the Canadian Pacific coast trawl fishery and average type of gear used, 1968-70 (Forrester et al. 1978). Source: Fisheries Research Board of Canada.

Tonnage class	Year and number of vessels		
	1968	1969	1970
All vessels			
3-24	12	13	11
25-49	27	26	20
50-74	18	17	19
75-99	7	6	5
100-124	6	4	3
125-195	3	5	5
265	0	1	1
Total vessels	73	72	64
Average gross ton	55.1	59.3	60.9
Vessels fishing 6 months or longer in each year			
12-24	3	4	4
25-49	17	13	14
50-74	17	16	11
75-99	4	4	4
100-124	4	3	1
125-195	2	2	3
Total vessels	47	42	38
Average gross tons	59.7	61.2	60.0

Average headrope length: 21.9 m.
Average ground rope length: 28.7 m.
Mesh size in intermediate and cod end: 112 mm.
Otter board size: 2.2 x 1.2 m.
Otter board weight: 325 kg.
Otter board type: steel or wood and steel.

Table 32.--Size distribution (gross tons) of vessels engaged in the United States Pacific coast trawl fishery and average type of gear used, 1969-70 (Forrester et al. 1978).

Tonnage class	Year and number	
	1969	1970
<24	32	37
25-49	105	109
50-74	46	42
75-99	19	18
100-124	15	12
125-195	4	6
200-224	0	0
Stern ramp trawler	1	1
Total	218	225
Average gross tons (excluding stern ramp trawler)	50.6	49.9
Specifications for the most common types of trawl gear used are as follows:		
	350-400 *Eastern*	350 *Cotton*
Headrope Length	58-71 ft (17.7-21.7 m)	65 ft (19.8 m)
Groundrope Length	81-94 ft (24.7-28.7 m)	95 ft (29.0 m)
Mesh Size		
Intermediate and forward	3.0-5.0 in (76.2-127.0 mm)	4.5 in (114.3 mm)
Codend	3.5-5.0 in (88.9-127.0 mm)	4.5 in (114.3 mm)
Otterboard		
Size	7.0×4.0 ft (2.1×1.2 m)	
Weight	760 lb (344.7 kg)	

Source: Washington State Department of Fisheries, Fish Commission of Oregon, and California Department of Fish and Game.

vicinity of known concentrations of fish, then hauled either by hand, machine power, or boats to herd the fish into the bag. In lift net fishing, the entire gear is submerged and kept there until a school of fish, lured to the net either by chumming or a light, is sufficiently concentrated. The net is then hauled quickly to entrap the fish in the bag.

Set Net Fisheries

In countries like Japan, where fish are known to migrate along the coast, conditions are very favorable for set net or fixed net fisheries. In areas where set net fisheries have developed, coastal currents are usually moderate, the coastline is uneven and interrupted by numerous bays, and weather conditions are ideal (Nomura and Yamazaki 1975). Exceptions are in places like Hokkaido where winter conditions can severely limit fishing.

Of the three types of set nets formerly used in Japan, the "otoshi ami" is the only one remaining and can be found in major bays along the Japanese coast including Sagami Bay, Kumano Bay, Tosa Bay, Toyama Bay, and Wakasa Bay.

The Japanese classify set nets as large, medium, and small. Examples of large set nets can be found in Mie Prefecture where they are fixed in water depths of about 30 m over mud and mud-sand bottom to catch yellowtail, tuna, sardine, mackerel, horse mackerel, and other coastal species.

The Japanese coastal fishery for salmon, which operates mostly in the Sea of Japan and along the eastern and western coasts of the northern half of Japan, also relies heavily on set nets in the nearshore areas. Most vessels make short 1-day trips in territorial waters. A few, however, make 2-3 day trips. In 1967-79, the set net produced about 26% of the total Japanese salmon catch.

The "otoshi ami" used in the salmon fishery consists of a leader net and a main net which has three components--the playground net, the funnel, and the trap net, which can be attached on either one or both sides.

Although the upper margins of the nets are fixed to be at sea surface, there has been a trend in recent years to set the net in deep waters of 50-60 m with the upper margins reaching only to the midlayers in the water column. This move toward deepwater sets was prompted by severe winter conditions, particularly around Hokkaido where bad weather severely restricts fishing (Yamaha 1980). These deepwater sets have produced higher catch rates than surface sets.

Among set nets of medium size is the sardine trap net. This net has an ascending portion, a trapping portion, and a fence net. Set 1.8-3.7 km from shore, the net measures 120 m long by 80 m wide and varies in depth from 20 to 40 m. The pocket is 18 m long and 50 m wide. Operation of the net requires three boats--one to raise the bag net entrance and the others to lift the entire remainder of the net. Fished mainly in spring and summer, these nets capture sardine as well as mackerel, horse mackerel, squid, and other species. These nets are fished along the Pacific and Sea of Japan coasts of Honshu.

Another set net of medium size is the herring trap net, used mainly along the coast of Hokkaido. This net usually measures 45 m long and 20 m wide in the bag net and has a 150 m long leader net. Operated by three boats, the net is usually fished for only 3 months from March through May. One boat lifts the net while the others serve as carriers. The target species is spawning herring.

A small trap net is operated year round in many small bays along the Japan coast. Consisting of a main net, leader net, and bag net with flappers, the net is operated by one boat crewed by two to three fishermen. Species taken usually include sea bream, Spanish mackerel, perch, cuttlefish, flatfish, croaker, and squid.

Haul Seine Fisheries

The haul seine is operated on the same principle as the trawl; that is, the net is dragged along the sea floor or in midwater. Essentially, the net has long wings which serve as barriers that drive the fish toward the bag. The top line or upper edge of the net is buoyed with floats whereas the bottom line, which drags along the sea floor, is weighted with sinkers. Most nets have pocket bunts similar to the cod end of a trawl. This pocket usually is made of heavy webbing to hold the fish. It can be centered, in which case the net is symmetrical, or off to one side or asymmetrical (Torban 1964).

Haul seines vary from small 100 m nets to large 2,000 m ones (Kask 1947; Torban 1964). Depth varies from 10 to as much as 40 m in some European nets. The cod end or pocket can be 10-12 m long. Meshes in the wing are graduated from 75 to 15 cm; the meshes near the center are smaller (1.5 to 2.0 cm). The ground lines and float lines are 1.5 cm in diameter; whereas the hauling lines or warps, attached to the wings, are 2.0 cm in diameter and about 1,500 m long. The warps serve a dual purpose; in addition to their use as a hauling line, some fisheries use the warps as frightening devices by attaching twigs, leaves, or straws to them.

Haul seines such as beach seines can be used in shallow water where fish are known to aggregate. The net is usually set with the aid of a skiff at the direction of a fishing master. Hauling in the warp and net can be done by hand but this operation requires considerable labor. Some European beach seine fisheries now resort to mechanical haulers.

The Hawaiian "hukilau" net is a typical example of a beach seine which requires many helping hands in hauling. The leaves of the ti plant are attached to the warp of this net which serves as a scare line. Species most commonly caught in the hukilau nets are jack, threadfin, bonefish, milkfish, goatfish, and mullet.

Okinawan fishermen use a variation of the haul seine which is set from two boats but also requires many hands. In this method, the haul seine is set at designated fishing grounds by small fishing boats, then the fishermen enter the water and begin hitting the surface with their hands or scare lines to startle the fish and drive them out from their hiding places between rocks and within coral heads. Some of the fish, in attempting to escape, become entangled in the wing net; however, most are driven toward the bag which is then hauled aboard the boats. Species caught by this method usually include wrasses, parrotfishes, golden banded fusiliers, and flyingfishes (Yamaha 1979b). Similar fishing methods are used in the Philippines where the fishery ranks fifth in terms of commercial fish production (Encina 1982). The major species caught are _Caesio_ spp., parrotfish, snapper, siganids, and nemipterids.

The Japanese have a form of net fishing called boat seining in which fish are caught by filtering midlayer waters with a net. The gear used in this type of fishing is different from that used in bottom trawling operations, and the target species differ (Yamaha 1983a).

Boat seining requires the following:

- Wing net.--Section of the net used to intimidate the fish and promote school formation.

- Main net.--This section prevents fish from escaping while guiding them into the bag area.

- <u>Bag net</u>.--This section holds the fish.

- <u>Tow rope</u>.--Rope used by the boat to tow or hold the net.

One type of boat seine ("patchi ami") in Japan is the largest net used in any of the boat seine fisheries, requiring two boats of up to 20 gross tons to tow it (Yamaha 1983a). Based on 1983 data, there are about 700 groups operating out of central and southern regions of Japan's Pacific coast. Target species for this fishery are sardine, anchovy (adults and fry), sand lance, and cuttlefish; however, sardine and anchovy predominate in the catch.

In "patchi ami" seining, the two boats are tied together at the bow and share the load of the net as they head toward the fishing grounds. After a school is located by a fish-finder on a search boat, the two boats are positioned up current from the school then advancing with their bows still joined, they lay out the buoys and then the bag net into the water. At this point, the two vessels separate and head off in opposite directions at full speed, laying out the main net and wing net as they steam along. When the entire net is set, the two boats turn 90° and run parallel to each other in the direction of the school, laying out sufficient tow rope to bring the mouth of the net to about the same depth as the fish school. When the net is finally positioned at the proper depth, towing begins.

In retrieving the net, the two boats come together and are again secured at the bow. Net haulers commence the retrieval onto large drums or reels mounted on the deck; however, the main net is hauled in by hand. Then the bag net is brought up to the surface, a transport boat is called up to the stern of the two net boats, and picks up the buoy, buoy line, and the bag net. Net specifications for this fishery are given in Tables 33 and 34.

Another type of boat seining called "gochi ami" (type B) in Japan, can be either a one- or two-boat operation. The net, which has a high ratio of shrinkage in the center section, expands into a large bag when placed across a current or towed (Yamaha 1983a). This net is ideal for towing alongside reefs or near the sea bottom; thus it can be used in places such as rough or rocky bottom where a standard bottom trawl cannot be used. It is highly effective in fishing for red sea bream, threeline grunt, silver whiting, lizardfish, barracuda, and porgy.

One-boat operations usually harvest small fish, whereas two-boat groups target large fish. The specifications of the net in a one-boat operation are presented in Table 35.

Lift Net Fisheries

Three typical examples of lift nets are the basnig (bag net) used in the Philippines, the conical type such as that used in the Hawaiian opelu (<u>Decapterus</u> spp.) fishery, and the stick held net used in Japan.

The main characteristic of this fishing method is that the net remains submerged until ready to be hauled up vertically and at least partially out of the water to catch fish, which congregate above it (Ben-Yami 1976).

Table 33.--Specifications for a Type A boat seine ("patchi ami") (Yamaha 1983a).

Name of parts	Mark	Material	Thickness	Mesh size	Quantity
Wing net	a	Polyvinyl alcohol	11 mm	240 cm	2
Main net	b	Polyvinyl alcohol	8 mm	120 cm	2
	c		7 mm	60 cm	2
	d		6 mm	30 cm	2
Mouth of bag net	e	Polyvinyl alcohol	6 mm	24 cm	2
Bag net	f	Nylon	No. 4 (0.329 mm) x 4 yarns	0.5 mm (Japanese minnow net-105 yarns per 50 cm)	2
	g				2
	h				2
	i				2
	j				2
	k				2
Trap (inside of bag net)	l	Nylon	*	0.5 mm	2
Sale rope	m	Polyvinyl alcohol	18 mm (diameter)	--	2
	n				2
Head rope	o	Polyvinyl alcohol	18 mm (diameter)	--	2
	p				2

Table 34.--Differences in specifications of Type A boat seine ("patchi ami"), by area, type of operation, and species targeted (Yamaha 1983a).

Area	Type	Main catch	Head rope length (m)	Bag net height (m)
Fukuoka, Nishiura	Two-boat operation	Red sea bream, etc.	45	20.2
Fukuoka, Fukuyoshi	Two-boat operation	Grunt and red sea bream	38.4-40.5	30
Saga, Yobo	Two-boat operation	Grunt and red sea bream	38.4-40.5	45
Saga, Yobo	One-boat operation	Sillaginoid and barracuda	27	18
Nagasaki, Aou	--	Red sea bream and grunt	22.5	15
		Red sea bream lizardfish and barracuda	22.5	15
		Lizardfish and barracuda	18	6-6.5

Table 35.--Specifications for a type B boat seine ("gochi ami") (Yamaha 1983a).

Mark	Name	Material	Standard No. of yarns	Standard Mesh size (mm)	No. of meshes Width	No. of meshes length	No. of sheets
A	Wing net	Nylon	36	61	4	4.5	2
B	Wing net	Nylon	6	43	100	5.7	2
C	Wing net	Nylon	6	43	50	7.2	2
D	Wing net	Nylon	6	43	100	7.2	2
E	Upper salvage	Polyvinyl alcohol	30	43	5-10	600	1
F	Bottom salvage	Polyvinyl alcohol	40	50	5-10	600	1
G	The side of bag net	Nylon	6	43	100	800	2
H	The bottom of bag net	Polyvinyl alcohol	8	38	150	250	1
I	Shirk net	Nylon	12	43	50	7.2	2
J	Upper triangle	Polyvinyl alcohol	30	43	25	25	2
	Lower triangle	Polyvinyl alcohol	40	50	20	20	2

Most lift net fishing is done with attracting lights, although the Hawaiian opelu net is used in conjunction with chumming.

The lift net is best for catching fish that form dense and compact aggregations. In the Philippines, the basnig is operated with a night light during the dark phase of the moon (Encina 1982). The gear consists of a pair of bamboo rafts, dugout, poles or booms, and a large net somewhat like an inverted mosquito net.

Improvements in the gear after World War II included larger boats propelled by marine diesel engines. To increase lighting power and thus attract more fish, high candlepower lamps or generators were used (Encina 1982).

In 1980, the basnig fishery contributed 106,194 MT of fish or roughly 21.7% of the total commercial fish production. The fleet consisted of 624 units or 26% of the total commercial vessels operating. Species targeted by the basnig fishery include round scad, anchovy, sardine, and slipmouth (BFAR 1975; Encina 1982). Table 36 gives the specifications and configurations of the net.

The Japanese stick-held lift net is used principally in the saury and mackerel fisheries in which the vessels have a large battery of lights. These lights can be classified into fish searching lights, fish gathering lights, and fish leading lights. The first step involves the use of searchlights to search for fish schools. The net, which is suspended from outrigger bamboo poles or booms and hauled toward the vessel when retrieving, is set after a school is located and the fish gathering lamps are turned on to attract the fish to the boat. A red, fish leading lamp with adjustable light intensity concentrates the school over the net (Nomura and Yamazaki 1975). This method of fishing has an advantage in that the net cannot only be adjusted to a specific light attraction system, but also

Table 36.--Specifications for a Philippine basnig (Food and Agriculture Organization of the United Nations 1965).

Data Sheet — FAO No. 501

NAME OF GEAR: Basnig (Bagnet)
TYPE: One-boat lift net
COUNTRY: Philippines
LOCALITY: Visayan Sea and Vicinity
REFERENCE: Philippine Journal of Fisheries, Vol. 3, No. 1
See also Modern Fishing Gear of the World pp [illegible]

Main species caught: Sardines, Mackerel, Round Scad

Fishing conditions: Depth: 10 - 30 fm
Sandy, muddy bottom. Calm to strong breeze, current 1 - 2 knots
Duration of operation: 1/2 to 1 1/2 hours. Fish attracted by electric lights above surface.

Vessels: Launch
L. O. A.: 26 m (85 ft)
Gross tonnage: 75
Horse power: 310
Crew: 25

WEBBING	A	B	C	D*	E*	F*	G*
Material	Cotton						→
Type of knot	⌧						→
Preservation	C						→
Colour							
Twine size Tex	300		→	300			→
Breaking strength kg. lb.							
Stretched mesh mm.	20		→	40			→
Upper edge	1500	2500	1500	750	6	6	750
Lower edge	1500	2500	1500	750	6	6	750
Depth	500	2000	500	6	1000	1000	6
Baiting rate	all p	all p	all p	all p	all m	all m	all p
Take-up				D:A=1:2	E:B=1:2	F:B=1:2	G:C=1:2
Selvedge							
Hanging m	0.5 15/30	0.5 20/40	0.5 20/40	0.5 15/30			

LINES, ROPES	a	b	c	d	a₁	b₁	c₁	d₁	e
Material	Cotton							→	Abaca
Preservation	C							→	D
Circumference in.	1 1/4			→	5/8			→	2 1/4
Diameter mm.	11			→	5			→	18
Breaking strength kg. lb.									
Construction	S								→
Lay	M								→
Length m.	15	20	20	15	15.6	20.8	20.8	15.6	55

FLOATS, SINKERS	(1)
Number	12
Material	Lead
Shape	
Diameter mm. / in.	89 3 1/2
Length mm. / in.	102 4
Static buoyancy kg.	6 - 8
Weight in air kg. lb.	
Weight submerged kg. lb.	

Accessories:

Electric generator 1 x 25 kva
Electric lamps 20 x 1 Kw

can be used to corral the fish between the net and the vessel's hull, thus reducing the chances of escape (Ben-Yami 1976).

ESTIMATES OF THE AMOUNT OF NET GEAR AVAILABLE FOR USE

The preceding sections demonstrated the diverse nature of net gear in use in the North Pacific, even within the same fisheries. Gill nets, trawls, and purse seine vary greatly in construction and design that it is almost impossible to designate one type as being typical for a particular fishery. For example, gill nets vary widely in length, mesh size, hanging ratio, thread size, and color so that there is no "typical" gill net for any one species. Likewise, trawls and purse seines vary considerably in size, webbing, meshes, and configuration. This variation in gear results from many factors, among them being fishermen or net manufacturer's preference, the behavior and life stages of the species sought, and regulations adopted for the fisheries.

Although there is wide variation in gear, what is of interest is a perspective of how much net gear is actually available to any given fishery. This estimate should provide an idea on the extent to which derelict fishing gear can become a component of the marine debris in the North Pacific. The estimates of available gear in the major net fisheries are first-order approximations based on data presently available.

Estimates of the amount of net gear available for use in the North Pacific are given in Table 37. It should be pointed out that because the data contained in Table 37 represent mostly major or large fisheries, the estimates are minimums. Many small, coastal fisheries have not been considered in the computation.

It can be seen in Table 37 that the amount of gill net used in the North Pacific far outstrips that of purse seines, trawls, and miscellaneous gear such as boat seines, set nets, and lift nets. Nearly 3.5 million units (shackles, Japanese tan, etc.) of gill net are available to the major fisheries. Strung end to end, these nets would stretch over 170,000 km, a distance 4.2 times the length of the Earth's Equator.

SPECULATION ON GEAR LOSSES

Because gear losses are never reported, it is not possible to estimate the extent to which they occur in any fishery. There is no doubt, however, that within the past two decades, fishing pressure on all the fishery stocks in the world's oceans has increased dramatically, and with it there has been a concomitant increase in the amount of fishing-related debris dumped into the sea (Wehle and Coleman 1983). Furthermore, the kinds of debris and derelict fishing gear finding their way into the ocean has changed. Whereas fishing nets manufactured before the "synthetic boom" were made of natural fibers and, therefore, were degradable within a relatively short period when they became derelict, the synthetic nets, ropes, and lines of the past three decades, when lost, were more buoyant, longer lived, and in some cases nearly invisible under water. The result of this change in fibers used for netting and lines has meant an increase in mortality of not only marine animals but also marine organisms. Unlike

Table 37.--Estimates of total length of nets available to the major net fisheries of the North Pacific (BFAR = Bureau of Fisheries and Aquatic Resources; PRC = Peoples Republic of China; IATTC = Inter-American Tropical Tuna Commission; INPFC = International North Pacific Fisheries Commission; JMAF = Japan Ministry of Agriculture and Forestry).

Fisheries	Net length: Float line (m)	Net length: Lead-rope (m)	Net length: Foot-rope (m)	Total units per available boat (No.)	Boats (No.)	Total fishing units (No.)	Estimated total length of net available for fishing (km)	Source of data
				Gill Net Gear				
PRC coastal Spanish mackerel	[1]26	--	--	--	--	426,000	11,076	Zhu 1980.
Taiwan high seas squid	50	--	--	500	63	31,500	1,575	Footnote 2 in text.
Japanese coastal salmon	[1]50	--	--	40	1,380	55,200	2,760	INPFC 1979; Nomura and Yamazaki 1975.
Japanese coastal billfish	50	--	--	[1]300	395	118,500	5,925	Suisan Sekai 1978.
Japanese coastal sardine, herring, and others	[1]50	--	--	[1]40	60,919	2,436,760	121,838	JMAF 1981.
Japanese high seas salmon	50	--	--	300	172	51,600	2,580	INPFC 1980.
Japanese land-based salmon	51.4	--	--	290	325	94,250	4,844	INPFC 1979
Japanese Bering Sea groundfish	46	--	--	[1]300	10	3,000	138	Forrester et al. 1983.
Japanese high seas squid	[1]50	--	--	[1]400	534	213,600	10,680	Footnote 2 in text.
Canadian salmon	366	--	--	1	2,508	2,508	917	Beacham 1984a, 1984b; Argue et al. 1983.
Canadian northeast Pacific herring	366	--	--	12	1,068	12,816	4,550	Forrester et al. 1983; Bourston and Haegele 1980.
U.S. coastal set net salmon	192	--	--	--	--	3,045	585	U.S. Department of Commerce 1978.
U.S. coastal miscellaneous species (California)	82	--	--	30	509	15,270	1,252	Spratt 1981; Plaschner 1983.
U.S. coastal drift net salmon	274	--	--	--	--	5,113	1,401	U.S. Department of Commerce 1978.
U.S. northeast Pacific groundfish	[1]274	--	--	12	105	1,260	345	Forrester et al. 1983.
Total						3,470,422	170,466	

Table 37.--Continued.

Fisheries	Net length: Float line (m)	Net length: Head-rope (m)	Net length: Foot-rope (m)	Total units per available boat (No.)	Boats (No.)	Total fishing units (No.)	Estimated total length of net available for fishing (km)	Source of data
Purse Seine Gear								
PRC coastal	600	--	--	1	[2]165	165	99	Bolecki 1966.
Philippines coastal	494	--	--	1	[2]471	471	233	(Philippines) BFAR 1975; Shomura et al. 1975.
Japanese one-boat coastal	731	--	--	1	[2]650	650	475	JMAF 1981.
Japanese two-boat coastal	1,100	--	--	1	[2]168	84	92	JMAF 1981.
Japanese tuna	2,400	--	--	1	[2]73	73	175	JMAF 1981.
Canadian salmon	402	--	--	1	532	532	214	Beacham 1984a, 1984b.
Canadian northeast Pacific herring	[1]440	--	--	1	188	188	83	Forrester et al. 1978, 1983.
U.S. coastal salmon	457	--	--	1	[2]1,231	1,231	563	U.S. Department of Commerce 1978.
U.S. northeast Pacific herring	457	--	--	1	173	173	79	Forrester et al. 1978, 1983.
Eastern Pacific tuna	1,200	--	--	1	220	220	264	IATTC 1983.
Total					3,316	2,044		
Trawl Net Gear								
South China Sea otter	--	40	54	1	[2]10,667	10,667	[3]1,003	Aoyama 1973.
South China Sea pair	--	100	[4]135	1	[2]8,090	4,045	[3]950	Aoyama 1973.
Japanese coastal small	--	55	65	1	[2]28,372	28,372	[3]3,405	JMAF 1981.
Japanese mother ship Danish seine	--	130	140	1				
Japanese mother ship pair	--	135	175	1	332	166	[3,5]55	INPFC 1979; Bakkala et al. 1979.
Japanese stern	--	52	63	1				
Japanese land-based	--	[1]54	[1]65	1	75	182	[3]22	Nelson et al. 1981.
Japanese independent	--	52	63	1	54	54	[3]6	Nelson et al. 1981.

Table 37.--Continued.

Fisheries	Net length: Float line (m)	Net length: Head-rope (m)	Net length: Foot-rope (m)	Total units per available boat (No.)	Boats (No.)	Total fishing units (No.)	Estimated total length of net available for fishing (km)	Source of data
Canadian northeast Pacific herring	--	22	29	1	87	87	[3]4	Forrester et al. 1978, 1983.
U.S. northeast Pacific groundfish	--	20	29	1	532	532	[3]26	Forrester et al. 1978, 1983.
Soviet Bering Sea groundfish	--	77	77	1	345	345	[3]53	Fruter 1976.
Soviet northeast Pacific groundfish	--	77	77	1	97	97	[3]15	Fruter 1976.
Total						44,547	[3]5,539	
				Miscellaneous Net Gear				
Japanese two-boat seining ("patchi ami")	--	[1]45+ [6]436	[1]45	1	[2]1,430	715	376	JMAF 1981.
Japanese one or two-boat seining ("gochi ami")	--	27	[1]27	1	7,082	7,082	382	JMAF 1981.
Japanese stick held lift net	200	--	--	1	5,232	5,232	1,046	JMAF 1981.
Philippine basnig	70	--	--	1	624	624	44	Encina 1982.
Japanese set net	[7]400	--	--	1	17,565	17,565	7,026	Kask 1947; JMAF 1981.
Total						31,218	8,874	

[1]Estimated from information on related fisheries.
[2]Assumption based on number of units operated.
[3]Calculation based on headrope and footrope lengths.
[4]Based on proportions of otter trawl.
[5]Based on data for pair trawlers, which predominate in fisheries.
[6]Total length of right and left wing nets.
[7]Total length of leader net and main body.

working nets, which are set and retrieved within a specific time period, the free-floating derelict net, often broken into large and small fragments, fishes indefinitely, thus representing miles of entanglement for fish, crustaceans, molluscs, marine mammals, turtles, and seabirds.

Of the various net gears reviewed, the gill net is perhaps the most likely to become lost or damaged and discarded during fishing operations. In the Icelandic cod fishery, for example, each gill-netter fishes about 100 nets per day. These nets last only a few weeks and each boat can use up to 400 nets in a 4-month season (Frechet 1964). Although bad weather is probably responsible for some of the nets lost or damaged, heavy fishing and shark damage also account for a good proportion of the nets being lost or discarded.

One study conducted by High (1981) demonstrated that derelict gill nets have the potential for causing major fish losses. Visits to sites where sunken derelict gill nets were found showed that they remained intact and continued to capture fish for more than 2 years. Living and dead fish of several species and numerous crabs were always present in one of the nets that covered about 186 m^2 (2,000 ft^2).

The ubiquitous gill net is without doubt the gear most disliked by the nongill net segment of the fishing industry, yet it provides support for many fishermen throughout the world. And although it is true that "gearing up" with gill nets to participate in a fishery does not require the kind of capital investment needed to enter a purse seine or trawl fishery, gillnetters, nevertheless, do encounter high losses in gear as well as in catches. For example, marine mammals have been accused of "gnawing a sizable gash" in the catches of commercial fishermen (Pleschner 1983). It has been estimated that seals alone cause losses totaling at least US$10,000 per boat per year.

In the purse seine and boat seine fishery, one can hardly expect gear losses to be high, because the operation requires that at least one end of the net be secured to the vessel at all times; however, it is possible for nets to become entangled on rocky bottom or coral if sets are made in shallow water. Net damage is also likely to occur if large predators, for example, sharks are caught together with small target species.

Trawls, like gill nets, can be easily lost should they become "hung up" on the bottom during trawling operations. Also, bottom trawls are highly susceptible to damage when being hauled over rough bottom. Loss and damage to trawl gear are probably highest during and immediately after the exploratory fishing phase when grounds are still unfamiliar to the trawl fishermen.

Among the miscellaneous gear, the lift net is unlikely to be lost since almost all operations are conducted over still, quiet waters. Moreover, the nets are attached to lines which are run to outriggers or bamboo poles that are secured to the fishing vessels. Fishing operations can be halted at any time and the net removed from the water should it become necessary to do so during sudden storms and changes in sea conditions.

The set net, on the other hand, can be subjected to severe damage or lost entirely, because for much of the time that the net is in the water, it is unattended. Although most set nets are strategically placed in locations where weather and sea conditions are not expected to be adverse, sudden storms and the resulting heavy seas could generate currents strong enough to break the mooring or anchor lines attached to the set nets, thereby setting them adrift to become components of marine debris.

SUMMARY

The major net fisheries of the North Pacific are reviewed to develop some perspective of the amount of gear available to them for fishing. For the 15 major gill net fisheries in the North Pacific, it was estimated that roughly 170,000 km of netting were available to them for fishing. For the 10 purse seine fisheries, the netting available was estimated to be a little over 2,000 km, whereas for 12 trawl fisheries the estimate reached 5,500 km.

Among the various net gear discussed, it was speculated that gear losses were highest in the gill net fisheries, followed by the trawl fisheries and set net fisheries. Because modern net gear is fabricated predominantly with synthetic webbing, and therefore, nondegradable, derelict netting remains a part of the marine debris indefinitely thus threatening air-breathing animals as well as fish, crustaceans, and molluscs in the marine environment.

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Appendix Table 1.--English and scientific names of fishes, molluscs, and crustaceans mentioned in this report.

English name	Scientific name
Abalone	Haliotidae
Albacore	*Thunnus alalunga*
Anchovy	Engraulidae
Angel shark	Squatinidae
Ark shell	Arcidae
Atka mackerel	*Pleurogrammas monopterygius*
Barracuda	*Sphyraena* sp.
Bastard halibut	*Paralichthys olivaceus*
Bigeye	*Priacanthus macracanthus*
Bigege scad	*Selar crumenophthalmus*
Billfish	Istiophoridae
Black porgy	*Acanthopagrus latus*, *A. cuvieri*
Bluefin tuna (northern)	*Thunnus thynnus*
Bonefish	*Albula vulpes*
Bonito	*Sarda* sp.
Bream	Sparidae
Chinese herring	*Ilisha elongata*
Chinook salmon	*Oncorhynchus tshawytscha*
Chub mackerel	*Rastrelliger* spp.
Chum salmon	*Oncorhynchus keta*
Clam	Pelecypoda
Cod	Gadidae
Coho salmon	*Oncorhynchus kisutch*
Crab	Brachyura
Crawfish	Macrura
Croaker	Sciaenidae
Cutlassfish	Trichiuridae
Cuttlefish	Sepioidea
Dorado	*Coryphaena* spp.
Drum	Sciaenidae
Dungeness crab	*Cancer magister*
Filefish	*Navodon septentrionalis*, *S. modestus*
Flatfish	Pleuronectiformes
Flounder	Pleuronectidae
Flyingfish	Excoetidae
Frigate tuna	*Auxis thazard*
Gizzard shad	Dorosomidae
Goatfish	Mullidae
Golden banded fusilier	*Caesio chrysozona*
Greenland turbot	*Reinhardtius hippoglossoides*
Grunt	Pomadasyidae
Haddock	*Melanogrammus aeglifinus*
Hairtail	*Trichiurus haumela*
Halibut	Pleuronectidae
Harvestfish	*Stromateoides nazavae*

Appendix Table 1.--Continued.

English name	Scientific name
Hemiramph	Hemiramphidae
Herring	Clupeidae
Horse mackerel	*Trachurus japonicus*
Indo-Pacific mackerel	*Rastrelliger* sp.
Jack	Carangidae
Jack mackerel	*Engraulis japonica*
Jewfish	Epinephelidae
King crab	*Paralithodes camtschatica*
Large yellow croaker	*Pseudosciaena crocea*
Laver	Rhodophyceae
Lizardfish	*Saurida* spp.
Mackerel	Scombridae, Carangidae
Mackerel scad	*Decapterus macarellus*
Mahimahi	*Coryphaena hippurus*
Marusoda	*Auxis rochei*
Menhaden	*Brevoortia* spp.
Milkfish	*Chanos chanos*
Mullet	Mugilidae
Nenipterid	Nemipteridae
Octopus	Octopodidae
Opelu	*Decapterus* spp.
Oyster	Ostreidae
Pacific round herring	*Etrumeus teres*
Parrotfish	*Scarus* spp.
Paste shrimp	*Acetes chinensis*, *A. japonicus*
Perch	Embiotocidae
Pink salmon	*Onchorhynchus gorbuscha*
Pomfret	Stromateidae
Porgy	*Sparus* sp.
Prawn	*Pandalus platyceros*, *Penaeus orientalis*, *P. chinensis*
Purple pike conger	*Muraenesox cinereus*
Red sea bream	*Chrysophrys major*
Red squid	*Ommastrephes bartramii*
Ray	*Rajida* sp.
Round herring	*Dussumieria acuta*
Round scad	*Decapterus maruadsi*
Sailfin sandfish	*Arctoscopus japonicus*
Salmon	Salmonidae
Sand lance	*Ammodytes personatus*
Sardine	Clupeidae
Saury (Pacific)	*Cololabis saira*
Scallop	Pectinidae
Sea bass	Serranidae
Sea bream	Sparidae
Sea cucumber	Holothuroidea
Sea mussel	Mytilidae

Appendix Table 1.--Continued.

English name	Scientific name
Sea sheat	_Plotosus anguillaris_
Sea slug	Nudibranchia
Sea urchin	Echinoidea
Shad	Dorosomidae
Shark	Chondrichthyes
Shrimp	Macrura
Siganids	Siganidae
Sillaginoid	Sillaginidae
Silver whiting	_Silago_ spp.
Skipjack tuna	_Katsuwonus pelamis_
Slipmouth	Leiognathidae
Small yellow croaker	_Pseudosciaena polyactis_
Snapper	Lutjanidae
Sockeye salmon	_Oncorhynchus nerka_
Sole	Pleuronectidae
Spanish mackerel (Japanese)	_Scomberomorus niphonius_
Spiny lobster	Palinuridae
Squid	Teuthoidea
Steelhead trout	_Salmo gairdneri_
Swimming crab	Portunidae
Swordfish	_Xiphias gladius_
Thornyhead	Scorpaenidae
Threadfin	_Polydactylus sexfilis_
Threadfin bream	_Nemipterus_ spp.
Threeline grunt	_Plectorhynchus cinctus_
Thresher shark	_Alopius vulpinus_
Trout	Salmonidae
Tuna	Scombridae
White seabass	_Synoscion nobilis_
Wrass	Labridae
Yellowfin tuna	_Thunnus albacares_
Yellowtail	_Seriola quinqueradiata_

DISTRIBUTION AND MIGRATION OF FLYING SQUID, OMMASTREPHES BARTRAMI (LESUEUR), IN THE NORTH PACIFIC

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ABSTRACT

Mantle length, surface temperature, and catch and effort data gathered from 1980 to 1983 in the Korean drift gill net fishery were examined to determine seasonal distribution and migration of flying squid, *Ommastrephes bartrami* (LeSueur), in the North Pacific.

Flying squid was taken by commercial fishing vessels in waters with surface temperatures ranging from 9° to 22°C. The best fishing occurred in water temperature of 15°-16°C in May through July and between 13° and 18°C in August through January. High densities of flying squid were found in thermal fronts of 18°C in August and 15°C in September. The densities of flying squid in the western North Pacific were higher than in the central North Pacific. The high densities of flying squid in the western North Pacific were attributed to the high gradient of oceanographic properties in the region.

Mantle length measurements of flying squid indicated dominant modes at 38-39 cm in the central North Pacific from June to July and at 30-31 cm in the northwestern Pacific from September to December.

The migration of flying squid in the North Pacific was hypothesized from observations of the monthly distributions of catch per unit effort, mantle length measurements in statistical blocks, and hydrographic features. Large squid appeared in the northern central Pacific region earlier than small squid during the northward migration period (from June to August). The southward migration from the subarctic frontal zone began in autumn, as waters cooled with the development of the Oyashio. Large squid started its southward migration from more northern waters than small squid but reached the spawning grounds ahead of the smaller squid.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

INTRODUCTION

The flying squid, <u>*Ommastrephes bartrami*</u>, LeSueur, has worldwide distribution in subtropical and temperate oceanic waters (Young 1972; Okutani 1973; Roper et al. 1984). The annual catches of this species in the North Pacific by Japan, Korea, and Taiwan averaged about 300,000 metric tons (MT) in recent years. Exploratory fishing in the North Pacific by Korean drift gill net vessels began in 1979 and by the 1983 season, about 100 vessels were operating in the area.

Even though there are many reports describing the distribution and movement of flying squid in the northwestern Pacific, mostly by Japanese scientists (Murakami 1976; Murata et al. 1976, 1981, 1983a, 1983b; Murata and Ishii 1977; Naito et al. 1977a, 1977b; Murakami et al. 1981; Kubodera et al. 1983), the reports do not contain information on the seasonal distribution and migration routes of the squid in the central North Pacific.

This study (1) examines the seasonal distribution and migration of flying squid in the North Pacific based on density distribution, oceanographic conditions, and body size composition of squid taken in the Korean drift gill net fishery from 1980 to 1983 and (2) develops a migration model of flying squid in the North Pacific Ocean.

MATERIALS AND METHODS

During the 1980-83 fishing seasons, about 207 Korean gill net vessels operated in the North Pacific. Of this total, 132 vessels provided 871 vessel-month catch and effort data. Vessel sizes ranged from 150 to 500 gross tons (GT), and half of them were in the 200-300 GT range. Each unit of gill net was 50 m long and 8 m deep (Table 1, Fig. 1), with mesh sizes ranged from 96 to 115 mm. The average number of gill nets used by one vessel per day was 200 in 1980 and 540 in 1983 (Table 2).

Annual and monthly catch per unit effort (CPUE) in kilograms per net were calculated for each statistical block (1° of latitude by 1° of longitude) corresponding with the format used by the Deep Sea Resources Research Division of the Korean National Fisheries Research and Development Agency for recording daily catches. Monthly dorsal mantle length (DML)

Table 1.--Details of the Korean flying squid gill net (mesh 0.497 mm).

Mesh size (mm)	Length of float line (m)	Hanging ratio		Depth of net (m)	Net
		Upper	Lower		
96	50	0.446	0.457	8.79	Nylon monofilament 0.497 mm.
105	50	0.446	0.454	8.74	Do.
110	50	0.459	0.470	12.30	Do.
115	50	0.461	0.471	7.80	Do.

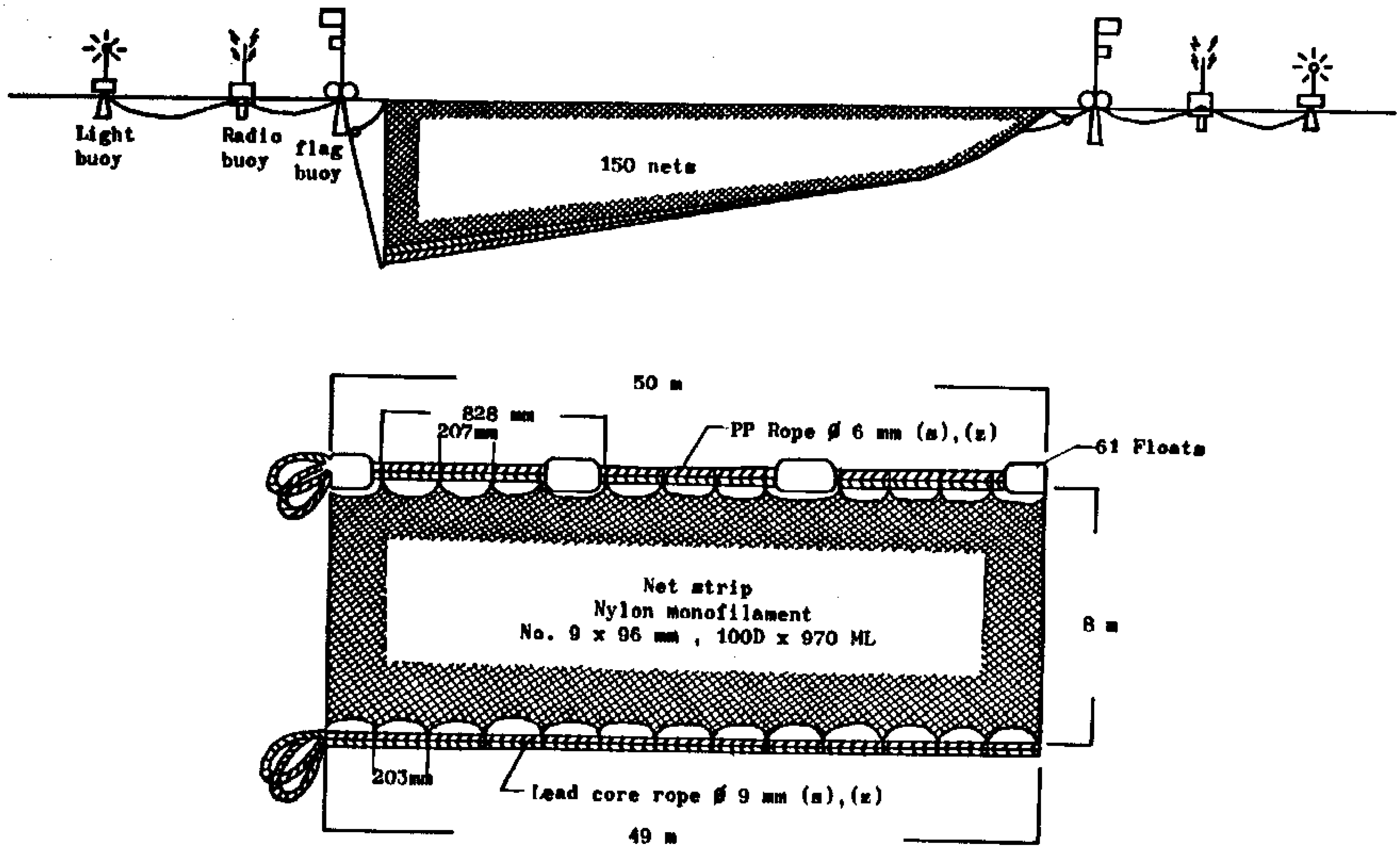

Figure 1.--Schematic diagram of the Korean flying squid gill net in the North Pacific.

Table 2.--Annual fishing effort, catch and catch per unit effort in the Korean flying squid gill net fishery in the North Pacific, 1980-83 by metric tons (MT) (parentheses indicate number of vessel-months).

Year	No. of vessels registered	No. of vessels sampled	No. of days fished	No. of gill net units	Catches by sampled vessels (MT)	Average No. of gill nets per vessel-month	Average No. of gill nets per vessel-day	Catch per vessel-month (ton/vessel-month)	Catch per unit net (kg/net)
1980	14	9 (44)	684	139,638	3,017.3	3,173.6	204.1	68.6	21.6
1981	34	9 (73)	1,374	194,060	6,061.6	5,398.1	286.8	83.0	15.4
1982	60	56 (327)	6,375	2,733,635	21,371.3	8,359.7	428.8	65.1	7.8
1983	99	56 (419)	7,560	4,070,372	27,130.5	9,714.5	538.4	64.8	6.7
Total or average	207	130 (871)	15,379	7,337,705	57,341.8	8,424.5	477.1	65.8	7.8

compositions were obtained for each 1° of latitude by 5° of longitude block.

The optimum temperature for flying squid fishing was calculated as a weighted mean of catch and surface temperatures in each statistical block having both temperature measurement and fishing record. Catch per unit effort for statistical blocks was plotted together with the surface thermal structure derived from the NOAA Satellite infrared data from the northwestern Pacific (Japan Fisheries Information Service Center 1983).

Based on the analyses of CPUE and temperature, an attempt was made to describe the density distribution and migration by size group of flying squid in the North Pacific.

RESULTS

Distribution of Catch Per Unit Effort

The distribution of annual CPUE (kilograms per net) by statistical block (1° of latitude by 1° longitude) for the Korean flying squid gill net fishery in the North Pacific from 1980 to 1983 is shown in Figure 2. The fishing grounds are found in the region of lat. 30°-45°N and long. 143°E-180° in 1980 and lat. 34°-46°N and long. 142°E-179°W in 1981. The fishing grounds expanded to the central North Pacific east of long. 170° and 165°W in 1982 and 1983, respectively. The number of statistical blocks with high CPUE's in the same region west of 180° tended to decrease in succeeding years from 1981 to 1983. The distribution of monthly CPUE by statistical block in the 1983 season is shown in Figure 3. The number of blocks having CPUE's higher than 6 kg/net increased in succeeding months from May to July in the area lat. 35° to 40°N and long. 150°E to 165°W. In August, the fishing grounds were formed north of lat. 40°N and the center of the grounds was farther to the west between long. 150° and 165°E in the northwestern Pacific. In September, the fishing grounds extended from Hokkaido to long. 165°E, and the eastern limit of the fishing ground moved gradually westward in subsequent months through December and January. The centers of fishing grounds thus tended to shift to the north by 2° or 3° in succeeding months from May to July in the central North Pacific, then west to off Hokkaido in August and September, and to south off northern Honshu in subsequent months through January.

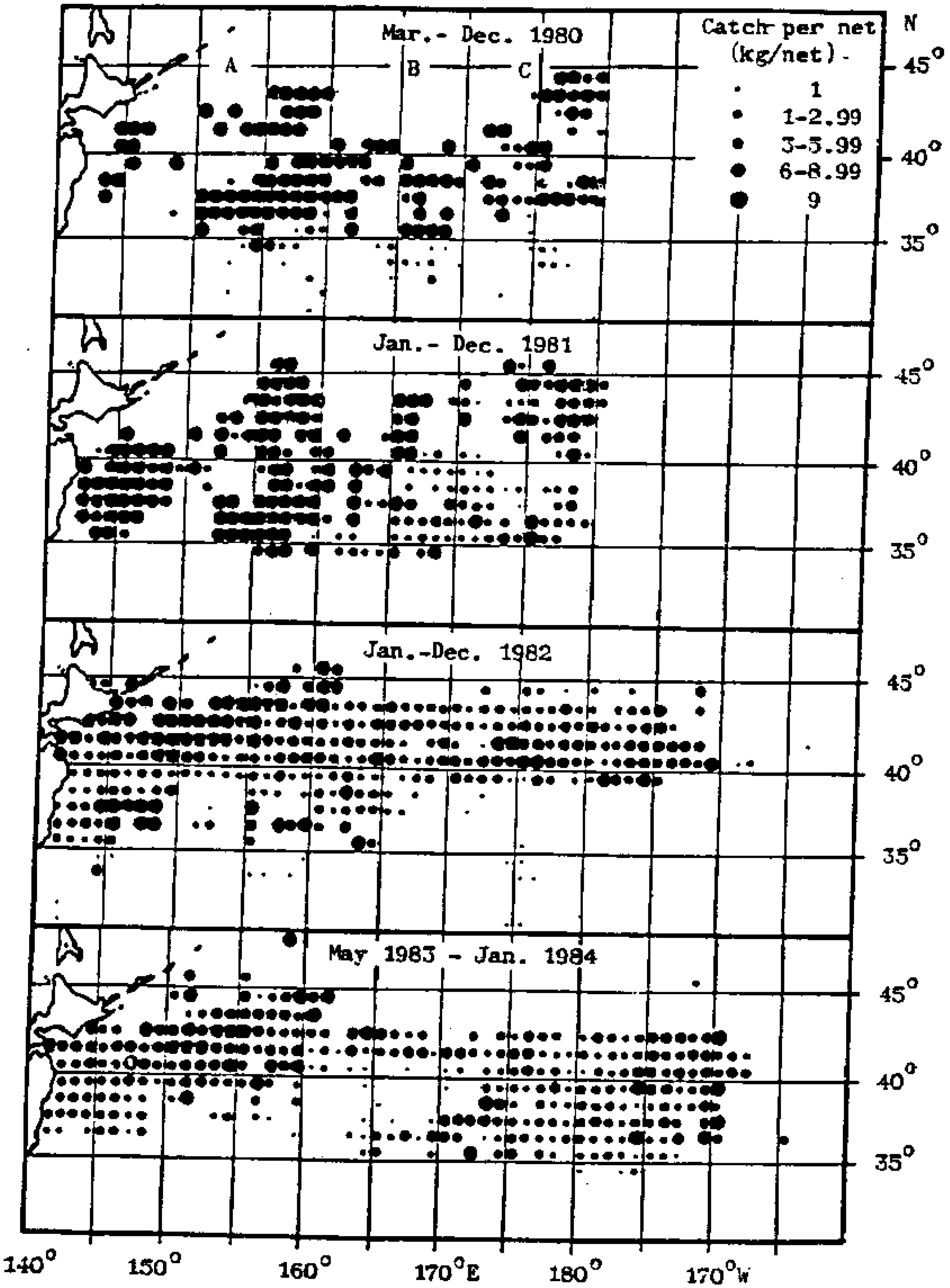

Figure 2.--Annual flying squid catch per unit net (kilograms per net) plotted by 1° squares in the Korean gill net fishery in the North Pacific from 1980 to 1983.

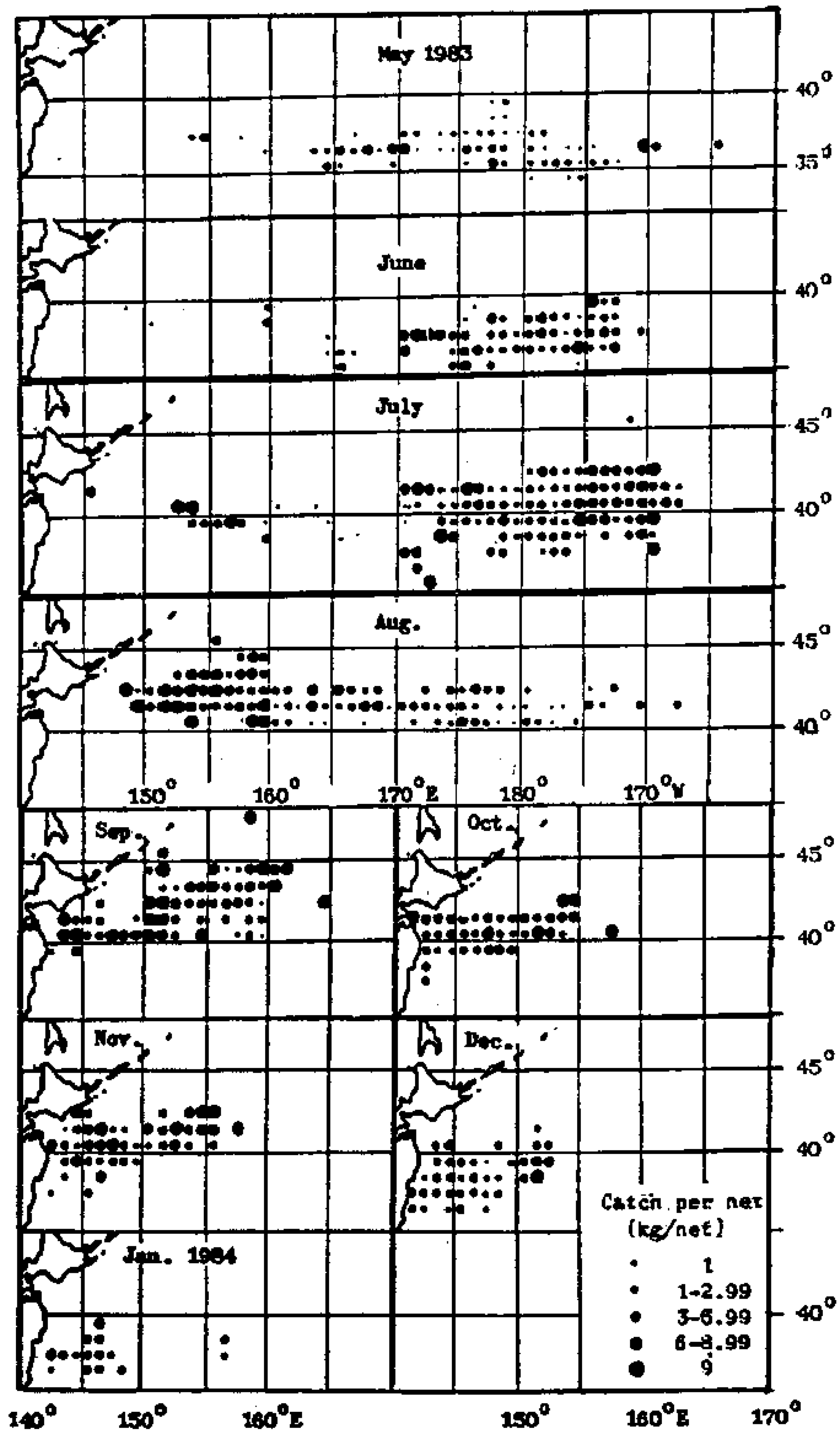

Figure 3.—Monthly flying squid catch per unit net (kilograms per net) plotted by 1° square in the Korean gill net fishery in the North Pacific from May 1983 to January 1984.

Monthly catches by 1° of longitude in the 1983 season are shown in Figure 4. In June and July the peak catch was located in the area east of long. 170°E, and the peak showed the trend gradually shifting westward from August to December except for November.

Monthly CPUE by 1° of longitude in the 1983 season is shown in Figure 5. In May CPUE's were high in the region along long. 170°W. In June and July CPUE's were quite high in the region along long. 170°E. In August, CPUE's were high in the region west of long. 160°E. From September through November high CPUE's were found in the area around long. 155°-165°E. Through the whole fishing season the area west of long. 160°E had slightly higher CPUE's than the area east of long. 160°E. However, there were no significant differences by area in distribution of CPUE's than there were in distribution of catches.

Catches Relative to Surface Thermal Structure

Monthly changes in frequency of catch of flying squid and surface temperature at the locations where Korean gill net vessels operated in the North Pacific are shown in Figure 6. The range of surface temperatures for commercial fishing of squid was 9°-22°C. The water temperature for the best fishing ranged from 15° to 16°C in May through July and from 13° to 18°C in August through January. The higher densities of flying squid were found in thermal fronts along the 18°C isotherm in August and the 15°C isotherm in September (Fig. 7).

Mantle Length Compositions of Flying Squid

Monthly DML measurements (sexes combined) in the 1983 season (Table 3) indicate four size groups in the catches: small (<25 cm), medium (27-32 cm), large (35-39 cm), and extra large (>40 cm). The dominant modes were at 38-39 cm in region C east of long. 170°E from June to July, and at 30-31 cm in region A west of long. 140°E from September to December.

The monthly frequency distributions of DML (Fig. 8a) indicate that in June large squid were present in the area south of lat. 39°N and medium-sized squid in the area north of lat. 39°N. From July to September large squid were found in the northern area while small squid were in the southern area. Large squid with modal lengths of 40 cm were found at lat. 41°-43°N in October and lat. 39°-40°N in November. The proportion of large squid decreased in the area south of lat. 38°N in December.

Frequency distributions of flying squid by 5° of longitude in the 1983 season are shown in Figure 8b. Generally, large squid occurred more commonly in the eastern areas from May to October, whereas medium-sized squid were more commonly found in the western region from November to December.

DISCUSSION

Exploitation of Flying Squid and Fishing Methods

Flying squid have been caught in the North Pacific in the Japanese squid jigging fishery since 1974 and in the drift gill net fishery since

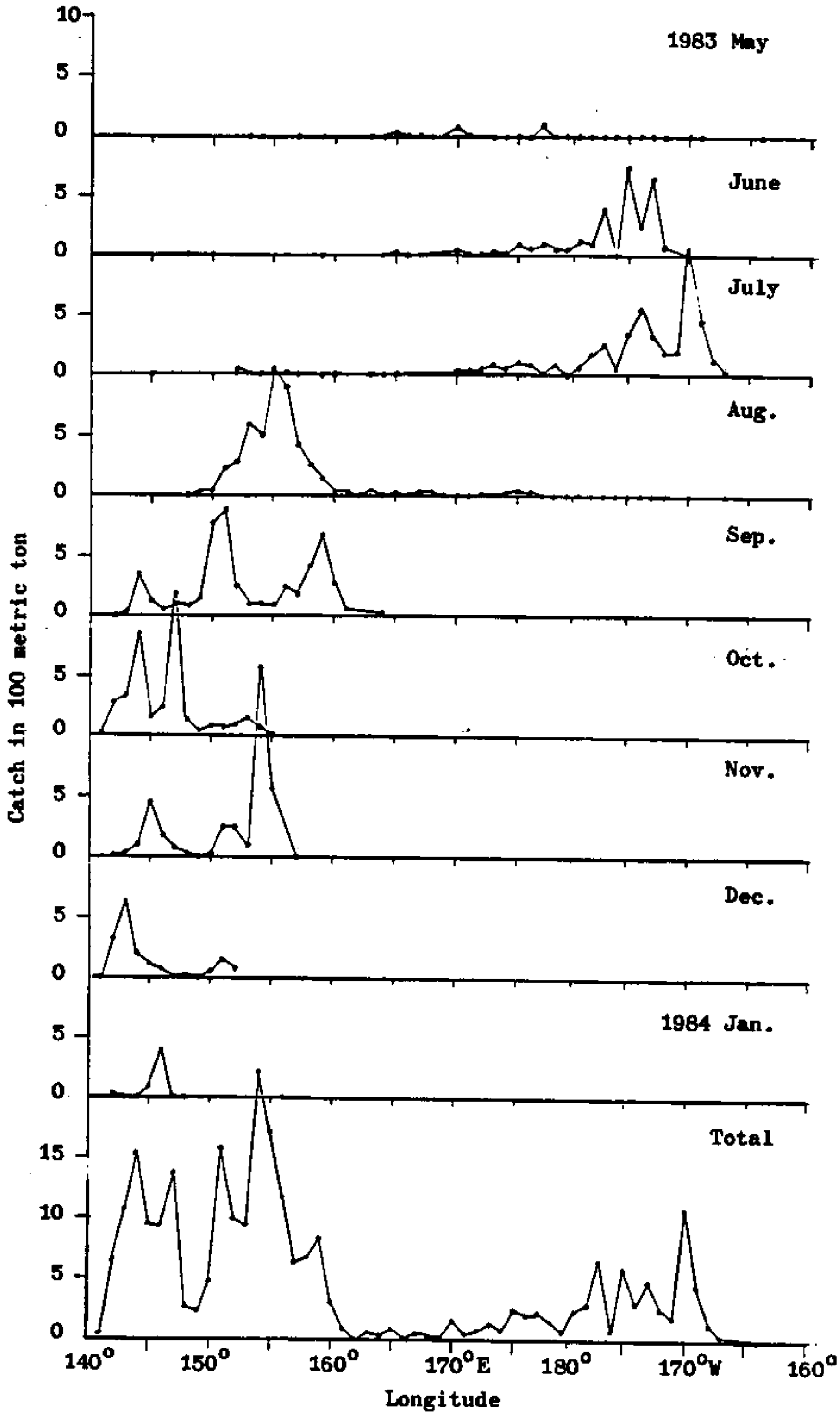

Figure 4.--Catch of flying squid by 1° of longitude in the Korean flying squid gill net fishery in the North Pacific, May 1983 to January 1984.

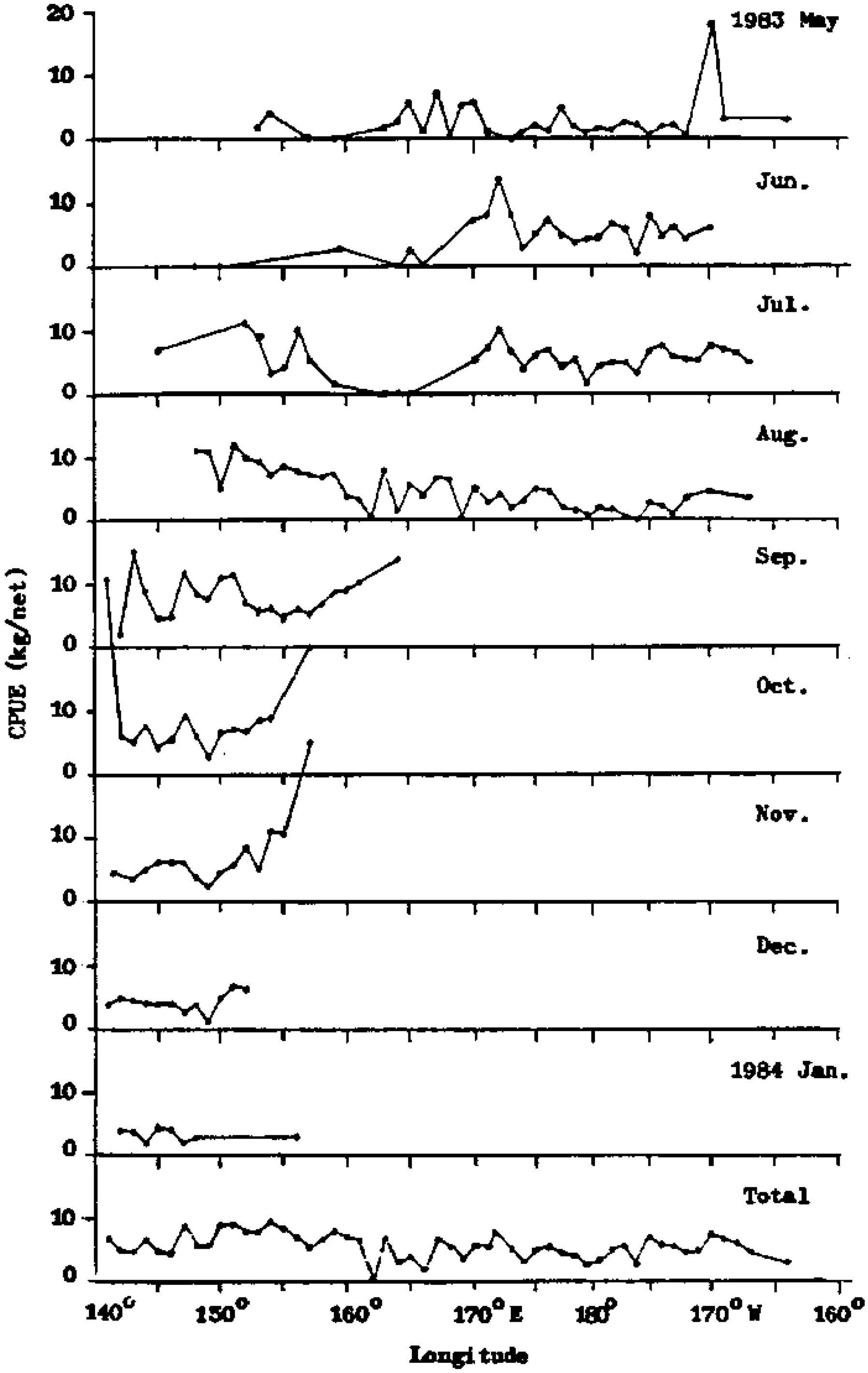

Figure 5.--Catch per unit effort of flying squid by 1° of longitude in the Korean gill net fishery in the North Pacific, May 1983 to January 1984.

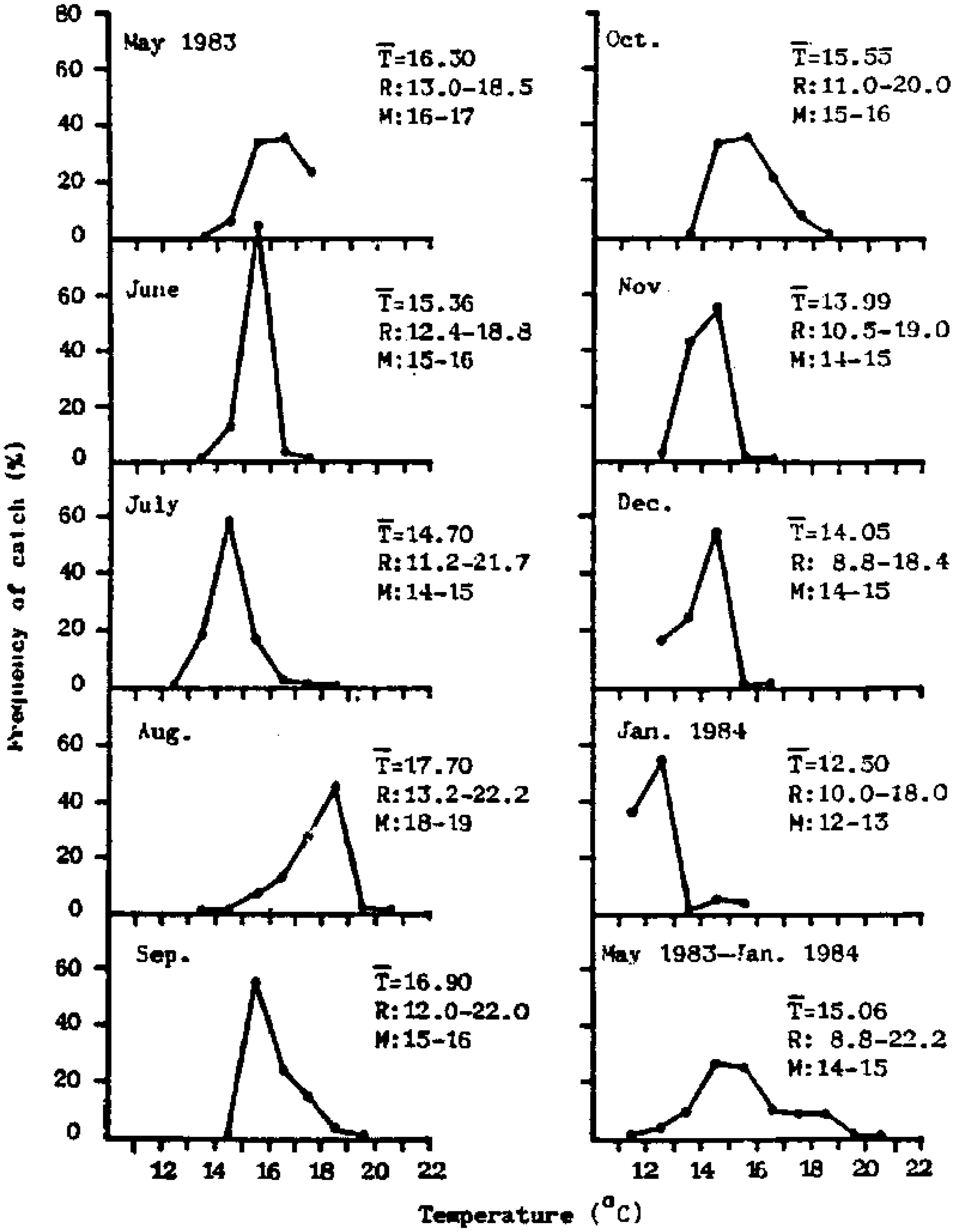

Figure 6.—Monthly plots of frequency of catches and surface water temperatures (°C) in the Korean gill net squid fishery, May 1983 to January 1984 (T = weighted mean temperature (°C); R = temperature range; M = mode).

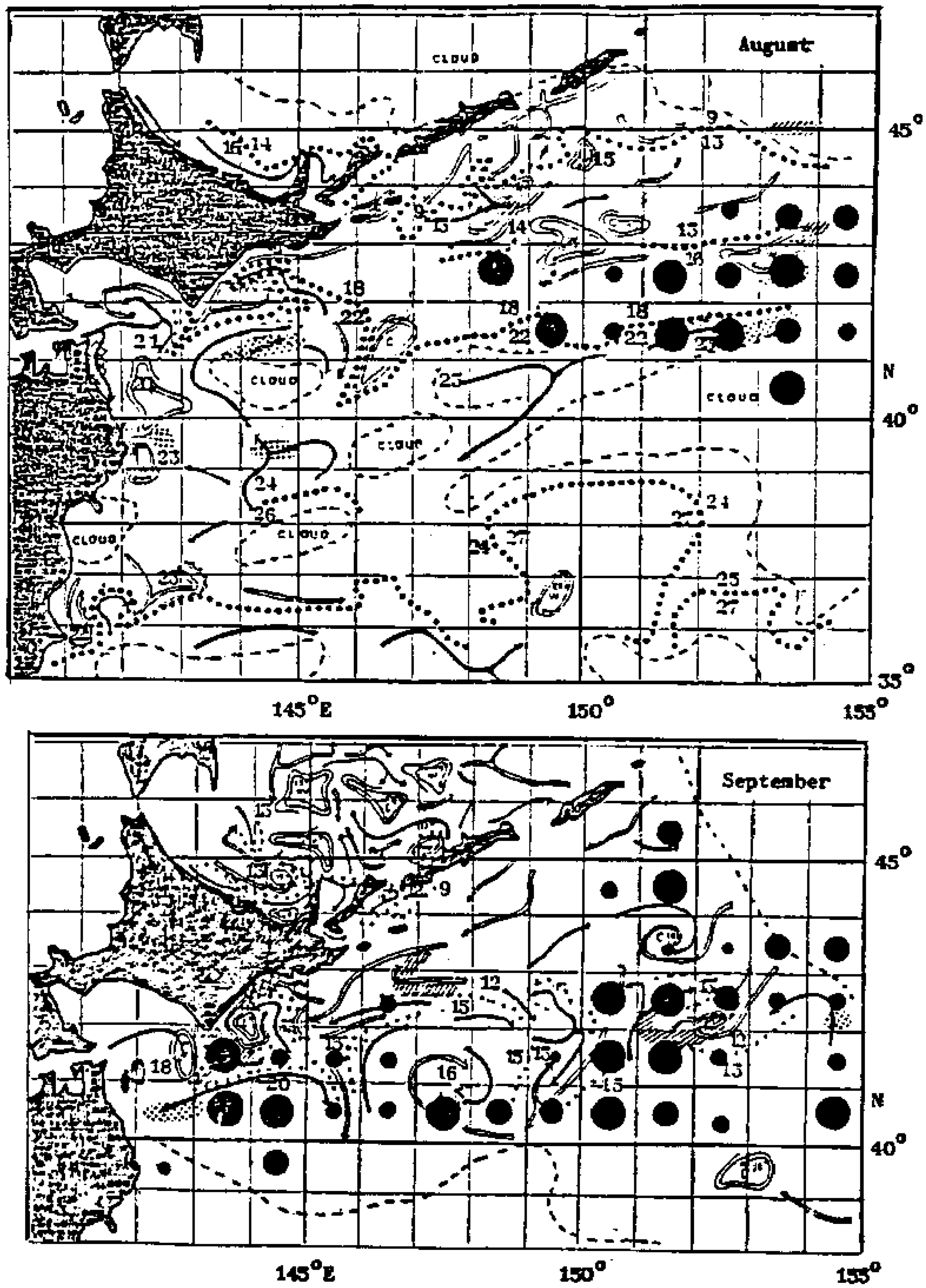

Figure 7.--Surface thermal structure based on infrared imagery from meteorological satellites of the National Oceanic and Atmospheric Administration and the catch per unit net of flying squid by statistical block (1° of latitude by 1° of longitude) from the Korean gill net fishery in the northwestern Pacific in August and September 1983. Thermal structure traced from Japan Fisheries Information Service Center (1983). Dark circle denotes catch per unit net. Small dotted lines denote the thermal fronts. Figures denote temperature in degrees Celsius.

Table 3.—Monthly modes of dorsal mantle lengths of both sexes of flying squid from the Korean gill net fishery in the North Pacific 1983 fishing season (S = small; M = medium; L = large; LL = extra large squids).

Month/ year	No. of samples	Modal length (cm)[1]							Main fishing area[2]
		S	M		L		LL		
May 1983	143	25	29	32	35	38	11	--	B,C
June	638	--	28	32	--	39	--	--	C
July	698	--	--	32	--	38-39	12	--	C
Aug.	639	25	--	32	35	--	40	--	A,B,C
Sept.	635	--	--	30	36	--	--	--	A
Oct.	718	25	--	30	35	--	40	--	A
Nov.	590	--	29	31	--	39	--	--	A
Dec.	569	--	--	31	35	--	40	--	A
Jan. 1984	217	22	27	31	--	--	43-45	49	A
Modes	4,847								

[1]A = west of long. 160°E; B = long. 160°-170°E; C = east of long. 170°E.

[2]Numbers underlined indicate the most dominant mode.

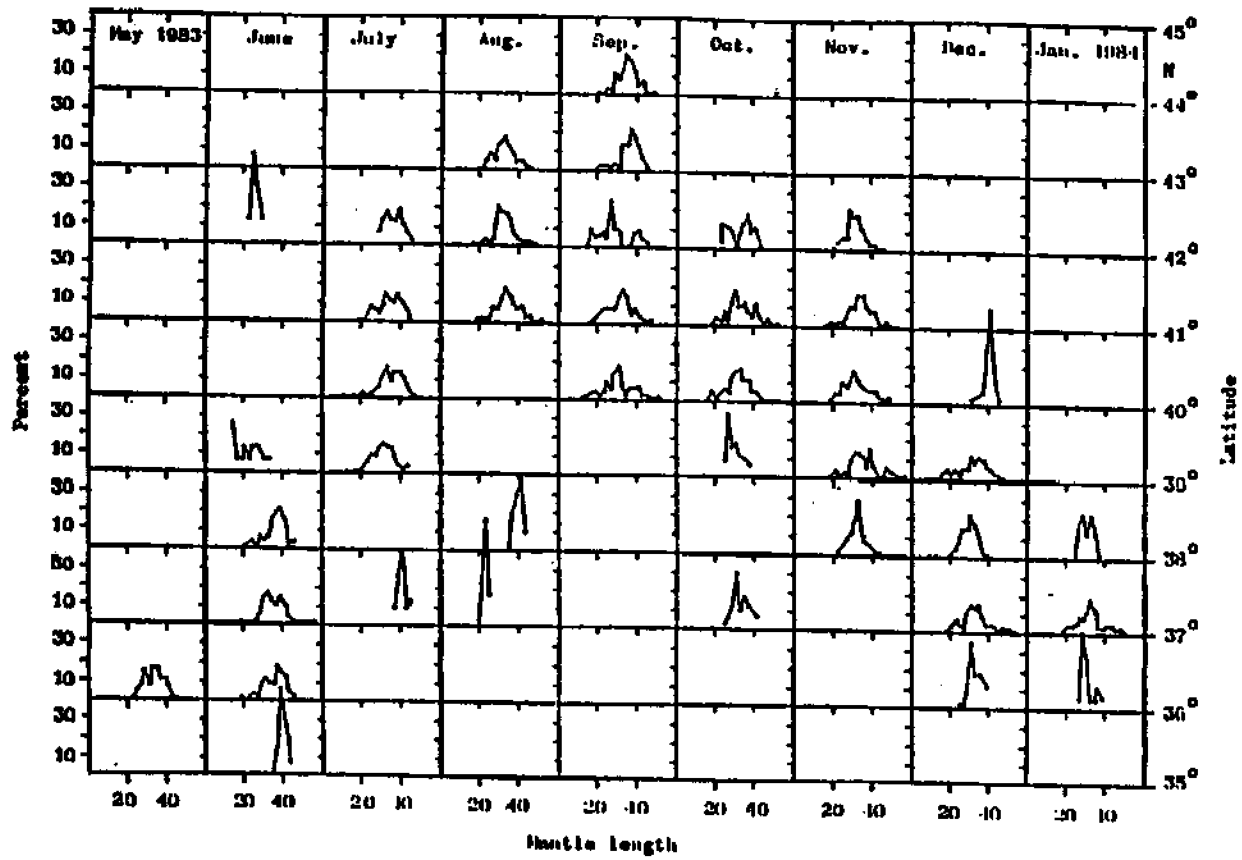

Figure 8a.--Monthly mantle length-frequency distributions of flying squid taken in the North Pacific Korean gill net fishery, May 1983 to January 1984, plotted in 1° of latitude.

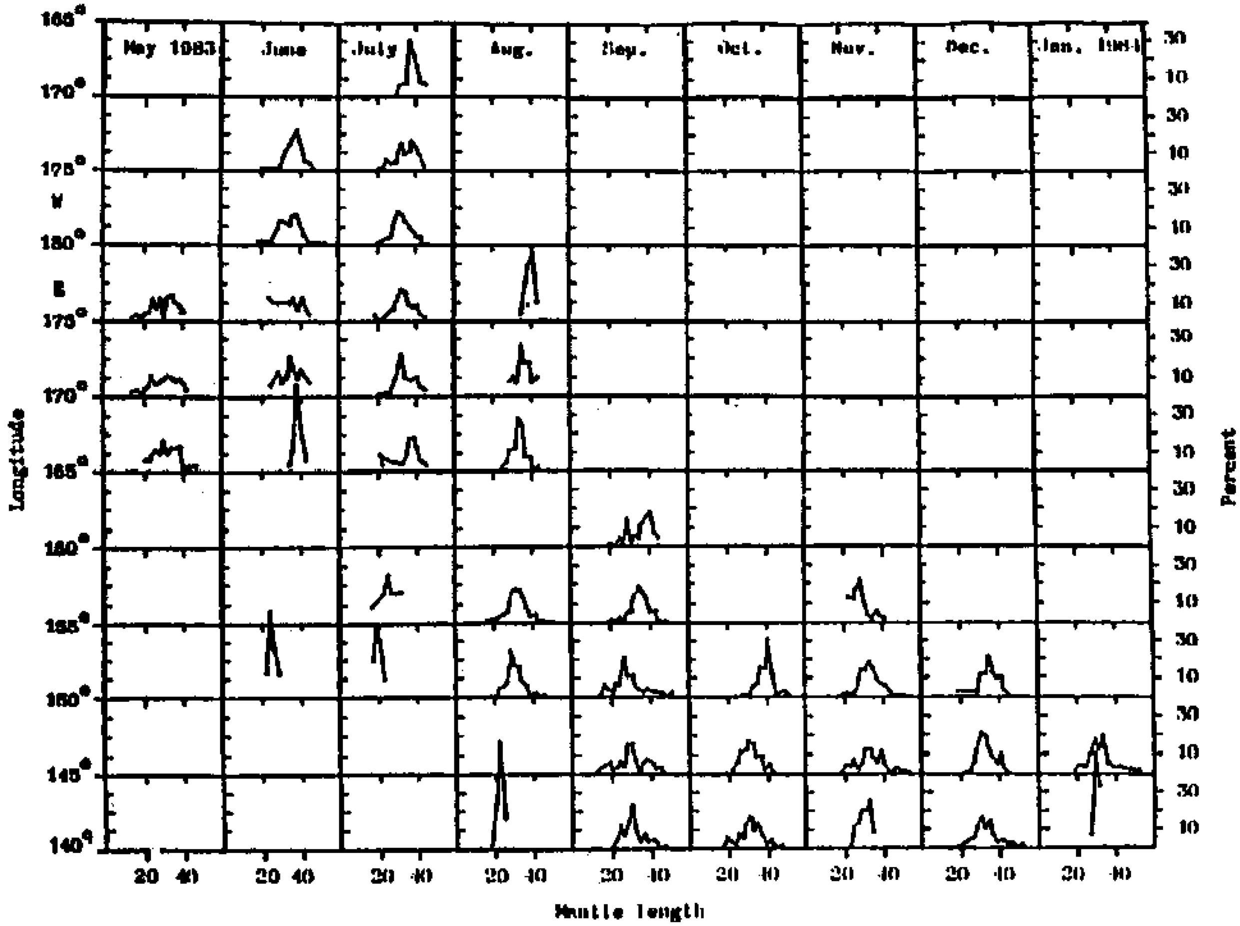

Figure 8b.--Monthly mantle length-frequency distributions of flying squid taken in the North Pacific Korean gill net fishery, May 1983 to January 1984, plotted in 5° of latitude.

1978 (Akabane et al. 1979; Kubota and Yasui 1980; Murata et al. 1980, 1981, 1982, 1983a, 1983b, 1984; Suisan Sekai 1982; Ogura 1984). With the decline of the stock of Todarodes pacificus in the Sea of Japan and with the economic difficulties in the tuna longline fishery, Korean gill net vessels, mostly converted tuna longliners, have increasingly shifted their efforts to the exploitation of flying squid in the North Pacific. Since 1982 catch and effort levels for this species have gone well beyond the exploratory stage. The catch of 54 monitored vessels was 27,131 MT in 1983 (Table 2). Projecting this catch for the 99 vessels registered for fishing in 1983 would yield a total of about 48,000 MT for the season.

The Korean gill net fishing grounds have extended eastward each year since 1979 and reached as far east as long. 161°W in 1983 (Fig. 2). The fishing season lasted about 9 months from May through January with peak catches occurring from July to November (Gong et al. 1984). As shown in the monthly distribution of CPUE, the center of the Korean gill net fishing grounds tended to move from east to west in succeeding months during the 1983 fishing season (Fig. 3).

Korean vessels usually began fishing at 1500 or 1600 with the setting of the nets. Setting was done at vessel speeds of 5 or 6 knots and was usually completed in 2 or 3 h. Net hauling began at 0200 or 0300, after 7 or 8 h of soaking, and was completed in about 8 h. Each set consisted of about 200-250 nets of varied mesh size in summer and 150 or 200 nets in winter. During the 1983 season the number of gill nets used averaged 540 per vessel per day.

Life History of Flying Squid

Ommastrephes bartrami has transoceanic distribution in the subtropical and temperate region of the North Pacific Ocean from Japan to North America (Young 1972; Okutani 1973; Naito et al. 1977a, 1977b; Baba and Akabane 1980; Murata et al. 1981, 1983b; Murakami et al. 1981; Ogura 1984). Recently it was reported that this species also occurred in the eastern Sea of Japan (Kasahara 1984; Sato et al. 1984).

Based on geographically separated spawning grounds, some authors (Baba and Akabane 1980; Murata et al. 1980, 1981, 1982) divide the flying squid into two groups: the northwestern Pacific (west of long. 170°E) and the central North Pacific. However, it is difficult to separate the population into two groups because the CPUE is rather high around long. 170°E based on the Korean gill net fishery.

The spawning season of the flying squid extends from January to May, and it has been reported that spawning occurs in Kuroshio waters south of lat. 35°N and west of 155°E. Considering the broad area of the Korean gill net fishery in winter and spring (Figs. 2, 3), it appears that the spawning grounds of flying squid would extend farther eastward in the central North Pacific.

The flying squid is known to undergo wide migrations. Baba and Akabane (1980) show that the species migrates northward early in the season and turns westward in the fall. It is possible to distinguish fast-growing and slow-growing groups. The former occurs earlier in the northern area than the latter (Murakami 1976; Murata and Ishii 1977; Roper et al. 1984). Naito et al. (1977b) and Murakami et al. (1981) reported that large squid always appear ahead of small squid during both the northward and southward migrations and that large squid are distributed farther offshore than small squid.

The monthly mantle length compositions from Korean catches show that large squid appear in the northern area earlier and are distributed farther eastward than small squid (Fig. 8a, 8b). However, it is noted that this is not always true.

Ishii (1977), Murata and Ishii (1977), and Tamura and Nakata (1983) believe that the flying squid spawns from late autumn to winter and the lifespan is 1 year. However, Murakami et al. (1981) and Kubodera et al. (1983) stated that large squid over 40 cm are 2-year olds.

Oceanographic Structure and Density Distribution of Flying Squid

There are many reports on water temperature in the northwestern Pacific flying squid fishing grounds (Murata and Araya 1970; Murakami 1976; Murata et al. 1976, 1980, 1983a, 1983b, 1984; Naito et al. 1977a, 1977b; Kubodera et al. 1983; Amano et al. 1984). However, none of these relate oceanographic conditions to fishery data. Kawakami (1983) reviewed the temperature range and optimum temperatures for squid fishing in the Kuril Front region. According to his report the range of water temperatures in which flying squid were caught throughout the fishing season in the North Pacific was 6°-24°C, and the higher catches were in 15°-20°C water. Kubodera et al. (1983) reported that seasonal changes in distribution and abundance of <u>Ommastrephes bartrami</u> appeared to be closely correlated with surface water temperature. Sea surface temperatures in the Korean drift gill net fishing grounds west of long. 161°W ranged from 9° to 22°C, and the most favorable temperature for flying squid fishing was 15°C (Fig. 6).

Kubodera et al. (1983) indicated that the thermal front and salinity front in the Subarctic Boundary Zone could be barriers to flying squid in the northward migration. The northern limit of the Korean flying squid gill net fishing ground reached the Subarctic Domain in autumn. The horizontal gradients of temperature and salinity in the Subarctic Boundary were higher in the west than the east (Muromtsev 1958; Dodimead et al. 1963; Favorite et al. 1976). It is easy to understand why the density of flying squid would be higher in the west than the east based on oceanographic features.

Migration Model of Flying Squid in the North Pacific

A migration model for flying squid is hypothesized based on the monthly distribution of abundance indices, monthly mantle length compositions by statistical block, and the hydrographic features of the North Pacific (Fig. 9).

As shown above from the horizontal distribution of oceanographic characteristics, the oceanic structure of the North Pacific is divided into

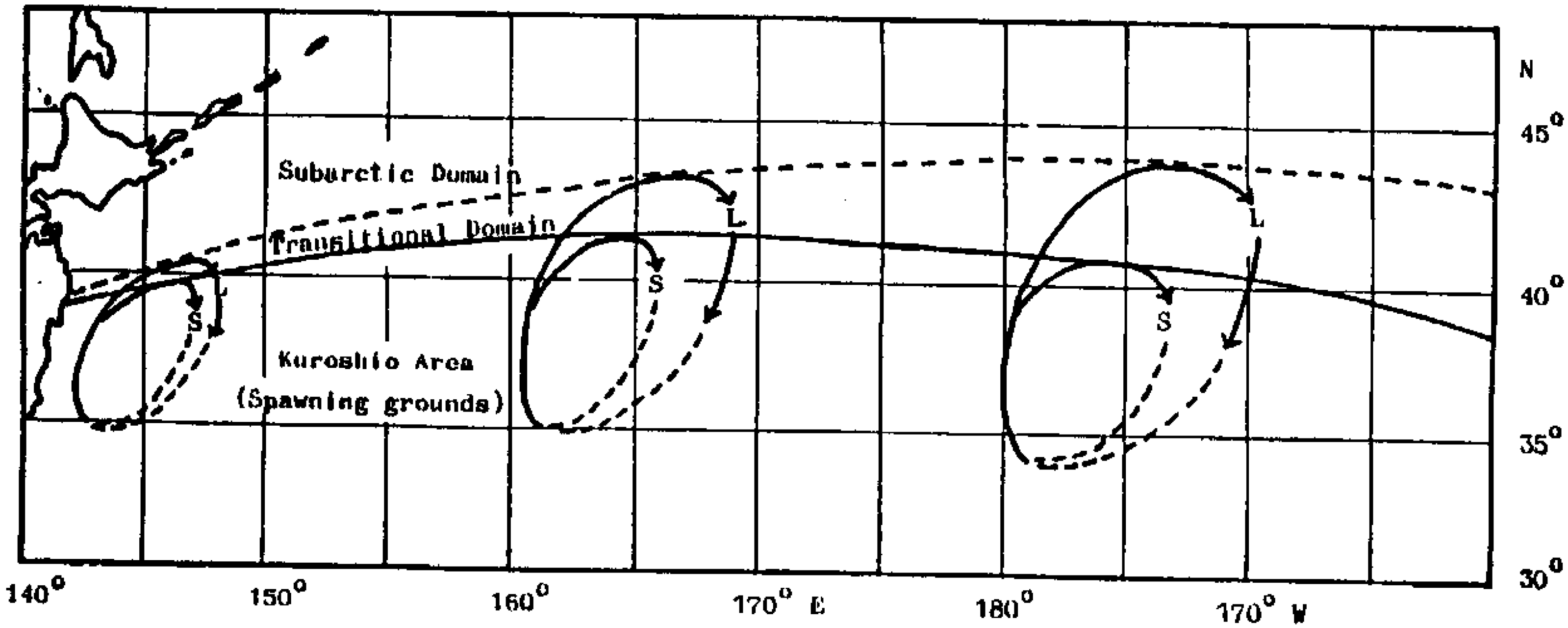

Figure 9.--Hypothetical migration routes by size groups of flying squid in the North Pacific. Full line denotes the Subarctic Boundary and dashed line the salinity front. L denotes the large sized group and S the small sized group of flying squid. Dashed lines in the migration circuit indicate the period of southward migration at the subsurface layer.

three different waters. The farther westward, the narrower the Transitional Domain and the higher the horizontal gradient of oceanographic characteristics. Based on monthly mantle length composition of flying squid captured by the Korean gill-netters, by grids of 1° of latitude by 5° of longitude, groups of large flying squid occurred more frequently in the northern and eastern areas of the fishing grounds. Naito et al. (1977a) indicated that the larger squid migrate faster and move ahead of the smaller squid during the northward and southward migration periods. In the beginning of the migration all groups start to migrate at the same time. However, the group of large squid starts to move southward from the north while the group of small squid starts to move from the south. In the fishing grounds, the larger squid move ahead of the smaller squid during the southward migration period. Accordingly, the group of large squid group does not always move ahead of the group of small squid everywhere in the North Pacific.

The flying squid which are spawned south of the Subarctic Boundary in winter carry out a northward migration in the warmwater system of the Kuroshio and grow relatively fast in spring and summer. The first born and faster growing squid of the large group enter the Transitional Domain after passing the thermal front in the Subarctic Boundary, but they are prevented from migrating farther north by the salinity front between the Transitional and Subarctic Domain. On the other hand the slow growing squid of the small group become concentrated in the thermal front. They begin the reverse southward migration in autumn with the onset of cooling and the development of the Oyashio. The large group start to return from the northern area and the small group from a more southern area, but the former reach the spawning ground earlier because they move ahead of the small group during the migration. The density of flying squid in the northwestern area is higher than that in the central North Pacific area because the gradient of oceanographic properties in the west is higher than in the east. Distances between oceanographic boundaries are narrower and the size of migration circuits smaller in the northwest than in the central areas as shown by the migration model (Fig. 9).

The general pattern of movement and migration of flying squid is clockwise in the North Pacific. However, the monthly movement of the center of the Korean drift gill net fishing grounds was counterclockwise.

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NET LOSS FROM TRAWL FISHERIES OFF ALASKA

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ABSTRACT

The most dominant fisheries off Alaska in terms of geographical extent, seasonal duration, and volume of catch is the trawl fishery for groundfish. This fishery began in earnest in 1954, mainly by foreign nations which now number seven, and only recently has been joined by domestic trawlers. The number of foreign trawlers increased rapidly to more than 400 vessels by 1963 and fluctuated around 300 vessels until 1975. Since then, the number of foreign vessels has decreased gradually. Domestic trawlers have remained small by comparison in numbers and physical size. However, expansion of the domestic trawl fleet has been rapid, from just a few vessels in 1979 to 93 in 1984. The total fleet size has, therefore, remained above 300 vessels. This paper traces the progression of these trawl fisheries by two regions--the Bering Sea-Aleutians region and the Gulf of Alaska region. Estimates are made of the number of boats and fishing effort. Effort is measured by number of vessel-months of operation. Since these trawling activities contribute to entanglement of marine mammals in active fishing gear as well as passive lost or discarded gear, the extent of net loss as a source of marine debris is estimated. These estimates are derived from data collected by the Foreign Fisheries Observer Program.

INTRODUCTION

Since the early 1960's, northern fur seal, Callorhinus ursinus, on the Pribilof Islands have been observed entangled in pieces of debris. Presumably this occurs as a result of encounters at sea with floating materials and the animals' behavioral attraction to this debris (Fiscus and Kozloff 1972). Studies have shown that a large portion of the animals was entangled in net debris, much of which was trawl net fragments (Fowler 1982). It was also noted that the animals are caught in large trawl net debris and that the large net fragments presented more mesh openings in which seals could become entangled.

The increased observations of entangled fur seals coincided with a period of rapid development of a large trawl fishery in the northeast

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

Pacific, particularly in the eastern Bering Sea. This fishery is now the most dominant off Alaska in terms of geographical extent, length of fishing season, amount of fishing effort, and volume of catch.

Since lost or discarded gear and other debris from the trawl fishery may contribute significantly to the entanglement of fur seals and possibly other marine mammals, it is the purpose of this paper to review the nature and extent of the trawl fishery and estimate the amount of gear that may have been lost or discarded.

HISTORY AND PROGRESSION OF FISHERIES

Historically the trawl fishery off Alaska has been predominantly foreign in origin. Japanese trawlers operated in the eastern Bering Sea during 1933-37 and 1940-41, but the major development of the foreign trawl fishery did not begin until 1954. The chronology of this development is outlined below:

1933 First commercial operations for flatfish by Japanese trawlers in the eastern Bering Sea for fish meal following explorations in 1929. The fishery was discontinued in 1937 (Fig. 1).

1940 Japan reentered the fishery with a mother ship fleet of 9 to 12 catcher vessels. Catches were mainly frozen for food. The fishery was interrupted by the second World War and terminated in 1941.

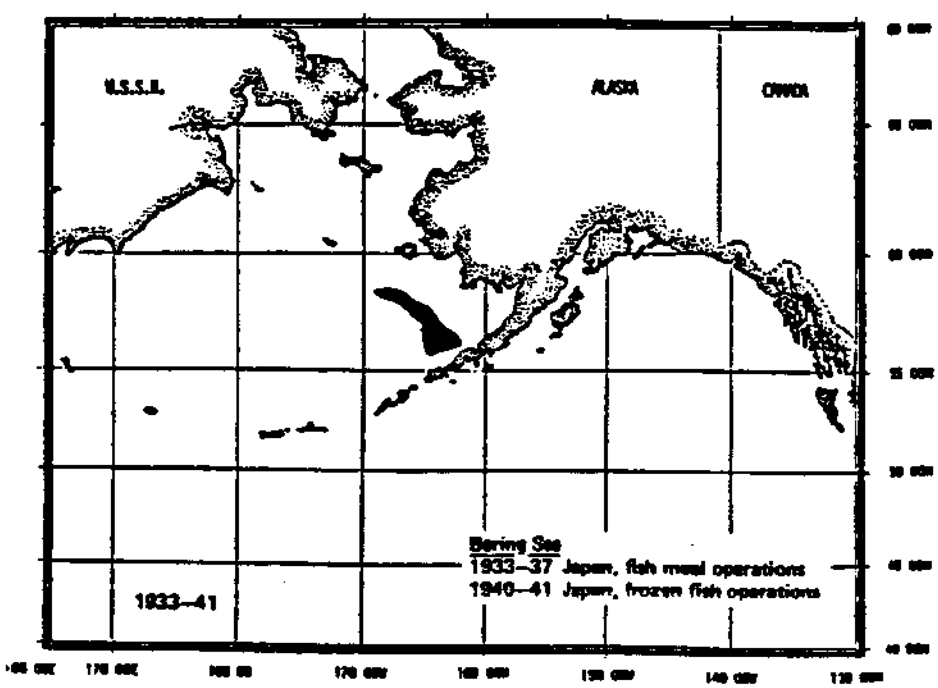

Figure 1.--Principal fishing grounds off Alaska, 1933-37 and 1940-41.

1954 Japan reentered groundfish fisheries on the eastern Bering Sea flats (Fig. 2). Flatfishes were the target species for processing into fish meal. Yellowfin sole, Limanda aspera, was the principal target species.

1959 The U.S.S.R. fishing fleets moved into the eastern Bering Sea after successful exploratory surveys in 1954 and 1958.

1961 Total catches of flatfish peaked near 610,000 metric tons (MT); yellowfin sole was apparently overharvested. Exploratory vessels were sent into the Gulf of Alaska by Japan.

1962 The U.S.S.R. started commercial operations in the Gulf of Alaska.

1963 Japan followed the example set by U.S.S.R. and moved some independent stern trawlers and longline vessels into the Gulf of Alaska which fished west of Kodiak Island.

1965 Fishing operations by Japan moved farther eastward and southward in the Gulf of Alaska.

1966 Fishing vessels of Japan and the U.S.S.R. operated along much of the North American coastline (Chitwood 1969, Fig. 3). Principal species harvested in the Gulf of Alaska were Pacific ocean

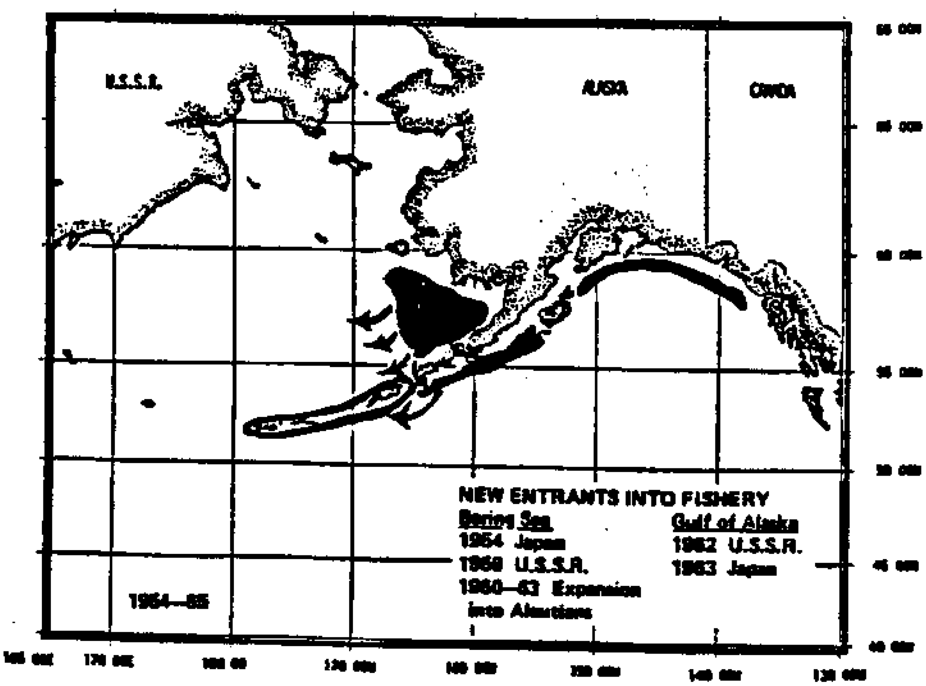

Figure 2.--Principal fishing grounds for flatfishes in the Bering Sea (1954-59) and expansion into the Gulf of Alaska (1962-65).

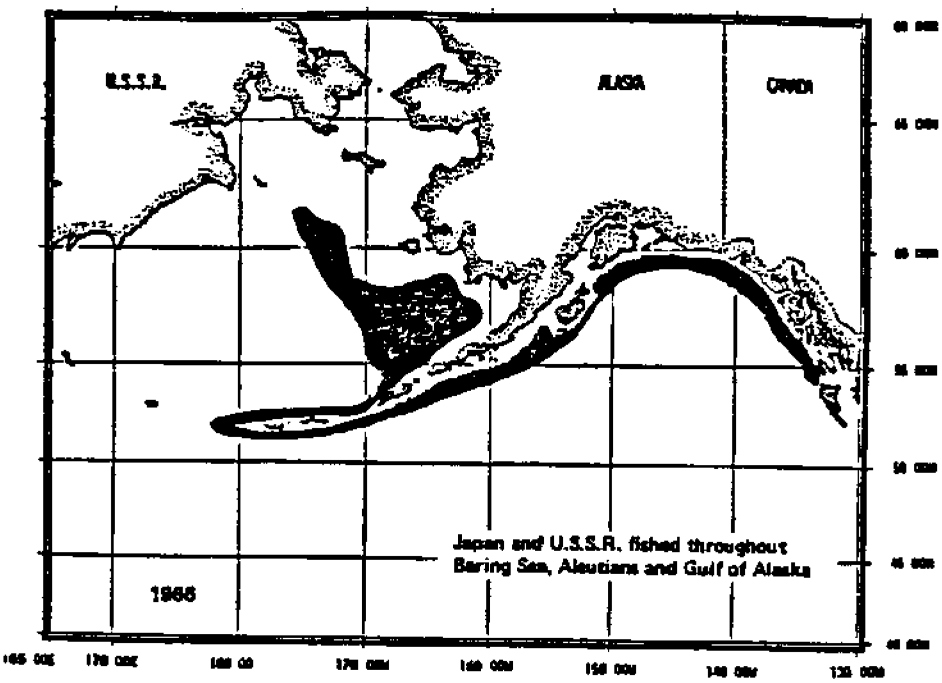

Figure 3.--Principal fishing grounds by vessels from Japan and the U.S.S.R., in the Bering Sea, Aleutians, and Gulf of Alaska in 1966.

perch, Sebastes alutus, and sablefish, Anoplopoma fimbria. In the Bering Sea, the abundance of yellowfin sole has been substantially reduced, Pacific ocean perch was being rapidly depleted, and walleye pollock, Theragra chalcogramma, became the prime target species as a result of introduction of automated "minced meat" processing operations aboard vessels.

1968 Trawlers from the Republic of Korea moved into the eastern Bering Sea (Fig. 4).

1974 Taiwan stern trawler initiated operations on groundfish in the eastern Bering Sea in December and a longliner fished in the Gulf of Alaska in 1975. A large stern trawler from the People's Polish Republic (Poland) entered the eastern Gulf of Alaska and targeted on Pacific cod, Gadus macrocephalus.

1977 The Magnuson Fishery Conservation and Management Act (Magnuson Act) was implemented which extended U.S. management jurisdiction over the fisheries resources within 200 miles of its coastline.

1978 First joint venture operation started in the Gulf of Alaska.

1979 Poland extended its fishery into the eastern Bering Sea. Mexico sent three stern trawlers to fish in the western Gulf of Alaska, but their fishery was discontinued after a short season. Regulations were enacted under the Magnuson Act to exclude foreign trawling from southeast Alaska.

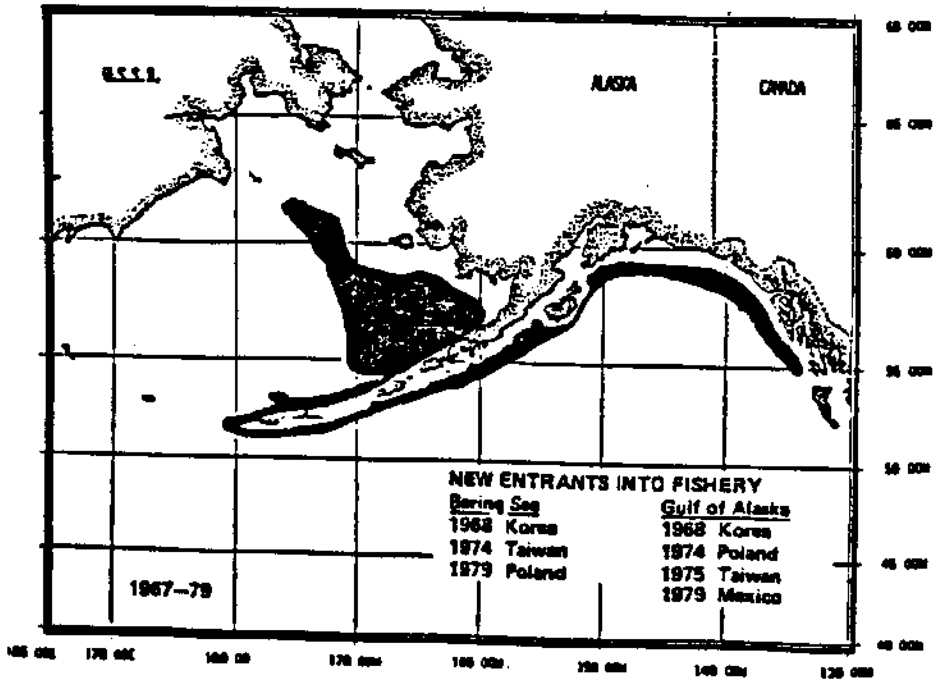

Figure 4.--Areas of groundfish fisheries off Alaska, by Japanese and U.S.S.R. vessels and those from new entrants into the fishery (Republic of Korea, Taiwan, Poland, and Mexico), in 1967-79.

1980 Joint venture fisheries started in the eastern Bering Sea and Aleutian Islands region and domestic trawling operations increased and expanded into the eastern Bering Sea, primarily for Pacific cod (Fig. 5). The U.S.S.R. was excluded from conducting a directed fishery off Alaska under regulations promulgated by the Magnuson Act. However, Soviet joint venture with United States vessels for yellowfin sole in the eastern Bering Sea and other species in the Gulf of Alaska were allowed to continue. A West German stern trawler entered into joint venture fisheries with United States vessels in the eastern Bering Sea, and this vessel was also allowed some directed fishing. As domestic fisheries developed after 1980, quotas for foreign fleets were reduced, resulting in lower fishing effort.

1982 Poland was denied permits to fish off Alaska.

1983 Taiwan did not conduct a directed fishery for groundfish but participated in joint venture operations.

1984 Joint venture and domestic fisheries had increased dramatically and were rapidly replacing foreign fishing effort. Joint ventures were conducted with processing vessels from eight countries (U.S.S.R., Republic of Korea, Japan, Taiwan, West Germany, Poland, Portugal, and Spain). Portugal entered trawl fishery in Bering Sea. The U.S.S.R. and Poland resumed trawl fisheries.

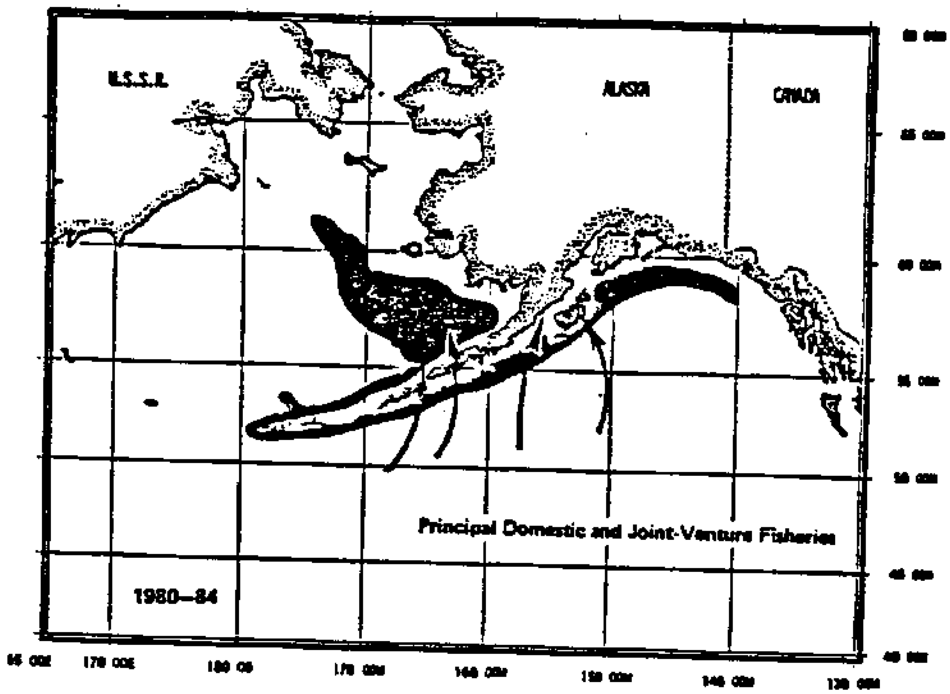

Figure 5.--Areas of U.S. domestic and joint venture trawl fisheries off Alaska in 1980-84.

In summary, eight foreign countries (besides Canada) have participated in the trawl fisheries off Alaska. Japan has had the longest history of fishing in the region and has mounted the greatest effort over the years. The U.S.S.R. had the second largest fishery until it was denied direct fishing privileges in 1980. The second position was then taken over by the Republic of Korea. The fishing effort of the remaining countries (Taiwan, Poland, West Germany, Portugal, and Mexico) was small by comparison and amounted to <5% of the total effort. Mexico no longer participates in the fishery after fishing only one short season in 1979.

MAGNITUDE OF CATCHES

Yellowfin sole in the eastern Bering Sea was the species that stimulated the development of Japanese and Soviet fisheries in 1954 and 1959, respectively. Catches of yellowfin sole peaked at 610,000 MT in 1961 and declined thereafter, due to overfishing (Bakkala et al. 1979). Total groundfish catches off Alaska, consisting mainly of yellowfin sole, peaked at about 680,000 MT during 1954-63 (Table 1, Fig. 6). More than 95% of the catches came from the eastern Bering Sea during this period.

As yellowfin sole declined in abundance, the fisheries began to target on Pacific ocean perch in the Aleutians, on the eastern Bering Sea, the continental slope, and the Gulf of Alaska. Catches increased from 1963 to 1966, but the resource was not large and was soon depleted. As the fishery for Pacific ocean perch shifted to the Gulf of Alaska during this period, the eastern Bering Sea component of the total catch off Alaska dropped to about 55-65%.

Table 1.--Total groundfish catches off Alaska and distribution between the Bering Sea-Aleutians region and Gulf of Alaska, 1960-83.

Year	Total catch (1,000 MT)	Percent distribution	
		Bering Sea-Aleutians	Gulf of Alaska
1954	13	100.0	0
1955	15	100.0	0
1956	25	99.4	0.6
1957	24	99.7	0.3
1958	51	99.9	0.1
1959	222	99.9	0.1
1960	538	99.9	0.1
1961	682	99.9	0.1
1962	607	99.9	0.1
1963	331	96.8	3.2
1964	759	67.3	32.7
1965	858	54.2	45.8
1966	684	75.4	24.6
1967	1,066	86.8	13.2
1968	1,202	88.0	12.0
1969	1,372	91.5	8.5
1970	1,804	94.7	5.3
1971	2,311	94.7	5.3
1972	2,515	92.8	7.2
1973	2,280	92.2	7.8
1974	2,180	91.2	8.8
1975	1,830	89.8	10.2
1976	1,752	90.3	9.7
1977	1,458	86.2	13.9
1978	1,573	89.3	10.7
1979	1,444	88.0	12.0
1980	1,585	86.0	14.0
1981	1,718	85.0	15.0
1982	1,697	86.0	14.0
1983	1,929	84.0	16.0

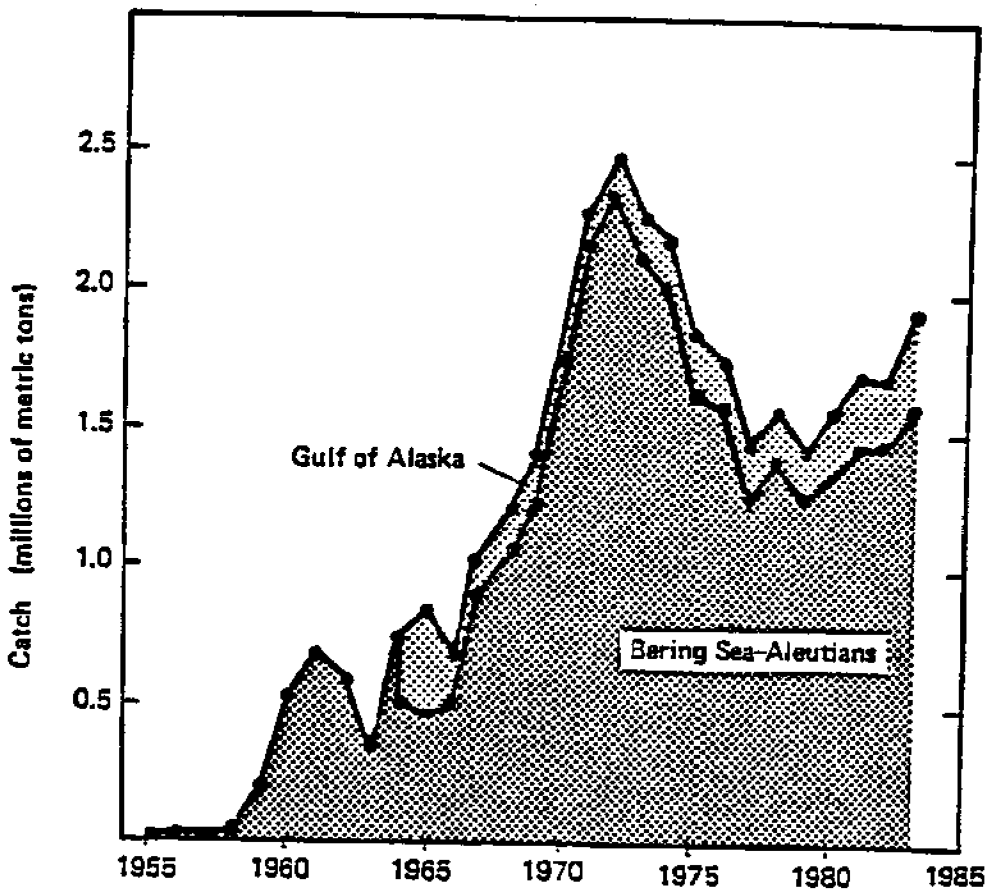

Figure 6.--Historical catches of groundfish off Alaska, 1954-83.

The groundfish catch increased dramatically again after the fisheries shifted to pollock as a target species beginning in 1964. The utilization of the abundant pollock resource became possible with the introduction of automated "surimi" (minced meat) operations aboard large fishing and mother ship vessels. Total groundfish catches peaked at 2.5 million MT 1972 and during the period from 1966 to 1977 pollock generally accounted for over 85% of the total catch. Since most of the pollock resource is concentrated in the eastern Bering Sea, the Bering Sea-Aleutians component of the catch gradually increased to over 85% of the catch off Alaska (Fig. 6).

In 1977, the Magnuson Act was implemented and catch levels became regulated. Catches were reduced from 1.8 million MT in 1976 to 1.5 million MT in 1977 as all the foreign fishing activities came under a common set of U.S. fishing regulations. Catches, however, increased again as conditions of groundfish resources in later years improved (Bakkala and Low 1984). In 1983, 1.6 million MT of groundfish were landed by the foreign and joint venture fishery.

VESSELS AND TRAWL GEAR

The trawl fisheries off Alaska use several types of vessels which can be divided into two main modes of operation: 1) mother ship fleet operations in which several small fishing boats deliver their catches to a mother ship for processing and 2) the independent trawler operations in which trawlers catch, process, and freeze their own catch. Functional descriptions of these vessels are given in Table 2 and their physical characteristics in Table 3. Comparative sizes of typical foreign and domestic vessels are illustrated in Figure 7. General descriptions of the vessels are provided by Chitwood (1969), Bakkala et al. (1979), and Nelson et al. (1981).

The mother ship fleets are composed of varying numbers of catcher boats (pair trawlers, Danish seiners, and stern trawlers); the size of an individual fleet is dependent upon the processing capacity of the mother ship. The catcher boats deliver their catches in detachable cod ends to the mother ship for processing. Small motor boats called "kawasaki" normally deliver the full cod ends to Japanese mother ships and return empty cod ends to the catcher boats. Recent U.S. joint venture operations, in which U.S. trawlers catch and deliver cod ends to foreign processor vessels, is another form of the mother ship fishery. The U.S. observers monitoring these joint venture operations have noted that cod ends full of fish have been lost during the transfer to the mother ship.

Typically, a Japanese mother ship is 175-m long and employs 6-20 catcher vessels varying in length from 27 to 51 m. Most of the mother ships are in excess of 10,000 gross registered tons (GRT), and the catcher boats from 200 to 500 GRT. The independent trawlers vary from the small (50 m, 350 GRT) class to the large catcher processors (110 m, 5,500 GRT).

Four fishing techniques have been employed in the groundfish fishery: pair trawling, Danish seining, side trawling, and stern trawling. Pair trawling is the primary technique employed by the catcher boats of the Japanese mother ship fleets. Unlike the other fishing gear which is towed by a single vessel, a pair trawl is towed between two boats moving along parallel course. The Danish seining differs from trawling in that the net is laid out along the bottom with wings spread. It is then towed slowly, causing the wings to close which drives the fish into the belly of the net. The gear is mainly employed by the Japanese mother ship fishery for highly concentrated fish such as yellowfin sole and pollock. Its use, however, has been reduced in recent years in favor of pair trawls. Japan utilizes all four techniques of fishing and fisheries of all other nations utilize stern trawls.

The size and dimensions of fishing gear utilized off Alaska depends on the size of the catcher boat. These characteristics are summarized in Table 4.

Cod end mesh sizes have been measured by U.S. observers, whereas the average area of netting material per trawl was derived from calculations of the net dimensions. The cod end mesh sizes vary from 8.0 to 13.0 cm, and the amount of netting material per trawl from 1,400 to 4,900 m^2 (Table 4).

FISHING EFFORT

An index of fishing effort, as it relates to the potential amount of trawl gear that could be lost or discarded and be a potential source of entanglement to marine mammals, is the number of vessel-months of trawl

Table 2.--Type of vessel utilized in the groundfish fishery off Alaska (GRT = gross registered ton).

Vessel class	Definition
Mother ship fleets	
Mother ship - surimi	Mother ship fleets with capacity to produce surimi (a minced fish product), frozen products, and meal.
Mother ship - freezer	Mother ship fleets with capacity to produce frozen products and meal.
Mother ship - joint venture	Mother ship fleets where the catcher boat fleet is composed of U.S. trawlers and the mother ship is of foreign registry. Fish caught are defined as U.S. landings.
Catcher boats Pair trawler Danish seiner Side trawler Dependent stern trawler	Fleet of 6 to 20 vessels which transfer catch to mother ship for processing. In the foreign directed fishery, side trawlers have been phased out and the numbers of Danish seiners and stern trawlers have been reduced. Pair trawlers predominate in the present Japanese fleets. In the growing joint venture fishery, the catcher boats are U.S. small stern trawlers.
Independent trawlers	
Large side trawler	Has been replaced by more efficient stern trawlers. May transfer catch to mother ships but could operate independently and process and freeze own catch. Soviet vessel abbreviation - SRTM.
Small stern trawler	Independent stern trawler <1,500 GRT. Processes and freezes own catch.
Large freezer trawler	Independent stern trawler 1,500 GRT or greater with capacity to produce frozen products and meal.
Large surimi trawler	Independent stern trawler 1,500 GRT or greater with capacity to produce surimi, frozen products, and meal.

Table 3.--Physical characteristics of foreign vessels in the Bering Sea-Aleutians and North Pacific groundfish fishery.

Nation	Vessel class	Gross tons	Length (m)	Horsepower	No. in crew
Japan	Mother ship (Surimi, freezer, and joint venture)	6,318-27,060	135-201	9,100	250-270
	Catcher boats				
	Pair trawler	125-215	32-38	--	12
	Danish seiner	97-150	27-38	--	18
	Small stern trawler	279-280	51-58	--	--
	Small stern trawler	350-500	50-60	1,200-2,700	22-32
	Large freezer trawler	2,000-4,000	75-102	3,400-4,400	45-60
	Large surimi trawler	2,700-7,500	92-143	3,400-5,000	60-100
U.S.S.R.	Mother ship (Freezer and joint venture)	4,000-18,000	110-174	2,000-5,000	<280
	Catcher boats				
	Small side trawler	265-335	38	300-400	22-26
	Medium side trawler	505-630	52	540-650	26-28
	Large side trawler (SRTM)	700	54	800	30
	Small stern trawler (SRTK)	775	55	1,000	--
	Large freezer trawler (BMRT)	2,300-3,800	76-89	1,900-2,000	87-96
	Large freezer trawler (RTM)	2,100-2,200	82-83	2,320	78-80
Republic of Korea	Mother ship (Joint venture)	8,506-23,799	52-74	--	--
	Small stern trawler	404-1,438	51-70	--	--
	Large stern trawler	2,000-4,000	75-102	3,400-4,400	45-60
Taiwan	Small stern trawler	620-904	52-55	--	--

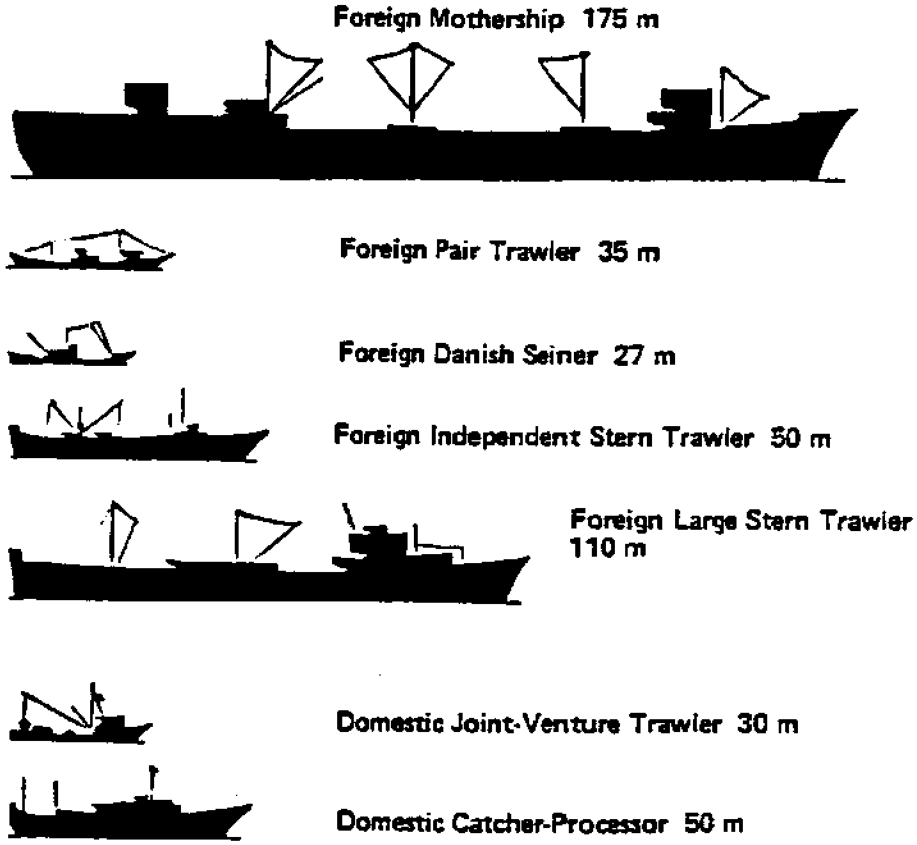

Figure 7.--Typical size of vessels employed in the trawl fisheries off Alaska.

Table 4.--Typical dimensions of trawl gear utilized off Alaska.

	Vertical opening (m)	Horizontal opening (m)	Headrope length (m)	Footrope length (m)	Cod end mesh (cm)	Area of netting material (m^2)
Japanese						
Dependent stern trawlers	4-9	24-30	36-54	8.0-8.5	8.0-8.5	2,100
Pair trawlers	7.5	56	130	148	8.0-9.0	4,150
Danish seiners	7	35	115	128	7.5-9.0	2,300
Large independent stern trawlers	7-27	22-35	50-85	54-90	9.0-13.0	4,900
Small independent stern trawlers	3.5-7.5	12-30	55-65	50-70	8.0-13.0	2,100
Soviet						
Bottom trawl	4.5-8	16-28	31-50	35-60	8.0-13.0	1,400
Pelagic trawl	25-30	35-45	70-120	70-120	8.0-13.0	4,900
Korean trawl	6-7.5	22-40	64-80	75-100	8.0-13.0	2,900
Polish trawl	18-23	20-68	55-112	55-112	8.0-13.0	2,900

operations. This effort unit can then be extrapolated to the number of trawl drags and the amount of netting material fished. Fishing effort also provides some indication of the amount of discarded fishing associated debris such as plastic banding material and fragments of netting. Fur seals have been noted to become entangled in these smaller pieces of debris (Fiscus and Kozloff 1972).

Number of Fishing Vessels

Drawing upon information provided by Chitwood (1969), Forrester et al. (1978), and annual reports on foreign fishing activities off Alaska issued by the National Marine Fisheries Service Law Enforcement Branch in Juneau, the composite compilation of the number of trawlers (excluding support vessels) that operated off Alaska in 1933-84 is shown in Table 5 and Figure 8.

Before World War II, the number of trawlers that operated off Alaska was no more than 13. The fishery resumed after the war with 11 vessels in 1954 which increased to 82 vessels by 1959 when the U.S.S.R. joined the fishery. The fleet size built rapidly to 432 vessels by 1963. During 1964-75, the number of vessels generally varied between 300 and 400. However, in 1976, just before the implementation of the Magnuson Act, the number of vessels increased dramatically to 422--a level at or near the historical peak for the fishery. Therafter, the number of foreign trawlers gradually declined as the domestic fisheries (joint venture with foreign

Table 5.—Estimated total numbers of trawlers that operated off Alaska, 1933–84.

Year	Japan	U.S.S.R.	Republic of Korea	Poland	Taiwan	West Germany	Mexico and Spain	United States joint venture	United States catcher processor	Total
1933	5									5
1934	5									5
1935	11									11
1936	8									8
1937	13									13
1940	8									8
1941	12									12
1954	11									11
1955	9									9
1956	13									13
1957	13									13
1958	29									29
1959	62	20								82
1960	190	80								270
1961	200	100								300
1962	200	150								350
1963	221	211								432
1964	150	196								346
1965	131	201								332
1966	166	240								406
1967	166	174								340
1968	157	115								272
1969	175	137								312
1970	221	175								396
1971	207	174								381
1972	218	158								376
1973	212	107								319
1974	211	126	15	1						353
1975	206	65	13	3	1					288
1976	237	[1]27	57	—	1					422
1977	288	35	18	2	1					344
1978	218	48	13	2	5					286
1979	210	41	17	13	3		3	3		284
1980	213	40	23	24	4	1	0	22	1	328
1981	210	6	31	25	3	1	0	36	1	313
1982	203	7	31	3	4	1	0	53	2	304
1983	205	8	29	—	3	1	0	65	6	317
1984[1]	185	7	28	4	3	1	1	85	8	322

[1]Preliminary estimates.

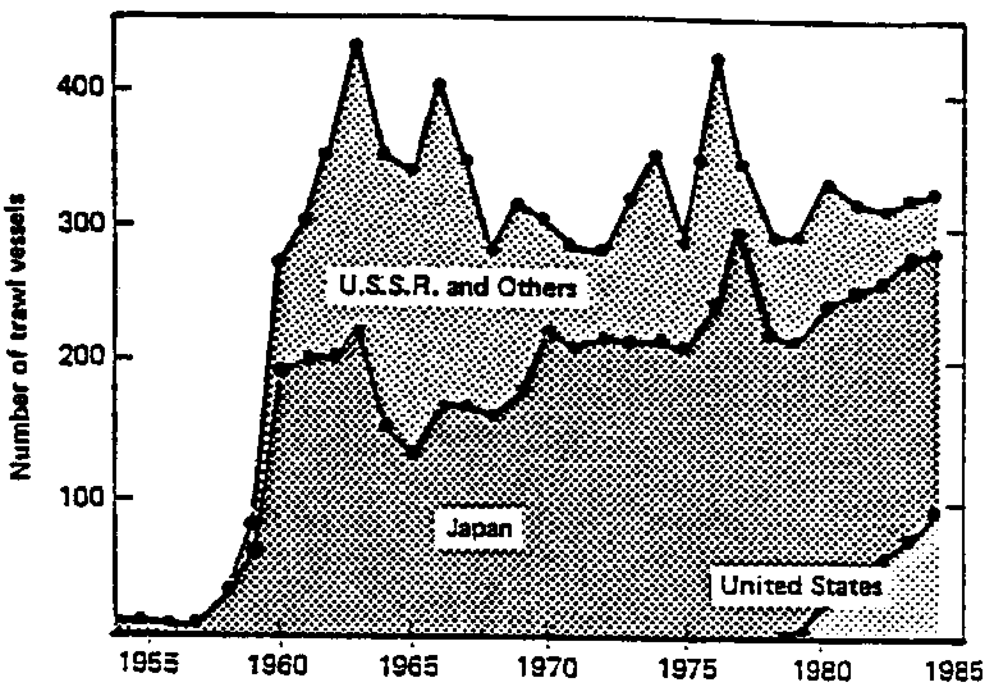

Figure 8.--Total number of trawlers that operated off Alaska, 1954-84.

vessels and purely domestic operations) became established and regulations became more restrictive on the foreign fisheries. In addition, the U.S.S.R. and Poland were denied direct fishing privileges during 1980-83 which resulted in further considerable reduction in the number of foreign vessels that operated off Alaska. By 1984, the number of foreign trawlers had been reduced to 229; however, the total number of vessels still exceeded 300 (322) considering the 93 U.S. trawlers.

Vessel-Months of Trawling

Before 1963, the vessel-months of effort were estimated by multiplying the number of vessels (sighted or reported) by typical days of operation per year. The typical number of days of operation and average number of drags per day were derived from data collected by the U.S. Foreign Fisheries Observer Program (Table 6). From 1964 to 1976, the number of vessel-months of operation was estimated from monthly sightings and reports of foreign vessel operations as given in "Foreign fishing activities in the Bering Sea and Gulf of Alaska" issued by the NMFS Law Enforcement Branch at Juneau, Alaska. The vessels that were on the grounds each month were assumed to have operated the whole month, even though the actual number of days of operation would vary depending on weather conditions and other factors. This method of calculation results in a maximum estimate of fishing effort. After 1976, the actual number of foreign fishing days off Alaska were provided by radio reports from the vessels under regulations promulgated by the Magnuson Act. The number of vessel-months of operation can be tallied from these reports. However, to maintain comparable estimates of fishing effort, the same procedure of estimation for 1964-76 was used for the 1977-83 period.

Table 6.--Typical number of vessel days of operation per year and average number of trawl drags per day for trawl vessels that operated off Alaska.

Country	Trawl vessels	Vessel-days of operation per year	Number of drags per day
Japan	Mother ship catcher boats	150	4
	Large trawler	220	5
	Small trawler	220	4
	Joint venture trawler	70	0
U.S.S.R.	Trawler	180	3
	Joint venture trawler	70	0
Republic of Korea	Trawler	200	5
	Joint venture trawler	130	0
Poland	Trawler	70	3
	Joint venture trawler	40	0
Taiwan	Trawler	100	3
	Joint-venture trawler	40	0
West Germany	Trawler	200	3
	Joint-venture trawler	80	0
Mexico	Trawler	180	3

Table 7 shows the estimated amount of trawl fishing effort off Alaska from 1954 to 83 by nation and geographical region. These data are also plotted in Figure 9. The total amount of fishing effort increased rapidly from 66 vessel-months of trawl operations in 1954 to 2,700 vessel-months in 1963. The effort declined to an average of about 2,200 vessel-months during the 12 years (1964-75). In 1976, the effort increased dramatically to a historical peak of 3,215 vessel-months. However, after the Magnuson Act was implemented a year later, the effort declined gradually to the level in the late 1960's.

Despite recent expansions in the domestic fisheries after 1980, the effort is still predominantly foreign. Japan has remained the nation with the largest fishing effort. Fishing effort by the U.S.S.R. was actually as high or higher than that of Japan during 1961-67, but declined after 1967 and in 1980 direct fishing operations ceased due to U.S. regulations. Fishing effort by the other countries is still a small percentage of the total.

Most of the fishing effort was concentrated in the Bering Sea-Aleutian region (Fig. 9). At the inception of the trawl fishery in the Gulf of Alaska when the fisheries targeted on Pacific ocean perch, fishing effort was relatively high. When this resource was depleted after 1967, the fishing effort decreased dramatically in the Gulf of Alaska and remained at a relatively constant level (11%) of the total fishing effort.

Although the trawl fishery is a year-round operation, most of the effort is concentrated during the warmer summer months. Typically, vessel-months of effort are distributed as follows:

Month	1	2	3	4	5	6	7	8	9	10	11	12
Percent	3.6	5.9	6.0	4.8	7.2	16.8	16.9	10.1	10.3	8.3	6.0	3.9

Table 7.--Estimated amount of trawl fishing effort off Alaska expressed in number of vessel-months of operation, 1954-83.

	Effort in vessel-months by nation				Effort by region	
Year	Japan	U.S.S.R.	Others	Total	Bering Sea-Aleutians	Gulf of Alaska
1954	66			66		
1955	54			54		
1956	78			78		
1957	78			78		
1958	174			174		
1959	350	50		400		
1960	1,400	300		1,700		
1961	1,100	900		2,000		
1962	1,100	900		2,000	1,600	400
1963	1,100	1,600		2,700	1,700	1,000
1964	760	1,360		2,120	1,220	900
1965	740	1,860		2,600	1,600	1,000
1966	875	1,180		2,055	1,093	962
1967	1,015	935		1,950	1,445	505
1968	1,275	675	5	1,955	1,728	227
1969	1,220	695	5	1,920	1,759	161
1970	1,560	835	5	2,400	2,176	224
1971	1,580	960	5	2,545	2,340	205
1972	1,555	790	10	2,355	2,102	253
1973	1,445	705	10	2,160	1,890	270
1974	1,565	770	25	2,360	2,114	246
1975	1,180	680	50	1,910	1,660	250
1976	1,935	1,000	280	3,215	2,965	250
1977	1,826	416	67	2,309	2,136	250
1978	1,832	363	122	2,317	2,078	239
1979	1,776	310	355	2,391	2,175	266
1980	1,860	141	390	2,391	2,029	337
1981	1,365	0	520	1,885	1,635	250
1982	1,356	0	420	1,776	1,571	205
1983	1,704	0	410	2,114	1,726	388

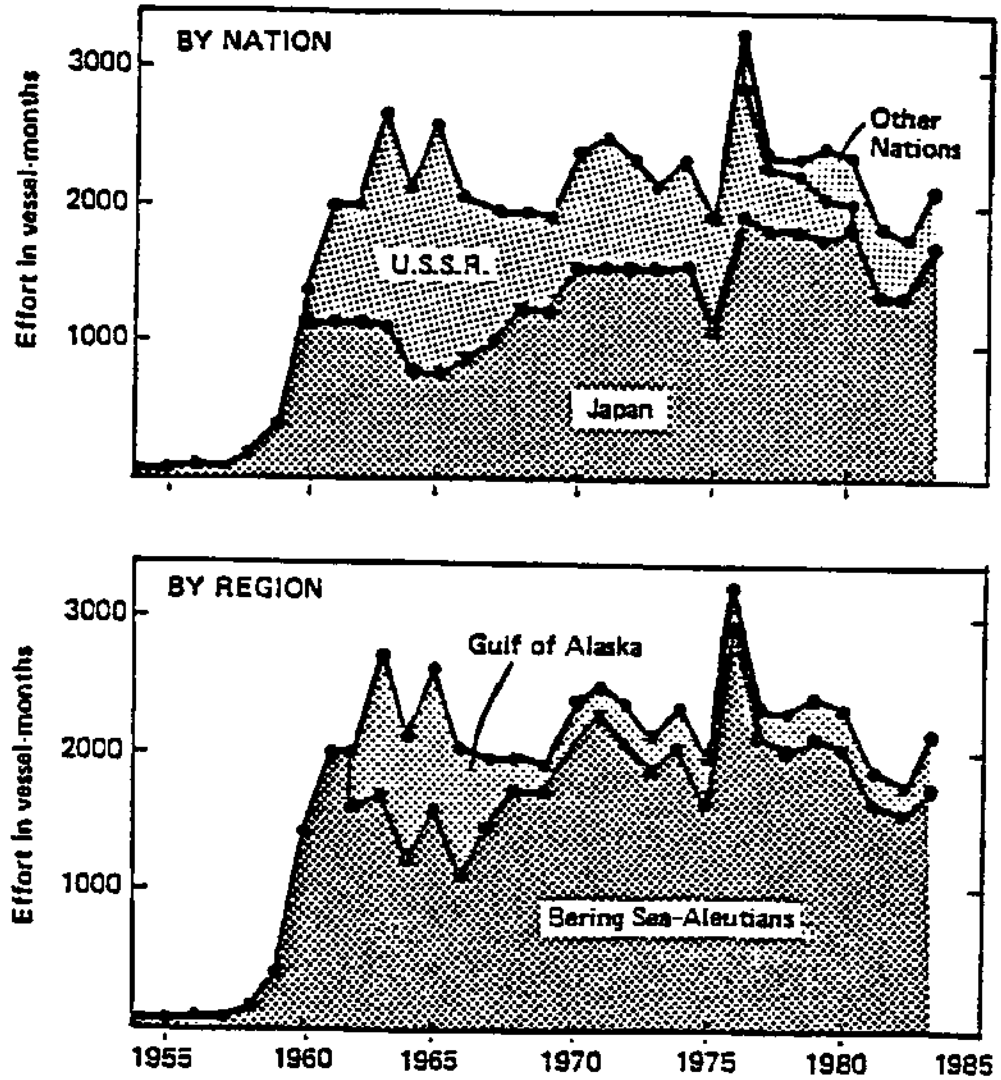

Figure 9.--Total fishing effort off Alaska, by nation (top panel) and by region (bottom panel), 1954-83.

Observations on Net Loss in 1983

The Magnuson Act requires that foreign vessels fishing in the U.S. 200-mile fishery conservation zone (FCZ) carry U.S. fisheries observers. Foreign vessels participating in joint ventures with U.S. catcher boats in federally managed waters in the FCZ (3-200 miles) are also subject to this requirement. The Magnuson Act authorizes the use of observers for the purposes of 1) collecting biological data needed for fisheries management, 2) monitoring compliance to fishing regulations, and 3) cooperating in research related to the conservation of living marine resources. The Northwest and Alaska Fisheries Center administers the observer program for foreign and joint venture fisheries in the U.S. FCZ in the eastern Bering Sea and northeast Pacific Ocean. This program has been used to provide data on a wide range of management, compliance, and research problems (French et al. 1982).

One of the areas in which the program has been involved is the collection of data on the number and type of marine mammals incidentally caught during fishing operations. Based on data collected by observers, Loughlin et al. (1983) reported on the number and type of animals caught by the trawl fishery from 1978 through 1981. In addition to this active interaction between marine mammals and the trawl fishery, Fiscus and Kozloff (1972) and Fowler (1982) have reported on a second type of interaction resulting in the entanglement of animals in trawl netting discarded or lost from trawl vessels.

In response to Fowler's report, the observer program instructed its observers to monitor the discarding and loss of trawl netting material in the foreign and joint venture fisheries. The purpose of the project was not necessarily to provide a quantitative measure of the amount of netting lost or discarded annually but to determine the type of information that could be collected by observers. A more detailed study would be developed and implemented at a later time if it was found that it was feasible for observers to collect data which could be used to quantitatively measure the type and amount of netting lost and discarded in the fishery.

In this initial study, observers were asked to monitor net-mending operations to determine how often nets were repaired and the number and size of pieces of webbing that were discarded during such occasions. They were also asked to determine the fate of any cod ends that were damaged beyond repair and to report on the loss of nets during trawling or in delivery to a mother ship or joint venture operation. The project was begun in the fall of 1982 and continued during 1983 and 1984. This report provides a summary of some of the information collected during 1983, the only complete year of data collection at this time.

During 1983, U.S. fisheries observers were stationed aboard foreign vessels in the Bering Sea-Aleutian region for 13,994 days which accounted for 44.2% of the total foreign effort. In the Gulf of Alaska region, observers spent 4,046 days aboard foreign vessels accounting for 50.6% of the total effort. There were 368 reports summarizing data collected on the discard and loss of netting in the Bering Sea-Aleutian region and 92 reports from the Gulf of Alaska region. From review of these reports, it is apparent that many observers had difficulties monitoring net-mending operations and thus collecting data on the number and size of materials discarded. Observers found that net-mending operations were usually performed during the period observers were busy performing sampling duties below deck. It was also noted that it was difficult to monitor net-mending activities without vessel personnel being aware of the observer's activity and purpose. Debris from net-mending activities would likely not be tossed overboard in the observer's presence. For these reasons, the information reported by observers which was found most useful for this report was the number of instances where nets or cod ends were accidentally lost during fishing operations.

In the Bering Sea-Aleutian region, 17 of the 368 reports submitted by observers indicated that a net or large portion of the net was lost during a fishing operation (Table 8). Of the 17 reports, 8 were from vessels participating directly in the foreign fishery. The eight reports cited the loss of eight nets or portions of nets. If it is assumed that these

Table 8.--Number of reports for U.S. observers of losses of nets or portions of nets and estimated number of losses in the entire foreign and joint venture groundfish fishery in the Bering Sea-Aleutian region and the Gulf of Alaska region in 1983.

Region/nation/vessel class	Total No. of reports	No. of reports with net loss	No. of reported lost nets	Percent observer coverage	Estimated No. of net losses[1]
Bering Sea-Aleutian					
Japan					
Mother ship	7	1	1	86.7	1
Large trawlers	29	1	1	71.8	1
Small trawlers	250	4	4	36.4	11
South Korea-trawlers	60	1	1	45.7	2
West Germany-trawlers	3	1	1	70.1	1
Total foreign fishery	349	8	8	43.5	16
Joint venture	19	9	15	56.6	26
Total all fisheries	368	17	23	44.2	42
Gulf of Alaska					
Japan					
Large trawlers	15	1	1	66.6	2
Small trawlers	30	1	1	57.1	2
South Korea	29	0	0	38.5	0
Total foreign fisheries	74	2	2	41.3	4
Joint venture	18	10	14	72.9	19
Total all fisheries	92	12	16	50.6	23

[1]Number of net losses determined by: Total number = Number of reported lost nets/percent observer coverage.

reports account for all of the number of nets lost during the period of observer sampling, then an estimate of the number of nets possibly lost during the 1983 fishery can be extrapolated to vessels without observers (total number of net losses equal number of reported net losses/percentage observer coverage). The resultant estimated number of nets or large portion of nets lost in the foreign fishery in 1983 was 16 (Table 8). The other nine reports were from the joint venture fishery. They listed 16 instances where cod ends were lost in the transfer of either full or empty cod ends between foreign processing vessels and U.S. catcher boats. The estimated number of cod ends lost in the entire joint venture fishery in the Bering Sea-Aleutian region in 1983 was 26 (Table 8). There were two reports from observers indicating the loss of two nets or portions of the nets in the foreign fishery in the Gulf of Alaska in 1983. These two reports result in an estimated loss of four nets or portions of nets in 1983 (Table 8). Observers reported 14 cod ends lost during transfers in joint venture fisheries in the Gulf of Alaska resulting in an estimated loss of 19 cod ends in the joint venture fishery (Table 8).

Therefore, a total of 65 nets or portions of nets were estimated to have been lost in the foreign and joint venture fisheries off Alaska in 1983. Most of the estimated losses (45) occurred in the process of transferring cod ends between processing vessels and catcher boats in joint-venture fisheries. It should be clearly noted that this estimate does not provide a measure of the amount of net material associated with these losses but only an indication as to the number of net losses which may have occurred in the 1983 trawl fishery.

EXTRAPOLATED ESTIMATE OF NET LOSS 1954-82

To provide the workshop a starting point from which to discuss the potential net loss associated historically with the trawl fishery, we have made an estimate of the net loss in the trawl fishery for 1954-82. There are no direct observations on the number of nets damaged or lost in the trawl fisheries other than from U.S. observers in 1983. If the assumption is made that the rate of loss for all years was the same as that observed in 1983, then it is possible to estimate the loss for earlier years. The 1983 data suggest that the rate of loss in the foreign fishery is distinctively different from that of the joint venture fishery. There are two possible sources of losses in the joint venture fishery: loss associated directly with trawling operations and the additional loss due to the at-sea transfer of cod ends. Therefore, in estimating net losses for years preceding 1983, two rates (number of nets or large portions lost per vessel-month) of loss were applied to the effort (vessel-months) from earlier years (Table 9).

It is difficult to determine how realistic the estimates of net loss are for 1954-82 because there is no corroborative information available. We have surmised that the estimates for 1977-82 may be good since the changes in gear used, target species sought, and grounds fished by the foreign fishery have been minor. We suspect that the gear loss in the Gulf of Alaska from 1965 to 1977 may have been higher than estimated since foreign vessels targeted on rockfish in areas in the eastern Gulf of Alaska over rather rough bottom. The likelihood of gear loss or damage would be increased in that type of fishery. We also suspect that for the period 1960-64, the amount of gear lost may have been substantially higher than estimated, since substantial foreign fisheries targeted on Pacific ocean perch over rather rough sea bottoms at that time. Before 1960, the fishery was to some extent still experimental; therefore, the probability of gear damage and loss may have been higher than estimated as well.

DISCUSSION

It is evident to us that there is no reliable estimate of the amount of trawl gear damaged or lost in the trawl fishery off Alaska. Although actual observations were made by U.S. observers in 1983, they may be

Table 9.--Extrapolated estimate of net or large portions of net loss in the trawl fisheries off Alaska, 1954-83.

Year	Bering Sea-Aleutians	Gulf of Alaska	Total
1954	1	0	1
1955	1	0	1
1956	1	0	1
1957	1	0	1
1958	2	0	2
1959	4	0	4
1960	10	4	14
1961	16	4	20
1962	16	4	20
1963	17	10	27
1964	12	9	21
1965	16	10	26
1966	11	10	21
1967	14	5	19
1968	17	3	20
1969	17	2	19
1970	22	3	25
1971	23	2	25
1972	21	3	24
1973	18	3	21
1974	21	3	24
1975	17	3	20
1976	29	3	32
1977	21	3	24
1978	21	3	24
1979	22	5	27
1980	20	15	35
1981	27	22	49
1982	34	22	56
1983	42	23	65

inadequate because of sampling circumstances. Rates of gear loss before 1977 are even less reliable because levels of fishing effort can only be approximated. The potential for obtaining future data which will provide more reliable estimates of the amount of gear lost now exists through the observer program. By law, all foreign vessels must now carry U.S. fisheries observers while participating in directed or joint venture fishing activities in the U.S. FCZ. There is a need to evaluate the work already performed by observers in this area and develop a plan for future data collections which will provide the information needed to measure the impact of the trawl fishery. Many foreign vessel operators seem to be acutely aware of the interest of observers in the collection of data on net loss and the discard of debris. It is apparent that the presence and activities of observers can also be used as a deterrent to the discard of debris by foreign vessels.

As we improve our sampling of the foreign and joint venture operations, however, we need to obtain equivalent data from the rapidly developing domestic trawl fisheries. The expansion of the domestic fleet has essentially limited foreign fisheries to targeting on pollock, yellowfin sole, and turbot in the eastern Bering Sea, and pollock in the Gulf of Alaska. Fisheries targeting on pollock and yellowfin sole operate over relatively smooth ocean bottoms or use midwater trawl gear. As such, the probability of gear damage and loss in these fisheries is low.

On the other hand, domestic fisheries have developed for Pacific ocean perch and Atka mackerel in the Aleutians and flatfishes and other bottom species in the Gulf of Alaska. These fisheries are often conducted over hard uncertain bottom where the probability of gear loss is higher. The need to monitor gear damage and loss in these fisheries may be greater than in other domestic fisheries that target on pollock, yellowfin sole, and Pacific cod over relatively smooth ocean bottom.

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THE OREGON EXPERIENCE

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ABSTRACT

There is virtually no information available to the Oregon Department of Fish and Wildlife to judge the extent of injury or death to fish, aquatic, and terrestrial wildlife resulting from ingestion of or entanglement in plastic debris. This paper describes the impacts of plastic debris on fish and wildlife along the 563 km (350-mi) Oregon coast based on the findings of a cleanup project.

To learn more about the presence of plastic debris on the Oregon coast, the department conducted a coastwide volunteer effort to pick up plastic on 13 October 1984. More than 2,000 individuals volunteered to collect and inventory the debris. By filling out questionnaires, they indicated pounds collected, miles walked, and whether debris was generated by beach use or ocean drift. Debris categories included food packaging and utensils, fishing gear, rope, strapping, six-pack holders, bottles and jugs, or bags and sheeting. Dead birds found on the beach this fall will be sent to the Oregon Marine Science Center for necropsy to check for plastic particles.

I am pleased to attend this workshop and share a unique experience I had during the past 5 months. It all began because the May-June issue of the Alaska Fish and Game Department's magazine was delivered to my office by mistake. Flipping through it, I was drawn to an article entitled, "The plague of plastics," by freelance writer, Tom Paul. He wrote about the increasing proliferation of plastic debris into the natural environment and the resulting ingestion or entanglement by wildlife.

Although I have no scientific background, I was aware birds become entangled in monofilament fishing line and six-pack rings, but I didn't know they had an appetite for styrofoam and small bits of plastic.

In July, I attended the annual meeting of the Western Association of Fish and Wildlife agencies. This gave me the opportunity to talk to fish and wildlife managers from the 14 western states, Alberta, and British Columbia. The folks I talked to agreed they had a vague awareness there was a problem with plastic but had not seen much written about it.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

At the end of the conference, the Western Association adopted a resolution asking its members to "inform legislative and administrative bodies and the general public of the danger of plastic debris to wildlife, and of the need to reduce its proliferation into the environment."

I had the idea of organizing a cleanup of plastic debris on Oregon's 563 km (350 mi) of coast. All but 42 km (26 mi) is publicly owned.

A steering committee was formed. We divided the coast into 14 zones and found local residents to be "zone captains" to identify which areas were accessible and where debris, once collected, could be stacked.

Our statewide newspaper, The Oregonian, published an article on 17 August explaining the project and my telephone has never stopped ringing. We had groups and individuals volunteer to help clean up debris, Chambers of Commerce and service clubs offer to feed volunteers, five coastal community banks contribute money for food, and food brokers donate 307 dozen hot dogs and buns to feed the volunteers. A public utility company provided 2,000 reprints of a Parks Magazine article entitled, "Plastic pollution: A worldwide oceanic problem," and these were mailed to each volunteer. A discount store chain printed 5,000 large posters asking marine users to keep plastic on board. The Oregon Sanitary Service Institute volunteered trucks and drivers and paid the landfill fees. They also provided special T-shirts for zone captains, steering committee members, and refuse collectors.

My original goal was 1,500 volunteers--roughly 10 for each of the 241 km (150 mi) of accessible beach. We picked Saturday, 13 October, to coincide with the Year of the Ocean and Coastweek activities. The pickup hours of 9 a.m. to 12 p.m. agreed with favorable tides.

The news media loved the idea from the beginning. Stories about the cleanup appeared statewide on a regular basis, raising the public's awareness about plastic debris and its impact on wildlife, and outlining how people with no special equipment or training could be personally involved.

On Friday, 12 October, the weather took a drastic turn for the worse. Gale force winds lashed the coast. Small craft and beach erosion warnings were repeated over and over on the radio and people were cautioned to stay off the north coast beaches.

Saturday morning dawned to more high wind, hail, and driving rain. Despite the black sky and bleak forecast, volunteers arrived by the car and busload, dressed for the weather and raring to go. Because emergency services closed two zones, some volunteers worked in the dune grass and along beach roads and parking areas.

At the designated meeting sites, each volunteer was given a 5.3-liter (20-gal) plastic collection sack, a free lunch ticket, a verbal warning about sneaker waves, and a questionnaire.

The questionnaire asked how many people were in the party, the number of males and females, and the range of age. It asked for the location and number of miles gleaned and whether it was sandy beach, estuary, rocky beach, or road access.

The questionnaire listed different types of plastic debris and had a category for special observations. They were on 12.7 x 17.8 cm (5 x 7 in.) card stock and included my name and return address for easy mailing.

In addition to listing plastic debris, volunteers were asked to note dead or sick sea lions or seals because of an outbreak of leptospirosis in marine mammals. Fresh dead birds were delivered to the Hatfield Marine Science Center Disease Laboratory for the Oregon State University staff to necropsy. Twenty-one birds were delivered to the center.

On Monday after the cleanup, I telephoned the zone captains to obtain an estimate of the number of volunteers participating and the sacks collected. A total of 2,100 volunteers in the 14 zones filled 2,412, 5.3-liter (20-gal) sacks. Over half of those who participated came from inland cities and drove at least 121 km (75 mi). There was excellent involvement by coastal residents as well.

To my amazement, over 1,600 questionnaires were filled out and returned. In addition to interesting reading, the cards have given us a data base of ocean debris. We know that on 13 October 1984, the Oregon coastal beaches produced: 48,898 chunks of styrofoam larger than a baseball. Most was found adjacent to our largest river mouths, especially those with marinas or houseboat moorages upstream. Styrofoam shows up on the Oregon coast from small bead size up to pieces as large as 0.9 x 1.2 m (3 x 4 ft). Coastwide, the average percentage of styrofoam was 60% but on the north coast, it was as high as 92%. By contrast, south coast zones had smaller amounts, except on the beaches adjacent to river mouths.

Strapping bands, of which there were 2,055, were most prevalent on open beaches. They come in all colors but are uniformly about 0.9 m (3 ft) long.

Rope is in high quantity on the entire coast; 6,117 pieces were collected. Small, 0.3-m (1-ft) lengths and tangles 0.9 to 1.5 m (3- to 5-ft) long wash ashore, wound up in globs of kelp.

There were 1,442 six-pack rings. They were most prevalent on beaches frequented by picnickers which may be due to Oregon's law requiring their breakdown within 120 days when exposed to ultraviolet light.

The 4,787 plastic milk jugs, bleach bottles, shampoo, and detergent bottles were collected. Many had foreign labels and appeared to have been afloat for a long time.

Most fishing nets were found at the mouth of the Columbia River. The 1,097 pieces of fishing gear--artificial worms, large and small sections of net, or lengths of monofilament line with hooks were collected. One large net which had been on the beach for several months, weighed over 136 kg (300 lb). Fifteen to 20 units of heavy cord and fiber trawl net in 9.1-12.2 m (30-40 ft) lengths had to be hauled away by truck.

The 4,909 bags or sheets of plastic appeared in all locations. They were generated equally from beach and ocean users.

The 5,339 plastic food utensils, including snap-in cups, forks, spoons, or plates collected were more prevalent in picnic areas.

The birds collected included 10 northern fulmar, Fulmarus glacialis, 4 western grebe, Aechmophorus occidentalist, 3 western gull, Larus occidentalist, 3 Cassin's auklet, Ptchoramphus aleutica, and 1 common murre, Uria aalfe. Plastic particles were only found in three fulmars. One had styrofoam, another had a hard, blue plastic ballpoint pen clip, and the third had two hard, green plastic chips. The fulmar also had feathers, pine needles, and bits of fish bone. The western grebe stomachs were crammed with feathers. All birds had good fat content and did not appear to be starving. The examinations gave no indication of the cause of death except as the result of the heavy storm.

SO WHAT DID WE LEARN FROM THE OREGON EXPERIENCE?

First, there is not much information on the impact of plastic debris on Oregon's wildlife. We know styrofoam chunks, bottles, and lids are present but aren't ingested in the form we picked up.

We do know it is possible to find over 2,000 individuals willing to get up at 5 a.m., drive to the coast, and go out on a cold, wet blustery day to work for at least 3 h, stooping over to pick up 26.3 tons of plastic and other debris, and lugging them back to their car or truck. And after they do that, they enjoy getting together with others to compare what they found. They are also willing to sit down and fill out questionnaires and attach postage to mail in the cards.

We learned the north coast zones, adjacent to the Columbia River, had the highest incidence of discarded net and styrofoam. The south coast zone captains felt most of their plastic debris was from ocean drift because severe winds tend to keep the beaches free of lightweight material. Percentage use of beaches by humans was higher in areas adjacent to parking lots on the main highway, especially those frequented by people from the larger inland cities.

Plastic was not the only culprit on Oregon's beaches. Aluminum foil and food containers, aerosol cans, wine and liquor bottles, paper containers, and newsprint were mixed with the plastic debris. This was especially true on the south coast where the majority of debris was not plastic.

Debris found in driftwood piles, dune grass, and rock areas had a higher percentage of ocean drift.

Because plastic is lightweight and floats, it was the most obvious debris collected. We have no way to determine the amount of other material which has been discarded in our rivers or the ocean.

In several locations, having completely cleaned a section of beach on the morning of 13 October, volunteers returned to the same section a second time in the afternoon and again the next morning following a high tide. A 5.3-liter (20-gal) sack could be filled each time, and the ratio of rope, strapping bands, styrofoam, jugs, and fishing gear was the same. This leads to the conclusion that the majority of the debris on the Oregon coast is from ocean drift.

SO WHAT MIGHT BE DONE TO REDUCE OCEAN DEBRIS?

I have heard from sport and commercial fishermen and other marine users that there are not adequate disposal containers at dockside. It is much easier to dispose of debris into the water unseen than have the hassle of hauling it home. We need to involve port officials, refuse collectors, and the users in our discussions.

Now we all know there is a fine line between emotionalism being the motivator for cleaning up the beach and those who want to find out the facts and work toward solving the problem. A 1984 Marine Debris Bulletin article forecast that "Plastic particle pollution may provide the next battleground for seabird research and management." I prefer looking at the problem as an opportunity to find solutions.

In an effort to raise the public's awareness about plastic debris and wildlife and how they can solve the problem, we are producing a 12-min educational film entitled, "Get the drift." Funded by contributions from a variety of interests, it will be available in early January for use on television and to show at schools and before civic groups.

There is a perception by the public that plastic cannot be recycled. I am pleased to announce that the Society for the Plastics Industry has allocated $5 million to establish a Plastic Recycling Foundation and Institute to aggressively pursue methods to make it economically feasible to recycle plastic in large quantities. Although recycling does not specifically intercept the debris ingested by wildlife or which results in entanglement, it does allow individuals an opportunity to take preventive action and be personally involved. The plastic industry will also explore a way of having some items degrade more quickly when exposed to ultraviolet light.

The proposal by the U.S. Department of Commerce to add wording relative to discarding at sea in the commercial fishing regulations is a beginning. I recommend similar language become a part of all angling and marine board regulations.

As a promoter of a volunteer effort, I know the problem we are discussing struck a responsive chord with the public. Their donations to date have had a dollar value to my agency of over $20,000.

All of you are professional scientists, policymakers, or journalists. My wish is that you will put your knowledge about the fate and impact of marine debris into "street language." Rather than triggering counterproductive action such as restrictive legislation which could cripple several industries, we need to get our information out of the laboratories and into the minds of those who can help find practical solutions.

I appreciate having the opportunity to share the Oregon experience and will be happy to answer your questions.

Thank you.

FISH NETS AND OTHER PLASTIC LITTER ON ALASKA BEACHES

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ABSTRACT

Quantities of fish net fragments and other plastic litter on Alaska beaches at eight locations were determined by foot surveys from 1972 to 1984. The beach survey sites extended about 3,000 km, from Amchitka in the Aleutian Islands to southeastern Alaska and, therefore, provided a measure of accumulated litter from a large oceanic area. Limitations and advantages of beach surveys as an indicator of oceanic litter are discussed. Most litter was from foreign fisheries. Fragments of trawl web always constituted the bulk of the litter by weight. Japanese gill net floats were usually the most numerous item. Numbers of gill net fragments of each mesh size provide a clue to the fisheries from which they originate, thereby helping identify specific fisheries that are major sources of lost gill nets. There was little variation in composition of litter items on different beaches or in different years, but quantities of litter on different beaches varied greatly. Quantities on southeastern Alaska beaches were usually much less than in the western Aleutians. On Amchitka Island, where surveys extended over the decade 1972-82, litter rapidly increased during 1972-74 (from 122 to 345 kg/km of beach), but decreased 26% by 1982 to 255 kg/km. Between 1974 and 1982, there was a 37% reduction in weight of trawl web on Amchitka beaches, and the number of gill net floats declined 47%. The decrease in litter on Amchitka between 1974 and 1982 is attributed to fewer trawlers and gill-netters fishing off Alaska and shows that marine litter could be rapidly reduced if disposal of litter at sea were restricted.

INTRODUCTION

A serious pollution problem has resulted from the enormous quantities of plastic litter afloat on the oceans of the world. In 1975, it was estimated that 6.4 million metric tons (MT) of litter is annually discarded from ships (National Academy of Sciences 1975), and in Alaska waters about 1,664 MT of plastic litter is lost or discarded annually from fishing vessels (Merrell 1980). In Alaska, plastic litter--especially fish net fragments--is common, even in the most remote, uninhabited areas.

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The question is often asked: "So what? Why be concerned about marine litter?" Litter is aesthetically offensive. Ropes and nets disable vessels by entangling propellers, and sheet plastic can block cooling water intakes for engines. Lost or discarded litter, particularly net fragments, traps marine mammals, birds, and fish, resulting in their suffocation or starvation.

Annually, between 1972 and 1974 and again in 1982, I conducted systematic surveys of ten 1-km beaches of Amchitka Island which is 2,400 km west of Anchorage, Alaska (Merrell 1980, 1984). In 1984, I expanded the surveys to southeastern Alaska but did not repeat the Amchitka surveys.

I tried to answer several questions by my surveys: What kinds of litter were on the beaches? What were the sources of litter? Did the kinds and amounts of litter vary from area to area and from time to time? Lastly, could I develop simple, quantitative methods for measuring beach litter, methods that could be used by inexperienced people for comparable results from different observers, different years, and different geographic areas?

In this paper, I discuss and compare results of my surveys on Amchitka Island with those of surveys in southeastern Alaska, emphasizing litter that traps marine animals--trawl web, gill nets, and straps. I describe, in detail, the methods used and discuss their limitations.

SURVEY METHODS

The methods were the same for surveys of Amchitka Island and southeastern Alaska. All pieces of plastic litter visible from walking height were recorded; that is, any pieces larger than about 5 mm. Only a part of the litter actually present was accounted for because I did not try to uncover litter partially buried in sand, cobbles, or driftwood. To minimize variability caused by differences in efficiency of different individuals, I participated in all surveys. A complete description of the methods and equipment is in the appendix.

LITTER ON AMCHITKA ISLAND AND SOUTHEASTERN ALASKA BEACHES

With minor exceptions, the proportions of each kind of litter on Amchitka Island beaches were the same in 1982 as in 1972-74 (Table 1) (Merrell 1984). Although hundreds of kinds of plastic items were found, only 23 items were found 5 or more times in 1982. Twelve items were used in commercial fishing; most of the other items were probably discarded as garbage from fishing vessels. The amount of litter on Amchitka Island rapidly increased during 1972-74 (from 122 to 345 kg/km of beach) but decreased 35% by 1982 (to 225 kg/km of beach).

During the 4 years of surveys on Amchitka Island, trawl-web fragments were, by far, the most common item: 76-85% of all litter, by weight (Fig. 1). Trawl fishing, primarily by Japan and the U.S.S.R., on the continental shelf of Alaska reached a peak in 1972, when 706 trawlers were fishing in the area (J. C. Hammond, Law Enforcement Br., Natl. Mar. Fish Serv., NOAA, Juneau Alaska, pers. commun.). Subsequently in 1976, as a result of

Table 1.--Weight and number per kilometer of 23 most common items of plastic litter on ten 1-km beaches on Amchitka Island, 1972-74 and 1982 (asterisks indicate commercial fishing gear).

Items of plastic litter	Kilograms per kilometer				Number per kilometer			
	1972	1973	1974	1982	1972	1973	1974	1982
Trawl web*	103.87	122.15	271.75	171.27	12.3	16.7	23.7	34.0
Trawl floats*	4.70	10.09	18.25	19.55	1.7	5.2	5.0	5.4
Rope*[1]	6.21	13.20	36.08	14.30	10.1	20.0	25.9	24.5
Inflatable buoys*	--	--	--	5.94	--	--	--	2.0
Beverage crates	0.19	0.96	1.91	3.40	0.1	0.5	1.0	1.7
Gill net floats*	3.15	4.44	6.03	2.82	65.6	92.5	125.6	58.7
Bulk liquid containers*	0.53	0.92	3.21	2.10	1.2	1.9	5.4	1.5
Bottles	0.77	1.30	2.47	1.90	12.6	23.1	45.3	38.0
Plastic fragments	0.12	0.23	0.57	1.09	33.5	64.0	137.4	305.0
Fish baskets*	1.08	2.14	3.03	1.08	1.0	1.2	1.7	1.0
Polyvinyl sponge floats*	0.16	0.18	0.54	0.40	2.3	2.6	8.0	1.6
Sandals	0.36	0.22	0.31	0.30	3.0	1.8	2.6	2.5
Pails	0.20	0.22	0.44	0.23	1.1	1.3	2.6	1.0
Crab bait containers*	0.01	0.04	0.12	0.23	0.1	0.5	1.6	1.2
Lids and tops	0.07	0.07	0.14	0.18	11.9	13.0	25.0	33.2
Chemical ampules*	0.04	0.04	0.13	0.14	3.0	2.9	9.0	9.9
Cups and bowls	0.09	0.08	0.12	0.11	2.1	1.9	2.9	2.7
Strapping*	0.05	0.05	0.11	0.092	30.1	32.0	70.7	57.6
Outboard oil containers*	0.035	0.06	0.12	0.035	0.6	1.1	2.0	0.6
Six-pack yokes	0.003	0.006	0.01	0.023	0.6	1.1	2.0	4.5
Cigarette lighters	0	0	0	0.022	0	0	0	1.1
Cap visors	0.003	0.005	0.018	0.013	0.1	0.2	0.7	0.5
Shotgun cases	0.002	0.002	0.003	0.007	0.2	0.2	0.3	0.7
Total	121.64	156.42	345.42	225.23	193.2	283.1	498.4	588.9
Total excluding plastic fragments	121.52	156.19	344.85	224.14	159.7	219.1	361.0	283.9

[1]Length per kilometer: 1972 = 255 m; 1973 = 501 m; 1974 = 802 m; 1982 = 565 m.

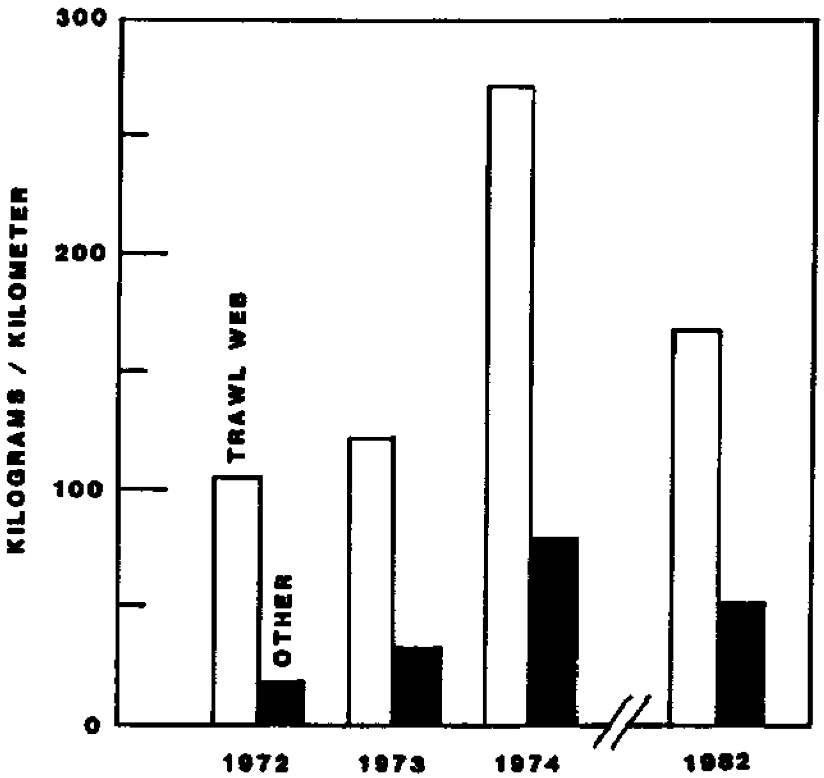

Figure 1.--Trawl web and other plastic litter on 10 Amchitka beaches, 1972-74 and 1982.

extension of U.S. fishery jurisdiction from 19 to 322 km (12 to 200 mi) offshore, the number of foreign trawlers declined 66%, to 232 trawlers in 1982 (Fig. 2). This large reduction was primarily a result of fewer Soviet vessels--from a peak of 377 vessels in 1972 to only 6 vessels in 1982.

It may be assumed that most trawl-web fragments are from Japanese fisheries, although the number of trawlers from other nations is increasing. In 1982, for example, over 80% of the foreign trawlers off Alaska were Japanese. Other percentages were: Republic of Korea 13%, U.S.S.R. 3%, Taiwan 2%, Poland 1%, and West Germany <1% (Hammond pers. commun.). The U.S. trawl fishery is rapidly expanding but has not been in existence long enough to contribute significantly to beach litter.

Because of this reduction in the trawl fishery, I expected smaller quantities of trawl web on Amchitka beaches in 1982 than in 1974. This was indeed the case--there was a 37% reduction in total weight of trawl-web accumulations on Amchitka beaches (from 272 kg/km in 1974 to 171 kg/km in 1982). During the same period, however, the number of trawl-web fragments increased, and the average weight of fragments decreased about 50%, from 11.5 to 5 kg per fragment.

Gill net floats do not cause entanglement, of course, but they do indicate the quantities of gill nets. On Amchitka Island, the number of gill net floats increased steadily between 1972 and 1974, then decreased by

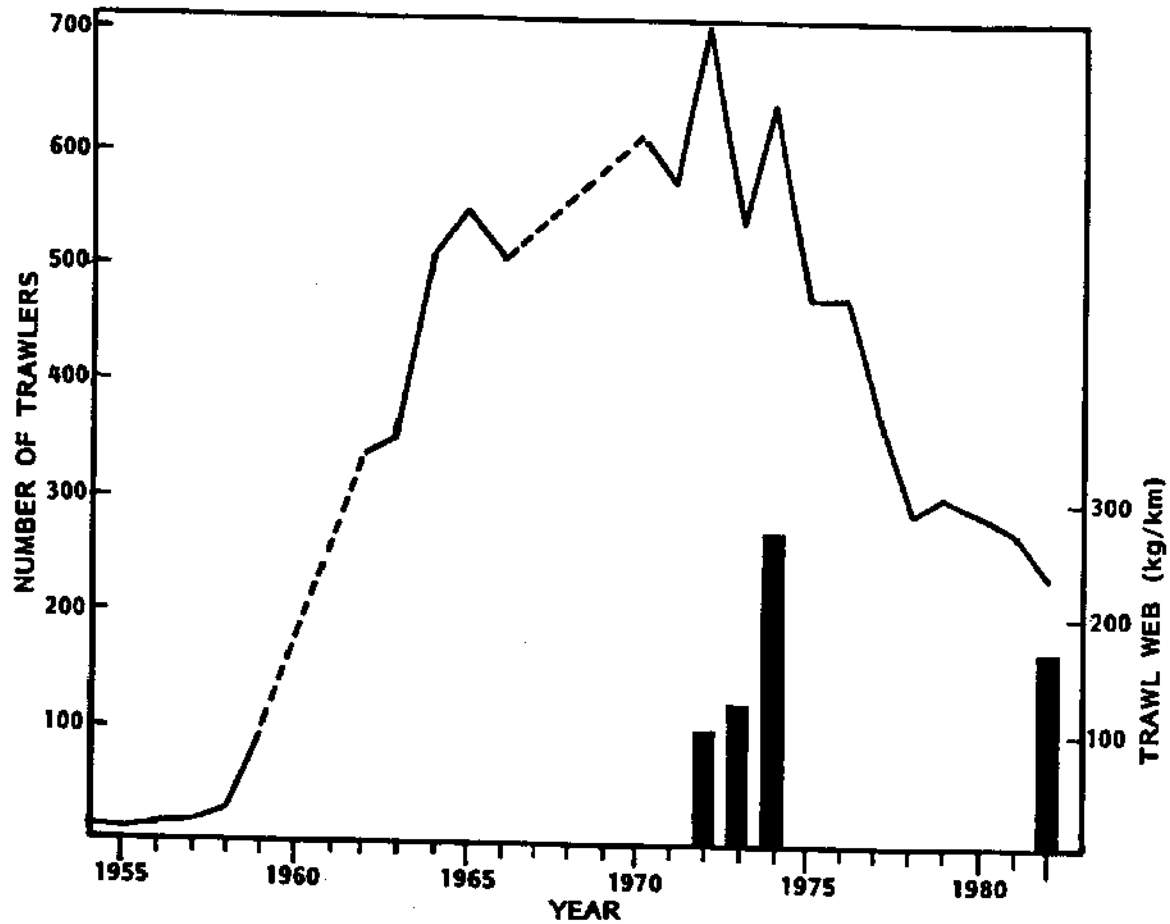

Figure 2.—Number of trawlers in the Bering Sea and northwest Pacific Ocean 1954-82 (solid and dashed lines) and weight of trawl web on Amchitka Island beaches (bars). Dashed lines are extrapolated for years with no Soviet trawl data. Source of data: 1954-59, Forrester et al. (1978); 1962-66, Chitwood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

1982. Most gill net floats and nets on Alaska beaches probably originated from the long-standing Japanese high seas fisheries. For over 30 years, Japan has been the principal nation fishing with monofilament gill nets in the North Pacific Ocean and the Bering Sea, although Taiwan and the Republic of Korea have recently begun gill net fisheries for salmon and squid. There are three major Japanese gill net fisheres in the North Pacific Ocean and the Bering Sea (Fig. 3): (1) a mother ship fishery for salmon in the Bering Sea and the northern North Pacific Ocean, (2) a land-based fishery, also for salmon, south of the mother ship fishery, and (3) a fishery for squid, south of the land-based salmon fishery. A fourth large-mesh, gill net fishery for marlins and other pelagic species exists in the central and western Pacific Ocean but is not discussed here.

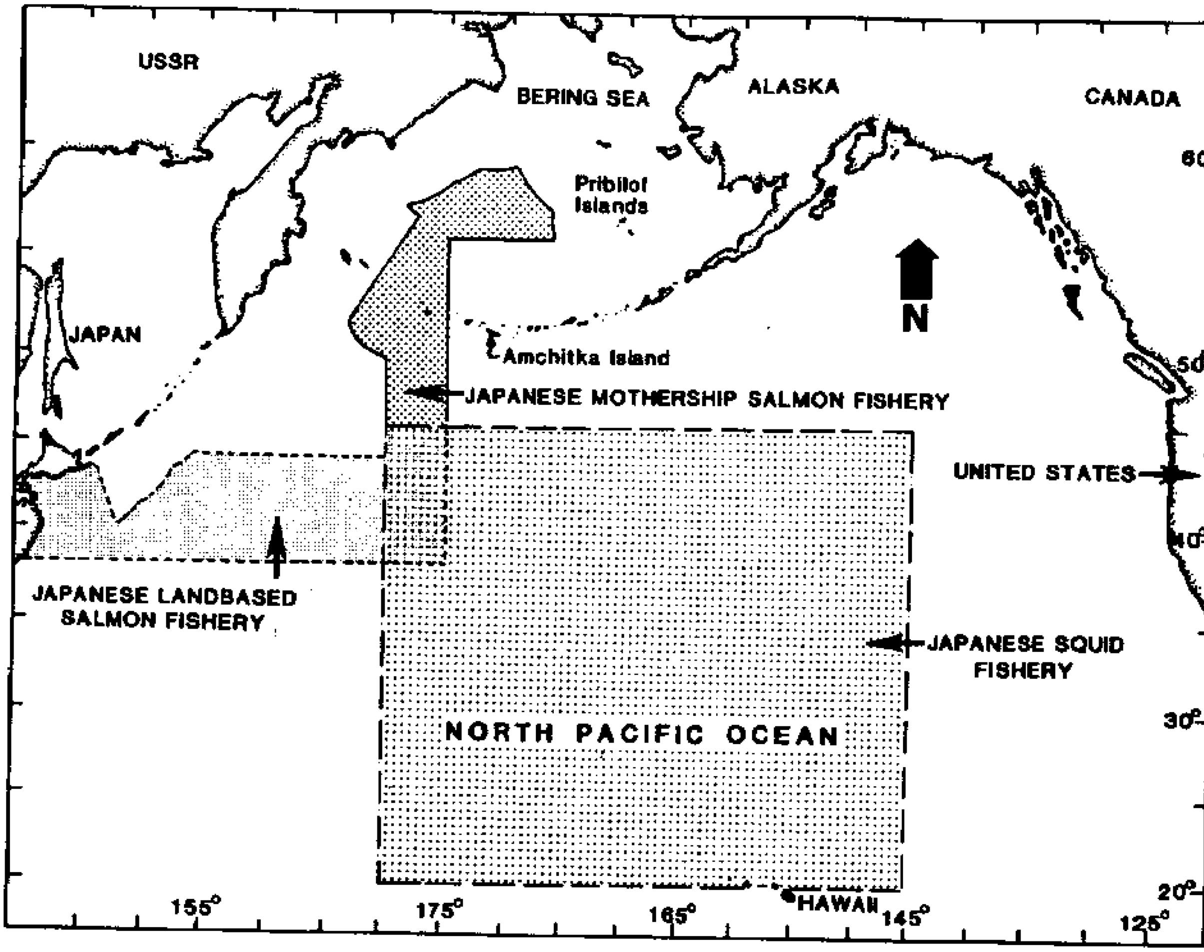

Figure 3.--Locations of Japanese mother ship and land-based salmon fisheries and squid fishery in the North Pacific Ocean and Bering Sea.

The area and number of gill nets fished in the Japanese mother ship fishery decreased greatly between 1974 and 1982 (Fig. 4). In 1977, the U.S.S.R. closed a large area to Japanese gill-netters off its coast in adjacent waters of the North Pacific Ocean and the Bering Sea. In the same year, the International North Pacific Fisheries Commission closed another midocean area between long. 175°E and 175°W and lat. 56°-46°N. In 1980, the number of Japanese salmon gill net boats was reduced nearly two-thirds in the area remaining open to fishing, from 447 boats in 1956 to only 172 boats. With fewer gill nets being fished and the elimination of gill-netting from a large oceanic area, the number of gill net floats on Amchitka beaches declined dramatically from 126/km of beach in 1974 to 59/km in 1982 (Fig. 5).

On the other hand, fishing effort in the Japanese land-based salmon and squid gill net fisheries is increasing, and Taiwan and the Republic of Korea have started new gill net fisheries for squid in the North Pacific Ocean. Little is known about these squid gill net fisheries, except that they are several times that of the combined Japanese mother ship and land-

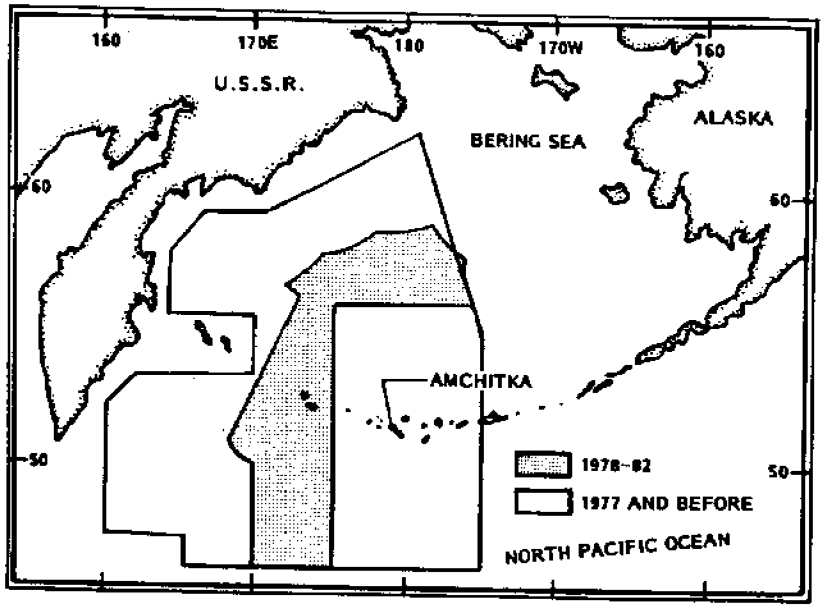

Figure 4.—Areas where Japanese salmon mother ship gill-netters fished in 1952-77 and 1978-82.

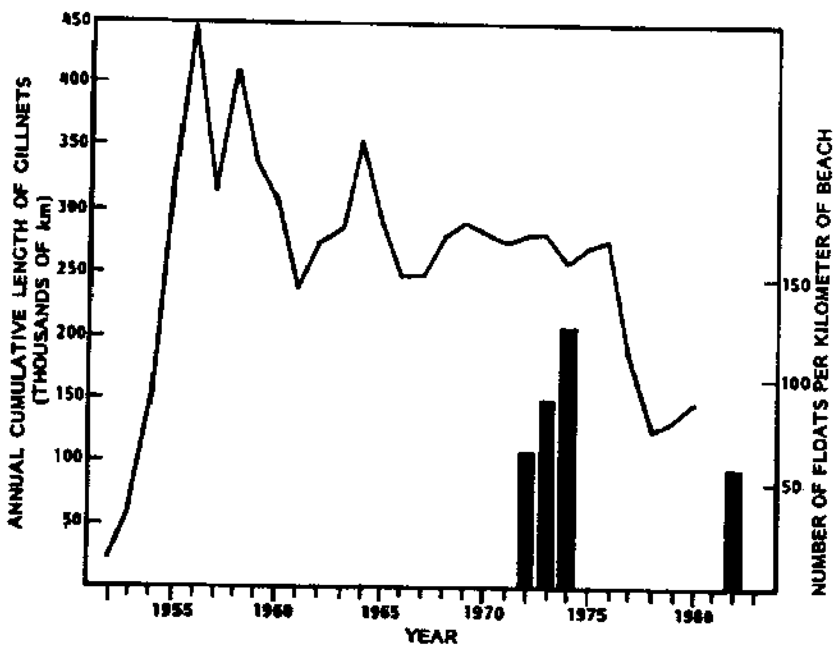

Figure 5.—Cumulative length (days by kilometers) of Japanese gill-netters in the salmon mother ship fishery (1952-80 (line) and number of floats on Amchitka Island beaches 1972-74 and 1982 (bars). Sources of data: 1952-77, Fredin et al. (1977), 1978-80, Michael L. Dahlberg (Auke Bay Laboratory, Natl. Mar. Fish. Serv., NOAA, Auke Bay, AK 99821, pers. commun.).

based salmon gill net fisheries and extend over a huge area of about 12 million km^2.

Plastic straps, used in trawl fisheries to bind boxes of frozen fish, nets, and other items for shipment, were also common on Amchitka Island. In 1982, straps were second only to gill net floats as the most abundant item. Coincident with the reduction in foreign trawl fishing off Alaska, there were 21% fewer straps on Amchitka beaches in 1982 than in 1974.

After my last surveys on Amchitka Island in 1982, there was increased concern about the numbers of marine animals entangled in litter, and in 1984, I was able to survey beaches at seven locations bordering the central and eastern Gulf of Alaska. Data from Amchitka Island indicated that the amount of litter from fisheries is roughly related to previous fishing effort. Because trawl fishing has decreased in the central and eastern Gulf of Alaska and is now prohibited east of long. 140°W and north of lat. 54°30'N off southeastern Alaska (Stauffer et al. 1983), I, therefore, hypothesized that there would be less fishery litter on beaches in southeastern Alaska.

As expected, trawl web and straps were less abundant in southeastern Alaska than on Amchitka Island, but there was a surprisingly large number of gill net floats, despite the fact that no high seas gill net fisheries have occurred nearby (Fig. 6). At two sites in southeastern Alaska, Middleton and Noyes Islands, the number of floats far exceeded the number at Amchitka Island. Many were weathered and had probably accumulated for years. The types and the proportion of other litter, however, were similar to those on Amchitka Island.

ENTANGLEMENT OF MARINE ANIMALS IN LITTER: IS IT A SIGNIFICANT PROBLEM?

Three types of plastic litter are known to entangle mammals, birds, and fish: trawl web, gill nets, and straps. There are many reports of marine mammals becoming entangled in trawl web but few data on the numbers of entangled animals that die. Shaughnessy (1980) has noted Cape fur seals entangled in trawl web in southern Africa breeding colonies since 1972, and Fowler (1982) concluded, on theoretical grounds, that as many as 50,000 northern fur seals die each year in derelict trawl-web fragments. At this workshop, there were several reports of other marine mammals found entangled in trawl web, including Steller and California sea lions, Hawaiian monk seals, northern elephant seals, and harbor seals.

Loss of discarded monofilament gill nets are also thought to significantly contribute to the entanglement problem, but evidence is lacking. I found only a few gill nets on beaches during the surveys, yet gill net floats were nearly always the most numerous plastic litter on the beaches. This is not surprising, perhaps because more than 2.5 million floats are in use in any year. Several questions must be answered before the extent of the gill net hazard can be assessed: How long after loss do gill nets pose an entanglement hazard? Do floating gill nets ball up soon after loss, thereby greatly reducing their entanglement potential? Do most nets eventually sink to the ocean bottom under the combined weight of leadline and entangled mammals, fish, and birds? (Once sunk, nets will

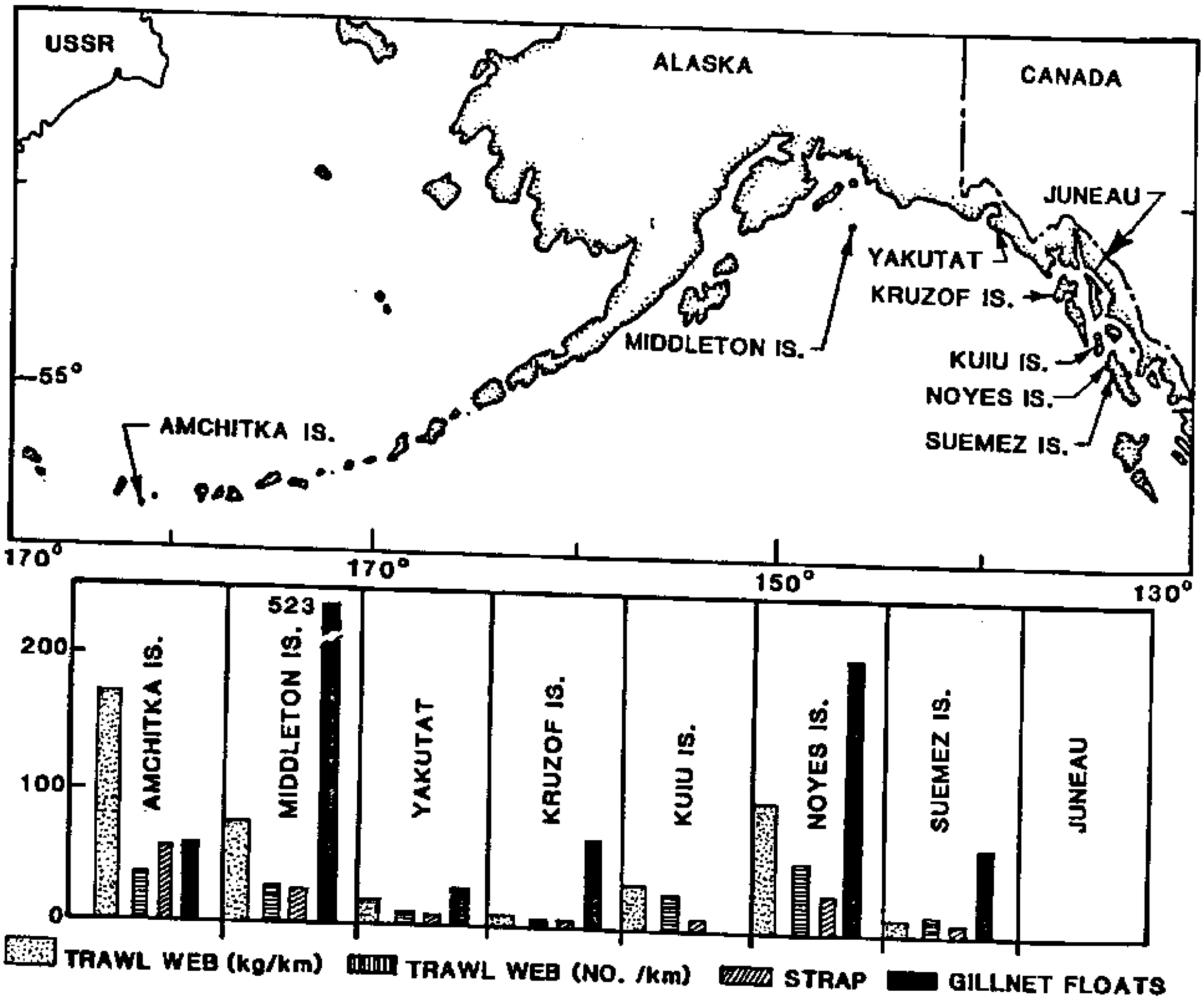

Figure 6.—Weight of trawl web and numbers of trawl-web fragments, strap, and gill net floats on beaches at Amchitka Island in 1982 and southeastern Alaska in 1984.

remain on the bottom because floats lose their buoyancy when permanently compressed by water pressure.) Why are gill net floats, unattached to net fragments or lines, nearly always the most numerous plastic litter item on beaches? How do floats come loose from the nets to which they are attached?

Straps, the third plastic litter item, form continuous loops (Fig. 7) that, if not cut before discarding, can entangle marine mammals. Six percent of the straps on Amchitka beaches in 1982 were uncut, and Fowler (1982) noted straps on about one-third of the entangled fur seals on the Pribilof Islands. Fur seals put their heads through the loops and are then unable to back out of them (Fig. 8). This source of entanglement could easily be eliminated if the straps were cut before being discarded.

Figure 7.--Uncut strap.

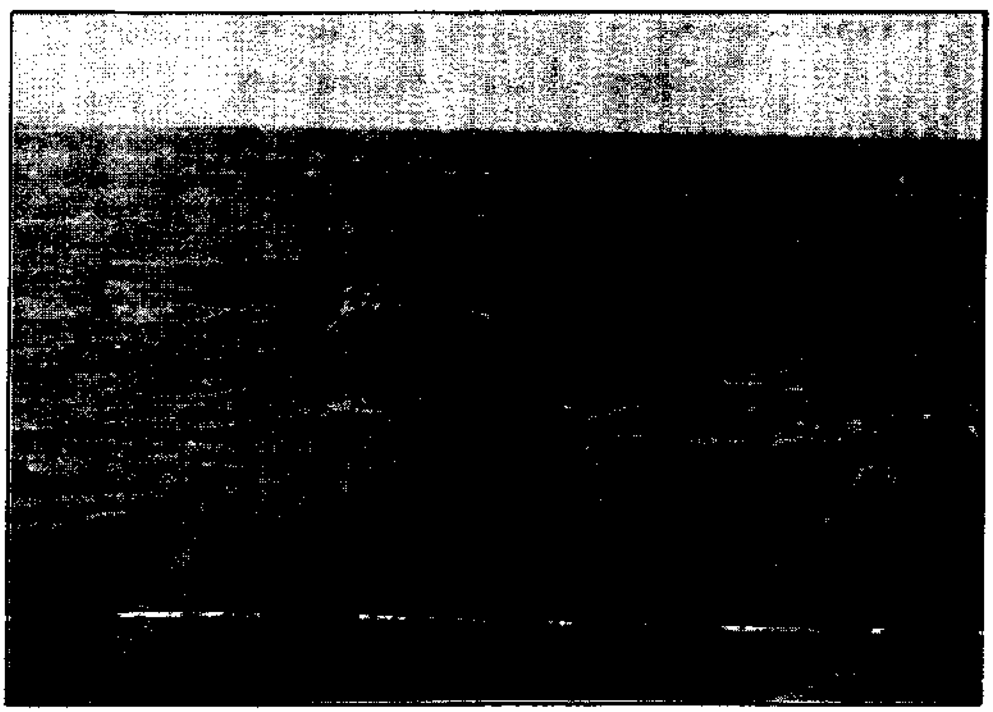

Figure 8.—Fur seal with uncut strap around shoulders, St. Paul Island, Pribilof Islands.

CAVEATS AND INTERPRETATION OF BEACH SURVEYS

Comparisons between the 1984 survey in southeastern Alaska and 1982 survey on Amchitka Island illustrate some of the problems affecting conclusions based on beach litter surveys (Fig. 6). For example, quantities of litter on beaches vary enormously, even on beaches with similar characteristics, such as Noyes and Kuiu Islands in southeastern Alaska. These islands are only about 32 km apart; both face southwest and have similar physical characteristics. Yet, compared to Kuiu Island, Noyes Island has about 4 times more trawl-web fragments, 10 times more trawl web (by weight), 4 times more straps, and 3 times more gill net floats. Middleton Island is another striking example of unevenly distributed litter. Beaches on the southern side of Middleton Island are awash in litter, whereas beaches on the northern side have almost none. Undoubtedly, tides, currents, and prevailing winds affect the distribution of litter. Thus, data from beach surveys should be used only for broad inferences. Quantities of litter are so variable and causes of variability so little understood that elegant statistical treatments are inappropriate and could be misleading.

Despite these caveats, some valuable insights can be gained from well-planned, carefully executed beach surveys. For example, based on gill net mesh sizes, I found that most of the gill net fragments on beaches in southeastern Alaska were from the land-based salmon and squid fisheries (Fig. 3). On 15 km of beach in southeastern Alaska, 21 fragments of gill net were found. Fourteen (67%) of these fragments were 110- or 115-mm stretch measure, which is the mesh size used in the Japanese land-based salmon and squid fisheries. Only three (14%) fragments were 120-mm stretch measure, the mesh size used by the Japanese mother ship fishery.

CONCLUSIONS AND RECOMMENDATIONS

I came to two conclusions from my surveys. First, beach surveys are a cost-effective method of assessing the quantities, types, and sources of litter and trends in accumulations, if surveys are standardized over measured sections of beach. Second, litter on beaches disappears quite rapidly if disposal or loss of litter at sea is reduced or eliminated.

Plastic marine litter could be drastically reduced if existing legal and regulatory mechanisms were used more effectively to control ship-generated litter. The principal international treaty regulating pollution of the marine environment by ships is the 1973 International Conference on Marine Pollution from Ships which is administered by the InterGovernmental Maritime Consultative Organization (IMCO). Annex V of this treaty limits the disposal at sea of plastics, including synthetic ropes and nets (IMCO 1977). As of 1 February 1985, only 21 countries, representing about 33% of the gross tonnage of the world's merchant shipping, have ratified Annex V. Japan, which has been one of the principal sources of plastic litter in Alaska waters, ratified the Annex V in October 1983, but none of the other countries with fishing fleets off Alaska (including the United States, U.S.S.R., Republic of Korea, and Taiwan) have done so. The North Pacific Fishery Management Council, which controls conditions under which fishing is permitted within 200 miles of the Alaska coast, could also be effective in reducing plastic pollution off Alaska. Ships could be required to retain aboard all garbage and scrap netting for shore disposal, as a condition for securing a fishing permit, and penalties could be imposed for violations.

Additional studies are needed: The countries that are sources of derelict fishing gear need to be identified, possibly by the physical and chemical characteristics of the gear itself. At present, this is usually not possible because most net material is manufactured in Japan and the nationality of the fishery that actually used a fragment of net cannot be determined. Distinctive chemical or visual tracers could be incorporated in nets during manufacture to identify the national origin, and nets could be designed so they would be less hazardous if lost. Future investigations of sources of derelict gill nets should probably place greater emphasis on land-based salmon and squid fisheries than on the mother ship salmon fishery. Beach surveys should be expanded to determine which regions have the greatest concentrations of litter. Experiments should be conducted with marked debris on beaches to determine whether most litter stays ashore once stranded. Finally, we need to inform fishermen that carelessly disposed nets and straps can trap and kill marine animals.

ACKNOWLEDGMENTS

I gratefully acknowledge the help of Sidney Taylor, Robert Budke, and especially Scott Johnson in making the 1984 surveys. The Marine Mammal Commission provided travel funds for the 1984 Alaska beach litter surveys and a part of my expenses to attend this workshop; neither would have been possible without this assistance.

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APPENDIX

INSTRUCTIONS FOR SURVEYING BEACHES AND RECORDING DATA

Careful preparations should be made before surveys begin. These preparations include: (1) precisely defined objectives, (2) detailed, explicit instructions on methods and procedures, (3) portable marking, weighing, and measurement equipment, and (4) large-scale maps of beach survey sites.

Equipment for beach surveys (available from Forestry Supplies, Inc., P. O. Box 8397, Jackson, MS 39204) is simple, inexpensive, and easily carried: a Hip-chain[1] to measure length of beach surveyed (Fig. A-1); a

Figure A-1.--Adjusting Hip-chain to begin measurement of beach survey.

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Trecoder Spotgun with orange dye to mark boundaries of beach surveys (Fig. A-2); a set of Pesola precision spring scales, 50 to 20 kg, to weigh fragments of netting and other debris (Fig. A-3); surveyor's fluorescent flagging tape; a clipboard with water-resistant, preprinted forms; No. 2 lead pencils; and 1:62,500 U.S. Geological Service quadrangle maps.

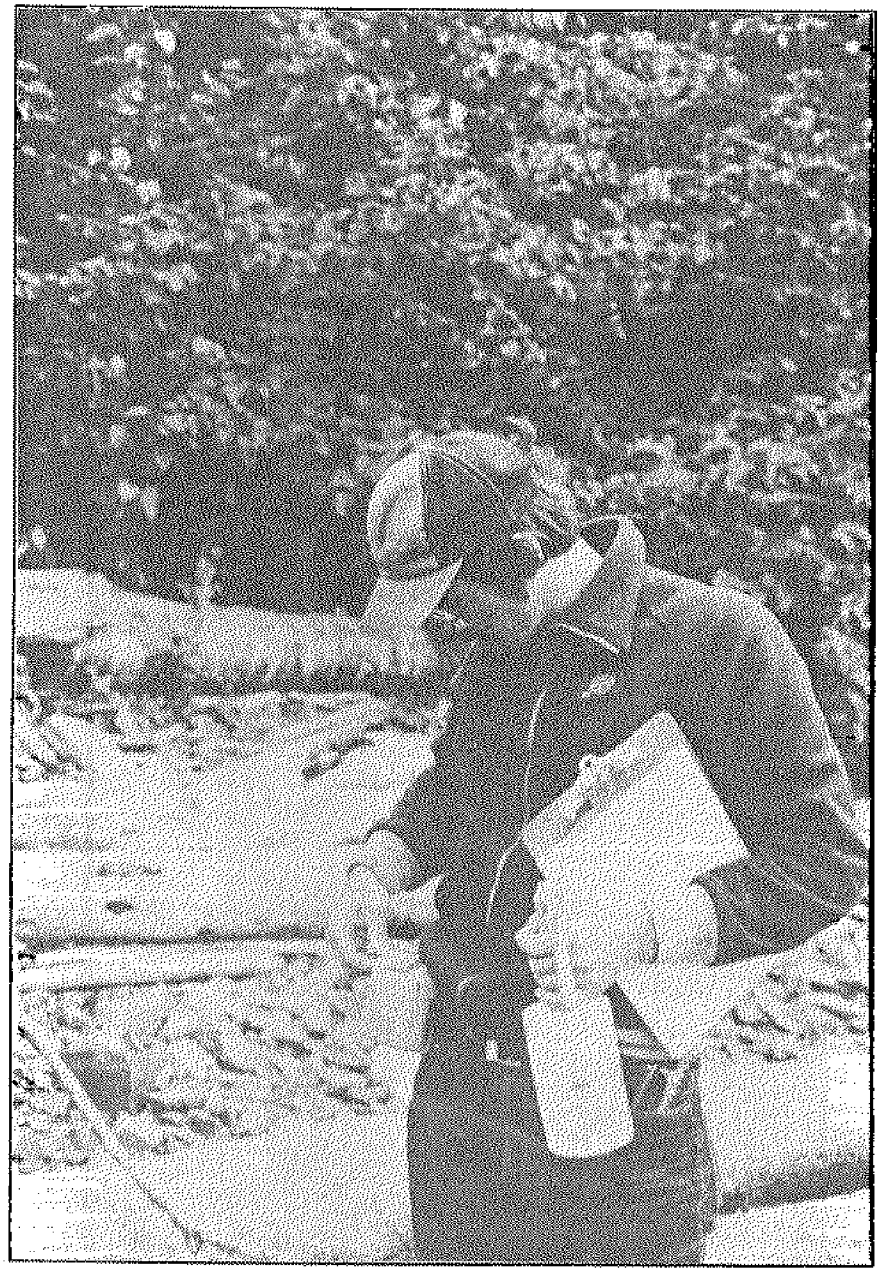

Figure A-2.--Trecoder spotgun with ink reservoir and form on clipboard, left hand.

Figure A-3.--Weighing trawl-web fragment with Pesola spring scale.

SELECTING BEACHES

Preferred beaches for litter surveys are moderate to steep, sand or gravel beaches that are exposed to the open sea. The beaches should have at least 1 km of similar substrate and slope and be as far as possible from urban areas to minimize bias from local garbage. Low-gradient beaches are unsuitable because storm winds and surf scatter litter inland, where it becomes hidden in vegetation. Boulder, as well as bedrock, beaches are also unsuitable: Litter in crevices between boulders is difficult to see, bedrock beaches are often too steep to walk on, and litter does not accumulate there.

MARKING AND DESCRIBING THE BEACH

Estimate, or preferably measure with a Hip-chain, the length of beach surveyed so that litter data from beaches of different lengths can be quantitatively compared. If possible, one end of the beach survey should be a permanent landmark (e.g., river mouth, rock outcrop, tree, or building). Permanently mark each end of survey with dye and surveyor's flagging. Write a brief description of the beach, mark the location on a large-scale map, and photograph the marked ends of the beach so the survey section can be relocated easily.

SURVEY METHODS

Depending on the amount of litter, it normally takes from 4 to 16 h for two people to survey 1 km of beach. Count litter items within the intertidal zone, from the water's edge to the seaward limit of terrestrial vegetation at the upper limit of normal high tide (Fig. A-4). Most litter

Figure A-4. Limits of intertidal survey area at Middleton Island, Gulf of Alaska: from edge of water (bottom and right of photo) to upper limit of normal high tide (center, where driftwood is concentrated). Extreme storm tides scatter litter across the lowland, which is vegetated to the bluff (upper left), but this area is not included in surveys.

is concentrated near the upper limit of normal high tides. Count all plastic items visible from a walking height (i.e., anything larger than about 5 mm). Do not search for litter within piles of driftwood (Fig. A-5). Tabulate and estimate the weight of only the visible portion of net fragments (Fig. A-6); ignore the buried portion. Do not dig or pull out net fragments partially buried in sand, driftwood, kelp, or cobbles. If a snarl of several sizes of netting cannot be separated, estimate the weight of each size (Fig. A-7).

INSTRUCTIONS FOR RECORDING OBSERVATIONS

See Figure A-8 for an example of a completed beach litter survey form. Use metric system for all measurements.

Right Margin

A metric scale is printed for measuring mesh sizes, twine diameter, etc.

Upper Left Heading

Name of surveyor(s) and date of survey.

Figure A-5.--Driftwood with trawl-web fragment in foreground. Information is recorded only for litter visible on the surface.

Figure A-6.--Trawl-web fragment partially buried in beach sand. Information is recorded only for portion which is visible.

Figure A-7.--Snarl of several sizes of trawl web. For each, mesh sizes are measured, but weights are estimated.

BEACH LITTER SURVEY — Sheet 2 of 3

Name of Surveyor: Scott Johnson
Date of Survey: 7/14/84
Location: Middleton Island
USGS Quad.: Middleton Island
Lat. ______ Longitude ______

Length of Beach (m): 1000
Sand: ______
Gravel: ✓
Boulder: ______
Time: noon to 8:30 pm

ITEM	PART FRAG	WT. kg (Est.)	STRETCH MESH (mm)	TWINE (mm)	COLOR	REMARKS	TOTAL EACH ITEM
TRAWL WEB		1.2 kg	235	3	B		1
	✓	(300g.)	50	5	BK	Under log	1
	✓	(400g.)	200	3	G	In gravel	1
	✓	(100g.)	70	5	Orange	Braided Knotless mesh	1
		.45kg	110	2	B		1
* STRAPS - OPEN		Y	B /	W	R	G /	2
CLOSED (cm. stretch)		1-50 cm					1
TRAWL FLOATS (cm. o.d.)		24 cm. BK	30 cm. Orange	26 cm BK			3
		26 cm BK					1
SYNTHETIC LINE (diameter & length)		16mm-5m	19mm-1m	35mm-5m	7mm-1m	35mm-5m 6mm-1m	6
		10mm-1m	16mm-2.5m	19mm-1m			3
BAIT CONTAINERS		|					1
GILLNET FLOATS		卌 卌 卌 卌 卌 ||||					29
BOTTLES		卌 卌 卌 卌 ||||					24
CAPS and LIDS		卌 卌 ||					12
FRAGMENTS - HARD		卌 卌 卌 卌 ||||					24
SOFT		卌 |||					8
BUOY BAGS		卌					5
OTBD./OIL CONTAINERS		||					2
6-PACK YOKES		|					1
Visqueen < 1m²		|||					3
Styrofoam		卌 卌 卌 |					16
Mono gillnet		Small wad, no floats - 55mm				stretch mesh	1
Pail							1
Beverage crate		1-Kirin Beer	1-Asahi Beer			1-Mitsuya cider	3

HIFU 5/84

* G = GREEN R = RED Y = YELLOW
W = WHITE B = BLUE BK = BLACK

TOTAL ITEMS THIS SHEET: 151

Figure A-8.--Example of completed beach litter survey form.

General location (e.g., 10 km south of Yakutat).

U.S. Geological Survey 1:63,500 quadrangle name (e.g., Yakutat B-5).

Specific location (latitude and longitude, etc.).

Upper Right Heading

Number each sheet and total number of sheets for each beach (e.g., Sheet 1 of 3).

Shoreline length of beach.

Check predominant composition of beach (sand, gravel, or boulder).

Beginning and ending times of survey.

Trawl Web

Use separate line for each fragment. Weigh and measure any fragment that has one or more complete meshes.

For partial fragments ("Part. Frag.").--Enter a check (✓) mark for each piece of webbing which is partially buried or tangled and weight of entire fragment cannot be determined; estimate weight of exposed portion only.

Weight (Wt.).--Select spring scale with appropriate range and weight to nearest whole scale marking. Obtain accurate weights of small fragments, especially <1 kg. Indicate "g" for grams or "kg" for kilograms for each weight.

Stretch mesh.--Knot to knot inside measure of one representative mesh, stretched tight.

Twine.--Diameter of mesh twine in millimeters (mm).

Color.--Indicate mesh color by symbol: G = green, W = white, R = red, B = blue, Y = yellow, BK = black.

Remarks.--Additional comments, e.g., "snarl of mixed mesh sizes and colors" or "weights of individual fragments in snarl not estimated."

Strap

Indicate strap color by symbol as above (Trawl Web section).

Open.--Stroke tally number of cut (open) straps, each color.

Closed.--Measure inside length of each strap stretched tight (equals one-half strap length). Use separate block for each strap.

Trawl Floats

Indicate diameter (often marked on float) and color.

Use separate block for each float.

Synthetic Line

Estimate or measure diameter and length of each piece. Use separate block for each piece.

Bait Containers

Stroke tally each container. Several types are used and can be recognized by numerous small holes drilled or moulded in sides of container.

Gill Net Floats

Stroke tally each whole float or fragment greater than one-half. Tally each float less than one-half as a "hard fragment."

Bottles

Stroke tally plastic containers, collectively lumped under the terms "bottles." Do not count tops or lids separately if on container.

Caps and Lids

Stroke tally those that are not on containers.

Fragments [2]

Stroke tally hard and soft fragments separately. This category defies precise definition. It is a subjective catchall for broken pieces of larger items. Most are small. Include any fragment less than half the original item. Arbitrarily decide whether it is "hard" or "soft" plastic. Most soft fragments are bits of synthetic line, trawl web composed of less than one complete mesh, or seine twine. Hard fragments are bits of gill net floats, buckets, etc.

Buoy Bags

Stroke tally without differentiating size. These are inflated commercial fishing floats, usually orange with dark blue tapered tip.

Outboard Oil Containers

Stroke tally without differentiating size (some are imperial quarts and some are U.S. quarts).

Six-Pack Yokes

Stroke tally.

Miscellany

Use blank lines at bottom of form for additional items not on printed list. Continue remarks on reverse of form to describe unusual litter.

---

[2] This classification has not yielded useful information and is time consuming--may be omitted.

Describe gill net wads, indicating mesh material (monofilament or multifilament nylon), float material (hollow or sponge plastic), color, number and type of floats, stretch-mesh size, weight (actual or estimated), whether corkline and leadline are single or double, and if leadline is lead-core or with attached leads. Also describe and photograph remains of any mammals, fish, or birds.

After completing each survey, immediately check information recorded on form to make sure all data are complete and legible. Add totals for each item on each sheet and record sum in right column; add totals of all items on each sheet and record sum at bottom of sheet, lower right.

OBSERVATIONS OF NET DEBRIS AND ASSOCIATED ENTANGLEMENTS IN THE NORTH PACIFIC OCEAN AND BERING SEA, 1978-84

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ABSTRACT

Since 1978, observers collecting marine mammal sighting data in the North Pacific Ocean and Bering Sea during the period May to August have also recorded sightings of discarded net debris and entangled animals. Sightings of net debris were made between lat. 38°28' and 57°31'N and between long. 151°28'W and 179°35'E. Of the net fragments that could be identified, three were trawl web, ranging in size from about 1 m to larger pieces of indeterminate size, and six were gill net, 20 to 150 m long. Two trawl net fragments had a total of three entangled northern fur seal, <u>Callorhinus ursinus</u>, but no marine mammals or other animals were observed in the remaining pieces. One other northern fur seal was observed with a small piece of gill net around its neck. In addition observers reported four instances of discarding of gill net fragments by fishing vessels.

Three abandoned gill nets were observed outside the western North Pacific fishing areas in 1978 and 1981. One of these was retrieved by a research vessel off Agattu Island, Alaska. Although there were no marine mammals, several hundred seabirds and salmon were entangled.

During this study, data on most sightings of net debris were collected incidentally. However, during five cruises in 1982-84, observers did search for net debris and record all sightings. During the 1984 field season, all marine mammal observers (n = 20) in the western North Pacific conducted searches for net debris during daylight transits. In addition, personnel aboard NOAA vessels began recording debris sightings in the eastern North Pacific. These data are being used to examine the distribution and to quantify the abundance of net debris. To date during 304 h of survey, there have been two sightings of gill net and one of trawl net fragments. This low incidence may be associated with difficulties in sighting debris or a low occurrence of floating debris in the area during this time of year. Marine mammal observers will continue search efforts for net debris and net entanglements during the 1985 and 1986 field seasons.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

INTRODUCTION

Two sources of potential entanglement of marine mammals and birds are fishing gear in active use and lost or discarded gear. Information concerning the latter is limited. Dixon and Dixon (1981) described three methods of obtaining information on the distribution, amount, and composition of litter in the ocean: estimation from the average amounts per day generated by various kinds of activities such as fishing or pleasure boating; observation of floating debris at sea; and surveys of litter on selected beaches.

Beach surveys have provided most information to date due to relative ease of conducting the work and cost effectiveness (Anonymous 1973; Cundell 1973; Dixon and Cooke 1977; Dixon 1978; Merrell 1977, 1980, 1981; Dixon and Dixon 1981; Fowler et al. 1982). This method, however, does not necessarily provide an accurate measure of the kind or amount of debris floating in the ocean.

Data have been collected at sea using surface tows (Carpenter and Smith 1972; Colton et al. 1974; Wong et al. 1974) and benthic trawls (Jewett 1976; Feder et al. 1978). These have provided information on plastic particles and miscellaneous debris but only limited information on net debris. DeGange and Newby (1980) reported one instance of a lost gill net in the western North Pacific Ocean. The only data on floating debris collected by sighting surveys during vessel transits are provided by Venrick et al. (1973) in the central North Pacific Ocean and Morris (1980) using similar methods in the Mediterranean Sea. Neither reported sighting net fragments.

Concern over incidental catch of marine animals has been expressed for turtles (Morris 1980), sharks (Anonymous 1977), seabirds (Tull et al. 1972; Bourne 1977; King et al. 1979), Cape fur seals (Shaughnessy and Payne 1979; Shaughnessy 1980; Bonner and McCann 1982), baleen whales (Perkins and Beamish 1979), small cetaceans (Best and Ross 1977), and northern fur seals (Waldichuck 1978; Kozloff 1979; Fowler 1982; 1985).

This paper summarizes data collected on net debris and associated entanglements in the western North Pacific Ocean and southern Bering Sea from May-August 1978 to 1984. These data provide quantitative information on the amount of net debris present in these areas during the summer, and comparisons between years may be possible. Data from two cruises in the eastern North Pacific are also included.

METHODS

Most data were obtained by United States biologists collecting marine mammal sighting data on Japanese salmon research vessels under the United States-Japan cooperative research program on Dall's porpoise. Each year Japan conducts salmon research in the North Pacific from long. 150°E to 175°W. Vessel tracks are at intervals of about 5° longitude. Since 1978, data have been collected by United States biologists on Japanese salmon research vessels operating from May to August along standard track lines between lat. 38° and 57°N in the western North Pacific Ocean and southern Bering Sea. Beginning in 1981, United States biologists were also placed aboard commercial fishing vessels of the Japanese mother ship salmon fleets operating from 10 June to about 31 July. Eight United States observers were aboard catcher boats each day and collected marine mammal sighting data during transits to and from the mother ship (Fig 1).

The biologists were trained at the National Marine Mammal Laboratory (NMML), Northwest and Alaska Fisheries Center, Seattle, Washington, to conduct marine mammal sighting surveys using the standard methods of the NMML Platforms of Opportunity Program. Observations were made from the flying bridge of the vessel and the forward 180° arc was scanned. Surveys were generally conducted when visibility was greater than 1,000 m and the sea state was Beaufort 4 or less. These are termed "on-effort" data and are used for quantitative estimates of marine mammal populations. Under less favorable conditions and during fishing operations (e.g., setting or retrieving gill nets), sightings were recorded but were considered "off-effort" and used only for determining distribution and seasonality.

During the period 1978 to 1983, data on net debris, abandoned gill nets, and associated entanglements were recorded inconsistently. Starting in 1984, biologists were instructed to search for and record all observations of net debris, including date and time of sighting, longitude, latitude, type and amount of gear, and the number and species of animals entangled. Binoculars (7 x 50 or 10 x 50 power) were used to obtain details of the sighting. The sizes of the fragments were estimated as the ship passed by them.

RESULTS

A total of 1,768.5 nmi were transitted during 196.5 h of "on-effort" observation for net debris during cruises in the period from 1978 to 1983 in the western North Pacific (Table 1). Two sightings of net debris were made: a trawl fragment at lat. 52°N and long. 170°E and a gill net fragment at lat. 38°N and long. 174°E (Fig. 2). There were no marine animals entangled in these net fragments (Table 2).

In 1984, 20 observers logged 973.2 h on "on-effort" surveys covering 7,559 nmi in the western North Pacific and 1,200 nmi in the Bering Sea, north of lat. 53°N. Three sightings of trawl net pieces were made; each piece was about 2 m in size. There were also nine sightings of gill net fragments ranging in size from <0.5 to 150 m (Table 2 and Fig. 2). No animals were entangled in these fragments. Four sightings of discarded gill net were within the mother ship salmon fishing area. Five sightings were in the area of the squid gill net and Japanese land-based salmon fisheries (Table 2).

In addition to those described above, 30 sightings of net debris during "off-effort" observations have been recorded. Four of these were trawl nets, 20 were gill nets, one had trawl and gill net fragments, and the remainder were not identified (Fig. 3). Of the trawl net fragments, two had a total of three entangled northern fur seal, *Callorhinus ursinus*. Two northern fur seals, 1 salmon shark, *Lamna ditropis*, 11 birds (various species), and an unknown number of salmon were also entangled in gill net fragments. The size of the gill net pieces ranged from 0.5 to 200 m.

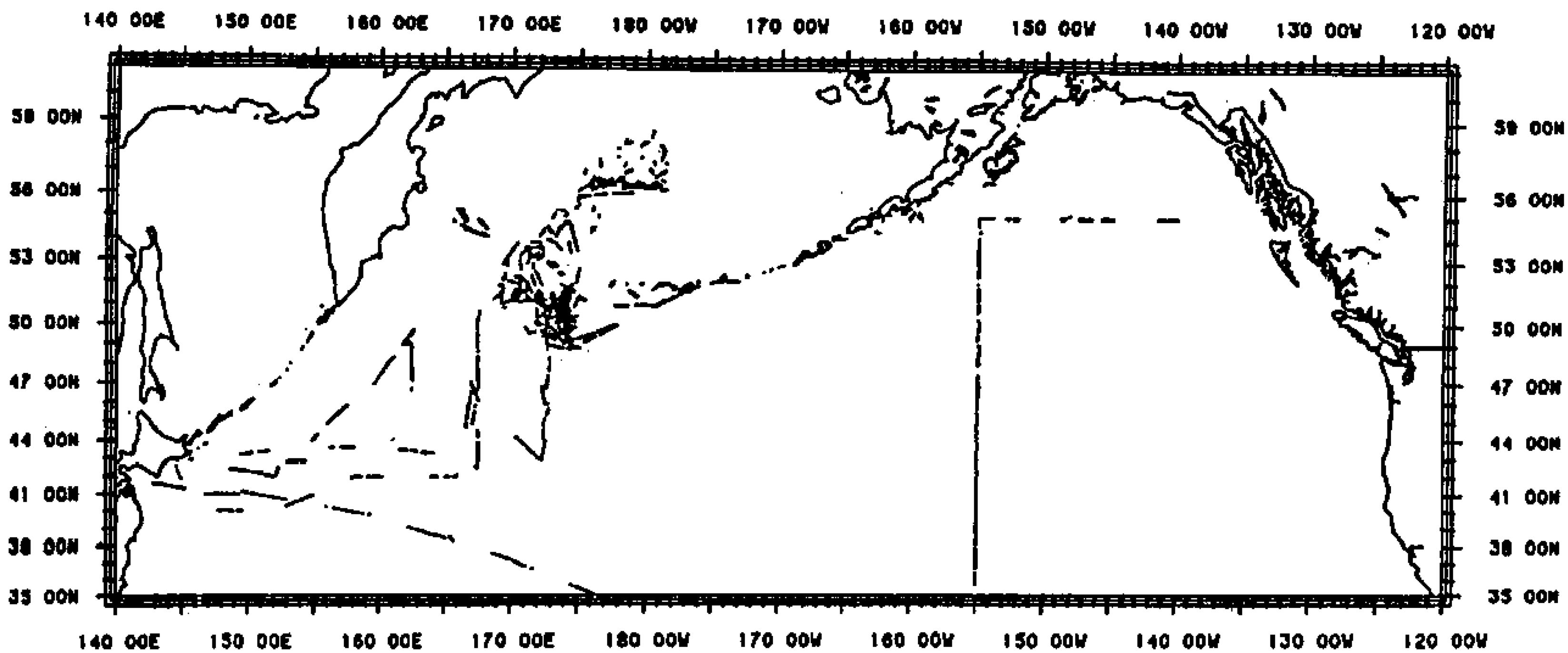


Figure 1.--Cruise tracks during observations for net debris and entanglement, 1978-84.

Table 1.--Hours of effort searching for net debris by Beaufort sea state, distance covered, and number sightings "on effort" of net debris (in parentheses).

Dates	No. of observers	Type of vessel	Distance covered (nmi)	Area[1]	Beaufort state 0	1	2	3	4	5	6	Total hours	No. of sightings
1982-83	2	Commercial	1,138.5	WNP	0	8.0	32.0	56.5(1)	24.0	6.0	0	126.5	1
1983	1	Research	630.0	WNP	0	1.5	17.0	9.0(1)	29.5	9.5	3.5	70.0	1
1984	16	Commercial	3,561.0	WNP	11.3	35.1(1)	90.2	180.2(2)	71.5	8.4	0	396.7	3
1984	8	Commercial	1,085.0	BS	4.8	8.0	34.1	41.5	25.9	2.4	0	116.7	0
1984	4	Research	4,113.4	NP	10.4	48.8(1)	118.1(4)	153.4(4)	87.4	36.0	2.9	457.0	9
Sightings per hour of effort (x^{10-2})					0.0	1.97	1.37	1.82	0.0	0.0	0.0		

[1]Abbreviations: WNP = western North Pacific Ocean; BS = Bering Sea, north of lat. 53°N; NP = North Pacific Ocean including eastern and western areas.

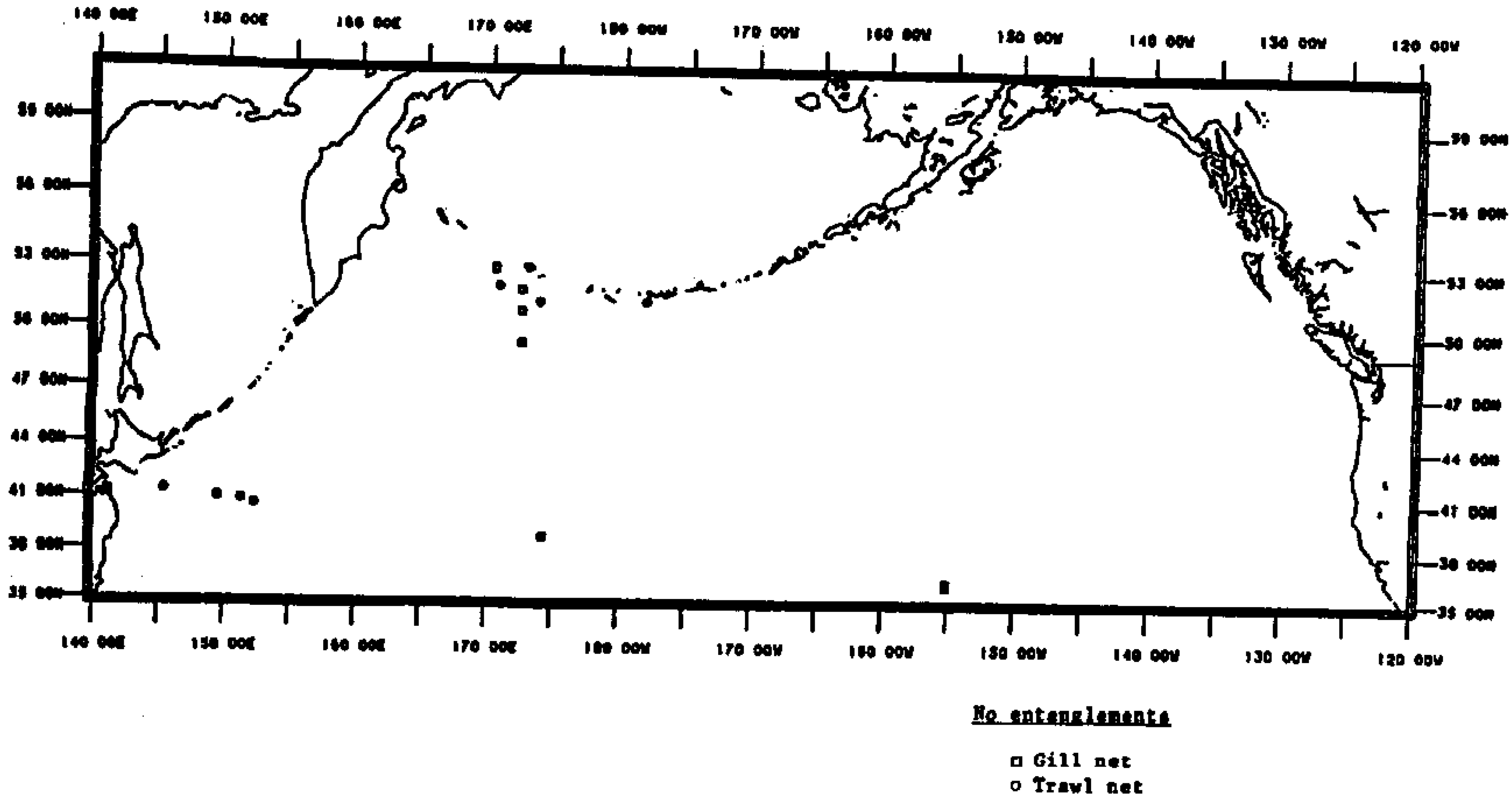
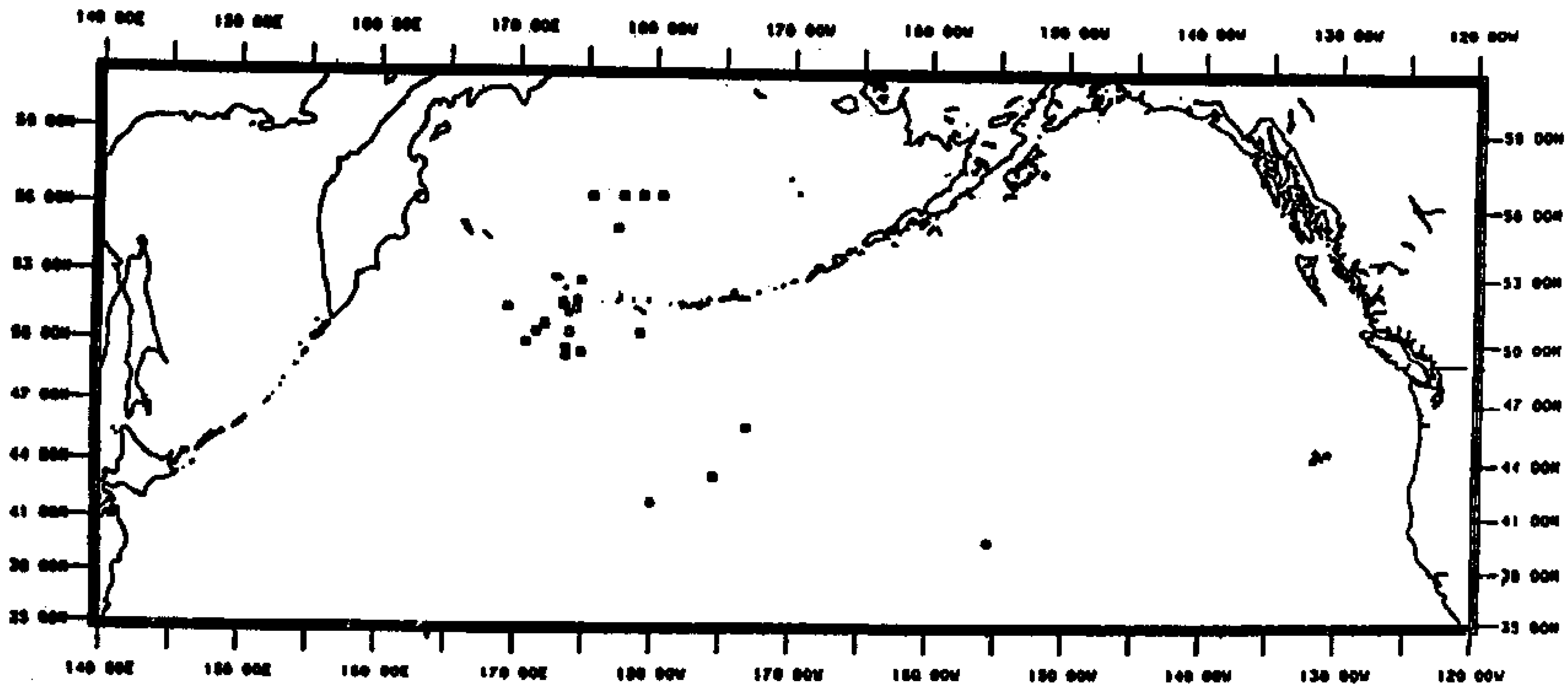


Figure 2.--Sighting of net debris during "on-effort" searches.

Table 2.--Sightings of net debris during "on-effort" searches by observers. See Table 1 for hours of sighting effort.

Date	Vessel type	Lat. N	Long.	Net type	Debris size	Entanglements
7/24/82	Research	38°28'	174°28'E	Gill net	20 m or more	None
6/20/83	Commercial	52°07'	170°35'E	Trawl	1 m or more	None
6/6/84	Commercial	51°16'	178°17'W	Trawl with yellow poly line	1 m^2	None
6/30/84	Commercial	50°58'	172°24'E	Gill net with floats	4 m	Kelp
7/19/84	Commercial	51°11'	173°40'E	Trawl, possibly broiler or sling	2 m^2	None
7/5/84	Research	40°59'	149°17'E	Gill net with floats	100-150 m	None
7/6/84	Research	52°52'	170°23'E	Gill net	Unknown	None
7/9/84	Research	51°55'	172°14'E	Gill net with floats	Unknown	None
7/12/84	Research	49°32'	172°37'E	Gill net	1 m^2	None
7/31/84	Research	36°01'	155°02'W	Gill net with floats	50 cm^3	None
7/31/84	Research	36°07'	155°02'W	Gill net with poly line	1 m	None
8/20/84	Research	40°47'	152°15'E	Gill net with floats	3 m	None
8/20/84	Research	40°55'	151°11'E	Gill net with floats	50 m	None
8/21/84	Research	41°18'	145°18'E	Trawl with 10 in. round, orange float	2 m	None



No entanglements

- □ Gill net
- ○ Trawl net

With entanglements

- ■ Gill net
- ● Trawl net

Other sightings

* With fishing debris

Figure 3.--Sightings of net debris during "off-effort" searches.

The majority of net debris sightings were gill net fragments in the western North Pacific (Table 3). Of seven sightings in the eastern North Pacific, one trawl fragment, two gill net fragments, and four unidentified fragments were recorded. In the Bering Sea, there were six fragments; one was trawl net, the remainder, gill net (Table 3 and Fig. 3). The preponderance of gill net fragments is a reflection of sighting effort being mainly in gill net fishing areas.

The effect of weather conditions on sighting of debris is shown in Table 1. There were no "on-effort" sightings of net debris in sea state of Beaufort 4 or greater although there were 309+ h of observation. During "off-effort" periods, net fragments were sighted on nine occasions in sea states of Beaufort 4 or greater, however, in five cases the fragment was entangled in the vessel's gill net or other gear being brought on board (i.e., fragments were not sighted free floating).

In 7 years there were eight records of gill net discard from vessels. Corklines and leadlines were removed in all but one case. Size ranged from a clump of net <0.5 m^2 to a 400 m length.

Since 1978, three lost or abandoned gill nets have been sighted. In 1978 DeGange and Newby (1980), aboard a salmon research vessel in the western North Pacific (lat. 49°15'N and long. 168°14'E), observed the retrieval of 1,500 m of gill net with 99 seabirds, 2 salmon shark, Lamna ditropis, 1 ragfish, Icosteus aenigmaticus, and more than 200 chum salmon, Oncorhynchus keta, and coho salmon, O. kisutch entangled. On 16 June 1981, an abandoned gill net (approximately 15 km) was retrieved off Agattu Island (lat. 51°38'N and long. 175°48'E) by the crew of a vessel dedicated to marine mammal research. No marine mammals were entangled but there were two salmon shark, L. ditropis. At least 255 auklets (several species), 14 horned puffin, Fratercula corniculata, 37 tufted puffin, Lunda cirrhata, 16 murres, Uria spp., 17 shearwaters, Puffinus spp., and 14 unidentified birds were also entangled. Salmon were in poor condition indicating the net had been fishing for at least several days. Salmon were counted for only 35 min of the nearly 3 h of the retrieval period; the minimum observed count was 175.

On 15 July 1984 at lat. 55°18'N and long. 174°20'E, one section of gill net (approximately 5 km) including radar, radio, and light buoys was lost during fishing operations. Two sections (approximately 10 km) were retrieved, with one Dall's porpoise, Phocoenoides dalli, one ancient murrelet, Synthliboramphus antiquus, two spiny dogfish, Squalus acanthias, and numerous salmon.

DISCUSSION

The amount of net debris and number of associated entanglements observed are low in spite of the fact the study was conducted primarily in the gill net fishing area. The low incidence of sightings may be a function of the difficulty of sighting debris or of infrequent occurrence of net fragments. Certainly fragments are difficult to see if weather conditions are poor or the distance from the vessel is large. Although the majority of our sightings involved spotting floats on the fragments, the floats are small, often drab colored, and therefore, often difficult to see

Table 3.--Locations and types of net debris collected during poor sighting conditions, fishing operations, and other periods of nonactive search for net debris ("off-effort").

Date	Vessel type	Lat. N	Long.	Net debris: Type	Net debris: Size	Entanglements
			A. Western North Pacific Ocean			
6/14/84	Commercial	50°44'	171°49'E	Gill net and trawl with floats	1-1.5 m ball	Kelp
6/24/84	Commercial	49°29'	173°35'E	Gill net with floats	5 m	None
6/26/84	Commercial	52°07'	174°34'E	Trawl	4 m^2	None
6/27/84	Commercial	51°46'	174°25'E	Gill net with floats	10 m	None
7/1/84	Commercial	49°57'	173°38'E	Gill net with floats	2 m	Salmon shark
7/3/84	Commercial	51°44'	174°12'E	Gill net with blue floats	10 m	None
7/4/84	Research	51°45'	169°28'E	Gill net	0.2 m^2	
7/12/84	Research	50°41'	173°51'E	Gill net	1 m^2	None
7/13/84	Commercial	51°33'	174°03'E	Float with black webbing	Unknown	None
7/14/84	Commercial	56°35'	179°05'W	Gill net, 3-5 floats		None
7/15/84	Commercial	51°55'	173°35'E	Gill net	1 m^2	None
7/15/84	Commercial	51°55'	173°35'E	Gill net, black	2 m^2	None
7/16/84	Commercial	50°40'	179°03'E	Gill net	3 m^2	None
7/18/84	Commercial	49°44'	174°47'E	Gill net	0.5 m^2 clump	Kelp
6/27/83	Commercial	52°51'	174°50'E	Gill net	100 m or more	Salmon, 11 birds
7/9/83	Commercial	50°59'	172°06'E	Gill net	20.3-cm ball	None
6/19/82	Commercial	50°16'	170°47'E	Gill net (?)	Small piece around animal's neck	Northern fur seal
6/20/81	Research	42°22'	180°00	Trawl (?)	Unknown	2 northern fur seals
			B. Eastern North Pacific Ocean			
6/4/84	Research	44°40'	130°23'W	Net with glass ball	Unknown	None
6/6/84	Research	44°39'	130°27'W	Unknown	2 m clump	None (entangled on CTD gear)
6/6/84	Research	44°37'	130°27'W	Net with yellow glass ball	Unknown	None
6/7/84	Research	44°44'	130°38'W	Net with yellow glass ball	Unknown	None
7/29/84	Research	39°27'	155°00'W	Trawl	0.5 x 2 m	None
7/13/78	Research	45°49'	172°59'W	Gill net	Unknown	1 northern fur seal
7/17/78	Research	43°30'	175°00'W	Gill net	200 m	Unknown
			C. Bering Sea			
6/30/84	Commercial	57°05'	177°43'E	Gill net	2 m clump	Kelp
7/13/84	Commercial	56°30'	179°21'E	Gill net	0.5 m^2 clump	Algae
7/12/84	Commercial	56°29'	177°52'E	Gill net with floats	Small amount	None
7/13/84	Commercial	56°40'	178°08'E	Gill net	5 m	None
7/16/84	Commercial	56°34'	175°39'E	Gill net with floats	5 + 1-2 m trailing	None
7/9/80	Research	57°31'	151°28'W	Trawl (?)	Unknown	1 northern fur seal

unless close by and weather and sea state conditions are good. Since gill net monofilament is nearly transparent in water, to date gill net debris without floats attached have only been recorded when they entangle on operational gear. Thus, our sightings of net debris may underestimate the amount present in this area.

Observations of the discard or loss of gill nets from research and commercial vessels have been rare. The economic incentive from selling used nets for recycling in Japan may help to reduce the amount of discard (K. Kasai, 6-2 Otemachi 2-Chome, Chiyoda-ku, Tokyo, Japan to M. Dahlberg, Auke Bay Lab., Northwest Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Auke Bay, AK 99821 pers. commun., July 1983).

Movements of live animals entangled in debris may attract an observer's attention and increase the likelihood of sighting. However, dead animals are often submerged and thereby missed by the observers, possibly resulting in an underestimate of the number of entangled animals killed.

The lack of observations of cetacean entanglement in net fragments may be related to the low probability of entanglement. In the Japanese mother ship salmon fishery, entanglement of porpoise is a relatively rare event, even in the large commercial nets 15 km long (less than one porpoise per set) (Jones 1984). Therefore, the probability of an animal being caught in a small fragment would also be expected to be low.

All our sightings of marine mammals entangled in debris were of northern fur seals. Although entanglement in gill nets is rare in the salmon fishery (<10 per year), fur seals are frequently observed playing near the nets. It is possible they similarly play with fragments and become entangled if the mesh and fragment size are large enough.

Determining the impact of net debris on marine animal populations will require more information on a number of factors: Distribution of animals in relation to fishing operations, size of mesh, size of fragments, and the fate of debris in relation to ocean currents carrying the debris from its original location. For example, one gill net (5 km long) became tangled into a "green rope" within 24 h during a severe storm (Jones pers. observ.). Surf action may tangle net debris similarly (Merrill 1977:fig. 1; photograph in Anonymous 1973). These actions will reduce potential adverse impact on marine animals. Data are also needed on the relationship between fragment and mesh sizes and catchability of different species.

FUTURE RESEARCH

United States biologists on Japanese commercial and research vessels will continue to collect data on net debris and associated entanglements in 1985 and 1986. Observations of net debris will also be recorded by the National Oceanic and Atmospheric Administration research vessels operating in the eastern North Pacific and Bering Sea.

ACKNOWLEDGMENTS

The authors would like to thank the biologists aboard research and commercial vessels for collecting data and M. L. Dahlberg for generously providing his. We also thank Fisheries Agency of Japan and Federation of Japan Salmon Fisheries Cooperative for their support of this project. In addition, we thank H. W. Braham, M. L. Dahlberg, C. W. Fowler, R. V. Miller, M. K. Nerini, and R. Pearson for reviewing earlier drafts and contributing helpful comments. Finally, our thanks to L. Hietala and C. Bouchet for their assistance in preparation of the manuscript.

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ACCUMULATION OF NET FRAGMENTS AND OTHER MARINE DEBRIS IN THE NORTHWESTERN HAWAIIAN ISLANDS
(Abstract only)

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ABSTRACT

Since 1982 Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, field personnel in the Northwestern Hawaiian Islands have monitored the presence and accumulation of webbing and other marine debris considered to pose a hazard to Hawaiian monk seals. This paper summarizes results of this effort in 1982 and 1983. Webbing samples have been grouped by twine diameter and mesh size and provisionally identified as to gear type. Rates of accumulation of marine debris are presented for Lisianski and Laysan Islands.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

OBSERVATIONS OF MAN-MADE OBJECTS ON THE SURFACE OF THE NORTH PACIFIC OCEAN

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ABSTRACT

Studies in the late 1970's of seabirds feeding on plastic and observations of the entanglement of marine mammals in man-made objects at sea have led to concern over the amount of debris accumulating in world oceans. In July and August of 1984, on the Japanese fisheries training vessel Oshoro Maru, a log was kept of man-made objects observed while transiting west from Cape Spencer, Alaska, along lat. 55°N until reaching long. 155°W and then traveling south to Honolulu, Hawaii; a second leg from Honolulu to Hakodate, Japan, was transited in mid-August of 1984. Sightings of 206 items were made between 13 July and 4 August during 124 h and 51 min of viewing while the ship traveled 2,917 nmi. Most (79%) of the debris items were seen between lat. 31° and 39°N along long. 155°W, an area of surface convergence. Only three sightings of net debris were made, and no animals were observed entangled in or near the small pieces of webbing. On the second transect from Hawaii to Hokkaido, Japan, 521 objects were seen between 12 and 21 August during 74 h and 10 min of viewing while the ship traveled 2,573 nmi. The highest density of material was seen between lat. 30° and 35°N. One small piece of gill net and one piece of unidentified webbing were seen. Again, no animals were observed entangled in the netting.

INTRODUCTION

The abundance of marine litter, especially plastic materials, has reached staggering proportions. Hundreds of millions of pounds of debris are being dumped into the sea each year; later, unknown portions of this debris appear on beaches, some of which are far from centers of human

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In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

population (Merrell 1980). Limited observations of marine debris in the central North Pacific Ocean during 1972 indicated that litter on the sea surface is not limited to the vicinity of shipping lanes (Venrick et al. 1973). The concern over marine debris is relatively new, and scientific knowledge about the fate and impact of marine debris is just developing. Little is known about the source, amount, and impact of this debris, and virtually nothing is known about the dynamics of marine debris distribution and disappearance.

In the present study, observations on marine debris were systematically observed during routine sighting surveys for marine mammals and marine birds conducted aboard a Japanese training vessel (TV) in July and August 1984. The summer cruise of 1984 was the maiden voyage across the North Pacific Ocean by the TV Oshoro Maru, which is operated by the Faculty of Fisheries, Hokkaido University, Hakodate, Japan. After a port call at Juneau, Alaska, a cruise track was followed to sample stations with oceanographic instruments, small mesh nets, and pelagic gill nets en route to Honolulu, Hawaii, mainly along long. 155°W (Fig. 1), and then back to Hokkaido--point of origin. A log of marine debris observed was maintained between stations while the vessel was underway.

SURVEY METHODS

Observations were made from either the bridge (8 m above the water) or the flying bridge (10 m above the water) while the vessel was traveling between stations or during the setting of gill nets. Items were usually sighted while scanning abeam and ahead of the vessel. Either 8 x 32 or 10 x 40 binoculars were used to identify and estimate the size of each item. For each sighting, the distance from the observer to the item and the azimuth from the ship's heading to the item also were estimated and recorded with the time of sighting. Geographic coordinates and weather conditions were observed on the ship's satellite navigation system and recorded on the hour and half hour. At the end of the cruise, a formula for dead-reckoning was used to estimate the geographic coordinates of each object sighted from the time of day and half-hourly navigational positions. The items observed were classified by date and time observed, geographic coordinates, distance and angle of sighting, and type, description, and estimated size of material. No object was placed in more than one classification.

RESULTS

Sighting Survey Effort

Sighting surveys were conducted during 32 days while the ship transited approximately 34 degrees of latitude, mostly along long. 155°W (Fig. 1). Observations on the Alaska-Hawaii transect commenced at lat. 55°01.8'N, long. 140°01.2'W, and terminated at the Diamond Head Lighthouse (lat. 21°15.5'N, long. 157°48.7'W), a distance of 2,587 nmi of which 1,516 nmi (59%) were surveyed. Survey effort averaged about 5.5 h per day, and about 82% of the survey time was spent in sea-surface conditions of Beaufort scale 4 or less (Table 1). During 16 of the 23 days, drift gill nets were fished overnight along long. 155°W while the vessel drifted a short distance; therefore, most (75%) of the cruise track along long. 155°W

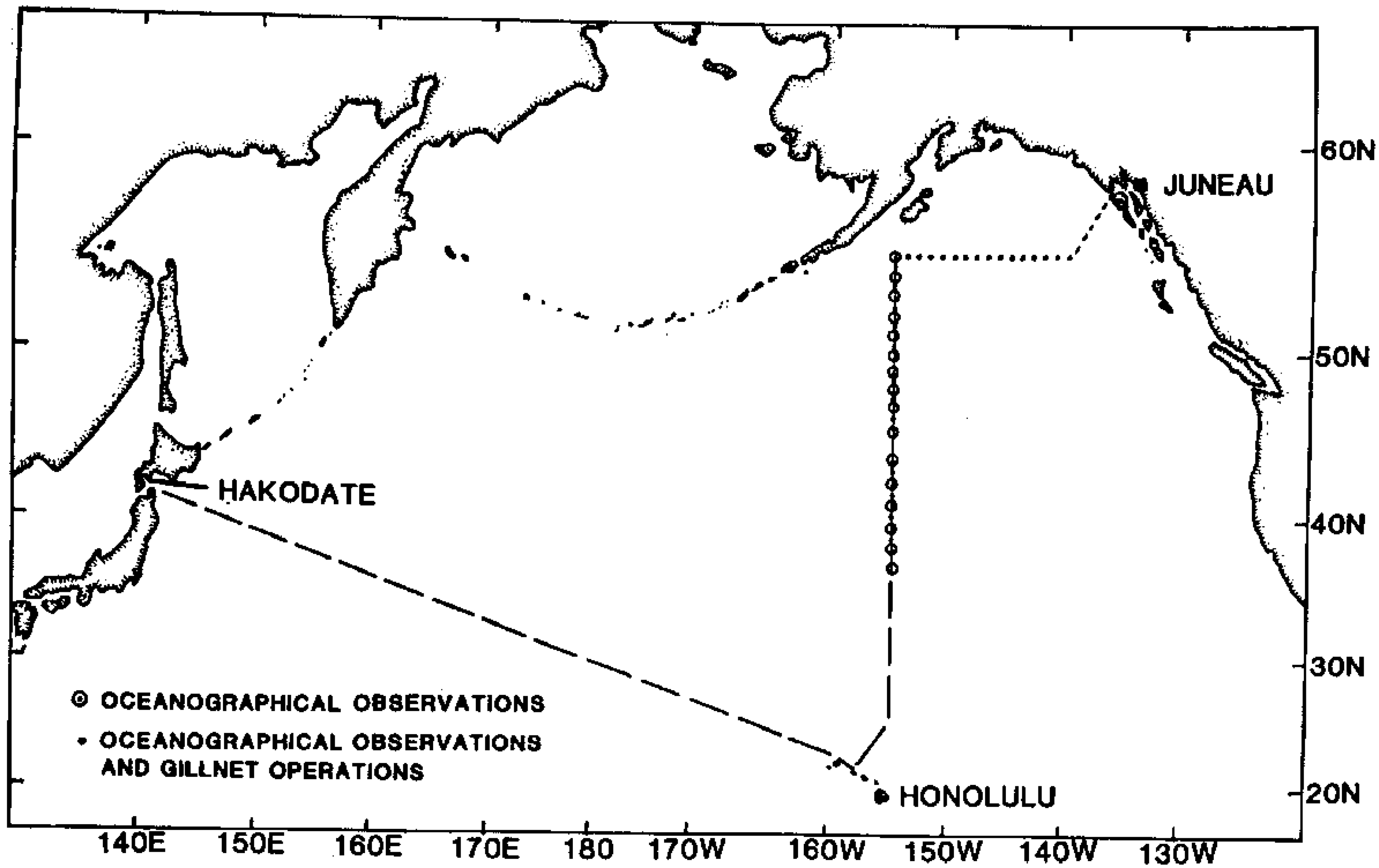


Figure 1.--Cruise track of TV Oshoro Maru, Alaska-Hawaii and Hawaii-Japan, July-August 1984.

Table I.--Sighting survey effort (in hours and minutes) by sea surface conditions during the Alaska-Hawaii (13 July to 4 August 1984) and Hawaii-Japan (12-21 August 1984) transects.

Date 1984	Beaufort scale No. 1	2	3	4	5	6	Total
			ALASKA-HAWAII				
7/13		3:12					3:12
7/14	1:55	1:06	3:28				6:29
7/15		4:40	1:35				6:15
7/16			1:41	1:11			2:52
7/17			2:40	1:51			4:31
7/18		1:16	1:54				3:10
7/19		3:00	1:23	0:55			5:18
7/20					1:01	2:54	3:55
7/21			0:30		3:31		4:01
7/22			0:30	4:39			5:09
7/23		1:20	2:28				3:48
7/24	0:25	5:10					5:35
7/25		2:58	0:34	3:06			6:38
7/26			3:14	2:48			6:02
7/27			6:36				6:36
7/28		2:59	3:35				6:34
7/29	2:50	2:54					5:44
7/30			1:27	3:42			5:09
7/31			6:42				6:42
8/1		4:19	1:30				5:49
8/2					7:39		7:39
8/3					8:00		8:00
8/4				5:43			5:43
			HAWAII-JAPAN				
8/12		2:10	4:40	3:20			10:10
8/13	4:40	3:30					8:10
8/14		2:00	8:00				10:00
8/16			0:40	6:20	1:40		8:40
8/17		0:40	0:40	1:40	5:00	0:30	8:30
8/18	0:30	4:00	4:00	0:20			8:50
8/19				5:00	1:30		6:30
8/20		3:00	2:30	1:40			7:10
8/21	0:30	0:50	4:50				6:10
Total time	10:50	46:04	65:37	43:05	30:01	3:24	199:01
Percent	5.4	23.1	33.0	21.6	15.1	1.7	
Cumulative percent	5.4	28.5	61.5	83.1	98.2	99.9	

was observed during daylight. Only 6 of the 35 one-degree parallels of latitude were not observed due to the ship's transiting these parallels during darkness (Table 2). During the transect from Hawaii to Japan, observations began at lat. 27°16.5'N, long. 166°53.4'W on 12 August and terminated at lat. 41°33.7'N, long. 143°15.2'E on 21 August. Survey effort totaled 953 nmi (37%) during the transect of 2,573 nmi, which was covered in 10 days. Since the vessel was running continuously, latitudes transited during darkness were not sampled on the second transect. During this transect line, survey effort averaged about 8.5 h per day, and about 86% of the survey time was spent in sea-surface conditions of Beaufort scale 4 or less (Table 1).

Objects Observed

The objects recorded were tabulated by various classifications, e.g., description and type of material, distance and angle observed, latitudinal band, and time of day observed. Most (80%) of the 727 objects were either foamed or structural plastic in the form of fishing floats, irregularly sized sheets, or fragments (Fig. 2, Table 2). Glass (bottles and floats), wood (logs and lumber), and paper (mostly cardboard) constituted a secondary group of materials, whereas metal and cloth items were rarely seen. Only three small pieces (two gill nets, one trawl) of netting and four lengths of synthetic rope were seen on the first transect. The latitudinal distribution of items observed showed striking peaks in the number of objects observed and the relative incidence (objects observed per nautical mile surveyed) between lat. 40° and 29°N (Fig. 3, Table 3). Only one object was seen between lat. 49° and 43°N, although 23% of the survey miles of effort was spent in that portion of the cruise track. Distance at which objects were first sighted seemed to be related to their size, color, shape, and buoyancy; even small white fragments of styrofoam were seen as far away as 100 m, whereas small clear sheets of plastic were never seen farther than 75 m away (Fig. 4). Since sighting effort was concentrated forward in approximately a 180° arc from the starboard beam to the port beam, few objects (4%) were seen abaft. Nearly twice as many objects were seen to starboard compared with port, because sighting effort from the bridge was done on the starboard side so as not to interfere with the watch officers. The time of day objects were observed was directly related to survey effort during the day. Most of the survey effort (81%) was between 0800 and 1600, during which time 88% of the objects were seen. The discrepancy in composition between effort and objects observed was due to more effort (8%) being expended over the time period 1900-2000 when gill nets were being set at slow speed; few objects (2%) were seen during this time because of decreased distance traveled and crepuscular lighting conditions.

There were two main concentrations of marine debris on the Alaska-Hawaii survey, one at lat. 50°-52°N and one at lat. 31°-39°N (Fig. 3). The first concentration roughly coincides with a small zone of surface downwelling in the area lat. 51°-54°N (unpublished CTD data from TV Oshoro Maru, courtesy of Faculty of Fisheries, Hokkaido University, Hakodate, Japan); this surface downwelling may be part of a small-scale eddy generated by seamounts in this region (Royer 1978; Shaw and Mapes 1979). The second, larger concentration of debris was in a zone of surface convergence caused by converging Ekman transports between lat. 28° and 42°N

Table 2.--Description of objects observed adrift on the surface of the North Pacific Ocean, July-August 1984.

Description	No. of occurrences
Bag	9
Ball	3
Bamboo	2
Basket	4
Board	4
Bottle	85
Bowl	1
Box	10
Bucket	9
Bucket lid	1
Can	2
Cap	5
Cardboard	1
Carton	3
Cloth	1
Crate	6
Cup	9
Dish	1
Disk	5
Drum	1
Float	58
Fluorescent lamp	4
Fragment	309
Gill net	3
Gill net float	23
Helmet	1
Incandescent lamp	5
Jar	5
Lid	2
Line	18
Log	12
Magazine	1
Matting	1
Netting	1
Pallet	1
Pan	3
Ring	3
Sandal	1
Screen	1
Sheeting	94
Shoe insole	1
Shovel	1
Sponge	3
Strap	1
Trawl float	6
Trawl webbing	1
Tray	5
Tube	1
Total	727

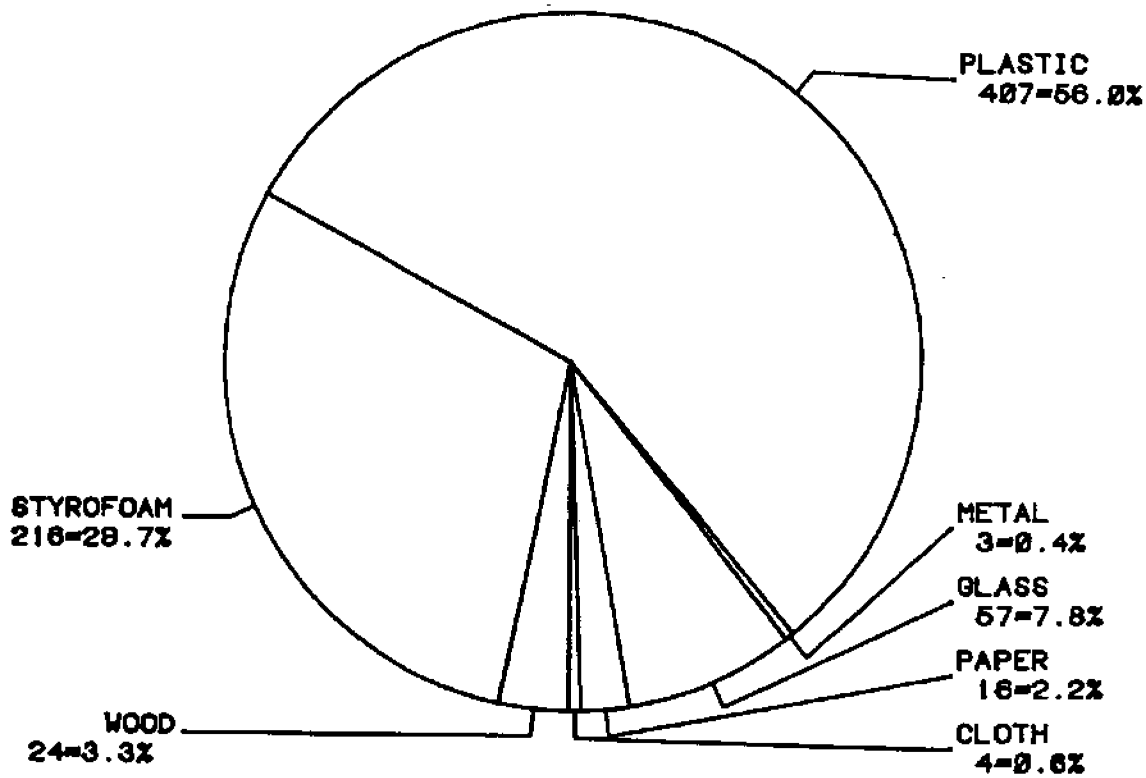
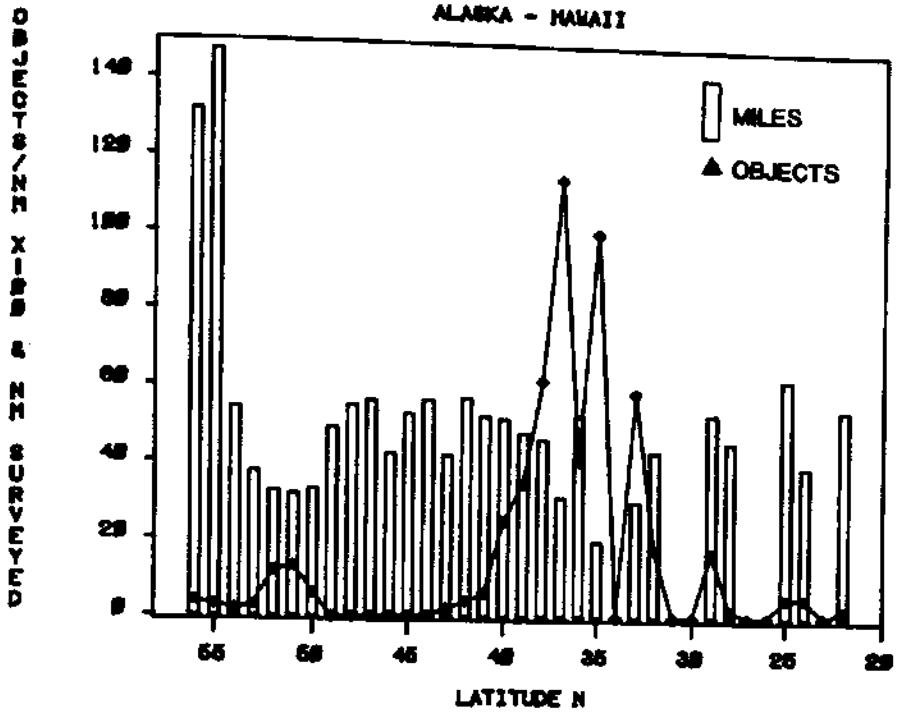


Figure 2.--Approximate composition of a sample of objects sighted on the surface of the North Pacific Ocean, July-August 1984.



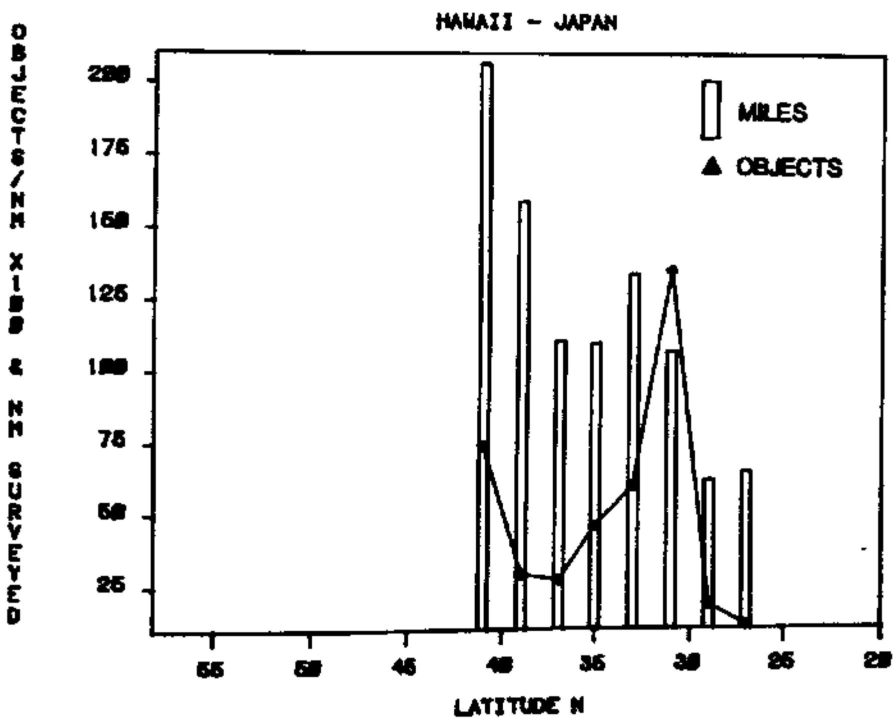


Figure 3.—Latitudinal distribution of nautical miles of sighting survey effort (bars) and objects observed per nautical mile surveyed (solid line).

Table 3.--Latitudinal distribution of the distance and area surveyed and the estimated density of objects and the density of plastic observed on the surface of the North Pacific Ocean in July-August 1984.

Lat. (°N)	Distance surveyed (nmi)	Area surveyed[2] (km^2)	Total No. of objects observed		No. of objects seen 0-50 m from ship	Density of objects[1] (No. per km^2)	No. of plastic objects seen 0-50 m from ship	Density of plastic objects (No. per km^2)
			No.	Objects per nmi x 100				
				ALASKA-HAWAII				
55-56	131.9	12.1	5	4	1	0.08	0	0
54-55	147.5	13.5	4	3	1	0.07	0	0
53-54	54.5	5.0	1	2	1	0.20	0	0
52-53	37.7	3.5	1	3	1	0.29	0	0
51-52	32.7	3.0	4	12	3	1.00	1	0.33
50-51	31.8	2.9	4	13	3	1.03	2	0.69
49-50	33.1	3.0	2	6	2	0.67	0	0
48-49	49.2	4.5	0	0	0	0	0	0
47-48	55.2	5.1	0	0	0	0	0	0
46-47	56.3	5.2	0	0	0	0	0	0
45-46	42.5	3.9	0	0	0	0	0	0
44-45	53.0	4.9	0	0	0	0	0	0
43-44	56.6	5.2	0	0	0	0	0	0
42-43	42.2	3.9	1	2	1	0.26	0	0
41-42	57.2	5.3	2	4	2	0.38	1	0.19
40-41	52.5	4.9	3	6	3	0.63	3	0.63
39-40	51.8	4.8	13	25	7	1.46	7	1.46
38-39	48.2	4.4	17	35	8	1.82	3	0.68
37-38	46.5	4.3	29	62	18	4.19	17	3.95
36-37	31.4	2.9	36	115	23	7.93	20	6.90
35-36	53.0	4.9	22	41	14	2.86	13	2.65
34-35	19.8	1.8	20	101	6	3.33	4	2.22
33-34	0	0	--	--	--	--	--	--
32-33	30.4	2.8	18	59	12	4.29	7	2.50
31-32	43.5	4.0	8	18	6	1.50	4	1.00
30-31	0	0	--	--	--	--	--	--
29-30	0	0	--	--	--	--	--	--

Table 3.--Continued.

Lat. (°N)	Distance surveyed (nmi)	Area surveyed[2] (km^2)	Total No. of objects observed: No.	Total No. of objects observed: Objects per nmi x 100	No. of objects seen 0-50 m from ship	Density of objects[1] (No. per km^2)	No. of plastic objects seen 0-50 m from ship	Density of plastic objects (No. per km^2)
28-29	53.6	4.9	9	17	4	0.82	4	0.82
27-28	46.1	4.2	1	2	0	0	0	0
26-27	0	0	--	--	--	--	--	--
25-26	0	0	--	--	--	--	--	--
24-25	62.9	5.8	3	5	2	0.34	2	0.34
23-24	39.7	3.6	2	5	2	0.56	1	0.28
22-23	0	0	--	--	--	--	--	--
21-22	55.0	5.1	1	2	0	0	0	0
HAWAII-JAPAN								
41-42	100.0	9.2	120	120	103	11.20	94	10.22
40-41	106.5	9.8	44	41	38	3.88	31	3.16
39-40	59.6	5.5	6	10	5	0.91	4	0.73
38-39	99.3	9.1	39	39	29	3.19	25	2.75
37-38	85.1	7.8	24	28	16	2.05	14	1.79
36-37	25.6	2.4	6	23	6	2.50	6	2.50
35-36	79.6	7.3	32	40	24	3.29	22	3.01
34-35	30.1	2.8	19	63	13	4.64	11	3.93
33-34	69.4	6.4	52	75	38	5.94	38	5.94
32-33	64.3	5.9	43	67	38	6.44	36	6.10
31-32	3.6	0.3	0	0	0	0	0	0
30-31	103.1	9.5	131	127	96	10.11	76	8.00
29-30	0	--	--	--	--	--	--	--
28-29	61.8	5.7	11	18	11	1.93	8	1.40
27-28	64.7	5.9	7	11	7	1.19	5	0.85

[1]Assuming all objects larger than 2.5 x 2.5 x 2.5 cm were seen within transect.
[2]Using a transect width of 50 m.

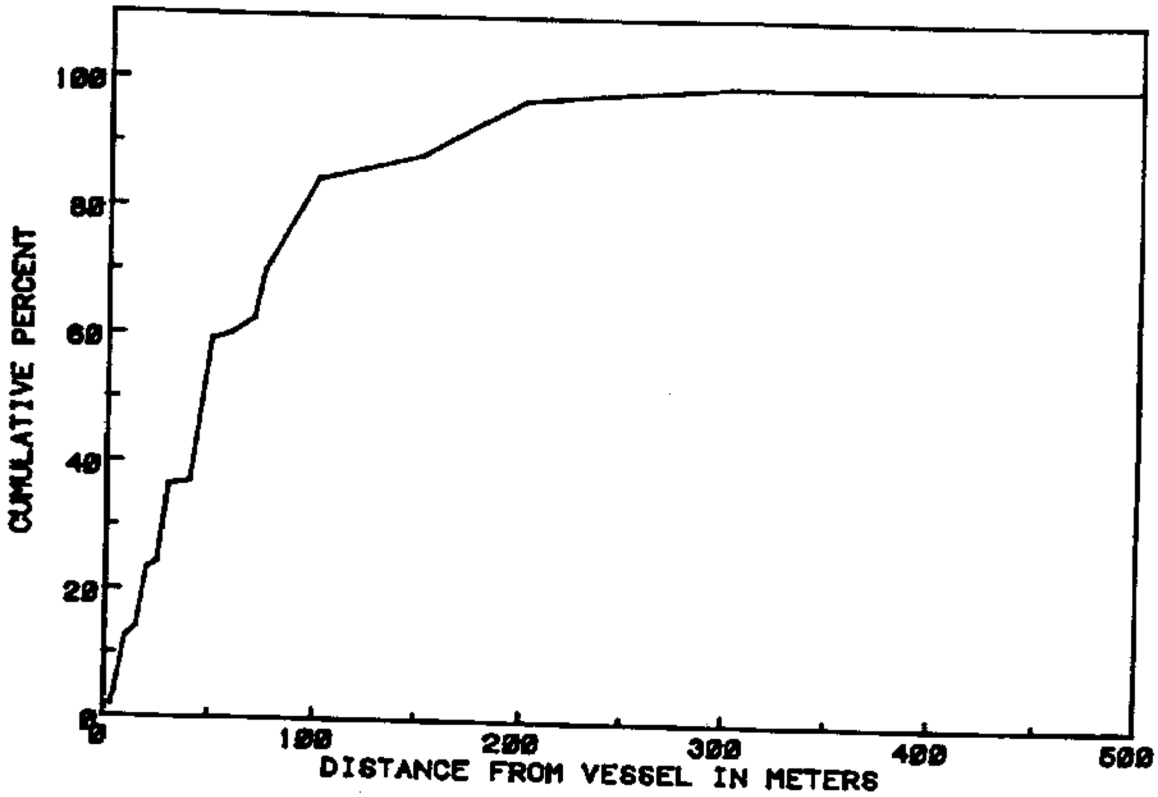


Figure 4.—Cumulative frequency distribution (%) of distance at which objects were first sighted from the vessel.

(Roden 1970). Shaw and Mapes (1979) also found plastic concentrations in the region of lat. 28°-38°N on a transect along long. 158°W, but found no plastic north of lat. 39°N.

There were also two main concentrations of marine debris on the Hawaii-Japan survey, one at lat. 30°-35°N and one at 41°-42°N (Table 2). The first concentration was again in the zone of converging Ekman transports (Roden 1970). The second concentration was in an area just east of Japan, which is an important source for marine debris in the western Pacific (e.g., see Merrell 1980).

On the evenings of July 31 and August 1 at lat. 34° and 31°N, respectively, small plastic pellets and fragments along with light-gauge thread, appeared in surface hauls of a surface ichthyoplankton net that was towed abeam the ship for 20 min per haul (Fig. 5). Plastic detritus did not appear in surface hauls at other stations between lat. 55° and 27°N. The band of surface water sampled by the circular net opening was approximately 20-30 cm, so very little area was swept by the gear, yet in several of four hauls on the above two nights, small pieces of plastic appeared floating in the pan used to sort catches immediately after the haul. The density of particulate plastics at the water surface must have been relatively high here for the net to have picked up much material (Shiber 1982; Gregory 1983).

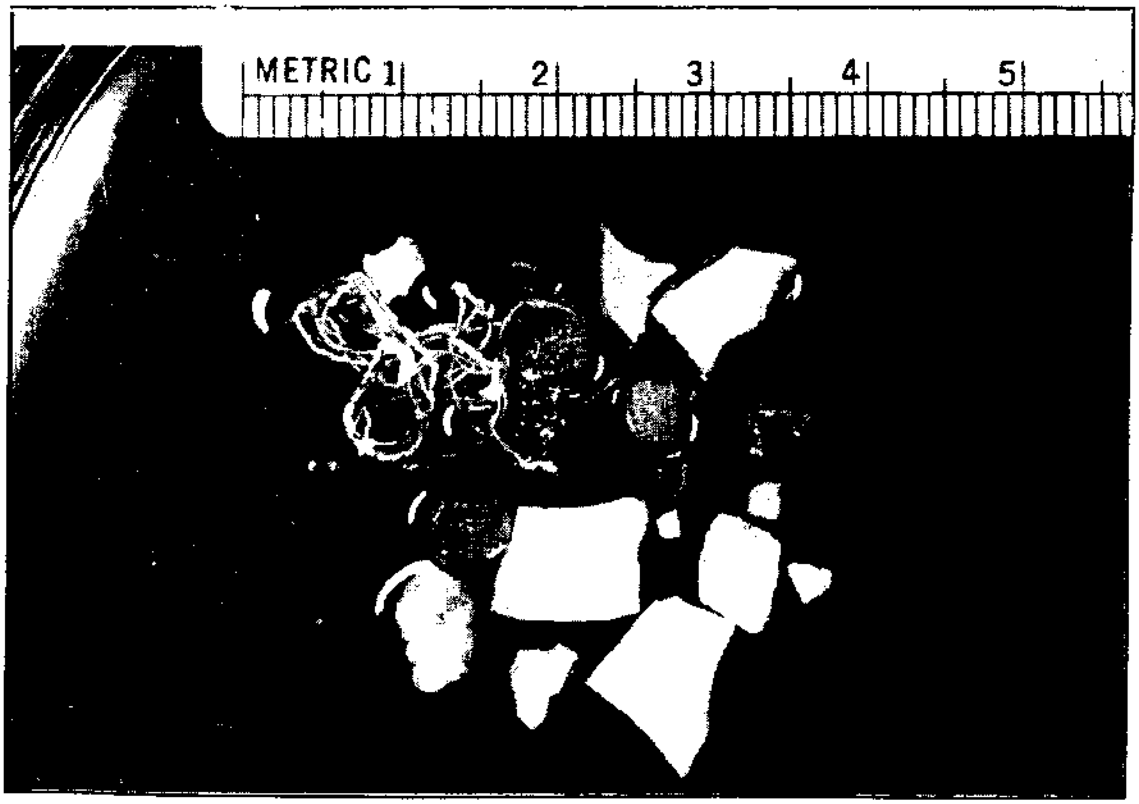


Figure 5.--Photo-micrograph of plastic debris caught in a surface haul of an ichthyoplankton net at lat. 31°N and long. 155°W.

DISCUSSION

The large proportion of plastic materials (86%) observed in this study is consistent with results of earlier studies of marine debris reported by Venrick et al. (1973) for the area between lat. 35° and 31°N and by Shaw and Mapes (1979) for a cruise between Alaska and Hawaii. Although Venrick et al. surveyed for debris for only 8.2 h, they saw 53 man-made objects, of which two-thirds were plastic. Plastic materials, rope, and twine constituted 60% of the frequency of occurrence of debris observed in trawl hauls in the Bering Sea during 1975 and 1976 (Feder et al. 1978). Plastic debris in general poses some problems to shipping (lines and nets foul propellers and plastic sheeting blocks seawater intake ports), but debris also has serious implications in animal mortalities (Coleman and Wehle 1984).

Entanglement of seabirds and marine mammals in derelict fishing nets and other man-made objects has been documented in several of the world's oceans (Tull et al. 1972; Shaughnessy 1980; Fowler 1982). Ingestion of marine debris, especially floating plastic, by seabirds also may cause mortality or decreased reproductive performance (Day 1980; Day et al. 1985). Northern fur seal, *Callorhinus ursinus*, were seen near the research gill nets during 7 of our 16 hauls in 1984. One fur seal escaped from the net as it was being hauled and one other was found dead in the net. Of 18 northern fur seals observed on 15 net-hauling occasions, none appeared entangled in any man-made objects. The low incidence of derelict fishing nets observed (<1% of all objects seen) and the fact that they were wrapped tightly in a ball may not make them available to entangling marine mammals.

Many of the objects we observed, especially the larger fishing gear floats, were heavily encrusted with fouling organisms, suggesting that the material had been adrift for a long time (Winston 1982). In addition, some of the plastic floats had faded considerably from international orange to a light pink, indicating long exposure. Determining the length of time marine debris is adrift may be possible through studies of marked gear released and monitored over a period of months or years with the aid of satellite tracking buoys coupled with periodic visits by vessels to observe and record the appearance of the gear.

Density estimates of debris were calculated keeping in mind the three significant problems associated with estimating at-sea densities of marine debris. First, paper objects are probably underrepresented due to sinking and rapid deterioration once this material is exposed to seawater. Second, the width of the transect surveyed is extremely difficult to define because of the large variation in the size of objects seen and their visibility due to distance, sea conditions, glare, color of the objects, and their buoyancy. Last of all, many objects sink and are never seen on censuses. Densities of marine debris in the study area were estimated, with four qualifications: (1) Estimates refer only to positively-buoyant debris (i.e., debris at the surface of the water); (2) estimates refer only to objects visible from the ship; the minimum size of objects sighted was approximately 2.5 cm^3; (3) density estimates were derived from only the inner 50 m of transect width; 59% of all objects were sighted in the inner 50 m of transect width, whereas only 24% were sighted in the next 50 m out from the ship (Fig. 4), indicating substantial fall-off of sightings; and (4) we assume that all objects larger than 2.5 cm^3 were seen within 50 m of the ship.

Using the above qualifications, we estimate that the average density of marine debris larger than approximately 2.5 cm^3 was 0.28 per km^2 in subarctic waters (lat. 39°-56°N) and 3.73 objects per km^2 in subtropical waters (lat. 21°-39°N in the Alaska-Hawaii surveys and lat. 27°-42°N in the Hawaii-Japan surveys). Densities of plastic averaged 0.15 objects per km^2 in subarctic waters and 3.15 objects per km^2 in subtropical waters (Table 3). For comparison with the data presented by Venrick et al. (1973), we estimated they saw an average of 4.24 pieces of marine debris per km^2, of which 2.24 pieces were plastic, in the subtropical North Pacific Ocean. Their observations were taken in the area lat. 31°-35°N, long. 145°-155°W, and were thus, in the zone of highest density of marine debris found 12 years later in our study. The only other comparable data are from the Mediterranean, where Morris (1980) found an average density of approximately 2,000 pieces of marine debris per km^2; 60-70% of this debris consisted of pieces of plastic. Although our estimates have several qualifications, they provide order-of-magnitude approximations of densities of medium-to-large pieces of plastic and other debris.

Quantifying the total amount of oceanic litter is difficult due to the wide variation in size, shape, and buoyancy of the material. Observations from ships may provide useful indices of the type and amount of debris, but beach surveys may be more useful and less costly in measuring the rate of loss of debris from the ocean. However, beach surveys would not reveal that debris lost from the surface by sinking. Beach surveys could also be used to test the predictions of surface transport models.

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THEORETICAL FIRST APPROXIMATIONS OF DENSITIES OF DISCARDED WEBBING IN THE EASTERN NORTH PACIFIC OCEAN AND BERING SEA

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ABSTRACT

First approximations of densities of discarded webbing in the eastern North Pacific Ocean and Bering Sea are developed and discussed. The approximations are based on estimates of northern fur seal mortality rates, assumed distributions of webbing, and assumptions on fur seal behavior. The results are examined with respect to the design of sea surveys to determine the validity of the assumptions and estimate densities of discarded webbing.

INTRODUCTION

Part of the task of determining the effect of marine debris on marine mammals is to estimate the density and distribution of marine debris on the surface of the ocean. This is particularly true for the types of debris that appear to be causing problems with marine mammals. This study makes first approximations of densities of marine debris that appear to be causing high mortality rates for the northern fur seal, *Callorhinus ursinus*.

An analysis of available data by Fowler (1982) indicated that populations of northern fur seals are undergoing higher than expected mortalities and that discarded trawl webbing and perhaps plastic wrapping bands could be the cause of the unexplained high mortalities. Further investigation by Fowler (1984) and Fowler et al. (1985) supported the first study by Fowler (1982).

The studies presented data showing that about 64% of fur seals found with entangling debris on the Pribilof Islands were entangled in trawl webbing and about 22% were entangled in discarded plastic packing bands. Their work indicated that discarded trawl webbing is probably more important than implied by the above data because seals entangled in large pieces of webbing probably do not reach the Pribilofs. The data also indicated that only a small portion (8.5%) of trawl webbing that washed up on beaches is of the size that causes most entanglements (20-25 cm stretched mesh). Thus, it appears that only a small portion of marine debris may be responsible for the increased mortality.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

Fowler (1982, 1984, pers. commun., Natl. Mar. Mammal Lab., Natl. Mar. Fish. Serv., NOAA, Seattle, WA 98115-6349, August and October 1984) and Fowler et al. (in press) indicated that much of the mortality is occurring during the first 2 years of life. For example, between the time that male fur seal pups leave the Pribilof rookeries and return as subadults (20 months), survival is only 30% instead of an expected 50%.

If it is assumed that mortality rates are constant over the 20-month period, the estimate of instantaneous rate of total mortality (Z) without the effect of marine debris is

$$0.5 = \exp(-Z(20/232))$$

$$Z = -(\ln 0.5)/(20/12)$$

$$= 0.42 \quad .$$

This is also an estimate of the rate of natural mortality (M), because it is assumed that there are no nonnatural sources of mortality. The estimate of Z given the assumed effects of marine debris is

$$0.3 = \exp(-Z(20/12))$$

$$Z = -\ln(0.3)/(20/12)$$

$$= 0.72 \quad .$$

An estimate of the rate of mortality caused by marine debris (D) is given by

$$Z = D+M$$

$$D = 0.72 - 0.42$$

$$= 0.3 \quad .$$

The expectation of death caused by marine debris in 1 year (U) is given by

$$U = D(1-\exp(-Z))/Z$$

$$= 0.21 \quad .$$

The expectation of death caused by marine debris over the 20-month period is given by

$$U = D(1-\exp(-Z(20/12))/Z$$

$$= 0.29 \quad .$$

The literature (e.g., Kajimura 1984) indicates that male pups undergo one or two migrations between the Pribilofs and California during the 20 months at sea. Assuming that the animals travel along the coast line (most sightings are between 70 and 130 km of the coast) and don't deviate from their course, they travel between 5,400 and 10,800 nmi in the 20 months.

The migration appears to take about 2 months in each direction. Thus it appears that about 4 to 8 of the 20 months are spent migrating, and the remaining time is spent making local movements related to feeding and other activities. If it is assumed that similar distances are covered during nonmigrating months, the pups travel about 27,000 nmi during the 20 months at sea (1,350 nmi per month or about 45 nmi per day). This amount of travel seems high, particularly in view of evidence that not all male fur seal pups make the complete migration. It seems reasonable to use 27,000 nmi as an upper bound and 5,400 nmi as a lower bound.

Since we estimate that expectation of death from webbing encounters is 0.29 during the 20 months, it is reasonable to estimate fatal encounters per nautical mile (EPM) to be

$$EPM = 0.29/5{,}400 \text{ to } 0.29/27{,}000$$

$$= 0.000054 \text{ to } 0.000011$$

or in other words, there is one fatal encounter per 18,600–93,100 nmi of travel.

There are no data available on the searching path width of fur seals. If the animals are detecting webbing visually, searching path width is probably around 10 m (0.0054 nmi) on each side. On the other hand, if acoustics are being used it is not unreasonable to assume that a fur seal could detect a school of fish associated with discarded webbing 1,000 m (0.54 nmi) away. Thus, there appears to be one fatal encounter with webbing per 200 to 100,548 nmi^2 of searched water (geometric average 4,484 nmi^2).

How do these estimates fit in with what has been reported on observations from vessels? A paper presented at the workshop (Jones and Ferrero 1985) reported that four items of trawl webbing were found during 1,153 h of searching, while traveling 10,528 nmi in the North Pacific. There was one sighting per 2,633 nmi. It seems reasonable that an observer could detect pieces of webbing 100–200 m (0.054–0.108 nmi) on each side of the vessel. Thus, it appears that there was one sighting per 284–568 nmi^2 searched. If Fowler's (1982, 1984, pers. commun.) estimate that only 8.5% of discarded trawl webbing causes most mortality is correct, then there would be one unit of webbing of the dangerous mesh size per 3,342–6,683 nmi^2 (geometric average 4,726 nmi^2).

To compare the estimated density derived from observations with estimates derived from mortality rates, it is necessary to make more assumptions. First, it is necessary to make an assumption about the percentage of encounters between fur seals and webbing that are fatal. Second, it must be assumed that vessels and fur seals are searching areas that have similar densities of webbing. It should be noted that vessel observations were made west of the major fur seal migration area in the Gulf of Alaska. It seems likely that not all encounters are fatal. If this is true the estimated density of webbing derived from mortality rates is too low. It also seems likely that the seals would search in areas that contain higher than average densities of webbing, because factors that concentrate webbing may also concentrate food. In addition there probably is some communication between animals that would increase searching ability. Kajimura (1984) noted that fur seals at sea tend to be solitary except when feeding in areas containing food concentrations. These factors would tend to cause density estimates based on mortality to be too high. Perhaps violations of an assumption that all encounters are fatal and of the second assumption would cancel each other out, and I will assume that this is true. Under this assumption the two estimates of webbing density are similar.

The results of the first approximations indicate two things. First, the density of webbing appears to be quite low. Second, there appears to be enough discarded webbing to cause the estimated mortalities.

These two conclusions lead to further conclusions. First, if it is desired to maintain populations of northern fur seals, serious research should be conducted to verify that the problem is as serious as it appears to be. Second, preliminary efforts should be begun to reduce the apparent problem.

The low density of webbing indicates that it is not likely to be efficient to use dedicated vessels to either study the problem through surveys or solve the problem by cleaning up the ocean. Piggyback surveys probably should be continued and could be improved by better quantifying the techniques and working in areas preferred by fur seals. Modification of fishing gear and practices probably have the highest probability of solving the problem.

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FISHING EFFORT BY NET FISHERIES IN THE NORTH PACIFIC OCEAN AND BERING SEA SINCE THE 1950'S

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ABSTRACT

A synthesis of data on the amount of fishing effort generated by a number of net fisheries in the North Pacific Ocean and Bering Sea since the 1950's is presented here so as to provide background information relevant to studies of the fate and impact of marine debris in the North Pacific Ocean. It is estimated that total trawl fishing effort in the Bering Sea-Aleutian Islands-northeast Pacific Ocean more than tripled between 1956-60 and 1971-75. Currently, overall effort remains near the high level of the early 1970's, but trends have differed between areas and fisheries. Gill net effort by high seas salmon fisheries in the Bering Sea and central-western North Pacific Ocean currently is less than one-half of what it was in the late 1950's and early 1960's. A tangle net fishery for crabs in the southeastern Bering Sea was terminated in 1973, and a herring gill net fishery in the Bering Sea was terminated in 1980. Peak effort for both fisheries had been in the mid-1960's.

INTRODUCTION

The history of commercial exploitation of fishery resources in the North Pacific Ocean and adjacent seas goes back more than a century, but it has only been within the past 30 years or so that a number of major net fisheries have developed for various species of fish. These include trawl fisheries for groundfish in the eastern and central Bering Sea, around the Aleutian Islands, and in the northeast Pacific Ocean; gill net and trawl fisheries for herring in the Bering Sea; a tangle net fishery for crabs in southeastern Bering Sea; and drift net fisheries for salmon in the Bering Sea and central and western North Pacific Ocean. Scale of development and duration of the various fisheries are indicated in published reports of catch statistics, but data on the amount of fishing effort generated by those fisheries over the years are not readily available in the literature. A synthesis of such data is presented here to provide background information relevant to studies of the fate and impact of marine debris in the North Pacific Ocean.

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BERING SEA-ALEUTIAN ISLANDS REGION

Groundfish, Shrimp, and Herring Trawl Fisheries

Post-World War II fishing by foreign trawlers in the Bering Sea-Aleutian Islands region (Fig. 1) began in 1954 when Japanese vessels initiated a fishery for flatfish in waters east of long. 170°W. Fishing was largely exploratory in nature and limited in scale until 1959 when Soviet trawlers, after having conducted surveys of fishery resources in the region in 1954 and 1958, also started fishing for groundfish (and herring) on a commercial scale in the eastern Bering Sea. From that year through 1962, there was a marked increase in trawling by the two nations, judging from catches reported for Japanese and Soviet vessels, and information on the numbers of mother ship fleets and independent trawlers engaged in Japan's fishery (Forrester et al. 1978).

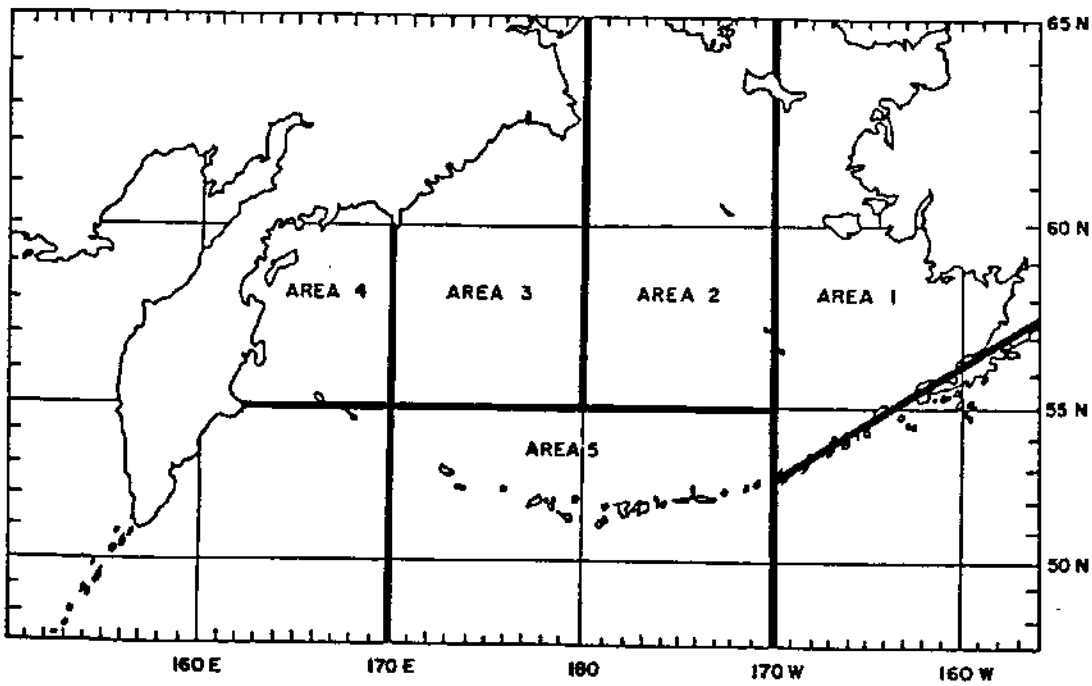

Figure 1.--The Bering Sea region as defined by the International North Pacific Fisheries Commission and its areal divisions.

Overall growth of the Japanese and Soviet trawl fisheries during 1954-62 is indicated by annual catches (in metric tons (MT)) of groundfish and herring (Forrester et al. 1978).

Year	Groundfish catch (1,000 MT)			Herring catch (1,000 MT)
	Japan	U.S.S.R	Total	U.S.S.R.
1954	13	--	13	--
1955	15	--	15	--
1956	25	--	25	--
1957	24	--	24	--
1958	46	5	51	--
1959	159	62	221	--
1960	435	96	531	10
1961	533	154	687	10
1962	476	140	616	80
				150

Since 1963, Japan has reported not only the catches taken by the various types of trawlers used in its groundfish fishery but also the number of hours fished annually or, in the case of Danish seiners, the number of sets made, which can be converted to hours of fishing (Appendix Table 1A). Hours of fishing by Japanese shrimp trawlers have also been reported for each year of operation since 1963.

Fishing effort by Soviet groundfish trawlers during 1963-76 can be estimated from their annual catches and data on effort-per-unit-catch (EPC) for Japanese trawlers, that is, the hours of fishing per ton of groundfish caught (Appendix Table 1B). Fishing effort by Soviet herring trawlers during 1963-76 can be directly estimated from catch and EPC data provided by the U.S.S.R. (Appendix Table 1C). Since 1977, 1976, 1977, 1979, and 1980, in that order, the U.S.S.R., Republic of Korea, Taiwan, Poland, and West Germany have reported the number of hours fished annually by their respective trawlers (Appendix Table 1A). Fishing effort by United States trawlers engaged in domestic and joint venture groundfish fisheries in the region since 1980 can be estimated from catches reported for those fisheries and EPC data for foreign trawlers combined (Appendix Table 1D).

Total annual trawl fishing effort for groundfish, shrimp, and herring during 1963-83, as reported or estimated for foreign and U.S. vessels in the Bering Sea-Aleutian Islands region, is given in Table 1 and shown in Figure 2. Effort was about 340,000 and 400,000 h in 1963 and 1964, respectively, but decreased to about 250,000 h in 1965 and 1966, mainly because of sharp drops in flatfish and herring catches by Soviet vessels. Effort then rebounded as the pollock fishery developed during the late 1960's and peaked at approximately 500,000 h in the early 1970's. Since then it has fluctuated around a level of about 450,000 h annually.

Effort by U.S. trawlers has accounted for an increasing fraction of the total effort in recent years, from 3% in 1980 to 18% in 1983, displacing more and more of the foreign effort.

Table 1.--Trawl fishing effort for groundfish, shrimp, and herring by foreign and United States fisheries in the Bering Sea-Aleutians region, 1963-83 (thousands of hours). Data sources: Japan, Republic of Korea, Taiwan, West Germany, and Poland - Appendix Table 1A; the U.S.S.R. groundfish 1963-76, Appendix Table 1B; herring 1963-76, Appendix Table 1C; groundfish and herring combined, 1977-83, Appendix Table 1A; and United States Appendix Table 1D.

Year	Japan		U.S.S.R.		Republic of Korea	Taiwan	West Germany	Poland	Total foreign nations	United States	
	Groundfish and herring	Shrimp	Groundfish	Herring	Groundfish					Domestic and joint venture	All nations
1963	172	--	75	90	--	--	--	--	337	--	337
1964	203	--	90	105	--	--	--	--	398	--	398
1965	168	23	55	--	--	--	--	--	246	--	246
1966	182	18	44	--	--	--	--	--	244	--	244
1967	262	2	63	--	--	--	--	--	327	--	327
1968	301	7	44	13	--	--	--	--	365	--	365
1969	310	2	54	50	--	--	--	--	416	--	416
1970	369	4	58	76	--	--	--	--	507	--	507
1971	390	4	86	27	--	--	--	--	507	--	507
1972	402	--	87	13	--	--	--	--	502	--	502
1973	341	--	68	9	--	--	--	--	418	--	418
1974	374	--	107	12	--	--	--	--	493	--	493
1975	357	--	93	9	--	--	--	--	459	--	459
1976	354	+	82	10	56	--	--	--	502	--	502
1977	371	+	27		8	1	--	--	407	--	407
1978	380	--	53		17	2	--	--	452	--	452
1979	367	--	33		26	1	--	5	432	--	432
1980	391	--	1		38	2	2	13	447	13	460
1981	364	--	--		30	4	3	12	413	30	443
1982	358	--	--		29	6	3	--	396	45	441
1983	330	--	--		32	--	--	--	363	82	444

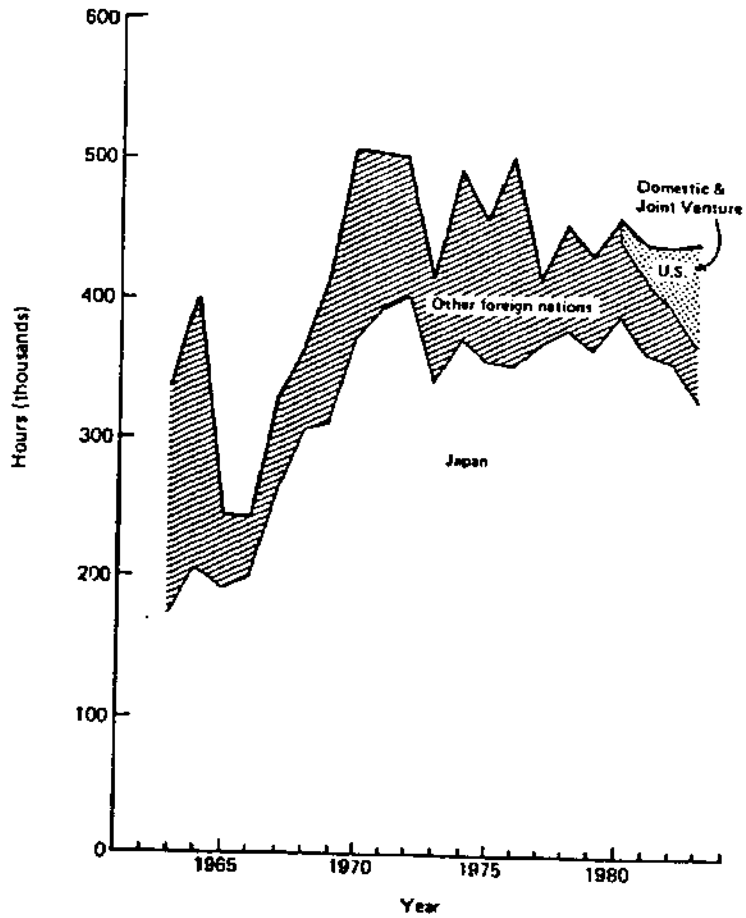

Figure 2.--Trawl fishing effort for groundfish shrimp and herring by foreign and U.S. fisheries in the Bering Sea-Aleutians region, 1963-83.

Pre-1963 fishing effort by Japanese and Soviet trawl fisheries for groundfish can be estimated by multiplying annual catches (text table, above) by 0.5, the average EPC for groundfish caught by Japanese trawlers during 1963-67, years when the average annual Japanese-Soviet catch was about the same as it was in 1962 (Appendix Table 1B). Similarly, herring trawl effort by Soviet vessels during 1959-62 can be estimated by multiplying their annual catches of herring by 0.6, the average EPC during 1968-73 (Appendix Table 1C). Resulting estimates of annual effort during 1954-62 are as follows:

Estimates of annual trawl fishing effort (1,000 h)

	Groundfish		Herring	
Year	Japan	U.S.S.R.	U.S.S.R.	Total
1954	6	--	--	6
1955	8	--	--	8
1956	12	--	--	12
1957	12	--	--	12
1958	23	2	--	25
1959	80	31	6	117
1960	218	48	6	272
1961	266	77	48	391
1962	238	70	90	398

As indicated previously by catch data, there was a rapid buildup of trawl effort beginning in 1959. By 1961, it reached the level of the early peak (1963-64) shown in Figure 2.

The areal distribution of trawl fishing effort since 1963, as indicated by data from the Northwest and Alaska Fisheries Center, National Marine Fisheries Service (NWAFC data file) for Japanese fisheries, which accounted for approximately three-fourths of the total trawl effort in the region during 1963-83, has been as follows:

		Percent effort by area			
Years	Average annual effort (1,000 h)	1	2	3+4	5
1963-69	236	39	45	10	6
1970-76	370	24	56	14	6
1977-83	367	29	53	+	18

Effort shifted from Area 1 to Area 2 in the early 1970's as the pollock fishery developed, and the closure of the U.S.S.R. 200-mile zone in 1977 led to a shift in effort from Areas 3 and 4 to Area 5 (the Aleutians area).

The distribution of Japanese fishing effort by vessel type (Appendix Table 1A) has been as follows:

Percent of average annual effort by vessel type

Years	Pair trawl	Side trawl-fish	Stern trawl-fish	Danish seine	Side trawl-shrimp	Stern trawl-shrimp
1963-69	6	12	20	59	3	+
1970-76	11	+	63	25	+	+
1977-83	8	0	83	9	+	+

Danish seiners and side trawlers fishing for groundfish accounted for most of the fishing effort through most of the 1960's, but stern trawlers have since become the predominant type of vessel used in the region. They presently account for about 85% of the total annual effort.

Herring Gill Net Fishery - Japan

The Japanese herring gill net fishery in the Bering Sea peaked in the mid-1960's (Table 2 and Fig. 3), when practically all of the fishing effort was in Areas 3 and 4, near the U.S.S.R. coast. During the 1970's, practically all of the fishing was done east of long. 170°W (Area 1). At its peak in 1965, cumulative total effort during the year represented about 37,000 km of gill net (one tan being a 46-m length of gill net). The fishery was terminated in 1980.

Crab Tangle Net Fishery - Japan

Japan's crab tangle net fishery in the southeastern Bering Sea began in 1953 and terminated in 1973. Peak effort (Table 2 and Fig. 4) was in 1963-64, representing a cumulative total of about 26,000 km of tangle nets set during a season, one tan being a 40-m length of net in this fishery.

NORTHEAST PACIFIC REGION

Foreign and Joint Venture Groundfish Trawl Fisheries

Foreign trawling for groundfish began in the northeastern Pacific region (Fig. 5) in 1962, when Soviet trawlers initiated a fishery for rockfish in the Gulf of Alaska. Japan started fishing in 1963. In 1966, both nations extended their fishing operations to waters off British Columbia, Washington, and Oregon, Soviet vessels accounting for most of the effort by a wide margin. The Republic of Korea and Poland began fishing in the region in the early 1970's, and Canadian and United States vessels initiated joint venture fisheries with other nations in 1978.

Japan has reported the number of hours fished annually by vessels in its groundfish trawl fishery in the region since 1963, and the U.S.S.R., Republic of Korea, and Poland since 1977 (Appendix Table 2A). Effort in the Gulf of Alaska by trawlers of the latter three nations prior to 1977 can be estimated from their catches and EPC data for Japanese stern trawlers (Appendix Table 2B). Effort by Soviet trawlers off British

Table 2.--Gill net fishing effort for herring in the Bering Sea, 1963-79, and tangle net fishing effort for crabs in the southeastern Bering Sea, 1953-72 (in thousands of tans). Data sources: herring, 1963-70 - International North Pacific Fisheries Commission (INPFC) Bulletin 37; 1971-79: - INPFC Statistical Yearbooks; crabs - INPFC Statistical Yearbooks.

Year	Japan	
	Herring gill net fishery	Crab tangle net fishery
1953	--	106
1954	--	61
1955	--	99
1956	--	147
1957	--	84
1958	--	99
1959	--	78
1960	--	93
1961	NA	292
1962	NA	438
1963	225	642
1964	454	639
1965	816	452
1966	503	447
1967	556	440
1968	404	485
1969	174	272
1970	84	252
1971	134	28
1972	122	12
1973	131	Fishery terminated
1974	96	
1975	46	
1976	128	--
1977	53	--
1978	--	--
1979	9	--
1980	Fishery terminated	--

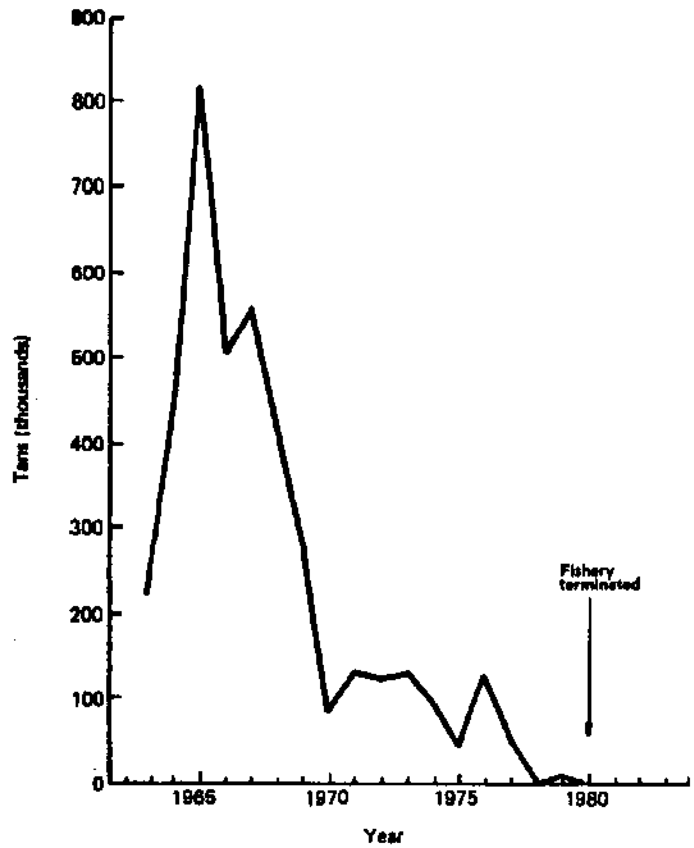

Figure 3.--Gill net fishing effort for herring by Japan in the Bering Sea, 1963-83.

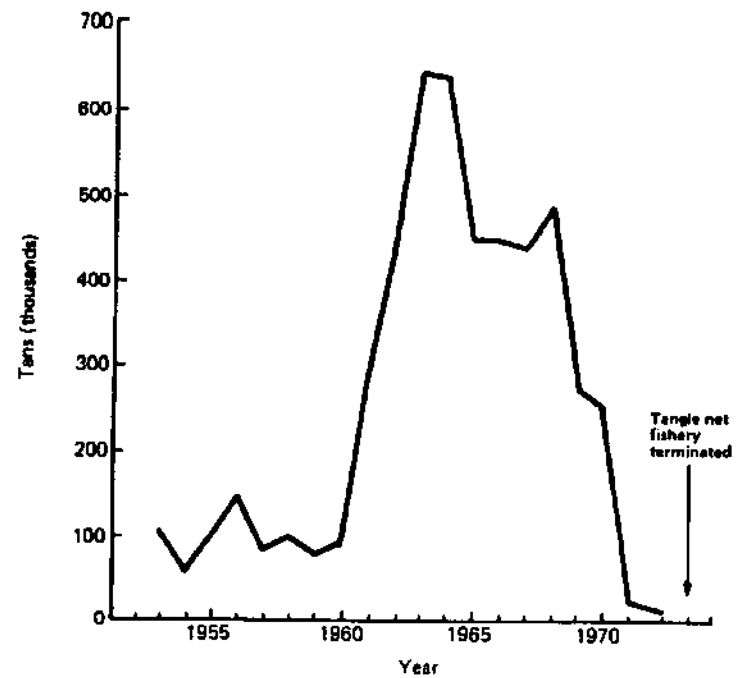

Figure 4.--Tangle net fishing effort for crabs by Japan in the southeastern Bering Sea, 1953-72.

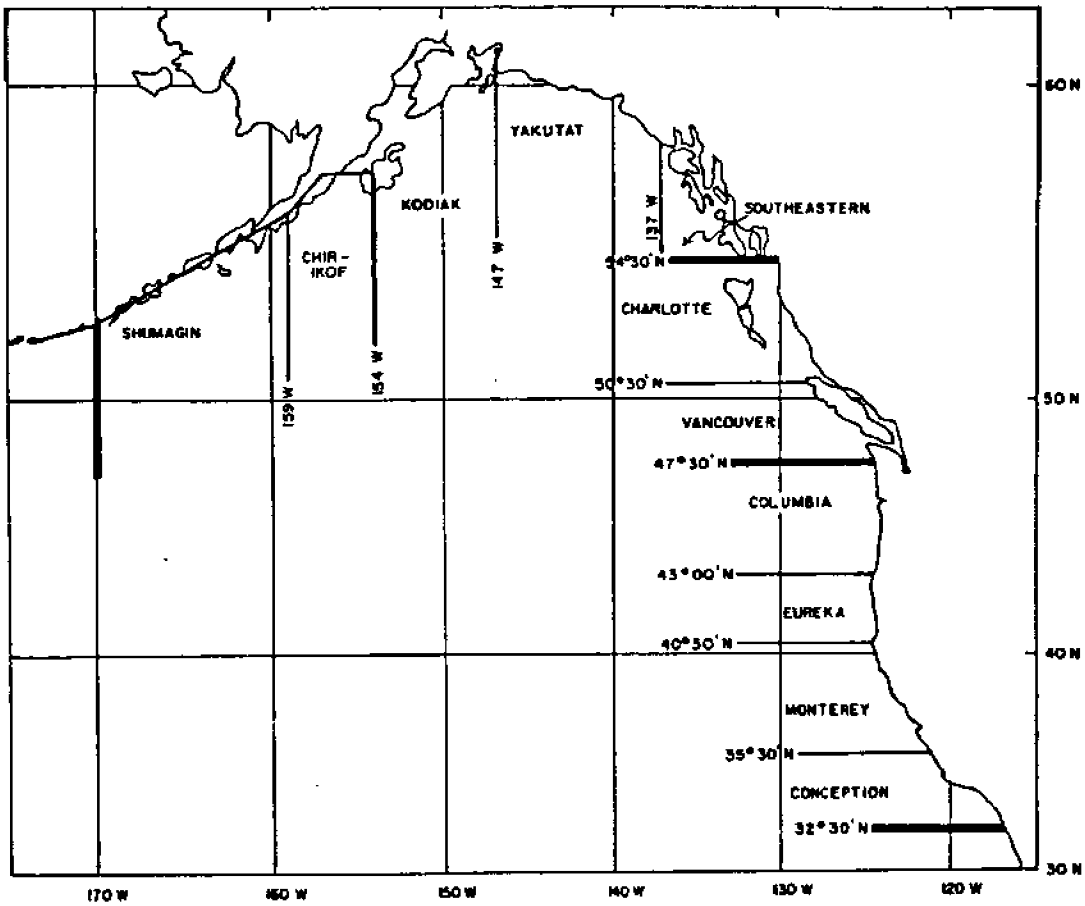

Figure 5.--The northeast Pacific region as defined by the International North Pacific Fisheries Commission and its areal divisions.

Columbia in 1966, when they targeted on rockfish, can be similarly estimated (Appendix Table 2C). Trawl effort by the U.S.S.R. and Poland off British Columbia during 1967-76 and off Washington-Oregon-California during 1966-76 can be estimated from the catches of hake by the two nations and EPC data for the Soviet hake trawl fishery (Appendix Tables 2C and 2D). Effort by Canadian and United States trawlers involved in joint venture fisheries in different sectors of the region since 1978 can be estimated from their groundfish catches and EPC data for the combined trawl fisheries of Japan, U.S.S.R., the Republic of Korea, and Poland (Appendix Table 2E).

Total annual trawl effort for groundfish by foreign and joint venture fisheries in the northeast Pacific region during 1962-83, as reported or estimated and excluding a relatively minor amount of effort by Japanese Danish seiners, side trawlers, and shrimp trawlers in the mid-1960's, is given in Table 3 and shown in Figure 6.

Effort increased from slightly less than 15,000 h in 1962 to nearly 170,000 h in 1967, decreased to the 100,000 h level during the next 5

Table 3.--Trawl fishing effort for groundfish in the northeast Pacific region by Japanese, U.S.S.R., Republic of Korea, Polish, Canadian joint venture and United States joint venture fisheries, 1962 to 1983, in thousands of hours (INPFC = International North Pacific Fisheries Commission). Data sources: Japan 1963-83 - Appendix Table 2A. U.S.S.R. 1962-76 - Appendix Tables 2B, 2C, 2D; 1977-78 - Appendix Table 2A. Republic of Korea 1972-75 - Appendix Table 2B; 1976-83 - Appendix Table 2A. Poland 1973-76 - Appendix Tables 2B, 2C, 2D; 1977-83 - Appendix Table 2A. Canada and United States joint ventures - Appendix Table 2E.

		Foreign					Joint venture			
Area	Year	Japan	U.S.S.R.	Republic of Korea	Poland	Total	Canada	United States	Total	Total
Gulf of Alaska	1962	—	13	—	—	13	—	—	—	13
INPFC areas	1963	2	27	—	—	29	—	—	—	29
Shumagin to	1964	3	35	—	—	38	—	—	—	38
southeastern	1965	8	51	—	—	59	—	—	—	59
	1966	13	12	—	—	25	—	—	—	25
	1967	14	15	—	—	29	—	—	—	29
	1968	16	13	—	—	29	—	—	—	29
	1969	24	6	—	—	30	—	—	—	30
	1970	15	2	—	—	17	—	—	—	17
	1971	19	9	—	—	28	—	—	—	28
	1972	29	24	1	—	54	—	—	—	54
	1973	37	24	2	—	63	—	—	—	63
	1974	36	31	1	—	68	—	—	—	68
	1975	39	52	6	1	98	—	—	—	98
	1976	35	40	7	—	82	—	—	—	82
	1977	34	15	5	+	54	—	—	—	54
	1978	28	14	5	1	48	—	+	+	48
	1979	23	7	5	4	39	—	+	+	39
	1980	32	17	4	3	56	—	1	1	57
	1981	36	—	8	8	52	—	5	5	57
	1982	29	—	6	—	35	—	22	22	57
	1983	29	—	3	—	32	—	39	39	71
British	1962	—	—	—	—	—	—	—	—	—
Columbia[1]	1963	—	—	—	—	—	—	—	—	—
INPFC areas:	1964	—	—	—	—	—	—	—	—	—
Charlotte	1965	—	—	—	—	—	—	—	—	—
and	1966	1	6	—	—	7	—	—	—	7
Vancouver	1967	5	6	—	—	11	—	—	—	11
	1968	5	19	—	—	24	—	—	—	24
	1969	4	25	—	—	29	—	—	—	29
	1970	3	12	—	—	15	—	—	—	15
	1971	2	3	—	—	5	—	—	—	5
	1972	4	2	—	—	6	—	—	—	6
	1973	3	8	—	—	11	—	—	—	11
	1974	7	1	—	—	8	—	—	—	8
	1975	4	2	—	8	14	—	—	—	14
	1976	3	2	—	1	6	—	—	—	6
	1977	3	—	—	1	4	—	—	—	4
	1978	+	—	—	+	+	+	—	+	+
	1979	1	—	—	1	2	1	—	1	3
	1980	1	—	—	2	3	5	—	5	8
	1981	+	—	—	1	1	7	—	7	8
	1982	1	—	—	—	1	5	—	5	6
	1983	—	—	—	—	—	7	—	7	7
Washington-	1962	—	—	—	—	—	—	—	—	—
Oregon-	1963	—	—	—	—	—	—	—	—	—
California	1964	—	—	—	—	—	—	—	—	—
INPFC areas:	1965	—	—	—	—	—	—	—	—	—

Table 3.--Continued.

Area	Year	Foreign					Joint venture			Total
		Japan	U.S.S.R.	Republic of Korea	Poland	Total	Canada	United States	Total	
Columbia to Conception	1966	+	83	--	--	83	--	--	--	83
	1967	2	126	--	--	128	--	--	--	128
	1968	1	40	--	--	41	--	--	--	41
	1969	+	55	--	--	55	--	--	--	55
	1970	+	65	--	--	65	--	--	--	65
	1971	1	65	--	--	66	--	--	--	66
	1972	1	43	--	--	44	--	--	--	44
	1973	2	51	--	1	54	--	--	--	54
	1974	4	62	--	18	84	--	--	--	84
	1975	3	51	--	14	68	--	--	--	68
	1976	3	51	--	8	62	--	--	--	62
	1977	--	26	--	4	30	--	--	--	30
	1978	--	19	--	5	24	--	+	+	24
	1979	--	31	--	5	36	--	3	3	39
	1980	--	--	--	12	12	--	7	7	19
	1981	--	--	--	20	20	--	14	14	34
	1982	--	--	--	--	--	--	19	19	19
	1983	--	--	--	--	--	--	20	20	20
Total: northeast Pacific region	1962	--	13	--	--	13	--	--	--	13
	1963	2	27	--	--	29	--	--	--	29
	1964	3	35	--	--	38	--	--	--	38
	1965	8	51	--	--	59	--	--	--	59
	1966	14	101	--	--	115	--	--	--	115
	1967	21	147	--	--	168	--	--	--	168
	1968	22	72	--	--	94	--	--	--	94
	1969	28	86	--	--	114	--	--	--	114
	1970	18	79	--	--	97	--	--	--	97
	1971	22	77	--	--	99	--	--	--	99
	1972	34	69	1	--	104	--	--	--	104
	1973	42	83	2	1	128	--	--	--	128
	1974	47	94	1	18	160	--	--	--	160
	1975	46	105	6	23	180	--	--	--	180
	1976	41	93	7	9	150	--	--	--	150
	1977	37	41	5	5	88	--	--	--	88
	1978	28	33	5	6	72	+	+	+	72
	1979	24	38	5	10	77	1	3	4	81
	1980	33	17	4	17	71	5	8	13	84
	1981	36	--	8	29	73	7	19	26	99
	1982	30	--	6	--	36	5	41	46	82
	1983	29	--	3	--	32	7	59	65	98

[1]Including waters off the United States southern boundary of the Vancouver area is lat. 47°30'N and the northern boundary of the Charlotte area is lat. 54°30'N.

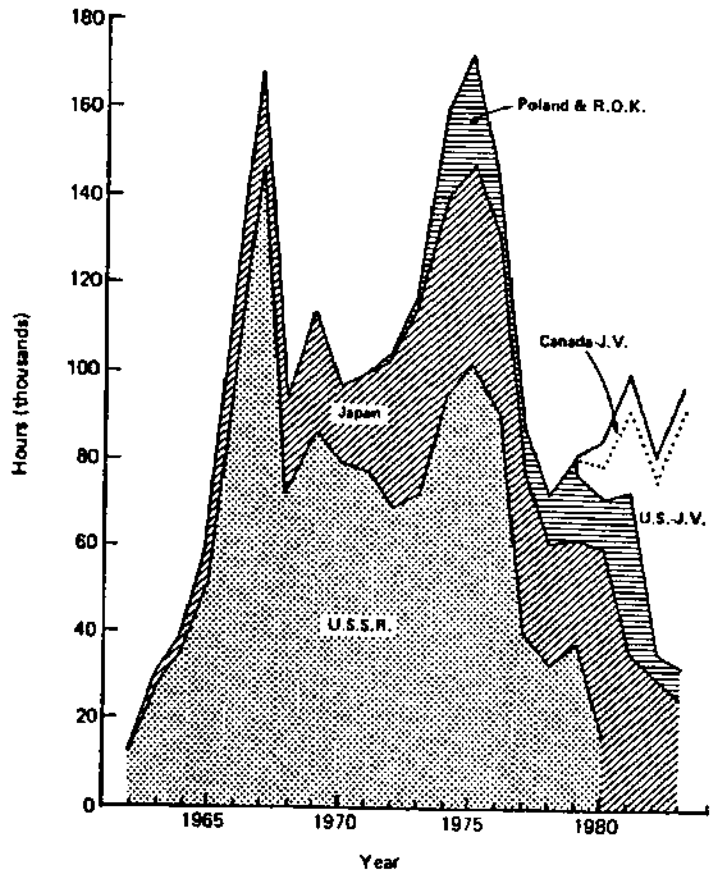

Figure 6.--Trawl fishing effort for groundfish in the northeast Pacific region by Japanese, U.S.S.R., Republic of Korea, Polish, Canadian joint venture and United States joint venture fisheries 1962-83.

years, and built up again to 180,000 h in 1975. It then dropped to about 70,000 h by 1978 and has since fluctuated between 80,000 and 100,000 h annually. Current level of effort is about 55% of the 1974-76 level.

Foreign trawl effort has declined markedly in the region as a whole since Canada and the United States established 200-mile fisheries jurisdiction zones. Effort by vessels engaged in joint venture fisheries has offset a substantial portion of the reduction in foreign fishing.

Trends in trawl fishing effort by foreign and joint venture vessels have varied in different sectors of the northeast Pacific region (Fig. 7). In the Gulf of Alaska, the overall trend in effort has been upward, although the current level of effort is less than it was in 1975-76. Off British Columbia, effort peaked at nearly 30,000 h in 1969 and then declined over the next 10 years. It has held at about 7,000 h in recent years (through 1983). Off Washington-Oregon-California, the overall trend in effort has been downward. Effort in 1983 was less than one-third of

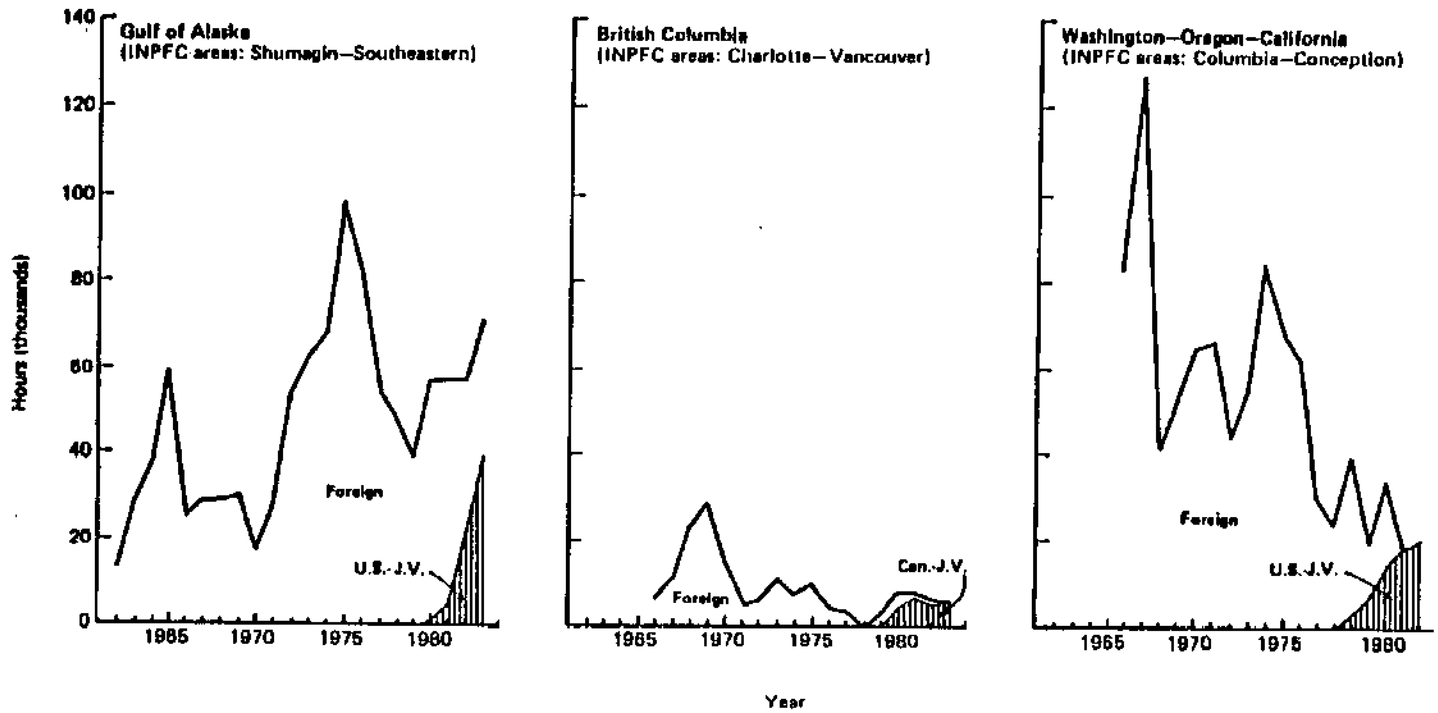

Figure 7.--Trawl fishing effort for groundfish in different sectors of the northeast Pacific region by foreign and joint venture fisheries, 1962-83.

the mid-1970's level and only one-sixth of the 1967 peak. Effort in joint venture fisheries in the Gulf of Alaska and off Washington-Oregon-California has increased markedly in the past 3 years.

Domestic Groundfish Trawl Fisheries - Canada and United States

Long before the advent of foreign and joint venture trawl fishing operations in the northwest Pacific region, Canada and the United States had domestic trawl fisheries for groundfish off British Columbia and Washington-Oregon-California. Annual effort by the domestic fisheries during 1956-83, as reported in publications of the International North Pacific Fisheries Commission (INPFC) or estimated in Appendix Table 3, is given in Table 4 and shown in Figure 8.

Total annual effort by the United States and Canadian domestic trawl fisheries for groundfish off British Columbia has been fairly stable since 1956. Effort off Washington-Oregon-California by the United States domestic trawl fishery also was fairly stable for about 15 years (1956-71), but it has since more than doubled.

JAPANESE HIGH SEAS SALMON GILL NET FISHERIES

Mother Ship Salmon Gill Net Fishery

Japan's post-World War II mother ship salmon gill net fishery began in 1952. Area of operation during 1959-76 is shown in Figure 9. Prior to 1959, some mother ship fleets operated west of long. 160°E in the North Pacific Ocean and in the Okhotsk Sea. In 1977, the U.S.S.R. 200-mile zone was closed to high seas salmon fishing, and in 1978 waters east of long. 175°E and south of lat. 56°N were also closed.

Annual fishing effort during 1952-82 in the area depicted in Figure 9 is given in Table 5 and shown in Figure 10. Effort is expressed in the cumulative number of tans of drift gill net fished each year, one tan representing 50 m of net.

Peak effort was in 1956, at close to 9 million tans. It declined over the next 20 years to about 6 million tans in 1976. Areal closures in 1977 and 1978 resulted in cutting the level of effort to about 3 million tans, all west of long. 175°E or north of lat. 56°N.

Land-Based Salmon Drift Net Fishery

Japan's land-based salmon, drift net fishery also began in 1952. Area of operation before and after the closure of waters east of long. 175°E in 1978 is shown in Figure 9.

Data on annual fishing effort by large vessels in the fishery, which are licensed to fish throughout the land-based drift net area (the smaller vessels being restricted to waters west of long. 149°E) and account for approximately 85% of the total catch, are available for 1962 and 1972-82 (Table 6 and Fig. 11).

Table 4.--Trawl fishing effort for groundfish by Canadian and United States domestic fisheries in the northeast Pacific region, 1956 to 1983, in thousands of hours. Data sources: Canada, 1956-70 - International North Pacific Fisheries Commission (INPFC) Bulletin 37; 1971-80 - INPFC Statistical Yearbooks; 1981 - Northwest and Alaska Fisheries Center (NWAFC) data file; 1982 - Leaman 1983; 1983 - Assumed same as in 1982. United States, 1956-61 - Appendix Table 3; 1962 - INPFC Bulletin 37; 1963 - Charlotte and Vancouver areas - Appendix Table 3; Columbia-Conception areas - INPFC Bulletin 37; 1964-70 - INPFC Bulletin 37; 1971-75 - INPFC Statistical Yearbooks; 1976 and 1979: Charlotte-Columbia areas - INPFC Statistical Yearbooks; Eureka-Conception areas - Appendix Table 3; 1977-78 and 1980 - INPFC Statistical Yearbooks; 1981 - Charlotte-Columbia Areas - NWAFC data file; Eureka-Conception Areas - Appendix Table 3; 1982-83: Appendix Table 3.

	INPFC Areas						
	Charlotte and Vancouver			Columbia-Conception	Total by nation		
Year	Canada	United States	Total	United States	Canada	United States	Total
1956	31	46	77	78	31	124	155
1957	26	41	67	83	26	124	150
1958	23	41	64	78	23	119	142
1959	22	49	71	74	22	123	145
1960	26	41	67	75	26	116	142
1961	23	40	63	74	23	114	137
1962	25	54	79	87	25	141	166
1963	23	48	71	72	23	120	143
1964	28	54	82	81	28	135	163
1965	29	50	79	87	29	137	166
1966	28	51	79	77	28	128	156
1967	26	46	72	71	26	117	143
1968	29	48	77	71	29	119	148
1969	33	53	86	74	33	127	160
1970	29	45	74	79	29	124	153
1971	31	41	72	85	31	126	157
1972	28	39	67	100	28	139	167
1973	24	37	61	106	24	143	167
1974	24	42	66	105	24	147	171
1975	34	44	78	122	34	166	200
1976	36	48	84	106	36	154	190
1977	35	47	82	112	35	159	194
1978	33	48	81	137	33	185	218
1979	38	52	90	148	38	200	238
1980	47	46	93	161	47	207	254
1981	39	46	85	179	39	225	264
1982	35	38	73	199	35	237	272
1983	35	39	74	174	35	213	248

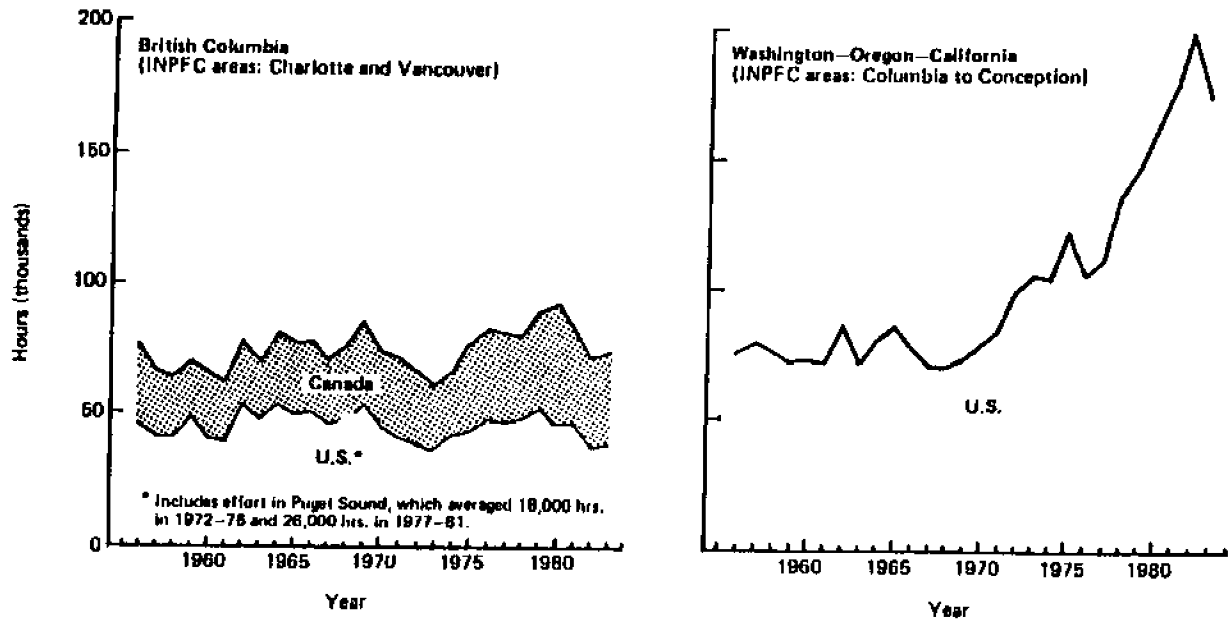

Figure 8.--Trawl fishing effort by Canadian and United States domestic fisheries in the British Columbia and Washington-Oregon-California sectors of the northeast Pacific region, 1956-83.

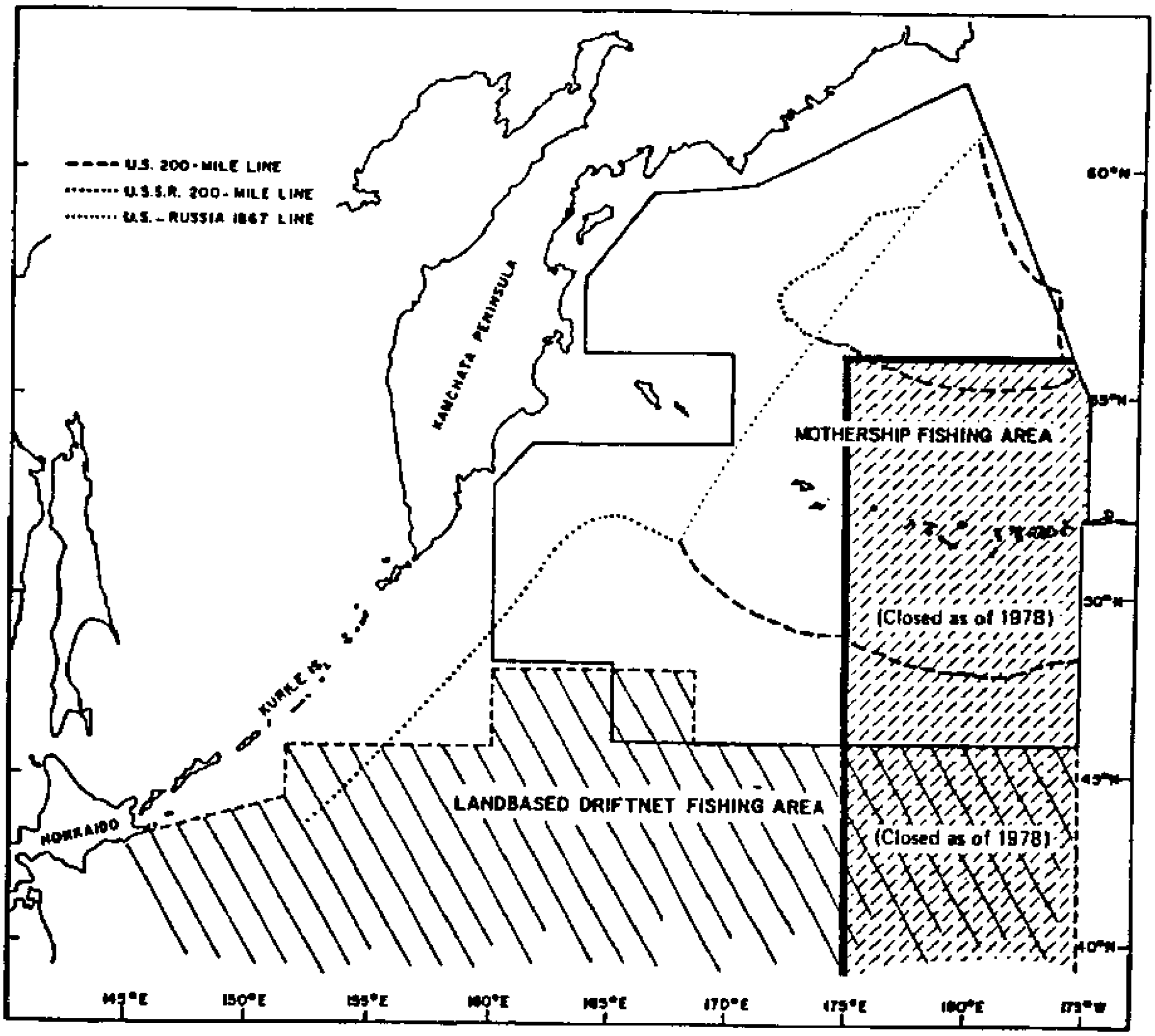

Figure 9.--Japanese high seas salmon gill net fishing areas.

Table 5.--Gill net fishing effort by the Japanese salmon mother ship fishery in the North Pacific Ocean, 1952 to 1982, in thousands of tans. Data sources: 1952-59 - Manzer et al. 1965; 1960-80 - International North Pacific Fisheries Commission (INPFC) Statistical Yearbooks; 1981-82 - Northwest and Alaska Fisheries Center data file.

Year	West of long. 175°E	East of long. 175°E			Total
		South of lat. 56°N	North of lat. 56°N	Total	
1952	311	160	--	160	471
1953	1,124	221	--	221	1,345
1954	3,225	83	--	83	3,308
1955	6,944	46	--	46	6,990
1956	6,377	2,215	137	2,352	8,729
1957	5,134	654	425	1,079	6,213
1958	7,098	16	--	16	7,114
1959	6,607	218	271	489	7,096
1960	4,842	1,029	646	1,675	6,517
1961	3,496	1,473	24	1,497	4,993
1962	5,285	565	--	565	5,850
1963	5,051	535	367	902	5,953
1964	5,016	1,483	1,021	2,504	7,520
1965	3,564	1,707	840	2,547	6,111
1966	3,785	952	459	1,411	5,196
1967	4,165	626	443	1,069	5,231
1968	4,118	788	1,020	1,808	5,926
1969	3,241	2,013	964	2,977	6,218
1970	1,943	2,332	1,754	4,986	6,029
1971	3,261	1,160	1,418	2,578	5,839
1972	3,391	639	1,889	2,528	5,919
1973	3,852	1,534	462	1,996	5,948
1974	2,870	1,885	680	2,565	5,435
1975	3,081	1,903	652	2,555	5,636
1976	3,030	1,973	808	2,781	5,811
1977	1,753	1,367	862	2,229	3,982
1978	2,562	--	158	158	2,720
1979	2,459	--	338	338	2,797
1980	2,604	--	543	543	3,147
1981	2,512	--	390	390	2,902
1982	2,451	--	485	485	2,936

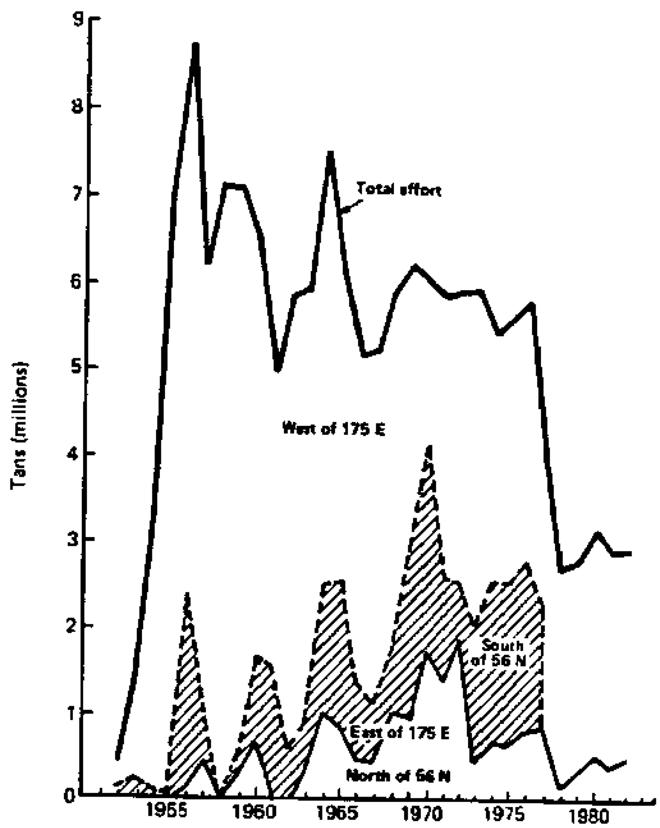

Figure 10.--Gill net fishing effort for salmon by the Japanese mother ship salmon fishery in the North Pacific Ocean, 1953-82.

Table 6.--Gill net fishing effort by large vessels of the Japanese land-based salmon fishery in the North Pacific Ocean, 1962 and 1972-82, in thousands of tans. Data sources: 1962 - International North Pacific Fisheries Commission (INPFC) Circular Letter, 21 October 1963; 1972-74 - Fisheries Agency of Japan (pers. commun.); 1975-76 - INPFC Sec.; 1977 - Fisheries Agency of Japan (pers. commun.); 1978-82 - Northwest and Alaska Fisheries Center data file.

Year	West of long. 175°E	East of long. 175°E	Total
1962	6,865	--	6,865
1963-71		Data not available	
1972	3,331	1,825	5,156
1973	4,583	1,169	5,752
1974	5,226	794	6,019
1975	4,933	1,057	5,990
1976	5,436	511	5,947
1977	3,186	533	3,719
1978	3,372	--	3,372
1979	3,219	--	3,219
1980	3,144	--	3,144
1981	3,234	--	3,234
1982	2,962	--	2,962

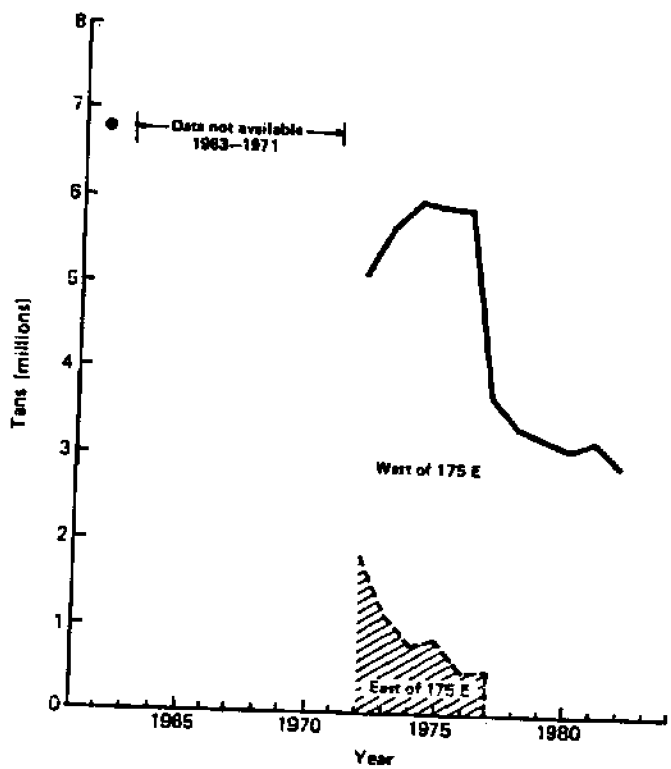

Figure 11.--Gill net fishing effort for salmon by the Japanese land-based salmon fishery in the North Pacific Ocean, 1962 and 1972-82.

The limited effort data for the land-based salmon drift net fishery point to a reduction in effort over the years similar in scale and timing of the reduction in effort for the mother ship salmon fishery.

OTHER HIGH SEAS GILL NET FISHERIES

Several new and major drift gill net fisheries have developed in the central and western North Pacific Ocean within the past decade or so. These include drift net fisheries by Japan, Republic of Korea, and Taiwan for squid and a Japanese drift net fishery for marlin and other species. Information on the amount of fishing effort generated by these fisheries is contained in documents submitted by T. Chen, Y. Gong, and K. Shima for the Workshop on the Fate and Impact of Marine Debris, held in Honolulu, Hawaii, in November 1984.

SUMMARY

Fishing by foreign trawlers in the Bering Sea-Aleutian Islands region began in 1954, but it was largely exploratory in nature and limited in scale until late in the 1950's. Between then and the early 1970's, there was a severalfold increase in fishing effort. During the past 10-12 years, the amount of effort has remained near the high level of the early 1970's, with effort by U. S. vessels engaged in domestic and joint venture fisheries accounting for an increasing fraction of the total effort in recent years.

In the northeast Pacific region, foreign trawlers began fishing for groundfish in 1962. Fishing effort by those vessels increased greatly in the mid-1960's, declined somewhat for a few years in the late 1960's, and then rose to a record high in 1975. It has since fallen off sharply, but fishing effort by United States vessels in joint venture fisheries, and to some extent by Canadian vessels engaged in similar fisheries off British Columbia, has offset a substantial portion of the reduction in foreign fishing. Current level of effort by the combined foreign and joint venture fisheries is about 55% of the 1974-76 peak reached by foreign trawlers.

Effort by Canadian and United States vessels in domestic trawl fisheries for groundfish from northern Washington to Dixon Entrance (INPFC's Charlotte and Vancouver areas) has been relatively stable since 1956. Farther south off the coast of Washington and off Oregon and California, the U.S. domestic trawl effort for groundfish also was fairly stable during 1956-71, but it has more than doubled since then.

Total trawl effort for (a) foreign, domestic, and joint venture fisheries in the Bering Sea-Aleutian Islands region and (b) United States and Canadian domestic trawl fisheries for groundfish from British Columbia to California has more than tripled since 1956. Estimates of annual average effort (third text table and Tables 1, 3, and 4) are as follows:

Years	Average annual effort (1,000 h)
1956-60	234
1961-65	537
1966-70	641
1971-75	782
1976-80	764
1981-83	794

Fishing effort by the Japanese mother ship salmon fishery, a high seas drift gill net fishery in the Bering Sea and central-western North Pacific Ocean, currently is about half of what it was during 1960-76 and an even smaller fraction of the level of effort in the late 1950's. Limited data for the Japanese land-based drift net fishery, another high seas net fishery for salmon in the North Pacific Ocean, point to a similar reduction in fishing effort by that fishery. There has been no high seas gill net fishery for salmon in the U.S.S.R. 200-mile zone since 1977, or east of long. 175°E, or south of lat. 56°N, since 1978.

Japan's tangle net fishery for crabs in southeastern Bering Sea was terminated in 1973, after 20 years of operation, and Japan's herring gill net fishery in the Bering Sea terminated in 1980. Peak effort for both fisheries had been in the mid-1960's.

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Appendix Table 1A.--Trawl fishing effort reported for foreign fisheries in the Bering Sea-Aleutians region, 1963-83, in number of hours (from the Northwest and Alaska Fisheries Center data file).

	Japanese fisheries								Other foreign trawl fisheries				
	Groundfish and herring					Shrimp			Groundfish				
Year	Pair trawl	Side trawl	Stern trawl	Danish seine[1]	Total	Side trawl	Stern trawl	Total	U.S.S.R.	Republic of Korea	Taiwan	West Germany	Poland
1963	15,646	33,115	0	123,218	171,979	0	0	0					
1964	11,799	40,003	1,884	148,358	202,644	0	0	0					
1965	6,960	30,410	4,043	126,856	168,269	23,163	0	23,163					
1966	11,800	39,817	6,345	123,970	181,932	17,543	0	17,543					
1967	20,626	32,421	48,719	160,616	262,382	1,730	206	1,936					
1968	15,242	9,756	130,623	145,852	301,473	4,666	2,105	6,771					
1969	13,889	10,241	137,459	148,438	310,027	0	2,094	2,094	See Appendix Table 1B				
1970	31,262	4,958	166,199	166,128	368,547	48	4,433	4,481		No fishing			
1971	42,868	2,989	219,012	124,660	389,529	44	4,413	4,457					
1972	46,322	1,734	248,854	104,896	401,806	0	0	0					
1973	46,961	0	197,649	96,708	341,318	0	0	0					
1974	46,931	0	261,634	65,222	373,787	0	0	0					
1975	42,337	0	268,284	46,334	356,955	0	0	0					
1976	39,651	0	273,830	40,220	353,701	0	347	347					
1977	35,727	0	296,797	38,500	371,024	0	244	244		55,640			
1978	32,254	0	312,723	34,842	379,819	0	0	0	26,811	7,782	1,280		
1979	33,004	0	299,908	34,422	367,334	0	0	0	53,395	17,495	1,699		
1980	34,737	0	319,250	37,074	391,061	0	0	0	32,726	26,323	1,014		4,643
1981	29,272	0	303,183	31,092	363,547	126	0	126	651	38,176	2,104	1,718	13,105
1982	28,595	0	305,396	24,296	358,287	0	0	0	0	29,536	3,694	3,469	12,115
1983	24,167	0	285,029	21,114	330,310	0	0	0	0	29,083	6,321	3,094	0
									0	31,579	0	0	0

[1]Hours fished by Danish seiners is estimated from number of drags reported at 2 h per drag.

Appendix Table 1B.--Estimates of U.S.S.R. trawl fishing effort for groundfish in the Bering Sea-Aleutians region, 1963-78, in number of hours (MT = metric tons).

Year	Japan			U.S.S.R.	
	Trawlers (fish net) and Danish seiners--groundfish and herring			Trawlers--groundfish	
	Effort (hours)[1]	Catch (MT)[2]	Hours per ton	Catch (MT)[3]	Estimated effort (hours)[4]
1963	171,979	211,581	0.8128	92,000	74,778
1964	202,644	350,663	0.5779	155,000	89,574
1965	168,269	350,561	0.4800	115,000	55,200
1966	181,932	414,521	0.4389	100,000	43,890
1967	262,382	747,052	0.3512	177,662	62,395
1968	301,473	916,979	0.3288	133,975	44,051
1969	310,027	1,072,132	0.2892	186,700	53,994
1970	368,547	1,477,219	0.2495	231,881	57,854
1971	389,529	1,802,880	0.2161	397,477	85,894
1972	401,806	1,913,897	0.2099	412,896	86,667
1973	341,318	1,752,331	0.1948	347,969	67,784
1974	373,787	1,526,183	0.2449	435,052	106,544
1975	356,955	1,299,261	0.2747	338,417	92,963
1976	353,701	1,210,629	0.2922	279,697	81,727

[1]From Appendix Table 1A.

[2]From International North Pacific Fisheries Commission (INPFC) Bulletin 37 and INPFC Statistical Yearbooks. Groundfish catch by pair trawl, side trawl (fish net), stern trawl (fish net), and Danish seines.

[3]From INPFC Bulletin 37 (Table 1) for 1963 and from Murai et al. (1981) for 1964-76.

[4]Hours per ton for Japanese vessels times U.S.S.R. catch.

Appendix Table 1C.--Estimates of U.S.S.R. trawl fishing effort for herring in eastern Bering Sea, 1963-76, in number of hours (MT = metric tons).

Year	Catch (MT)[1]	No. of tows[2]	No. of hours at 3.4 h/tow[3]	Hours per ton	Effort (hours)[4]
1963	150,000	NA	--	[5](0.6)	(90,000)
1964	175,000	NA	--	[5](0.6)	(105,000)
1965	--	--	--	--	--
1966	--	--	--	--	--
1967	--	--	--	--	--
1968	22,255	3,885	13,209	0.5935	13,209
1969	94,491	14,762	50,191	0.5312	50,191
1970	117,202	22,236	75,602	0.6451	75,602
1971	23,000	8,008	27,227	1.1838	27,227
1972	54,000	3,805	12,937	0.2396	12,937
1973	34,361	2,536	8,876	0.2583	8,876
1974	19,800	NA	--	[5](0.6)	(11,880)
1975	14,206	NA	--	[5](0.6)	(8,523)
1976	16,812	NA	--	[5](0.6)	(10,087)

[1]From Murai et al. (1981).

[2]From catch and catch per unit effort data (by vessel class) provided by U.S.S.R. during United States and U.S.S.R. fisheries meetings.

[3]From data provided by U.S.S.R. for 1974 for eastern Bering Sea. (Average hours per tow for three vessels classes: BMRT-7; SRTM-6; and SRTR-6.)

[4]Catch times hours per ton.

[5]Rounded average of 1968-73 data.

Appendix Table 1D.--Estimates of trawl fishing effort for groundfish by the U.S. domestic and joint venture fisheries in the Bering Sea-Aleutians region, 1980-83, in number of hours.

	1980	1981	1982	1983
Estimated number of hours of trawling by foreign nations, incuding Danish seine drags (Japan) converted to hours at 2 h per drag (from Appendix Table 1A)	446,815	412,487	396,785	361,889
Foreign catch of groundfish by trawlers (from R. Nelson, Northwest and Alaska Fisheries Center (with longline catch subtracted)) (pers. commun.)	1,282,114	1,258,347	1,178,050	1,111,003
U.S. trawl catch of groundfish				
Domestic landings	5,858	14,187	24,800	41,368
Joint venture landings	32,668	78,535	108,603	211,155
Total	38,526	92,722	133,403	252,523
(from R. Nelson pers. commun.)				
Hours per ton of catch for foreign trawlers (1 ÷ 2)	0.3485	0.3278	0.3368	0.3257
Estimated equivalent number of hours trawled by U.S. vessels in the domestic and joint venture fisheries (4 x 3)	13,426	30.394	44,930	82,247
Estimated total hours of trawling by U.S. and foreign vessels for groundfish (1 + 5).	460,241	442,881	441,715	444,136

Appendix Table 2A.--Trawl fishing effort for groundfish as reported for foreign nations in the northeast Pacific region, 1963-83, in number of hours. (Canadian vessels and Japanese and Danish seiners and shrimp trawlers excluded.) Data sources: Japan 1963-70 from the International North Pacific Fisheries Commission (INPFC) Bulletin 37; 1971-80 from the INPFC Statistical Yearbooks. All other data are from the Northwest and Alaska Fisheries Center data file.

	Gulf of Alaska Shumagin-southeastern areas				British Columbia Charlotte-Vancouver areas			Washington-Oregon-California Columbia-Conception areas		
Year	Japan	U.S.S.R.	Republic of Korea	Poland	Japan	U.S.S.R.	Poland	Japan	U.S.S.R.	Poland
1963	2,275	(1)	(2)	(2)	0	0	0	0	0	0
1964	2,507	(1)	(2)	(2)	0	0	0	0	0	0
1965	7,789	(1)	(2)	(2)	0	0	0	0	0	0
1966	12,560	(1)	(2)	(2)	923	(3)	0	92	(4)	0
1967	13,925	(1)	(2)	(2)	4,564	(3)	0	1,823	(4)	0
1968	16,042	(1)	(2)	(2)	5,457	(3)	0	803	(4)	0
1969	23,789	(1)	(2)	(2)	3,829	(3)	0	236	(4)	0
1970	14,704	(1)	(2)	(2)	2,641	(3)	0	210	(4)	0
1971	18,808	(1)	(2)	(2)	2,141	(3)	0	599	(4)	0
1972	29,013	(1)	(1)	(2)	4,377	(3)	0	1,142	(4)	0
1973	37,297	(1)	(1)	(2)	3,306	(3)	0	2,414	(4)	(4)
1974	36,342	(1)	(1)	(2)	7,056	(3)	0	3,925	(4)	(4)
1975	38,894	(1)	(1)	(1)	4,190	(3)	(3)	2,678	(4)	(4)
1976	34,715	(1)	6,523	0	3,226	(3)	(3)	2,667	(4)	(4)
1977	33,651	14,967	4,797	374	2,716	0	1,484	0	26,036	3,785
1978	27,842	14,317	5,315	702	362	0	141	0	19,473	5,415
1979	22,884	7,360	4,869	3,917	556	0	848	0	31,448	5,209
1980	31,694	17,247	3,901	2,663	502	0	1,556	0	0	12,302
1981	36,195	0	8,499	8,223	298	0	1,183	0	0	19,796
1982	29,080	0	6,406	0	581	0	0	0	0	0
1983	28,665	0	3,162	0	0	0	0	0	0	0

[1] See Appendix Table 2B.
[2] No fishing.
[3] See Appendix Table 2C.
[4] See Appendix Table 2D.

Table 2B.--Estimates of trawl fishing effort for groundfish by the U.S.S.R., Republic of Korea, and Poland in the Gulf of Alaska (Shumagin-southeastern areas), 1962-76, in number of hours (MT = metric tons). (Estimates are based on catch rates by Japanese trawlers.)

	Japanese trawlers			Catch (MT)[1]			Estimated effort (hours)[2]		
Year	Effort (hours)[3]	Catch (MT)[4]	Hours per ton	U.S.S.R.	Republic of Korea	Poland	U.S.S.R.	Republic of Korea	Poland
1962	--	--	--	50,000	--	--	[5](12,655)	--	--
1963	2,275	8,989	0.2531	108,000	--	--	27,335	--	--
1964	2,507	16,347	0.1534	230,000	--	--	35,282	--	--
1965	7,789	51,512	0.1512	340,000	--	--	51,408	--	--
1966	12,560	84,004	0.1495	83,000	--	--	12,408	--	--
1967	13,925	72,852	0.1911	76,937	--	--	14,703	--	--
1968	16,042	72,518	0.2212	59,422	--	--	13,145	--	--
1969	23,789	82,521	0.2883	20,015	--	--	5,770	--	--
1970	14,704	64,429	0.2282	9,336	--	--	2,130	--	--
1971	18,808	66,259	0.2839	30,719	--	--	8,721	--	--
1972	29,013	84,851	0.3419	68,864	4,042	--	23,545	1,382	--
1973	37,297	91,402	0.4081	59,522	4,332	--	24,291	1,768	--
1974	36,342	90,715	0.4006	77,942	2,237	--	31,224	896	--
1975	38,894	70,851	0.5490	95,465	11,800	2,132	52,410	6,478	1,170
1976	34,715	69,678	0.4982	79,873	34,348	--	39,793	(5)	--

[1]From Pruter (1976) for 1962-63; from Murai et al. (1981) for 1964-76.

[2]Hours per ton for Japanese trawlers times catch by indicated nation.

[3]From Appendix Table 2A.

[4]From International North Pacific Fur Commission (INPFC) Bulletin 37 and INPFC Statistical Yearbooks.

[5]Hours per ton for Japanese trawlers in 1963 times U.S.S.R. catch in 1962.

Appendix Table 2C.--Estimates of trawl fishing effort for groundfish by the U.S.S.R. and Poland off British Columbia (Charlotte-Vancouver areas), 1966-76, in number of hours (MT = metric tons). (Except for 1966, estimates are derived from data for the U.S.S.R. hake fishery.)

Year	U.S.S.R. Hake catch (MT)[1]	No. of tows[2]	Effort (hours)[3]	Hours per ton	Poland Hake catch (MT)	Estimated effort (hours)
1966	0	NA	[4](5,861)	--	0	0
1967	11,260	2,458	6,145	0.5457	0	0
1968	35,804	7,708	19,270	0.5382	0	0
1969	52,792	10,050	25,125	0.4759	0	0
1970	25,491	4,701	11,752	0.4610	0	0
1971	5,021	1,028	2,570	0.5119	0	0
1972	5,816	931	2,328	0.4003	0	0
1973	13,840	3,101	7,752	0.5601	0	0
1974	1,799	403	1,003	0.5575	0	0
1975	3,493	NA	(1,768)	[5](0.5063)	15,704	(7,951)
1976	3,918	NA	(1,983)	[5](0.5063)	2,054	(1,040)

[1]From Murai et al. (1981). No hake catch in 1966, but total groundfish catch of 33,000 MT.

[2]From catch and catch per unit effort data (by vessel class) provided by U.S.S.R. during United States and U.S.S.R. fisheries meetings.

[3]At 2.5 h per tow as derived from data for 1974 for British Columbia, Washington, Oregon, and California.

[4]Hours per metric tons for Japanese trawlers (923 h per 5,198 MT, or 0.1776) times 33,000 MT (U.S.S.R. groundfish catch).

[5]Average for 1967-74; used to estimate effort.

Appendix Table 2D.--Estimates of trawl fishing effort for groundfish by the U.S.S.R. and Poland off Washington-Oregon-California (Columbia-Conception areas) in the northeast Pacific region, 1966-76, in number of hours (MT = metric tons). (Estimates are derived from data for the U.S.S.R. hake fishery.)

	U.S.S.R.				Poland	
Year	Hake catch (MT)[1]	No. of tows[2]	Effort (hours)[3]	Hours per ton	Hake catch (MT)[1]	Estimated effort (hours)[4]
1966	128,000	NA	[5](82,432)	--	0	0
1967	195,092	50,346	125,636	0.6440	0	0
1968	67,896	16,054	40,135	0.5911	0	0
1969	109,225	21,893	54,733	0.5011	0	0
1970	200,754	25,825	64,562	0.3216	0	0
1971	146,726	26,157	65,392	0.4457	0	0
1972	111,269	17,277	43,192	0.3882	0	0
1973	139,060	20,566	51,415	0.3697	2,220	821
1974	156,708	24,725	62,175	0.3968	44,354	17,600
1975	155,405	NA	[6](51,066)	[7](0.3286)	41,542	13,650
1976	154,129	NA	[7](50,646)	[7](0.3286)	23,668	7,777

[1]From Murai et al. (1981).

[2]From catch and catch per unit effort data provided by U.S.S.R. for 1967-73. Data on number of tows and hours fished in 1974 provided by U.S.S.R.

[3]At 2.5 h per tow, as derived from data provided by U.S.S.R. for 1974.

[4]Catch times hours per ton for U.S.S.R. fishery.

[5]Based on hours per ton for 1967.

[6]Estimated from average hours per ton in 1974 and 1977.

[7]Average for 1974 and 1977. Hours per ton in 1977 derived as follows: Hours fished 26,036; hake catch 99,938; hours per ton 0.2605.

Appendix Table 2E.--Estimates of trawl fishing effort for groundfish by the United States joint venture and Canadian joint venture fisheries in the northeast Pacific region, 1978-83, in number of hours (MT = metric tons).

		Japan-U.S.S.R.-Republic of Korea-Poland combined			United States joint venture		Canada joint venture	
Area	Year	Effort (hours)[1]	Catch (MT)[2]	Hours per ton	Catch (MT)[3]	Estimated effort (hours)[4]	Catch (MT)[5]	Estimated effort (hours)[4]
Gulf of Alaska Shumagin-southeastern area	1978	48,176	151,468	0.3181	48	15	--	--
	1979	39,030	130,787	0.2984	1,522	454	--	--
	1980	55,505	163,598	0.3393	1,911	648	--	--
	1981	52,917	198,942	0.2660	16,966	4,512	--	--
	1982	35,486	121,546	0.2920	74,450	21,739	--	--
	1983	31,827	115,950	0.2745	142,984	39,249	--	--
British Columbia Charlotte-Vancouver areas	1978	503	3,952	0.1273	--	--	1,814	231
	1979	1,404	8,310	0.1690	--	--	4,233	715
	1980	2,058	5,676	0.3626	--	--	13,210	4,790
	1981	1,481	3,840	0.3857	--	--	18,400	7,097
	1982	581	2,421	0.2400	--	--	20,051	4,812
	1983	--	--	[6](0.2569)	--	--	27,715	(7,120)
Washington-Oregon-California Columbia-Conception areas	1978	24,888	99,028	0.2513	856	215	--	--
	1979	36,657	124,065	0.2955	8,834	2,610	--	--
	1980	12,302	48,505	0.2536	27,537	6,983	--	--
	1981	19,796	61,203	0.3234	43,557	14,086	--	--
	1982	--	--	[7](0.2810)	67,465	(18,958)	--	--
	1983	--	--	[7](0.2810)	72,100	(20,260)	--	--

[1]From Appendix Table 2A.
[2]From Northwest and Alaska Fisheries Center (NWAFC) data file.
[3]From Berger et al. (1984)
[4]Catch times hours per ton for Japan, U.S.S.R., Republic of Korea, and Poland.
[5]Data for 1978-80 are from INPFC Statistical Yearbook for 1980. Data for 1981-83 are from Pacific Marine Fisheries Commission Annual Reports for 1982-83.
[6]Average for 1978-82.
[7]Average for 1978-81.

Appendix Table 3.--Trawl fishing effort for groundfish by the U.S. domestic fishery in the Charlotte-Vancouver and Columbia-Conception areas of the northeast Pacific region, 1956-83, as reported or estimated, in number of hours (MT = metric tons). Data sources: Catch: 1956-70, International North Pacific Fisheries Commission (INPFC) Bulletin 37; 1971-80, INPFC Statistical Yearbooks; 1981, Charlotte-Vancouver-Columbia areas, Northwest and Alaska Fisheries Center (NWAFC) data files; 1981, Washington-Oregon-California landings, Pacific Marine Fisheries Commission (PMFC) annual report; 1982-83, Washington-Oregon-California landings PMFC annual reports; effort (reported): 1962-70, INPFC Bulletin 37; 1971-80, INPFC Statistical Yearbooks; 1981, NWAFC data file.

	Charlotte-Vancouver			Columbia-Conception			Columbia only		
Year	Effort (hours)	Catch (MT)	Hours per ton	Effort (hours)	Catch (MT)	Hours per ton	Effort (hours)	Catch (MT)	Hours per ton
1956	(46,489)	21,826	[1]2.13	(78,302)	27,571	[2]2.84	—	—	—
1957	(41,137)	19,313	[1]2.13	(82,894)	29,188	[2]2.84	—	—	—
1958	(41,460)	19,465	[1]2.13	(78,276)	27,562	[2]2.84	—	—	—
1959	(48,743)	22,884	[1]2.13	(73,931)	26,032	[2]2.84	—	—	—
1960	(41,369)	19,422	[1]2.13	(74,985)	26,403	[2]2.84	—	—	—
1961	(40,479)	19,004	[1]2.13	(74,476)	26,224	[2]2.84	—	—	—
1962	53,972	20,504	2.63	86,982	28,727	3.03	35,216	14,405	2.44
1963	(47,612)	22,353	[1]2.13	71,782	29,035	2.47	12,535	13,373	0.91
1964	53,769	19,472	2.76	81,128	27,489	2.95	28,500	13,205	2.16
1965	49,878	24,154	2.06	87,110	30,605	2.85	27,065	14,454	1.87
1966	50,580	30,861	1.64	77,437	28,220	2.74	22,114	11,844	1.87
1967	45,787	28,362	1.61	71,173	31,444	2.26	19,431	16,303	1.19
1968	47,932	27,327	1.75	71,092	23,097	3.08	19,825	7,148	3.08
1969	52,611	26,929	1.95	74,048	25,494	2.90	20,882	7,993	2.61
1970	44,595	22,552	1.98	79,155	26,048	3.04	23,052	7,576	3.04
1971	41,081	19,045	2.16	84,729	28,975	2.92	25,278	9,600	2.63
1972	39,217	19,065	2.06	99,745	35,569	2.80	26,279	8,982	2.93
1973	36,855	18,275	2.02	105,562	36,565	2.89	24,090	8,081	2.98
1974	42,108	19,476	2.16	105,374	40,902	2.58	25,858	9,633	2.68
1975	43,661	17,257	2.53	131,895	38,392	3.18	33,771	10,143	3.33
1976	48,118	19,237	2.49	(105,769)	43,348	[3]2.44	34,851	14,298	2.44
1977	47,319	22,428	2.11	112,503	50,376	2.23	29,431	14,297	2.06
1978	47,612	23,271	2.05	136,904	64,999	2.11	46,740	23,563	1.98
1979	51,923	26,110	1.99	(148,053)	79,173	[3]1.87	72,195	38,693	1.87
1980	46,065	21,948	2.10	160,531	83,703	1.92	58,870	42,010	1.40
1981	46,141	18,565	2.49	(178,505)	88,369	[4]2.02	77,335	29,134	2.65
1982	(38,240)	[5]19,120	[6]2.00	(199,388)	99,694	[6]2.00	—	—	—
1983	(38,990)	[5]19,495	[6]2.00	(173,670)	86,835	[6]2.00	—	—	—

[1]Average for 1962 and 1964-81. Used to estimate total effort.
[2]Average for 1962-75. Used to estimate effort.
[3]Hours per ton for Columbia area. Used because of similarity of rates after 1967.
[4]Average for Columbia area in 1980-81.
[5]50% of Washington landings assumed to have been fish taken in the Vancouver area.
[6]Assumed value.

SUMMARY OF JAPANESE NET FISHERIES IN THE NORTH PACIFIC OCEAN[1]

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Summary of Japanese net fisheries in the North Pacific Ocean

Type of fisheries	Operating area	Operating season	No. of vessels	No. of net setting (/day·vessel) (B)	No. of days engaged (/year·vessel) (C)	No. of operation (/year) (D) =(AxBxC)	No. of net used (/operation) (E)	No. of net used (/year) (F) =(DxE)	Quality of net used
Medium trawl (Hokuten)	Bering Sea	Whole year	70	3	200	42,000	1	42,000	Polyethylene
Medium trawl (Other than Hokuten)	Bering Sea	Whole year	16	3.5	110-290	11,800-16,200	1	11,800-16,200	Polyethylene
Large trawl (North Pacific)	Bering Sea	Whole year	Larger 22	4.5	90-260	8,900-25,700	1	8,900-25,700	Polyethylene polyester
	Gulf of Alaska		smaller 14	3	120-240	9,200-10,100		8,200-10,100	
Mother ship type trawl	Bering Sea	June-Oct.	M. 6 C.B. 84	3	120-150	20,200-25,200	1	20,100-25,200	Polyethylene
Mother ship salmon drift gill net	Northwest	June-July	M. 4 C.B. 172	1	50	8,600	300 (tan)[1]	2,838,000 (tan) 127,710 km	Nylon (monofilament)
Land-based type salmon drift gill net	Northwest Pacific	May-July	209	1	40	8,400	300 (tan)	2,772,000 (tan) 124,740 km	Nylon (monofilament)
Squid drift gill net	North Pacific	June-Dec.	511	1	60	30,700	700 (tan)	21,490,000 (tan) 967,100 km	Nylon (monofilament)
Marlin and others drift gill net	North Pacific	Whole year	East of 170°E 140	1	40	5,600	260 (tan)	1,456,000 (tan) 65,520 km	Nylon (multifilament)
			West of 170°E 460	1	30	13,800	200 (tan)	2,760,000 (tan) 124,200 km	

[1] 1 tan = 45 m

Note: Average figures are used on this table. The figures of the above columns, (C), (D), and (F) are calculated on the assumption that all vessels operated all days engaged. Therefore, actual figures are lower level than figures in each column. The number of the catcher boats of mother ship type trawl includes 20 pairs of two-boat type trawls.

[1] The contents of this table were presented orally at the Workshop on the Fate and Impact of Marine Debris. Provisional as of 1983.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

HIGH SEA GILL NET FISHERIES OF TAIWAN

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INTRODUCTION

In recent years, Taiwan's gill net fishing industry has developed rapidly. Its production increased from 8,475 metric tons (MT) in 1970 to 53,856 MT in 1982, indicating an average annual increase of 3,782 MT. In 1970, there were 524 gill-netters with a total gross tonnage of 4,917 MT; most vessels were <50 MT. By 1982, the number of gill-netters had increased to 1,284, total gross tonnage of 33,479 MT, but 1,209 vessels were <50 MT and 75 were between 200 and 500 MT.

TYPES OF HIGH SEA GILL NETS

Large Mesh Gill Nets for Marlin and Sailfish

Construction: The gear consists of net, float, and rope, with one piece of net made of synthetic fiber, 340 meshes long and 108 meshes deep. The knots are double trawler knots, with a mesh size of 30 cm for shark, 16 cm for sailfish.

<u>Webbing</u>

Color: blue
Twine size: 210 D/3x6 - 210 D/3x2 for shark
210 D/3x6 - 2x0 D/3x8 for sailfish
Hanging coefficient: 0.55 - 0.60 upper
0.75 - 0.80 lower

<u>Buoy line</u>

Material: Polyethylene (PE) (diameter 11 mm) x 2
One in S twist
One in Z twist

<u>Floats</u>

Number: 4-5 for each piece
Shape: Sphere
Diameter: 0.3 m (1 ft)

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

Sink line

Material: Polypropylene (PP) (contains lead line, 8 mm) x 2
One in S twist
One in Z twist

Weight: 150 g/m - 200 g/m (in air)

Squid Gill Nets Used in the
Northwestern Pacific Ocean

Webbing (each piece)

Material: Nylon monofilament
Type of knot: Double trawler knot
Color: White-blue or white-green
Diameter of monofilament: 0.5-0.7 mm
Length: 500-900 meshes long
Depth: 60-120 meshes deep
Hanging coefficient: 0.57-0.60 (upper)
0.60-0.64 (lower)
Mesh size: 11.5-9.0 cm

Buoy line

Material: PE (diameter 9 mm) x 2

Float

Number: One by each meter
Shape: Elliptical
Buoy force: 250 g/m

Sink line

Material: PP (contains lead 50 g/m) x 2
One in S twist
One in Z twist

Weight: 140 g/m (in air)

SQUID GILL NET FISHERY

Taiwan started its squid fisheries in 1972 and operated in the Sea of Japan from July to October. When the 200-nmi economic zone was enforced by the Soviet Union and Japan in 1977, the squid fishing vessels began to fish in the northwestern Pacific. At first, automatic squid jigging machines were used, but about 1980, some of the squid fishing vessels changed to gill nets because of their high fishing efficiency and energy economy. Now they are the most important squid fishing gear in Taiwan.

Squid Fishing Vessels

In 1980, only 12 squid fishing vessels used gill nets, but the number of squid gill-netters increased to 101 to 1983. Most of the squid gill-netters were converted from tuna longliners. Only about 17% of the vessels were newly built. The vessels range from 100 to 400 MT and about 50% are over 200 MT.

FISHING GROUNDS

Northwestern Pacific
(Fig. 1)

In the northwestern Pacific, the squid fishing season begins in the middle of April and ends in November. But 80 to 90% of total squid catches are made from July to October.

The distribution and composition of squid vary with temperature and some other factors. The fishing grounds are located between lat. 35° and 45°N and long. 152°E and 158°W in water 11°-15°C. The species of squid include Ommastrephes bartrami, Onychoteuthis borealijaponica, and Moroteuthis robusta. Ommastrephes bartrami is the most important species. The mantle length of this species measures 25-40 cm, and the body weight is between 450 and 2,200 g.

Squid fishing vessels operating in the northwestern Pacific and their production:

	Squid jigging		Gill net		Total	
Year	No. of vessels	Production (MT)	No. of vessels	Production (MT)	No. of vessels	Production (MT)
1977	6	880	--	--	6	880
1978	14	2,505	--	--	14	2,505
1979	23	3,385	--	--	23	3,385
1980	27	4,824	12	908	39	5,732
1981	28	4,686	44	10,719	72	15,405
1982	25	5,462	73	19,287	98	24,749
1983	34	9,180	101	14,257	135	23,436

South Pacific

The fishing grounds are about 200 nmi off northeastern Australia. The gill nets are usually set about 10 m below the surface of the water to prevent the propellers of fishing vessels from being entangled with the nets. Eight floats are used when they are set near the surface. Recently, monofilament nets have been used, especially in the marlin and sailfish gill net fishery. Owing to their transparency, good catches are obtained with these nets in spite of hardness of the monofilament.

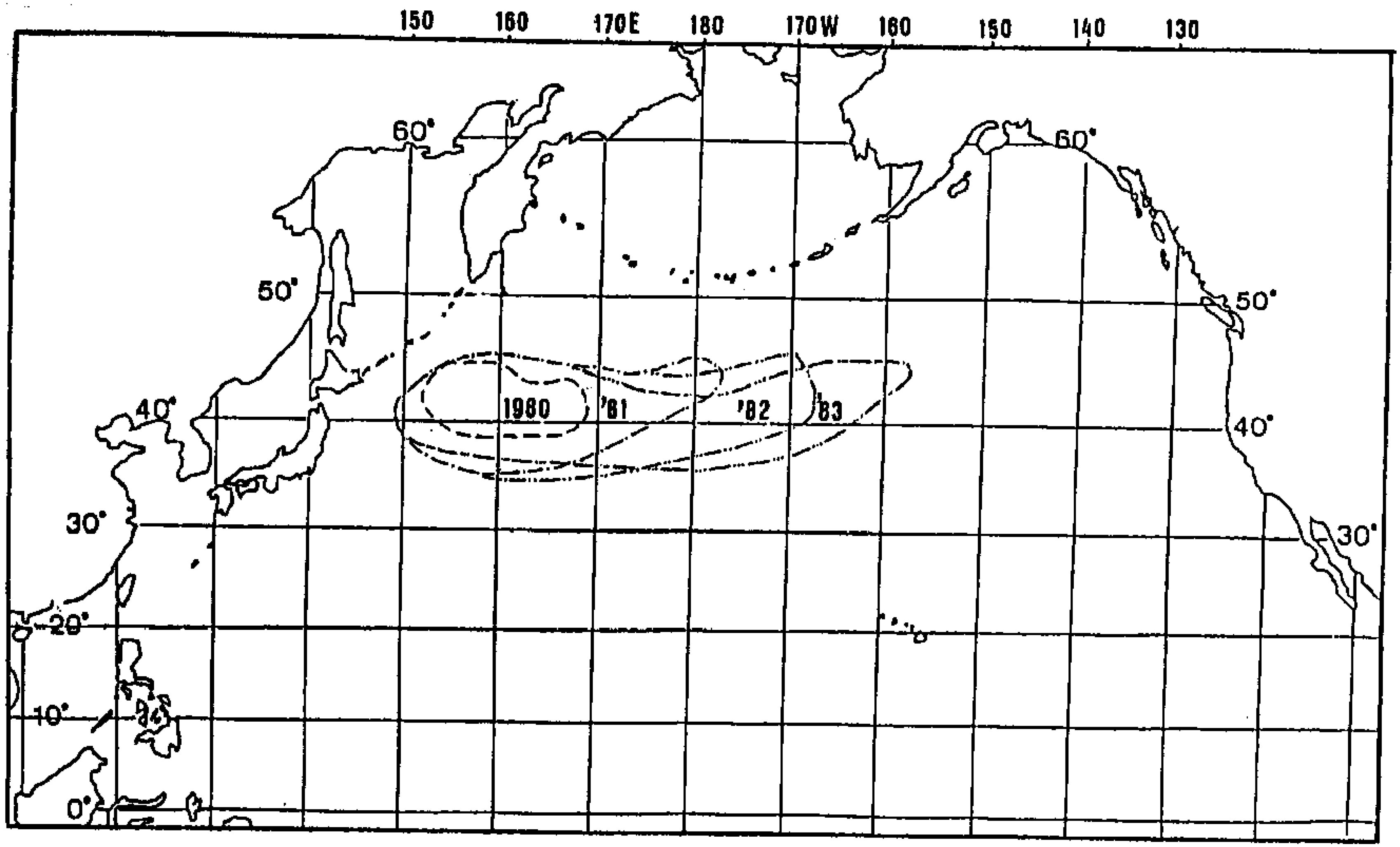
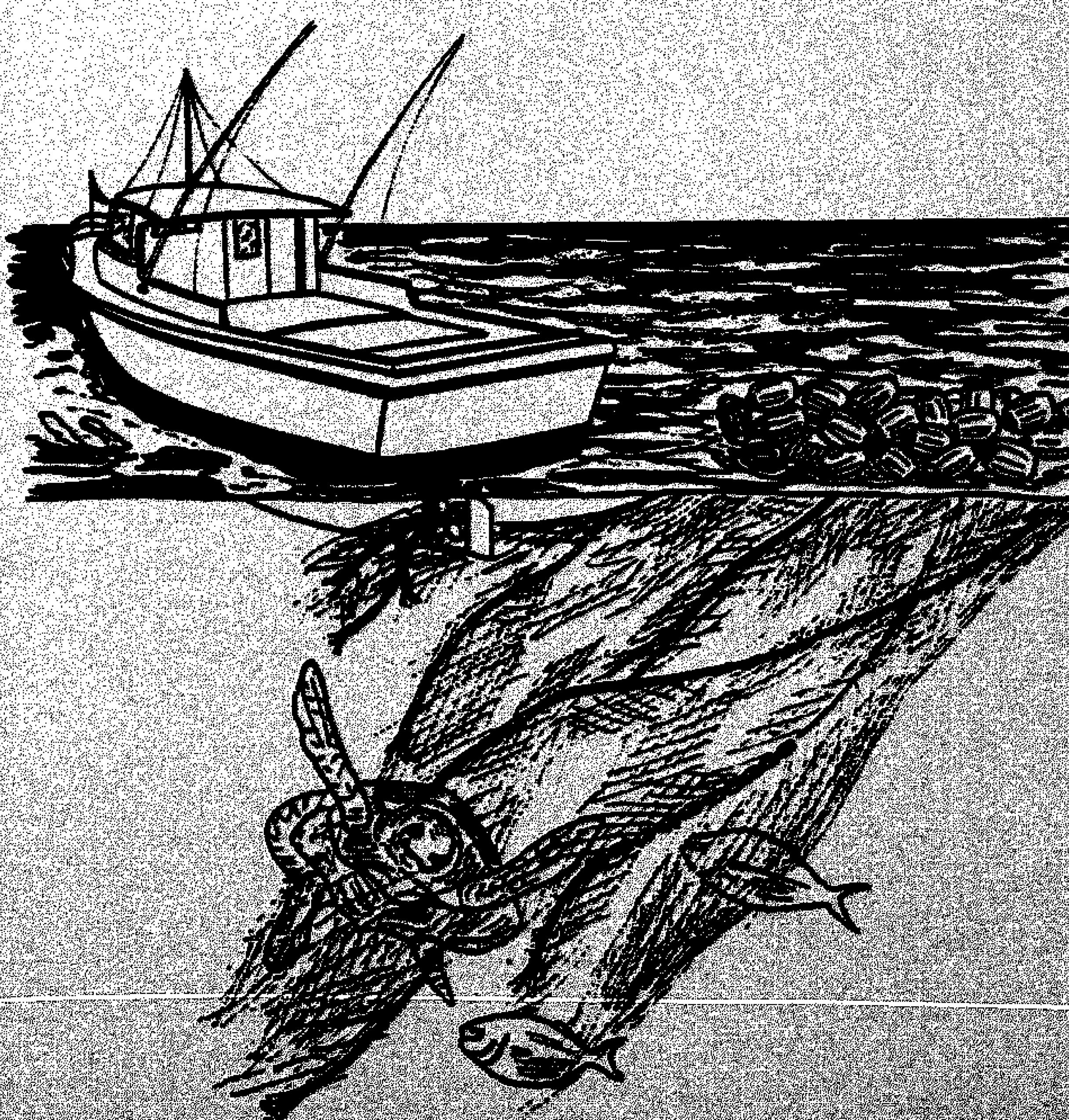


Figure 1.--Taiwan's deep-sea squid fishing ground in northwestern Pacific.

SESSION II

IMPACTS OF DEBRIS ON RESOURCES



DEBRIS ENTANGLEMENT IN THE MARINE ENVIRONMENT: A REVIEW

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ABSTRACT

A review of the literature shows debris entanglement is now evident for many species in all oceans of the world. Types of debris range from large intact fishing nets to small plastic fragments of unidentifiable origin. Nonbiodegradable plastic objects form a large portion of the debris. The term entanglement herein covers interactions with objects by ingestion and by encirclement or snagging of body parts in netting and loops. Behavior leading to entanglement is categorized as accidental, indiscriminate, or deliberate. Birds, fish, and sea turtles become weakened or die from both types of entanglement, through accidental or indiscriminate encounters. Marine mammals suffer primarily from encirclement through accidental catch in nets, indiscriminate hauling out on balls of netting, and deliberate playing with loops and openings; they die from increased drag and severed tissue. Humans are harmed primarily by snagging of objects during ship operation and underwater activity. Significant ecological harm is occurring in certain areas and species. Significant commercial loss may be occurring through fish mortality and ship hazards.

Beach deposition, sinking, and environmental degradation are possible natural removal mechanisms. Potential human removal mechanisms are a complete halt to dumping, retention of caught debris, and beach clearing.

INTRODUCTION

The use of nonbiodegradable material in fishing gear, containers, packaging, and objects has become commonplace throughout the activities occurring in the marine environment. Disposal of these materials at sea has resulted in significant mortality in birds, fish, marine mammals, sea turtles, and possibly humans. This entire problem has been referred to as debris entanglement: The unintentional harassment, injury, and mortality of organisms through physical means by objects of foreign material in the marine environment. Entanglement includes ingestion, primarily of small particles, and wrapping, snagging, or encirclement of body parts by debris.

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

Debris entanglement can occur either in abandoned netting or simple trash. Incidental entanglement in nets actively used for fishing is discussed elsewhere.

SOURCES

Marine debris consists of a range of objects, reflecting the entire spectrum of substances used in modern society including glass, metal, wood, rubber, and plastic. Plastic causes the major portion of harm, is the longest-lasting substance, and is the most important of these in debris "pollution."

In certain areas such as the Bering Sea, near major fishing grounds and not near shipping lanes, the vast majority of persistent plastics appears to originate with the fishing industry (Merrell 1980). This includes discard of whole fishing gear, fragments of netting, and a range of plastic trash. It is estimated that in 1980, debris from the fishing industry alone was being dumped into the Bering Sea at 1,361 metric tons (MT) (3 million pounds) per year. Discarded net fragments from this industry in the Bering Sea was estimated at 145,000 pieces per year (Merrell 1984). The worldwide rate for 1975 from the fishing fleet was 23,587 MT (52 million pounds) of plastic packaging material discarded, and 135,172 MT (298 million pounds) of plastic fishing gear, including nets, lines, and buoys (National Academy of Sciences 1975).

Discarded netting ranges from whole nets down to small fragments of several ounces. The high seas salmon gill net fishery of the North Pacific sets 8- to 10-nmi long nets, and the squid fishery sets 18- to 20-nmi nets. At least 15,000 nmi of drift gill net are used each day in the North Pacific. All of this has potential for loss, tear, abandonment, and accidental catch on the bottom. In addition, at least a large portion of gill nets wear out after 1 year of use, leading to discard of thousands of miles of net each year (U.S. Department of Commerce 1984).

In other areas, where general shipping is the dominant offshore industry, the majority of plastic debris appears to originate with the merchant fleet industry (Dixon and Dixon 1981). This is confirmed by Shaughnessy (1980) in an increase in Cape fur seal entanglement during decline of fishing industry. Approximately 71,000 ships were in operation in 1979, according to Lloyd's of London. Each crewmember disposes of 1.1 to 1.6 kg of refuse per day, plus 290 MT per ship per year of cargo-associated waste. The solid waste from this fleet amounts to 6.5 million MT per year for marine litter from the merchant fleet (Horsman 1982). From these figures, it appears the merchant fleet may be a source of as much or more plastic than the fishing industry. The total discard for merchant ships was estimated at 590 MT per year (1.3 million pounds per year) (Dixon and Dixon 1981) of total solid waste, about four times the weight of the fishing industry's plastic waste. It is not clear what the contents of shipboard trash may be, although Horsman (1982) presents an in depth analysis for two ships. Nonbiodegradable material accounted for 26-30% of total ships' waste, including glass and metal, so the fishing and merchant fleet plastic contribution may be about equal.

Trash for our purposes includes any object of foreign material, usually of plastic, except netting. Monofilament lines, rope, twine, packing bands, both for the fishing industry and cargo ships, floats, plastic baggies, beer six-pack holders, lifejackets, and styrofoam packing pellets are some examples. Horsman (1982) estimated 639,000 plastic containers are discarded daily into the sea, along with other items. This was based on an average of 30 people per ship. These figures do not include navies, however, which have, for example, floating cities of 5,000 people on each aircraft carrier. Pleasure boats, research vessels, and oil tankers also contribute large amounts of trash (National Academy of Sciences 1975). Venrick (1973) confirmed this scale of the discard problem with a pelagic survey estimating 5 to 35 million plastic bottles on the surface of the North Pacific from direct sampling.

Land sources such as coastal factories have generally been concluded to be the source of the small (2-5 mm) "raw" plastic pellets or beads. About the size of the head of a match, these are regularly shaped, rounded pellets from intermediate processes in the plastics industry. Colton et al. (1974) suggested that the plastics industry itself may be the source of this debris in the rivers, estuaries, and coastal waters of the United States. Studies showed concentration of up to 21 items per 2.5 cm^3 in sediments downstream from factory outlets, and deposition in sediment continued downstream into estuaries. Surface concentrations of 101-250 g/km^2 were found several hundred miles offshore, indicating that river dumping of this plastic leads directly to pelagic plastic pollution. Carpenter and Smith (1972a) identified this problem in the Sargasso Sea ($3,500/km^2$), Hays and Cormans (1974) found the source by sampling factory effluent, Colton et al. (1974) demonstrated wide distribution off North America, Kartar et al. (1973, 1976) for the United Kingdom, Gregory (1977) for New Zealand beach concentrations at maximum of 100,000/lineal meter, Van Dolah (1980) for the Gulf Stream, Shiber (1979, 1982) near eight factories in Spain and for Lebanon, and Wong et al. (1974) for the Pacific ($34,000/km^2$ maximum). The New Zealand beaches have been described as covered with "plastic sand." The plastics industry, through the Plant Emission Study of the Society of the Plastic Industry, concluded to the contrary that factory effluent was not responsible.

The scientific commentaries above on pellet sources could be partly challenged by Morris' (1980b) South Atlantic survey. Aside from a probable misinterpretation of the rounded ends as evidence of weathering, he presents excellent data suggesting these pellets are now a ubiquitous, high-density worldwide contaminant to the extent that the source is now unimportant. He found $1,000-2,000/km^2$ on average in the Cape Basin of the South Atlantic. This constancy throughout the world is confirmed by sampling in the North Pacific (Wong et al. 1974) which found a maximum of $34,000/km^2$ including a distinct concentration peak in the eastern Pacific, and Rothstein's (1973) discovery of the same pellets from Leach petrel stomachs in 1962. He points out that these pelagic birds feed not only in the open ocean, but avoid the Sargasso Sea, indicating widespread distribution of pellets outside of low wind stress areas, even before the current sampling device, the neuston net, was invented.

The sources are not at all clear for the small, jagged particles of all sizes also now found around the world. Rothstein (1973) notes many of these particles were also found in Leach's petrels in 1962. They are undoubtedly the result of the breakup of plastic trash, but the sources of the trash are not clear. Higher concentration offshore even in industrialized areas indicates they are not shore-produced (Van Dolah et al. 1980). Morris (1980a) gives a density of 2,000/km^2 in the eastern Mediterranean for plastic pieces larger than 1.5 cm. Given the tremendous worldwide concentration of these pieces, until an estimate is made of the origin of these pieces, it would perhaps not be wise to allow ourselves the simple conclusion either of fishing or merchant fleet discard as the largest source of persistent plastics.

The source of elastic threads (rubber "offcuts") found in puffins on the coast of England and Scotland and around the necks of dogfish off Norway has not been identified. They may come from the garment industry. If so, they appear to have come from the European Continent, or be the result of illegal dumping in Great Britain. There appears to be no reason to ignore the notion the thread could have floated from the continent to the British coast, since there is no particular reason for them to sink.

The possibility that beach debris is produced by "picknickers" seems to have been put to rest. Scott (1972) in a study specifically aimed at this question, concluded from the condition, markings of origin, time and place of observation that the contribution of "picknickers" to shore litter was minimal relative to sea deposition. Dixon and Dixon (1981) and Merrell (1984) also confirmed this, Merrell by selecting a spot virtually inaccessible and quite unappealing to recreational bathers, Amchitka Island.

FATES

Since the plastic in netting is of either positive or neutral buoyancy, discarded netting generally stays suspended at the surface. Plastic and glass floats also usually stay at the surface.

When suspended, large pieces of net and monofilament line often "ball up." Balls of up to 9.1 by 30.5 m (30 by 100 ft) have been sighted. Monofilament line may wrap around other objects, providing more opportunities in loops and twists for entangling. Netting which has caught on the bottom, either causing abandonment or after discard, will stay vertical in the water if the floats are still attached. Sometimes these floats have considerable buoyancy and keep a large net "hanging" like a curtain for years. The nets will also, of course, stay vertical and continue to drift if they still have their floats and are not caught on the bottom. Most of this plastic at the surface is lightweight polypropylene and polyethylene. Abrasion or "crazing" of the surface of the debris may evidence a long time in circulation.

Other plastic material sinks partly or completely through the water column depending on its density. Medium-weight pieces (possibly polystyrenes, styrene copolymers) are thought by Morris (1980a, 1980b) to stay suspended in the water column, in the colder, denser layers. Heavy pieces (such as acrylics, cellulosics, substituted polymers, vinyl polymers) are found on the bottom, along with glass floats, netting, crab pots, wire, cans and metal fragments, cloth, synthetic rope, and twine, etc. (Feder 1978). The variation in the water column for the same type of objects has not been investigated or explained.

Dixon and Dixon (1981) holds that most debris begins its journey with deposition within 400 km of land. Wong et al. (1974) also found a much wider range of debris close to land; papers, elastic bands, and wood were present only up to 500 nmi from shore. Carpenter and Smith (1972b) found a much greater range of plastic types within several hundred miles of shore, and Morris (1980b) found only the lightest plastics, polypropylene, and polyethylene in the open ocean far from any sources. The accumulation of abandoned net at this time seems particularly concentrated in the Bering Sea, most likely because of its tremendous fishing fleets (Merrell 1985). Plastics and styrofoam sheeting are the other types of debris found in the open ocean. The small pellets or beads in particular seem to occur quite far from their probable source, in accord with other indications of having been at sea for a long time. On the other hand, one must note generally the lack of midcolumn and benthic research in these pelagic areas for the deep waters and nonfishing areas.

Plastic and other debris has been shown in several studies to follow the standard pattern of drifting particulates at the surface, influenced by wind and current. It moves with major currents until slowing down with the current and little wind pressure. A significant concentration is evident along long. 143°W of the eastern North Pacific, where the North Pacific Current slackens, and other debris such as tar balls is known to accumulate.

Wong et al. (1974), in their track eastwards along lat. 35°N (roughly Tokyo-Los Angeles), found that plastic, although widespread throughout the Pacific, was relatively absent in the western Pacific, completely absent at long. 125°W, had a huge peak of accumulation in the eastern Pacific at long. 143°W (coinciding with zero annual wind stress), and smaller peaks in areas of the broad, slacker subtropical current from the western Pacific. Shaw and Mapes (1979) also found the dominant factor of low net wind stress southwards along long. 158°W. In interpreting the more southerly distribution of plastics, combined with Wong et al.'s easterly concentration, Shaw and Mapes suggest sources in the western Pacific and the eastern Pacific and, a fairly long lifetime in the water, in contrast to Wong et al.'s suggestion of a possible large contribution by Hawaii.

The Atlantic studies generally confirm the overall widespread distribution and significant influence by currents. Van Dolah et al. (1980) showed likely entrainment in the Gulf Stream, and Winston (1982), from the sources of debris on a Florida coast, found evidence of entrainment in the Guiana, Antilles, and Caribbean Currents. From Carpenter's (1972a, 1972b) direct sampling of the Sargasso Sea surface, and Winston's sampling of debris in Sargassum rafts washed ashore in Florida, considerable accumulation is indicated in this low wind stress area, and in the windrows at the edges of convection cells.

Netting debris has also been reported on the coast of an island just off the Antarctic continent. Gajardos (pers. commun.) saw a net fragment on South Shetland Island at the north tip of the Antarctic Peninsula, close to the circumpolar current.

The length of time this debris remains in the ocean appears quite variable, from days to decades. The upper limit is most likely the ghost nets completely submerged in cold water, since they are most resistant to degradation and are exposed to the minimum of light, heat, and abrasion. It is not known how long the plastic material survives under these conditions. Wehle and Coleman (1983) indicate plastic particles on beaches may last 5 to 50 years, so the upper limit for sunken nets is most likely above 50 years.

Dixon and Cooke (1977), using detailed dating techniques of containers in a beach survey in confined waters close to the heavily traveled Straits of Dover, showed that 83% were <2 years old and 87% <3 years, indicating fairly quick removal from the sea surface (not necessarily by beach deposition). In a controlled release experiment from a nearby city, 69% of containers were beached within 24 days. This rapid removal is confirmed by my winter beach survey in Argentina of a completely clean 100 m of beach, and only two synthetic fragments in 1 km. A local biologist (Lopez pers. commun.) said the beaches have considerable continuous debris during the summer when fishing vessels are offshore.

Merrell (1984) generally confirms this rapid rate of removal: Decreased foreign fishing effort resulted in decreased beach litter in the Bering Sea. Although the total reduction in fishing vessels is not clear from Merrell's work because of inclusion of only foreign vessels, a significant discrepancy between reduction of foreign trawl vessels (66%) and reduction of trawl-web accumulations (37%) could show that 1) debris discarded in open ocean far from shore takes considerable time to drift in and be deposited, or 2) that netting drifts more slowly than containers, or 3) that number of discards per vessel increased though weight decreased, or 4) that the same vessels are now fishing farther offshore, but a significant portion of the nets are sinking before drifting ashore or coming ashore on other beaches, or remaining in the ocean in a gyre.

The 10-year span of Merrell's study would tend to affirm at-sea survival time for floating netting generally of <10 years. The longest float time estimates for recovered netting is 2 years (Tinney 1983). A plastic packing bag found by Merrell (1984) was 4 years old. DeGange estimated a trip of over 100 km in 30 days for a 3,500 m net in the North Pacific, or roughly 3.3 km/day, suggesting long drift times in the open Pacific.

Four natural types of removal from the sea have been discussed. Beach deposition is the only well-documented mechanism. There seems to be no significant deposition on rocky beaches, some on pebbled beaches, and the most on sandy beaches. Deposition increases during winter storms over the normal rate of deposition in the Bering Sea (Merrell 1980) and in the Mediterranean (Shiber 1982).

After deposition, the debris is subject to burial, wind transport to vegetation, gnawing by rats, and resuspension. Dixon and Cooke (1977) found 6% of the material reexposed by storms after burial. To these processes are added the environmental and microbial decay presented below. Based on my beach survey, it appears that a virtually complete elimination of debris is possible in certain circumstances.

The second mechanism is sinking. For netting, with accumulation of fish and other species caught in the net, snagging on the bottom, and the release of floats, the netting may sink at some point. The netting may be removed effectively at this point, or it may start to interact with benthic communities of crabs, lobsters, and other organisms. Considerable debris has been found in benthic surveys of the Bering Sea. Debris was incidental to the biota collected, but in the better sampling series of 1976, Feder (1978) found that 41% of the trawls contained debris. Twenty-three of 43 items were plastic in a category including synthetic rope and twine, plastic objects, and fishing gear categories. Also in 1976, Jewett (1976) found 57% of benthic trawls contained human-made debris. This included large numbers of metal items. This indicates sinking is also a significant mechanism in the removal of debris, although one must question whether this is truly a removal.

A third process is environmental degradation, by the ultraviolet portion of sunlight, through photooxidation, erosion by sand abrasion, molecular breakdown by heat and aging, and fragmentation by wave action. The much lower incidence of reported debris entanglement in tropical latitudes may be due to this photooxidation mechanism. More brittle plastics appear to break down rather quickly in light and heat. Dixon and Dixon (1981) showed that older plastic containers (over 4 years) on beaches were disproportionately fragmented, indicating these processes together occur within 4 years of discard. He suggests photooxidation generally embrittles plastics within 2 years of discard, and that rates of decay for plastic, glass, and paperboard containers are essentially the same. More flexible netting and synthetic twine are not nearly as vulnerable to these processes, and Wehle and Coleman (1983) suggest some plastics may remain on beaches for 5 to 50 years.

The fourth mechanism is microbial action. Although this is mentioned in various papers, it is not enumerated or quantified.

The fifth mechanism, not one of volume but of great potential for research purposes, is regurgitation of debris on land by seabirds.

Based on observations of rapid declines in beach deposition, it appears there is generally a high rate of removal of debris by natural mechanisms. As noted above, 100% elimination is possible for particular areas. On the other hand, for the small pelagic pellets, because of relatively slow rates of degradation at sea, there may be an opposite net effect, that is, a cumulative increase with no equilibrium point, for this one type of debris (Morris 1980b).

The only human removal mechanism now in effect is beach clearing. Merrell (1984) noted trawl floats and inflatable crab pot buoys are prized by collectors, and Dixon (1978) reported on a large annual municipal cleanup in Britain. Although trawl fisheries bring up debris in almost every set in the North Pacific (Branson pers. commun.), it is not retained at this time. The overall volume of debris removed by humans is insignificant, though important for the areas cleared.

INTERACTIONS

An analysis of interactions of marine organisms with debris shows three distinct behavior types. Some involvement with debris is entirely accidental. The object is simply not perceived. The animal gets caught in a net, line, or transparent plastic object which it simply does not see.

Other encounters are indiscriminate. This is particularly true of the ingestion of debris by birds and turtles, and its use as nesting material by birds. The animal sees the object, but cannot distinguish it from an appropriate, natural object. Among birds in particular, this type of behavior varies from species to species, and thus the impact of debris varies as well. Scavenging birds will tend to interact more with debris, whereas "picky" species will not. Thus species which benefit in other ways from flexibility in adaptation to humans will suffer more from the detrimental effects of debris by entanglement than species which are more discriminating and less adaptable to humans otherwise.

Third, some incidents must be categorized specifically as deliberate. Young pinnipeds, with their natural curiosity, deliberately seek out objects with which to interact and in cases of debris come in contact with very differing objects. Indeed, the novelty and variety of the objects may be part of their attraction. In these cases, the type and distribution of debris will have much less effect on the overall rate of interaction and impact of debris on these species.

EFFECTS

Birds

Birds are affected by four types of debris: Particles which are eaten; trash and net fragments with openings in which their head, feet, and wings are caught; lengths of monofilament and string which wrap around wings, beaks, and feet; and large pieces of netting in which they drown immediately.

Rothstein (1973) drew attention to the existence of significant numbers of raw plastic pellets and broken pieces in Leach's petrel stomachs collected in 1962. At least 74% of Laysan albatross carcasses examined in 1966 has plastic in their stomachs or gizzards. The young birds had apparently been fed the pieces by their parents after pick up at sea. Kenyon and Kridler (1969) also observed that the albatross carcasses were the source of abundant plastic litter on Laysan Island, where the tide could not have deposited it. Although the overall amount of mortality was not significant at this large colony, Kenyon and Kridler hypothesized that the young nestlings cannot regurgitate the bulky indigestible pieces along with the usual squid beak castings. He found two pieces of regurgitated plastic sandwich bags. Of the 243 plastic items found in the carcasses, only 1 piece of this baggie material was found; container caps, toys, and broken pieces of plastic made up the rest.

Obviously, such ingestion has been occurring now for at least 22 years, and more likely for as long as plastic has been manufactured. As of 1983, 15% of the 280 species of seabirds are known to have eaten plastic (Wehle and Coleman 1983). This now appears to be a widespread problem of the feeding ecology of seabirds; species in the North and South Pacific, North and South Atlantic, and the subantarctic have been found with plastic in their stomachs.

Ingestion probably affects birds (and other organisms) in four ways: blockage of passages, ulcerations through constant friction, toxic accumulation from the plasticizers, and decreased appetite. Energy resources may not be available for the demands of the reproductive season if the bird's crop is full of plastic and it feels "full." Ingestion seems to affect species differently, depending on their natural capacity for regurgitation and other factors. If the bird is a scavenging species capable of regurgitating, such as gulls and terns, it seems to be able to clear its stomach (and gizzard) of accumulated debris. Elastic thread and many other types of particles are found in regurgitations at gull roosts (Parslow and Jefferies 1972).

If the bird cannot regurgitate, then the debris stays in the birds, adding to the stress and possible death. Puffins, which usually eat only living fish and macrozooplankton, were found to have eaten elastic thread. In the gizzard, the elastic thread balls up, forming a knot 1 cm across in one bird, and blocking the gizzard exit in another. Four of six puffins collected in Great Britain outside the breeding season had elastic thread in their gizzards. Hypothetical reasons for the ingestion of the elastic threads were mistaken identity as pipefish, or ingestion during play. None of three puffins collected during the breeding season from colonies had ingested elastic thread. This species is known to travel considerable distances over the North Sea, wintering out of sight of land, and Parslow and Jefferies (1972) suggest the presence of thread just in nonbreeding birds indicates that this material is widespread in the North Sea. On the other hand, over 100 guillemots and razorbills which frequently pick and play with small floating objects, and also auks, collected in the same area had no elastic in the gizzards.

Birds also become entangled in simple openings in trash, for instance, six-pack holders, and styrofoam cups (Evans 1970). When they dive for an object in the water, the plastic becomes jammed into the head or beak, and the bird starves. A royal tern in Puerto Rico had its lower jaw impaled even in a rigid plastic cup, but a common tern chick in New York was able to free itself from a six-pack holder in which it would have been stuck if it had been older and larger (Gochfeld 1973).

Entanglement in line begins with the earliest known reference to entanglement (Jacobsen 1947). Today the main problem is monofilament fishing line. Common terns and black skimmers from New York colonies (Gochfeld 1973), brown pelicans in California (Gress and Anderson 1983), and the masked booby in Hawaii (Conant 1984), are some examples. A black-crowned night heron was rescued from a tree on the New York coast, to which it had become stuck by its dragging fishing line (Simon 1984). There is little quantification of this impact, though it seems significant only for the pelican, an endangered species. Puncture of the pelican pouch by hooks at the end of the line is also a hazard.

The most serious impact on birds is most likely drowning in ghost nets. High seas drift gill nets with the floats intact are right at the surface, and the birds see the concentration of fish but not the netting. Entanglement is almost always immediate and fatal. Based on data from incidental take by the same process and gear, birds are caught to a depth of several meters, and diving birds such as murres are caught at the greater depths in the nets, and birds including shearwaters and alcids are caught in the top layers. Diving birds comprise approximately 60 to 80% of the seabirds caught in actively used gill nets and may also comprise that proportion of birds caught in ghost nets as well. The presence of other species is thought to depend on distance from shore, time of year, proximity of breeding colonies, type of fish in the area, and mesh size.

Fish

Fish also suffer from ingestion of particles and netting. Although most important commercially, and very important ecologically, impact on fish is the least researched and documented area.

The small plastic pellets have been found in the stomachs of eight species of fish off southern New England (Carpenter 1972b). Kartar et al. (1973) also showed that bottom-dwelling fish in the Severn Estuary, England have debris in their stomachs. One dogfish was caught off Norway with an elastic band around its neck, similar to those eaten by puffins in the North Sea (Parslow and Jefferies 1972). Fish in the Danube have also been caught with debris around their bodies. These incidents do not appear to be significant in harm or mortality.

Manta rays, another commercially fished species, have been documented to be entangled in lost single strands of monofilament lines. The lines wrap tighter and tighter around the wings as the ray swims through the water, and slice through the 20.3 to 25.4 cm (8 to 10 in.) thick, fibrous cartilage. Monofilament is known to have nearly severed these 3- to 4.6-m (10- to 15- ft) wings (Waterman pers. commun.).

An unknown and possible huge mortality up to twice the size of bird loss may be occurring from ghost nets. Nets washed ashore typically have numerous fish carcasses, and one abandoned gill net was 3,500 m long. Less than half (1,500 m) of the estimated total which was pulled aboard contained over 200 chum and silver salmon, and other marine life including 99 seabirds.

Salmon returning to Alaska have crosshatch markings on their sides, indicating problems with netting. Concern has been expressed by the industry about damage to this fishery from incidental catch, and such concerns would also be applicable to the free-floating abandoned gill nets.

Marine Mammals

Marine mammals, although not the most severely affected group as a whole, are the most well documented and involve the most critically endangered species.

Marine mammals die from debris entanglement in essentially three different ways. If the fragments are large (more than about 4.5 kg (10 lb) for the northern fur seal) the animal drowns. Medium fragments (2 to 4.5 kg (4.5 go 10 lb) for northern fur seals) lead to exhaustion, depletion, and starvation due to increased drag. The effort to swim, breathe, and catch food becomes too much for the energy level of the animal (Feldkamp 1983). One unusually large piece removed from a live northern fur seal in

1982 measured 50 m unraveled. Small fragments, including most of the simple trash, kill slowly over months as the animal grows into the loop. Fur, skin, blubber, muscle, and eventually vital organs are constricted or cut through.

In the most dramatic instance of entanglement, 11 of the 26 Hawaiian monk seal pups born in 1983 on one of the few breeding islands either were entangled in netting or playing among netting and debris in the water. Four pups of this critically endangered species were caught in 1983 in netting which snagged on coral, and would have drowned with the next tide had they not been cut out by scientists (Tinney 1983).

Debris entanglement is estimated to cause 50,000 to 90,000 deaths per year in the northern fur seal. The population in 1983 was dropping on the main rookery in Alaska at about 8% per year. At least 50,000 deaths are thought to be due to entanglement; the other 40,000 deaths possible entanglement or possibly some unknown factor such as disease (Fowler 1983). The proportion of entanglement from packing bands rose quickly from 5% in 1970 to 38% in 1973.

Cape fur seals have been documented to be entangled, primarily in plastic, the largest component being packing bands, and also in wire, leather, and rubber rings. These animals were nearly all male (Shaughnessy 1980).

The southern sea lion, Otaria flavescens, (primarily males) has also been documented to be entangled on the Argentine coast, again primarily in packing bands (Ramirez 1984). Cardenas and Cattan (1984) report on entanglement of the Juan Fernandez fur seal, Arctocephalus phillippi, in Chile, again mostly in packing bands.

The endangered West Indian manatee becomes entangled with crab pot lines. One was found with plastic sheeting or bags in the stomach (Wehle and Coleman 1983).

A minke whale was seen ingesting plastic while feeding on the garbage of a commercial fishing ship. The pygmy sperm whale, rough-toothed dolphin, and Cuvier's beaked whale are also known to have ingested debris (Wehle and Coleman 1983).

Sea Turtles

Sea turtles mistake floating plastic bags for jellyfish. Upon being swallowed, the bag does not pass through the turtle and kills it through intestinal blockage. Four of the seven marine turtle species have been found to have ingested plastic (Wehle and Coleman 1983). Ingestion of plastics has been documented in leatherbacks from New York, New Jersey, French Guiana, South Africa, and France; in green turtles from Japanese, Central American, and Australian coastal waters, and in the South China Sea; in hawksbills from the Caribbean coast of Costa Rica; and in olive ridley turtles from the western coast of Mexico. A sea turtle was also seen swimming in the Mediterrean wrapped in a large plastic sheet (Morris 1980a, 1980b).

In addition, young sea turtles which are supposed to feed on small crustaceans crawling on sargassum rafts, now bite styrofoam packing pellets and tar balls (Pace 1984).

Land Mammals

The Spitzbergen reindeer, a small hardy reindeer of the northern island of Spitzbergen, Norway, often becomes entangled in the masses of netting washed ashore on the island (Tressault pers. commun.). A reindeer on Atka Island, Alaska, was also reported entangled in a fishing net (Beach et al. 1976).

Humans

It is thought that some loss of human life during storms in the Bering Sea may be due to loss of power or maneuvering ability from fouling of propellers, shafts, and intakes. Some loss results from ships becoming entangled in their own gear, and some from floating fragments and trash.

Nets caught on obstacles such as rocks, offshore oil structures, and pipelines are a danger to divers and repair workers. Scuba divers are familiar with ghost nets and these are thought to be responsible for some double drownings. Sunken nets are a formidable obstacle and recognized danger to research and military submarines; near fatal encounters have been reported (Evans 1970). Some catalogues of obstacles and wrecks exist to help avoid these areas.

Navigational Hazard

As discussed briefly above, debris is a cause of ship disablement. Most ships carry a scuba diver to free the ship or debris. The impact of the debris varies greatly with the size of the ship; large propellers can chop through small lines easily, but a fragment from a container can easily clog the intake of a small pleasure boat.

Commercial Loss

The most direct and probably largest commercial loss is in the commercial fishing industry. First, the ghost net targets the fishery for which the net mesh and fishing technique were designed. Thus a discarded squid net would be most effective at catching squid, and crab pots keep catching crabs. Secondly, other incidentally taken commercial species, such as salmon, would be lost proportionally with the amount of discard. Third, the netting will take additional resources as it moves (such as sinking) into different areas. Sunken gill nets are thought to entrap lobsters and crabs, and would affect such species as the king crab.

When a ship is disabled, it must pay the mechanical repair costs, including that of disentangling the propellers, added to the lost fishing line, and each lost piece of netting must be replaced at full price.

Other industries, such as cargo shipping and recreational boating are incurring costs in repair of damage caused by debris fouling. Governments also must pay to repair the same type of damage on Navy ships and for the

Coast Guard to rescue ships under dangerous conditions when disabled by debris.

Commercial, subsistence, and recreational use industries involving seabirds are also affected by "ghost fishing." Slender-billed shearwaters, sooty terns, eiders, thick-billed murres, common puffins, and at least 20 to 30 other species are harvested commercially for meat, eggs, and stomach oil. Several of these are species which suffer the highest mortality from netting (Cline et al. 1979).

Guano production of South American and African marine birds although most likely not affected by debris netting at this time, may be susceptible since significant expansion in fisheries is expected in some nearby areas.

Subsistence use of birds by natives in Canada, Alaska, and elsewhere is an important part of their diet. The Faroese take puffin and murres, and Eskimos and Indians on the Arctic coast of Alaska and the Northwest Territories have traditionally taken marine birds and eggs in an annual spring hunt. The more isolated the community is, such as Banks Harbor, Holman Island, Pint Hope, and Point Barrow, Diomeide Island, the greater the importance this element is in diet and culture (Cline et al. 1979).

Recreational activity related to marine birds is an increasing industry for certain areas as well. The small isolated St. Paul and St. George Islands Aleut communities take in hundreds of thousands of dollars each year from birdwatchers (in 1975, $160,000), one of the only commercial sources of income. Companies in almost all North American coastal states and provinces of both coasts have boat or airplane excursions to marine bird viewing areas offshore; and Alaska and Washington State Governments and private organizations have ferries or excursions to seabird colonies (Cline et al. 1979).

Shore communities and resort areas are incurring costs to clean beaches. It is unknown what portion of the litter is sea-deposited, but it is known that large-scale, thorough clean up of almost exclusively sea debris on county and statewide bases requires funding for organization and trash disposal.

Some comment has been made that sharks attracted to entangled fish and corpses of marine mammals have made bathing beaches dangerous and may in some cases force the closing of these areas, resulting in a loss to the local dependent business.

Apart from these economic costs is the aesthetic and cultural costs. This includes beaches and the open sea. Not only is this "cost" often paid by those not responsible for the debris, but it lowers everyone's benefits and expectations for benefits in the future. Although we have become somewhat used to seeing spoiled beaches, this cost is not necessary, and we could raise the standards back to the pleasure of the uncluttered beaches of a century ago.

A final cost is the loss of feedstock to the plastics industry. The cost of fishing and netting to produce plastic raw materials could be avoided by retention and recycling of already manufactured netting.

Commercial Benefits

Debris from discard may be perceived as an economic advantage to the plastic industry through an increased demand for netting when its tearing, repair, and loss bears no cost for disposal of used netting.

The killing of marine mammals by debris may also be perceived as a beneficial result. By removing a competitor for certain species of fish, the availability of those species would be increased, though the catch of target species by the discarded netting would be increased simultaneously.

A small souvenir trade in glass floats has also developed. A single float approximately 4 in. in diameter now sells for about $10 apiece.

Ecological Impacts

Apart from impacts on single species, several ecological impacts have been noted, but there has been no thorough study.

Plastic serves as an additional substrate for marine organisms. Plastic in the Atlantic supports a limited number of species also found on sargassum and some not found on the seaweed. There was a clear dominance of one bryozoan, *Elletra tenella*, which is not found on sargassum, over other bryozoans which normally dominate the available seaweed substrate in that area. *Elletra tenelia*'s large success off the Atlantic coast of Florida is thought to be due to the large amounts of plastic debris in that area (Winston 1982). Higher up the scale, tube worms are using the small raw plastic pellets to build their tubes.

Secondary food uptake of plastic pellets has been noted from the South Atlantic and South Pacific. Fish that ate pellets in Ecuadorean ports were taken by blue-footed boobies in the Galapagos Islands and by short-eared owls. A broad-billed prion and its ingested pellets have been found in the stomach of a South Polar skua in the South Atlantic (Wehle and Coleman 1983).

Seven endangered species are specifically vulnerable to debris entanglement. The Hawaiian monk seal, four species of sea turtles, the brown pelican, and West Indian manatee have died, in descending degree, due to entanglement.

Military Impacts

Evans (1970) pointed out the danger to Navy submersibles from ghost nets nearly 15 years ago. Since then the interaction of submarines with actively used fishing nets has grown to a rate of several per year around the British Isles. The disability of either the fishing vessel or the submarine or both appears to have resulted. Although technically an "incidental take" at the first moment, the encounters can be expected to lead inevitably to tearing and debris in the course of the entanglement.

CONCLUSIONS

Entangling debris in general and plastic in particular appear to have been in the marine environment for at least 22 years and probably since the beginning of large-scale plastic manufacturing. In some form, such as pellets, it is a ubiquitous, worldwide pollutant, and in other forms, such as netting and trash, appears to be a large problem in areas of heavy fishing and shipping. Natural removal mechanisms have a significant annual impact on decreasing amounts.

Up to one hundred thousand marine mammals and possibly more die each year. Half or more of the individuals of certain marine reptile species are affected by the plastic litter, and beachcombing land mammals become snarled in nets and die. Loss of human life may be occurring from disabling ships, and sunken nets are a hazard to underwater work on structures and deep submersibles. Direct financial loss may be occurring to the fishing and recreational industries.

The debris portion of the entanglement problem may be virtually eliminated in perhaps 10 years by two simple steps: no dumping and retention of debris brought up during sets.

For certain species, areas, and industries, alleviation before 10 years is highly desirable. Two additional actions, clearing beaches and retrieving sighted debris, will be effective in reducing the problem quickly for critical areas in about 2 years.

Research funds would seem to be best spent equally on producing information directly related to the motivation of fishers, and on monitoring the impact on endangered species to identify areas of critical action.

The plastic itself may be shredded and recycled through melting and respinning. Burning produces highly toxic, undesirable and unmanageable chemical fallout. Biodegradable plastic netting is not perceived as feasible by the fishing or plastics industry. Fortunately, attitude and operational changes can ameliorate the vast majority of the problem immediately. Preventive measures should be taken in the last pristine areas, the Antarctic and the southern ocean.

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STUDIES ON FUR SEAL ENTANGLEMENT, 1981-84, ST. PAUL ISLAND, ALASKA

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ABSTRACT

The incidence of northern fur seals entangled in debris has been monitored during the commercial harvest of subadult male seals on St. Paul Island, Alaska since the late 1960's. In 1981, more intensive studies were initiated on the types of entangling debris, the mode of entanglement, the condition of the entangled seals, and the frequency of occurrence by age and sex of seals. Beach surveys were also conducted to document the occurrence and accumulation of net fragments, plastic packing bands, strings, and ropes. The majority of the entangled fur seals examined during the harvest were entangled in large mesh (>20 cm) trawl net fragments. Plastic packing bands were the next most frequently occurring entangling debris. Fur seals were less frequently observed in a variety of items such as ropes, strings, rubber bands, plastic rings, and a metal headlight ring. The seals entangled in net fragments were primarily entangled around their neck in mesh loops rather than in tears or holes in the webbing. Most of the entangled seals did not have lacerations from the debris. Observations were also made on seals which did not have entangling debris but had scars and wounds indicative of a prior entanglement. Entangled fur seals tagged and released in 1983 were sighted in 1984 indicating the seals can survive at least 1 year with the debris intact. Some of these tagged seals had lost the debris and others still had deep wounds.

INTRODUCTION

The entanglements of northern fur seal, Callorhinus ursinus, in debris were first reported on the Pribilof Islands in the 1930's. These early reports were primarily of seals entangled in rubber bands cut from inner tubes (Scheffer 1950). Subsequent observations of entangled seals were noted frequently through the early 1960's. In the late 1960's concerns over an apparent increase in the number of fur seals observed entangled in net fragments during the commercial harvest resulted in a North Pacific Fur Seal Commission (NPFSC) recommendation that member countries should make efforts to document the incidence of entanglement and attempt to identify and record the types and origin of fishing gear responsible for the problem

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

(NPFSC 1967). Fur seal managers in the United States have monitored the incidence of entangled seals observed during the harvest since 1969 (Fiscus and Kozloff 1972; Scordino and Fisher 1983). Monitoring studies were expanded in 1981 to include more detailed information on the nature and extent of fur seal entanglement.

This paper presents preliminary results of current investigations on fur seal entanglement in 1981-84. The studies were primarily on entangled subadult males observed during the commercial harvest. Although surveys were conducted in the breeding and the haul-out areas, the information presented on the types of debris and the condition of the animals is solely from the entangled seals that were rounded up for the harvest. Tabulations of the entanglement data and the details of the data collection methods are included in the background papers which have been submitted to the Standing Scientific Committee of the North Pacific Fur Seal Commission (Scordino and Fisher 1983; Scordino et al. 1984; Scordino et al.[1]).

METHODS

In 1981 debris from entangled fur seals taken in the harvest was collected and described. Studies were expanded in 1982 to include information on gross pathology and age-weight-length information as described in Scordino and Fisher (1983). The skins from the entangled seals, as well as other skins having characteristic scars or bruises in the neck area from a prior entanglement, were closely examined.

In 1983 and 1984, studies were further expanded and included the participation of Japanese scientists. Entangled fur seals appearing during the harvest were restrained, examined, tagged, and released with the debris intact as described in Scordino et al. (1984). The entangling debris was examined and sampled when possible, and the animal's gross pathology was described. Seals without debris but bearing the characteristic scars or cuts indicative of a previous entanglement were included in the harvest and closely examined. The skins from these "scarred seals" were reexamined in the processing plant after the blubber was removed. Efforts were made to resight the tagged entangled seals and to survey breeding areas to determine the entanglement rate in breeding males and females. Surveys for debris on selected beaches were also conducted to document the occurrence and accumulation of net fragments, plastic packing bands, strings, and ropes.

RESULTS AND DISCUSSION

Incidence of Entanglement

A total of 403 entangled seals were observed during the harvest in 1981-84 which represents an average of 0.42% of the number of seals harvested. This average is similar to the incidence of entanglement

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[1]Scordino, J. N. Baba, H. Kajimura, and A. Furuta. Fur seal entanglement investigations, St. Paul, Alaska. Manuscr. in prep. Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way, NE, Seattle, WA 98115.

observed in earlier years which has averaged about 0.4% (Table 1). It should be noted that the 0.4% is a comparative indicator of the rate of entanglement among harvested seals each year. However, the actual rate of entanglement among subadult males may be lower since there are many more seals included in the entanglement observations that are not harvested. The harvest numbers include only the seals taken and do not include oversized seals that are released and others that escape back to the hauling grounds.

Table 1.--Northern fur seals observed entangled in debris during the harvest on St. Paul Island, 1967-84.

Year	Number of seals harvested	Number of entangled seals				Percent of harvest
		Net	Band	Other	Total	
1967	50,229	--	--	--	75	0.15
1968	46,893	--	--	--	75	0.16
1969	32,819	--	--	--	66	0.20
1970	36,307	71	5	24	101	0.28
1971	27,289	69	35	6	113	0.41
1972	33,173	85	53	6	144	0.43
1973	28,482	82	54	1	137	0.48
1974	33,027	90	100	--	190	0.58
1975	29,148	105	101	--	206	0.71
1976	23,096	50	47	--	97	0.42
1977	28,444	45	54	--	99	0.35
1978	24,885	75	40	--	115	0.46
1979	25,762	63	34	7	104	0.40
1980	24,327	83	36	--	119	0.49
1981	23,928	68	20	14	102	0.43
1982	24,828	62	26	14	102	0.41
1983	25,768	79	18	15	112	0.43
1984	22,066	50	20	17	87	0.39

Surveys of the breeding areas in June through August of 1982-84 resulted in few sightings of entangled seals. The incidence of entanglement among adult males and females is considerably less than that observed among subadult males taken in the harvest. The incidence of entangled females averaged <0.04% of the female seals observed in the breeding areas. The incidence of harem bull (males holding females in their territory) entanglement is rare; only one such animal has been reported in recent years.

Entangling Debris

A variety of items have been found on subadult male fur seals (Table 2). Most of the items float, thus it is likely that the seals encounter them on the water surface. A notable exception is a metal headlight ring found on the neck of a seal in 1983 which was probably picked up off the bottom nearshore. The predominant debris found on fur seals in 1981-84 was

Table 2.--Types of entangling debris observed on fur seals during the harvest on St. Paul, 1981-84.

Type of debris	Number of seals				
	1981	1982	1983	1984	Total
Net fragment, mesh size over 20 cm	45	52	52	37	186
Net fragment, mesh size under 20 cm	4	5	6	3	18
Net fragment, undetermined mesh size	19	5	21	10	55
Monofilament gill net fragment	0	3	2	4	9
Cord used in net construction/repair	3	4	2	2	11
Plastic packing band	20	26	18	20	84
String	5	3	2	4	14
Rope	1	2	2	5	10
Rubber band	3	0	1	0	4
Plastic ring	1	0	1	1	3
Plastic gasket	0	0	2	0	2
Monofilament line	0	1	0	0	1
Plastic six-pack holder	0	1	0	0	1
Plastic packing web	0	0	1	0	1
Plastic object	0	0	0	1	1
Lawn chair material	1	0	0	0	1
Cloth sack band	0	0	1	0	1
Metal headlight ring	0	0	1	0	1
Total	102	102	112	87	403

trawl webbing followed next by plastic packing bands. Infrequently occurring items include ropes, cords, strings, and rubber or plastic bands. The more unique items found on seals were a plastic six-pack holder for canned drinks which was broken and stretched between two of the six holes, a cloth band which is used to seal burlap on synthetic sacks, and a flat 13 cm wide piece of half-moon shaped plastic which had a small hole that was just large enough to go around the seal's lower jaw.

Trawl webbing accounted for 62-72% of the entangling debris. Most of the webbing examined since 1981 has had a stretched mesh size of greater than 20.0 cm with the 23.0 cm mesh occurring most frequently (Table 3). The larger mesh webbing (>20 cm) has a greater entanglement potential than the smaller mesh since each mesh loop in the larger webbing can become entangled over a seal's head; whereas smaller mesh webbing would require holes or tears of appropriate size to entangle a seal. Most seals entangled in trawl webbing were caught in the mesh loops rather than in holes. The high occurrence of larger mesh webbing on seals contrasts with the composition of webbing washed up on the beaches of St. Paul, St. George, and Amchitka Islands. Fowler et al. (1985) reported over 70% of the net fragments on these beaches were of smaller mesh sizes (<20 cm). If the debris on the beaches of these three islands is representative of the debris at sea, then most of the webbing at sea (which is of smaller mesh sizes) has low entanglement potential.

Table 3.--Mesh sizes of net fragments (excluding monofilament gill nets) on fur seals observed during the harvest on St. Paul, 1981-84.

Mesh size (cm)	Number of seals				
	1981	1982	1983	1984	Total
7.0	1	--	--	--	1
7.5	--	1	--	--	1
10.0	--	--	1	--	1
11.5	1	--	--	--	1
12.5	1	1	--	--	2
13.5	--	--	--	1	1
14.0	--	--	2	--	2
15.0	1	--	--	1	2
16.5	--	2	2	--	4
18.0	--	1	--	--	1
19.0	--	--	2	1	3
20.5	3	5	--	1	9
21.5	4	5	12	12	33
23.0	31	36	28	12	107
24.0	3	2	6	8	19
25.5	3	2	--	2	7
26.5	--	--	2	1	3
28.0	1	1	1	1	4
29.0	--	1	2	--	3
30.5	--	--	1	--	1
39.5	--	1	--	--	1
Undetermined	19	5	21	10	55
Total	68	[1]63	[2]80	50	261

[1]One oversized seal with two different nets is tallied twice; once as a 16.5-cm mesh and once as a 39.5-cm mesh.

[2]One oversized seal with two different nets is tallied twice; once as a 14.0-cm mesh and once as a 16.5-cm mesh.

Note: This table does not include nine seals observed entangled in monofilament gill net fragments as follows:

1982 - Three seals were entangled in 11.5 cm mesh gill nets.

1983 - Two seals were entangled in gill net; one in 11.0 cm mesh and one in 11.5 cm mesh.

1984 - Four seals were entangled in gill net; one in 11.0 cm mesh, one in 12.0 cm mesh, and two in undetermined mesh size.

Plastic packing bands were the next most frequently occurring debris entangled on seals. The incidence of plastic packing bands ranged from 16 to 26% of the debris entangled on seals. This greatly contrasts with the period 1974-77, when the bands accounted for 48-55% of the debris entangled on seals, with the number of bands exceeding the number of net fragments in both 1974 and 1977. Most plastic bands entangled on seals were hot-sealed into loops and the remainder were tied into a loop with a knot. The loops had a circumference of 38-96 cm, and the bands varied in width from 0.3 to 1.6 cm. The yellow plastic packing band occurred most frequently followed by blue, white, green, black, and pink. It is unknown if fur seals are attracted to particular colors or if the incidence of some colors is related to occurrence of the debris at sea.

United States and Japanese gear experts examining the nets removed from seals in 1982 and 1983 determined that all of the net fragments (other than gill nets) were polyethylene trawl nets. The majority of the net fragments (67) were from bottom trawls; 9% were midwater trawl webbing, and 24% could not be identified to trawl gear type. The larger mesh sizes commonly found entangled on seals were from the belly and wing areas of the trawl nets.

The largest piece of debris found on a seal was a piece of trawl webbing weighing 6.75 kg. However, the most frequently occurring debris on seals were small pieces of trawl webbing weighing <150 g. The smaller pieces of debris (weighing <150 g) including the small pieces of webbing, plastic bands, and other debris account for over 60% of the debris found on seals. The high incidence of small debris entanglements may be due to the seals "playing" with smaller pieces of debris, as they do with kelp, and becoming entangled in the process. Observations of seals avoiding contact with actively fished high seas gill nets (Jones 1982) indicate that seals are probably aware of larger pieces of webbing and therefore do not haphazardly become entangled. It is likely that entanglement is probably due to the seal's investigative nature rather than seals "blindly" running into debris at sea.

Effects of the Debris

Entangling debris can detrimentally affect a seal if the debris is constricting, causes lacerations, or impairs swimming or feeding abilities. Most entangled seals have the debris around their neck, but a few had webbing around their flippers that might directly impair swimming. Also the increased drag caused by larger net fragments as described by Feldkamp (1984) may indirectly impair swimming and feeding ability. In some instances the debris may directly impair feeding. An example of this is three seals observed in 1983 that had webbing around their head and mouth that would impair food passage.

Most (64%) of the entangled seals observed in 1982-84 did not have cuts or wounds. This may be because the animals became entangled recently, or it could be that it takes a long time for cuts to develop. The type and quantity of debris appear to affect the progression of skin trauma. The animals with 360° wounds were most frequently entangled in small single-strand pieces of debris. Conversely, there was only one seal with an open wound among those with more than eight mesh loops of webbing around their neck. The thin pieces of debris, such as the monofilament gill nets and strings (when tightly bound on the neck), appear to cut the skin more rapidly since all seals observed with this debris had open wounds.

The incidence of wounds on entangled seals increased with increasing age. Open wounds were observed on 24% of the entangled 2-year olds, 30% of the entangled 3-year olds, 50% of the entangled 4-year olds, and 82% of the entangled seals 5 years and older. This increased incidence of wounds with age suggests the possibility that seals can survive entanglement for long periods of time as the debris slowly cuts into the skin as the seal grows. Supporting this is the observation of one seal, entangled in webbing and without wounds in 1983, which as resighted a year later with debris intact, still without wounds. However, other observations (Table 4), such as five seals with debris and without wounds in 1983 and subsequently resighted in 1984 with wounds, might suggest the debris cuts through the skin in a relatively short period of time. Unfortunately, the ages of these tagged seals were not determined (since they were released alive), and the possibility of differential growth rates cannot be assessed.

Entanglement Scars on Seals Without Debris

Each year a number of seals are observed without debris but possessing characteristic cuts, bruises, or scars on their necks and shoulders. These marks have been determined to be caused by prior entanglements (Scordino and Fisher 1983). Before 1981 these "scarred seals" were included in the skin processing plant tally of skins with entanglement scars, but they were not tabulated separately from the skins which came from seals that had entangling debris on them when taken. Conversely, some of the skins from entangled seals do not have marks or scars and because of this, they may not have been included in past processing plant tallies. Due to these discrepancies, pre-1981 processing plant tallies could not be used to determine the number of seals having prior entanglement. To obtain information on the numbers of seals that were previously entangled, the studies in 1982-84 emphasized observations on entanglement scarred seals during the harvest and observations of skins in the processing plant. Entanglement scars are not always obvious and sometimes difficult to see on live animals, but are usually apparent in the dermis after the blubber has been removed or when the guard hair has been removed during the finishing process. One example of this is a skin observed in the processing plant that had a monofilament gill net imbedded in the blubber around the neck area, yet no scars nor abnormalities were visible in the hair.

In 1982, 91 (0.37%) of the seals harvested had characteristic scars or bruises in the hair and skin around their necks or shoulders indicative of a prior entanglement. Most scars were not evident on live seals, becoming evident only on the skin during processing: 22% were observed on the animals during the field harvest; 37% were observed on skins in the skin processing plant on St. Paul; and 41% were observed on skins after the guard hair was removed.

Eighty-two (0.32%) of the seals harvested in 1983 and 68 (0.31%) of the seals harvested in 1984 had scars or bruises indicative of a prior entanglement. The 1983 and 1984 figures do not include observations made on the 1982 skins after guard hair removal and therefore may be low. Most

Table 4.--Comparative observations of entangled seals tagged in 1983 and observed in 1984 with debris intact.

Tag No.	1983 Observations	1984 Observations
423	Net green; tight on low neck. 360° deep open wound, 2 cm wide. Mesh entanglement; 21 cm mesh.	Net green; on tight. 360° open wound; 2 cm wide, skin bulging. One mesh loop around neck.
436	Net green; tight but not binding on neck. No wounds. Five mesh loops around neck; 23 cm mesh.	Net green; on neck. Deep cut.
444	Net gray; loose on neck. No wounds. Five mesh loops around neck; 23 cm mesh.	Net gray; on tight. 360° open wound; skin bulging.
464	Rope greenish; tight on neck. 270° open wound; 90° healed over ventrally. Tied into loop via one knot.	One strand of undetermined debris. 360° open wound. Knot ventrally with 3 cm of twine hanging.
466	Net gray; loose on neck. 360° deep open wound; 2-6 cm wide. Two mesh loops around neck; 23 cm mesh.	Net gray; on neck. (No further observations reported.) Net removed by biologists on St. George.
468	Net brownish red; tight on neck. No open wounds. Two mesh loops around neck; 21.5 cm mesh.	String yellowish; on neck. 360° open wound; wide, deep wound.
471	Net gray; tight on neck. No open wounds. Ten mesh loops around neck; 21.5 cm mesh.	Net gray; on tight but not binding. No open wounds.
472	Net gray; tight on neck. No open wounds. Eight mesh loops around neck; 23 cm mesh.	Net gray; on tight. 360° open wound; not deep; but through skin.
480	Net green; very tight on neck. 360° open wound; not deep, but through skin. More than two mesh loops around neck; 24 cm mesh.	Net green; very tight on neck. 180° open wound dorsally; does not appear cut ventrally. Fur scars at gape of mouth suggesting mesh loops may have entangled around mouth.
487	Net green; tight but not binding on neck. No open wounds. Large quantity of net; 16.5 cm mesh. Webbing had whitish repair cords entwined.	Net gray; on neck. 360° open wound; very deep cut, skin bulging. One strand of debris with large knot ventrally.
489	Plastic gasket; tight on neck. 360° open wound; not deep, but through skin.	Plastic gasket; on neck. 360° deep open wound down to muscle. Gasket was cut off and seal released alive. Seal sighted 2 weeks later with healed wound.
497	Net gray; tight on neck. 360° deep open wound. Four strands around neck.	Net yellowish; on neck. Deep cut.

(60%) of the entanglement scars in 1983 and 1984 were observed during the field harvest. Although observations during the harvest of larger males with entanglement scars have been recorded, they are not included in the above totals since these animals, which are longer than the established harvest size limit, are allowed to escape the harvest. Since no efforts were made to examine each of these escaping seals, the number of previously entangled seals on the haul outs may be greater than that reported above.

The occurrence of these entanglement scarred seals clearly indicates that the seals can rid themselves of entangling debris, and that entanglement does not always result in death. Observations of seals without debris, but with open wounds around their neck indicate that seals can rid themselves of debris even after it has cut into the skin. This is further evidenced by observations of skins with prior-entanglement scars that had new skin growth, indicating a prior open wound.

Tagging Studies

Over 150 entangled fur seals (primarily subadult males) were tagged and released with the debris intact in 1983 and 1984. These tagging studies provide new insights not only on the longevity of entangled seals, but also on the incidence of debris loss. Although it was known that some seals rid themselves of entangling debris, as evidenced by observations of past entanglement scars, it was not known how frequently this occurred nor what types of debris were involved. It was assumed that seals entangled in large or trailing pieces of webbing could snag the webbing on rocks and pull themselves out, but it was never thought that seals could rid themselves of tightly bound small pieces of debris such as plastic packing bands.

Of the 95 entangled seals tagged in 1983, 25% were resighted in 1984. This was a much greater return than anticipated. A comparison of this with the tag recovery of unentangled seals under similar conditions (Griben 1979) shows no statistical difference ($P \geq 0.95$) in the returns of entangled seals (A. York pers. commun.). This suggests that the mortality of entangled seals is not significantly different from that of "normal" seals over a 1-year period. It was also assumed when these studies began in 1981 that entangled seals with 360° open wounds would not survive more than a few months (Fowler 1982), but as shown in Table 4, wounded entangled seals can survive at least 1 year with the debris intact. Of the entangled seals resighted with debris intact in 1984, 50% had open wounds when tagged in 1983.

Of the entangled seals tagged in 1983, 18% were resighted without debris (Table 5). Most of these had no open wounds when tagged, and many had no marks or scars visible when resighted. The entangling debris on these seals was: 35% small pieces of webbing, 18% larger pieces of webbing, 18% plastic packing bands, and 29% miscellaneous debris such as strings, rubber bands, gaskets, and other items. It was surprising to find the higher frequency of loss of smaller pieces of webbing, since these pieces are not large enough to get stuck on rocks or other objects to enhance the seal's escape. It is not obvious as to how seals rid themselves of small debris. The plastic bands and the trawl webbing are made of polyethylene and therefore would not break off the seals easily.

Table 5.--Observations of entangled seals tagged in 1983 and subsequently observed without debris.

Tag No.	Date tagged	Observations at time of tagging	Date observed without debris	Notes
403	7/5/83	Net green; tight but not binding on neck. No open wounds. Very small quantity of net. Sighted 7/25/83 with debris intact.	7/28/83	No debris.
411	7/8/83	Band yellow; tight but not binding on low neck. No open wounds.	7/27/84	No debris. No open wounds; slight indentation in skin over left shoulder.
420	7/11/83	Rubber band on head. No open wounds.	8/2/83	No debris. No marks.
425	7/12/83	Band white; loose on neck. 180° open wound. Sighted 8/1/83 with debris intact.	7/11/84	Seal not observed, but one tag was found during harvest drive. As no previously tagged, entangled seals were seen in the harvest; the seal may have lost the debris.
428	7/13/83	Net green; tight but not binding on neck. No open wounds. Small quantity of net.	7/16/83 and 7/6/84	No debris. No marks.
429	7/13/83	Net green; tight but not binding on neck and flipper. No open wounds. Medium amount of net. Sighted 7/25/83 with debris intact.	7/20/84	No debris. No marks.
430	7/13/83	Net green; tight but not binding on neck. No open wounds. Large amount of net. Sighted 7/20/83 with debris intact.	7/2/84	No debris. No marks.
434	7/13/83	Band yellow; tight but not binding on neck. No open wounds.	8/3/83	No debris. Fur mark on neck, 8 cm wide.
438	7/14/83	Net green; on neck and flipper. No open wounds. Large amount of net; 25 mesh loops around neck. Sighted 7/19/83 with debris intact.	7/25/83	No debris.
441	7/15/83	Net gray; loose on neck. No open wounds. Small amount of net.	8/8/83	No debris. No marks.

Table 5.--Continued.

Tag No.	Date tagged	Observations at time of tagging	Date observed without debris	Notes
442	7/15/83	Net gray; very tight on neck. 270° open wound. One mesh loop total. Sighted 7/25/83 with debris intact.	7/5/84	Debris not observed. 360° open wound. Sighted again on 7/19/84; definitely no debris; laceration healed.
476	7/28/83	Plastic packing material; tight on shoulders. No open wound.	7/24/84	No debris. Slight 60° fur mark on right shoulder.
477	7/29/83	String beige; tight on shoulders. 70° open wound on each shoulder. Sighted 8/3/83 with debris intact.	7/6/84	No debris. Obvious fur marks on shoulders; appear to be recently healed.
482	7/29/83	Net gray; loose on neck. No open wounds. Small amount of net.	7/22/84	No debris. Scars present on neck.
493	8/5/83	Rubber gasket; tight on neck. No open wounds.	8/1/84	No debris. Faint scars present.
495	8/5/83	Net gray; loose on neck and flipper. No open wounds. Small amount of net.	6/24/84	No debris.
498	8/5/83	Cloth band white; loose on neck. No open wounds.	7/27/84	No debris. No marks.

Also it is unlikely that the debris would slip off over the seal's head since it is likely that the debris would move posteriorly to larger parts of the body as the seal swims forward and the posteriorly sloping guard hairs would tend to resist movement of the debris anteriorly towards the head.

CONCLUSIONS

These studies provide basic data on fur seal entanglement and shed new light on the potential impact of entanglement on northern fur seals. Fur seal mortality resulting from entanglement may not be as high as has been assumed (e.g., see Fowler 1982). The tagging and resight data suggest that entangled seals may not experience increased mortality, at least over a 1-year period. Previous assumptions by Fowler (1982) that seriously wounded seals would die in a short period of time are not supported by the tagging data. The likelihood of entangled seals ridding themselves of debris is much higher than previously assumed especially in view of the observations of seals that had rid themselves of various types of debris and the relatively high incidence of entanglement scars on fur seals without debris. These observations and others made during this study, such as the apparent low probability of entanglement in much of the debris at sea, indicate that past analysis and assumptions on the potential impact of entanglement of the fur seal population need to be reevaluated and further investigated.

Further studies on the incidence and effects of entanglement by age and sex are needed. Current studies were essentially limited to the subadult male seals during the harvest and should be expanded to include detailed information on all entangled seals including females occurring on land from June through September. Increased resighting effort is needed to obtain further information on entanglement mortality and loss of debris. Surveys of debris washed up on the beaches of the Pribilof Islands, other areas in the Bering Sea, and in the North Pacific should continue so as to determine the abundance of debris with entanglement potential and the deposition and recyling of such debris.

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AN EVALUATION OF THE ROLE OF ENTANGLEMENT IN THE POPULATION DYNAMICS OF NORTHERN FUR SEALS ON THE PRIBILOF ISLANDS

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ABSTRACT

The population of northern fur seal, Callorhinus ursinus, on the Pribilof Islands has been declining since the mid- to late 1970's at the rate of about 4.0-8.0% per year. Previous work has pointed to the possibility that mortality caused by entanglement in fishing debris and plastic packing bands is contributing to this decline. In this earlier work crude estimates of mortality rates were derived, some being based on a comparison of the composition of debris on seals with that on beaches. Evidence that entanglement may be involved in the population decline is seen in the fact that the observed entanglement and the decline correspond in time. At a more detailed level, correlations exist between estimated mortality rates, rates of change for two components of the population, and observed entanglement.

In this paper details concerning these correlations are presented. One of the most important correlations is that observed between the rates of change in estimated numbers of pups born and entanglement observed in the harvest. All of the difference between the expected rate of increase at current population levels and the current rate of decline is accounted for statistically in this correlation when the rates of decline are lagged to account for the mortality and maturation of the parental females. There is a similar correlation for adult territorial males with females, again lagged to account for maturation. Details of the correlation between entanglement rates and the discrepancy between expected and observed early mortality in males are also presented. Based on this correlation none of the extra 15 to 20% mortality currently observed would be expected if entanglement rates were zero. Changes in the index of the survival of animals of the ages taken in the harvests, as based on changes in the age structure of the harvest, correspond in time with observed entanglement rates but are not correlated with them.

Although the contribution of entanglement to the current decline appears significant, a precise estimate of entanglement

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

caused mortality has not been produced. Advances have been made, in this regard, through the analysis of the age structure of entangled animals in the male harvest as compared with the entangled animals.

INTRODUCTION

The population of northern fur seal, Callorhinus ursinus, on the Pribilof Islands, Alaska, has been declining for about the past decade at approximately 4.0-8.0% per year (with a mean of about 6.1%) as determined from the numbers of pups born each year since the mid-1970's (Fig. 1). This decline occurred after the development of extensive commercial fisheries in the late 1960's in areas used by fur seals, so commercial fishing was suggested as a potential causal factor. It was thought that reduced food supplies might explain the decline (U.S. Department of Commerce 1980). However, changes in growth, pup survival, and other characteristics of the seals themselves (i.e., the health of individual animals) were found to be inconsistent with a limited food supply (Fowler 1984b). Diseases, predation, and toxicants have been identified as other possible contributing factors although none of the limited data for these factors have been found to show any significant relationship with the decline.

Northern fur seals on the Pribilof Islands have been observed entangled or caught in debris since at least 1936 (Fiscus and Kozloff 1972). Early observations indicated that seals were entangled in rubber bands, cords, strings, and rawhide. In the early 1960's fishing effort in the North Pacific and Bering Sea increased (Low et al. 1985), as did the use of synthetic nonbiodegradable fibers in fishing nets and packing bands. The entanglement of seals in such materials increased from the mid-1960's to the early 1970's (Fig. 1). Currently (1984-85) about 0.4% of the harvested juvenile males are entangled. This figure includes a few older animals taken specifically because they are entangled. Entanglement rates have been recorded from the harvest consistently since the mid-1960's and, as such, are both close to and serve as good indices of the portion of harvestable-aged males that are entangled. About two-thirds of the pieces of debris found on these animals are fragments of trawl net webbing. Most of the remaining objects are plastic packing bands (Fowler 1982a; Scordino and Fisher 1983).

Entanglement in lost or discarded fishing gear or other debris, as a potential contributor to the decline in fur seals, has been seen as historically associated with the increase in fishing activity and the decline in fur seals (Fig. 1). The general temporal correspondence of these events was the basis for suggesting that entanglement might be the cause of the decline (Fowler 1982a, 1982b). These circumstances alone, however, were insufficient to clearly identify the extent to which entanglement might be contributing to the decline. Early estimates of the mortality rate caused by entanglement were provisional; improvements were needed.

All attempts to estimate entanglement-caused mortality rates have involved making various sets of assumptions for which there are limited data. These exercises, and the associated population modelling (Fowler 1982a, 1982b, 1984a; Swartzman 1984), clearly demonstrated the feasibility

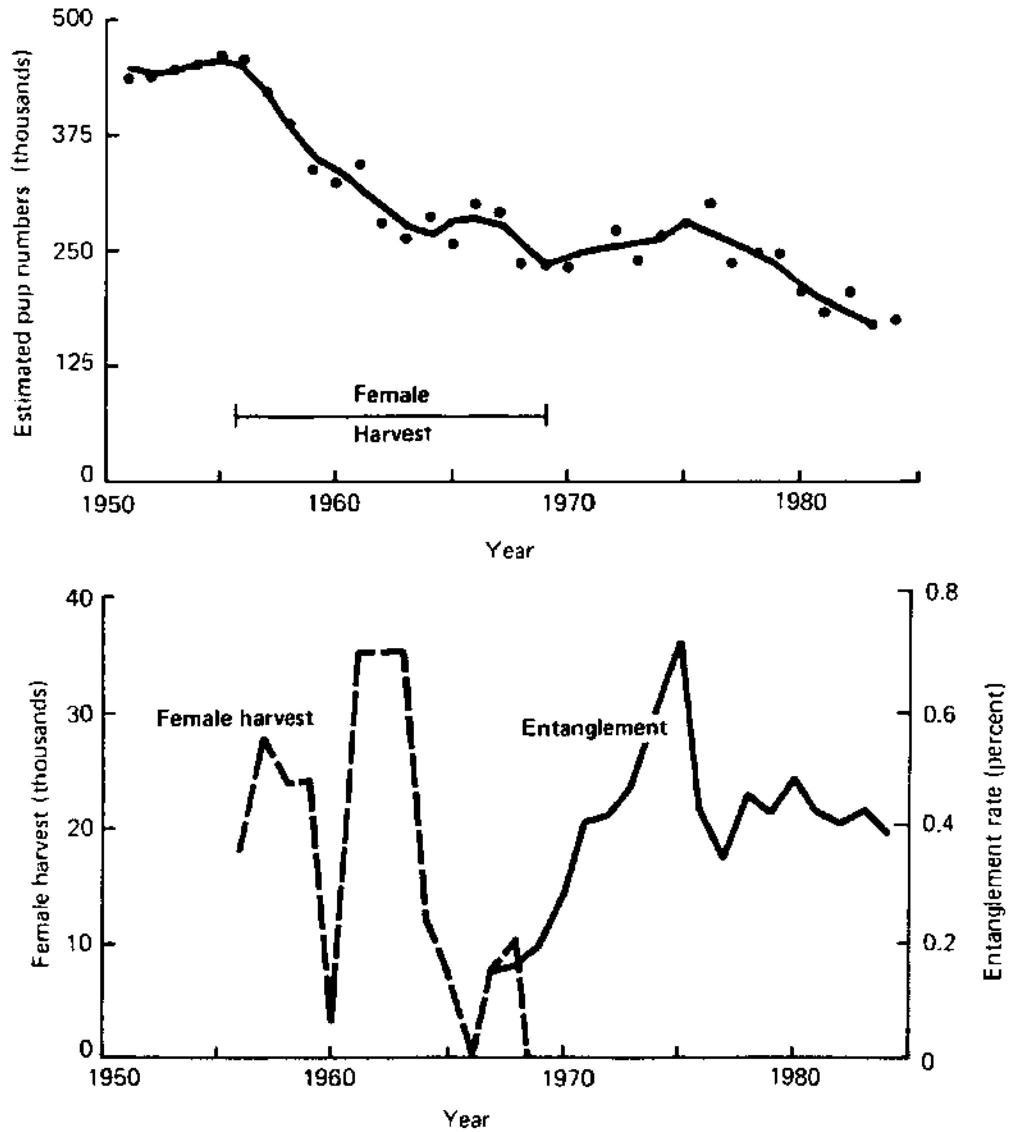

Figure 1.--The estimated number of pups corresponding to the female harvest and observed entanglement for St. Paul Island, Alaska, 1950-84. The dots in the top panel show estimated pup numbers for 1950 to 1984. The solid line represents the running arithmetic mean of 3. The bottom panel shows the female harvest for St. Paul and the entanglement rate observed in the harvest of subadult males.

of entanglement as a cause of the declining fur seal population but made very limited progress toward statistically reliable estimates of the resulting mortality. Increases in the estimated mortality of juvenile males during the first 20 months at sea did not rule out reduced reproduction as a contributing factor in the overall population decline, but helped focus attention on entanglement and other possible sources of mortality such as diseases, toxic substances, and predation.

In this paper, statistical analyses of the correlations between the decline and entanglement rates are presented, along with an attempt to estimate entanglement-caused mortality of males between the ages of 2 and 3 based on the age structure of entangled animals compared with the nonentangled males taken in the harvest on St. Paul Island. Information regarding changes in the survival of older males is also presented.

Correlation Between Survival and Entanglement

In choosing among emigration, changes in survival, and changes in reproduction, the three principal possible causes for the current decline, scientists have made special note of the decrease in the survival of subadult males (North Pacific Fur Seal Commission 1982, p. 26). The current decline has been explained by assuming that the survival of females is equivalent (or nearly equivalent) to that estimated for males (Trites 1984). Between 1965 and 1970 the mean estimated survival during the first 20 months at sea for young males was about 41% whereas the current rates (1980-85) are down to nearly 30% (Fowler 1982a).

Observed entanglement rates rose between 1965 and 1970. Prior to 1965, the estimated survival of young males (0- to 2-year olds) at sea was correlated with the survival of pups on land (Lander 1981). Following 1965, however, this correlation no longer existed (Fig. 2; Fowler 1982b). To examine the potential role of entanglement in this unexpected change, tests were conducted to see if the discrepancy between observed survival and that expected from pup survival on land was correlated with observed entanglement rates.

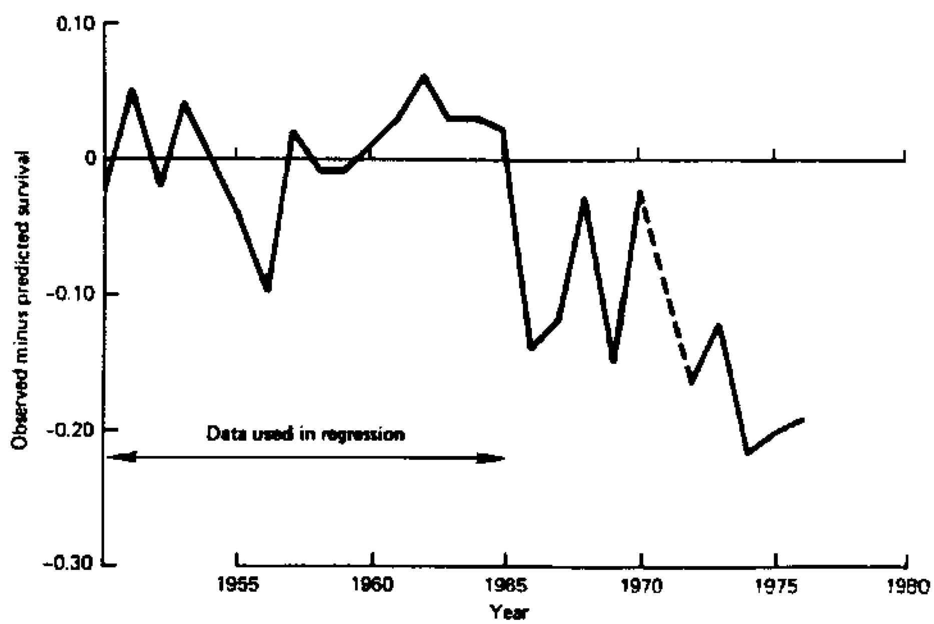

Figure 2.--The discrepancy between predicted and observed survival during the first 20 months at sea for males, based on a correlation between at-sea survival and on-land survival at St. Paul Island from 1950 through 1965 (updated from Fowler 1982b).

First, a simple linear analysis of covariance was conducted to see if estimated survival of young males at sea is correlated with pup survival on land. No significant correlation was found when using all available data from 1950 to the present in spite of a significant correlation for the data from 1950 to 1965. When the observed entanglement rate was introduced as a covariant (assuming zero rates for years earlier than 1967), the resulting multiple regression model was found to represent a significant relationship ($P < 0.05$). These results indicated the need to look more closely at the effect of entanglement in spite of some of the violations of the assumptions involved in linear regression analysis (e.g., that the independent variables exhibit variance).

Another approach was designed to examine specifically the relationship between observed entanglement rates and the unexpected reduction in survival shown by the multiple regression model described above. First, to elucidate any trend that might be hidden by year-to-year variability, the interannual variability of the discrepancy shown in Figure 2 was removed by calculating a running arithmetic mean of three yearly observations. These (means) were then plotted against the rate of entanglement observed in the year of birth of the cohort to which the survival rate applies (Fig. 3).

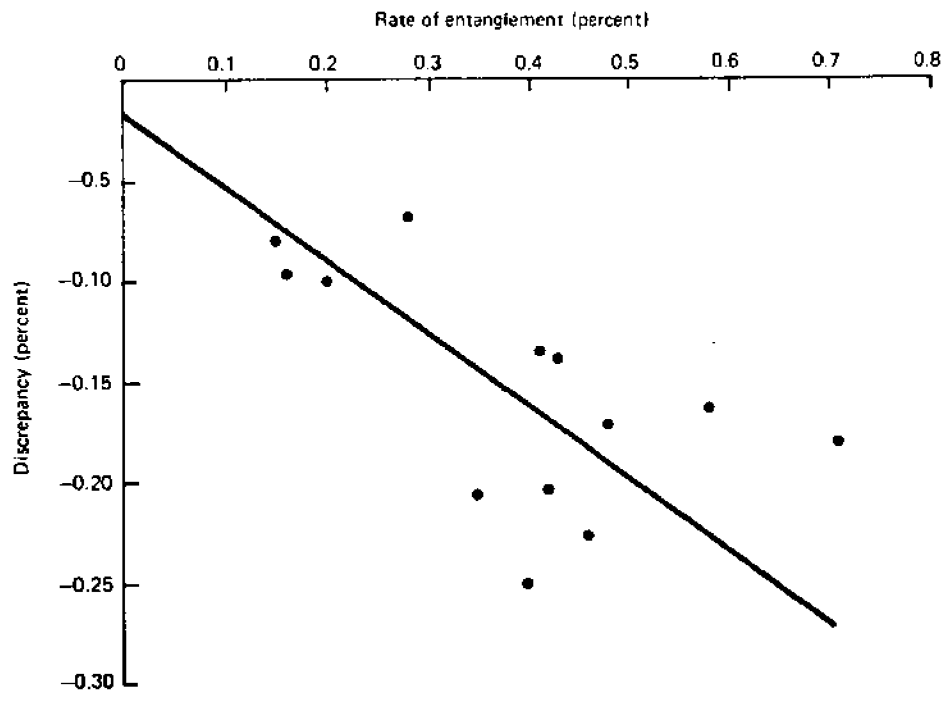

Figure 3.--The correlation between the discrepancy between predicted and observed survival of juvenile male fur seals and entanglement rates 1 year later.

The two variables defined were found to be significantly correlated (Fig. 3) using rank correlation tests ($P < 0.05$). The line shown in Figure 3 was determined by minimizing the sum of the squared error defined as the perpendicular distance between the points and the regression line (Ricker 1973, 1984). This process was used in place of ordinary linear regression since both variables exhibit a nonzero variance. The objective was to find the underlying relationship between the two variables.

The equation for the regression line of Figure 3 is

$$y = -0.016 - 0.360x \qquad (1)$$

where y is the discrepancy defined above and x is the observed entanglement rate for the year after the birth of the year class for which the estimated survival was calculated. From this relationship, if there were no entanglement we would expect almost no difference between the observed survival and that expected from the correlation with pup survival on land. This expectation is consistent with the view that natural survival (survival as affected by factors other than entanglement) is responding in a density-dependent fashion, but overall survival currently includes a significant effect due to entanglement. There is a statistically significant relationship between early survival at sea and the two variables of estimated pup numbers and observed entanglement rates (Fowler 1984b). Neither variable is significantly related to early survival alone.

One potential problem with the approaches taken above involved the introduction of serial correlation in the dependent variable by taking mean over time. Therefore, further analyses were conducted using the raw data (i.e., no 3-year averages) for the discrepancy in Figure 2 as correlated with observed entanglement rates. Again, rank correlation tests found a significant relationship ($P < 0.05$). The intercept of the regression line resulting from ordinary linear regression analysis of the raw data was not found to be significantly different from zero (i.e., not different from a regression equation which would predict zero discrepancy at zero levels of entanglement).

Correlation Between Rate of Change in Pup Numbers and Entanglement

If high mortality of young animals (0- to 3-year olds) is causing the decline in population, and if this mortality is caused by entanglement, a correlation between the rate of change of pup numbers and observed entanglement rates should be observed. This correlation would be expected to involve a time lag to account for the time required by females to reach reproductive maturity (about 6 years, York 1983).

The historical data were examined for such a correlation by removing interannual variability in estimated pup numbers by using the mean of three adjacent data points in place of that of the second year (Fig. 1). The rate of change was then calculated from these means as a simple annual net rate of change (y):

$$y = (N_{t+1} - N_t)/N_t \qquad (2)$$

where N_{t+1} = pup numbers (mean of 3 years) for year t+1 and

N_t = pup numbers (mean of 3 years) for year t.

These rates of change were then plotted against the observed rate of entanglement of subadult males from 6 years earlier (Fig. 4). Rank correlation analysis showed this relationship to be significant ($P < 0.05$). The line shown in Figure 4 resulted from applying the procedure of Ricker (1973, 1984) with the regression equation:

$$y = 0.0760 - 0.2782x \qquad (3)$$

where x is the observed entanglement rate 6 years prior to the year of calculated change.

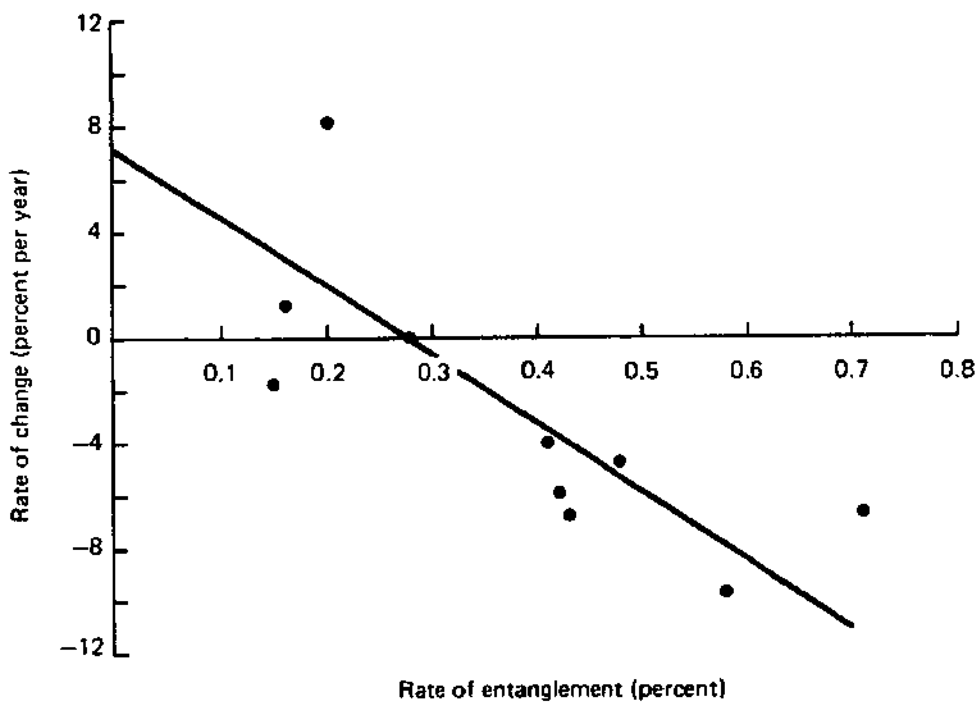

Figure 4.--The correlation between the rate of change in estimated fur seal pup numbers (as determined from a running mean of 3) and observed entanglement rates 6 years earlier.

Although serial correlation of the dependent variable may influence, to some extent, the accuracy and precision of the results of the analyses above, we have identified in Equation (3) a relationship between entanglement and the rate of change in pup numbers on St. Paul Island. Assuming that this relationship can be represented by Equation (3) and that it represents the role of entanglement, an increase in pup numbers at the rate of about 7.6% a year would be expected if the entanglement rate were zero. The current rate of decline of about 6.1% per year corresponds to the approximate 0.5% observed entanglement rate of 6 years ago (obtained as the mean of entanglement rates observed in 1975-77).

As mentioned above, the intercept of the regression line in Figure 4 can be interpreted as a prediction that pup numbers would be increasing at the rate of 7.6% per year if the entanglement rate were zero. This rate is insignificantly different from 7.4% per year, the rate of change observed in the early to mid-1920's when pup numbers were last at currently observed levels. The difference between the current rate and the rate observed in the early 1900's is 13.5% (7.4 + 6.1 = 13.5). In other words, pup numbers are changing at rates 13.5% less than expected for current population levels. The relationship shown in Figure 4 accounts for all of the difference.

Conventional linear analysis, again potentially influenced by serial correlation, produced similar results. The intercept of the resulting regression equation was not significantly different from 7.4% (at zero entanglement). In this case, however, there is another potential problem associated with the variance in the observed entanglement rate as the independent variable. Conventional linear regression assumes zero variance for the independent variable.

A final analysis of this relationship involved rank correlation in which the rates of change were used directly, without taking running means of 3. Again a statistically significant relationship was found ($P < 0.05$).

Correlations Between Rate of Change in Numbers of Adult Males and Entanglement

Counts of adult male fur seals are conducted each year. Territorial males with females are a well-defined component of this population and have been counted since the early 1900's. An analysis of the entanglement rate of females is not possible since no reliable and precise estimates of the total number of females have been produced. However, for males it is possible to test for any correlation between entanglement rates observed in the harvest and reduced recruitment.

Figure 5 shows the rate of change in numbers of adult males with females on their territories plotted against the observed entanglement rate in the male harvest 9 years earlier. This lag was introduced to account for the time required for males to reach active reproductive status in the breeding population (Johnson 1968). The rate of change was calculated using Equation (2) with adult male numbers (raw data) instead of the smoothed data for pup numbers. The relationship is significant as determined by rank correlation ($P < 0.05$), assuming any problems introduced by serial correlation are insignificant. The line shown is the regression equation resulting from the application of the equations in the Appendix.

Age Composition of Entangled Versus Nonentangled Males

Young fur seals appear to become entangled at greater rates than older animals (Fowler 1984a). Work by Japanese scientists supports this (North Pacific Fur Seal Commission 1984, p. 39). Using captive animals and video recording equipment at the Izo Mito Oceanarium in Japan, it was noted that the younger animals (mostly females) become entangled more often than older animals.

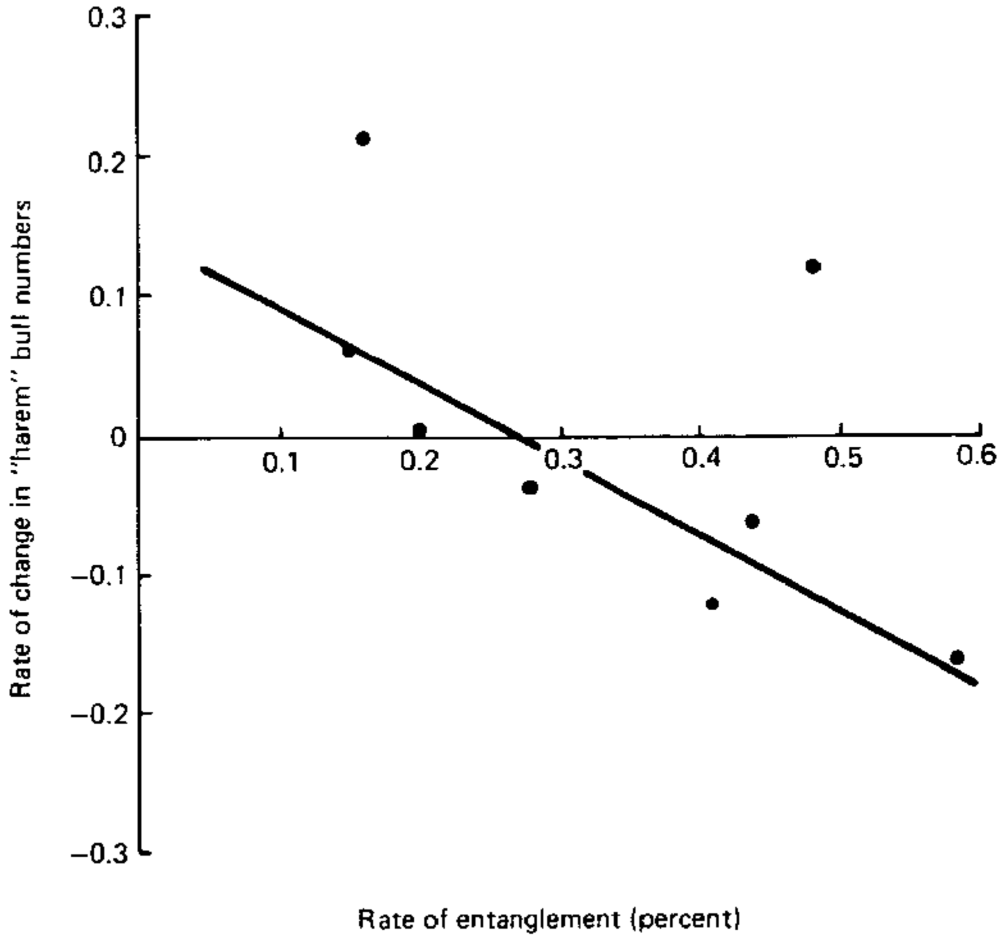

Figure 5.--The correlation between the rate of change in territorial male fur seals with females at St. Paul Island, Alaska, and observed entanglement 9 years earlier.

If the animals of harvestable age are subject to entanglement-caused mortality, the age composition of entangled animals in the harvest should differ from that of unentangled animals. If young animals suffer more of this type of mortality, the age composition of young entangled animals should differ from that of two other groups. First, their age composition would be expected to differ from that of unentangled animals of the same age. Secondly, it would be expected to differ from the age composition of older animals regardless of entanglement. Thus, assuming that the probability of being taken in the harvest is independent of being entangled, the ratio of 3-year olds to 2-year olds in the harvest should be the same for each group (entangled and nonentangled) if no additional mortality occurs among the entangled animals.

Table 1 is a presentation of the number of animals in each age category, broken down by whether or not they were entangled, for the 1982 harvest of males (Scordino and Fisher 1983). A chi-square contingency test shows that the distributions of the two categories are not the same. The ratio of 3-year olds to 2-year olds is different for the two categories.

Table 1.--Age composition of the harvest of entangled and unentangled male fur seals on St. Paul Island, Alaska, 1983 (from Scordino and Fisher 1983).

Age	Number (percent of total in category)	
	Entangled	Unentangled
2	13 (13)	2,078 (8)
3	44 (43)	15,167 (61)
4	30 (30)	7,046 (29)
5	6 (6)	517 (2)
>5	8 (8)	23 (<1)
Total	101	24,831

No attempt is made to drive entangled 2- or 3-year-old animals for harvest in preference to unentangled animals of the same age (J. Scordino pers. commun.). It seems safe, then, to assume that, within each age class, both entangled and unentangled animals have equal probabilities of being harvested. Under these conditions, the ratio of 2-year olds to 3-year olds in each category should be the same after applying a conversion factor to account for any difference (D) which presumably would be due, at least in part, to mortality:

$$D\frac{13}{44} = \frac{2078}{15167} \qquad (4)$$

$$D = 0.46 \qquad (5)$$

The entangled animals in this sample have an estiamted 54% (1.0 - 0.46 = 0.54) lower survival rate between the ages of 2 and 3 than the natural mortality experienced by the unentangled animals. This difference could be the result of several factors including the loss by the seal of its entangling gear, entanglement-caused mortality, or a violation of the assumption of equal probability of being taken (differential recruitment).

These data are consistent with the conclusion that younger animals are more prone to entanglement-related mortality than are older animals. As seen in Table 1, older age classes do not show the difference in age distribution between the entanglement categories that are observed between 2 and 3 primarily because older entangled animals are actively selected for the harvest. Also, data presented by Scordino (1985) indicate that older animals may not experience as much entanglement-caused mortality as is indicated for 2-year olds above. If animals (including females) between birth and the age of 2 are more prone to entanglement than older animals, only part of the 54% reduced survival shown need be attributed to entanglement-caused mortality to be of sufficient importance to cause the decline.

Entanglement and Recent Changes in the Age Composition of the Harvest

The mean age of the harvest animals taken on St. Paul Island has declined since 1970 as indicated by an increase in the portion of 2-year-old animals and a decrease in the portion of 4-year olds (Fowler 1984b). This change may have been due to either a change in survival or age-specific utilization rates. If utilization rates are consistent, an index of survival can be obtained by relating the numbers of animals of one cohort to the number of animals from the same cohort taken the previous year.

Such an index was calculated for all cohorts and normalized to produce comparable values. The results are plotted in Figure 6 and show an increasing trend in the index of survival for the period over which the population declined in response to the female harvest (1956-68). Since 1970, however, the survival index of animals between the ages of 2 and 5 has declined nearly to levels observed in the 1960's.

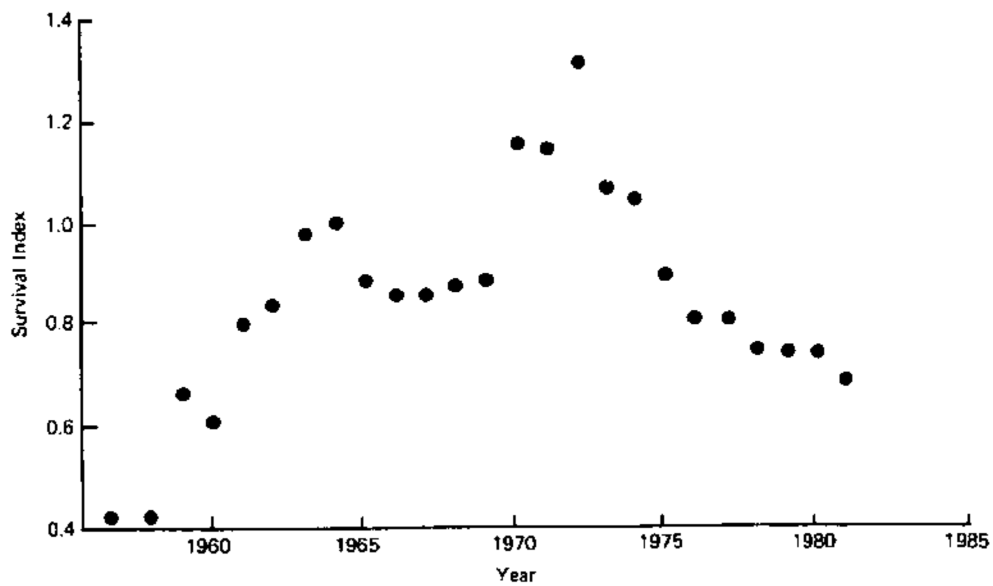

Figure 6.--A survival index for 2- to 5-year-old male fur seals as calculated from the age composition of the harvest, 1957-81, St. Paul Island, Alaska.

The declining trend in the index of survival implied by these data coincides in time with the occurrence of observed entanglement. Any relationship between the two variables is supported only by this temporal correspondence, however. There is no statistically significant correlation between the variables. It is possible that survival has changed little and that instead the harvest rate of males has increased in parallel with changes observed for other species (Fowler 1980) for which effective effort increases as the harvest population declines. Data presented by Scordino (1985) indicate that mortality attributable to entanglement among older males is less than for younger animals. If this is the case, changes in the age structure may be wholly a product of gradual changes in the harvest to result in increasing utilization rates among younger animals. This is a conclusion reached by York (1985).

DISCUSSION

Attempts to estimate entanglement-caused mortality have been based on limited data (Fowler 1982a, 1982b). Assumptions about the size composition of net fragments involved in entanglement, the mortality rate of animals entangled in small debris, and the degree to which females are entangled were necessary to arrive at these estimates. Further analysis and more recent information showed that earlier estimates were probably low (Fowler 1984a), but resulted in no more accurate estimates. However, consistency among the various estimates supports the view that there is a cause-and-effect relationship behind the correlations in Figures 3, 4, and 5. Nevertheless, it remains difficult to produce precise estimates of the mortality rates caused by entanglement.

Recent information emphasizes that entanglement is more of a problem for young seals than for older seals. Work by Japanese scientists indicates that young animals exhibit a greater tendency to investigate debris and become entangled than do older aniamls. (An observation made at the Honolulu Workshop on the Fate and Impact of Marine Debris, November 26-29, 1984. Also see page 39 of North Pacific Fur Seal Commission 1984.) Their work also shows that young females become entangled and that animals of both sexes often can free themselves once entangled in debris. The reaction of the population on St. Paul Island is consistent with higher juvenile mortality as indicated by the importance of time lags between observed entanglement rates and reduced pup production (presumably because of reduced recruitment of females) and the decline in the numbers of adult males. The difference in age structure between entangled and unentangled animals in the harvest is also consistent with lower survival for entangled animals between ages 2 and 3 than for unentangled animals.

If most entanglement involves animals in their first few months at sea, and if seals in small net fragments suffer mortality at the rate indicated by the age distribution of harvested animals, it is possible that only 9.7% of the animals entangled in smaller debris return to be seen as 3-year olds ($0.46^3 = 0.097$ from the 0.46 survival of Equation (4) applied over 3 years). The total entanglement in small debris would be about $0.003/0.097 = 0.031$ or 3.1% (0.003 being the approximate fraction of 3-year olds in the harvests that are observed entangled, Table 1). Accounting for the size composition of the net fragments, 15.5% ($0.031/0.2 = 0.1555$) of the young seals may become entangled. (By making the same assumption as in previous work (Fowler 1982a, 1982b, 1984b) that the probability of animals getting caught is independent of net fragment size and that beach samples represent the composition of debris at sea, it is possible to account for animals which have died and not returned to land.) The majority, 90.3% ($1.0 - 0.097 = 0.903$), of these would die.

It is possible that the correlations presented in this paper are the fortuitous result of other correlated causal factors which have so far gone unnoticed, or that chance alone has resulted in the other observations that indicate entanglement could account for the current decline. The correlations observed might also be affected by the analytical procedures. However, we are not faced with only one or two isolated cases of this nature. There is a growing number of such factors. They include the several correlations between entanglement and the decline, the several estimates of mortality due to entanglement which are consistent with each other and with the decline in fur seal herd, and the ways such factors combine into quantitative models which mimic recent dynamics of the fur seal population. When considered collectively, these observations indicate that entanglement-caused mortality is a major contributing factor in the decline in the fur seal population of the Pribilof Islands. So also do details concerning the size composition of entangling debris, beach samples of debris, captive animal studies, studies of the occurrence of debris at sea, and studies of age composition of entangled animals in the harvest. The levels of mortality consistent with the data, in each case, are sufficient to explain the decline as verified through modelling studies (Swartzman 1984; Trites 1984). It is unlikely that such a combination of circumstances would occur if entanglement were not causing or contributing significantly to the present decline.

There exists a number of other factors which may be considered of potential importance in the decline of fur seals on the Pribilof Islands. These include such things as emigration, predation, diseases, the commercial harvest of males, reduced reproductive rates, reduced food supply, and toxic substances. Although there are often limited data, and further research is needed, the existing information generally indicates that the influences such factors are having on the population are not abnormal and that presently there is little or no reason to believe they are contributing to the decline (Fowler 1985). Some possibilities are inconsistent with observed changes in the population. For example, reduced food supplies are inconsistent with the density dependent responses of increased growth rates (body size) and increased pup survival (Fowler 1984b). A correlation exists between estimated juvenile survival and eastern Pacific sea-surface temperatures (York 1985). Such a correlation may imply an effect through the food chain which could be contributing to the decline but would again be inconsistent with increased body size. Further exploration of these possibilities is presented in Fowler (1985) where it is again emphasized that further research is needed.

CONCLUSIONS

Entanglement and several aspects of the population dynamics of the northern fur seal population on the Pribilof Islands, Alaska, are significantly correlated as indicated by data from St. Paul Island. The difference between the current rate of decline in pup numbers and the rate of increase experienced in the 1920's (when the population was last at current levels) is explained through a correlation between rates of change in pup numbers and entanglement observed in the male harvest (Fig. 4). Similar correlations exist for the rate of change in the count of breeding males with females in their territories (Fig. 4). Unexpected increased in juvenile mortality (estimated for males and assumed to apply to females as well) are explained through correlations with observed entanglement (Fig. 2).

Analyses of the limited data emphasize that mortality rates caused by entanglement are consistent with those which would cause the current population trend. Furthermore, most of the existing information indicates that entanglement-caused mortality is primarily a problem for animals younger than 3 years of age, but involves most age classes to some extent.

Although it seems clear that entanglement is an important factor, limited progress has been made in providing accurate estimates of entanglement-caused mortality. The precise extent to which entanglement is contributing to the decline of northern fur seals on the Pribilof Islands has not been determined. There is a continuing need for studies to determine the degree to which females are involved in entanglement and estimates of resulting mortality.

Because of the consistency between the observed rates of entanglement and recent population trends, future studies should be directed toward determining better estimates of the entanglement-caused mortality by age and sex. Because of limited direct cause-and-effect information, and recognizing that other contributory causes of the decline may exist, future research should include studies of possible changes in reproductive rates, the effect of diseases and toxins, and changes in the fur seal's ecosystem. The need for studies of the influence of environmental conditions is emphasized by the recent work of York (1985).

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APPENDIX

The following equations were used to perform regression analysis for this paper and resulted in the regression lines shown in the figures. In each case x_i is the ith observation of the independent variable and y_i the corresponding observation of the dependent variable. These equations result from assuming both variables show a nonzero variance and minimizing the perpendicular distance between the data point and the line of regression. The regression equation for the underlying relationship is assumed to be:

$$Y = a + bX \tag{5}$$

The estimate of the intercept (a) is:

$$a = \left(\sum_{i=1}^{n} y_i - b \sum_{i=1}^{n} x_i \right) / n \tag{6}$$

where n is the sample size of the points defined by x and y and b is estimated by:

$$\hat{b} = \min \left(\frac{-q \pm \sqrt{q^2 + 4p^2}}{2p} \right) \tag{7}$$

where

$$p = \sum_{i=1}^{n} x_i y_i - \frac{\sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n} \tag{8}$$

and

$$q = \left(\frac{\left(\sum_{i=1}^{n} y_i \right)^2}{n} - \sum_{i=1}^{n} y_i^2 \right) - \left(\frac{\left(\sum_{i=1}^{n} x_i \right)^2}{n} - \sum_{i=1}^{n} x_i^2 \right) \tag{9}$$

STELLER SEA LION ENTANGLEMENT IN MARINE DEBRIS

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ABSTRACT

Observations of Steller sea lions involved in entanglement of marine debris have been made throughout the Gulf of Alaska and in southeastern Alaska. Two categories of debris, closed plastic packing bands and net material, account for the majority of instances of entangled animals. Net material appears to be primarily from fishing trawls, although the exact origin remains obscure.

Photographic evidence and necropsies show extensive tissue damage suffered in the neck area of entangled animals. Some animals have scars on the neck indicating recovery from entanglement. However, severity of wounds observed suggests that, in many cases, the encounter is fatal.

In theory, sea lions swim forward only, and they apparently seldom "back up," thus, once foreign material encircles the neck, there is little likelihood of it being removed. Polypropylene or plastic netting material or packing band material is known to be long lasting and, therefore, can remain on the animal's neck as an abrasive irritant over long periods. Decay of the foreign material possibly could be hastened by agents which may be produced from the necrosis of tissue allowing some animals to eventually shed the entanglement material, and if the damage is not too severe, survive the encounter.

Two beaches in the northern Kodiak Archipelago were surveyed for marine debris. Emphasis was placed on material which was considered to have potential for entanglement with sea lions. One beach was surveyed on the west side of Afognak Island which was exposed to the drift mechanisms of Shelikof Strait, and the other beach surveyed was exposed to the Gulf of Alaska and the North Pacific Ocean.

Debris noted was divided into four categories: nets, plastic bands, ropes, and buoys. The first three categories were further divided as follows: nets--potentially entangling since $>1\ m^2$ and not entangling since $<1\ m^2$; plastic bands--open or closed loop; ropes-->1 m and knotted on the ends as potentially

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entangling and <1 m or not knotted on the ends as not entangling. Buoys by themselves were not considered as potentially entangling and lines attached to buoys were considered under the category of ropes. Some interesting differences were noted between the two beaches. Substantially more net material >1 m^2 was observed on the beach in Shelikof Strait than the beach exposed to the North Pacific Ocean. Most plastic band material found was cut. One beach had no closed packing band loops. Slightly less than half of the rope material found was potentially dangerous to sea lions and far more rope material was found on the beach exposed to the Pacific Ocean than the beach exposed to Shelikof Strait. More buoys were also found on the Pacific Ocean beach.

INTRODUCTION

The Steller sea lion, _Eumetopias jubatus_, is a conspicuous, large pinniped which inhabits the North Pacific Ocean and adjacent seas. Sea lion habitat in these areas extends from approximately 25 m above mean high tide at rookeries and haul-out areas to the continental shelf break on the high seas. They are highly mobile animals and movements exceeding 1,500 km have been documented (Calkins and Pitcher 1982). During May through July, Steller sea lions gather on traditional rookeries to pup and breed. Other haul-out areas continue to be used during this time by nonreproductive animals. Although there are at least 100 locations in the Gulf of Alaska and southeastern Alaska where sea lions haul out on a regular basis, only 11 of these are major breeding concentrations, or rookeries (Calkins and Pitcher 1982). The largest sea lion concentrations in the world are found near Kodiak Island.

Steller sea lions eat primarily off bottom, schooling fishes such as walleye pollock, _Theragra chalcogramma_, and Pacific cod, _Gadus macrocephalus_ (Pitcher 1981). They are often sighted in the vicinity of fishing activity for these two species. Observers have even speculated that sea lions are attracted by noises generated during retrieval operations of trawls (Loughlin and DeLong 1983).

The Alaska Department of Fish and Game has carried out an extensive research project on Steller sea lions which involved observations and data collections on the biology and life history of sea lions including observations of entangled animals. This work was primarily supported through Federal funds, initially through the Outer Continental Shelf Environmental Assessment Program which was funded to provide information before offshore oil lease sales and subsequent offshore oil exploration and development. In recent years, sea lion research by Alaska Department of Fish and Game has been supported with funds provided by the National Marine Fisheries Service, Alaska Region.

Part of the information presented here was gathered during other studies. The entanglement observations are entirely incidental to other sea lion studies. Information presented on debris from beach surveys in the Kodiak area was not intended to be a final report on work performed. Indeed this report is only intended as an interim progress report. The beach surveys were primarily designed to provide baseline data to design better future study.

STUDY AREA

The information provided in this study was collected in the Gulf of Alaska, primarily in nearshore areas bounded in the southwest by Unimak Pass and in the southeast by Dixon Entrance (Fig. 1).

Two beaches were chosen to be surveyed for debris considered potentially harmful to sea lions (Fig. 1). Debris considered potentially harmful was based upon observations of entangled sea lions. The first beach (beach 1) was located in Marmot Strait, on the east side of Afognak Island, north of Kodiak Island. This beach was chosen because it was thought to be exposed to the North Pacific Ocean directly. The second beach (beach 2) was located north of Malina Bay on the west side of Afognak Island. This area was chosen because it is exposed to Shelikof Strait between the Kodiak Archipelago and the south side of the Alaska Peninsula.

METHODS

Observations of entangled animals were made incidental to other studies carried out at rookeries and haul-out areas. Animals were photographed whenever possible, and, in one case, an animal was collected (in conjunction with other studies) which had a packing band around its neck. Most information on sea lion entanglement available at this time has been primarily anecdotal and no attempt has yet been made to quantify mortality involved in entanglement. Data presented here are not sufficient to provide statistically valid analysis.

Beaches were surveyed on 23 May and 24 May by six people at beach 1 and four people at beach 2. The beaches were arbitrarily divided into unequal sections and each person surveyed a single section. Thus beach 1 was divided into six sections, and beach 2 was divided into four sections. Wherever possible, each person removed debris which was considered to have potential for entanglement with Steller sea lions. The debris considered as potentially entangling to sea lions was divided into three categories: nets, plastic bands, and ropes. Although not considered harmful by themselves, buoys were also surveyed. The three categories were further divided as follows: nets--potentially entangling as $>1\ m^2$; plastic bands--open or closed loop; ropes-->1 m and knotted on the ends as potentially entangling, and <1 m not knotted on the ends as not entangling. Buoys by themselves were not considered as potentially entangling; and lines attached to buoys were considered under the category of ropes.

Some net fragments and large pieces of rope were either partially buried or sufficiently tangled on stationary objects such as trees or large rocks to make them impossible to remove. In these instances, we removed as much as possible and noted the location of the remainder. The collected debris was taken to a central location where it was catalogued and stored above the highest storm tide level to prevent its return to the beach. In some cases, buoys without ropes were placed above maximum storm tide level near the locations they were found to save time.

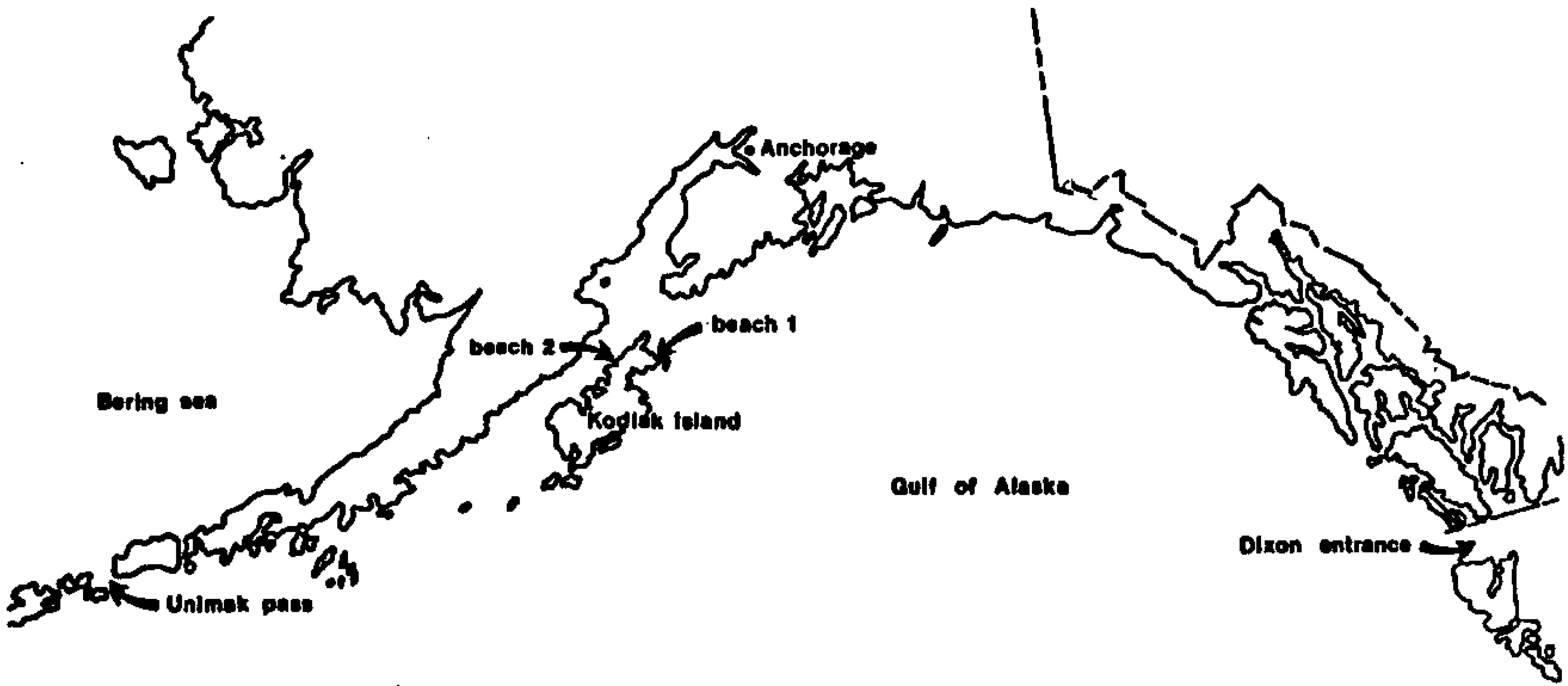

Figure 1.--Study area for Steller sea lions. Arrows indicate beaches surveyed.

RESULTS AND DISCUSSION

From my observations and photographs there appear to be two categories of debris which account for the majority of instances of entangled animals: closed plastic packing bands and net material. Both categories seem to involve animals 2- to 3-years old and older. Both sexes appear to be susceptible although more adult females have been observed entangled and no adult males. We have no records of neonatal sea lions being entangled. Perhaps the reason why few young animals are seen entangled is that entanglement results in extremely high mortality in this age class and therefore would not be seen, or they do not normally become entangled. In the case of closed packing bands, sea lions probably become entangled as they attempt to swim through them either from curiosity or accidently. Once the band is over the head, it probably remains there until it decays, or is broken, or kills the sea lion. It is my opinion that sea lions probably do not have the ability to remove debris once they become entangled. However, the one possible way a sea lion may remove a band or net from the neck is by breaking it with a claw.

Packing bands around the neck cause tissue damage in two ways. If the animal is a subadult when it acquires the band, and if the band is sufficiently small, it may cut into the tissue as the sea lion grows. Often when animals are sighted they have what appears to be an open wound, completely encircling the neck. At times it is difficult to determine if the foreign material has been removed or if the animal has grown around it. It is even possible that some of the healed wounds we see may still have some foreign material ingrown.

The other possibility for tissue damage from packing bands is simple abrasion. If the band is too large to cause constriction, or if the animal is already an adult and has stopped growing, then the band is generally visible and the injury is often characterized by being noncontinuous around the neck. Often this type of injury is either directly on the dorsal and occasionally on the ventral surface of the neck. This type of injury is probably caused from an abrasive action generated while the animal is swimming, either from water pressure forcing the band against the neck or pulling it from the opposite side.

In addition to curiosity sea lions can be entangled in floating net material and by attempting to haul out on it or remove fish from it. They may also become entangled in trawl nets being actively fished and either break free or are cut free, thus retaining a section of net on their bodies. Net fragments are most often seen around the neck, although occasionally a fragment may cover other parts of the body. The majority of net fragments which I have been able to identify on sea lions have been of the type used in trawl gear in the high seas groundfish fishery. I have not identified gill net or seine gear of the type used in nearshore commercial salmon fisheries entangled on sea lions. It is certainly possible for sea lions to become entangled in nearshore commercial salmon gear since extensive fisheries take place in this area, although this does not appear to be a major problem.

Net fragments entangled on sea lions are usually small pieces (probably $<2\ m^2$) around the neck and usually appear to be tightly lodged. Occasionally long pieces of net trail from the neck. Injuries from net fragments appear to be similar to those caused by smaller plastic bands. There is often a continuous wound encircling the neck where the net is lodged, and a band of necrotic tissue on either side plus often what appears to be scar tissue beyond that. It is possible that some of the healed wounds we see that we intrepret as a recovery from an entanglement are from net material which the animal successfully escaped.

Table 1 shows the debris collected during the two beach surveys. As can be seen from Table 1, substantially more net material $>1\ m^2$ was found on beach 2 than on beach 1. Apparently many people are cutting plastic bands before discarding them into the ocean, as far more cut bands were found than closed loops. In fact on beach 1 no closed loop bands were noted. A great deal of rope was found on both beaches although beach 1 had the most. Slightly less than half of the total rope material found was considered potentially dangerous to sea lions.

Table 1.--Marine debris collected on two beaches of Afognak Island, Alaska, May 1984.

	Nets		Plastic bands		Ropes		Buoys
	Potentially entangling $>1\ m^2$	Not entangling $<1\ m^2$	Open	Closed	Potentially entangling 1 m and knotted	Not entangling 1 m or not knotted	Not entangling
Beach 1	8	9	8	0	23	24	30
Beach 2	17	3	3	3	14	21	23

The decision to divide net and rope fragments into the above categories was arbitrary. It was felt that although $1\ m^2$ is a sizable piece of net, it seems unlikely that a sea lion would initially become entangled in net fragments much smaller that $1\ m^2$. Although we do see sea lions with net fragments which appear to be smaller than $1\ m^2$ around their neck, it is my opinion that when acquired, the fragments were probably larger. Rope fragments $>1\ m^2$ and knotted were considered potentially dangerous to sea lions because we have seen many rope fragments which have frayed and unraveled to a point where they resemble large bundles of monofilament. These appeared to have substantial potential for entanglement.

The beaches surveyed were selected from charts of the coastline; however, after surveying the actual beaches, it appeared that beach 1 may not have been a typical beach exposed to the Pacific Ocean and North Gulf of Alaska. The large amounts of rope material and buoys, and smaller amounts of net, particularly trawl net may be indicative of the more localized crab fishery in Marmot Bay and Marmot Straits rather than the north gulf as a whole.

At present I am unable to fully assess the impact of marine debris on Steller sea lions. There are several aspects of the problem which need to be more completely investigated before we can accurately predict the actual effects on the sea lion population. A number of beaches should be surveyed within important sea lion habitat to determine the extent and accumulation rates of debris which are potentially dangerous to sea lions. The beaches should be selected relative to the major drift patterns of the North Pacific, the southwestern Gulf of Alaska, Shelikof Strait, and the southeast Bering Sea. Several beaches should be selected to avoid localized effects. The amounts of potentially entangling materials presently adrift in the same areas mentioned above would provide a more complete understanding of the problem, although I believe this type of information is extremely difficult to acquire. I also consider it worthwhile to estimate the amounts of material being deposited into the oceans. Such an estimate might be derived through interviews with fishermen. Finally, an important aspect which can be measured is an estimate of the percent of sea lions entangled in marine debris and from this an estimate of debris caused mortality. I expect to begin a study designed to determine this estimate by surveying large numbers of sea lions on rookeries and haul-out areas, recording all observed incidents of entanglement by sex and age class where possible, and recording the total numbers of animals present by sex and age class.

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ENTANGLEMENT OF PINNIPEDS IN NET AND LINE FRAGMENTS AND OTHER DEBRIS IN THE SOUTHERN CALIFORNIA BIGHT

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ABSTRACT

We documented cases of pinnipeds with various kinds of debris entangling them at San Nicolas and San Miguel Islands, California, from 1978 through 1982. In 1983 and 1984 we conducted systematic surveys to document the frequency of entanglement of northern elephant seal, *Mirounga angustirostris*; California sea lion, *Zalophus californianus*; and harbor seal, *Phoca vitulina richardsi*, in marine debris. Approximately 0.08% of the animals in each population had materials encircling their necks or torsos while another 0.06 to 0.10% had scars indicating previous encounters with entangling materials. Encounter with marine debris could be confirmed as the cause of entanglement in only a few cases; trawl net fragments and plastic packing bands were the entangling debris in these instances. Most entanglements appeared to be related to interactions of pinnipeds with operational commercial and perhaps sports fisheries rather than with debris. Although some pinnipeds in southern California waters are apparently being entangled by marine debris, the magnitude of debris-related mortality remains unknown. Assessment of the impact of marine debris on pinniped population will require 1) that entanglement during fishing operations be distinguished from encounter and entanglement with discarded or lost gear fragments and other debris and 2) determination of mortality rates of debris-entangled pinnipeds.

INTRODUCTION

The interactions between marine mammals and commercial or sport fisheries that result in injury to or death of animals have been grossly divided into two types. "Incidental take" refers to mortality of marine mammals that become tangled or trapped in operational fishing gear and either drown or are shot or clubbed before they are disentangled or cut free from the gear. It may also refer to shooting of animals by fisherman at sea or on rookeries or collision of vessels (or their propellers) with marine mammals. "Entanglement" has been used by some authors to describe the phenomenon of animals becoming entrapped in discarded net fragments (i.e., "passive fishing gear") and other debris as well as in active

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

fishing gear. Fowler (1982), however, reserved the term "entanglement" to refer to marine mammals being wrapped or caught in debris (including fishing gear) that had been lost or discarded at sea. Since marine mammals caught in actively fished gear may be cut free, leaving some net or line fragments attached to them, it is often difficult to confirm that certain kinds of entangling material observed on animals were actually debris when the animals encountered them. Here we use the terms "entangled" and "entanglement" to describe all cases of man-made items encircling the bodies of pinnipeds observed during our surveys. We do, however, consider the possibility that pinnipeds may have encountered these items while interacting with active fishing gear rather than debris at sea.

The extent of interactions of pinnipeds with commercial and sports fisheries has received much attention recently (e.g., Northwest and Alaska Fisheries Center 1980; Anonymous 1981; Everitt et al. 1981; DeMaster et al. 1982; Fowler 1982; Miller et al. 1983; Swartzman and Haar 1983; Metleff and Rosenberg 1984) primarily because these interactions result in damage to fishing gear and loss of marketable fish. The effects of pinniped mortality from fishery interactions (including entanglement in gear and gear debris) on the status and trends of pinniped population have, however, received limited attention. Anecdotal observations have been reported of pinnipeds with various kinds of man-made items encircling their necks or torsos; tissue damage has been observed in many cases. Few cases, however, have been observed or reported of pinnipeds that have died as a result of entanglement in debris. The effects of pinniped entanglement in marine debris on population trends have therefore been difficult to assess. Interpretations of the potential effects have often been limited by a lack of information on the proportion of a population that becomes entangled in debris, the sex and age structure of those entangled animals, and the fate of entangled animals.

Fowler (1982) summarized systematic observations on the occurrence of net fragments and other debris entangling northern fur seal, <u>Callorhinus ursinus</u>, at the Pribilof Islands since the mid-1960's and examined the potential effects of mortality resulting from entanglement on population trends. Entanglement of other species of pinnipeds has been noted by several authors (e.g., Kenyon 1981; Bonner 1982; Allen and Huber 1983; Canil and Canil 1983; Henderson 1983; Huber et al. 1983) but most accounts are anecdotal; the magnitude of entanglement by various types of marine debris and the extent of mortality resulting from entanglement are unknown.

Since 1978, we have made ground censuses of pinniped populations at San Nicolas and San Miguel Islands at intervals varying from weekly to monthly (e.g., Stewart 1980, 1981; Stewart and Yochem 1984). Before 1983 we noted any animals observed on these censuses that were entangled in debris. We recorded the types of debris entangling animals as well as that found on beaches. The number of entangled animals observed during that period was low but our surveys of entangled animals were not systematic and therefore the data are not useful in assessing the frequency of entanglement in each population.

In 1983 we began systematic surveys of northern elephant seal, <u>Mirounga angustirostris</u>, California sea lion, <u>Zalophus californianus</u>, and harbor seal, <u>Phoca vitulina richardsi</u>, at San Nicolas Island (SNI) and of northern elephant seal and harbor seal at San Miguel Island (SMI) to document the frequency of pinniped entanglement in various kinds of debris. We also continued to document debris (type, amount, size) that had washed ashore on these islands. Surveys for entangled animals were conducted simultaneously with, but independently of, population censuses. We chose small groups of animals in each census area (see Stewart and Yochem 1984) and surveyed them using binoculars or a spotting scope. We also used a Celestron C-90 spotting scope to photo-document entangled animals. At SNI, where most of the work was concentrated, pinniped rookeries and hauling areas extend along approximately 13 km of coastline on the south side of the island. The populations are naturally subdivided into smaller groups (census areas) along this area by topography. In each census area we surveyed small groups of seals and sea lions and recorded the number examined, the number entangled, and the number scarred from prior entanglement. We classified each animal examined by age and sex; only those animals whose entire bodies could be seen clearly were included in the "entanglement survey."

RESULTS AND DISCUSSION

Although our surveys were often more frequent, we used only a single survey per month (usually mid-month) to determine the magnitude of entanglement for each species (Tables 1, 2, and 3). We assume that each monthly sample is independent of other monthly samples and therefore that each sample is of a unique number of animals. Any tendency for entangled animals to spend more time hauled out than nonentangled animals may bias the analysis and result in inflated estimates of entanglement. The season of the sample may also affect estimated entanglement rates if entangled animals remain at the rookeries longer than do nonentangled animals of similar age and sex classes that may migrate and be entirely absent or in low abundance at certain seasons. Combined estimates of entanglement rates then may be more accurate if based on seasonal samples taken throughout the year. Combining all sampling periods, we examined 13,175 sea lions, 11,054 elephant seals, and 1,877 harbor seals. Approximately 0.08% of sea lions, 0.08% of elephant seals, and 0.05% of harbor seals had synthetic items encircling their bodies and an additional 0.10% of sea lions, 0.06% of elephant seals, and 0.05% of harbor seals had scars suggesting previous entanglement with debris or encounters with actively fished nets or longlines. We were generally unable to discriminate among polypropylene, polyethylene, or other synthetic multifilament synthetic materials such as "poly."

Of the 11 sea lions observed entangled, 2 had packing bands (1 plastic, 1 rubber) around their necks, and 5 were entangled in monofilament gill net fragments; 1 yearling sea lion with a gill net fragment tightly constricting its neck was later observed dead. Four sea lions had tangled lengths of monofilament fishing line caught around their necks (Table 4); we did not observe hooks attached to any of the fishing line. Thirteen sea lions had scars encircling their necks; the scar patterns were suggestive of thin monofilament, either fishing line or gill net, rather than of the thicker multifilament materials or more robust packing bands. Therefore, of 24 sea lion "entanglements" observed, 13 (54%) were of animals that had lost the entangling material. In 22 of these 24 "entanglements" it is likely that the sea lions acquired the entangling material or scars during interactions with commercial or sport fisheries. Two of the "entangled" sea lions had apparently been entangled in debris (packing bands).

Table 1.--Incidence of entanglement of California sea lions at San Nicolas Island.

Date	Adult males	Subadult males	Females and juveniles	Yearlings	Pups	Total
Dec. 1983						
Sampled	1	26	721	20	468	1,237
Entangled	0	0	0	0	0	0
Scars	0	0	1	0	0	1
Jan. 1984						
Sampled	0	46	596	83	510	1,235
Entangled	0	0	0	0	0	0
Scars	0	1	0	0	0	1
Feb. 1984						
Sampled	0	115	843	18	518	1,494
Entangled	0	0	0	2	0	2
Scars	0	0	1	0	0	1
Mar. 1984						
Sampled	0	35	389	46	425	895
Entangled	0	0	0	0	1	1
Scars	0	0	0	0	0	0
Apr. 1984						
Sampled	0	0	315	32	218	565
Entangled	0	0	1	0	0	1
Scars	0	0	1	0	0	1
May 1984						
Sampled	16	31	489	62	0	598
Entangled	0	0	0	1	0	1
Scars	0	0	1	0	0	1
June 1984						
Sampled	100	86	626	120	35	967
Entangled	0	1	0	1	0	2
Scars	1	1	0	0	0	2
July 1984						
Sampled	228	355	607	96	340	1,626
Entangled	0	0	0	2	0	2
Scars	1	4	1	0	0	6
Sept. 1984						
Sampled	0	31	1,683	210	501	2,425
Entangled	0	0	1	1	0	2
Scars	0	0	0	0	0	0
Oct. 1984						
Sampled	0	0	234	31	457	722
Entangled	0	0	0	0	0	0
Scars	0	0	0	0	0	0
Nov. 1984						
Sampled	0	78	703	53	577	1,411
Entangled	0	0	0	0	0	0
Scars	0	0	0	0	0	0
Total						
Sampled	345	803	7,206	771	4,049	13,175
Entangled	0(0%)	1(0.012%)	2(0.03%)	7(0.91%)	1(0.02%)	11(0.08%)
Scars	2(0.58%)	6(0.75%)	5(0.07%)	0(0%)	0(0%)	13(0.10%)

Table 2.--Incidence of entanglement of northern elephant seals at San Nicolas and San Miguel Islands.

Date	Adult males	Subadult males	Females	Juveniles	Yearling	Pups	Total
San Nicolas Island							
Dec. 1983							
Sampled	43	51	32	35	115	10	286
Entangled	0	2	0	0	0	0	0
Scars	0	0	1	0	0	0	1
Jan. 1984							
Sampled	111	48	486	0	9	415	1,069
Entangled	0	1	0	0	0	0	1
Scars	0	0	0	0	0	0	0
Feb. 1984							
Sampled	120	56	210	0	4	316	706
Entangled	0	0	0	0	0	0	0
Scars	0	0	0	0	0	0	0
Mar. 1984							
Sampled	18	22	30	0	0	315	385
Entangled	0	0	0	0	0	0	0
Scars	0	0	0	0	0	0	0
Apr. 1984							
Sampled	0	0	310	315	18	65	708
Entangled	0	0	0	1	0	0	1
Scars	0	0	0	0	0	0	0
May 1984							
Sampled	0	0	0	249	75	0	324
Entangled	0	0	0	0	0	0	0
Scars	0	0	0	1	0	0	1
June 1984							
Sampled	0	42	268	26	0	0	336
Entangled	0	0	0	0	0	0	0
Scars	0	0	0	0	0	0	0
July 1984							
Sampled	24	43	15	10	0	0	92
Entangled	0	0	0	0	0	0	0
Scars	0	0	0	0	0	0	0
Sept. 1984							
Sampled	1	0	0	266	67	35	369
Entangled	0	0	0	0	1	0	1
Scars	0	0	0	0	0	0	0
Oct. 1984							
Sampled	0	8	15	80	15	221	339
Entangled	0	0	0	0	0	0	0
Scars	0	1	0	0	0	0	1
Nov. 1984							
Sampled	5	25	45	178	15	181	449
Entangled	0	0	0	1	0	1	2
Scars	0	0	1	0	0	0	1
San Miguel Island							
Jan. 1984							
Sampled	385	315	975	0	128	1,268	3,071
Entangled	0	0	2	0	0	0	2
Scars	0	0	0	0	0	0	0
Feb. 1984							
Sampled	312	265	865	0	65	1,413	2,920
Entangled	0	0	0	0	1	0	1
Scars	0	1	1	0	0	0	2
Total							
Sampled	1,019	875	3,251	1,159	511	4,239	11,054
Entangled	0(0%)	3(0.34%)	2(0.06%)	2(0.17%)	2(0.39%)	1(0.02%)	10(0.09%)
Scars	0(0%)	3(0.34%)	3(0.09%)	1(0.09%)	0(0%)	0(0%)	7(0.06%)

Table 3.--Incidence of entanglement of harbor seals at San Nicolas and San Miguel Islands.

Date	San Nicolas Island			San Miguel Island		
	Adults and juveniles	Pups	Total	Adults and juveniles	Pups	Total
Dec. 1983						
Sampled	72		72			
Entangled	0		0			
Scars	0		0			
Jan. 1984						
Sampled	65		65	165		165
Entangled	0		0	0		0
Scars	0		0	0		0
Feb. 1984						
Sampled	146		146	315		315
Entangled	0		0	1		1
Scars	0		0	0		0
Mar. 1984						
Sampled	168	14	182			
Entangled	0	0	0			
Scars	1	0	1			
Apr. 1984						
Sampled	210	18	228			
Entangled	0	0	0			
Scars	0	0	0			
May 1984						
Sampled	98	4	102			
Entangled	0	0	0			
Scars	0	0	0			
June 1984						
Sampled	235	19	254			
Entangled	0	0	0			
Scars	0	0	0			
July 1984						
Sampled	115	10	125			
Entangled	0	0	0			
Scars	0	0	0			
Sept. 1984						
Sampled	71	3	74			
Entangled	0	0	0			
Scars	0	0	0			
Oct. 1984						
Sampled	86	0	86			
Entangled	0	0	0			
Scars	0	0	0			
Nov. 1984						
Sampled	63	0	63			
Entangled	0	0	0			
Scars	0	0	0			
Total						
Sampled	1,809	68	1,877			
Entangled	1(0.06%)	0	1(0.05%)			
Scars	1(0.06%)	0	1(0.05%)			

Table 4.--Types of synthetic items observed entangling (E) pinnipeds or believed to have caused scars (S) observed on pinnipeds.

	Monofilament				Polypropylene trawl net		Packing bands		Total	
	Line		Gill net							
	E	S	E	S	E	S	E	S	E	S
Sea lions										
Adult males		2								2
Subadult										
Males		6	1						1	6
Females		3								3
Juveniles	2	2							2	2
Yearlings	2		[1]3				2		7	0
Pups		1							1	0
Total	4	13	5				2		11	13
Elephant seals										
Adult males										0
Subadult										
Males	2	3							2	3
Females	1	3					1		2	3
Juveniles	1	1			1				2	1
Yearlings					2				2	0
Pups	1								1	0
Total	5	7			3		1		9	7
Harbor seals										
Adults	1									1
Juveniles							1		1	
Pups										
Total		1					1		1	1

[1]One of these found dead 5 days after first seen entangled.

Of nine elephant seals observed entangled, four had monofilament fishing line encircling their necks (no hooks attached), one had monofilament encircling its torso, three were entangled in "poly" trawl net fragments, and one seal had a plastic packing band around its neck (Table 4). Seven other elephant seals had scars encircling their necks which appeared to have been caused by monofilament line or gill net. Therefore, of 16 elephant seal "entanglements," 7 (44%) were instances where seals had been entangled by materials (probably monofilament line or gill net from active fishing gear) but had lost the material, presumably when it became brittle and broke loose. Four (25%) of the elephant seals showing evidence of entanglement were apparently victims of debris (three entangled by trawl net fragments, one entangled by a packing band).

One harbor seal (adult) was observed with a thin scar around its neck (apparently from previous entanglement with monofilament) and one juvenile was observed with a plastic packing band encircling its neck.

Our observations suggest that many pinnipeds may be freed from materials entangling them, primarily monofilament fragments (gill net or longline). Trawl net fragments and packing bands may be lost less easily since we have seen no animals with scars suggesting that they had been previously entangled with these kinds of debris. This may suggest that animals that become entangled in trawl net fragments or packing bands have greater mortality rates than those entangled by monofilament fragments or that entanglement rates of seals and sea lions in monofilament (operational and debris) are higher than those for other debris. However, the data are not adequate to test either of these hypotheses. The only entangled animal that we observed dead (a sea lion yearling) was entangled in a monofilament gill net fragment.

We observed and collected samples of debris, representative of each type observed entangling animals, on beaches at San Nicolas and San Miguel Islands (Table 5). In addition, we found other types of debris in small amounts. The most common type of debris found was "poly" line fragments of various lengths (Table 5). Although these fragments, when tangled, are capable of entangling pinnipeds, we did not observe any animals entangled in "poly" line.

Because systematic surveys of pinniped entanglement with marine debris in the Southern California Bight have not previously been reported, our data can serve only as a baseline for comparison with data collected with similar methods in the future. However, when considering the impact of "marine debris" on pinniped populations, care should be taken when considering whether all cases of "entanglement" are debris-related. Packing bands, other nonfishing gear items, and trawl net fragments encircling the bodies of pinnipeds are most likely encountered as debris. Entanglement in monofilament line and small gill net fragments probably occurs most often when animals are caught in actively fished gill net or become tangled in actively fished longline gear. If this is true, then most (86%) of the pinnipeds observed (in the Southern California Bight) that showed evidence of entanglement probably encountered the entangling material while interacting with actively fished commercial fishing gear (apparently monofilament gill nets) rather than as debris. The marine debris that appear to be entangling small numbers of pinnipeds in the Southern California Bight are trawl net fragments (with holes in the mesh) and plastic packing bands. Juveniles appear to be the most likely to become entangled in debris and this may be related to their greater degree of curiosity or playfulness or perhaps to their higher rate of encounter with debris sources. California sea lions and northern elephant seals are migratory and (especially young animals) disperse over long distances (primarily northward from rookeries) during the first several years of life.

Assessment and interpretation of the population effects (in the Southern California Bight) of mortality due to entanglement with marine debris require data on 1) the origin, movement, and fate of various kinds of debris with respect to the dynamics of seasonal sex and age class distributions of pinnipeds in eastern North Pacific waters (i.e., rate of

Table 5.--Weights and dimensions of debris found on beaches (B) or removed (E) from entangled dead or live pinnipeds at San Nicolas and San Miguel Islands.

	Sample							
Types of debris	1	2	3	4	5	6	7	8
Monofilament lines								
Weight (g)	227/E	20/E	12/E					
Diameter (cm)	0.15	0.12	0.05					
Monofilament gill net								
Weight (g)	70/E							
Diameter (cm)	0.10							
Mesh size (cm)	20.3							
Dimensions (cm)	61x55							
"Poly" net								
Weight (g)	100/B	500/E	100/B	100/B				
Diameter (cm)	0.35	0.35	0.35	0.35				
Mesh size (cm)	10.2	26.7	26.7	13.1				
Dimensions (cm)	30x15	91x92	46x58	63x39				
"Poly" line[1]								
Weight (g)	43.5/B	1,174/B	78.4B	883/B	639/B	340/B	144/B	48/B
Diameter (cm)	0.8	0.7	0.5	0.9	0.33	0.12	0.8	1.1
"Poly" gill or trammel net								
Weight (g)	86/B	93/B						
Diameter (cm)	0.2	0.2						
Mesh size (cm)	25.4	25.4						
Dimensions (cm)	91x107	111x106						
Lobster pot floats with line								
Weights (g)	676.4/B	812/B	642/B	1,026/B	467/B	1,121/B	787/B	
Buoys with line								
Weights (g)	2,300/B	1,436/B	3,000/B	3,100/B	1,011/B	1,232/B		
Buoys without line								
Weights (g)	1,856/B	1,204/B	665/B	531/B	564/B			
Other								
Weight (g)	227/E	(SKYRO/Fig. 3)						
Dimensions (cm)								

[1]Representative sample selected from a total of 28 samples collected from beaches.

encounter with debris capable of entanglement) and 2) on the probability of mortality of pinnipeds once they become entangled. Proper interpretation of entanglement and the role of debris in entanglement also require that entanglement resulting from encounters with active fishing gear be distinguished from that resulting from encounters with debris.

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A REVIEW OF HAWAIIAN MONK SEAL ENTANGLEMENTS IN MARINE DEBRIS

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ABSTRACT

Hawaiian monk seals may become entangled in net fragments and other flotsam carried by currents from the North Pacific to the Hawaiian Islands. Through 1984, 27 entanglements have been observed, and at least 8 additional seals are scarred from entanglements. One of these entanglements was probably fatal, and six would likely have resulted in the death of the seals had biologists not intervened. Although weaned pups comprise only about 11% of the total population, pups were involved in 41% of the observed incidents. Mechanisms to account for this disparity are proposed. Observed entanglements have declined since initiation of a regular program to gather and burn potentially hazardous debris.

INTRODUCTION

The Hawaiian monk seal, Monachus schauinslandi, inhabits the rocky islands and low, coral atolls which extend 1,850 km from Nihoa Island to Kure Atoll in the Hawaiian Archipelago, a region known as the Northwestern Hawaiian Islands. Within this range, land area on which the seals haul out comprises approximately 17.7 km^2, but the offshore reefs surrounding these islands, which the seals frequent to forage, mate, or raise their pups, comprise considerable additional area. The 18.3-m (10-fathom) contour surrounding emergent land in the Northwestern Hawaiian Islands encloses approximately 1,257 km^2 (U.S. Department of Commerce[1]). The Hawaiian Archipelago is situated in the subtropical gyre, and flotsam from the North Pacific could be carried towards the islands by southern movement of water from the eastward flowing North Pacific Current to the westward flowing North Equatorial Current. Fisheries which might serve to generate debris are the high seas squid gill net fishery and the groundfish trawl fishery in the North Pacific and Gulf of Alaska. Trawl fisheries, particularly joint venture operations, may be susceptible to loss of nets and other gear

[1]U.S. Department of Commerce. 1980. Proposed designation of critical habitat for the Hawaiian monk seal in the Northwestern Hawaiian Islands. Draft Environmental Impact Statement, 77 p. + appendices.

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(Low et al. 1985). No Hawaii-based net fisheries exist in the vicinity of the Northwestern Hawaiian Islands.

Except for protracted periods ashore during pupping (approximately 5 weeks) or molting (approximately 2 weeks), an individual seal will generally remain at sea for up to 2 weeks before returning for several days' rest on land (Stone 1984). It is not known how far individuals range from land, but it is during these forays at sea that seals may encounter debris which is either drifting or has become fouled on offshore reefs. Seals, such as recently weaned pups, which remain near emergent land, may also encounter flotsam which has become fouled close to shore. This report will summarize all observed occurrences of monk seal entanglement in fishing debris or other flotsam through 1984, as well as observations of seals scarred in a manner suggestive of previous entanglement.

Observations of entangled seals are dependent on the amount of sighting effort, which is not constant, since the number and duration of visits to the different Northwestern Hawaiian Islands by biologists have varied. No systematic surveys of Hawaiian monk seals were undertaken before 1957. Between 1957 and 1974, biologists visited the islands for only a limited time (several days) to census seals and other biota. Not until 1974, when annual field camps (of approximately 1 month) commenced at French Frigate Shoals, were biologists present at any particular location in the Northwestern Hawaiian Islands for any extended time. Post-1974 sighting effort on each island will be summarized under "entangled seals."

SCARRED SEALS

Seals which become entangled in small pieces of debris may bear scars from injuries inflicted by the constricting item. Such scars generally girdle all or part of the animal's body, around the neck, shoulders, or abdomen, and are easily distinguishable from scars resulting from shark bites. The latter, though sometimes forming long clefts, are more irregular in shape than scars resulting from entanglement. Hereafter "scarred seal" will refer to seals bearing scars resulting from entanglement.

Scarring by debris requires that the entanglement be sufficiently prolonged to cause injury without causing the eventual death of the victim. Because of these conditions, scarred seals represent only one component of the minimum number of seals known to have become entangled, and cannot be used to estimate total incidence. Moreover, given the limited number of haul-out locations and the small population of Hawaiian monk seals, multiple sightings of any individual scarred seal are likely, necessitating added care to identify individual animals.

Scarred seals have been observed primarily at French Frigate Shoals. Kenyon and Rauzon[2] presented photos of two scarred adult seals they saw in 1977. Balazs (1979) also reported seeing two scarred adults during his studies at French Frigate Shoals from 1973 to 1978, one of which was an

[2]Kenyon, K. W., and M. J. Rauzon. 1977. Hawaiian monk seal studies, French Frigate Shoals, Leeward Hawaiian Islands, National Wildlife Refuge, 15 February to 5 April 1977. Unpubl. rep.

animal previously reported by Kenyon and Rauzon. Schulmeister[3] reported two scarred seals (one male adult, one female adult) present at French Frigate Shoals in 1981, one of which was a seal reported previously. Schulmeister also noted a fresh, rope-inflicted neck wound on a female juvenile. Biologists at French Frigate Shoals in 1984 saw at least four scarred seals: a previously reported male adult, two female subadults, and one juvenile of unknown sex (J. Eliason pers. commun. 1984). Assuming one of the subadults was the same animal as the female juvenile reported by Schulmeister, two additional scarred seals were present at French Frigate Shoals in 1984. Thus, a minimum of seven scarred or wounded seals have been sighted at French Frigate Shoals since 1973.

At Sand Island, Midway, in 1983 the author saw a male subadult bearing a fully healed neck scar resulting from a constricting line or band. This seal had been seen previously at Midway on several occasions in 1983 (C. E. Bowlby pers. commun. 1983). The animal appeared to be in good health.

ENTANGLED SEALS

Although Kenyon (1980) mentioned that he and his co-workers had seen "several" entangled monk seals during their visits to the Northwestern Hawaiian Islands (in the late 1960's and 1970's), the record is not clear whether some or all of these "several" are included in other reports described below. Nonetheless, it is likely that entangled seals were present and observed in the Northwestern Hawaiian Islands before 1974.

French Frigate Shoals

As mentioned above, prolonged presence of biologists at French Frigate Shoals commenced in 1974 with the initiation of annual, 1-month field camps to study green sea turtle nesting activity. These camps represented the only routine observation by biologists until mid-1979 when the U.S. Fish and Wildlife Service established an all-year field station on Tern Island, with a complement of two to four personnel. In 1982 the National Marine Fisheries Service initiated an expanded field program at French Frigate Shoals, entailing camps on islets other than Tern Island, which resulted in an increased presence of observers throughout the shoals.

Balazs (1979) saw one entangled seal, a male subadult, during annual trips to French Frigate Shoals from 1973 to 1978. The seal, seen in 1974, was encircled by a piece of plastic strapping, which appeared to be cracking, fraying, and likely to eventually break. Since the strap had not inflicted a wound, the individual seal was not recognizable by means other than its "collar." Thus the animal's fate is unknown.

In 1977 Kenyon and Rauzon (footnote 2) witnessed an adult seal of unknown sex investigating a polypropylene line being used to mark a shark fishing station. The seal repeatedly swam through a loop which was of sufficient circumference to allow passage of the seal without entanglement.

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[3]Schulmeister, S. D. 1982. Summary of Hawaiian monk seal, *Monachus schauinslandi*, data collected at French Frigate Shoals from July 1971 through December 1981. Unpubl. rep.

This is the first, and perhaps most definitive, documentation of an investigatory behavior of monk seals which can result in entanglement. In 1979 Balazs (pers. commun. 1985) observed an adult seal on Whale-Skate Island encircled by one loop of a tangle of line. The seal was not injured, indicating recent entanglement in the debris. The loop was posterior to the foreflippers and was too small to pass over the back and rump. The line was removed over the seal's head. The tangle of line did not completely immobilize the seal, but certainly would have impeded the animal's swimming.

In 1980 the first entanglement of a weaned monk seal pup was documented (Andre and Ittner 1980). The pup, of unknown sex, was entangled in a piece of polypropylene net which was itself fouled in water approximately 0.5 m deep. Although the seal could swim sufficiently to remain afloat, its eventual death due to exhaustion or starvation was likely, and biologists released it. The net fragment measured 9 by 2 m with a 15 cm stretched mesh and 2.3 mm twine diameter.

Schulmeister (footnote 3) in summarizing monk seal research at French Frigate Shoals from mid-1979 through 1981, reported two entangled seals. In 1981 a female adult was observed with a piece of "nylon strapping" around her neck. The individual was identifiable on the basis of old scars, and was subsequently sighted free of the strap and suffering no apparent effects. The second entangled seal observed was an adult of unknown sex which was encircled about the abdomen by a single piece of rope. Biologists removed the rope using a boat hook. The rope was pulled off easily and the report makes no mention of a wound, suggesting that the seal was uninjured.

In 1982, Ittner[4] observed a female subadult bearing a fishhook in the lower lip. The hook was of the round type used in the Hawaii-based fishery for snappers and groupers (Ralston 1982) and may have resulted from the seal's encountering gear which was actively fishing. The seal was an identified individual and was subsequently observed to have lost the hook.

The author observed two entangled seals in 1983. On Tern Island a pregnant female seal was seen encircled about the abdomen by a loop of knotted line. The following day, the line was found on the beach where the seal had hauled out. The seal showed no effects of the temporary entanglement and gave birth later in the year. A male pup was observed on Whale-Skate Island entangled about the neck and shoulders by a piece of gray polypropylene net. The pup was 6-7 weeks postweaning and might have eventually lost the fragment during its postweaning weight loss. Nevertheless, the net was likely to inflict a wound in the interim and was removed.

In 1984 two entangled seals were seen. The first, a subadult of unknown sex, was observed with a plastic band tightly encircling the neck (S. Lautenslager pers. commun. 1984). The band was a white, rigid ring, possibly a shard of a plastic bucket, and had abraded a wound through the

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[4]Ittner, R. 1983. The Hawaiian monk seal, *Monachus schauinslandi*, at French Frigate Shoals, 1982. Unpubl. rep.

skin of the seal. An attempt to restrain the animal and remove the band was unsuccessful (G. Fairaizl pers. commun. 1984). The individual was recognizable by the wound, was never again seen, and, therefore, probably died. The second entangled seal was a male and known to be a yearling from a bleach mark ("GA") which had been applied in 1983 when the seal weaned. The individual was tightly encircled about the neck and shoulders by a fragment of net. The seal would likely have been seriously injured or ultimately killed by the fragment, which was removed.

Laysan Island

Long-term field camps (up to 6 months long) were established annually at Laysan from 1977 to 1980 and from 1982 to 1984. No entangled or scarred seals were reported by field personnel present at the 1977-80 field camps. In 1982 however, Alcorn (1984) observed three entangled seals. Two female weaned pups became entangled in pieces of flotsam. One individual caught its muzzle in a 115-mm diameter plastic ring; the second became entangled about the neck by a life preserver. The third seal, a female subadult, was entangled about the neck by a piece of line and net. All three pieces of debris were removed by field personnel.

No entangled or scarred seals have been observed on Laysan since 1982.

Lisianski Island

Field personnel were on Lisianski for 5 weeks in 1980, for 6 months in 1982, and for 4-5 weeks in 1983 and 1984. The first entanglement observed was in 1980 when a fragment of net was removed from a male subadult (W. G. Gilmartin pers. commun. 1982). The net was tightly constricted and had cut through the dermal tissue, causing a deep wound and surrounding necrosis. The seal had apparently picked up the fragment at a younger age and had "grown into" it. The animal would likely have died as it continued to grow. The individual seal, albeit scarred, was still present at Lisianski as of July 1984.

During the 6-month field camp in 1982, 10 seals became entangled in debris, although 3 of these were encircled only temporarily. Five of the incidents have been reported by Henderson (1984) and involved four weaned pups and one female adult. Three of these pups were entangled in nets and line which were fouled on offshore reefs, effectively immobilizing the victims. The remaining pup and the adult were seen "wearing" net fragments and a tangle of net and line. The adult female escaped after approximately 1 h without assistance; the pups were all freed.

Three other pups became entangled in flotsam in 1982. Stone (1984) reported a pup with a 90-mm diameter plastic ring around its muzzle. T. Johanos (pers. commun. 1983) observed two entangled pups, one of which had a plastic mesh bag (later removed) about its neck and shoulders, while the other was temporarily caught about the neck by a plastic band. A fourth seal, a juvenile, had been caught by this same band earlier on the same day that the pup was encircled. The pup evidently acquired the band shortly after the juvenile lost it.

A male adult was observed with a line encircling its abdomen, but the seal apparently escaped, since the line was subsequently found (D. Alcorn pers. commun. 1984).

In 1983 only one entangled seal was observed. A female pup was encircled about its neck by a blue rubber ring. The ring was removed, and the seal was not injured.

Kure Atoll

Biologists have maintained 6-month camps at Kure Atoll from 1981 to 1984. During this period only one incident of entanglement has been observed. In 1981 Ittner observed an adult of unknown sex apparently entangled in a large piece of net (W. G. Gilmartin pers. commun. 1984). The seal was ashore on "West Point" and may have hauled out atop the mass of net with its neck only recently (and temporarily?) inserted through a hole in the webbing. The animal was released, but the report is not clear if the animal was actually "trapped."

Other Northwestern Hawaiian Islands

Although long-term field camps have been established at other locations in recent years (Pearl and Hermes Reef 1983-84; Necker Island 1983), no net-scarred or entangled seals have been observed at any of these sites.

SUMMARY AND CONCLUSIONS

The number of incidents of seal entanglements observed since 1974 are summarized in Table 1. A total of 27 incidents were observed, and an additional 8 seals bear scars resulting from entanglement. It is not known whether any of the entanglements observed were repeat occurrences involving the same seal. Nonetheless, considering the years, the locations of occurrences, and the approximate ages of the seals affected, the 27 events certainly involve at least 19 individuals. The current population likely numbers between 1,000 and 1,500 in any one year, and there are no data to indicate that certain seals have more propensity to investigate debris than do others. It is therefore probable that the 27 incidents, in fact, represent entanglements of 27 different seals. The eight scarred seals are certainly eight different individuals. (The seal scarred as a result of its 1980 entanglement on Lisianski is included as "entangled.") Thus the total number of observed entanglements and seals scarred as a result of entanglement is 35.

No Hawaiian monk seal has ever been observed to die as a result of debris entanglement, nor has an entangled carcass ever been found. Of the 35 entanglement and scarring incidents reported here, only 1 (3%) probably resulted in death of the seal, 6 (17%) were judged to have been potentially lethal without intervention, 17 (49%) resulted in unassisted escape by the seal (including the 8 scarred individuals), and 11 (31%) resulted in rescues of seals which may have been able to ultimately free themselves.

The rate of entanglement throughout the Hawaiian monk seal population cannot be determined at this time. The absolute population size is not known, and data are insufficient to estimate annual reproductive or mor-

Pre-1974	Unknown	"Several"	E	Net	M (?)	Escaped	Kenyon 1980	
1974	FFS	1 male subadult	E, shoulders	Plastic strapping	M	Probably escaped	Balazs 1979	
1975-76	FFS	3 adults[3]	S	N/A	N/A	N/A	Kenyon and Rauzon 1977; Balazs 1979	
1977	FFS	1 adult	E, body	Shark fishing line	M	Escaped	Kenyon and Rauzon 1977	
1979	FFS	1 adult	E, body	Line	M	Rescued	Balazs[4]	
1980	FFS	1 pup[5]	E, neck	Net	I	Rescued	Andre and Ittner 1980	Probably would have died.
	LI	1 male subadult	E, neck	Net	M	Rescued	Gilmartin[6]	Seal scarred, alive in 1984; would have died.
1981	Kure Atoll	1 adult	E, neck, body	Net	I (?)	Rescued	Gilmartin[6]	
1979-81	FFS	1 adult	E, body	"Rope"	M	Rescued	Schulmeister 1982	
		1 female adult	E, neck	"Nylon strapping"	M	Escaped	Schulmeister 1982	
		1 female juvenile	S, neck	N/A	N/A	N/A	Schulmeister 1982	
		1 female adult	S, neck	N/A	N/A	N/A	Schulmeister 1982	
1982	LI	4 male pups	E, neck (2), body (1), shoulders (1)	Net and line	I (3); M (1)	Rescued	Henderson 1984	3 probably would have died.
		1 female pup	E, muzzle	Plastic ring	M	Rescued	Stone 1984	
		1 female adult	S, neck	Net and line	I (?)	Escaped	Henderson 1984	Female with pup.
		1 pup and 1 juvenile	E, neck	Plastic band	M	Escaped	T. Johanos[7]	Both seals same band, same day.

Table 1.--Continued.

Year	Location	No. and kind of animal	Incident[1]	Type of material	Mobile(M) or immobile(I)[2]	Fate of seal	Reference	Comments
1982	LI	1 pup	E, neck, shoulders	Plastic mesh bag	M	Rescued	T. Johanos[4]	Probably would have survived.
	LI	1 male adult	E, body	Line	M	Escaped	Alcorn[4]	
	Laysan	1 female pup	E, muzzle	Plastic ring	M	Rescued	Alcorn 1984	
		1 female pup	E, neck	Life preserver	M	Rescued	Alcorn 1984	Probably would have survived.
		1 female subadult	E, neck	Net and line	M	Rescued	Alcorn 1984	Probably would have survived.
	FFS	1 female subadult	E, lip	Fish hook	M	Hook came out	Ittner 1982	Possibly interaction with actively fishing gear.
1983	LI	1 female pup	E, neck	Rubber ring	M	Rescued	Johanos[4]	
	Midway	1 male subadult	S	N/A	N/A	N/A	Henderson observation	
	FFS	1 female adult	E, body	Line	M	Escape	Henderson observation	Pregnant female.
		1 male pup	E, body	Net	M	Rescued	Henderson observation	Probably would have survived.
1984	FFS	1 subadult	E, neck	Plastic ring	M	No rescue	Lautenslager[4]	Probably died.
		1 male juvenile	E, neck, shoulders	Net	M	Rescued	Henderson observation	Probably would have died.
		1 female subadult	S	N/A	N/A	N/A	Eliason[4]	
		1 juvenile	S	N/A	N/A	N/A	Eliason[4]	

[1]E = entanglement, S = scarred seals.
[2]Mobile = seal bearing piece of debris; immobile = seal trapped in pile of debris.
[3]If sex unspecified, sex not known.
[4]Personal communication.
[5]All pups are weaned pups.

tality rates, parameters which must be determined to estimate the total number of seals which could potentially have been entangled from 1974 to 1984. Nevertheless, because each haul-out location supports a relatively discrete population (Johnson and Kridler 1983), minimum entanglement rates at certain islands can be approximated. Furthermore, because interisland movement is not common, island-specific entanglement rates are more important in assessing impact of entanglement on the Hawaiian monk seal.

The seal population at Lisianski Island in 1982 was 215 animals other than pups (Stone 1984). Of this total, three (1%) were entangled in 1982. The number of pups surviving to weaning at Lisianski in 1982 was 26 (Henderson 1984). Of this total, seven (27%) were entangled, four entangled in fishing debris (Henderson 1984), and three caught by plastic and other flotsam.

On Laysan Island, 28 pups survived to weaning in 1982 (Alcorn 1984), of which 2 (7%) became entangled in flotsam the same year. The subadult entangled on Laysan in 1982 represents <1% of the nonpup population there.

The observed incidents suggest that weaned monk seal pups are more likely to become entangled than are other age classes. Of the 27 entanglements observed, 11 (41%) involved weaned pups of the year, whereas pups comprise approximately 11% of the population (Gerrodette[5]). Several possible mechanisms may contribute to this disparity: (1) since pups remain near shore for 1-2 months after weaning, their entanglements, even temporary ones, are more likely to be observed; (2) the nearshore reefs serve to catch and "concentrate" floating debris, and because pups spend proportionately more time in this area, entanglements are more probable; (3) recently weaned pups are learning to feed, hence are more likely to explore all objects in their novel environment; and (4) pups are smaller and weaker than older seals and are therefore less able to escape from debris.

The large number of observed incidents in 1982 prompted the National Marine Fisheries Service and the U.S. Fish and Wildlife Service to begin gathering and burning potentially hazardous debris, and since that time the number of observed incidents has declined despite the continued presence of observers in the Northwestern Hawaiian Islands. At Lisianski Island in particular, the 10 incidents observed in 1982 have dropped to 1 in 1983 and 0 in 1984, and incidents have also diminished at Laysan Island. Removing debris from the beaches and nearshore reefs in the Northwestern Hawaiian Islands can reduce the amount of Hawaiian monk seal entanglement and remove a hazard to which weaned seal pups seem particularly susceptible.

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ENTANGLEMENT IN, AND INGESTION OF, PLASTIC LITTER BY MARINE MAMMALS, SHARKS, AND TURTLES IN NEW ZEALAND WATERS

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ABSTRACT

Since 1975 a marked increase in entanglement in, and ingestion of, plastics by marine mammals, fishes, and turtles has been observed in New Zealand. Plastic litter has increased with the development of nearshore fisheries, especially in the subantarctic, and polypropylene strapping can now be found on beaches the length of the country. New Zealand fur seal, _Arctocephalus forsteri_, is now frequently reported with bands about its neck. Whales and seals have been observed entangled in discarded fishing gear. Leatherback turtles and a juvenile minke whale have been observed to have ingested polythene bags at sea before becoming stranded.

The increasing use of polypropylene strapping suggests that fur seals will continue to be regularly entangled in this nondegrading litter.

INTRODUCTION

The presence of plastic and synthetic debris in the oceans of the world has become of increasing concern to marine scientists and ecologists. Plastics of many kinds are now acknowledged to be marine contaminants of global significance (Gregory et al. 1983), and, while they are especially common in the vicinity of highly populated, industrialized coastal areas (Morris 1980; Gregory et al. 1983), plastics pollution is also a feature of remote areas. Attention has been drawn to the widespread distribution of virgin plastic granules in surface waters of the major oceans of the world. A number of studies of the feeding habits of oceanic seabirds such as prions, petrels, and shearwaters has revealed that these birds, which feed on small buoyant organisms taken at the sea surface, ingest floating plastic pellets and expanded polystyrene granules along with normal prey items (Bourne and Imber 1982; Furness 1983).

The other more visible synthetic pollutants found along shores and adrift are normally the result of garbage disposal from ships at sea. Wehle and Coleman (1983) state "...that commercial fishing fleets alone dumped more that 52 million pounds of plastic packaging material into the

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In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

sea and lost approximately 298 million pounds of plastic fishing gear including nets, lines, and buoys."

In the New Zealand region the expansion of commercial fishing over the last decade in coastal and distant waters within the 200-mile exclusive economic zone (EEZ) has resulted in a noticeable increase in plastic and other synthetic litter such as buoys, cordage, sheet plastic, fishing net, plastic strapping, and domestic rubbish along the shores of mainland New Zealand (Ridgway and Glasby 1984) and particularly the subantarctic islands. Of all this litter one item stands out: polypropylene strapping of the sort used to secure crates, bales of netting, frozen bait, and other items is now ubiquitous on shores the length of New Zealand and throughout the subantarctic islands. In this report data are presented on the entanglement in, and ingestion of, plastic debris by marine mammals, reptiles, and fishes within the New Zealand region and the materials involved.

METHODS

Incidental observations of marine mammals and other animals involved with synthetic debris have been gathered during the course of routine data collection at marine mammal strandings, fur seal haul-out sites, and coastal fishing ports (Table 1, Fig. 1). Where possible live animals with collars or ligatures around their necks and bodies are captured, the offending material removed, and the animal released.

PINNIPEDS

Plastic Strapping

Reports of otariid seals being found in the wild with collars around their necks have been increasing in recent years. Mostly these have referred to northern fur seals and Steller sea lions in the Bering Sea and on the adjacent coasts, but examples have been reported of collars on Cape fur seals from southern Africa and Antarctic fur seals from South Georgia (Bonner and McCann 1982). The first record of an entangled New Zealand fur seal, _Arctocephalus forsteri_, was made in 1975 (R. Mattlin pers. commun.), and collared animals have been sighted regularly since then.

The materials involved are primarily polypropylene strapping (46%) followed by netting and rope. Polypropylene strapping systems were first introduced in New Zealand about 1969, and this tough, buoyant material is preferred by producers of bait and ship's chandlery. The strapping is hard with an embossed surface, about 16 mm wide, 1.5 mm thick, and sharp edged. It is generally light blue and is fastened around a package either by heat sealing or with a mechanical metal crimp. It appears to be common practice at sea to slip the loop of strapping off the end of a package rather than cutting it free, and the loop is then cast overboard along with other ship's garbage.

Most of the animals found with collars around their necks are near populous haul-out sites or rookeries and can be recognized by either the vivid blue collar or their impeded movement and swollen, injured, neck tissues. Apparently juvenile fur seals play with the bands which slip over their heads, and push down as far as the shoulders, and stick against the lie of the fur.

Table 1.--Record of incidental observations on encounters of marine mammals and other animals with synthetic debris in New Zealand waters.

Incident	Species	Location	Year	Material	Entangled	Ingested
1	New Zealand fur sea	Open Bay Island	1975	Polypropylene strapping	X	
2	Southern minke whale	Palliser Bay	1976	Polythene bag		X
3	New Zealand fur seal	Cape Palliser	1978	Polypropylene strapping	X	
4	New Zealand fur seal	Campbell Island	1979	Netting	X	
5	Killer whale	Bay of Plenty	1979	Rope and floats	X	
6	Rig	Porirua Harbor	1979	Plastic tag	X	
7	Leatherback turtle	Whakatane	1980	Polythene bag		X
8	New Zealand fur seal	Wanganui	1980	Polypropylene strapping	X	
9	New Zealand fur seal	Cape Palliser	1980	Polypropylene strapping	X	
10	Hooker's sea lion	Auckland Island	1981	Net	X	
11	New Zealand fur seal	At sea lat. 42°30'S long. 178°08'E	1982	Net	X	
12	New Zealand fur seal	Wellington	1982	Rope	X	
13	New Zealand fur seal	Stewart Island	1983	Polypropylene strapping	X	
14	New Zealand fur seal	Palliser Bay	1984	Polypropylene strapping	X	
15	Southern right whale	Christchurch	1984	Rope and floats	X	

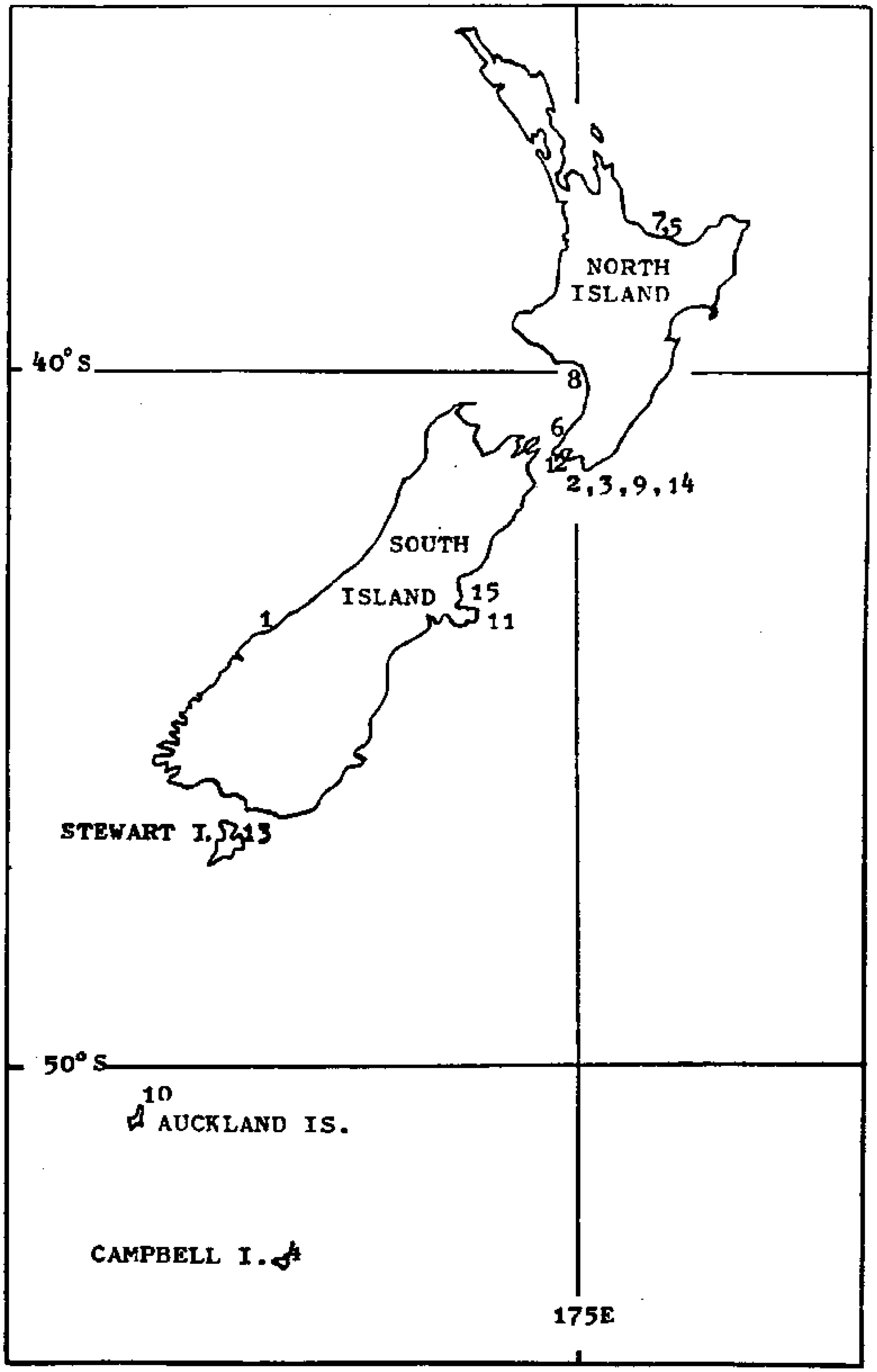

Figure 1.--Locations of incidental observations on encounters of marine mammals and other animals with synthetic debris in New Zealand waters.

As the juvenile grows the neck swells within the ligature, and the sharp-edged plastic cuts through the epidermis into the neck musculature. In four of the six observed cases of plastic collars on fur seals, wounds were raw, suppurating and swollen, and the animals lean or emaciated. One fur seal only was observed with a rope collar. The animal was a juvenile and although the collar was firmly fixed just forward of the shoulders the seal appeared in good condition. In the austral summer of 1974-75, a female fur seal was observed at Open Bay Island, South Westland, collared with blue plastic strapping and trailing a free end of the material about 3 m behind.

There have been isolated unverified reports to fishery officers of fur seals off the west coast of the South Island being sighted wearing carefully constructed rope or strapping harnesses. Locally important trawl fisheries exist in the area, and fur seals have apparently become acclimated to vessels. In 1981, a subadult male fur seal boarded the government RV James Cook at sea by climbing up the stern ramp while the vessel was trawling. The fur seal spent about 1 h aboard before leaving the ship down the stern ramp--the way it had come aboard. It has been suggested that animals such as this could have been captured, harnessed, and kept aboard vessels before they escaped back to sea.

Netting

There have been three observations of otariid seals entangled in discarded fishing net. All of these were sighted in areas where important trawl fisheries exist. In 1979 a large male fur seal was observed at sea off Campbell Island (lat. 52°33'S, long. 169°13'E) with about 1.5 m of net entangled around it neck and the upper right foreflipper. The animal appeared to be in good condition with no visible wounds, and its movements did not appear to be impeded.

Since 1978 a trawl squid fishery has developed near the Auckland Islands (lat. 50°52'S, long. 166°05'E). The Auckland Islands are the center of distribution of New Zealand's indigenous sea lion, Hooker's sea lion, *Phocarctos hookeri*. In 1981 a juvenile male Hooker's sea lion was observed onshore with a piece of discarded netting about 1 m long about its neck. The net collar was not tight, and it appeared the animal would have little difficulty shaking it off. Pups at the sea lion rookeries in the Auckland Islands are often observed playing with fragments of rope and other man-made materials.

During a voyage from Bluff to Wellington the MS Union Lyttelton reported a fur seal about 50 nmi east of Banks Peninsula, "caught in a fragment of fishing net. The seal dived as the vessel approached."

The entanglement of pinnipeds in netting in areas of intensive fishing is a widespread problem and has been reported by Waldichuck (1978) Shaughnessy (1980), Fowler (1982), and Wehle and Coleman (1983). Fisheries in New Zealand waters are expanding rapidly, and it is unlikely that the problem of entanglements in discarded fishing gear will be reduced in the near future.

CETACEANS

Although cetaceans have frequently become entangled in fishing gear, especially in large set trap fisheries around Newfoundland (Perkins and Beamish 1979) the absence of this type of fishery in New Zealand waters would preclude this type of entanglement. However, the extensive use of floating synthetic buoylines on rock lobster pots and deep-set nets has resulted in fouling of at least two whales in recent times (Table 1). In 1979 a killer whale, Orcinus orca, was discovered by fishermen in a distressed state entangled in ropes and floats in the eastern Bay of Plenty. How it became entangled is unknown, but fishermen believed the whale was fouled while investigating either set fishing gear, or floating debris at the surface which is frequently encountered in this area of intensive nearshore fishing.

In February 1984 a 10.45-m juvenile male southern right whale, Eubalaena australis, became stranded just north of Banks Peninsula. The whale had been reported moving slowly, north of the stranding point the day before it came ashore and was obviously in distress. It died soon after stranding and was found to have a long length of polypropylene rope, with a small polystyrene buoy attached, wrapped around its tail stock. The rope had cut 20 cm into the leading edges of both flukes. How the whale came to be entangled is unknown since no reports of damaged or lost gear were received, but the wounds were sufficiently severe to have caused the young animal considerable distress.

The only other cetacean to have died--probably as a result of plastic litter ingestion--was a juvenile minke whale, Balaenoptera acutorostrata, which became stranded in Palliser Bay, east of Wellington in 1976. The distressed juvenile had been in the area for 2 days before stranding and after repeated efforts by locals to return it to deep water it died. Necropsy revealed a compacted polythene bag stuck deep in the esophagus. Assuming the bag had been in place for some time this would account for the whale's lack of condition and thin blubber. Minke whales are known to be attracted to ships at sea and this curiosity may, in part, be responsible for their being reported eating plastic debris thrown from fishing vessels (Wehle and Coleman 1983).

Ingestion of plastic bags has been reported in other cetacean species including pigmy sperm whales, rough toothed dolphins, and Cuvier's beaked whales (Wehle 1983).

REPTILES

Marine turtles are also noted for consuming plastic bags at sea (Anonymous 1983). It is most probable that these neutrally buoyant bags are mistaken by the turtles for food items such as salps and medusae, the major food items of leatherback turtles (Wehle and Coleman 1983). Although turtles are uncommon visitors to New Zealand they are not rare. In the austral summer of 1979-80 six leatherback turtles were reported from New Zealand coastal waters. One of these became moribund and beached itself near Whakatane in the Bay of Plenty. Soon after coming ashore the turtle died and necropsy revealed the esophagus packed with polythene bread bags. Presumably the shape and color of these bags in the water are similar to those of natural prey.

FISH

Only one fish species has been reported entangled in plastic debris (Table 1). In 1979 a rig, Mustelus lenticulatus, was recovered encircled by a plastic tag of the sort used to suspend salamis and similar large sausages. The tag completely encircled the body posterior to the pectoral fins and had cut 50 mm into the dorsal fin yet the fish was not unduly disadvantaged. Sharks have been reported fouled in plastic bands and strapping (Noonan 1977; Bird 1978), but this is the first reported incidence in New Zealand of the sublethal effect of sausage tags on elasmobranchs.

CONCLUSIONS

The longevity of plastics in the marine environment is not known. The general characteristics which make synthetics so useful, namely light weight, strength, durability, flexibility, and buoyancy, contribute to most of the problems encountered by marine animals. The desirability of polypropylene strapping is likely to increase and with it the potential for continued entanglement of seals. When one animal dies as a result of a synthetic collar, that collar ultimately becomes available to yet another animal to play with and become entangled in.

In New Zealand requests have been made to bait producers and packers to print a notice on the bands that they should be severed rather than slipped off a package. The plastics manufacturers will be urged to incorporate photooxidants into their products to ensure that such materials as plastics and polypropylene strapping do not recycle. Regulations governing litter disposal at sea must be tightened, and the general public must be made aware of the dangers of these near indestructible, yet so useful materials.

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INGESTION OF PLASTIC POLLUTANTS BY MARINE BIRDS

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ABSTRACT

To date, ingestion of plastic pollutants has been recorded in 50 species of marine birds from around the world. Procellariiform birds ingest plastic most frequently, and phalaropes and some alcids also have relatively high rates of ingestion. Penguins, pelecaniform birds, larids, and most alcids ingest little or no plastic. Species feeding primarily by surface-seizing or pursuit-diving have the highest frequencies of plastic ingestion. Species feeding primarily on crustaceans or cephalopods have the highest frequencies of plastic ingestion; secondary ingestion of plastics via fish appears to be unimportant. Although some species ingest plastic randomly, most exhibit selective preferences for certain types of plastic. Monomorphic seabird species show no sexual differences in rates of plastic ingestion. Subadult seabirds ingest more pieces of plastic than do adult seabirds. Geographic and seasonal variations in plastic ingestion have been recorded. Plastic ingestion has increased since it began in the early 1960's. Limited detrimental effects of ingested plastic on the physical condition of seabirds have been documented, although red phalaropes, Laysan albatrosses, and northern fulmars show evidence of some physical impairment and parakeet auklets show evidence of decreased reproductive performance.

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INTRODUCTION

The presence of plastic pollution in marine waters was first recorded from marine birds in the northwestern Atlantic Ocean in 1962 (Rothstein 1973). Since then, a series of papers on plastic pollutants in the ocean has reported on the qualitative and quantitative distributions of floating plastic (Carpenter et al. 1972; Carpenter and Smith 1972; Cundell 1973; Kartar et al. 1973; Venrick et al. 1973; Colton et al. 1974; Hays and Cormons 1974; Morris and Hamilton 1974; Wong et al. 1974; Gregory 1977, 1978, 1983; Shaw 1977; Shaw and Mapes 1979; Shiber 1979, 1982; Merrell 1980; Morris 1980a, 1980b; Van Dolah et al. 1980), the occurrence of plastic in the benthos (Kartar et al. 1973, 1976; Hays and Cormons 1974; Morris and Hamilton 1974; Jewett 1976; Feder et al. 1978), and the mechanisms that disperse or concentrate plastic and other marine pollutants (Colton et al. 1974; Wong et al. 1974, 1976; Shaw and Mapes 1979; Van Dolah et al. 1980).

Although most of the early work documented the distribution and abundance of plastic pollution at sea, it is clear that plastic pollutants were entering food webs quite soon after their appearance in the oceans (Kenyon and Kridler 1969; Rothstein 1973). A survey of work in the last decade, however, shows that the ingestion of plastic pollutants by marine birds is being recorded with greater frequency and that our impression of the problem is changing from one of a series of interesting observations to recognition of a pollution problem facing seabirds worldwide (Coleman and Wehle 1984). Concern over this problem culminated in a recent study by the senior author (Day 1980) of the dynamics of plastic pollution in a suite of 37 species of marine birds in Alaska, a relatively pristine environment remote from source areas of plastic. In that study, plastic was recorded in 15 (40.5%) of the 37 species and 448 (22.8%) of the 1,968 birds examined, illustrating how extensive plastic pollution had become in the 16 years since it was first recognized in seabirds.

In this paper, we attempt to synthesize all information available on global patterns of plastic ingestion in marine birds and we discuss the dynamics and characteristics of plastic pollutants ingested. The emphasis is on the North Pacific, for which the most complete data exist. We do not discuss the interactions of marine birds with gill net fisheries (i.e., Tull et al. 1972; Ainley et al. 1981; Coleman and Wehle 1983; Carter and Sealy 1984; Piatt et al. 1984; Piatt and Reddin 1984), the entanglement of marine birds in other marine debris (e.g., Gochfeld 1973; Bourne 1976; Coleman and Wehle 1984; Conant 1984), or the mortality of marine birds from oil or heavy-metal pollution (e.g., Bourne 1976; Ohlendorf et al. 1978).

RESULTS

General Aspects of Plastic Ingestion in Marine Birds

All ingested plastic found has been in the gizzards and (occasionally) proventriculi of the birds examined. Plastic has not been found in intestinal tracts or feces (Rothstein 1973; Day 1980; Pettit et al. 1981), indicating that passage through the intestines is minimal. This lack of passage is surprising, inasmuch as some particles are too small to handle for measurements (Day 1980).

Raw polyethylene pellets (= "nibs" of Colton et al. 1974) appear to be the major form of plastic ingested (Rothstein 1973; Baltz and Morejohn 1976; Day 1980; Anonymous 1981; Bourne and Imber 1982; Van Franeker 1983; M. J. Imber, Wildlife Service, Wellington, New Zealand pers. commun.). Asymmetrical fragments, generally broken from larger polyethylene pieces, are commonly eaten by marine birds (Rothstein 1973; Day 1980; Furness 1983; Van Franeker 1983), whereas polystyrene spherules and styrofoam (i.e., foamed polystyrene spherules) appear to be much less common (Hays and Cormons 1974; Connors and Smith 1982; Furness 1983; Van Franeker 1983; T. J. Dixon, Nature Conservancy Council, Aberdeen, Scotland pers. commun.) The presence of unfoamed polystyrene in marine birds was unexpected, because this synthetic material is neutrally or negatively buoyant (Hays and Cormons 1974; Morris and Hamilton 1974). Many other types and shapes of plastic have been recorded, including toys, polyethylene bottle caps, clear plastic sheets, and nylon, monofilament, and polypropylene line (Kenyon and Kridler 1969; Baltz and Morejohn 1976; Bourne 1976; Day 1980; Pettit et al. 1981; Harrison et al. 1983; Conant 1984).

Eleven recognized colors of plastic were ingested by seabirds in Alaska (Day 1980). Eighty-five percent of these colors were in the "light brown" color range (white, yellow, tan, and brown). Another 8% were in the other "light" shades (light blue, green, and red-pink), making over 93% of the total 833 particles ingested light in color or shade. The remaining 7% of the particles were dark in color or shade: black-gray and darker shades of blue, green, and red-pink.

The individual weight of 830 particles ingested by seabirds in Alaska averaged about 0.02 g for most species; this figure includes raw polyethylene pellets and variably sized asymmetrical fragments after post-ingestion wear (Day 1980). Mean volumes of individual particles from Alaska averaged 0.03-0.04 ml after post-ingestion wear. The mean dimensions of particles from seabirds in Alaska were 4.2 x 3.5 x 2.0 mm, again including some large plastic fragments. Unworn raw polyethylene pellets range from 3 to 5 mm in diameter (Carpenter and Smith 1972; Colton 1974; Colton et al. 1974; Gregory 1977, 1978, 1983; Shiber 1982) and average 0.014 g each in the Atlantic (Colton et al. 1974) and 0.026 g in New Zealand (Gregory 1978), Nova Scotia, and Bermuda (Gregory 1983).

Nearly all plastic particles ingested by seabirds float at the water's surface (Kenyon and Kridler 1969; Day 1980); the specific gravity of polyethylene, excluding air vacuoles, is about 0.9 (Carpenter 1976). The few negatively buoyant particles recorded are assumed to have been broken from larger floating objects or to contain air vacuoles, thereby decreasing their densities and allowing them to float.

Ingestion of Plastic Pollutants by Marine Birds: A Global Perspective

As of November 1984, ingestion of plastic pollutants had been recorded in 50 species of marine birds from around the world (Table 1). In this total, we do not include three bird species in which plastic has been recorded because they represent instances of secondary ingestion via predation of plastic-contaminated seabirds: bald eagle, Haliaeetus leucocephalus, preying on parakeet auklets in Alaska (Day unpubl. data),

Table 1.--List of seabird species that have been recorded ingesting plastic as of November 1984. Phylogenetic sequence for procellariiform birds and pelecaniform birds follows Mayr and Cottrell (1979), and for all other species follows the American Ornithologists' Union (1983).

Species	Scientific name
Wandering albatross	*Diomedea exulans*
Royal albatross	*Diomedea epomophora*
Black-footed albatross	*Diomedea nigripes*
Laysan albatross	*Diomedea immutabilis*
Gray-headed albatross	*Diomedea chrysostoma*
Northern fulmar	*Fulmarus glacialis*
Great-winged petrel	*Pterodroma macroptera*
Kerguelen petrel	*Pterodroma brevirostris*
Bonin petrel	*Pterodroma hypoleuca*
Cook's petrel	*Pterodroma cookii*
Blue petrel	*Halobaena caerulea*
Broad-billed prion	*Pachyptila vittata*
Salvin's prion	*Pachyptila salvini*
Antarctic prion	*Pachyptila desolata*
Fairy prion	*Pachyptila turtur*
Bulwer's petrel	*Bulweria bulwerii*
White-chinned petrel	*Procellaria aequinoctialis*
Parkinson's petrel	*Procellaria parkinsoni*
Pink-footed shearwater	*Puffinis creatopus*
Greater shearwater	*Puffinis gravis*
Sooty shearwater	*Puffinis griseus*
Short-tailed shearwater	*Puffinis tenuirostris*
Manx shearwater	*Puffinis puffinis*
White-faced storm-petrel	*Pelagodroma marina*
British storm-petrel	*Hydrobates pelagicus*
Leach's storm-petrel	*Oceanodroma leucorhoa*
Sooty storm-petrel	*Oceanodroma tristrami*
Fork-tailed storm-petrel	*Oceanodroma furcata*
Blue-footed booby	*Sula nebouxii*
Red-necked phalarope	*Phalaropus lobatus*
Red phalarope	*Phalaropus fulicaria*
Laughing gull	*Larus atricilla*
Heermann's gull	*Larus heermanii*
Mew gull	*Larus canus*
Herring gull	*Larus argentatus*
Western gull	*Larus occidentalis*
Glaucous-winged gull	*Larus glaucescens*
Glaucous gull	*Larus hyperboreus*
Great black-backed gull	*Larus marinus*
Black-legged kittiwake	*Rissa tridactyla*
Red-legged kittiwake	*Rissa brevirostris*
"Terns"	*Sterna* spp.
Dovekie	*Alle alle*
Thick-billed murre	*Uria lomvia*
Cassin's auklet	*Ptychoramphus aleuticus*
Parakeet auklet	*Cyclorrhynchus psittacula*
Least auklet	*Aethia pusilla*
Rhinoceros auklet	*Cerorhinca monocerata*
Tufted puffin	*Fratercula cirrhata*
Horned puffin	*Fratercula corniculata*

Antarctic skua, *Catharacta antarctica*, preying on broad-billed prions in the South Atlantic (Bourne and Imber 1982), and short-eared owl, *Asio flammeus*, preying on blue-footed boobies in the Galápagos Islands (Anonymous 1981). We also omit the Antarctic fulmar, *Fulmarus glacialoides*, and the Atlantic puffin, *Fratercula arctica*, which have been reported to ingest elastic threads but not plastic (Parslow and Jefferies 1972; Crockett and Reed 1976). In addition, great frigatebird, *Fregata minor*, may pick up pieces of marine debris, but do not appear to ingest them (Conant 1984).

All seabird species that have been examined for plastic ingestion, and their rates of ingestion, are listed in Table 2. Twenty-eight (56%) of the species ingesting plastic are procellariiform birds, 1 (2%) is a pelecaniform bird, 2 (4%) are phalaropes, 11 (22%) are gulls and terns, and 8 (16%) are alcids.

The highest frequencies of plastic ingestion are recorded in procellariiform species and in the parakeet auklet, an alcid breeding in the North Pacific. The highest mean number of particles ingested, 21.7 particles per bird, was found in short-tailed shearwaters from California (Baltz and Morejohn 1976). Greater shearwaters from South Africa (Furness 1983) and parakeet auklets from Alaska (Day 1980) exhibited the second and third highest amounts of plastic ingestion, respectively. Of the 50 species containing plastic, only 12 have been recorded ingesting a mean of one or more particles per bird (Table 2).

We have summarized the data from Table 2 in terms of frequencies of ingestion in families and in groups of similar species (Table 3). To determine the approximate mean frequency of occurrence of plastic per species within a particular taxon, we: (1) estimated the frequency of occurrence of plastic for each species from Table 2, where possible; and (2) calculated mean frequencies of occurrence from these estimates. These mean values are approximate and should only be viewed as indicating trends among taxa.

Procellariiform birds exhibit high overall rates of ingestion; 28 (90%) of 31 species examined contained plastic. This group also has a relatively high mean frequency of occurrence per species, indicating that many individuals of many species have ingested plastic. Penguins and sea ducks have not yet been recorded with plastic. Pelecaniform birds contain little or no plastic, and have a very low mean frequency of occurrence per species. Among the charadriiform birds, phalaropes and some alcids (auklets-dovekie and puffins) have both high rates of ingestion and relatively high frequencies of occurrence per species. In contrast, larids have a high overall rate of ingestion but a low frequency of occurrence per species, indicating that only a few individuals of many species in this taxon have ingested plastic.

Effects of Feeding Ecology on Variation in Plastic Ingestion

The only analysis of the relationships between feeding ecology and plastic ingestion is from Day (1980). Twenty-six percent of the birds from Alaska classified as primarily pursuit-divers contained plastic, the highest incidence among all feeding methods; 16% of those seabirds feeding

Table 2.--A list of all species of seabirds that have been examined for plastic ingestion and their rates of ingestion. Phylogenetic sequence for procellariiform birds and pelecaniform birds follows Mayr and Cottrell (1979), and for all other species follows the American Ornithologists' Union (1983).

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Wandering albatross	?	1-5	"Low"	Subantarctic (Chatham Islands)	?	Manufactured pieces, usually red.	M. J. Imber pers. commun.
	?	Present	?	South Atlantic (Gough Island)	?	From chick regurgitations.	Furness 1983.
Royal albatross	?	1-5	"Low"	Chatham Islands	?	Manufactured pieces, usually red.	M. J. Imber pers. commun.
Black-footed albatross	172	Present	?	Hawaiian Islands	1978-81	One adult died from choking on toy; broken fragments, manufactured pieces, cellophane, styrofoam, thermal underwear.	Harrison et al. 1983; M. Naughton pers. commun.
	?	Present	?	Hawaiian Islands	1981	From chick found dead; plastic bags, bottle caps, plastic fragments.	Conant 1984.
Laysan albatross	100	76	2.4	Hawaiian Islands	1966	From chicks found dead.	Kenyon and Kridler 1969.
	1	0	0	Alaska	1969-77	--	Day 1980.
	183	Present	?	Hawaiian Islands	1978-81	Plastic chips, styrofoam, monofilament line.	Harrison et al. 1983.
	4	100	?	Hawaiian Islands	1979-80	From chicks found dead; intestinal blockage, ulceration of proventriculus.	Pettit et al. 1981.
	50	90	?	Hawaiian Islands	1982-83	From chicks found dead; three chicks with plastic impaction and ulcerative lesions.	S. I. Fefer pers. commun.
	4	50	?	Hawaiian Islands	1982-83	From adults.	S. I. Fefer pers. commun.
Gray-headed albatross	?	Present	?	Subantarctic (Marion Island)	?	--	Furness 1983.
Antarctic fulmar	26	0	0	New Zealand	1973-75	Birds found dead.	Crockett and Reed 1976.
Northern fulmar	38	58	2.8	Alaska	1969-77	Both raw plastic and fragments; primarly light-colored.	Day 1980.
	36	3-33	?	Scotland	?	Nylon threads and plastic combined; some plastics causing stomach ulcerations; much other man-made debris.	Bourne 1976.
	3	100	11.3	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	214	40	?	Canadian Arctic	1978-79	--	M. S. W. Bradstreet pers. commun.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Northern fulmar	?	<10	?	Scotland/North Sea	?	Foamed polystyrene.	T. J. Dixon pers. commun.
	88	80	5	Netherlands	1981-82	From birds found dead; raw plastic, other plastic types.	Van Franeker 1983.
	29	76	4	Jan Mayen Island	1983	Also reported large nail embedded in thick layer of fatlike tissue in distal part of gut of one bird.	Van Franeker and Camphuijsen 1984.
Great-winged petrel	?	10	"Low"	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
Kerguelen petrel	26	4	<0.1	New Zealand	1981	From dead birds; raw plastic.	Reed 1981.
Bonin petrel	144	Probably present	?	Hawaiian Islands	1978-81	Regurgitation; presence of plastic not confirmed.	Harrison et al. 1983; C. S. Harrison pers. commun.
Cook's petrel	?	10	"Low"	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
Blue petrel	?	20	?	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
	27	100	?	New Zealand	1981	From dead birds.	Reed 1981.
Broad-billed prion	?	50	"Low-high"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
	?	Present	?	Chatham Islands	?	Raw plastic.	Bourne and Imber 1982.
	?	Present	?	Gough Island	1979	Recorded in only one of a few birds examined; the one contained 33 pieces of raw plastic.	Bourne and Imber 1982.
Salvin's prion	?	50	"Low-high"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
Antarctic prion	?	50	"Low-high"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
Fairy prion	?	10	"Low"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.
Bulwer's petrel	100	Present	?	Hawaiian Islands	1978-81	Regurgitation.	Harrison et al. 1983.
White-chinned petrel	20	5	0.5	South Africa	1981	Fragments.	Furness 1983.
Parkinson's petrel	?	10	"Low"	New Zealand	?	Found dead; raw plastic.	M. J. Imber pers. commun.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Pink-footed shearwater	5	20-40	2.4	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
Greater shearwater	1	100	?	Scotland	?	Nylon threads.	Bourne 1976.
	98	40	?	Eastern Canada	1974-78	Raw plastic.	Brown et al. 1981.
	?	"Low"	?	Massachusetts	1977	Regurgitations	Powers and Van Os 1979.
	2	100	22	Gough Island	1980	Primarily polyethylene; also polyolefin and nylon.	Randall et al. 1983.
	?	Present	?	Eastern Canada	1981	--	M. S. W. Bradstreet pers. commun.
	10	90	20.6	South Africa	1981	Raw plastic and polystyrene spheres.	Furness 1983.
Wedge-tailed shearwater	233	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Sooty shearwater	76	43	1.1	Alaska	1969-77	Both raw plastic and fragments; primarily light-colored.	Day 1980.
	21	43-67	6.9	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	35	17	?	Eastern Canada	1974-78	Raw plastic.	Brown et al. 1981.
	1	100	?	Scotland	?	Nylon threads.	Bourne 1976.
	37	51	?	California	1977	Both raw plastic and fragments; white, red, blue, and brown.	K. W. Chu pers. commun.
	154	49	?	California	1978-79	Both raw plastic and fragments; white, red, blue, and brown.	K. W. Chu pers. commun.
	?	Present	?	Eastern Canada	1981	--	M. S. W. Bradstreet pers. commun.
	?	10	"Low"	New Zealand	?	Raw plastic.	M. J. Imber pers. commun.
	13	0	0	South Africa	1981	--	Furness 1983.
Short-tailed shearwater	200	84	5.4	Alaska	1969-77	Both raw plastic and fragments; great diversity of colors.	Day 1980.
	6	100	21.7	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	189	47	1.0	Australia/Tasmania	1979-80	--	I. J. Skira pers. commun.
Christmas shearwater	182	0	0	Hawaiian Islands	1978-81	From regurgitations	Harrison et al. 1983.
Manx shearwater	?	Present	?	?	?	--	Van Franeker 1983.
Gray-backed storm-petrel	?	0	0	Chatham Islands	?	--	M. J. Imber pers. commun.
White-faced storm-petrel	?	50	"Low-high"	Chatham Islands	?	Raw plastic.	M. J. Imber pers. commun.

Table 2.—Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
British storm-petrel	?	Present	?	?	?	--	Van Franeker 1983.
Leach's storm-petrel	7	14	0.3	Eastern Canada	1962	From adults.	Rothstein 1973.
	7	57	1.0	Eastern Canada	1964	From adults.	Rothstein 1973.
	8	25	0.2	Eastern canada	1964	From chicks.	Rothstein 1973.
	4	25	3.0	Alaska	1969-77	Primarily broken fragments; light-colored; very small pieces.	Day 1980.
Sooty storm-petrel	10	10	0.1	Hawaiian Islands	1978-81	From regurgitations; broken fragments.	Harrison et al. 1983; M. Naughton pers. commun.
Fork-tailed storm-petrel	8	100	6.2	Alaska	1969-77	Primarily broken fragments; light-colored; very small pieces.	Day 1980.
	?	Present	?	Alaska	?	--	Ohlendorf et al. 1978.
Common diving petrel	?	0	0	Chatham Islands	?	--	M. J. Imber pers. commun.
Emperor penguin	?	0	0	Antarctic	?	--	M. J. Imber pers. commun.
Little blue penguin	?	0	0	Chatham Islands	?	--	M. J. Imber pers. commun.
Red-tailed tropicbird	270	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Great frigate-bird	284	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Double-crested cormorant	4	0	0	Alaska	1969-77	--	Day 1980.
Shag	2	0	0	Scotland	?	--	Bourne 1976.
Red-faced cormorant	2	0	0	Alaska	1969-77	--	Day 1980.
Pelagic cormorant	3	0	0	Alaska	1969-77	--	Day 1980.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Gannet	3	0	0	Scotland	?	--	Bourne 1976.
Masked booby	305	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Blue-footed booby	?	Present	?	Galapagos Islands	?	Raw plastic; secondarily via fish.	Anonymous 1981.
Red-footed booby	360	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Brown booby	244	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Greater scaup	3	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Harlequin duck	6	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Oldsquaw	11	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Surf scoter	11	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
White-winged scoter	5	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Barrow's goldeneye	17	0	0	Alaska	1977-78	--	D. V. Derksen pers. commun.
Red-necked phalarope	3	67	1.0	Alaska	1969-77	All light-colored pieces.	Day 1980.
	2	0	0	California	1981	Northbound migrants.	Connors and Smith 1982.
Red phalarope	20	"Most"	?	California	1969	From starving birds; up to 36 particles per bird.	Bond 1971.
	4	25	0.2	California	1979	Southbound migrants.	Connors and Smith 1982.
	7	86	5.9	California	1980	Northbound migrants; primarily polyethylene; a few pieces of styrofoam.	Connors and Smith 1982.
"Skuas"	3	0	0	Scotland	?	--	Bourne 1976.
Pomarine jaeger	1	0	0	Alaska	1969-77	--	Day 1980.

Table 2.—Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Parasitic jaeger	1	0	0	Alaska	1969-77	--	Day 1980.
"Gulls"	?	Present	?	New York	1971	Probably herring gull.	Hays and Cormons 1974.
"Large gulls"	13	0	0	Scotland	?	--	Bourne 1976.
Laughing gull	?	Present	?	Florida	1975-78	From regurgitated casts; plastic occasionally present.	Below 1979.
Bonaparte's gull	4	0	0	Alaska	1969-77	--	Day 1980.
Heermann's gull	15	7-13	0.1	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
Mew gull	10	0	0	Alaska	1969-77	--	Day 1980.
	4	25	0.3	California	1974-75	Plastic fragment.	Baltz and Morejohn 1976.
	?	Present	?	Germany	?	--	Vauk-Hentzelt and Schumann 1980 cited in Vauk-Hentzelt 1982.
Herring gull	?	Present	?	Germany	1967	--	Vauk and Lohmer 1969 cited in Vauk-Hentzelt 1982.
	5	0	0	Alaska	1969-77	--	Day 1980.
	?	Present	?	Maine	1979-82	Plastic bags, styrofoam, cellophane.	D. H. S. Wehle pers. observ.
Western gull	?	Present	?	North Pacific	?	--	H. Ogi pers. commun.
Glaucous-winged gull	63	0	0	Alaska	1969-77	--	Day 1980.
	8	13	0.1	California	1974-75	Plastic fragment.	Baltz and Morejohn 1976.
	?	Present	?	Alaska	1984	Small plastic toy in regurgitated cast, western Aleutian Islands.	R. S. Wood and A. W. DeGange pers. commun.
Glaucous gull	33	3	0.0	Alaska	1969-77	--	Day 1980.
Great black-backed gull	?	Present	?	Maine	1979-82	Plastic bags, styrofoam cellophane.	D. H. S. Wehle pers. observ.
Black-legged kittiwake	188	5	0.1	Alaska	1969-77	Primarily broken fragments; light-colored.	Day 1980.
	8	13-25	0.5	California	1974-75	Both raw plastic and fragments.	Baltz and Morejohn 1976.
	50	12	?	Canadian Arctic	1978-79	--	M. S. W. Bradstreet pers. commun.
	28	4-7	?	Scotland	?	Nylon threads and plastic combined.	Bourne 1976.

Table 2.--Continued.

Species	Sample size (n)	Frequency of occurrence (%)	Mean No. of particles per bird	Location	Year(s)	Comments	Source
Red-legged kittiwake	46	13	0.2	Alaska	1969-77	Raw plastic; primarily light-colored.	Day 1980.
Sabine's gull	1	0	0	Alaska	1969-77	--	Day 1980.
Ivory gull	1	0	0	Alaska	1969-77	--	Day 1980.
"Terns"	?	"A few"	?	New York	1971	Regurgitated casts; common and roseate terns breed here.	Hays and Cormons 1974.
Arctic tern	21	0	0	Alaska	1969-77	--	Day 1980.
Aleutian tern	8	0	0	Alaska	1969-77	--	Day 1980.
Gray-backed tern	272	0	0	Hawaiian Islands	1979-81	From regurgitations.	Harrison et al. 1983.
Sooty tern	356	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Brown noddy	354	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
Black noddy	494	0	0	Hawaiian Islands	1979-81	From regurgitations.	Harrison et al. 1983.
Blue-gray noddy	111	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
White tern	241	0	0	Hawaiian Islands	1978-81	From regurgitations.	Harrison et al. 1983.
"Auks"	37	3-5	?	Scotland	?	Nylon threads and plastic combined.	Bourne 1976.
Dovekie	303	Present	?	Canadian Arctic	1978-79	--	N. S. W. Bradstreet pers. commun.
	?	4	?	North Atlantic	?	--	Van Franeker 1983.
Common murre	191	0	0	Alaska	1969-77	--	Day 1980.
Thick-billed murre	138	1	0.0	Alaska	1969-77	Raw plastic; light-colored.	Day 1980.
	283	1	?	Canadian Arctic	1978-79	--	N. S. W. Bradstreet pers. commun.
Pigeon guillemot	18	0	0	Alaska	1969-77	--	Day 1980.
Marbled murrelet	61	0	0	Alaska	1969-77	--	Day 1980.

Species	size (n)	occurrence (%)	of particles per bird	Location	Year(s)	Comments	Source
Kittlitz' murrelet	3	0	0	Alaska	1969-77	--	Day 1980.
Ancient murrelet	16	0	0	Alaska	1969-77	--	Day 1980.
Cassin's auklet	10	40	3.8	Alaska	1969-77	Both raw plastic and fragments; light-colored; very small pieces.	Day 1980.
Parakeet auklet	?	Present	?	Alaska	?	Raw plastic; light-colored.	Ohlendorf et al. 1978.
	116	75	13.7	Alaska	1969-77	Raw plastic; light-colored.	Day 1980.
	1	100	8	Hawaiian Islands	1980	Found dead; all particles black.	Pettit et al. 1981.
Least auklet	89	1	0.0	Alaska	1969-77	--	Day 1980.
Whiskered auklet	5	0	0	Alaska	1969-77	--	Day 1980.
Crested auklet	85	0	0	Alaska	1969-77	--	Day 1980.
Rhinoceros auklet	20	0	0	Alaska	1969-77	--	Day 1980.
	26	4	0.1	California	1974-75	Plastic fragment.	Baltz and Morejohn 1976.
Tufted puffin	348	15	0.5	Alaska	1969-77	Primarily raw plastic; light-colored; diversity of colors.	Day 1980.
Atlantic puffin	6	0	0	United Kingdom	1969-71	Birds found dead; elastic threads, but no plastic.	Parslow and Jefferies 1972.
Horned puffin	?	Present	?	Alaska	?	--	Ohlendorf et al. 1978.
	148	37	0.9	Alaska	1969-77	Primarily raw plastic; light-colored; diversity of colors.	Day 1980.

Table 3.--Rates of plastic ingestion in families of birds and in groups of similar species, calculated from the data in Table 2. The approximate mean frequency of occurrence of plastic per species was calculated by: (1) estimating the frequency of occurrence of plastic for each species from Table 2, where possible; and (2) calculating a mean frequency of occurrence for these estimates. These mean values are approximate and should only be viewed as indicating trends among taxa.

Taxon	No. of species examined for plastic in taxon	Frequency of occurrence of plastic in taxon (%)	Approximate mean frequency of occurrence of plastic per species (%)
PROCELLARIIFORMES			
Diomedeidae	5	100	28
Procellariidae	21	86	24
Gadfly petrels	4	100	8
Prions	4	100	40
Shearwaters-fulmars	9	67	31
Other	4	100	32
Hydrobatidae	6	83	38
Pelecanoididae	1	0	0
SPHENISCIFORMES			
Spheniscidae	2	0	0
PELECANIFORMES			
Phaethontidae	1	0	0
Fregatidae	1	0	0
Phalacrocoracidae	4	0	0
Sulidae	5	20	? (low)
ANSERIFORMES			
Anatidae	6	0	0
CHARADRIIFORMES			
Scolopacidae (phalaropes)	2	100	45
Laridae	≥26	≤47	≤3
Skuas-jaegers	3	0	0
Gulls	14	71	6
Terns	≥9	≤11	? (very low)
Alcidae	≥16	≤50	≤11
Murres-guillemots-murrelets	≥6	≤17	<1
Auklets-dovekie	6	67	18
Puffins	4	75	14

by surface-seizing, 9% of those feeding by dipping, and none of those feeding by plunging or piracy contained plastic (Table 4). Some bias is present in these results, however, because shearwaters, which were classified as primarily pursuit-divers, also feed extensively by surface-seizing. If the data for shearwaters are combined with those for surface-seizers, as many as 52% of the surface-seizers and as few as 16% of the pursuit-divers contained plastic. This bias notwithstanding, a significant number of species previously considered to be exclusively subsurface-feeding contained plastic found only at the surface of the water, suggesting that many pursuit-divers exhibit a greater range of feeding behaviors than was believed previously.

Table 4.--Frequency of occurrence of plastic in seabirds from Alaska with respect to primary feeding method (from Day 1980). Feeding method classifications are from Ashmole (1971) and Day (1980).

Feeding method	No. examined (n)	No. with plastic	Frequency of occurrence (%)
Pursuit-diving	1,532	399	26.0
Surface-seizing	157	25	15.9
Dipping	256	24	9.4
Plunging	21	0	0
Piracy	2	0	0

Birds feeding by plunging or piracy show no evidence of plastic ingestion. Plungers generally sight individual prey items below the surface of the water (Ashmole 1971), where floating plastic is not found, and they probably cannot distinguish objects as small as plastic particles from the air. Those birds feeding by piracy take food dropped by other birds; such food is primarily fish (Ashmole 1971) and appears to contain little or no plastic.

Birds feeding by hydroplaning, a method not used by Alaska's seabirds, also exhibit high rates of plastic ingestion (Tables 2 and 3). The prions use this method to filter surface water, where the plastic occurs, through their bill lamellae (Ashmole 1971). Approximately 50% of the prions examined by M. J. Imber (pers. commun.) contained plastic (Table 2).

Another feeding method, scavenging at the sea's surface, is used to varying degrees by seabirds throughout the world (Ashmole 1971). Unfortunately, its importance relative to other feeding methods is often difficult to quantify. Scavenging is common in many procellariiform birds and in gulls (Ashmole 1971); interspecies variation in degree of scavenging probably accounts for some of the variation in ingestion frequencies seen in these groups.

Plastic ingestion also can be correlated with a given species' preferred prey (Table 5). Generally, those species of seabirds from Alaska relying primarily on crustaceans or cephalopods had a higher frequency of plastic ingestion than did those relying primarily on fishes (Day 1980): species feeding primarily on crustaceans had a significantly higher frequency of ingestion than did fish-feeders ($\chi^2 = 305.6$; 1 df; $P < 0.001$; chi-square R x C test; Conover 1971), as did cephalopod-feeders when compared with fish-feeders ($\chi^2 = 68.2$; 1 df; $P < 0.001$). Thus, secondary ingestion of plastic via fish is evidently low, although it has been proposed for blue-footed boobies in the Galapagos Islands (Anonymous 1981). Cephalopod- and crustacean-feeding seabirds showed no significant difference in the frequency of plastic ingestion ($\chi^2 = 1.1$; 1 df; $P > 0.05$), indicating that both were important in effecting plastic ingestion.

Table 5.--Frequency of occurrence of plastic in seabirds from Alaska with respect to primary prey type (adapted from Day 1980). Prey type classifications are from Ashmole (1971) and Day (1980).

Prey type	No. examined (n)	No. with plastic	Frequency of occurrence (%)
Crustaceans	566	270	47.8
Cephalopods	39	22	56.4
Fishes	1,363	156	11.4

Prey type was a better predictor of plastic occurrence in seabirds than was feeding method, probably because of the particles' similarities (location in the water column and in physical attributes) to known and probable prey items. A number of known and probable prey items occur regularly in surface waters, where plastic might be mistaken for, or ingested, along with these prey. In Alaska, squid larvae live primarily within the upper 0.5 m of the sea's surface; in addition, the adults undergo a circadian pattern of vertical migration and are found at the sea's surface at night (Clarke 1966; C. G. Bublitz, Institute of Marine Science, University of Alaska, Fairbanks, Alaska pers. commun.). The planktonic larvae and adults of many pelagic crustaceans (e.g., copepods, euphausiids), which many of the light-brown particles of raw plastic eaten by seabirds resemble (Table 2), are also found at or near the water's surface (Mauchline 1980; Raymont 1983).

The eggs of many fishes are also found at the surface of the ocean (Hart 1973). These pelagic eggs are rarely recorded in seabirds, probably because they are rapidly digested in the birds' stomachs. Flyingfish (Exocoetidae) eggs attached to plastic have been found in Laysan and black-footed albatrosses (Pettit et al. 1981; Harrison et al. 1983), and some sea ducks and gulls eat the benthic eggs of some nearshore fishes (Outram 1958; Gjosaeter and Saetre 1974). Colton (1974) originally mistook the light-brown pellets of raw plastic that he had caught in neuston tows for pelagic fish eggs, and several scientists at the University of Alaska mistook the samples of Day (1980) for fish eggs. The small, round pellets could also be mistaken by the birds for the eyes of squids or fishes or for the bodies of larval fishes. Thus, it is not surprising that those seabirds feeding primarily on crustaceans or cephalopods exhibit a higher occurrence of plastic than do those species feeding primarily on fish.

Interspecific Variation in Plastic Ingestion

An obvious question to be asked is whether seabirds actively select specific kinds of plastic or randomly eat any plastic that they encounter at sea. Examination of two data sets from the North Pacific suggests that the former hypothesis is correct.

Table 6 compares the numbers and frequencies of colors of 833 plastic particles ingested by Alaska seabirds (Day 1980) with numbers and frequencies of colors of 250 pieces of floating plastic sighted from the deck of a ship during a cruise in the subtropical North Pacific from Honolulu, Hawaii, to Hakodate, Japan, between 10 and 22 August 1984 (Dahlberg and Day 1985; Day unpubl. data).

We make two assumptions about this latter data set: (1) We assume that the frequencies of plastic colors in the subtropical North Pacific are representative of the frequencies of colors of plastic in the subarctic North Pacific, where the seabirds were collected; and (2) since about 73% of the plastic particles ingested by these seabirds are raw polyethylene pellets rather than plastic fragments, we assume that the frequencies of raw polyethylene pellets in the ocean are reflected in the frequencies of colors of these larger plastic objects. We see no reason why there should be geographic variation in frequencies of colors of plastic in the ocean; Dahlberg and Day (1985) found no geographic variation in frequencies of types of marine debris. No data are available for determining the accuracy of the second assumption.

There is a significant difference between frequencies of colors of plastic objects in the stomachs of seabirds from Alaska and frequencies of colors of floating plastic objects ($X^2 = 1,280.4$; 7 df; $P < 0.001$; chi-square goodness-of-fit test; Zar 1984). In this test, we omitted the color columns "orange" and "transparent" (Table 6), since they could not be adequately compared; although both colors were recorded in short-tailed shearwaters, they were not recorded in subsamples examined. Hence, the adjusted sample size for the subtropical North Pacific is 229. White, yellow, and blue occurred significantly less frequently in the birds than they did in the ocean (partial chi-square value for cells = 214.5, 21.8, and 34.5, respectively), whereas tan and brown occurred more frequently in birds than they did in the ocean (partial chi-square value for cells = 78.9 and 225.6, respectively). Yellow, brown, blue, red, green, and black-gray did not occur in proportions significantly different from that in the ocean (partial chi-square values for each cell did not exceed 1.9), suggesting that seabirds randomly ingest particles of these colors. There was some selection for the "light brown" colors (white, yellow, tan, brown; see following paragraph) as a group, however, for they constituted 79.0% of the plastic in the ocean but formed 85.0% of the plastic in the birds' stomachs.

Table 6.--Numbers and percentages of colors of plastic ingested by seabirds in Alaska (from Day 1980) and numbers and percentages of colors of floating plastic objects recorded in the subtropical North Pacific, 10-22 August 1984 (Day unpubl. data). Chi-square contributions are for deviations from expected values, which are calculated from frequencies seen in the North Pacific; total chi-square from goodness-of-fit test = 1,280.4 (7 df; Zar 1984).

	Sample size (n)	Color[1]							
		White	Yellow	Tan	Brown	Blue	Red	Green	Black-gray
Alaska seabirds	833	152	6	459	92	40	20	40	24
Frequency (%)		18.2	0.7	55.1	11.0	4.8	2.4	4.8	2.9
Expected values[2]		469.2	32.7	134.6	21.8	98.2	18.2	40.0	18.2
X^2 contribution[3]		214.5	21.8	781.9	225.6	34.5	0.2	0.0	1.9
Subtropical North Pacific	229	129	9	37	6	27	5	11	5
Frequency (%)		56.3	3.9	16.2	2.6	11.8	2.2	4.8	2.2

[1]The colors orange and transparent were recorded in the North Pacific (n = 15 and n = 6, respectively) and in Alaska seabirds (short-tailed shearwaters; Day pers. observ.), but not in subsamples of plastic examined. Because no estimates of frequencies in seabirds were available for these two colors, they were omitted from the table and the test.

[2]Expected number of particles in each color category, based on the frequency of each color in the environment (i.e., the North Pacific).

[3]Chi-squared for P = 0.05 is 14.067; for P = 0.01 is 18.475; for P = 0.001 is 24.322 (all for 7 df).

An analysis of color-shape combinations of plastic particles ingested by seabirds from Alaska (Day 1980) also provides evidence of selective ingestion. To determine preferences for certain combinations of colors and shapes of particles, the particles ingested by each species were classified into four color-shape categories ("light brown-regular," "light brown-irregular," "other color-regular," and "other color-irregular"), and deviations of frequencies of each particle type from the combined frequencies of all species were determined with a chi-square test for independence (Zar 1984). "Light brown" colors, which resemble the colors of many natural prey items, were white, yellow, tan, and brown, and the "other" color category included the remaining colors. "Regular" shapes were pill, cylinder, sphere, and box-cube (as classified in Day 1980). All regularly shaped particles were roughly similar in size and shape, in contrast to the highly variable "irregular" particles.

The total X^2 of 108.3 shows a significant dependence between the species of seabird and the type of plastic eaten (Table 7). Only sooty shearwaters, short-tailed shearwaters, and tufted puffins appeared to ingest plastic at random, whereas the others showed strong affinities for or avoidances of certain color-shape combinations. The parakeet auklet, which feeds primarily on zooplanktonic crustaceans (Bedard 1969), was the most extreme in preferences: 94% of its plastic were in the light brown-regular category. These preferences support the hypothesis that at least some species mistake many particles for food items.

Other evidence for selective ingestion comes from the extreme interspecific variation in ingestion frequencies seen in Table 2. Also, some seabirds (e.g., Leach's storm-petrel, fork-tailed storm-petrel, Cassin's auklet) selectively ingest very small plastic particles (Day 1980), indicating selectivity for size of particles rather than for color or shape. Hence, although some species may ingest plastic randomly, most are quite specific in the types of plastic that they eat.

Sex and Age-Related Variation in Plastic Ingestion

No significant differences in the number of plastic particles ingested were found between sexes in any of the six seabird species examined from Alaska (Table 8). This observation compares well with data on feeding habits of monomorphic seabird species (most have monomorphic bills), in which there is almost 100% overlap in intersexual food habits (Tuck 1960; Bedard 1969; Sealy 1975; Wehle 1982).

Significantly more plastic particles were found in subadult parakeet auklets and tufted puffins from Alaska than in adults (Table 8). No significant differences between subadult and adult horned puffins were found, although the relatively small sample size of subadults may have affected the validity of the statistical test. Age-related differences in food habits have been found in ancient murrelets (Sealy 1975) and tufted and horned puffins (Wehle 1982), but not in marbled murrelets (Sealy 1975).

Subadult birds of many species are less efficient at foraging than are adults (Orians 1969; Recher and Recher 1969; Dunn 1972; Morrison et al. 1978; Searcy 1978). Hence, there should be selective pressures on subadults to compensate for poorer foraging efficiency by broadening their feeding niches, possibly increasing the amount of nonfood items eaten. The

Table 7.--Numbers and percentages of color-shape combinations of plastic particles ingested by six seabird species in Alaska (data reanalyzed from Day 1980). Also included are chi-square values for deviations from expectation, using a chi-square R x C test for independence (Zar 1984); total χ^2 of 108.3 shows a significant ($P < 0.001$; df = 15) dependence between the species of seabird and the type of plastic eaten.

	Sample size (n)	"Light brown" colors[1]		"Other" colors[1]		
		"Regular" shapes[2]	"Irregular" shapes[2]	"Regular" shapes	"Irregular" shapes	Total species χ^2 value
Northern fulmar	97	56	34	3	4	
Frequency (%)		57.8	35.1	3.0	4.1	
χ^2 contribution[3]		2.6	29.6	0.9	2.5	35.6
Sooty shearwater	77	50	10	6	11	
Frequency (%)		64.9	13.0	7.8	14.3	
χ^2 contribution		0.5	0.1	0.9	2.6	4.1
Short-tailed shearwater	164	114	24	10	16	
Frequency (%)		69.5	14.6	6.1	19.8	
χ^2 contribution		0.1	0.0	0.2	0.2	0.5
Parakeet auklet	120	113	0	4	3	
Frequency (%)		94.2	0	3.3	2.5	
χ^2 contribution		8.6	17.1	1.0	5.4	32.1
Tufted puffin	139	117	10	6	6	
Frequency (%)		84.2	7.2	4.3	4.3	
χ^2 contribution		3.1	4.9	0.3	3.2	11.5
Horned puffin	127	68	25	10	24	
Frequency (%)		53.5	19.7	7.9	18.9	
χ^2 contribution		5.8	2.6	1.5	14.6	24.5
Combined total	724	518	103	39	64	108.3
Frequency (%)		71.5	14.2	5.4	8.8	

[1] "Light brown" = white, tan, yellow, brown; "other" = dark blue, medium-light blue, dark red, medium-light red, dark green, medium-light green, black-gray.

[2] "Regular" = pill, cylinder, sphere, box-cube; "irregular" = string, cone, asymmetrical, other.

[3] Chi-squared for P = 0.005 is 24.996; for P = 0.01 is 30.578; for P = 0.001 is 32.801 (all for 15 df).

Table 8.--Results of tests for sexual (A) and age-related (B) differences in the number of plastic particles ingested by Alaska seabirds (from Day 1980). Parakeet auklets were tested with a Mann-Whitney test; all other species were tested with a median test (Conover 1971).

Species	Sample sizes (n)[1]	df	Test statistic	Significance
(A) Male versus female (all two-tailed tests)				
Northern fulmar	17/12	1	1.129	NS[2]
Sooty shearwater	37/26	1	1.397	NS
Short-tailed shearwater	101/73	1	0.590	NS
Parakeet auklet	49/36	1	[3]1,034.5	NS
Tufted puffin	43/38	1	0.294	NS
Horned puffin	23/45	1	0.008	NS
(B) Adult versus immature (all one-tailed tests)				
Parakeet auklet	32/10	1	[4]231.5	0.01<P<0.05
Tufted puffin	81/17	1	17.080	P<0.001
Horned puffin	68/8	1	0.349	NS

[1]Sample sizes for the two classes tested are separated by a slash.

[2]NS = not significant at $\alpha = 0.05$.

[3]$W_{0.95} = 1{,}067.0$.

[4]$W_{0.95} = 2.5.7$; $W_{0.99} = 238.7$.

increased amount of plastic ingested by subadults also may be due to a poorer perception of what constitutes a "good" food item, or to the possibility that subadults naturally ingest a wide range of food items to learn differences among them.

Geographic Variation in Plastic Ingestion

Day (1980) analyzed geographic variation in plastic ingestion in seabirds from Alaska, dividing the marine waters of the state into three regions: the Gulf of Alaska, the Aleutian Islands, and the Bering and Chukchi Seas (Fig. 1). Five species of birds provided reasonable sample sizes from each of these three regions. Two of these species (black-legged kittiwake and thick-billed murre) had frequencies of plastic ingestion too low for meaningful intraspecies comparisons, and thus, were not tested. In the remaining three species (parakeet auklet, tufted puffin, and horned puffin), the highest frequencies of ingestion and mean numbers of particles per bird occurred in Aleutian Islands waters (Table 9; chi-square R x C test; Conover 1971).

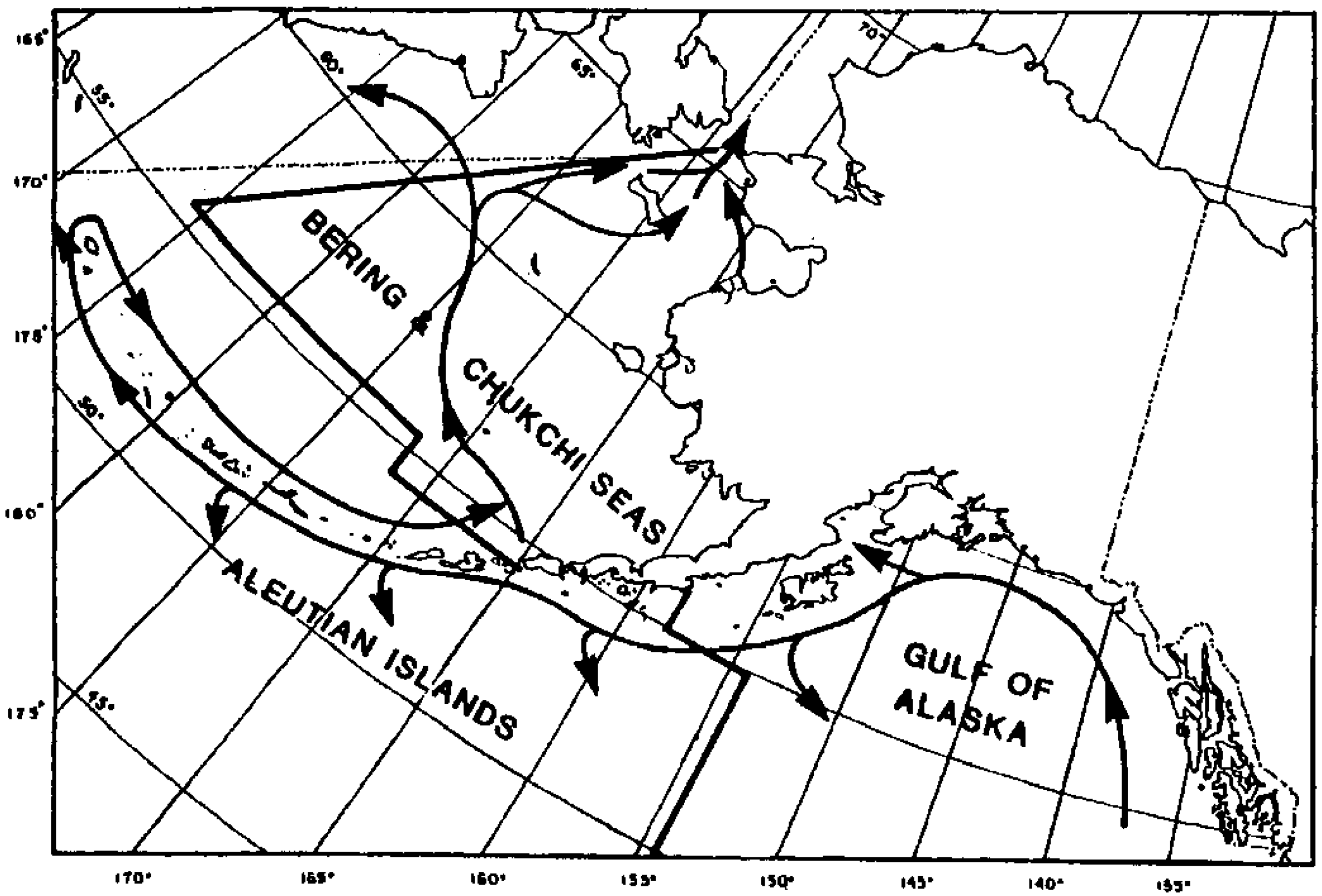

Figure 1.--Location of three geographic regions of Alaska in which differences in rates of plastic ingestion were tested (from Day 1980). The approximate locations of major currents are adapted from Coachman et al. (1975), Tabata (1975), Favorite et al. (1976), and T. C. Royer (pers. commun.).

Table 9.--Geographic variation in the frequency of occurrence of plastic (A) and in the mean number of plastic particles per bird (B) in the parakeet auklet, tufted puffin, and horned puffin in Alaska (from Day 1980).

(A) Frequency of occurrence of plastic

	Gulf of Alaska			Aleutian Islands			Bering and Chukchi Seas		
Species	(n)	No. with plastic	Frequency (%)	(n)	No. with plastic	Frequency (%)	(n)	No. with plastic	Frequency (%)
Parakeet auklet	13	11	84.6	55	50	90.9	45	24	53.3
Tufted puffin	190	20	10.5	122	35	20.5	35	5	14.3
Horned puffin	41	11	26.8	74	37	50.0	20	6	30.0

(B) Mean number of plastic particles per bird

	Gulf of Alaska		Aleutian Islands		Bering and Chukchi Seas	
Species	(n)	Mean ± SD	(n)	Mean ± SD	(n)	Mean ± SD
Parakeet auklet	14	21.1 ± 22.6	55	21.3 ± 22.8	46	2.6 ± 4.0
Tufted puffin	190	0.2 ± 0.8	122	0.7 ± 2.1	36	0.6 ± 2.9
Horned puffin	41	0.8 ± 1.7	87	1.0 ± 1.5	20	0.6 ± 1.2

Parakeet auklets in the Gulf of Alaska (X^2 = 4.3; 1 df; $P < 0.05$) and the Aleutian Islands (X^2 = 18.1; 1 df; $P < 0.001$) had higher frequencies of plastic ingestion than did birds in the Bering and Chukchi Seas. No significant difference in frequencies was found between birds in the Gulf of Alaska and the Aleutian Islands, although one of the expected values was too small for valid statistical testing.

Horned puffins in the Aleutian Islands had a higher frequency of plastic ingestion than did birds in the Gulf of Alaska (X^2 = 5.9; 1 df; $P < 0.05$); significant differences were not found in any other test for this species. Tufted puffins from the Aleutian Islands had a higher frequency of plastic ingestion than did birds from the Gulf of Alaska (X^2 = 5.9; 1 df; $P < 0.05$), but no other significant differences were found for this species.

When the combined data for all birds of all species ingesting plastic were tested among the three regions, a similar pattern emerged. A Kruskal-Wallis test (BMDP program; Dixon and Brown 1979) showed significant differences ($P = 0$) in the number of particles ingested among the three regions. The birds in the Gulf of Alaska averaged 2.4 $\pm$ 5.9 particles per bird (n = 634), about two-thirds that of birds in the Aleutian Islands ($\bar{X}$ = 3.8 $\pm$ 11.3 particles per bird; n = 391). Birds in the Bering and Chukchi Seas averaged 0.6 $\pm$ 2.2 particles per bird (n = 413), about one-seventh that of birds in the Aleutians and about one-fifth that of birds in the gulf. This geographic variation may be explained in terms of nonuniform geographic input of plastic and subsequent dispersal by currents.

The synthesis of plastic requires large amounts of petrochemicals; southern California and Japan are the two major petrochemical and plastics manufacturing centers in the North Pacific (Guillet 1974; Wong et al. 1976). Any plastic entering the ocean in southern California probably moves southward (i.e., away from Alaska) in the California Current system. Any plastic entering the ocean in eastern Japan probably moves eastward in the North Pacific Drift Current (see Tabata 1975 and Favorite et al. 1976; also see Wong et al. 1976, for information on "downstream" contamination of the North Pacific Drift Current east of Japan by tar balls), which splits to form the California Current and the Alaska Current. Of the plastic transported into the northern Gulf of Alaska by the Alaska Current, some apparently moves inshore and is eaten by seabirds; most of the water moves across the Gulf far offshore, however, far from where most of the seabirds examined by Day were feeding. Some plastic must also enter inshore waters there from the small population centers and fishing activities. Recent studies by Royer (1975, 1983) indicate that there is little surface divergence in this region, suggesting that most of the plastic should be carried far offshore past this region.

The Alaska Current-Aleutian Stream system flows closely along the southern edge of the Aleutian Islands (Fig. 1), and the proximity of plastic in this nearshore current to birds breeding and feeding there probably accounts for the high level of plastic ingestion observed there. Surface flow into the Bering Sea is concentrated in Near Island Pass and Commander Pass, and appears to be relatively small (Tabata 1975; Favorite et al. 1976), explaining the lower amount of plastic ingested by birds in the Bering and Chukchi Seas.

The availability of large quantities of plastic in regions of plastic production, which are more polluted than Alaska, may allow a much higher degree of ingestion than in areas remote from plastic production. A comparison of plastic ingestion between seabirds in California (Baltz and Morejohn 1976) and Alaska (Day 1980) illustrates this point (Table 10). Of seven species that were examined for plastic in both regions, all seven from California were found to ingest plastic, whereas only four from Alaska did. Of the four species that contained plastic in both regions, California birds averaged about four times as many particles per bird as did Alaska birds. Thus, we predict that seabirds foraging near areas of extensive plastic production or manufacturing will have a higher incidence of plastic and a higher mean number of particles per bird than will seabirds foraging in areas of minor plastic production or manufacturing.

Table 10.--A comparison of plastic ingestion in seven seabird species examined from Alaska and California. Data for Alaska birds are from Day (1980) and for California birds are from Baltz and Morejohn (1976).

	Sample size (n)		Frequency of occurrence (%)		Mean No. of particles per bird	
Species	Alaska	California	Alaska	California	Alaska	California
Northern fulmar	38	3	58	100	2.8	11.3
Sooty shearwater	76	21	43	43-67	1.1	6.9
Short-tailed shearwater	200	6	84	100	5.4	21.7
Mew gull	10	4	0	25	0	0.2
Glaucous-winged gull	63	8	0	13	0	0.1
Black-legged kittiwake	188	8	5	13-25	0.1	0.5
Rhinoceros auklet	20	26	0	4	0	0.1

Temporal Variation in Plastic Ingestion

Inter- and intra-annual variations in plastic ingestion have been examined by Day (1980). The primary species providing enough data to examine long-term variations in plastic ingestion is the short-tailed shearwater; samples examined by D. L. Serventy (CSIRO Wildlife Research, Helena Valley, W. A., Australia pers. commun.) and R. Mykytowycz (CSIRO Wildlife Research, Canberra, Australia, fide D. L. Serventy) range as far back as the 1950's. The general trend shows an increase in all characteristics of plastic ingestion over time, especially in the frequency of occurrence of plastic and in the mean volume of plastic per bird (Fig. 2). Given that world plastic production is increasing by about 6% each year (Guillet 1974), and that plastic litter may also be increasing exponentially (Guillet 1974), these increases in ingestion rates probably reflect the continually increasing availability of plastic in the oceans.

Laysan albatrosses in the Hawaiian Islands have also shown an increase in frequency of occurrence of plastic over time. In 1966, 76% of 100 chicks found dead contained plastic (Kenyon and Kridler 1969), whereas 90% of 50 chicks examined there in 1982-83 did (S. I. Fefer, U.S. Fish and

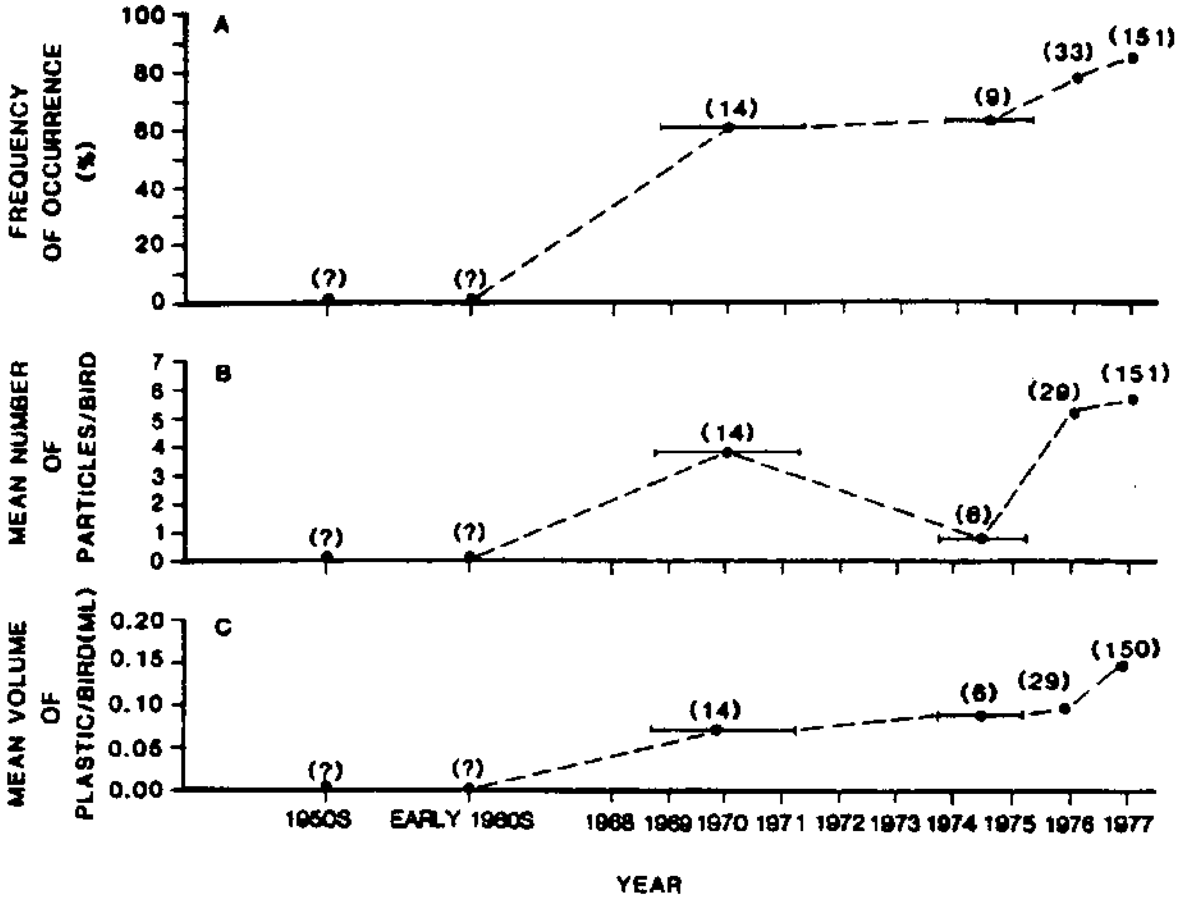

Figure 2.--Changes in plastic ingestion in the short-tailed shearwater, 1950's to 1977 (adapted from Day 1980). Sample sizes are in parentheses, and horizontal bars represent combined data for the periods 1969-71 and 1974-75. Data from the 1950's and early 1960's are from D. L. Serventy (CSIRO Wildlife Research, Helena Valley, W. A., Australia pers. commun.) and R. Mykytowycz (CSIRO Wildlife Research, Canberra, Australia, *fide* D. L. Serventy); they examined hundreds of short-tailed shearwaters during the course of their studies. Data from the period 1969-77 are from Alaska (Day 1980). (A) Frequency of occurrence of plastic; (B) mean number of plastic particles per bird; (C) mean volume (ml) of plastic per bird.

Wildlife Service, Hawaiian and Pacific Islands National Wildlife Refuge pers. commun.); this increase in frequency of occurrence is significant ($\chi^2 = 4.2$; $P < 0.05$).

No plastic was found in any of the parakeet auklets collected at St. Lawrence Island in the mid-1960's (J. Bedard, Universite Laval, Quebec, Canada pers. commun.), yet approximately 50% of the parakeet auklets from the Bering and Chukchi Seas contained plastic in the period 1974-77 (Table 9). Thus, it appears that ingestion of plastic by marine birds first occurred in the early 1960's in the Pacific (Kenyon and Kridler 1969) and that plastic ingestion is increasing annually; plastic ingestion also appears to have begun in the Atlantic in the early 1960's (Rothstein 1973).

Marine birds in Alaska also show intra-annual variation in plastic ingestion (Day 1980). Figure 3 shows the mean number of plastic particles per bird and the frequency of occurrence of plastic in short-tailed shearwaters collected in Alaska and Australia and in tufted puffins collected in Alaska.

In May, the mean number of particles per short-tailed shearwater was relatively small, although about 80% of the birds contained plastic (Figs. 3A, 3B). The birds began ingesting plastic in large numbers in June ($\bar{X}$ = 6.5 particles per bird). By July, the mean number of particles per bird decreased slightly, so the rate of ingestion was not so high as the rate of loss through wear. The percentage of birds with plastic had risen slightly, to 84%, indicating that ingestion was still occurring. A second period of heavy plastic ingestion occurred in August, when the mean number of particles per bird again increased; 98% of the birds contained plastic at this time. The mean number of particles ingested again declined in September, although virtually 100% of the birds contained at least some plastic. During winter, the rate of ingestion was low, as indicated by the data from Bass Strait: only 47% of the birds contained plastic, and approximately 72% of these had two or fewer particles.

Essentially the same pattern is seen in tufted puffins (Figs. 3C, 3D): Low frequencies of occurrence and low mean numbers of particles per bird in May, high rates of plastic ingestion in midsummer, and decreased ingestion rates and subsequent loss through wear late in the summer. A similar pattern was also seen in parakeet auklets and horned puffins from Alaska (Day 1980).

The frequency distributions for the wear classes (a relative grade of how worn individual particles are) of individual particles support the evidence that most plastic in boreal birds is ingested during the summer (Fig. 4). In May, only the more-worn wear classes were represented, indicating little ingestion during the winter and following the pattern predicted from the decreased ingestion rates seen in Australian birds. During June, the mean wear class decreased from 4.6 (worn-very worn) to 3.6 (relatively worn-worn), indicating that many less-worn particles were being ingested; 50% of the particles were in wear classes 1-3, the less-worn categories. The lack of wear-class 1 (fresh) particles is attributable to the likelihood that not all particles are in wear class 1 when ingested.

The frequency distributions for July and August were similar, with those particles in the stomach wearing down. The bulk of the particles was concentrated in wear classes 4 and 5, the more-worn categories. Although "fresher" particles (wear classes 1-3) were being ingested, the mean wear class increased (i.e., particles became more worn) because the newly added fresh particles constituted a proportionally smaller percentage of the number of particles than they had in May and June. The mean wear class again increased in September, and particles in the fresher wear classes only constituted 10% of the sample at this point, indicating that the rate of ingestion had decreased.

In summary, during the northern winter, the birds apparently eat little plastic. Consequently, that plastic remaining in the stomach wears down (mean wear class approaches 5) and some is lost (the mean number of

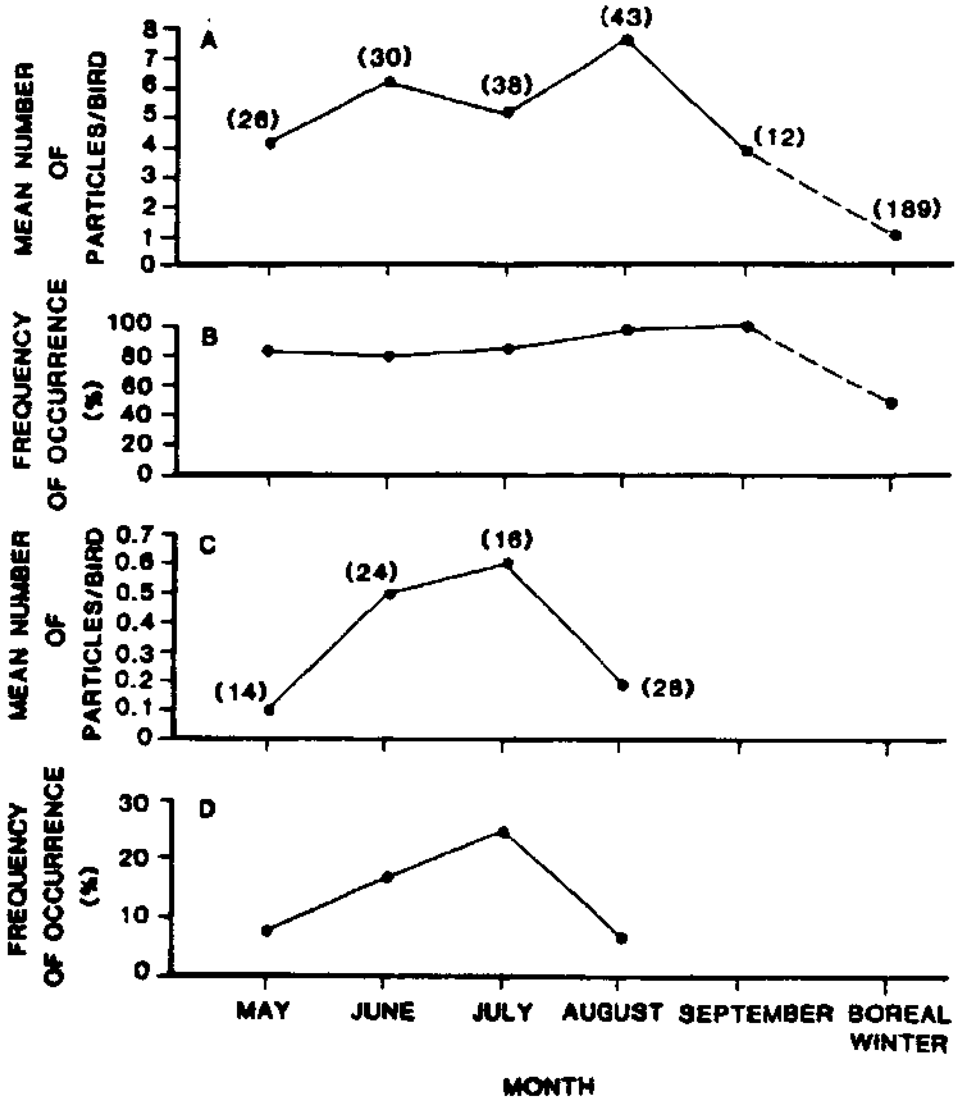

Figure 3.--Temporal variation in plastic ingestion in short-tailed shearwaters (A, B) and in tufted puffins (C, D) in Alaska (adapted from Day 1980 and Day unpubl. data). (A) Mean number of plastic particles per bird in short-tailed shearwaters of unknown age collected near Kodiak Island in 1977 and in Bass Strait, Australia, during the boreal winters of 1978 and 1979 (I. J. Skira, National Parks and Wildlife Service, Sandy Bay, Tasmania pers. commun.); sample sizes are indicated in parentheses. (B) Frequency of occurrence of plastic in short-tailed shearwaters, as above. (C) Mean number of plastic particles per bird in adult tufted puffins collected at Buldir Island in 1975; sample sizes are indicated in parentheses. (D) Frequency of occurrence of plastic in tufted puffins, as above.

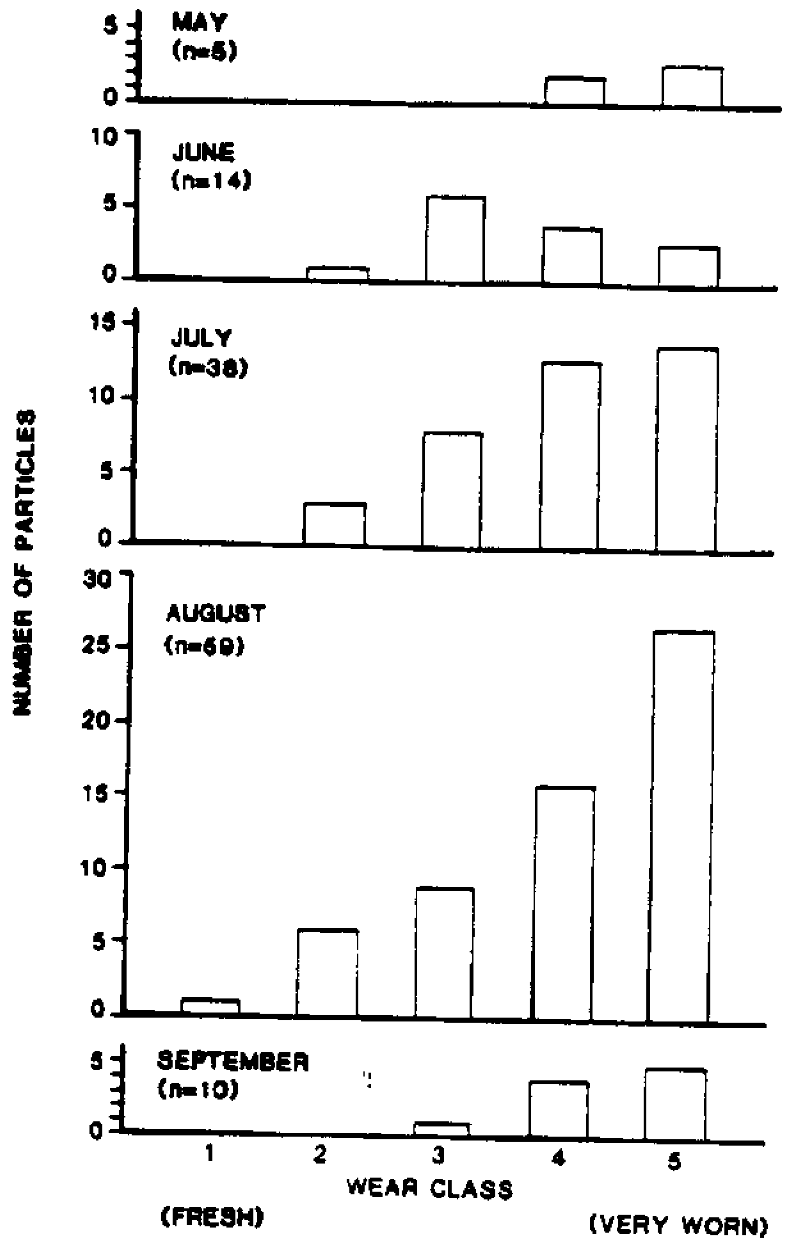

Figure 4.--Frequency distributions of the wear class of individual plastic particles found in short-tailed shearwaters collected in Alaska during the summer of 1977 (from Day 1980). All birds were collected near Kodiak Island, as in Figure 3. Wear on each piece was determined by classifying the degree of angularity of the piece's edge and by examining the general surface of each piece. The degree of wear was quantified by a five-point visual index (fresh, relatively fresh, relatively worn, worn, and very worn), as described in Day (1980).

particles per bird decreases). This condition exists until May. In late spring and early summer, the birds again begin eating plastic, causing a sharp rise in the mean number of particles per bird and a sharp decrease in the mean wear class of the plastic, as seen in the June birds. In contrast to the June data, midsummer (July and August) means show relatively little change, indicating that consumption of new particles is roughly balanced by loss of particles through wear. The ingestion of plastic decreases near the end of the summer, and smaller particles continue to be lost through wear; the mean number of particles per bird decreases, and the mean wear class approaches 5 (very worn) again. Wear then continues into the winter months, completing the cycle. Although migratory seabird species from higher latitudes appear to ingest plastic only during some months, it is believed that nonmigratory tropical species are able to ingest plastic all year (S. I. Fefer pers. commun.).

Since the particles do not pass into the intestine, the mean residence time of plastic in the birds' stomachs may be estimated. Although Day (1980) estimated residence times of 2-3 months for "soft" polyethylene and 10-15 months for "hard" polyethylene, the data showing rapid loss rates in short-tailed shearwaters and tufted puffins presented here and data for phalaropes from Connors and Smith (1982) suggest that the mean residence time of individual particles is shorter and is on the order of 6 months. Obviously, there could be great variation in these rates, depending on the number, size, and type of particles and other hard objects (e.g., pumice) in a particular bird's stomach.

The available data permit examination of the impact of the birds' ingestion of the at-sea density of plastic. At the peak of summer ingestion, short-tailed shearwaters average about 7.4 particles per bird (Fig. 3). With an estimated population of 18×10^6 birds (I. J. Skira pers. commun.), this yields an estimated "standing stock" of 133×10^6 particles in the stomachs of this species. The average residence time of the particles is estimated to be 6 months. Therefore, the average removal of plastic by this species is approximately 0.7×10^6 particles per day in the middle of the summer. The peak of plastic ingestion by the short-tailed shearwater was in June, with a mean increase of 2.1 particles per bird; thus, a peak of 1.3×10^6 particles per day were removed from the ocean during June by this species.

Shaw (1977) estimated that plastic density in Alaska waters is about one piece per 9,000 m^2 of ocean surface (= 111.1 pieces per km^2); using a rough estimate of 3.0×10^6 km^2 of ocean surface in the waters around Alaska, we estimate that there are approximately 333×10^6 pieces of ingestible plastic in the waters around Alaska. The rate of "recruitment" into this "plastic population" is probably low, since estimates of water circulation times in the subarctic North Pacific range between 2 and 5 years (T. Royer, Institute of Marine Science, University of Alaska, Fairbanks, Alaska pers. commun.). When one considers that the short-tailed shearwater alone removes about 80×10^6 particles from the waters around Alaska during June and August (primarily in shelf and shelf-break waters), and that other species are ingesting plastic at the same time, it appears that birds are decreasing the at-sea density of plastic in Alaska waters. Although our estimates of rates of ingestion may be high and Shaw's estimates of plastic density may be low, it is apparent that the birds are decreasing the density of plastic enough to cause the synchronous late-summer decline in ingestion seen in all species (Fig. 3).

Effects of Plastic Ingestion on the Physical Condition and Reproduction of Marine Birds

Perhaps the most important question to be asked about plastic ingestion is whether or not the presence of plastic in the gut has a detrimental effect on the physical condition or reproductive performance of the birds. These effects could take several forms, including direct ones such as starvation, intestinal blockage, ulceration, and internal injury, or indirect ones, such as decreased physical "quality" or reproductive performance.

Starvation could be caused by the physical presence of plastic in the stomach. In birds, hunger and satiety are regulated by receptors in the hypothalamus, where various stimuli reaching the central nervous system influence food intake (Sturkie 1965). Appetite (hunger) can be stimulated by the contraction of an empty stomach, cold temperatures, or the sight of food, and can be inhibited (satiety) by dehydration, distension of the stomach or intestines, warm temperatures, or exercise (Sturkie 1965). A large amount of plastic in the stomach of a bird could decrease feeding activity by maintaining stomach distension and preventing stomach contraction, thus signaling "satiety" to the hypothalamus. Although plastic has been associated with starvation in some birds (Bond 1971; Bourne and Imber 1982), Bourne and Imber correctly pointed out that one must be careful with this interpretation, for it is often difficult to determine if the plastic ingested caused the starvation or if the plastic was ingested because the bird was starving.

Intestinal blockage—preventing the passage of food into the intestine—can only occur if a bird eats a large volume of plastic or a particularly bulky piece of plastic. Intestinal blockage by elastic thread cuttings (Parslow and Jeffries 1972) and by nylon threads (Bourne 1976), which tend to roll into a ball in the stomach (Parslow and Jeffries 1972; R. H. Day pers. observ.), has also been documented. Intestinal blockage by large, bulky items has been documented in Laysan albatross chicks (Kenyon and Kridler 1969; Pettit et al. 1981; S. I. Fefer pers. commun.).

Ulceration and internal injury could be caused by the presence of jagged edges on plastic fragments or by a long period of contact between the plastic and the mucosa of the stomach wall. Van Franeker and Camphuijsen (1984) found a nail embedded in a thick layer of fatlike material in the distal part of the gut of a northern fulmar. Local ulcerations of stomach mucosa as a result of plastic ingestion have been recorded in northern fulmars (Bourne 1976) and in Laysan albatross chicks (Pettit et al. 1981; S. I. Fefer pers. commun.).

Indirect effects of plastic ingestion may take the form of decreased physical "quality" of the bird or decreased reproductive performance. To test for the effects of plastic ingestion on the physical quality of the birds, Day (1980) calculated linear regressions for the number, weight, and volume of plastic particles versus the body weight and body fat class of short-tailed shearwaters and parakeet auklets from Alaska. In all cases, weak ($r^2 \leq 0.17$) negative slopes were found for the lines, and the lines were not significantly different from zero ($P > 0.05$), indicating a slightly negative and weak relationship between increasing amounts of plastic and weights of the birds. No relationship was found when the above variables were plotted against body fat class. Thus, plastic ingestion had limited effects on the physical quality of these birds, at least in terms of body weight and body fat condition. A negative relationship between the amount of plastic and body fat condition has been found in red phalaropes in California, however (Conners and Smith 1982).

The ingestion of plastic may have detrimentally affected the reproduction of parakeet auklets in Alaska in 1976 (Day 1980). Nonbreeding adults average twice as many particles ($\bar{X} = 34.3 \pm 23.9$ particles per bird; $n = 12$) as did breeding adults ($\bar{X} = 17.4 \pm 16.3$ particles per bird; $n = 25$); these differences were significant ($T = 216.5$; $P < 0.01$; Mann-Whitney one-tailed test; Conover 1971). The nonbreeder category included failed breeders and birds that had bred in previous years. Some of the parakeet auklets had up to 81 pieces of plastic in the stomach, which appeared to distend the stomach fully. In several cases, many of the particles had become embedded in "sockets" that had formed in the mucosa of the stomach; under these conditions, the presence of plastic appears to have been detrimental to the function of the stomach. Day (1980) suggested that the decrease in reproductive performance also could have been related to decreased feeding during the prebreeding season.

Another interpretation of this observation is possible. Since, as we have shown, there is age-related variation in the amount of plastic ingested by subadult versus adult parakeet auklets (Table 8), there is a possibility that there is also age-related variation in plastic ingestion within the "adult" category. If this is true, young adults would ingest more plastic than would older adults. Young adult seabirds tend, in general, to increase in reproductive success with increasing age and experience, and many fail at reproduction in their first or second years of breeding (Richdale 1957; Asbirk 1979; Thomas 1983). As a result, the observed poor reproductive success of parakeet auklets containing large amounts of plastic may have actually been the result of normally poor reproductive success of first or second time breeders.

A decrease in reproductive performance could also result from hydrocarbon pollutants associated with plastic. Hydrocarbons such as DDE and polychlorinated biphenyls (PCB's) are suspected of lowering the levels of one or more steroid hormones, resulting in delayed ovulation (Peakall 1970); any delay in normal reproductive cycles in arctic seabirds may contribute to reproductive failures. Although no data are available for raw polyethylene pellets, polystyrene spherules have been found to have PCB's concentrated from seawater onto their surfaces (Carpenter et al. 1972). An increase in the number of particles ingested would thus bring more hydrocarbons into the birds' bodies, preventing successful reproduction.

An explanation alternative to our interpretation can be proposed from the above data. Birds in poor condition may eat more plastic than do healthy birds because they are in poor condition; since these birds are already in poor condition, they probably will not reproduce anyway, yielding the same results. This possibility notwithstanding, the likelihood of decreased reproductive performance as a result of plastic ingestion warrants further investigation.

DISCUSSION AND CONCLUSIONS

Sources of Plastic

Two major types of plastic are ingested by marine birds: plastic fragments and raw plastic pellets. Other types of plastic such as polystyrene spherules, foamed polystyrene (i.e., styrofoam), toys, and other objects, are eaten by seabirds only rarely (Day 1980). Only Laysan albatrosses eat much of these latter types of plastic (S. I. Fefer pers. commun.).

The primary sources of plastic fragments appear to be at-sea solid-waste disposal and (particularly) by discarding plastic objects from fishing boats and marine shipping (Scott 1972, 1975; Cundell 1973; Venrick et al. 1973; Colton 1974; Shaw 1977; Feder et al. 1978; Merrell 1980; Morris 1980a). In the early 1970's, for example, approximately 4.5 x 10^5 metric tons of plastics were discarded at sea each year (National Academy of Sciences 1975 cited in Merrell 1980); Guillet (1974) contends that plastic packaging litter is presently increasing at an exponential rate. Some of the nearshore plastic evidently comes from nearby population centers (e.g., Cundell 1973), although currents and winds play a major role in distributing most of this debris far from its origin (e.g., Venrick et al. 1973; Scott 1975; Merrell 1980). This larger debris is subsequently broken into smaller fragments, which are then ingested by seabirds. The areas of origin of this widely dispersed plastic are often difficult to determine. Studies in the Pacific Ocean, however, have shown that 108 of 109 identifiable plastic items eaten by Laysan albatrosses from the Hawaiian Islands originated in Japan (Pettit et al. 1981) and that most of the litter found on beaches in the Aleutian Islands originated from Japanese and American fishing boats (Merrell 1980). At the latter site, countries represented by identifiable plastic litter were Japan, the United States, the U.S.S.R., Republic of Korea, Canada, Bulgaria, Rumania, and the Netherlands, in order of decreasing frequency. Work in Scotland has shown that most of the plastic debris there also comes primarily from shipping (Scott 1975).

Raw polyethylene pellets are the raw form of polyethylene as it is synthesized from petrochemicals; these pellets are then shipped around the world to manufacturing sites, where they are melted down and fabricated into bags, squeeze bottles, toys, and many other everyday items. Because these pellets are shipped worldwide, the origins of pellets found at sea are difficult to determine. Although the country of origin of these pellets cannot be determined, there are many ways in which they enter the sea. Many pellets probably enter the sea in effluents from plastic-synthesis plants, as has been reported for polystyrene in the North Atlantic (Kartar et al. 1973, 1976; Hays and Cormons 1974; Morris and Hamilton 1974). In Goa, India, plastic factories simply dump their waste plastic into the nearby river, which then carries it to the sea (Nigam 1982). Pellets are also used as packing around larger objects in ships' holds and sometimes are moved in bulk, as is grain; errors in loading and unloading ships at ports allow escapement into the sea. Pellets are sometimes used on the decks of ships to reduce friction for moving large objects, then are washed from the decks and into the sea (Anonymous 1981). After entering the sea, pellets are dispersed through the world's oceans by currents and winds.

There are several mitigating actions that could reduce entry of plastics into the oceans. Filtering effluents from synthesizing-manufacturing plants is relatively easy and will save the companies money. Reducing effluent loss of polystyrene spherules from manufacturing sites in the United Kingdom caused a rapid reduction in ingestion of those spherules by organisms in nearby waters within 3 years (Kartar et al. 1976). Improving loading and unloading procedures at docks would also decrease entry into the oceans. Reductions in the at-sea discarding of plastic litter could be effected by making litter control a requirement for fishing permits (as suggested by Merrell 1980) or by making shipboard incinerators a requirement for licensing a ship.

Another mitigating action is to alter the degradation rates of the plastics themselves. Guillet (1974) and Gregory (1978, 1983) have shown that weathering of polyethylene and styrofoam occurs naturally and eventually leads to disintegration and dispersal as "dust." Gregory (1983) stated that it would require 3-50 years for complete disintegration to occur on the beach, and apparently much longer at sea. One way to accelerate degradation is to make the plastics highly degradable under normal conditions. The plastics industry has encountered many practical problems in trying to produce degradable plastics, however (Taylor 1979; contra Guillet 1974), leaving regulation of loss into the sea as a more feasible and realistic method of reducing the abundance of plastic in the oceans.

Rates of Ingestion in Marine Birds: A Look to the Future

We feel that it is appropriate to discuss the monitoring of species or groups of seabirds for rates of plastic ingestion. Those species or groups ingesting the most plastic (either with the highest frequencies of occurrence or the highest mean number of particles per bird) should be monitored closely in the future. As we have shown, procellariiform birds are the seabirds most vulnerable to plastic pollution (Tables 1-3). A high percentage of the species examined contain plastic, the two highest average amounts of ingestion occurred in this group, and the earliest records of plastic ingestion by marine birds were from this group (Kenyon and Kridler 1969; Rothstein 1973). Procellariiform birds tend to scavenge at sea and to ingest randomly any plastic that they encounter (Table 7; Ashmole 1971; Day 1980; Day pers. observ.). They also tend to eat large or oddly-shaped plastic objects (see comments in Table 2) that may cause intestinal blockage or internal injury (e.g., Bourne 1976; Pettit et al. 1981). These birds also pass ingested plastic on to their chicks through regurgitation-feeding (e.g., Kenyon and Kridler 1969; Rothstein 1973), perhaps increasing prefledgling mortality. Procellariiform birds also feed at or near the sea's surface and eat a high frequency of crustaceans and cephalopods (Ashmole 1971), two prey groups that are correlated with high rates of plastic ingestion (Tables 4, 5). On the other hand, procellariiform birds are able to eliminate some plastic by egesting casts containing indigestible items, such as squid beaks.

Another species of major concern is the parakeet auklet (Table 2). This species averaged the highest number of plastic particles of 37 species of seabirds in Alaska, 13.7 particles per bird, and showed evidence of decreased reproductive performance there as a result (Day 1980). This species preys primarily on crustaceans, a prey group linked to high rates of ingestion of plastic (Table 5). Some of the stomachs examined by Day were fully distended because so much plastic was present. Phalaropes also should be monitored closely for ingestion, because the few data available (Table 2) indicate a capacity for high rates of plastic contamination. At present, the other species of seabirds appear to have low rates of plastic ingestion, indicating that less-intensive monitoring is needed.

Monitoring should be done at selected sites in the Northern and Southern Hemispheres and in all oceans. Birds found dead on beaches and birds collected for museums should be examined closely for frequencies of ingestion and for the amount of plastic ingested; birds found dead should also be checked for the cause of death and chlorinated hydrocarbon levels should be determined. Any sampling gaps can then be filled with selective collecting of species of interest. We suggest a 2- or 3-year cycle for monitoring.

Feeding Habits and Plastic Ingestion

A few species of seabirds evidently ingest at random any plastic or objects that they encounter. Before the production of plastics, most objects encountered by birds at the sea's surface were digestible (except for floating pumice); selection may have favored those species that ingested any such objects (Rothstein 1973). Many species, however, select for specific kinds, colors, shapes, color-shape combinations, or sizes of plastic (Day 1980). Such selection suggests that these species are mistaking plastic objects (a recent addition to the surface of the ocean) for prey items. Prey items that the light-brown pellets most resemble to the authors are planktonic crustaceans and pelagic fish eggs. Other colors of pellets may resemble the eyes of fishes or squids, the bodies of larval fishes, or other, unknown food items.

It is likely that not a single factor, but a suite of (sometimes) interacting factors, affects the amount of plastic ingested by seabirds. These factors include the feeding method and prey type of the species, the tendency for generalism or specialization in feeding habits, age of the birds, time of year, at-sea density of plastic, and geographic location of the birds.

The Problem of Effects of Plastic Ingestion

It is unfortunate that we still do not know the true extent of the effects of plastic ingestion. We suspect that, for most species, the rates of ingestion and the amounts of plastic ingested are low enough that there is little detrimental effect on the birds involved. There are several species, mentioned earlier, that have been shown to exhibit sufficiently high rates of ingestion to warrant concern. Decreased feeding rates before breeding may result in poorer physical condition of the bird, leading to an inability to secure or maintain a breeding territory, to lay high-quality eggs, or to successfully incubate those eggs. Data from parakeet auklets

(Day 1980) suggest that any or all of these conditions may apply to that species, and data from short-tailed shearwaters (Day 1980) and red phalaropes (Connors and Smith 1982) suggest a link between high amounts of plastic ingested and decreased physical "quality." The possibility of hydrocarbon contamination through plastic ingestion (Carpenter et al. 1972) also has serious implications. Consequently, we believe that carefully controlled experiments on the effects of plastic ingestion need to be performed to determine whether or not a serious problem really exists. These experiments could conceivably be performed in conjunction with zoos or schools of veterinary science.

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IMPACT OF OCEAN DEBRIS ON MARINE TURTLES: ENTANGLEMENT AND INGESTION

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ABSTRACT

Marine turtles are affected to an unknown but potentially significant degree by entanglement in, and ingestion of, synthetic oceanic debris. Nearly all known records of olive ridley turtle, Lepidochelys olivacea, in the Hawaiian Islands have resulted from entanglement in drifting scraps of fishing gear. In the North Pacific (lat. 35°-45°N), incidents of leatherback turtle, Dermochelys coriacea, fatally entangled in pieces of monofilament mesh have been recorded. However, as with many such cases involving marine turtles, it is unclear if entanglement occurred in discarded fragments or in intact gear being actively fished.

Marine turtles have been found to eat a wide array of synthetic drift items, including plastic bags, styrofoam beads, and monofilament fishing line. Toxic chemicals released by these materials, as well as physical obstruction to the digestive tract, are two possible adverse impacts.

INTRODUCTION

International efforts to conserve and manage sea turtles effectively have been periodically hampered by the discovery of new or previously unidentified impacts on surviving populations. Sea turtles are already known to be directly threatened by an array of human activities on nesting beaches and in marine foraging habitats. Major impacts include intensive exploitation for meat, eggs, shell, and skin (all of which are often taken for commercial purposes), the incidental capture and drowning of turtles in shrimp trawls, and alteration of habitat by coastal development. Other problems that have received far less attention in the literature include petroleum and toxic chemical pollution, incidental catch by a variety of fisheries (e.g., pound nets, gill nets, drift nets, purse seines, longlines, lobster and other types of traps), ingestion of plastics and tar, disease, cold waves, and predation by large sharks. Considered separately, each of these lesser known impacts may not necessarily cause high rates of mortality or morbidity. However, their combined effect over an extended

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period could very well be a significant retardant to the recovery of certain populations. It is, therefore, imperative that each adverse element be adequately examined and understood.

All sea turtles have been legally protected in the United States since 1978 under provisions of the Endangered Species Act. A number of other countries have also implemented protective measures in recent years and engaged in cooperative efforts to conserve and study these turtles (Bjorndal 1982; Groombridge 1982; Bacon et al. 1984).

A basic problem in determining the scope and magnitude of impacts on sea turtles is that all species lead an oceanic existence during portions of their life history. Broad gaps exist in the knowledge of sea turtles away from land because they are seldom seen, let alone studied. In contrast, reasonably good ecological data exist for the breeding phase when adult females, eggs, and hatchlings are accessible on land. The leatherback, Dermochelys coriacea, and olive ridley, Lepidochelys olivacea, seem to be the most pelagic species, living well offshore from the time they leave the beach as hatchlings until they return to breed as adults. Others, like the green turtle, Chelonia mydas, loggerhead, Caretta caretta, and hawksbill, Eretmochelys imbricata, inhabit coastal waters as adults, but spend varying segments of their immature life in the open ocean. Even then the adults regularly undertake breeding migrations which place them for a time over deep water. The limited information available on the Australian flatback, Chelonia depressa, and the severely depleted Kemp's ridley, Lepidochelys kempi, suggests that these species also pass through pelagic phases of development.

Man-made debris floating at the surface in the same oceanic habitat occupied by sea turtles presents a potential for substantial interaction. The amount of refuse now entering the world's oceans, especially plastics and tar, appears to have reached huge proportions (Carpenter and Smith 1972; Venrick et al. 1973; Wong et al. 1974, 1976; Morris 1980a, 1980b; Van Dolah et al. 1980; Eldridge 1982). For example, Horsman (1982) estimates that 639,000 plastic containers (including bags) are dumped into the sea daily from merchant ships alone. Floating material of a natural and synthetic nature is known to collect in drift lines that result from converging offshore currents or strong winds sweeping the sea surface. In the Caribbean, where rafts of sargassum are prominent, such areas are believed to be preferred habitat for some, and possibly most, small sea turtles of the region (Fletemeyer 1978; Carr and Meylan 1980; Carr 1983). A similar situation probably occurs in the Pacific and elsewhere, although sargassum rafts would not be a common feature since in many areas they do not exist. Plastic particles, tar, and other floating debris that aggregate in drift lines are likely to be consumed by turtles that normally feed on small surface-dwelling invertebrates and other plankton. Another form of discarded plastic, transparent bags and sheets, has also been implicated in recent years as being harmful to sea turtles, particularly adult leatherbacks. This material is apparently mistaken for drifting jellyfish (Scyphomedusidae), a principal food item of the leatherback.

Another aspect of the debris problem--the entanglement of turtles in floating and bottom-fouled scraps of line, net, or other lost or abandoned gear--has only infrequently been noted in the literature. Unlike the ingestion of plastic bags, little publicity has appeared in the mass media on debris entanglement. Because turtles are incidentally caught in many kinds of fisheries, there is difficulty in determining whether entanglement actually involves debris per se, or represents capture in actively fished gear that somehow tore free. Nevertheless, it is apparent that sea turtles are prone to all kinds of entanglement as a result of their body configuration and behavior. Entanglement in debris may therefore be best considered as an extension of the incidental catch problem.

The phenomena of sea turtles ingesting and becoming entangled in debris have not previously been the subject of a comprehensive review. The objective of this paper is to assemble and evaluate existing information, most of which is scattered throughout the literature or contained in unpublished records. The availability of a consolidated source of data may then serve as a useful starting point to assess the scope and magnitude of the problem. It will also provide a basis for determining what future research is needed to address the problem adequately.

METHODS OF DATA COLLECTION

Documented records of turtles that had ingested or become entangled in debris were compiled through an extensive literature search, and by personal inquiries to numerous researchers worldwide. In addition, a relatively large number of unpublished cases for the Hawaiian Islands were included that had been gathered by the author since 1973.

To the extent that they exist, pertinent details from each case were abstracted and assembled in an annotated data table. This information included the species of turtle, date, location, carapace length, weight, sex, and a concise description of the event, often with quotations from the original source. For cases of ingested debris, usually only synthetic items were listed, and not the natural food items present. The literature citation or other origin of the report was also entered into the data table. Summaries of all cases were tabulated to identify geographic distribution, species involved, age composition of the turtles, and types of impacting debris.

In accomplishing this study, it was realized that many more cases undoubtedly exist than are contained herein. With the circulation of this paper, it is hoped that old and new reports of debris ingestion and entanglement will be sent to the author for use in a future revision.

RESULTS

Overall Findings

Concise case-by-case descriptions of debris ingestion and entanglement by species are presented in Tables 1 and 2. It was possible to locate 79 reports dealing with ingestion (Table 1) and 60 dealing with entanglement (Table 2). None of the cases occurred before the 1950's; 95% have taken place since 1970.

Debris ingestion involving only single turtles comprises 60% of the cases shown in Table 1, while 32% cover multiple accounts representing at

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
				***Chelonia mydas*, green turtle and *C. agassizi*, black turtle**	
I-Cm-1	Late 1950's	Golfito, Costa Rica (Pacific coast)	—	Mass mortality attributed to the ingestion of plastic banana bags thrown from a wharf.	A. Carr. pers. commun. cited in Cornelius 1975; Hirth 1971b; Wehle and Coleman 1983; Meter 1983.
I-Cm-2	1958, 1976-77	Tortuguero, Costa Rica	Adult, F	"Some rather unconventional kinds of food" were consumed in the internesting habitat, including terrestrial plant material. Four of 11 turtles (37%) had eaten plastic, and 2 (18%) had eaten cloth.	Meylan 1978.
I-Cm-3	1972-73	Ascension Is.	—	"When refuse is dumped from ships or from shore, turtles sometimes move in to feed on it." Turnip tops have been found in stomachs.	Carr et al. 1974; A. Carr pers. commun. cited in Coston-Clements and Hoss 1983.
I-Cm-4	1979	Pisco, Dep. Ica, Peru	52 to 89 cm	Nine of 39 stomachs (23%) examined contained plastic bags.	Brown and Brown 1982.
I-Cm-5	Ca. 1980	New South Wales, Australia	"Subadult"	Washed ashore freshly dead "with length of fishing line hanging out both its mouth and cloaca." Preserved in the Australian Museum (Sydney) but not dissected.	C. Limpus pers. commun.
I-Cm-6	1/4/72	Kochi Prefecture, Japan	S-43 cm	"Vinyl film" found in stomach.	I. Uchida pers. commun.
I-Cm-7	9/5/83	Wakasa Bay, Fukui Prefecture, Japan	S-74 cm, 55 kg, F	Orange, yellow, and green pieces of synthetic line found in stomach. Also a transparent plastic bag and pieces of a synthetic fishing net with fish eggs attached.	I. Uchida pers. commun.
I-Cm-8	9/69	Iles Scilly (Motu-Honu), Fr. Polynesia	—	Long piece of plastic found in one of several stomachs examined.	Hirth 1971a, 1971b.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cm-9	10/23/81	Fakaofo Atoll, Tokelau (lat. 9°22'S, long. 171°16'W)	C-105 cm, F	Entire digestive tract empty except for a 2 by 15 cm piece of blue plastic sheet.	Balazs 1983b.
I-Cm-10	1976	Kwajalein, Marshall Is.	--	Turtles scavenge on kitchen scraps that are thrown into the ocean each day from the U.S. military facility.	Pritchard 1977.
I-Cm-11	1974-79	Hawaiian Is.	--	Items occasionally found in the digestive tract include hard plastic fragments, pieces of plastic bags, cloth, small diameter line, and terrestrial vegetation. Also tar stains in the mouth.	Balazs 1980.
I-Cm-12	1975	Oahu, Hawaii, U.S.A.	30 cm	Turtle that had been reared in captivity from a hatchling ingested a sheet of transparent plastic ca. 20 by 20 cm that accidentally fell into its pen. Twisted tip of plastic seen protruding from cloaca and pulled out. Turtle appeared unharmed. It is unknown if turtle could have voided plastic without assistance.	G. Balazs unpubl. data.
I-Cm-13	12/13/76	Tern Island, FFS, NWHI	S-45 cm	Fresh dead stranding 19 months after release from captive rearing. Sighted regularly during this period feeding on food scraps discarded by U.S. military facility. Digestive tract contained synthetic fiber cloth 8 by 20 cm, and numerous fish bones. Cause of death undetermined.	G. Balazs unpubl. data.
I-Cm-14	5/82	Midway, NWHI	C-36 cm	Man-made fibers in stomach, as well as crab legs and <u>Janthina</u>. Same as Case E-Cm-8 found entangled in a scrap of blue net.	G. Balazs and M. Pillos unpubl. data.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cm-15	10/78	Lanai, Hawaii	C-96 cm, F	Large pieces of black and transparent plastic bags twisted throughout the intestines of a turtle speared by a fisherman. Plastic in feces near cloaca suggested that blockage had not occurred.	Balazs 1980.
I-Cm-16	2/9/76	Hutchinson Is., Florida, U.S.A.	10 cm	Found dead on the beach with tar in its mouth. Had been released 20 days earlier following captive rearing.	Witham 1978.
I-Cm-17	8/2/77	Merritt Is., Florida, U.S.A.	32 cm	Found in the surf zone "upside down and disoriented." Tar was removed from the mouth, and the turtle recovered.	L. M. Ehrhart pers. commun. cited in Witham 1978.
I-Cm-18	1978-79	Florida Keys to Cape Canaveral, Florida, U.S.A.	"Small"	Weathered petroleum (tar) sealed the mouths and nostrils. Impacted turtles can be cleaned using vegetable oil or a soapless hand cleaner followed by thorough rinsing. This procedure "rehabilitated some tar-impacted turtles, but all oiled turtles died." "Widespread dispersal of petroleum residues suggests that indeterminate numbers of sea turtles may be dying at sea." "27 small sea turtles of three species were handled," but the number of green turtles was not stated. See also Case I-Cc-8 and I-Ei-43.	Witham 1983.
I-Cm-19	9/5/80	Port Canaveral, Florida, U.S.A., (lat. 28°24'30"N, long. 80°35'00"W)	12 cm	Found alive with "tar ball" in mouth. Treated and released. Turtle had previously been reared in captivity by the Florida Department of Natural Resources.	Mann and Lee 1981.
I-Cm-20	2/14-19 1981	Hutchinson Is., Florida, U.S.A.	9 to 14 cm	Seven turtles found stranded alive with tar in mouth and on body.	Anonymous 1981a.
I-Cm-21	2/18/81	Indian Harbor Beach, Florida, U.S.A.	14 cm	Found alive with dense tar packed in the throat. Treated and released 3/24/81.	Anonymous 1981b.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cm-22	4/20/82	Long Key, Florida, U.S.A. (lat. 24°45'N, long. 80°45'W)	18 cm	Found alive covered with tar which had also been ingested.	Roche and Witham 1982.
I-Cm-23	6/29/82	Homestead Bay-front Park, Florida, U.S.A. (lat. 25°30'N, long. 80°25'W)	22 cm, 16 cm	Live strandings with tar in mouth and covering body.	Kasqowitz 1982.
I-Cm-24	9/14/84	Mustang Island, Texas, U.S.A. (lat. 27°49.8'N, long. 97°03.3'W)	8-5.6 cm	Dead stranding with tar in roof of mouth and "minute pieces of plastic-colored foil and spherule of plastic used when polyethylene is cast." Pieces of three flippers missing.	A. F. Amos pers. commun.
I-Cm-25	10/9/84	Kaena Point, Oahu, Hawaii	8-35 cm	Died 1 day after being found floating offshore and unable to dive. Turtle not emaciated. Intestine contained a distinct blockage consisting of frayed plastic line and hard dried fecal matter.	G. Balazs unpubl. data.
			Caretta caretta, loggerhead turtle		
I-Cc-1	10/67	Madeira (lat. 32°45'N, long. 17°W)	--	Pieces of plastic in the stomach. "Like pick-nickers may litter the countryside with refuse, ships are beginning to litter the surface of the sea. While cruising in an area north of the Azores, where sometimes a day or two went past without ships being sighted, their presence at sea was demonstrated by boxes, jars, etc., made of plastic floating on the surface of the sea. Apparently turtles mistake these objects for food and swallow them. One wonders whether in the end the intestine of the turtle will not become blocked by such undigestable matter.	Brongersma 1968, 1969.

Table 1.—Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cc-2	1968-73	Cape Agulhas, South Africa	6.6 cm	Strandings of posthatchlings revealed that 2 of 32 stomachs (6%) with contents contained small plastic beads (1-2 mm cylinders and two 1-mm sphere). Pieces of fine plastic sheet 2 by 3 cm were found in two other turtles. The nature of identifiable contents "suggests that loggerhead hatchlings will eat anything that is floating and small enough to swallow."	Hughes 1970, 1974a.
I-Cc-3	<1974	South Africa	C-60 to 70 cm	Stomach contents from four of nine turtles (44%) contained synthetic debris including plastic strip, plastic bags, and pieces of glass. Bark and sugarcane also present.	Hughes 1974b.
I-Cc-4	8/2/75	Cabrera, Balearic Is., Mediterranean	40 cm, 10 kg	Intestines contained pieces of plastic, rope, tar, and onion.	Salvador 1978.
I-Cc-5	>1974	Cumberland Is., Georgia, U.S.A.	—	Dead stranding with an iron bolt imbedded in roof of the mouth causing distortion of the skull.	C. Ruckdeschel and C. R. Shoop pers. commun.
I-Cc-6	4/6/80-11/1/80	Cumberland Is., Georgia, U.S.A.	--	Seventeen of 43 guts (43%) examined from stranded turtles contained large amounts of ocean-dumped, man-caught food, including fish, shrimp carapaces, and squid remains. The intestines were often packed with fish bones. Likely sources of this food debris included unwanted catch from shrimp trawlers and discharge from seafood processors. Incidental feeding may cause an artificially large turtle population in the trawler impacted fishing area.	Shoop and Ruckdeschel 1982
I-Cc-7	11/78	Cape Canaveral, Florida, U.S.A.	62 kg	Live capture in trawl. Heavy monofilament fishing line protruding from mouth. 60-90 cm piece pulled out. Numerous encrusting organisms, primarily mussels, growing on line and partly digested. Presence of bile on swallowed portion suggested that the line had entered the small intestine.	L. Ogren pers. commun.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cc-8	1978	Florida Keys to Cape Canaveral, Florida, U.S.A.	"Small," 57 cm	Weathered petroleum (tar) sealed the mouths and nostrils. "27 small sea turtles of three species were handled," but the number of loggerheads was not stated. A 57-cm loggerhead was seen with a small amount of tar in its mouth, but appeared to be unaffected. See also Case I-Cm-18 and I-Ei-4.	Witham 1983.
I-Cc-9	1976-79	Texas, U.S.A.	---	Digestive tract of dead stranding contained pieces of a plastic bottle, as well as bird feathers and sargassum seaweed.	B. Fulls pers. commun. in Rabalais and Rabalais 1980.
I-Cc-10	Early 1970's	Mon Repos, Queensland, Australia	Adult, F	Stomachs of three turtles drowned in shrimp trawls in internesting habitat contained fish, shrimp, and cuttlefish. Though not suggested by the author, the apparent atypical nature of this food indicates it may have been unwanted catch discarded by trawl fishermen (compare with Case I-Cc-5).	Limpus 1973.
I-Cc-11	10/31/72	Hyogo Prefecture, Japan	S-30 cm	Plastic debris found in stomach. Had been released at Tokushima Prefecture 90 days earlier following captive rearing from a hatchling.	I. Uchida pers. commun.
I-Cc-12	5/19/75	Owase, Japan	S-69 cm, 35 kg, F	Transparent and blue plastic sheet found in stomach.	I. Uchida pers. commun.
I-Cc-13	6/75	Kushimoto, Japan	S-60 cm, 33 kg, F	Plastic debris found in stomach.	I. Uchida pers. commun.
I-Cc-14	9/29/80	Hyogo Prefecture, Japan	S-84 cm, 83 kg, F	Plastic debris found in stomach.	I. Uchida pers. commun.
I-Cc-15	5/14/84	Shimane Prefecture, Japan	S-33 cm	Plastic bag, piece of synthetic line, and domestic vegetables found in stomach. Had been released at Okinawa 50 days earlier following captive rearing from a hatchling.	I. Uchida pers. commun.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Cc-16	12/29/78	Cocoa Beach, Florida, U.S.A.	S-73 cm, 54 kg	Found with 3 monofilament lines protruding from the mouth and cloaca. Lines were cut flush with the jaw and skin, and the turtle was kept in captivity. It floated abnormally at the surface and would not feed. After 6 weeks in this condition, it excreted 4.6 m (15 ft) of line. Thereafter, a dramatic change occurred in its behavior and it fed voraciously. It was released 1 month later on 3/14 weighing 48 kg. At the time the line was passed, it weighed 45 kg.	L. Ehrhart, T. Clabaugh, S. Gravel, and R. Witham pers. commun.
I-Cc-17	10/5/84	Chesapeake Bay, Virginia, U.S.A.	S-51 cm	Captured alive in a pound net and found to have the "half-round base of a plastic champagne cork stuck around the base of the lower left jaw." Turtle appeared healthy but had a small necrotic spot on the jaw beneath the cork.	J. A. Musick pers. commun.
I-Cc-18	1979-80	Madeira (lat. 32°45'N, long. 17°W)	S-27 to 52 cm	Three turtles purchased at Funchal were found to contain pieces of glass up to 4 cm long, pieces of plastic, nylon thread, and numerous small clots of oil throughout the digestive tract.	Van Nierop and Hartog 1984
I-Cc-19	6/4/81	Sao Miguel, Azores (lat. 37°33'N, long. 25°27'W)	S-26 cm	Purchased from fisherman. The caecum contained a piece of white paper 3 by 3 cm, 4 pieces of nylon thread 1-3 cm, a ball of thread 4 by 1 by 1 cm, 6 pieces of polyethylene 1 by 1 by 0.5 cm, and clots of oils throughout the digestive tract.	Van Nierop and Hartog 1984
I-Cc-20	5/25/80	Salvagen Grande (lat. 30°09'N, long. 15°52'W)	S-22 cm, F	Caught 1 mile offshore. Gut contained a piece of nylon thread 5 cm long, 5 pieces of firm transparent plastic up to 1 cm long, and clots of oil dispersed throughout the tract.	Van Nierop and Hartog 1984

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
			Eretmochelys imbricata, hawksbill turtle		
I-Ei-1	--	Ascension Is.	--	Invertebrate fauna "appears to be extremely lean, and there is little submerged vegetation of any kind. This may account for the peculiarly scrawny look of Ascension hawksbills, and also may explain their observed tendency to group about any refuse that is dumped in shore waters."	Carr and Stancyk 1975
I-Ei-2	1970-72 (July-October)	Tortuguero Bank, Costa Rica	Adults, 2 F, 2 M	Four out of 20 stomachs (20%) containing food were found to have plastic and other man-made litter. "A compacted ball of well-chewed sheet plastic" was present in one of the stomachs.	Carr and Stancyk 1975, cited in Witzell 1983.
I-Ei-3	10/22/78	Selvagen Pequena, eastern Atlantic (lat. 30°2'N, long. 16°1'W)	36 cm, M	"Colon and rectum appeared to contain a variety of man-made litter, viz., 15 pieces of hard plastic (two orange coloured, the rest white; largest piece measuring about 28 by 20 by 3 mm) and several thin membranaceous fragments (one yellow, one black, rest whitish or transparent)." Turtle taken from "bay on east coast."	Hartog 1980, cited in Witzell 1983.
I-Ei-4	1978-79	Florida Keys to Cape Canaveral, Florida, U.S.A.	"Small"	Weathered petroleum (tar) sealed the mouths and nostrils. "27 small sea turtles of three species were handled," but the number of hawksbills was not stated. See also Case I-Cm-18 and I-Cc-8.	Witham 1983.
I-Ei-5	1/16/81	Jupiter Island, Florida, U.S.A.	8-21 cm, F	Emaciated beach stranding with styrofoam precursor (plastic bead) and paper in digestive tract. Injury to front flipper.	Meylan 1984.
I-Ei-6	2/81	Ft. Lauderdale, Florida, U.S.A.	8-14 cm, F	Emaciated beach stranding with plastic particles and tar droplets in digestive tract.	Meylan 1984.
I-Ei-7	2/16/81	Jensen Beach, Florida, U.S.A.	8-14 cm	Beach stranding with styrofoam precursors in digestive tract. Tar present on head and throughout digestive tract.	Meylan 1984.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Ei-8	2/16/81-2/17/81	Hutchinson Is., Florida, U.S.A. (lat. 17°17'N, long. 80°13'W)	10 cm, 15 cm	Two turtles found alive with tar in mouth and around head. One died the next day.	Anonymous 1981a.
I-Ei-9	6/23/82	Big Pine Key, Florida, U.S.A. (lat. 24°39'N, long. 81°19'W)	18 cm	Stranding with tar in mouth and covering body. Cleaned and released.	Klett 1982.
I-Ei-10	7/13/83	Hutchinson Is., Florida, U.S.A.	8-20 cm	Beach stranding with styrofoam, plastic sheet, plastic particles and tar droplets in digestive tract. Carapace and limbs coated with tar. Nostrils and mouth sealed.	Meylan 1984.
I-Ei-11	10/15/84	Kahana Bay, Oahu, Hawaii	8-36 cm, 5.4 kg	Died 2 days after stranding in an emaciated condition. Left front flipper completely amputated but healed. Gooseneck barnacles on carapace suggested a pelagic existence. Large pocket of numerous plastic particles and semi-hard fecal matter found at midpoint of intestine. Intestinal wall had expanded into stomachlike compartment. Plastic and fecal matter mass weighed 780 g.	G. Balazs unpubl. data.
			Dermochelys coriacea, leatherback turtle		
I-Dc-1	8/4/68	Ameland Is., Netherlands	158 cm, 485 kg, F	Dead stranding with piece of plastic in the gut.	Brongersma 1969, 1972.
I-Dc-2	7/7/70	Ramsgate, Natal, South Africa	C-160 cm, 340 kg, F	Dead stranding. "Duodenal tract completely filled by a sheet of heavy plastic measuring 3 by 4 m when spread out. The sheet was so tightly packed that considerable force was required to open it initially, and it must have had a serious effect on the passage of food from the stomach. Whether a complete blockage had been effected was difficult to ascertain because there was pink fluid in the lower gut." 697 well-developed eggs present.	Hughes 1974a.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Dc-3	7/29/71	Cornwall, England	C-142 cm, 224 kg, F	Small plastic bags found in the stomach and posterior gut. Turtle had become entangled in the lines of lobster pots.	Brongersma 1972; Hartog and Van Nierop 1984.
I-Dc-4	7/30/77	Hyogo Prefecture, Seto Sea, Japan	S-120 cm	A 60 by 70 cm piece of twisted vinyl fiber was pulled from the cloaca after a 5 cm piece became visible. The turtle had been entangled 10 days earlier in a gill net. Died the following day.	I. Uchida pers. commun.
I-Dc-5	9/22/80	Smith Point State Park, New York, U.S.A. (lat. 40°45'N, long. 72°48'W)	183 cm	Badly decomposed. Had ca. 180 m of heavy duty nylon fishing line in the gastrointestinal tract, with leading piece extending from the mouth.	Sadove 1980.
I-Dc-6	10/22/81	Beach Haven, New Jersey, U.S.A. (lat. 39°33'33"N, long. 74°14'10"W)	150 cm, F	Fresh dead stranding. "Large number of plastic bags in posterior stomach and extending 13 cm into intestine; claylike mass blocking intestinal valves."	Schoelkopf 1981.
I-Dc-7	Summer 1982	Long Island, New York, U.S.A.	---	Eleven out of 15 leatherbacks (73%) that washed ashore during a 2-week period had plastic bags "totally blocking their stomach openings." Ten of the beached turtles had four to eight quart-sized bags in their stomachs. One had eaten 15. Turtles have been seen swimming around transparent bags in the ocean with their mouths open, as if they thought the discarded plastic was their favorite meal. The turtles found were too badly decomposed for full autopsies, but "the plastic bags either contributed to the cause of death or may have been the cause of death." (All information was provided by Samuel Sadove, see also Sadove[3].)	Anonymous 1983b.

Table 1.—Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Dc-8	1980-84	New York Bight, U.S.A.	—	"Of a total of 42 sea turtle strandings reported since 1980, almost 50% of these animals contained significant amounts of plastic in their stomachs. One animal had 15 quart-size clear plastic bags in its stomach. Although death from plastic ingestion could only be determined for four animals, it is possible that a number of animals' demise or susceptibility to injury causing death could be the result of stress from partial blockage caused by the plastic."	Sadove[3].
I-Dc-9	1979-80	Pucusana, Depto. Lima, Peru	—	Plastic bags and film were noted in intestinal tracts of 19 of 140 specimens (13%) examined. All cases involved sizable pieces of plastic. The plastic was within the lumen of the digestive tract and in a twisted, elongate form suggesting peristaltic transport.	Fritts 1982.
I-Dc-10	1970-80	Worldwide	—	Evidence showing that ingestion of plastic is common; 7 out of 16 stomachs (44%) contained plastic or cellophane. Turtles are different from those quantitatively summarized by Fritts (1982) and Sadove (see footnote 3).	Mrosovsky 1981.
I-Dc-11	—	—	—	Large amounts of plastic commonly occur in the intestines.	J. Frazier personal observations in Eisenberg and Frazier 1983.
I-Dc-12	—	Coast of France	—	Seven out of eight (87.5%) turtles had swallowed plastic.	Duron and Duron 1980.
I-Dc-13	1980	Coast of France	—	Plastic bags were found in the stomachs of 2 of the 3 dead stranded turtles examined.	Duguy and Duron 1981.
I-Dc-14	1981	Coast of France	C-160 cm, M C-152 cm, M	Plastic bags were found in the stomachs of 2 of the 3 dead stranded turtles examined.	Duguy and Duron 1982.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Dc-15	6/10/79	Coast of France	C-160 cm, F	Dead stranding with plastic bags in the stomach that appear to cause a blockage to the movement of food.	Duguy et al. 1980; Duguy 1983.
I-Dc-16	1980-84	Massachusetts, U.S.A.	--	Of 9 dead strandings examined over a 5-year period, 4 contained plastic. Two had balls of accumulated plastic in the upper part of the colon, and 2 had pieces of plastic in the esophagus. One of the latter cases involved a small piece of a plastic bag and the plastic-coated label from a prescription bottle of medication.	R. Prescott and N. Fraser pers. commun.
I-Dc-17	10/17/83	Chesapeake Bay, Virginia, U.S.A.	C-130 cm	Bloated stranding that was found to have a "plastic wrapper from a ketchup packet in its intestine."	J. A. Musick pers. commun.
I-Dc-18	1979-80	Bay of Plenty, New Zealand	Adult	Died shortly after beaching itself. Necropsy revealed the esophagus to be "packed with polythene bread bags."	Cawthorn 1985.
I-Dc-19	9/7/80	Scilly Isles, England	Est. 500 kg, M	Caught alive in the lines of a lobster pot. Pylorus of stomach was "more or less blocked by a ball of compressed plastic composed of a transparent plastic bag 15 by 17 cm, a frayed sheet of white plastic and many small shreds 0.4-4 cm."	Hartog and Van Nierop 1984.
I-Dc-20	8/4/81	Terschelling Is., Netherlands	510 kg, M	Caught alive at sea, but died aboard the vessel. Stomach contained a "well-preserved plastic bag 13.5 by 17.5 cm." A small bird feather was found in the intestine.	Hartog and Van Nierop 1984.
				<u>*Lepidochelys kempi*</u>, Kemp's ridley turtle	
I-Lk-1	6/27/82	Ft. Lauderdale, Florida, U.S.A.	23 cm	Tar in mouth and covering body. Taken for treatment.	Fletemeyer 1982.

Table 1.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
I-Lk-2	1980's	Padre Island, Texas, U.S.A.	Immature	When large numbers of captive-reared yearlings have been released, there are sometimes a few that wash up on the beach during the following week. Many of these appear to have eaten tar balls, as indicated by tar on their beak and mandible. A few of the stranded turtles are dead, but most appear to be healthy when cleaned up and re-released. Also, a milk carton was found to have been ingested by a turtle stranded a year after being released.	T. Wibbels pers. commun.; Anonymous 1983c.
I-Lk-3	1980's	Texas, U.S.A.	—	Out of a number of stranded turtles necropsies, two were found to have debris in the gut. One had "parts of a beer can" and the other contained a plastic bag.	D. Owens pers. commun.

[1]FFS = French Frigate Shoals; NWHI = Northwestern Hawaiian Islands.
[2]C = curved; S = straight.
[3]S. Sadove, Okeanos Ocean Research Foundation, P. O. Box 776, Hampton Bay, N.Y. 11946, unpubl. rep., 1984, 2 p.

Table 2.--Worldwide records of marine turtles entangled in oceanic debris

Case No.	Date	Location[1]	Carapace length;[2] weight, and sex	Description	Reference
				***Chelonia mydas*, green turtle**	
E-Cm-1	--	Tortuguero, Costa Rica	Adults, F	Several times over the years nesting turtles have come ashore with monofilament line wrapped around a flipper, sometimes so tight there was considerable tissue necrosis. Loss of limb predicted if the line had not been removed. No cases have been published.	K. Bjorndal and A. Carr pers. commun.
E-Cm-2	1982	Bundaberg, Queensland, Australia	"Subadult"	"Washed in dead tangled in rope with a light reef anchor attached. Origin and purpose of anchor undetermined."	C. Limpus pers. commun.
E-Cm-3	7/30/84	San Gabriel California, U.S.A.	Est. 90 kg	Reported to be seen with fishing line entangled around the tail and a long piece of wood.	H. S. Stone unpubl. data.
E-Cm-4	6/29/74	East Is., FFS, NWHI	Adult, F	Synthetic line and large float found entangled around the neck of a turtle coming ashore to nest.	G. Balazs unpubl. data.
E-Cm-5	5/19/80	Trig Is., FFS, NWHI	Adult, F	Large piece of synthetic trawl net found entangled around the neck of a turtle lying motionless on a nesting beach. Net cut free and turtle released in apparently good health.	G. Balazs unpubl. data.
E-Cm-6	9/80	East Is., FFS, NWHI	S-5 cm	Dead hatchling found on land with right front flipper entangled in strip of cloth debris.	J. Andre pers. commun.
E-Cm-7	4/8/82	Lisianski Is., NWHI	S-43 cm	Left front flipper entangled in large piece of synthetic net snagged on reef flat close to shore. Necrosis at site of constriction. Turtle tagged and released.	Henderson 1984.
E-Cm-8	5/82	Midway, NWHI	C-36 cm	Found dead floating nearshore entangled in a piece of blue synthetic net. Deep cut in right front flipper.	G. Balazs unpubl. data.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Cm-9	4/18/82	Whale-Skate, FFS, NWHI	Adult, M	Rib bones and metal flipper tag found entangled in a scrap of synthetic trawl net washed ashore.	J. Andre pers. commun.; Balazs 1983a.
E-Cm-10	6/30/84	Tern Is., FFS, NWHI	Adult, M	Stranding with neck and left front flipper entangled in long piece of blue synthetic rope. Deep flipper abrasion from line. Rope snarl was also entangled in anchor line of lobster larvae collector which came ashore with the turtle. Tumors present.	J. R. Henderson pers. commun.
E-Cm-11	6/7/84	Trig Is., FFS, NWHI	Adult, M	Heavy monofilament fishing line tightly entangled around left front flipper producing a deep cut. Line removed and turtle released.	G. Balazs unpubl. data.
E-Cm-12	12/76	Oahu, Hawaii	C-34 cm	Found severely emaciated and entangled in rope. Died within a few days.	R. Bourke pers. commun.
E-Cm-13	8/3/77	Waimanalo Bay, Oahu, Hawaii	C-44 cm	Portion of a plastic container stuck tightly around turtle's neck. Object sawed-off and the turtle released in apparently good condition.	Balazs 1980.
E-Cm-14	1/23/78	Punaluu, Kau, Hawaii	S-57 cm	Hand captured while scuba diving. Monofilament fishing line wrapped tightly about right front flipper producing deep wound. Turtle tagged and released after cutting out line. Injury completely healed when recaptured 6 years later at same location.	G. Balazs and A. Kam unpubl. data.
E-Cm-15	6/79	Maunalua Bay, Oahu, Hawaii	S-47 cm	Drowned turtle with right front flipper tangled in monofilament fishing line snagged on the bottom.	J. Rutka pers. commun.
E-Cm-16	4/81	Oahu, Hawaii	--	Entangled in a piece of synthetic green trawl net floating offshore; turtle released alive.	S. Kaiser and L. Aguiar pers. commun.; Balazs 1982b.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
H-Cm-17	6/19/81	Kailua Bay, Oahu, Hawaii (lat. 21°24'N, long. 157°43'48"W)	C-64 cm	Entangled in rope attached to an abandoned anchor. One turtle dead, the other very weak--treated and released.	Mooney and Naughton 1981.
H-Cm-18	2/83	Kawainui marsh, Oahu, Hawaii	S-43 cm	Found entangled in "kite string" in a lethargic condition. Died in captivity a few days later.	P. Burnett pers. commun.
H-Cm-19	6/23/83	Malaekahana, Oahu, Hawaii	---	Decomposing carcass washed ashore with synthetic netting and line imbedded in the neck.	D. Eckert pers. commun.
H-Cm-20	1/10/84	Kailua-Kona, Hawaii	C-85 cm, F	Found resting on the bottom in a small boat harbor. Large quantity of monofilament fishing line wrapped tightly around right front flipper. Large tumors also present.	K. Spinney, P. Hendricks, K. McCoy pers. commun.
H-Cm-21	8/30/84	Kiholo, Hawaii	S-66 cm	Hand captured while snorkeling. Monofilament fishing line wrapped around right front flipper producing wound. Line removed and turtle released.	G. Balazs and A. Kam unpubl. data.
H-Cm-22	7/28/79	Texas, U.S.A.	Juvenile	Found with a fishing line wrapped around its flipper. The flipper was gangrenous and had to be amputated. "Young juveniles seem to have a propensity for becoming entangled in fishing line."	Hildebrand 1980.
H-Cm-23	6/24/81	Boca Raton, Florida, U.S.A. (lat. 26°23'N, long. 80°04'W)	19 cm	Found alive with "fishing line around right front flipper" which had "cut into bone."	Anonymous 1981c.
H-Cm-24	10/8/84	Kahului, Maui, Hawaii	Est. 46 kg	Front flipper tangled in buoy line of derelict, bottom fouled gill net. Turtle swam off with a piece of the line still attached to it.	F. Ball pers. commun.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Cm-25	ca. 1980	Johnston Atoll (lat. 16°45'N, long. 169°31'W)	—	Large dead turtle found "tangled in a Japanese fish net" washed up near East Peninsula of Sand Island.	Balazs in press.
			Caretta caretta, loggerhead turtle		
E-Cc-1	5/29/78	Panama City, Florida, U.S.A.	C-84 cm, F	Fresh dead; found by scuba diver entangled in monofilament fishing line at "Warsaw Hole" 4 miles offshore at depths of 23-24 m (75-80 ft). Line fouled in limestone reef outcrop. Death presumed to be from drowning.	L. Ogren pers. commun.
E-Cc-2	1979	Panama City, Florida, U.S.A.	Subadult	Skeletal remains found on the beach. Humerus encircled with heavy monofilament fishing line twisted numerous times.	L. Ogren pers. commun.
E-Cc-3	6/30/84	Ponce Inlet, North Channel, Florida, U.S.A.	C-27.6 cm, 2.8 kg	"Caught and drowned in an abandoned gill net that had washed up on a rock jetty at the mouth of the inlet."	L. M. Ehrhart pers. commun.
E-Cc-4	1980-83	Barbuda, Leeward Is., Lesser Antilles (lat. 17°40'S, long. 61°50'W)	—	On several occasions a fisherman found loggerheads floating at sea entangled in pieces of netting. Sightings were believed to be associated with Japanese fishing boats in the area. Believed that the entangled turtles had been cut loose from trawls and left to drift.	Meylan 1983.
E-Cc-5	>1974	Cumberland Is., Georgia, U.S.A.	—	Dead stranding entangled in rope. Growth of a flipper was stunted due to constriction.	C. Ruckdeschel and C. R. Shoop pers. commun.
E-Cc-6	7/28/82	Hutchinson Is. Florida, U.S.A.	C-70 cm	"Foreflippers entangled in line and netting."	J. R. Wilcox pers. commun.
E-Cc-7	8.24/84	East Florida, U.S.A.	S-65 cm 37 kg	Left front flipper nearly severed by piece of monofilament line. Injured limb was amputated and the wound sutured prior to tagging (No. AAH-724) and release.	R. Witham pers. commun.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
			Eretmochelys imbricata, hawksbill turtle		
E-Ei-1	8/14/77	Kaneohe Bay, Oahu, Hawaii	S-76 cm, F	Found entangled and decomposing in a lost but intact 183 m (600-ft) long monofilament gill net.	Balazs 1978.
E-Ei-2	4/13/82	Palm Beach, Florida, U.S.A. (lat. 26°40'N, long. 80°02'W)	15 cm	Found entangled in fish net by surfers. Taken for treatments where it recovered but "damaged flipper dropped off."	Fletcher 1982.
E-Ei-3	4/24/82	Delray Beach, Florida, U.S.A. (lat. 26°30'N, long. 80°03'30"W)	20 cm	Washed up in surf alive covered with tar and entangled in fishing line.	Wolf 1982.
E-Ei-4	6/11/82	Rock Harbor, Florida, U.S.A. (lat. 25°05'N, long. 80°27'W)	15 cm	Found alive with monofilament line wrapped around left front flipper, causing edema of limb.	Broadrick 1982.
E-Ei-5	7/14/83	Melbourne Beach, Florida, U.S.A.	S-19.5 cm, 0.9 kg	Found stranded in a weakened condition entangled in a 1-m length of braided synthetic rope 1.3 cm in diameter. Unraveled strands at the rope end were tightly bound around the base of the left front flipper. A "flat metal clip" deeply imbedded in the flesh held the line in place. A heavy mass of sargassum was also caught in the tangled rope. The turtle was held in captivity for 2 months where it recuperated, but lost its necrotic flipper.	Redfoot et al.[3]
E-Ei-6	5/25/77	Texas, U.S.A.	Juvenile	Found with line wrapped around a front flipper that developed gangrene and had to be amputated.	Hildebrand 1980.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Ei-7	1/78	Texas, U.S.A.	Juvenile	Found with a fishing line "wrapped around the upper body." Line was caught on an obstruction and apparently the turtle had been on a tether for a considerable time. "Although emaciated, the animal was healthy. A large number of oysters had settled under the raised edges of the scutes."	Hildebrand 1980.
E-Ei-8	8/9/83	Port Aransas, Texas, U.S.A. (lat. 27°50.3'N, long. 97°03.1'W)	C-29 cm	Found with a "piece of plastic onion bag" entangled around neck. "Abraded a groove in neck, but no infection was present." Turtle held in captivity, then tagged and released on 9/3/83 near an offshore oil rig.	A. F. Amos pers. commun.
E-Ei-9	12/20/83	Port Aransas, Texas, U.S.A. (lat. 27°50'N, long. 97°03'W)	C-25 cm	Found entangled in monofilament fishing line in a boat basin with 6.5°C seawater. Severe constriction to left front flipper. Turtle revived after being warmed up, but died 3 days later.	A. F. Amos pers. commun.
			Lepidochelys olivacea, olive ridley turtle		
E-Lo-1	3/73-6/73	Eastern Pacific (ca. lat. 2°-10°N, long. 85°-97°W)	---	Shipwrecked sailors adrift in a rubber raft occasionally had turtles become entangled in the ropes securing their drogue. Turtles were an important food source for survival.	Bailey and Bailey 1974.
E-Lo-2	7/20/81	Kailua-Kona, Hawaii	C-78 cm, F	Entangled in a large piece of synthetic trawl net floating several miles offshore. Turtle was tagged and released in good condition.	P. Hoogs and L. Ahlo pers. commun.; Balazs 1982b.
E-Lo-3	11/28/81	Pukoo, Molokai, Hawaii	S-22 cm	Washed ashore entangled in synthetic line. Deep cuts from the line present on three flippers. Turtle moderately emaciated, but successfully rehabilitated at the Waikiki Aquarium.	Afelin and Puleloa 1982; Balazs 1982b.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Lo-4	7/29/82	Oahu, Hawaii	S-38 cm	Entangled in a piece of green synthetic net floating 6-7 miles offshore. Turtle tagged and released in good condition.	S. Henderson pers. commun.
E-Lo-5	5/19/83	Kana, Maui, Hawaii	C-62 cm	Entangled in a 1.5 m^2 piece of green, synthetic net floating 1 mile offshore. Rehabilitated, tagged, and released.	E. Merrill pers. commun.
E-Lo-6	1980-84	Pacific coast of Costa Rica	Adults, F	A few turtles (3-4) found with "short pieces of monofilament and nylon webbing wrapped around limbs." One had a flipper totally paralyzed from webbing. Great numbers of nesting olive ridleys have been examined over the past 5 years, but only these few have been found entangled.	S. Cornelius pers. commun.
				***Dermochelys coriacea*, leatherback turtle**	
E-Dc-1	8/8/67	Bermuda	150 cm "head to tail," est. 500 kg.	"Tangled in a fishing net and drifting helplessly."	D. B. Wingate cited in Lee and Palmer 1981.
E-Dc-2	8/79	North central Pacific (lat. 41°N, long. 178°W)	Adult	Observed swimming at the surface trailing a piece of rope.	G. Naftel pers. commun.
E-Dc-3	1980	North central Pacific (lat. 35°-45°N, east of long. 170°E)	Adult	At least five dead turtles seen floating at the surface entangled in pieces of monofilament squid net. Probably cut adrift by Japanese or Taiwanese fishermen.	J. Ray pers. commun.; Balazs 1982.
E-Dc-4	12/82	Kailua-Kona (OTEC buoy), Hawaii	682 kg, F	Entangled at night 2 miles offshore in a "parachute anchor." Turtle reportedly dragged a boat around for several hours before being killed. Carcass brought in and weighed on a scale to within 10 kg.	Anonymous telephone calls to G. Balazs.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Dc-5	6/16/81	Watch Hill, New York, U.S.A. (lat. 40°43'43"N, long. 72°52'56"W)	157 cm, M	Found dead, "tied up in rope" in an advanced state of decomposition.	Sadove and Smith 1981.
E-Dc-6	1982-84	Rhode Island, U.S.A.	—	Dead stranding; a rope with longline fish hook imbedded in a flipper.	C. R. Shoop pers. commun.
E-Dc-7	8/1/84	Cape Town, South Africa	Adult	Came ashore with a piece of nylon rope around a foreflipper. Wound caused by rope appeared to have healed, but there was a huge weight of *Mytilus* mussels and gooseneck barnacles growing on the rope.	G. R. Hughes and R. Rau pers. commun.
E-Dc-8	11/18/79	Saint-Clement-des-Baleines, France	C-157 cm, M	Dead stranding; nylon line snarled around decomposing remains of left front flipper.	Duguy 1983.
				Species unknown	
E-Un-1	8/79	Eastern Mediterranean	"Small"	Turtle seen at the surface attempting to swim with a large piece of what appeared to be plastic sheet wrapped around its shell.	Morris 1980a.
E-Un-2	8/82	Oahu, Hawaii	Subadult	Vertebrae and ribs of sea turtle found tightly entangled in a piece of trawl net floating about 10 miles offshore.	J. Naughton pers. commun.
E-Un-3	5/82	West Molokai, Hawaii	—	Entangled in a piece of green synthetic trawl net floating offshore.	S. Kaiser and L. Aguiar pers. commun.
E-Un-4	1/1/84	Waianae Harbor, Oahu, Hawaii	Est. 45 kg	Observed swimming entangled in a piece of brown net. Seen by others at different times at the same location. Likely to have been a green turtle.	A. Endo and P. Conant pers. commun.

Table 2.--Continued.

Case No.	Date	Location[1]	Carapace length,[2] weight, and sex	Description	Reference
E-Un-5	5/84	High seas southwest of Hawaii	--	Turtle entangled in fishing line seen floating at the surface by personnel of the NOAA ship _Townsend Cromwell_.	B. Burch pers. commun.

[1]FFS = French Frigate Shoals; NWHI = Northwestern Hawaiian Islands.
[2]C = curved; S = straight.
[3]W. E. Redfoot, L. M. Ehrhart, and P. W. Raymond. A juvenile Atlantic hawksbill turtle, _Eretmochelys imbricata_, from Brevard County, Florida. Manuscr. in prep. Seminole Community College, Sanford, FL 32771.

least 160 turtles. The remaining cases (8%) describe instances of turtles seen foraging on debris, but the actual numbers were not given. Except for this latter category and Case I-Cm-12 and I-Dc-4, all accounts of debris ingestion were derived from stranded turtles (74%) or turtles taken by fishermen (26%), where the mouth, or some portion of the gastrointestinal contents, had been examined. Most of the stranding cases (84%) involved dead animals. Case I-Cm-12 and I-Dc-4 dealt with the removal of plastic sheets from the cloacae of live turtles.

Cases of debris entanglement shown in Table 2 almost exclusively (92%) involved single turtles. Slightly more than half came from strandings, and the remainder from chance sightings at sea. Only 38% of the entangled turtles were dead or later died. Many more would undoubtedly have died in the absence of human intervention.

It is apparent that strandings represent a principal source of information on debris ingestion and entanglement. A stranded turtle, to be of scientific worth, must be found by someone who properly reports it before it washes or swims away, becomes covered with sand, or decomposes completely. Even when a prompt and accurate report has been made, it is likely that a carcass showing advanced decay would not be cut open and inspected for ingested contents as often as a fresh specimen. A further constraint to collecting data on debris ingestion and entanglement is that most turtles dying in the water probably do not stay afloat long enough to reach shore. This would be especially true for those turtles living on or migrating through the high seas.

Several reports that were located or received were significant for their absence of findings relevant to debris ingestion and entanglement. Mortimer (1981) found no signs of synthetic debris in the stomach contents of 243 green turtles taken in a fishery off the Caribbean coast of Nicaragua. At Cumberland Island, Georgia (U.S.A.), more than 600 dead stranded loggerheads have been cataloged between 1974 and 1984. Gastrointestinal contents were examined in many of these turtles. No plastics or other debris were seen, except for an iron bolt in the roof of one turtle's mouth and a fishhook in the small intestine of another (C. Ruckdeschel and C. R. Shoop pers. commun.). Also, only a single instance of entanglement (E-Cc-5, Table 2) was found among these 600 strandings. At Little Cumberland Island, Georgia, no entanglement in debris has been recorded in stranded or nesting loggerheads monitored since the early 1960's (J. I. Richardson pers. commun.). Only two cases of plastic ingestion have been found in hundreds of turtles (loggerhead, Kemp's ridley, and leatherback) examined during recent summers in Virginia, Maryland, and Delaware (J. A. Musick pers. commun.).

Geographic Distribution

Reports on debris ingestion originated from 19 worldwide locations, and those on debris entanglement came from 10 (Table 3). The coastal continental U.S. accounted for a large portion of debris ingestion (40.8%) and entanglement (31.7%). An established reporting network in the region undoubtedly influenced the outcome. Hawaii, which is listed separately in Table 3, accounted for 46.7% of entanglement cases. This was due to first-hand reports compiled by the author. If better coverage could be achieved, a similar increase would likely be experienced at certain other locales.

Table 3.--Geographic distribution of known cases of debris ingestion and entanglement by marine turtles.

Location	Percent cases reported in this paper	
	Ingestion	Entanglement
Azores	1.3	--
Ascension Island	2.6	--
Australia	2.6	1.7
Balearic Islands	1.3	--
Bermuda	--	1.7
Costa Rica	3.9	3.3
England	2.6	--
France	5.3	1.7
French Polynesia	1.3	--
Hawaii (U.S.A.)	9.2	46.7
Japan	10.5	--
Johnston Atoll	--	1.7
Lesser Antilles	--	1.7
Marshall Islands	1.3	--
Madeira (Portugal)	2.6	--
Mediterranean (eastern)	--	1.7
Netherlands	2.6	--
New Zealand	1.3	--
Pacific Ocean (high seas)	--	6.7
Peru	2.6	--
Selvagen Islands	2.6	--
South Africa	3.9	1.7
Tokelau	1.3	--
United States (mainland)	40.8	31.7

Debris Ingestion

Debris was ingested by five species of sea turtles (Table 4). The green turtle was the most commonly documented (32%), followed by the loggerhead (26%), leatherback (24%), and hawksbill (14%). Only a small number of reports on Kemp's ridley was obtained (4%). No reports were located for the olive ridley or flatback. In four of the five species found to eat debris, immature turtles were more frequently involved than adults (Table 5). This could be due to the greater proportion of immature turtles expected in the population, or a greater tendency for immature turtles to feed on floating debris. The leatherback alone contrasted sharply with this pattern; only adults ingested debris. Immature leatherbacks, especially juveniles, are rarely seen anywhere.

The various types of ingested debris were grouped into 14 categories (Table 4). Plastic bags and sheet were the most prevalent material (32.1%), followed by tar balls (20.8%), and plastic particles (18.9%). Some of the more unusual, but less frequently reported, items consisted of cloth, fishing net, paper, glass, and metal. Pieces of synthetic rope and

Table 4.--Percent occurrence of types of debris found ingested by marine turtles. (Compiled from data listed in Table 1 where many cases involve turtles that ingested two or more types of debris.)

Species	Plastic bags and sheets	Plastic and styrofoam particles	Tar	Kitchen scraps	Synthetic line and thread	Monofilament fishing line	Cloth	Fishery by-catch	Net	Paper	Glass	Metal	No. of cases from Table 1
Green turtle	25.8	6.5	32.3	9.7	12.9	3.2	6.5	--	3.2	--	--	--	25
Loggerhead	14.7	32.4	11.8	5.9	11.8	5.9	--	5.9	--	2.9	5.9	2.9	20
Hawksbill	16.7	38.9	33.3	5.5	--	--	--	--	--	5.5	--	--	11
Leatherback	94.4	--	--	--	--	5.6	--	--	--	--	--	--	19
Kemp's ridley	20.0	--	40.0	--	--	--	--	--	--	20.0	--	20.0	3
All species	32.1	18.9	20.8	5.7	7.5	3.8	1.9	1.9	1.0	2.8	1.9	1.9	78

Table 5.--Age composition of marine turtles ingesting and becoming entangled in debris.

Species	Percent composition from cases reported in this paper: Adult	Percent composition from cases reported in this paper: Immature	Sample size N
	Ingestion		
Green turtle	19.0	81.0	21
Loggerhead	18.7	81.3	15
Hawksbill	9.0	90.9	11
Leatherback	100.0	0	11
Kemp's ridley	0	100	3
All species	30.6	69.4	62
	Entanglement		
Green turtle	41.7	58.3	24
Loggerhead	0	100	4
Hawksbill	11.1	88.9	9
Olive ridley	50.0	50.0	4
Leatherback	100.0	0	7
All species	41.7	58.3	48

monofilament line showed up in the digestive tracts of green, loggerhead, and leatherback turtles under conditions that did not seem to involve swallowing a baited hook. Another interesting aspect shown in Table 4 is the ingestion by loggerheads of unwanted fishery by-catch jettisoned from shrimp trawlers.

Quantitative data of debris ingestion were available in 16 of the cases covering 4 species (Table 6). Various plastics were again the most prevalent items, ranging from 6 to 87% occurrence in the turtles sampled. Noteworthy among these were Case I-Dc-9 where 13% of 140 leatherbacks examined had eaten plastic bags, Case I-Cm-4 where 23% of 39 green turtles contained plastic bags, and Case I-Cc-6 where 43% of 43 dead stranded loggerheads contained discarded fishery by-catch.

Debris Entanglement

Five species of sea turtles were involved in entanglement with debris (Table 7). Species identification was not possible in 5 of the 60 cases. The green turtle accounted for 42% of all cases; no records were located for Kemp's ridley or the flatback. Immature turtles were entangled more frequently than adults, but the pattern was not as pronounced as in debris ingestion (Table 5). Again, only adult leatherbacks were found entangled.

The debris responsible for entanglement was grouped into nine categories (Table 7). Monofilament fishing line accounted for 33.3% of all

,--Quantitative reports cited in this paper of debris found ingested by marine turtles.

	Sample size N	Type of debris	Percent with debris	Case No. in Table I
e	11	Plastic	37	I-Cm-2
	11	Cloth	18	I-Cm-2
	39	Plastic bags	23	I-Cm-4
	32	Plastic beads	6	I-Cc-2
	32	Plastic sheet	6	I-Cc-2
	9	Plastic and glass	44	I-Cc-3
	43	Fishery by-catch	43	I-Cc-6
	3	Plastic, glass, and thread	100	I-Cc-18
	20	Plastic and other synthetic litter	20	I-Ei-2
	42	Plastic bags	50	I-Dc-8
	140	Plastic bags	13	I-Dc-9
	16	Plastic	44	I-Dc-10
	8	Plastic	87	I-Dc-12
	3	Plastic bags	33	I-Dc-13
	3	Plastic bags	33	I-DC-14
	9	Plastic	44	I-Dc-16

Table 7.--Percent occurrence of types of debris found entangled on marine turtles. (Compiled from data listed in Table 2 where each case was considered to involve only a single type of entangling debris.)

Species	Monofilament fishing line	Rope	Trawl net	Monofilament net	Plastic object	Plastic sheet or bag	Line with hook	Cloth	Parachute anchor
Green turtle (N = 25)	36.0	24.0	24.0	8.0	4.0	--	--	4.0	--
Loggerhead (N = 7)	57.1	28.6	--	14.3	--	--	--	--	--
Hawksbill (N = 9)	55.6	1.1	--	22.2	--	11.1	--	--	--
Olive ridley (N = 6)	--	33.3	50.0	16.7	--	--	--	--	--
Leatherback (N = 8)	12.5	37.5	--	25.0	--	--	12.5	--	12.5
Unknown species (N = 5)	20.0	--	60.0	--	--	20.0	--	--	--
All species (N = 60)	33.3	23.3	20.0	13.3	1.7	3.3	1.7	1.7	1.7

cases. Some of these could have resulted from encounters with tended fishing gear. However, none of the reports appearing in this category mentions a fishhook attached to monofilament line, or hooked into the turtle. For several cases (E-Cm-15, I-Cc-1, and E-Ei-7), it is evident that turtles had become entangled in lost pieces of line snagged on the bottom.

Other major categories of debris found on turtles included segments or snarls of rope (23.3%), pieces of trawl webbing (20.0%), and monofilament net (13.3%). Fishing-related debris was involved in 68.3% of all cases. The category of "rope" is not included in this figure, even though a fair amount of rope debris probably does come from fishing efforts.

DISCUSSION

Impacts of Ingested Debris

Sea turtles occasionally consume naturally occurring debris such as bird feathers, terrestrial vegetation, bottom substrate, and pumice. In this paper it has been well documented that they may also eat all sorts of man-related litter. However, in most instances the actual impact of this material is unclear in terms of mortality or morbidity. Certainly the adverse effects of tar balls and oil droplets can be readily perceived when a turtle's jaws become stuck together, throats are packed with tar, and toxic hydrocarbons are transported across the gut wall. As for plastic bags and sheets being eaten, the available evidence for direct harm or mortality is much less conclusive. Seven of the strandings presented in Table 1 describe the ingestion of plastics in quantities large enough or compacted in such a manner to have definitely caused blockage (Cases I-Cm-25, I-Ei-11, I-Cc-16, I-Dc-2, I-Dc-8, I-Dc-15, and I-Dc-18). In contrast, some reports documenting ingestion of plastics deal with seemingly healthy turtles caught by fishermen (Case I-Cm-4, I-Cm-15, I-Ei-2, and I-Dc-90). The twisted configuration of the plastic found throughout the intestines in several turtles suggests that such material can be moved along and voided naturally by peristaltic transport. In Case I-Dc-4, the twisted tip of a plastic sheet was seen protruding from the cloaca of a large leatherback accidentally caught alive in a net. A similar condition was observed in a juvenile green turtle raised in captivity (Case I-Cm-12). However, in both cases, the plastic was pulled out manually by researchers before they discerned whether it would have been expelled naturally.

Even if there is no direct mechanical blockage, there are still potentially serious problems such as lost nutrition, reduced absorption of nutrients while the plastic lines the gut wall, and absorption of toxic plasticizers (PCB's). Unfortunately, very little is known of these aspects in sea turtles, although PCB's have been found in the eggs of green turtles nesting at Ascension Island (Thompson et al. 1974), and Duguy (1983) reports that high levels of PCB's and DDE were found in tissue from three female turtles and one male leatherback turtle (see also Duguy et al. 1980).

Similar effects could be envisioned for turtles that ingest hard plastic fragments, styrofoam, synthetic line, and other plastic derivatives that make up 31.2% of the debris types shown in Table 4. An additional adverse factor may result from plastic objects grinding upon each other during muscular contractions in the digestive process. Such abrasive action could cause pinocytotic absorption of microscopic particles of plastic in the intestine, as has been suggested for albatrosses by Pettit et al. (1981). Furthermore, there would be a reduced ability to maneuver and dive away from predators when buoyant pieces of plastic and styrofoam are present in the gut. Buoyancy of this sort was clearly evident in Case I-Ei-11.

Another potentially serious aspect of the debris ingestion problem, but one that may prove easier to assess and alleviate, is the consumption of fishery by-catch by loggerheads. As suggested in Case I-Cc-6 by Shoop and Ruckdeschel (1982), the unwanted catch dumped from shrimp trawlers could be creating artifically high concentrations of foraging turtles. The turtles attracted would then be more susceptible to accidental capture and drowning from the intensive shrimp fishery. Increasing numbers of dead loggerheads washing ashore in the southeastern United States suggest that attraction to by-catch may indeed be a contributing factor.

Factors Causing Debris Ingestion

Several plausible explanations can be offered as to why sea turtles eat various debris. First, the object may resemble an authenic food item in size, shape, and even movement as it drifts at the surface or through the water column. Its color, translucence, and reflection may also be stimuli that induce a feeding response. In considering these factors, Hartog (1980) raised the interesting question as to why pieces of litter, particularly plastic objects, are not rejected by a turtle once "seized and tasted." A logical answer might be that marine organisms commonly encrusting or residing on debris may emanate an acceptable natural smell that masks the artificial nature of the object. Drift plastic is often covered with growth and, with increased ocean dumping, is considered to be an expanding pelagic niche for marine invertebrates (Winston 1982). In some cases, a luxuriant growth of marine life may be the principal sensory cue to initiate feeding by turtles. In Case I-Cm-7, a piece of synthetic net taken from the stomach of a green turtle had numerous fish eggs cemented to it. Although certain kinds of fish eggs are commonly attached to seaweed, floating debris like nets and other objects are also suitable habitat. Fritts (1981) presented information indicating that clumps of fish eggs may be an important nutritional source to sea turtles in the pelagic environment. In Case I-Cc-7, a piece of heavy monofilament fishing line pulled from the digestive tract of a loggerhead was found to have numerous encrusting organisms, the most abundant of which were mussels. It was surmised that the turtle ingested the line due to the presence of typical forage items for this species (L. Ogren pers. commun.). Gooseneck barnacles have been found in the stomachs of juvenile green turtles in Hawaii and elsewhere. These same barnacles have also been seen growing on small tar balls that have washed ashore in the Northwestern Hawaiian Islands. In the Atlantic, similar lumps of tar have been sighted at sea covered with barnacles, other crustaceans, and algae (Heyerdahl 1971). However, marine life of this sort may not always be necessary to attract turtles to eat floating tar. Owens (1983) mentioned preliminary studies suggesting that tar balls or soluble oil fractions by themselves might be inherently attractive to neonatal sea turtles (see also Hall et al. 1983).

The ingestion of plastics by turtles has recently generated some interest in Florida, where plastic seaweed mats may soon come into common use to control beach erosion (Van Dam 1984). Concern has also been expressed about fish aggregating devices made of vinyl screen which are anchored offshore 18 m (60 ft) beneath the surface. Foraging turtles, especially loggerheads, might bite into the vinyl while trying to eat encrusting organisms, or they may mistake the entire 1.8-m (6-ft) long parasol for a giant jellyfish (Benet 1984; R. Witham pers. commun.).

Under conditions of extreme hunger, turtles may be motivated to feed on debris that they would not otherwise eat. For example, at certain breeding sites there is a scarcity of forage to help sustain females through the 1- to 3-month nesting season. Ingestion of plastics, cloth, and other refuse by green turtles and hawksbills has been recorded in internesting habitats off Costa Rica and Ascension Island (see Case I-Cm-2, I-Cm-3, I-Ei-1, and I-Ei-2).

Another way in which sea turtles might ingest debris is through a secondary route, where the turtles' prey items have themselves eaten litter. There are no cases known at present to support such a mechanism; nevertheless, the increasing volume of minute plastic particles dispersed over the seas makes it a distinct possibility. For example, plastics and vegetables believed to have been dumped from fishing boats have been found in the stomachs of squid in the North Pacific (Araya 1983).

Impacts of Debris Entanglement

The adverse effects of debris entanglement on sea turtles are far more direct and obvious than more subtle negative impacts resulting from ingestion. As shown in Table 2, when turtles become entangled most of them are unable to function normally in feeding, diving, surfacing to breathe, and other basic behaviors. Constricting line and netting can inflict lesions and reduce blood supply to limbs, causing necrosis. Escape from predators is made more difficult, if not impossible. In addition, dense marine growth on entangling debris can weigh down a turtle, making it less likely to survive (see Case E-Dc-7). With the widespread use of synthetic line and net over the past few decades, there is little chance for entangling debris to rot away, or for a turtle to break loose on its own. Unfortunately for sea turtles, fishing gear of even greater durability (hence persistence) is now being advertised for sale (Anonymous 1983a).

Factors Causing Debris Entanglement

It is easy to understand how turtles can become entangled and drown in nearly invisible gear like monofilament netting. If the material is difficult to see underwater, a turtle may simply swim into it and become hopelessly tangled. Mortality from this cause has been reported from the intensive use and loss of large monofilament drift nets on the high seas northwest of Hawaii (Case E-Dc-3; Neuweiler 1982). Entanglement in other kinds of debris besides monofilament netting is more difficult to comprehend, since most are readily visible. Sea turtles, especially leatherbacks and green turtles, have a distinct propensity for entangling their front flippers and heads in rope. It is unknown exactly how these bizarre entanglements take place. Lazell (1976) describes a possible entanglement scenario for a leatherback trying to "eat" a buoy tied off with a rope.

Scraps of trawl net at sea seem to act like magnets to sea turtles. A likely explanation for this behavior is that floating masses of net offer the same advantages as sargassum mats or drift lines, where shelter and concentrated food can be obtained.

Once residency is established around a piece of net, the chances for a turtle becoming entangled may be quite high as it swims over and through the netting seeking food. In Hawaii, floating scraps of trawl net (often called "cargo" net) are viewed by fishermen as an asset due to their fish aggregating capabilities. Olive ridleys have been rescued alive from these nets by fishermen trolling around them (Case E-Lo-2, E-Lo-4, and E-Lo-5), even though this species does not normally occur in the nearshore waters of Hawaii. It is unknown if the surrounding high seas are normal habitat, or if the turtles became entangled at a distant site and passively drifted here.

Many kinds of drifting debris in addition to netting are known to aggregate marine life under and around them (Gooding and Magnuson 1967; Tsukagoe 1981). Sea turtles themselves can even act as natural aggregating objects. In Hawaii, trollers have caught several game fish at once lingering beneath a healthy immature turtle floating at the surface (Balazs 1981). Possibly the schooling behavior sometimes observed at sea for olive ridleys and other species has the benefit of attracting sources of food that can then be directly exploited by the turtles. Shipwrecked survivors adrift in a rubber raft north of the Galapagos Islands often had turtles (probably olive ridleys) around them in association with other marine life (Bailey and Bailey 1974). The turtles would rub against the bottom of the raft and, as might be expected, sometimes become entangled in ropes securing a sea anchor (Case E-Lo-1).

RECOMMENDATIONS

Short of severely curtailing the ocean dumping of all plastics and other material identified in this paper, there is probably not much that can be done to lessen the adverse effects of debris on sea turtles. The ubiquitous nature of the material and the mostly concealed oceanic life of many turtles, especially in their early development stages, present a difficult setting in which to work. There are, however, some immediate activities that could be undertaken to better understand the nature of the impacts. Of course the recognition that a problem exists, as has been facilitated through this debris workshop, is in itself an important first step.

It is recommended that the following actions be carried out.

1. There should be greater efforts worldwide to record stranded turtles and conduct necropsies aimed at documenting debris ingestion and entanglement.

2. Studies should be conducted that involve the controlled feeding of plastics and other debris to turtles in captivity to gain definite information on intestinal obstruction, absorption of plasticizers, and feeding behavior.

3. Field studies aimed at elucidating the pelagic life of sea turtles along drift lines in the Pacific should be undertaken north of the Hawaiian Islands.

4. A more thorough assessment should be made of sea turtle interactions with jettisoned by-catch from shrimp trawlers and other fisheries.

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SOME CONSEQUENCES OF LOST FISHING GEAR

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ABSTRACT

Directed studies and incidental observations of derelict crab pots, longline gear, and sunken gill nets show some long-term damage to living marine animals. More than 30,000 crab pots have been lost in the western Gulf of Alaska since 1960. About 20% of legal size and 8% of sublegal king crab in these pots at the time of loss, fail to escape. The king crab which escape pots after a 10-day or more confinement, reenter the fishery at a very low rate, suggesting that relatively short-term confinement contributes to high mortality. Crab which die in a pot tend to repel other crab. Bright, bare hooks on halibut longline gear occasionally take fish, but plated hooks quickly rust or snag on sea floor objects. Although the nylon ground lines and gangions remain intact for several years, the hooks quickly cease to function. Three salmon gill net segments lost by Washington State fishermen have been observed for several years. The deployed segments ranged from 5.5 to 18.3 m (18 to 60 ft) below the surface. Each continued to fish for more than 2 years, taking a variety of fish, invertebrates, and seabirds. Underwater studies of the sunken gill net fishery for Pacific cod, Gadus macrocephalus, showed that only about 14% of the entangled cod escape before the net was retrieved. Consequently, most cod gilled, or otherwise tangled in sunken gill nets lost by fishermen remain until they die. Because set net fisheries are often concentrated on rough sea floor areas and among sunken man-made objects, significant loss of nets do occur. Some fishing gears are modified to quickly reduce their fishing capacity when lost.

INTRODUCTION

One hazard of the commercial fishing industry is the loss of fishing gear to a variety of causes. For some fisheries such as demersal longline and purse seine, the consequences of the gear components remaining in the sea may be slight. On the other hand, substantial injury or mortality to a wide variety of marine creatures occurs when traps (pots), gill nets, and other gear constructed of netting are lost.

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A number of experiments were conducted and field observations made by the author in cooperation with the Washington State Department of Fisheries, Alaska Department of Fish and Game, and the International Pacific Halibut Commission since 1974 to assess the potential loss of marine animals in derelict (ghost) gear.

DERELICT CRAB POTS

Hundreds of pots that are used in Dungeness crab, Cancer magister, fisheries are lost each year in coastal waters from Alaska southward to central California. Also, pots set in exposed shallow waters are often buried in sand during storms and unless crabs promptly escape from these pots, they will be killed from long confinement or during the sanding-in process (Tegelberg 1974).

Experiments were conducted using conventional, commercial-style crab pots to learn whether Dungeness crabs could escape from unbaited pots (High 1976). Legal (17.1 mm (6-3/4 in.) across the carapace) and sublegal crabs were placed in pots with functional triggers and escape rings. After 12 days, 55 and 23%, respectively, remained. Seventeen percent of the confined crabs died. Dungeness crabs were also placed in pots having functioning triggers across the tunnel as in the above experiment but with the normal 10.8 mm (4-1/4 in.) diameter escape ring sealed. After 74 days, 33% sublegal and 79% legal size crabs remained in the pots with 8 and 25% mortalities. It is likely that triggered pots which contain either sublegal or commercial size crabs at the time of the pots' loss will retain many until their death.

Similar experiments were conducted for king crab, Paralithodes camtschatica, because fishermen in Alaskan waters report losing about 10% of their pots per season as a result of various mishaps. With a fishery extending for over 24 years and considering the number of vessel licenses issued each year, more than 30,000 derelict pots could remain on the fishing grounds in operating condition (High and Worlund 1979). Interviews with fishermen revealed common causes of pot loss included: 1) buoyline breakage from chafing or entanglement in vessel propellers; 2) buoy puncture by sea lions; 3) pots carried into deeper water when tangled in gear such as trawls, longline, or other pots; and, 4) buoyline entanglements during setting, so that the line is shortened and buoys are carried under the surface.

King crab mortality from confinement in derelict pots occurred among those crabs in the pot at the time of its loss and crabs which, subsequently, enter because of 1) some form of bait, 2) the attraction of confined crabs, or 3) shelter offered by the pot (Fig. 1). However, entry of king crabs into a derelict pot is a nonproblem if the crabs can readily escape without injury. Experiments demonstrated that about 80% of legal size (about 145 mm carapace length) king crabs and 92% of sublegal king crabs would eventually escape. Interpreted conversely, 20 and 8%, respectively, would not escape. In addition, from tagging experiments, we learned that king crabs confined in a simulated derelict pot more than 10 days before release resulted in reduced recovery. Undoubtedly, extended confinement contributes to increased mortality.

Figure 1.--This abandoned Japanese-type snow crab pot, recovered 3 months after close of the commercial fishing season, contained 12 king crab and 14 snow crab. One of each species was dead.

Pots baited with plastic jars containing Pacific herring, Clupea harengus pallasi, pieces attracted large numbers of king crabs at a decreasing rate up to 7 days, but did not cause the crabs to remain in the pot longer than in an unbaited pot. Some bait remained for the 7 days but decomposed quickly after 3 days. Dead crabs in pots did not attract king crabs to the pots.

Some fish species such as Pacific cod, _Gadus_ _macrocephalus_, and Pacific halibut, _Hippoglossus_ _stenolepis_, at times enter king crab pots in relatively large numbers. Fishermen reported that under some conditions, halibut were present in up to 9% of their commercial pot lifts, and up to 6% of our test fished pots contained halibut. When these species die in a derelict pot, the pot becomes rebaited for a short time. Although our studies of Dungeness crab and king crab pots did not establish the number of crabs which enter a pot following its loss, it is clear that large numbers of those crabs present at the time of the pot's loss and which subsequently enter while the pot remains intact are killed. Occasional derelict pot recoveries confirm that crabs continue to enter them. The problem of derelict pots, then, lies with the frequency with which crabs enter lost pots, the number of fishable derelict pots, and the mortality of crabs entering them. Estimates of the latter two parameters are now established.

GILL NETS

Gill nets deployed at the surface and near bottom have clearly demonstrated their effectiveness in many parts of the world. Because they are relatively cheap, easy to repair, and capable of fishing without constant care and attention of the fisherman, gill nets are often placed in loss-prone areas. For example, United Kingdom fishermen intentionally set gill nets across sunken shipwrecks because of the known fish aggregations. But gill nets can continue to fish for long periods after loss, even when only partially intact. Therefore, as derelicts, the nets create a potential for major loss to target and incidental species and also create concerns for vessels, people, and equipment.

Experiments were conducted to determine the escape of Pacific cod from sunken gill nets and the characteristics of the gear while fishing or after its loss. Only about 14% of cod observed tangled in commercial gill nets escaped prior to their retrieval.

Nets designed to fish from the sea floor 2.4-3.6 m (8-12 ft) up into the water column did so only during slack water periods. Even low, tidal generated currents caused the gill net to lie flat, thereby increasing the likelihood of serious snagging and entrapment of bottom species such as crabs and flounders.

Sunken gill nets fished in Alaska waters were required to be deployed at least 45 cm (18 in.) above the bottom to allow passage of crabs. Unfortunately, during several hours of each tidal cycle, these nets lay completely or in part across the sea floor, which defeated the objective of sparing the crabs.

Several large pieces of derelict salmon gill nets have been discovered in the course of other studies in Puget Sound, Washington. Each net, apparently abandoned, had become snagged at a depth of 24.4 m (80 ft) or less on some submerged object. For the most part, the netting pieces were left as found to observe the consequences of their presence. At irregular intervals, over a period of up to 6 years (at the time of this report), the nets were assessed for condition and contents.

Because of the relatively shallow depths of most of the nets, heavy algal growth developed within a year or less on the netting, and the catch of fish and diving birds decreased somewhat as algae density increased. Nonetheless, these animals continued to be caught for more than 3 years (High 1981). Crabs on the other hand, continued to become entangled after 6 years (Fig. 2).

Figure 2.--A red rock crab, Cancer productus and kelp crab, Pugettia producta, are shown entangled in an abandoned piece of salmon gill net.

Tidal currents, with time, caused some of the netting to roll into a pile or sausage-shaped bundle on the bottom. Fish and birds are less often entangled by rolled netting than are crabs.

The synthetic net material remains adequately strong to hold living animals 6 years after its loss, although no objective test of thread tensile strength has been made.

Like the marine animals of which we most often speak, man himself has become the victim of his own synthetic technology. Divers have occasionally, over many years, suffered the usually frightening experience of temporary entanglement in monofilament fishing lines. However, more recently, near tragic encounters have occurred with active and derelict set nets. Diver magazine of London, England graphically describes several near fatal entanglements by recreational divers (Anonymous 1984). Vessel wrecks are the common attraction for the diver and commercial fishermen. As stated elsewhere in this report, fishermen of the United Kingdom intentionally set nets across wrecks, accepting a high loss of gear to harvest the abundant fish attracted to the artifical reef. Likewise, divers seek out the same wrecks as highly desirable work and recreational areas. Members of my own diving team underwent extensive training and modified their dive gear to better prepare them to work near active and derelict nets. Nonetheless, entanglement was common. Recreational divers are ill prepared to deal with the stress and constraints imposed by netting.

Diver knives are poorly designed and maintained to cut loose nettings. The knife itself often becomes the initial snag site and cannot be removed from its sheath. All divers who have a high likelihood of encountering line or netting underwater should carry a second, small, very sharp knife near their wrist or upper arm, specifically to help cut such entanglements.

LONGLINE

Demersal halibut longline gear, composed of individual hooks attached by leaders (gangions) at intervals along a groundline, fishes effectively only while the hooks are baited. One study shows that <25% of herring, Clupea harengus pallasi, bait remained after 2 h of fishing, whereas octopus, Octopus dofleini, a more durable bait, remained on the hook for several hours (High 1980).

Occasionally, halibut was observed to attack a bare, bright hook (High in press). However, hooks in the water tarnish within a few days and it is not likely they continue to attract fish even though many thousands of hooks on longlines are lost each year (Fig 3).

SUMMARY

It is clear that some derelict fishing gear contributes to a loss of marine animals for as long as the gear remains intact. Studies show that nets can still entangle fish after more than 6 years underwater. Crab pots, because of their extremely rugged construction, may fish for even longer periods. Some small and commercial sized crabs confined in derelict pots fail to escape or are possibly injured in some way by long confinement which reduces their survivability. Halibut longline gear is lost in quantity but the hooks have their bait removed within hours by predators and only occasionally do fish take the bare hook.

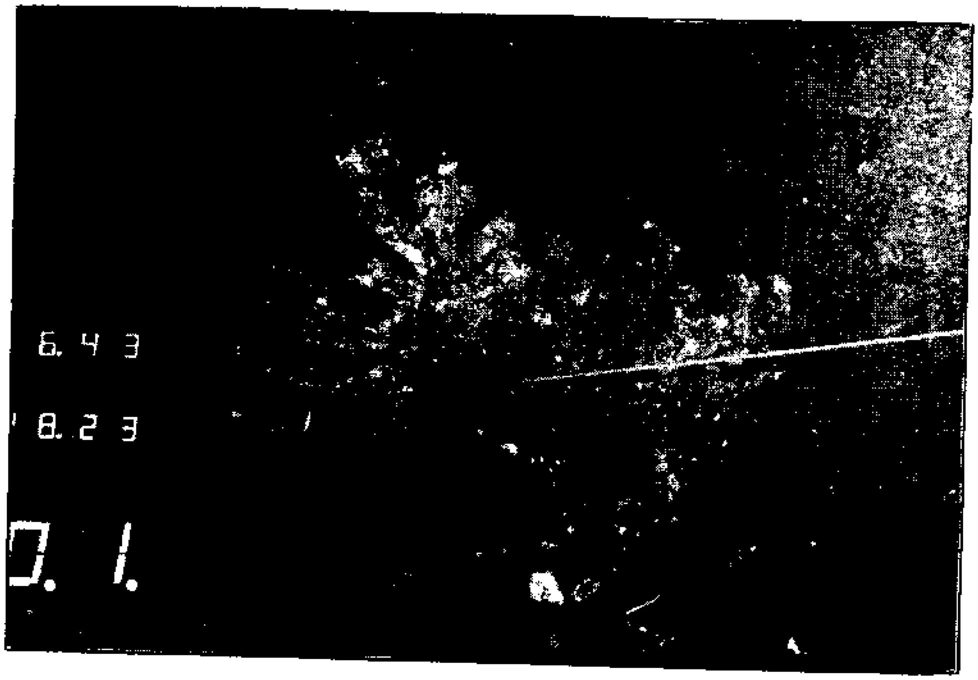

Figure 3.--An underwater view of halibut longline entangled on a barnacle encrusted boulder.

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UNDERWATER SURVEY OF SIMULATED LOST DEMERSAL AND LOST COMMERCIAL GILL NETS OFF NEW ENGLAND

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ABSTRACT

The increase in commercial and recreational fishing pressure in the New England ground fishery over the last decade has intensified the problems of gear conflict and preemption of prime fishing bottom by one particular gear. A major issue has been the demersal gill net, especially when it may be lost and ghost fishing. The Massachusetts Division of Marine Fisheries initiated two investigations on simulated ghost gill nets. The purpose of this effort was to establish methods to evaluate certain characteristics of a net set over an extended period of time, to evaluate net profile, and to monitor the catch rate and fate in the nets. One net was set in May 1982 and monitored periodically through June 1982. The catch, primarily spiny dogfish, *Squalus acanthias*, usually tangled in the net and depressed the height of the net. The second net was set mid-February 1983. Eleven dives were made on the net before its retrieval late April 1983. This commercial net had marked panels that assisted detailed assessment of the net profile and fate of fish caught in the net. The predominant species caught was Atlantic cod, *Gadus morhua*. Also caught were cunner, *Tautogolabrus adspersus*, sea raven, *Hemitripterus americanus*, and tautog, *Tautoga onitis*.

In July 1984, the National Marine Fisheries Service and the Massachusetts Division of Marine Fisheries initiated a more thorough study of ghost gill nets using the submersible *Johnson Sea-Link II* and the RV *Johnson*. Part of this 3-year study was to survey prime fishing sites for the frequency of lost nets and to determine the impact of these nets on the fishery resource. Fifteen submersible dives surveyed over 40.5 ha of bottom in the Gulf of Maine. We saw nine ghost gill nets, six balled up and rising off the bottom to heights up to 3.6 m; three stretched out horizontally but with reduced float line heights. Extensive

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In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

video and still shots documented the nets and the catch in the nets. The catch, live or decaying, included Atlantic cod; Atlantic wolffish, *Anarhichas lupus*; spiny dogfish; winter flounder, *Pseudopleuronectes americanus*; American lobster, *Homarus americanus*; and crabs, *Cancer* spp. The ghost gill nets seen on these dives may be over 3 years old. We estimated the age of the nets observed through the marine invertebrates attached to the nets and by comparing eight of the nets to one net known to have been lost 3 years ago. Also discussed are the probable reason of the loss of these nets, the impact of these nets to the fishery resources, and future research to reduce any impacts.

INTRODUCTION

The increase in commercial and recreational fishing pressure in the New England ground fishery over the last decade has intensified the problems of gear conflict and preemption of prime fishing bottom. A major issue in this controversy is the use of the demersal gill net.

Gill nets are a fixed type of fishing gear marked by floats at each end of the net. In the Gulf of Maine demersal gill nets, each being about 91 m (50 fathoms) long, are usually set in strings of 10 to 12, (one string) totaling 914 to 1,097 m (500 to 600 fathoms). A single vessel sets between five to six strings, thus occupying a considerable expanse of ocean.

Mobile gear fishermen and those utilizing fixed gear are often in conflict when they try to use the same sea bottom. Due to recent advances in trawl gear allowing draggers access to rougher bottom terrain, gill-netters have been forced to set their nets in more concentrated areas. The areas are those often preferred by recreational fishermen in private vessels as well as those on charter and party boats. Many recreational fishermen fish by drift fishing and jigging off the bottom, seeking the same species (cod, haddock, and pollock) as the gill-netters. The conflict is obvious: The drift fishing recreational fishermen use the same areas as the gill-netters and become fouled in the gill nets.

Ghost or derelict gill nets are nets lost due to storms or entanglement with mobile gear. Some evidence exists that ghost gill nets continue to catch fish and foul mobile gear. The bodies of gill nets are typically constructed of monofilament netting line, hence there is a question as to the longevity of ghost gill nets and their possible effects on the fish stocks and interference with other gear types.

Bottom trawlers (draggers) have retrieved lost gill nets in Massachusetts waters (Capt. Dan Arnold, Capt. Frank Mirarchi, pers. commun. 1981). Fish entangled in the nets were found in various stages of decay. Party boats have also reported hooking ghost gill nets and retrieving pieces of net containing entangled and dying fish, lobsters, and crabs.

Canadian biologists have researched the question concerning the continued fishing of ghost gill nets (Way 1977). The conclusions, although still controversial to some, are that generally the lost nets continue to fish at uncertain rates for undetermined periods of time. The damage intensity and longevity appear related to finfish and crustacean species and abundance, the net characteristics, bottom type, current, and surge. Research into the problem has been accomplished using retrieval techniques. Little work has been reported on in situ techniques using underwater observation and evaluation. Quantitative data dealing with this problem are, therefore, very limited.

The Massachusetts Division of Marine Fisheries (MDMF) initiated an investigation by setting two demersal gill nets and leaving them on the sea bottom to simulate ghost gill nets. The first was set in May 1982 and the second in February 1983. The purpose of this effort was to perfect an in situ research method utilizing scuba to evaluate change in net profile over time, and monitor the catch rate and fate of the nets. The results are reported herein.

In August 1983, personnel from the National Marine Fisheries Service (NMFS) and the MDMF conducted a 7-day cruise with assistance from the recreational and commercial fishing industries to assess the usefulness of various surface operated gear in detecting ghost gill nets. Seven sites of recent conflict between the above mentioned fishing interests were surveyed using high resolution sonars, grappling gear, and underwater television. The results demonstrated that actively fished nets can be easily detected through a variety of acoustic methods when the bottom is not very irregular. No ghost nets were seen or retrieved during this survey.

In 1984, with the question of the effects of ghost gill nets unresolved, NMFS and MDMF undertook a more thorough study using the submersible Johnson Sea-Link II and the support vessel RV Johnston, from the Harbor Branch Foundation, Ft. Pierce, Florida. The first phase of a 3-year study was 1) to study prime fishing sites for the frequency of ghost gill nets and to begin to determine impact of these nets on the fishery resource and 2) to work with gill-netters to observe fish behavior in and around active commercial gill nets.

METHODS AND MATERIALS

In May 1982, we initiated the in situ gill net investigation by setting a 91.4 m (300 ft), 14 cm (5.5 in.) mesh monofilament demersal net in 18.3 m (60 ft) of water in Cape Cod Bay. The net, similar to those used by most gill-netters in the area, was marked with numbered plastic tags on the float and leadlines every 9.1 m (30 ft) so that divers could accurately survey the net profile and catch of each 9.1-m panel. Four scuba dives were made on this net. Divers utilized clipboards with waterproof paper to record visual observations. A diagram of the net, divided into 10 numbered 9.1-m panels, was illustrated on the waterproof paper, allowing divers to record the vertical profile of the net, where and how each species was caught, and the life state of each fish.

Fish are caught in gill nets three ways. The most common is by being "gilled," i.e., a fish swims into the "invisible" monofilament net where the head fits, but the girth of the fish prevents complete passage through the mesh. The fish cannot back out of the net because the mesh catches on the open operculum. A fish may also become wedged in a mesh, i.e., it swims into the mesh until it is held tightly around the body. The third method of net capture can be referred to as "tangling" or "entanglement;" the fish does not penetrate a mesh but is snared either by its teeth, maxillaries, fins, or other projections.

A second gill net of similar construction was deployed on 14 February 1983, for a period of 74 days. The net was set at the same depth, perpendicular to, and 0.5 nmi from shore. The only difference in the net was the marked panel interval, which was reduced from 9.1 to 4.6 m (30 to 15 ft). Scuba dives were scheduled once a week. Divers recorded the same information as in the previous experiment.

In June 1984, the submersible _Johnson Sea-Link_ spent 9 days in New England waters diving in areas recognized as active commercial gillnetting sites (Fig. 1). The submersible dive sites were selected through three methods:

1) by a survey of gill net gear distribution from the NOAA RV _Gloria Michelle_ in April 1984 when gillnetting was most active,

2) through current information acquired from mobile and stationary gear fishermen,

3) from groundfish party boat operators who operate daily in the same fishing areas.

We chose specific submarine dive transects after a review of the bottom topography and a limited amount of additional bottom profiling of the sites. The _Johnson Sea-Link_ carried a pilot and scientist forward in the sphere, and a scientist and crewmember aft in the lockout chamber. During each dive, the pilot would normally follow a defined transect unless a net was encountered; in this case, the net was fully surveyed and then the transect continued. Each scientist had an audio tape recorder and a Benthos[1] 35-mm still camera mounted externally on the submersible to record his observations. The team in the forward sphere also had an externally mounted video camera that they were able to manually pan, tilt, and zoom. The _Johnson Sea-Link_ was tracked via sonar from the RV _Johnson_. Location fixes of the launch, net locations, and recovery were recorded using the loran C navigational system.

RESULTS AND DISCUSSION

In Situ Scuba Observations

Diving on the first net (set in May 1982 and lost mid-July 1982) was instrumental in perfecting in situ surveying procedures utilizing scuba. The predominant species caught was the spiny dogfish, _Squalus acanthias_. On the first dive, 18 h following the set, spiny dogfish, struggling to free themselves, effectively caused tangling and overlapping of float and leadlines throughout more than half the net. In 42 h the vertical profile

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

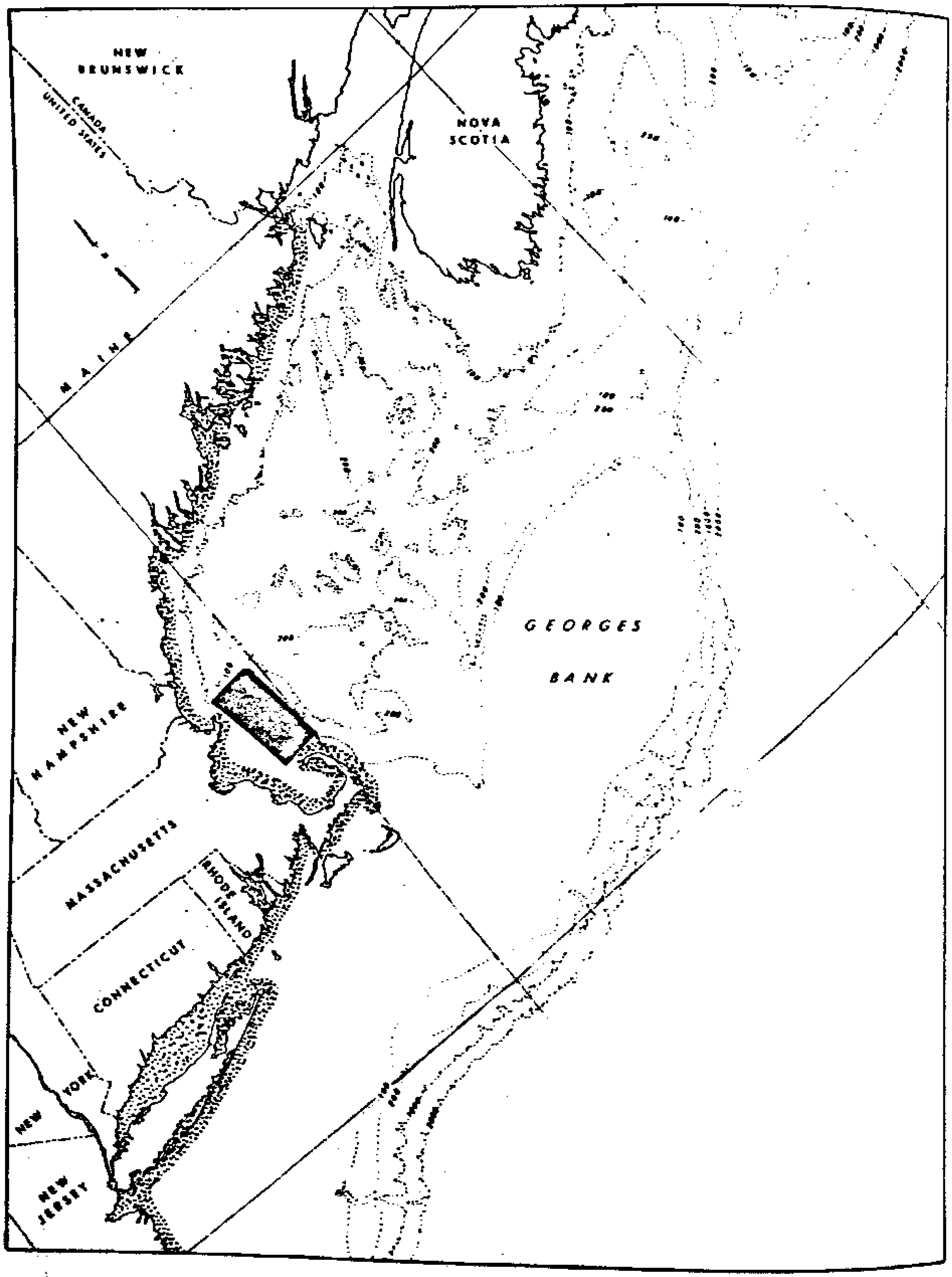

Figure 1.--New England-Gulf of Maine study area.

of 50% of the net was depressed to <0.6 m (<2 ft) off the bottom. A month later the entire net, twisted, and tangled, was similarly reduced to <0.6 m. The sketched diagram of the net used by divers assisted the plotting of profile and catch. However, the low visibility, <4.6 m (<15 ft), made identification of specific net panels difficult using float and leadline tags spaced 9.1 m (30 ft) apart. Further, it was discovered that diving surveys should be weekly or more frequent, to better understand the fate of the catch.

The second net was set for a period of 74 days between 14 February and 28 April 1983. The northeast end was fixed to a shipwreck and the southwest end anchored with cement blocks. Currents at this site were usually <1 knot. The net maintained its 1.8-m vertical profile for 10 days. Within 30 days, the net, after a northeast gale, had swung 90° from its initial set, from southwest to southeast. Most of the panels were still nearly 1.8 m in height with the exception of sections that came into contact with various debris such as lost lobster pots (Table 1). In 50 days, 60% of the net had a height not exceeding 1.2 m. By the 73d day 85% of the net was twisted with a mean height <1.2 m (4 ft). The loss of vertical profile appeared related to storm surge and fouling on fixed bottom debris.

Table 1.--Net profile (%) of gill net set, February-April 1983.

Panel mean height (in feet)	February	March				April		
	22	1	14	21	29	5	12	28
6	100	100	70	20	10	25	--	--
>4	--	--	30	50	50	40	45	15
2-4	--	--	--	30	25	40	35	30
<2	--	--	--	--	--	--	5	45
Tangled or twisted	--	--	--	--	15	20	15	10

Various species of algae began to collect on the knots of the net within 8 days of the set. This fouling continued to increase over time, but did not clog the net nor did it appear to cause a major reduction in net height profile. Large blades of Laminaria and pieces of Ulva sp. were swept into the net, but collected mainly near its base.

Although this net was set in shallow water that was not commercially fished by gill nets and the algae that fouled the net were different from any that would be usually found in commercially set areas, we believe that the fouling condition exaggerated what would normally happen in commercial areas and were interested to observe that the net did not collapse to the bottom because of this algal fouling.

The predominant finfish species caught were cod, Gadus morhua, and tautog, Tautoga onitis (Table 2). Most of the cod were caught between days

Table 2.--Catch (by species) in gill net set between February and April 1983.

	February			March				April				
	15	17	22	1	14	21	29	4	7	12	28	Total
Day	2	4	9	16	29	36	44	51	53	58	74	--
Species												
Gadus morhua	--	--	1	--	6	4	2	5	--	--	--	18
Urophycis tenuis	--	--	--	--	--	--	--	--	--	--	1	1
Pseudopleuronectes americanus	--	--	--	--	--	--	1	--	1	--	--	2
Scophthalmus aquosus	--	--	--	1	--	--	--	--	--	--	--	1
Tautoga onitis	--	--	--	--	--	--	--	--	--	1	13	14
Tautogolabrus adspersus	--	--	--	--	--	--	1	1	2	1	--	5
Hemitripterus americanus	--	--	--	--	--	--	--	--	2	--	--	2
Raja sp.	--	--	--	--	1	3	2	--	--	2	1	9
Cancer borealis	--	--	1	3	7	17	14	15+	16+	12+	12+	97+
Homarus americanus	--	--	--	--	--	1	--	--	--	--	--	1
Seawater temperature °C	1°		1°			4°					10°	

17 and 51 of the set. The catch of cod was probably higher during this period because of their coastal migration in early April. Tautog were caught near the end of the experiment, between days 54 and 74 when waters were warming up and they moved into the area for late spring-summer residency.

A similar commercial net was set next to the experimental net on 5 April for a 2-day period. The purpose was to compare the catch of the clean gill net with the "ghost" gill net during a time when cod were present in the area. No fish were caught in the freshly set net. One tautog, a cunner, *Tautogolabrus adspersus*, and two skate, *Raja* sp., were noted as new catch in the experimental net.

Submersible Observations

The submersible *Johnson Sea-Link* made 15 dives that averaged 2-1/2 h each. Twelve dives were made on Jeffreys Ledge and 3 on Stellwagen Bank (Fig. 2). Thirteen of the dives searched areas for ghost gill nets. Two dives, both on Stellwagen Bank, investigated active commercial gill nets. We surveyed over 40.5 ha (100 acres) of active gill net fishing areas and located 10 ghost gill nets. All of the ghost nets had bryozoans growing on the monofilament. The anemone, *Metridium* sp., and stalked ascidian, *Boltenia* sp., were also attached to some nets. Most of the ghost gill nets were located on ledges with rocks and boulders.

Four of the ghost gill nets were twisted into snarled bundles rising up to a maximum of 3.6 m (12 ft). These vertical configurations were 0.6 to 0.9 m (2 to 3 ft) and varied between 1.5 and 3.6 m (5 and 12 ft) high. The floats, usually encrusted with barnacles, kept the twisted mass buoyant while the leadline was caught in the rocky bottom. Two of the four nets

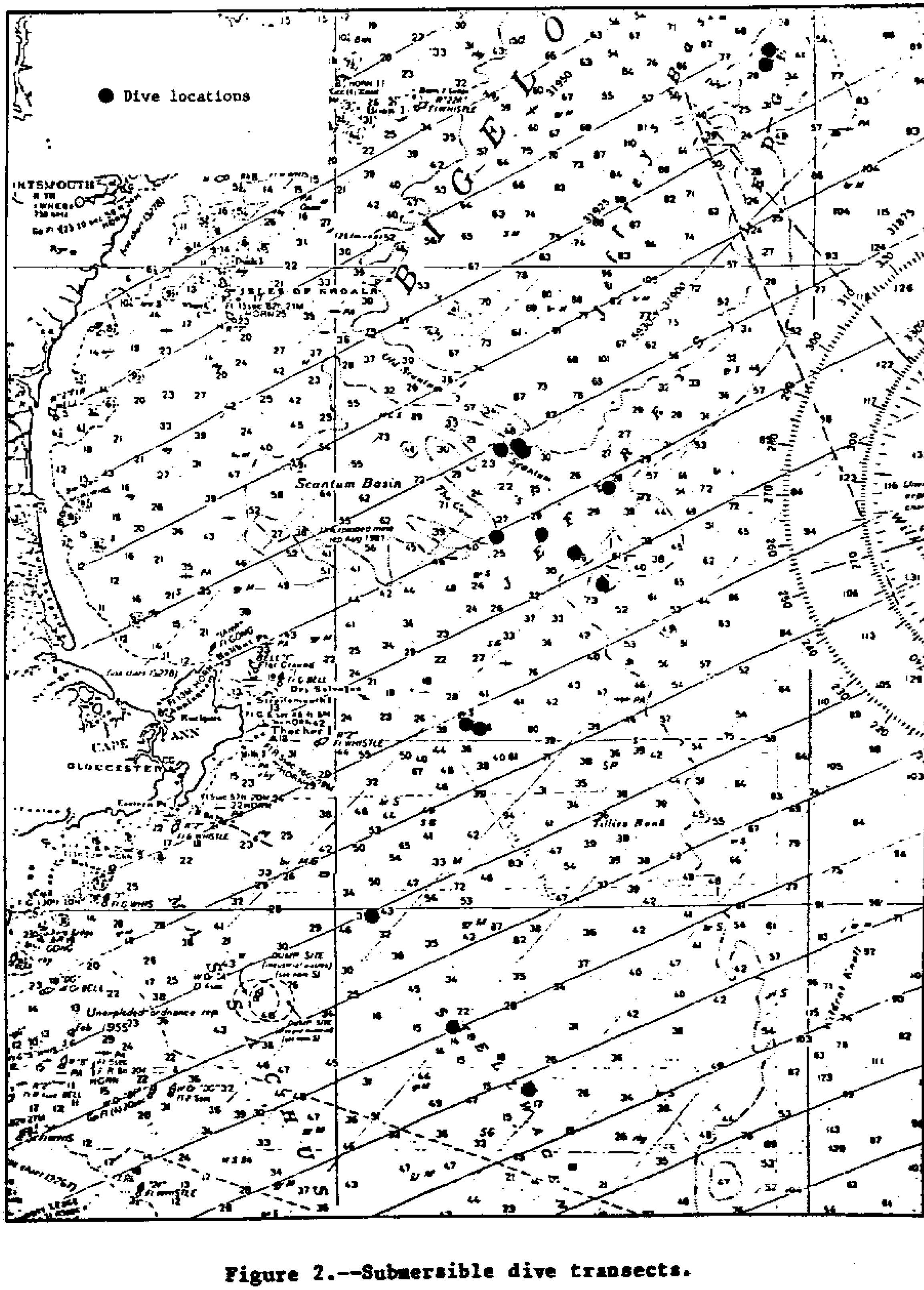

Figure 2.--Submersible dive transects.

had one and two dead dogfish, respectively, each tangled in the webbing. No other species were caught.

Two nets were actually short horizontal pieces <9.1 m, with a twisted, vertically rising mass on one or both ends. One of these net fragments, stretched horizontally for approximately 9.1 m, had a snarled mass on one end rising up 3 m (10 ft) off the bottom. The horizontal segment had several tears in the webbing and a twist between the float line and leadline. Its maximum float line height was 0.6 m off the bottom. One dogfish and three lobsters, Homarus americanus, were caught in this section. No fish were caught in the vertically twisted mass. The other net consisted of a 6.1-m (20-ft) horizontal piece between two vertically twisted bundles. The only fish caught were two dogfish in the stretched section. Although the end bundles had no fish, numerous starfish, Solaster endeca and Asterias sp., were clustered at the base of each. This suggests that these snarled masses, although barren of any catch during our observations, had snared fish that provided a source of food for the starfish.

Four ghost nets found were stretched horizontally along the bottom, varying in length from 61.0 to 228.6 m (200 to 750 ft) with a vertical profile usually reduced to <0.6 m (<2 ft). These nets caught the most fish, even though each net had a combination of float and leadline twists, large irregular holes in the webbing, and a reduced vertical profile. The predominant species caught was the dogfish. A typical example of the catch in any 91.4 m (300-ft) section of net was 12 dogfish, 1 wolffish, Anarhichas lupus, 1 sea raven, Hemitripterus americanus, and a lobster. All were tangled in the net. The dogfish, judging by their color and state of decomposition, were recently caught. A notochord near the leadline of the net was evidence of predation around its vent. Cancer crabs and starfish were in and near the net; some starfish were feeding on the caudal region of a dogfish. Pollock, Pollachius virens, and cunner swam through portions of the net.

All of the ghost nets appeared to have been underwater for 2 years or more. We determined this by the colonization of bryozoans on the monofilament and the presence and size of the anemones, stalked ascidians, and Halichondrina sponge on the float lines. We also knew the age of one net. Its condition enabled us to compare the growth and level of deterioration of that net to the other nets. This horizontal net, placed 3 years before our survey, went down with the gill net vessel during deployment of a string of nets. One submersible dive surveyed the vessel and the nets still attached to the vessel.

The nets that lay stretched horizontally had a mean vertical profile of 0.4 to 0.6 m (1-1/2 to 2 ft). This represented a vertical profile that was 25 to 33% of an active demersal net used in New England waters. The efficiency of these nets was further reduced by the growth of bryozoans on the monofilament which made the net more visible, and by the numerous holes in the net. We estimated the total linear distance of all reduced horizontal gill net sections observed in 1984 to be 548.6 m (1,800 ft).

We have no definitive explanation for the three different net configurations found. Discussions with gill-netters, trawler fishermen, and recreational fishermen led to several hypotheses: The horizontally stretched nets may have lost their buoy lines and therefore became lost; the vertically tangled nets may have become fouled on rocky bottom which prevented successful retrieval, or they may have been fouled by the mobile trawlers.

Limited observations were made on commercially set nets. The dives on active gill nets were intended to observe cod, which unfortunately were displaced by the influx of spiny dogfish. During surveys of three gill nets set for dogfish, we acquired interesting video documentation of the entanglement behavior of dogfish, winter flounder, *Pseudopleuronectes americanus*, skate, and cod. The second purpose of the initial survey was completed successfully: A survey of areas of high gillnetting activity was carried out and a determination made of relative ghost gill net abundance in these areas: 10 lost nets of varying length on 4.0 ha (10 acres) of bottom.

We believe it is premature to draw any firm management or economic impact conclusions on the effects of ghost gill nets on the fishery resources off New England from the information gained on this initial survey. The most abundant catch was dogfish which at present has minimal economic importance to the industry. Although gill-netters did report cod in the vicinity, cod were not observed as the primary catch in the ghost gill nets, nor were any substantial skeletal remains observed around the base of the nets.

During the second year of this program, our initiative will be threefold:

1) To look at active gill nets and ghost gill nets when cod are more abundant. The purpose is to observe another stage or window of activity of the nets and the impact on the cod resource.

2) To return to several of the ghost gill nets found in the summer survey of 1984 and record their status 1 year later.

3) To experiment initially with modifications to a demersal gill net to see if its continued fishing, when lost, can be reduced.

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THE PROBLEM OF FUR SEAL ENTANGLEMENT IN MARINE DEBRIS

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ABSTRACT

Many fur seals die by entanglement in fishing nets discarded or lost by fishing boats. This is reported to be a major cause of the present decrease in the number of fur seals and has been the subject of discussion by the North Pacific Fur Seal Commission.

A 3-year study started in 1983 placed particular emphasis on analyzing the actual reasons why fur seals become entangled and how they behave while entangled.

The main study items are as follows:

1. Collection of data concerning the actual condition of lost nets, the number of entangled fur seals, the feeding behavior of seals, etc., at sea.
2. Survey of the rookery islands to count fur seals entangled in marine debris, survival period of entangled fur seals, rate of fur seal escapement from entangling nets, effect of entanglement on the growth of fur seals, counting nets washed ashore, etc.
3. Experiments using fur seals raised in captivity to determine how fur seals (a) become entangled in fragments of nets, (b) escape from nets, (c) are injured by nets, and to determine how the weight of the net is related to the feeding behavior of the fur seals, etc.

The preliminary data collected in these surveys and experiments are reported in this article.

INTRODUCTION

The first report on the net entanglement problem of fur seals was submitted by the U.S. scientist to the Standing Scientific Committee of the 10th Annual Meeting of the North Pacific Fur Sea Commission. At that time,

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

the decision was made to proceed with the collection of research material to analyze the problem in more detail. At the 11th meeting, the American representative proposed a survey to carry out a detailed analysis of net entanglement, and a study to determine the origin of 50 samples of net fragments recovered in the Pribilof Islands was assigned to the Japanese team. Results of the determination on the origin of the samples was reported to the 12th annual meeting by Japanese scientists (Japan 1969). The report stated that except for one piece of rope used in crab gill net fisheries and two plastic bands, all samples were of trawler net fragments. It was estimated that most of the fragments, excluding a small portion, would be of Japanese origin. However, since nets made in Japan are exported in quantity, it was impossible to identify the country that was actually responsible.

In the subsequent 12 years up to the 24th annual meeting, a few reports on this problem had been submitted by the United States and the Soviet Union, and although the impact of marine debris on the fur seal population remains unclear, it was agreed that the problem was of major importance and that research efforts should be intensified. At the Standing Scientific Committee meeting of the 25th Annual Meeting of the North Pacific Fur Seal Commission, the United States reported that the fur seal population of the Pribilof Islands had been reduced by 5% due to net entanglement, and that the problem was causing a deterioration in fur seal population. In response, the Japanese stated that the base value was based on erroneous data and that a 5% rate could hardly be assumed. The United States also agreed that it was still too early to draw such a conclusion. In 1983 at the Standing Committee meeting of the 26th annual meeting, the United States reported a death rate of almost 10% due to net entanglement, and in the general meeting stressed that although the decline of the population in the Pribilof and Robben Islands could not be directly related to net entanglement, that it was a prime candidate, and should be promptly investigated by the member countries. In response, Japan and Canada replied that the death rate due to net entanglement had not changed over the last 10 years, and that the population decline was perhaps exaggerated. The Soviet Union was of the opinion that the fragments were simply part of the pollution of the oceans and did not recognize any increase in net-related deaths. Nevertheless, all member nations agreed to proceed with trying to find a solution to the problem.

Taking into account the above progress, the Japanese acknowledged that a scientific approach was critical and started the following 3-year survey running from 1982 to 1985.

METHODS

The investigative plan consisted of three sections: an oceanic survey, an investigation of the rookery islands, and an experimental investigation of seals under controlled conditions. The goal was to identify the actual extent of net entanglement, mechanism of the entanglement, and determine the behavior of entangled seals.

Oceanic Survey

In addition to the standard survey factors (fur seal distribution, migrations, mixing, age composition, feeding habits, habitat, reproductive rates, etc.), other factors such as the number of net fragments floating in the ocean, the number of fur seals entangled, and the feeding activities of entangled fur seals were also investigated.

Investigation on the Rookery Islands

Data were collected on the entanglement and escape rates of male fur seals, as well as the average period of their survival under entangled conditions. Also, the entanglement rate of female fur seals and the number of net fragments washed on shore and the growth of seals which had been entangled were also investigated.

Experimental Research

Under a contract with an aquarium, the Far Seas Fisheries Research Laboratory proceeded with research into the conditions under which fur seals become entangled in drifting net fragments, the possibility of escapement from it, the development of scars caused by net entanglements, and the relation of net fragment weight and feeding activities of entangled fur seals.

RESULTS

Oceanic Survey

A report on the estimated number of floating net fragments and entangled fur seals in the survey areas will be summarized and presented at the end of the 3-year research period in 1985. Therefore, this report will only present data obtained by the surveys from 1982 through 1984.

Survey by One Research Vessel, 1982

Survey area.--Okhotsk Sea near Robben Island.

Survey period.--3 July to 11 July 1982.

Purpose.--The survey was done to determine if rope and net fragments could be detected by visual search.

Results.--Seven floating trawler net fragments were discovered, and in three of them was entangled either a fur seal or harbor seal. One of the fur seals was already dead when discovered.

Survey by Two Research Vessels, 1983

Survey area.--Pacific coastal waters off northern Japan and Hokkaido.

Survey period.--1 November to 26 December 1983.

Results.--Three salmon gill net fragments, three squid gill net fragments, and four trawler net fragments were discovered. A fur seal was found entangled in one of the trawler net fragments.

Survey by Two Research Vessels, 1984

Survey area.--Pacific coastal waters off northern Japan and Hokkaido and the coastal waters off the Pribilof Islands in the Bering Sea.

Survey period.--18 January to 17 March 1984 and 3 July to 30 August 1984, respectively.

Results.--Four salmon gill net fragments, 1 plastic band, and 10 trawler net fragments were discovered. A fur seal was found entangled in one of the trawler net fragments.

Investigation on the Rookery Islands, 1983 and 1984

Two scientists from Japan were dispatched to St. Paul Island to conduct a joint survey with United States scientists to investigate net entanglements of fur seals on the rookery islands. The investigation covered the number of male fur seals entangled, identification of the entangling materials, scarring, escape rates, growth of seals after having been entangled, and types and weights of fragments found on the shores of the islands. The results of 1983 survey were reported in 1984 (Scordino et al. 1984).

The 68 samples of net fragments collected on St. Paul Island during the 1982 breeding season were sent to Japan for analysis in 1983, and the results were reported in 1984 (Yoshida et al. 1984).

About 1,500 samples of net fragments and plastic bands collected on the shores of the rookery islands during 1982-84 and recovered from fur seals during 1981-84 were sent to Japan for analysis. This material is currently being studied.

Experimental Research

In 1983 experimental research was conducted at the aquarium on the conditions under which seals became entangled, the possibility of escapement, the effects on feeding of entanglement, and the injuries and scars caused. The results have already been reported in "The 1983 report on the fur seal entanglement problem aquarium experimental research." This research is continuing. The results of the 1983 research is as follows:

Twenty-two fur seals were studied; 20 had been captured along the coast of Japan and kept in captivity for 2-4 years, and the other 2 were shipped from Robben Island while young and raised at the aquarium on artificial milk.

The net fragments utilized were eight pieces of polyethylene trawler net in total, with mesh sizes of 24 and 40 cm, and weights of 100 and 200 g, respectively. In addition, four polypropylene cargo bands 15.5 mm wide, and 16 cm in diameter, colored blue and yellow, respectively, were also used.

The total number of fur seals entangled in either net fragments or bands was 9 out of 22 (41%), with a total of 12 cases of entanglement observed.

The period until the seals became entangled ranged from 18 h to 34 days, and entanglement usually resulted when they charged forward at high speed without recognizing the floating objects. For the young seals, entanglement during play was also frequent.

Of the seals becoming entangled, 10 were observed to escape from the fragments, within a range of 2-5 days after becoming entangled. The two young seals were frequently entangled in and escaped from the fragments.

No effect on the behavior of the seals after their entanglement was observed.

Temporary drops in the amount of feeding by entangled seals were observed for periods of up to 10 days.

There was no apparent drop in seal weight during the time they were entangled, and some even gained weight.

There was almost no scarring due to entanglement, and even the seal that was entangled for the longest time only suffered a slight ruffle of fur.

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INCIDENTS OF MARINE MAMMAL ENCOUNTERS WITH DEBRIS AND ACTIVE FISHING GEAR

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INTRODUCTION

This paper summarizes the encounters of marine mammals with debris and active fishing gear that I have observed (with an emphasis on the Oregon coast) since 1968 or that have been reported to me with substantiating evidence by reliable sources. From 1968 to 1972, most of the observations were my own, during doctorate research, on the numbers of sea lions utilizing the Oregon coast throughout the year (Mate 1975). During this time, I was stationed at the Oregon Institute of Marine Biology in Charleston, Oregon and most of the observations were made within 100 km of that location. From 1973 through 1975, I was a less frequent observer along the coast and my attention was only drawn to incidents through personal contacts. Since 1976, I have been based at an active marine laboratory in Newport, Oregon and my observations have been supplemented by a network of collaborating Oregon agencies (Department of Fish and Wildlife, State police, highway department, and State parks), Federal authorities (National Marine Fisheries Service enforcement agents and the U.S. Department of the Interior parks personnel), and colleagues participating in the Northwest Marine Mammal Stranding Network. Most of the information for this paper is on file at the Oregon State University's (OSU) Hatfield Marine Science Center in the form of stranding reports and collection records. Some of these occurrences have been reported through the Smithsonian Scientific Event Alert Network (SEAN), but often without the cause of death completely diagnosed. Many of the dead pinnipeds were held in frozen storage after collection for later examination. Many necropsies were performed by R. Stroud, J. Harvey, and R. Brown. In general, most rates of encounters were extremely low and, whenever possible, these are estimated in this text with the number of observer hours or thousands of animals observed.

CETACEANS

Lines

Gray whales have been the most common cetacean involved with fishing gear along the Oregon coast, probably as a result of the large number of individuals found nearshore, compared with other species. Approximately 16,000 gray whales annually pass the coast twice each year. The most frequent entanglement problem since 1968 was associated with experimental

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

crab fishing with helicopters in a short period from 1976 to 1978. Conventional commercial crab pots were fitted with the usual line and two surface buoys. The buoys were separated by a longer length of line to facilitate hooking them from the helicopter (particularly in heavy seas). This gear was often fished closer to shore early in the season because of high seas from winter storms. Most problems occurred during good weather when gray whales tended to migrate closer to shore in shallow water (Herzing and Mate 1984). Entanglements invariably involved the rope between the two floats getting caught between the baleen plates (probably during surfacing), and often became complicated by further entanglement of the flukes or pectoral flippers. I have seen the latter occur when the animal was making sharp turns, in an apparent effort to dislodge the rope. Between five and eight entrapments were reported during each of the helicopter crabbing seasons of 1975-76 and 1976-77. Problems have continued even after helicopter crabbing ended. Vessel-based crabbers move their gear closer to shore during the spring as weather improves and the crabs start to reproduce in shallow water (D. Snow pers. commun.). An average of two whales each year are now reported entangled in crab pot lines along the central Oregon coast. The fate of these animals is unknown, although in February 1977 an adult female gray whale was found beach cast with a conpicuous fracture of the coccygeal vertebrae (tail stock) and associated wounds, which were diagnosed as the principle cause of death (Stroud 1978). A beach cast minke whale collected in 1982 had a crab pot line through its mouth which had worn through the soft gum tissue and 2 cm into the jaw bone. The adult specimen was not fresh enough to discern whether other factors had also contributed to its death (J. Harvey pers. commun.).

I have a video tape taken by fishermen in 1982 showing a similarly entrapped humpback whale towing king crab gear in Alaska. The whale made an enormous effort to keep at the surface, swimming with its head out of the water at a 30° to 45° angle. In spite of this exertion, it was able to swim evasively at over 5 knots for at least 15 min to avoid the fishing boat, which was finally able to catch the dragging lines and cut the whale free. The rope was shorter than the water depth and was still attached to three crab pots.

During four seasons (1977, 1980, 1983, and 1984) of studying gray whales in San Ignacio Lagoon, Baja, Mexico, OSU crews have spent 6 months in this winter calving area and have seen five gray whales entangled in lines. Four of these have been calves, which may favor the shallower water where fishermen try to maintain modest winter fishing activities.

Nets

From 1975 to 1984, I am aware of only three net entanglements in Oregon, all involving gray whales. Two incidents involved gray whales in Columbia River gill nets: One was a live whale which subsequently died, and a second was an animal that had recently died and drifted into the net. A third incident, involving a yearling gray whale during August 1981, was investigated by OSU graduate student J. Sumich. He worked from a U.S. Coast Guard vessel to untangle most of a monofilament salmon gill net from a gray whale off Newport, Oregon (unpubl. data). The net was subsequently identified as being from southeast Alaska and was most likely brought south by the whale, which appeared quite fatigued. Only a few strands of net were left on the whale. No whales with net marks were subsequently reported ashore through the SEAN system in the next several months.

Boat Encounters

Annually, several instances of gray whales rubbing against anchor chains or boats are reported to the Marine Science Center by local salmon fishermen or sail boaters, but I am only aware of two instances where the whale hit the boat hard. Both times, people on board the vessels (without engines running) were watching gray whales and the whale was apparently unaware of the boat before striking it "accidentally." In my experience, whales react quickly and forcefully when unexpectedly "touched." Such a reaction has survival value for an animal preyed upon by sharks. I have also seen two gray whales blunder into floating logs with the same reaction. Boats also strike whales. A 10.7-m dead gray whale, examined at Cape Mears, had been struck by a vessel. There were large, evenly spaced, serial lacerations from a propeller, which cut through the blubber and into the muscle. There were also numerous shark bites up to 48 cm across, but these did not overlap sufficiently with the lacerations to determine which had occurred first. It is not known what caused the animal's death. It may have been dead before being hit by the boat, although the carcass was reasonably fresh.

Beach Cast

I am not aware of any cetaceans which have died as a direct result of debris in Oregon. However, it is worth a note of caution on the interpretation of death rates from beach cast animals. Unless the animal has died very close to shore, the likelihood of it becoming beach cast in Oregon is quite small. Currents and winds vary to affect the beaching of dead animals. A narrow shelf and a relatively steep continental slope reduce the chances of a whale, which dies offshore and sinks, from washing ashore. In Oregon, dead animals have washed up on rocky headlands, gently sloping sandy beaches and on mudflats in estuaries, but less than 10% have been in advanced stages of decomposition when they first came ashore. Most are fresh or only slightly bloated. Because the Oregon coast is so accessible, I believe that 90+% of the large whales which become beach cast are reported to the Oregon stranding network, although not always in real time.

Evidence of whales dying offshore is apparent from the frequency with which whale parts are reported or brought in by bottom-trawl fishermen. Most of what is brought ashore tends to be skull parts from large rorquals. The rollers on the bottom of trawl nets probably roll over small bones, which may also pass through the wide mesh of the trawl wings. Despite the fact that fishermen say they discard most of the whale material at sea, the Marine Science Center gets at least six calls each winter from fishermen wanting to donate unusually large specimens. Weathered whale parts can also be seen around the community. In most cases, it has been impossible to determine from the bare bones how long the whale has been dead. Thus, although trawl netting of whale parts may be 10 times more frequent than beach cast carcasses, the frequency of encountering the old material is at least partially the result of long-term accumulation. Old parts may also be renetted time after time because most fishermen dump them back into the sea. In 1984, the still oily skull base and lower jaws of a blue whale were recovered from a fisherman's trawl and were larger than 95% of all other known specimens of this species. There is no reason to believe that net-collected specimens died as a result of fishery interactions.

PINNIPEDS

Nets and Packing Bands

The pinnipeds most frequently encountering commercial fishing gear are seals on the Columbia River during active gill net fishing. The Washington Department of Fish and Game has collected considerable data on incidental take of seals since 1980. Although harbor seals do interact with other fisheries, I am not aware of seals being involved in any other fishing gear or debris-related mortalities in Oregon. In a 3-year study of 57 beach cast pinnipeds in Oregon, Stroud (1978) concluded that shooting was the leading diagnosable cause of death for adult harbor seals (7 of 16).

Steller and California sea lions have been observed with neck lacerations typical of net entanglement. During visits to three Steller sea lion rookery sites in June 1968, 2 animals (a female and an adult male), out of a total population of approximately 1,450, had visible neck lacerations. During the following 3 years, records were kept on individually recognizable Steller (n = 158) and California (n = 954) sea lions. Recognizable animals probably represented <10% of the animals using the areas surveyed throughout the year. Among the recognizable sea lions, 10 had open neck wounds (8 Steller and 2 California) and 2 (1 of each species) had healed neck scars. All neck wounded animals were all subadult males and females with the exception of one breeding male Steller. One of the open wounds was caused by a rusting metallic packing band. The healed California sea lion was seen on five occasions over a 2-year period. None of the others were resighted beyond the season in which they were described. The longest observation of an animal with an open neck wound was that of a subadult Steller over a period of 27 days during the 1970 breeding season. Of the 200+ pinnipeds examined by myself or OSU-based colleagues in 8 years, only one northern fur seal and one Steller sea lion have been found dead and beach cast with obvious net-induced neck lacerations. Both were emaciated. In 8 years, two additional live fur seals have been reported to the Marine Science Center as beached animals encumbered with net debris, but these were not confirmed. When fur seals come ashore in Oregon, they have most frequently been within 161 km (100 m) of the Columbia River.

Ingestion of Debris and Fishing Gear

One subadult northern elephant seal and one adult Steller sea lion choked to death on styrofoam cups (R. Stroud and B. R. Mate unpubl. data). We have also examined two pinnipeds which choked to death on fish.

Each year, it is common to see at least one Steller sea lion with a salmon troller's "flasher" (a chrome lure) hooked in its lip. These are almost certainly acquired during an encounter with an active fishing gear and not discarded gear. In 1969, a territorial Steller male had a troller's "flasher" in its lower lip for at least 7 days, before it was dislodged.

One of 38 sperm whale stomachs, examined from the stranding of 41 whales at Florence, Oregon in June of 1979 (Rice et al. in press), contained about 1 liter of tightly packed trawl net (J. Harvey unpubl. data).

SUMMARY

There does not appear to have been a dramatic observable increase in the occurrence of debris-induced marine mammal mortality in Oregon since 1968. The number of animals involved with debris appears to be low. Except for one instance of ingested netting by a sperm whale, cetacean associations with "debris" have been limited to fishing gear entanglements (with lines and nets). The most frequently reported involvements are gray whales towing buoy lines, most often caught in the mouth. Whales appear to be most vulnerable to the line between two buoys, often used by fishermen to mark and more easily recover stationary gear (traps, pots, and long-lines). In all but one case involving whales and nets, the whale probably became entangled while the fishing gear was in use. If whale mortalities occur primarily offshore in Oregon, it is doubtful that much evidence from beach cast carcasses would accumulate. Pinnipeds have become entangled in active and discarded fishing gear and have also choked to death on swallowed debris and on fish. The observation of healed neck wounds on sea lions indicates that at least some individuals survive such ordeals. The low resighting of neck-wounded sea lions over a 3-year period may reflect one or more of the following: 1) a high mortality rate, 2) normal looking pelage concealing healed wounds, or 3) a failure to resight the animals during later census periods.

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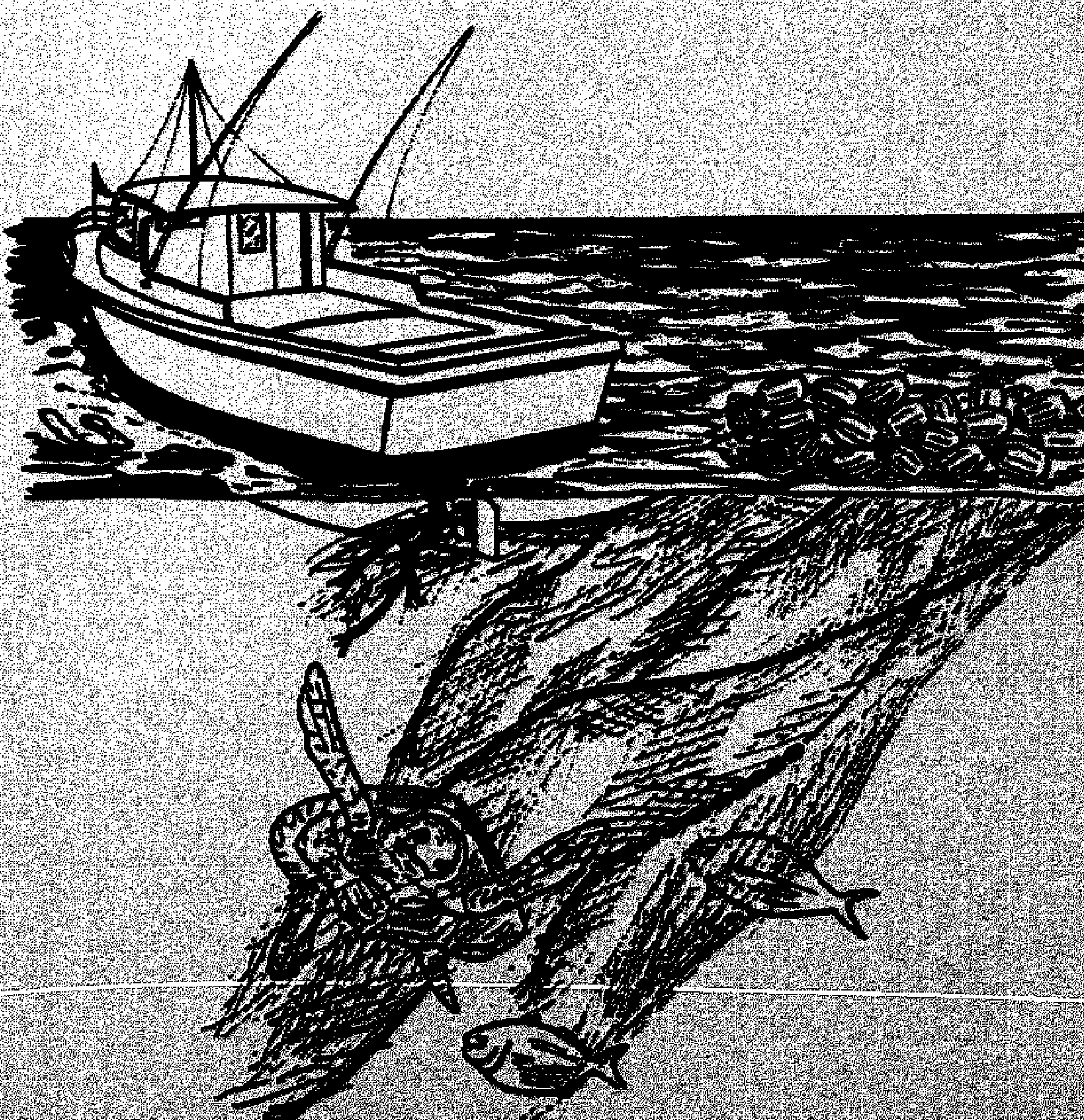
SESSION III

FATE OF MARINE DEBRIS



CURRENTS OF THE TROPICAL AND SUBTROPICAL NORTH PACIFIC OCEAN

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ABSTRACT

Systematic observations of ocean properties began during the second half of the last century. These included the ship drift observations that became the foundation of our knowledge about ocean currents. Hydrographic station data collected aboard research vessels during the last 60 years greatly added to our understanding of the ocean circulation. During the last decade, the NORPAX satellite-tracked drifting buoy program provided information about the behavior of North Pacific surface currents that will be most helpful in learning how to predict the fate of marine debris. Using this information, the major tropical and subtropical ocean currents are described and the limitations in terms of predicting the fate of marine debris are discussed.

INTRODUCTION

Soon after he took to the sea, man must have learned about ocean currents and probably discovered that currents carry debris. Indians of the Puget Sound paddling their canoes certainly knew about tidal currents and the great navigators of the Pacific, the Polynesians, must have been aware of the equatorial currents and currents around their islands. All this knowledge was not broadly useful, however, without being recorded and published.

EARLY CURRENT CHARTS

As intercontinental ocean trade developed during the 17th century, the need for knowledge about the ocean and its currents became evident. During the next century, the Franklin-Folger Chart of the Gulf Stream (Fig. 1) was an early attempt to chart currents. It was not until the middle of the last century, however, that real progress was made in charting ocean currents. A very energetic, American hydrographer and pioneer oceanographer, Matthew Fontaine Maury, knew that ship captains kept detailed accounts in their logbooks of all environmental conditions they encountered including observations of winds, currents, and air and water temperatures. He realized that if this information were collected and summarized, valuable atlases could be produced and ocean currents could be charted. In a pilot study, he did just that and was able to

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

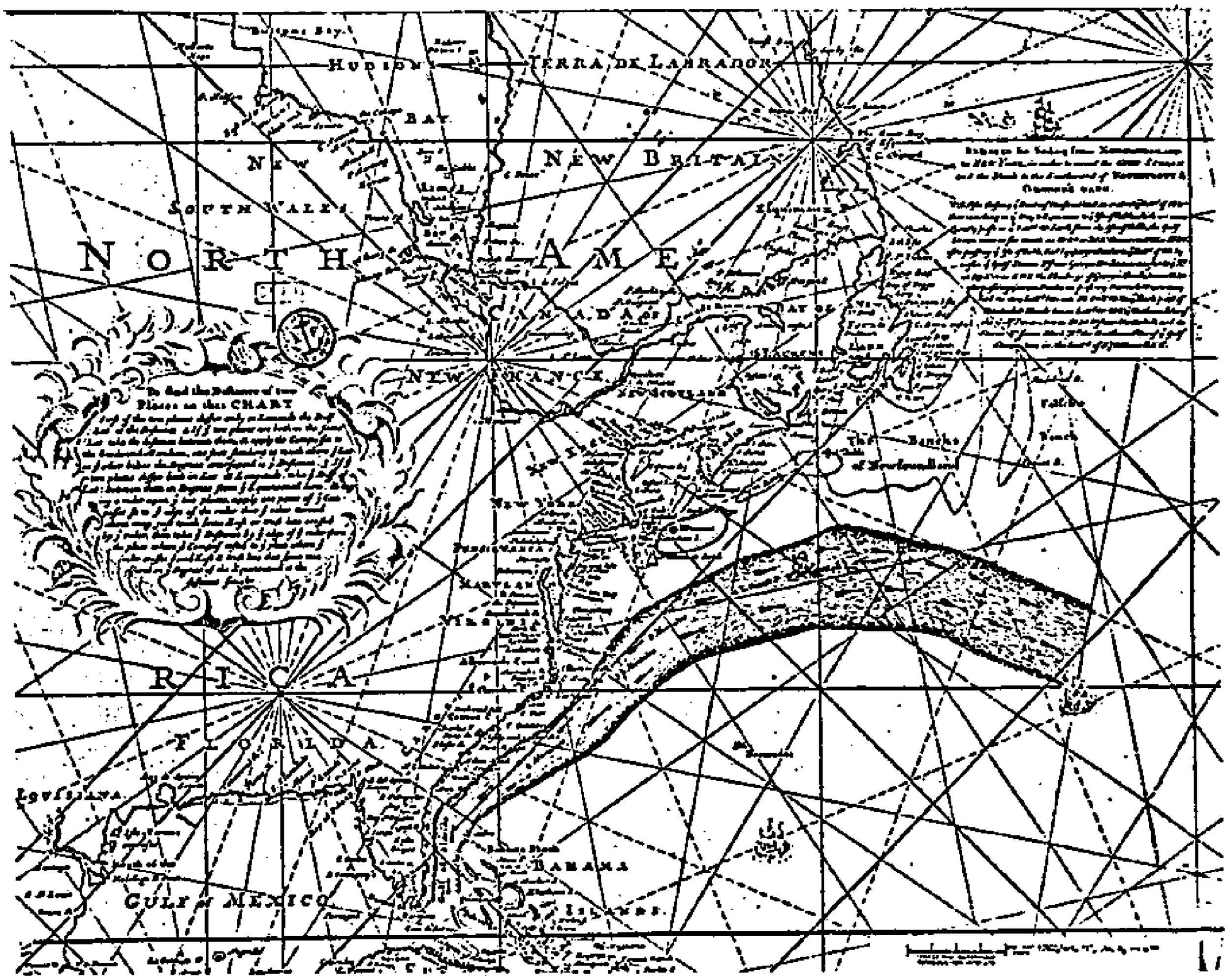

Figure 1.--The Franklin-Folger chart of the Gulf Stream printed by Mount and Page in London ca. 1769-70 (Richardson 1980).

demonstrate the economic benefits. He persuaded the government of the United States to propose a uniform system of observations at sea and to "invite all the maritime states of Christendom to a conference upon the subject." The idea was enthusiastically endorsed at the famous 1853 conference in Brussels where "a plan of observations which should be followed on board the vessels of all friendly nations" was recommended (Maury 1855).

An important part of these observations was ship-drift determinations based on the difference between the dead reckoning position and the actual position of the ship at the time of celestial navigation fixes. These data, collected during the second half of the last century and the beginning of this century, became the primary source of information for comprehensive charts of ocean currents. Two examples produced by Schott (1935) for the Indian and Pacific Oceans are shown in Figure 2a (August-September) and Figure 2b (February-March). These charts show the general ocean circulation as we know it today. The size of the arrows in the figures indicate the strength and direction of the currents. The major

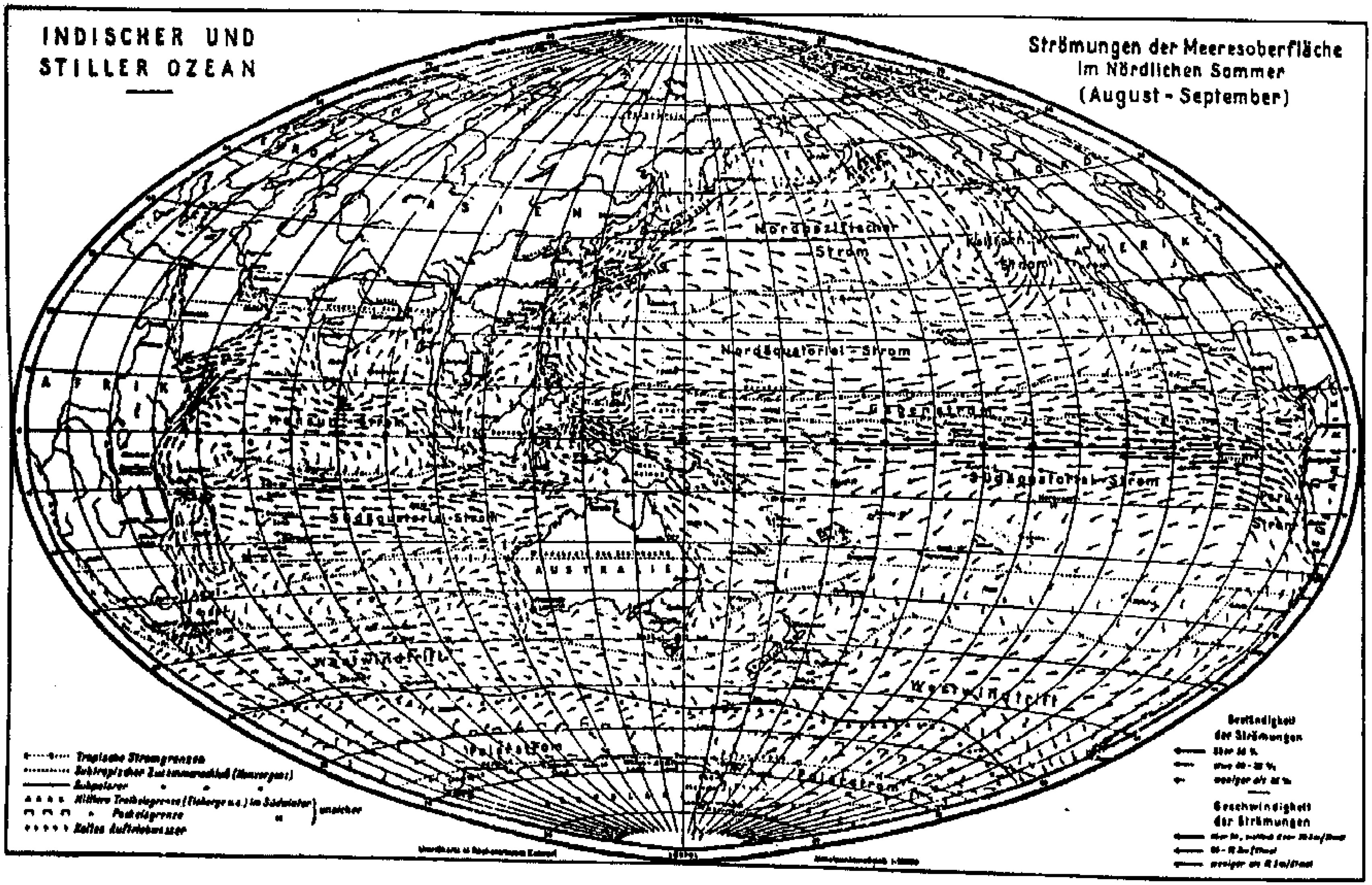

Figure 2a.--Currents of the Indian and Pacific Oceans (August-September) (Schott 1935).

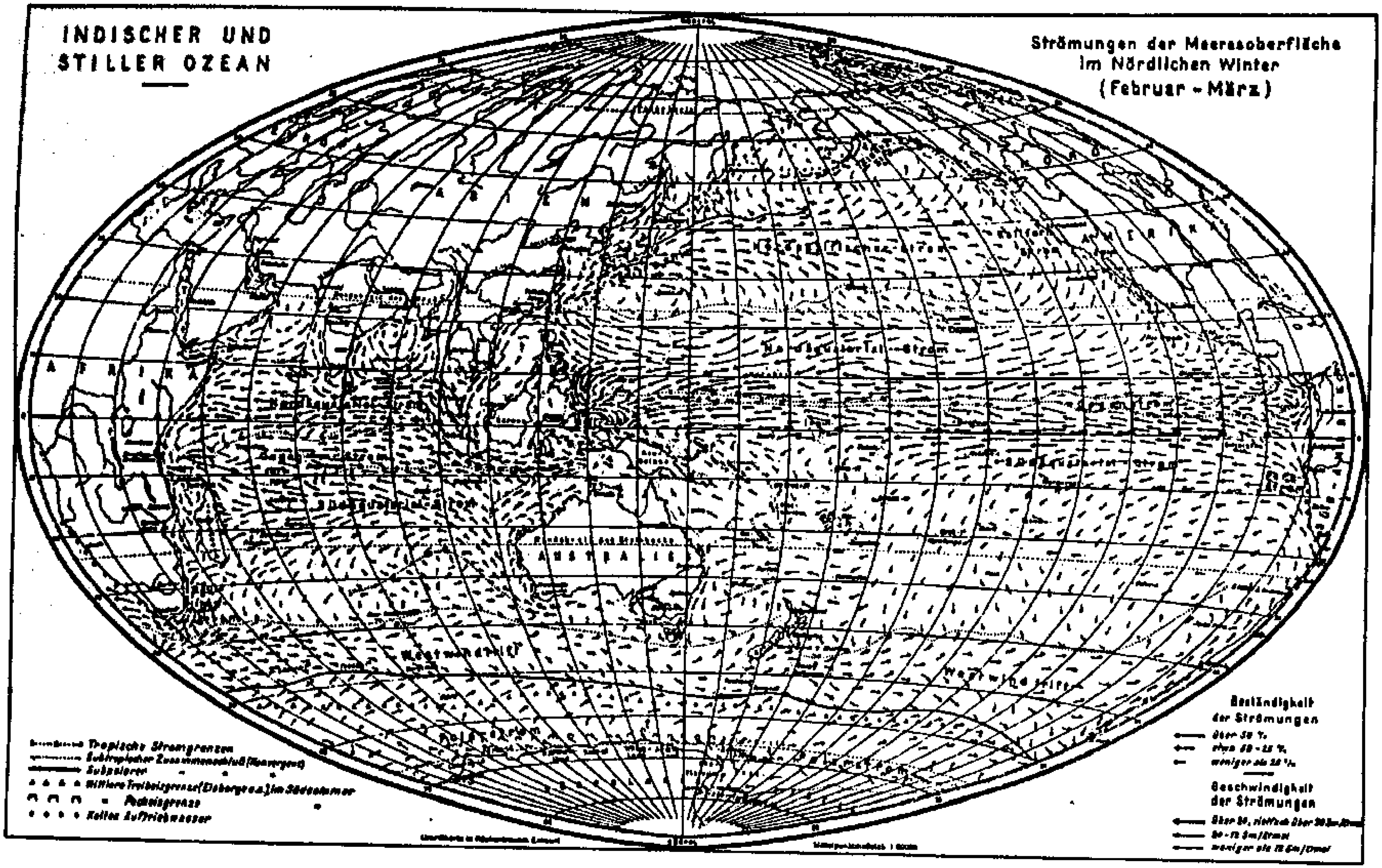

Figure 2b.--Currents of the Indian and Pacific Oceans (February-March) (Schott 1935).

currents are the following: In the western North Pacific, there is the strong, northeastward flowing Kuroshio and the eastward flowing North Pacific Current which is also called the West Wind Drift Current. On the eastern side of the ocean, the eastward flowing current splits into the northward flowing Alaska Current and the southward flowing California Current. To the south, between lat. 10° and 20°N is the westward flowing North Equatorial Current. These currents form the main segments of what is often called the subtropical gyre. South of the North Equatorial Current, between about lat. 5° and 10°N, there is the eastward flowing Equatorial Countercurrent. The westward flowing South Equatorial Current, which Schott shows to be very strong in the eastern half of the Pacific, lies south of lat. 5°N.

Interpretation of details in these charts must be made with caution. Although many thousands of observations went into their production, ship-drift determinations are subject to relatively large errors. Nevertheless, interseason differences can be noted, such as, changes in the intensity, width, and shifts in location of currents. For example, the Equatorial Countercurrent which Schott shows to be wide and well developed during the summer in the eastern half of the Pacific is narrow or almost absent during the winter. I will return to a discussion of this current later.

Although current charts such as those produced by Schott have been updated and refined, they show no major changes of the basic flow pattern he described. Useful charts for mariners are the Pilot Charts which are produced for each month by the Defense Mapping Agency.[1] These charts primarily give meteorological information, but they also show the currents for each month (again based on ship-drift data). An example is shown in Figure 3.

GEOSTROPHIC CURRENTS

While merchant ships routinely were collecting meteorological and oceanographic data, oceanography as a separate discipline developed with research expeditions that explored all the oceans. Important on these expeditions were vertical soundings for water samples so that temperature and salinity versus depth profiles could be determined at many locations of the oceans. With this information, after calculating first the density and then the potential height of the sea surface above a given reference level, it was possible to chart the dynamic or geopotential topography of the sea surface. This information is used to determine the ocean circulation indirectly.

Reid (1961) used the data from many research expeditions to produce a chart of the geopotential topography for the Pacific (Fig. 4). Interpretation of the chart in terms of the geostrophic currents is similar to the interpretation of atmospheric pressure charts in terms of geostrophic winds. Flow is along the contours; when the contours are close together, the flow is fast and when they are far apart, it is slow. The

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[1] [U.S.] Defense Mapping Agency, Department of Defense, Pilot chart of the North Pacific Ocean. (Monthly.) Washington, D.C.

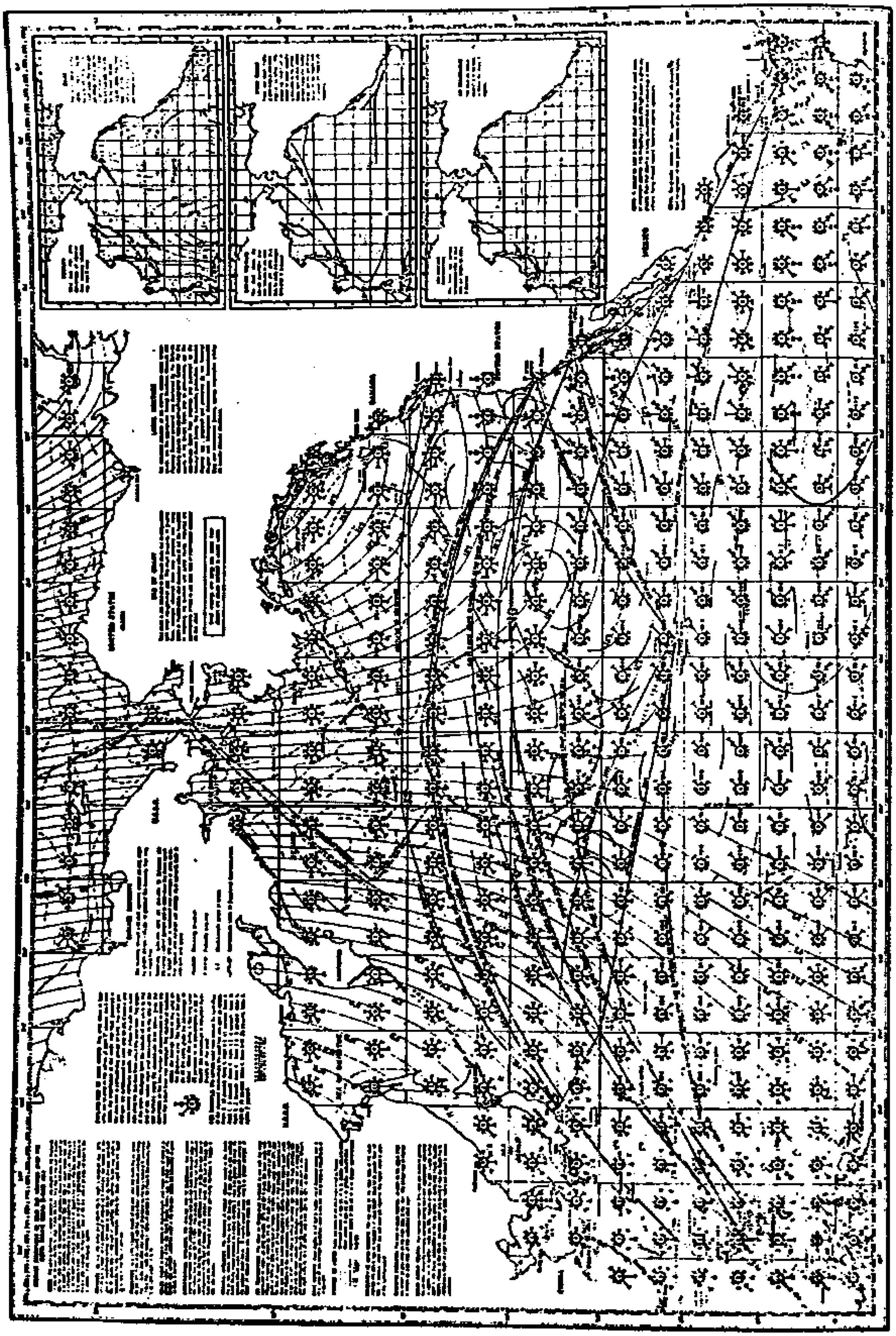

Figure 3.—Pilot chart of the North Pacific, July 1984.

Figure 4.--The anomaly of geopotential distance between the 0- and 1,000-decibar surfaces in the Pacific Ocean, in dynamic meters (Reid 1961).

geostrophic interpretation cannot be used on the Equator and becomes uncertain within 1° to 2° of latitude of the Equator.

The geostrophic current is an idealized current in which a steady state (no acceleration) and no friction are assumed. Also, the geopotential topography does not reflect the wind-induced surface drift. Nevertheless, the subtropical gyre with the major currents as described before can be recognized. Note the closely spaced contours near Japan indicating that the Kuroshio is a fast current. Also note the wide spacing between contours in the central North Pacific indicating a slow net flow. Again, the North

Equatorial Current, the Equatorial Countercurrent, and the South Equatorial Current are clearly evident. Through the use of large data banks in modern computers, new geopotential height charts have been produced. However, they do not differ materially from Reid's chart shown here.

THE EQUATORIAL UNDERCURRENT

There is one important current that has escaped detection by both the ship-drift and the dynamic topography method of mapping ocean currents. This current is the Equatorial Undercurrent which is also called the Cromwell Current because it was first recognized by Townsend Cromwell in 1953. Cromwell was an oceanographer at the Pacific Oceanic Fishery Investigations (POFI) Laboratory (now called the Honolulu Laboratory, Southwest Fisheries Center). While participating on an exploratory fishing cruise, he noted that a longline set out on the Equator was drifting in the "wrong" direction, namely to the east rather than to the west, the direction of the South Equatorial Current. He suspected and subsequently confirmed the existence of the subsurface current (Cromwell et al. 1954).

Since its discovery, the Equatorial Undercurrent has become the subject of many investigations and has been described through direct current meter measurements. The results of early measurements at long. 140°W are shown in Figure 5 (Knauss 1960). The current profiles show the core of the current to be at a depth of about 100 m with speeds of more than 2 knots (>100 cm/s). Eastward flow extends from about 30 m to more than 200 m and from about lat. 2°S to 2°N. The current extends all the way from the Galapagos Islands to the western Pacific, long. 150° to 160°E. The boundaries of the current as well as its maximum speed may vary with time and it has been observed to come to the surface during El Niño years.

Excepting the occasions when it comes to the surface, the Equatorial Undercurrent may not be important in terms of carrying drifting debris. However, subsurface fishing gear may become hopelessly tangled when set out on the Equator because of the large shear produced by the strong westward flowing surface current and the equally strong eastward flowing subsurface current. Thus, the tangled gear, if not recovered, will contribute to the drifting debris in the ocean.

OBSERVATIONS OF CURRENTS USING MODERN TECHNOLOGY

Ocean current charts based on ship-drift determinations or geopotential height calculations provide only gross pictures of ocean currents because they are based on averages of many observations made over a period of many years. These charts will give us a general idea where drifting debris may eventually end up but they cannot provide the information that is important for the prediction of debris paths, namely information about eddies, periodic fluctuations, or interannual variations of the currents.

During the last decade, a direct method of measuring ocean currents has become feasible. This method simply involves tracking the position of a drifting buoy with an attached drogue by satellite. These buoys are sometimes called Lagrangian drifters because it is possible to plot the path of a parcel of ocean water, assuming that the buoy stays in the same

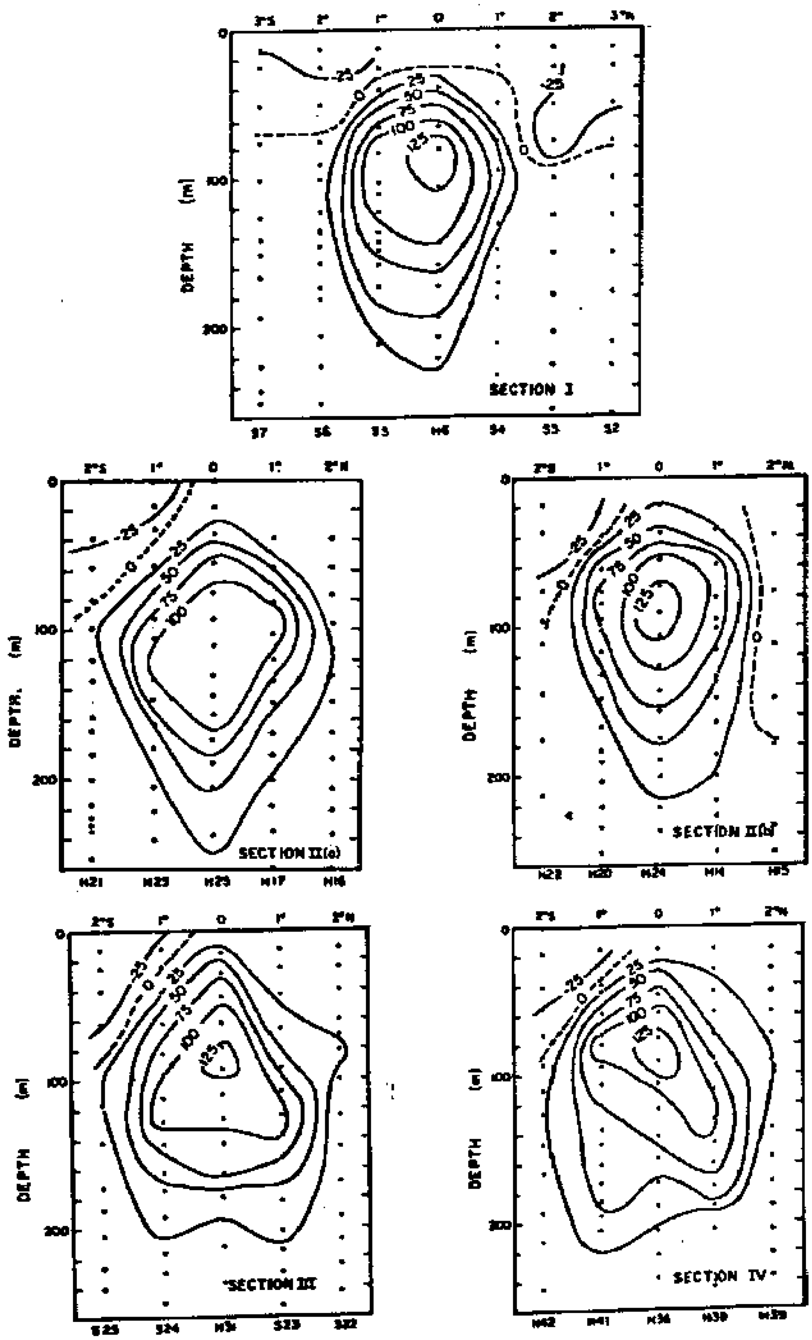

Figure 5.--Velocity cross section at long. 140°W. Dots are observed points, velocity is in cm/s; plus is eastward- and minus is westward-flowing current. Section I, 6-9 April, section II, 12-18 April (two sets of data), section III, 20-22 April, section IV, 23-27 April (Knauss 1960).

parcel of water. The drifting buoy method is really quite old but was not feasible on a large scale because it required a ship to stand by to record the changing position of the buoy.

RESULTS OF THE NORPAX DRIFT BUOY PROGRAM

During the last decade, about 130 satellite-tracked drifting buoys were deployed in the North Pacific as a part of the North Pacific Experiment (NORPAX). The buoys consisted of 3 m long fiber glass cylinders, 39 cm in diameter, ballasted to float vertically 1 m above the sea surface. The buoys were drogued at a depth of 30 m with a 9-m diameter personnel parachute. McNally et al. (1983) summarized the results of the program in terms of the near surface circulation of the North Pacific by describing the paths of 16 drifters (Fig. 6). We see that, in general, the paths conform to the current pattern previously described. More detailed analysis by the authors indicates that in the northern limb of the gyre, east of long. 170°W, the near surface flow has a large annual signal that correlates with the annual signal in the westerlies. In the eastern and southern limbs of the gyre, the drift trajectories tend to cross the

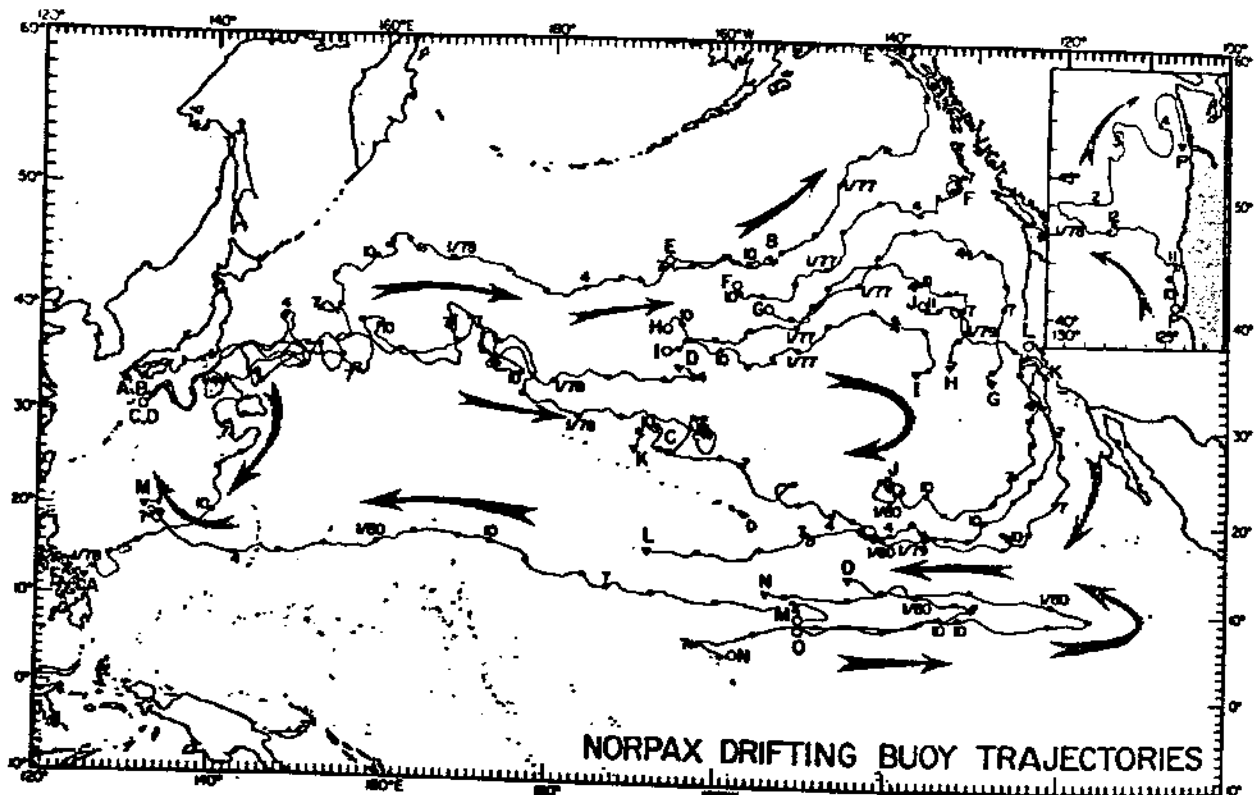

Figure 6.--Trajectories of 16 satellite-tracked drifting buoys deployed from 1976 through 1980 during various experiments. Open circles indicate the deployment locations, solid circles indicate the first day of each month, and triangles indicate the last reported locations. The large stippled arrows show the directions of the trajectories (McNally et al. 1983).

contours of the dynamic topography to the right. Both of these results indicate the importance of the wind-driven surface flow in determining the paths of drifting debris. McNally et al. found that the drifter speeds in the western limb of the gyre are the highest found around the gyre, which agrees with the geostrophic speeds evident in Figure 4. In the Kuroshio extension, just east of Japan, the drifter paths reflect the complicated nature of the circulation which is also evident in the dynamic topography shown in Figure 4.

The results of the drifter program provided some interesting statistics. The drifter trajectories traversed 20,845 km in 1,653 days (4.5 years) with an overall average speed of 15 cm/s (about a third of a knot). Average speeds around the gyre ranged from 10 to 17 cm/s. The transit time across the Pacific going east in midlatitudes and west in the equatorial regions was approximately 700 days (about 2 years) in each. Speeds of selected drifters in the major currents were as follows: Kuroshio - 61 cm/s, Kuroshio extension - 15 cm/s, North Pacific - 10 cm/s, California - 15 cm/s, North Equatorial - 17 cm/s.

McNally (1981) analyzed the wind-buoy trajectory relationships of those satellite-tracked drifters of the NORPAX program that were set out in the central, midlatitude North Pacific (Fig. 7). He found that when the monthly average wind direction in an area 5° of latitude by 5° of longitude was compared with the monthly average buoy drift direction during fall, winter, and spring, the buoys drifted to the right of the wind direction with a difference angle of 28°. (Drift to the right of the surface wind was first observed by Nansen during the Norwegian North Polar Expedition at the end of the last century (Nansen 1902). This observation became the basis for fundamental theories in oceanography.) Using 5-day running averages of four times daily determinations of the wind and drift vectors, McNally plotted histograms which show that at wind speeds of below about 2.5 m/s, this relationship did not hold. The overall monthly windspeed increased from a minimum of 2 m/s in August 1976 to 10 m/s in January and February 1977. This explains why the relationship between wind and direction of drift was not observed during the summer. The drifter speeds were approximately 1.5% of the wind speeds. The drift pattern during the summer of 1976 (Fig. 8) is one of slow, eastward eddying flow.

At some time during their life, buoys lost their drogues. This gave McNally an opportunity to compare the behavior of undrogued drifters with drogued drifters. He found that the difference in speed and direction was small and concluded that there was a lack of vertical shear in the horizontal currents of the upper 30 m during periods of strong and persistent atmospheric forcing. Additionally, one can conclude that the direct effect of the wind on the drift of the buoys also was small.

THE NORPAX DRIFTER EXPERIMENTS AND VARIABILITY OF CURRENTS

A most interesting result of McNally's (1981) study, in terms of predicting the drift of debris, is reproduced in Figure 9. The buoy displacements from the beginning to the end of the month are plotted on the mean sea level atmospheric pressure chart for December 1976, January, February, and March 1977. The buoy drift was parallel to the isobars.

This relationship is explained by the fact that observed winds tend to be directed 20° to 30° to the left of the geostrophic winds which are parallel to the isobars, and the buoy drift is directed 20° to 30° to the right of the wind direction. The result shows that as the sea level pressure pattern and, therefore, the wind pattern changed from month to month during fall and winter, so did the surface current.

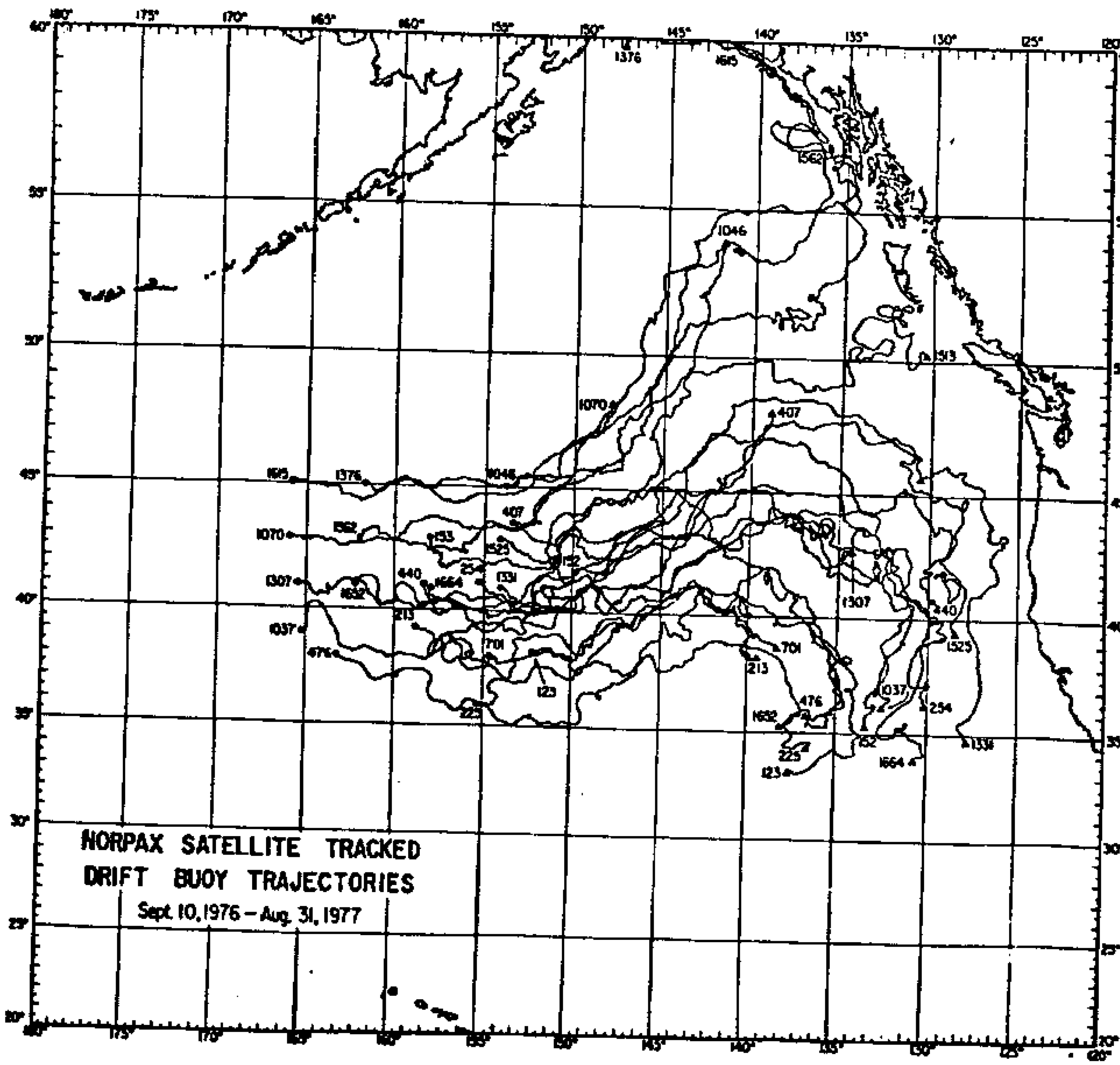

Figure 7.--Trajectories of drifters for the period September 1976 to August 1977. Solid dots indicate initial positions; solid triangles indicate last position (McNally 1981).

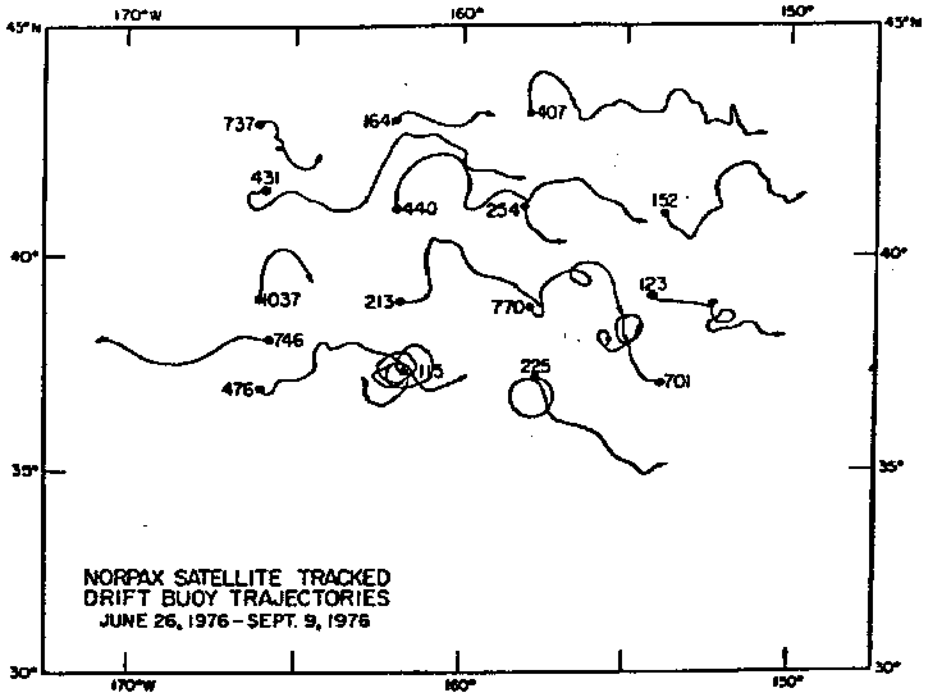

Figure 8.--Trajectories of drifters for the period June 1976 through September 1976. Solid dots indicate initial position; solid triangles indicate last position (McNally 1981).

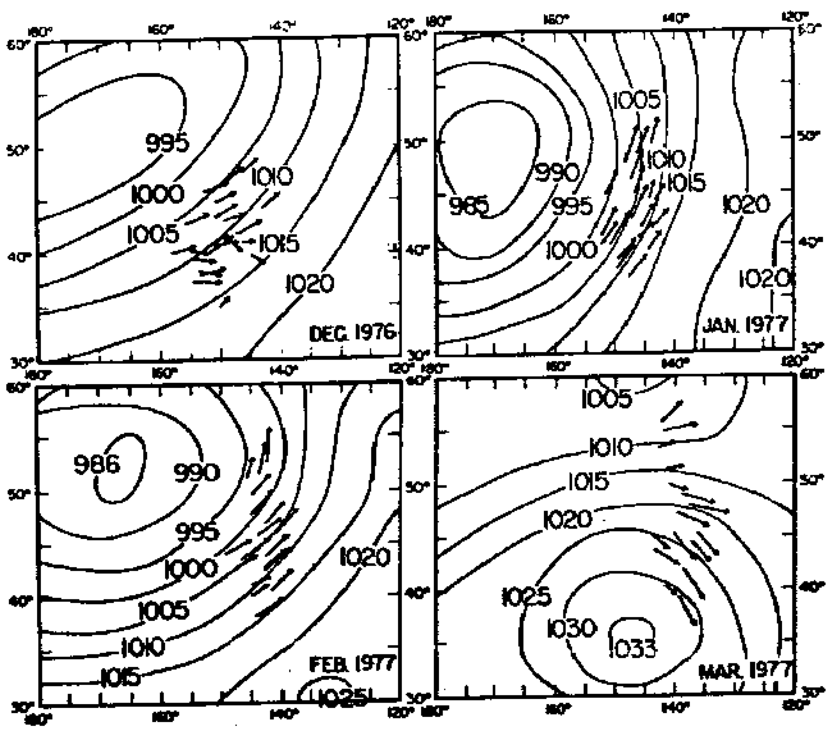

Figure 9.--Drifter positions superimposed on monthly mean sea level pressure charts. The arrows indicate monthly displacements of individual drifters (McNally 1981).

If the drift monthly mean pressure relationship shown in Figure 9 holds during other years and is not caused by the atmospheric circulation peculiar to the fall and winter of 1976-77, then, on the basis of sea level pressure charts, one can infer large interannual variations in the surface currents of the midlatitude Pacific. Mean winter (December, January, and February) sea level pressure charts (Namias 1975) are used to illustrate interyear differences. Figure 10a, the 1947-72 mean winter pressure distribution, is included for reference showing the Aleutian Low as a single low pressure system. During the winter of 1955-56 (Fig. 10b), this low is split into a western and an eastern low pressure cell, separated by a pressure ridge between long. 160°W and 180°. Using the convention of Figure 9, one would infer an entirely different surface circulation than one would from the pressure distribution such as in Figure 10a. In another example, during the winter of 1956-57 (Fig. 10c), high pressure in the eastern North Pacific has shifted the Aleutian low to the west. One can postulate that in the pressure ridge region, wind speeds would be low and that the drifters would behave more like they did in summer of 1976, without a relationship to the wind.

The NORPAX drifter program also confirmed pronounced annual variations in the Equatorial Countercurrent that already were apparent in Schott's (1935) charts. During the Hawaii to Tahiti Shuttle Experiment of 1979 and 1980 (Wyrtki et al. 1981), four deployments of satellite-tracked buoys were made in the Equatorial Countercurrent of the central Pacific. The results of this work have not yet been published other than in a preliminary report (Patzert and McNally 1980). The buoy trajectories resulting from these deployments have kindly been made available to me by G. J. McNally of the Scripps Institution of Oceanography and are shown in Figure 11.

The buoys were released in the winter of 1979, the summer of 1979, the winter of 1980, and the spring of 1980. In the two winter releases, buoys drifting eastward in the Countercurrent did not reach long. 140°W before recirculating into the North Equatorial Current. In the summer release of 1979, recirculation into the North Equatorial Current occurred east of long. 120°W. In the spring release of 1980, the extent of the eastward drift was not determined before observations were terminated. Most of the buoys drifted past long. 120°W and two buoys drifted eastward of long. 110°W.

Oceanographers have long been aware of the annual variation in the flow of the Equatorial Countercurrent. The results of this drifter experiment, however, for the first time, show the clear-cut annual variation in the eastern extent of the Equatorial Countercurrent. These results may have pertinence to questions of tuna migration and distribution. For application to the debris drift problem, the results are a good illustration of how the paths of drifting objects are affected by annual variations in not only the speed, but also, the extent of ocean currents.

Finally, Wyrtki (1974) used tide station data from islands in the tropical Pacific to derive indices of current speeds. Time series of these indices for the equatorial currents are reproduced in Figure 12. The time series show that large annual and interannual variations occur in the North and South Equatorial Currents as well as in the Equatorial Countercurrent.

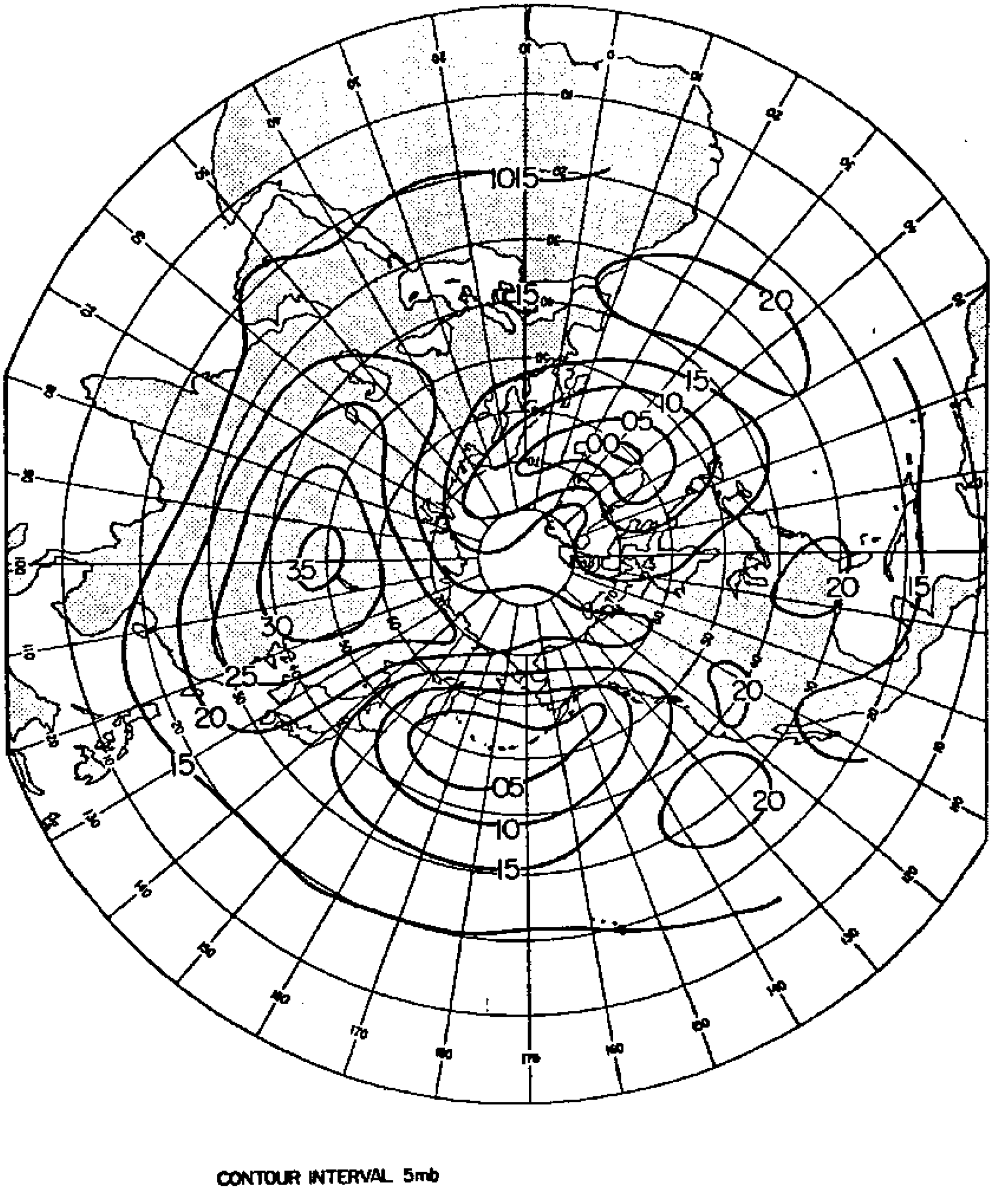

Figure 10a.--Sea level pressure, 26-year mean, winter 1947-72. The Aleutian Low is the area of lowest pressure over the mid-latitude North Pacific (Namias 1975).

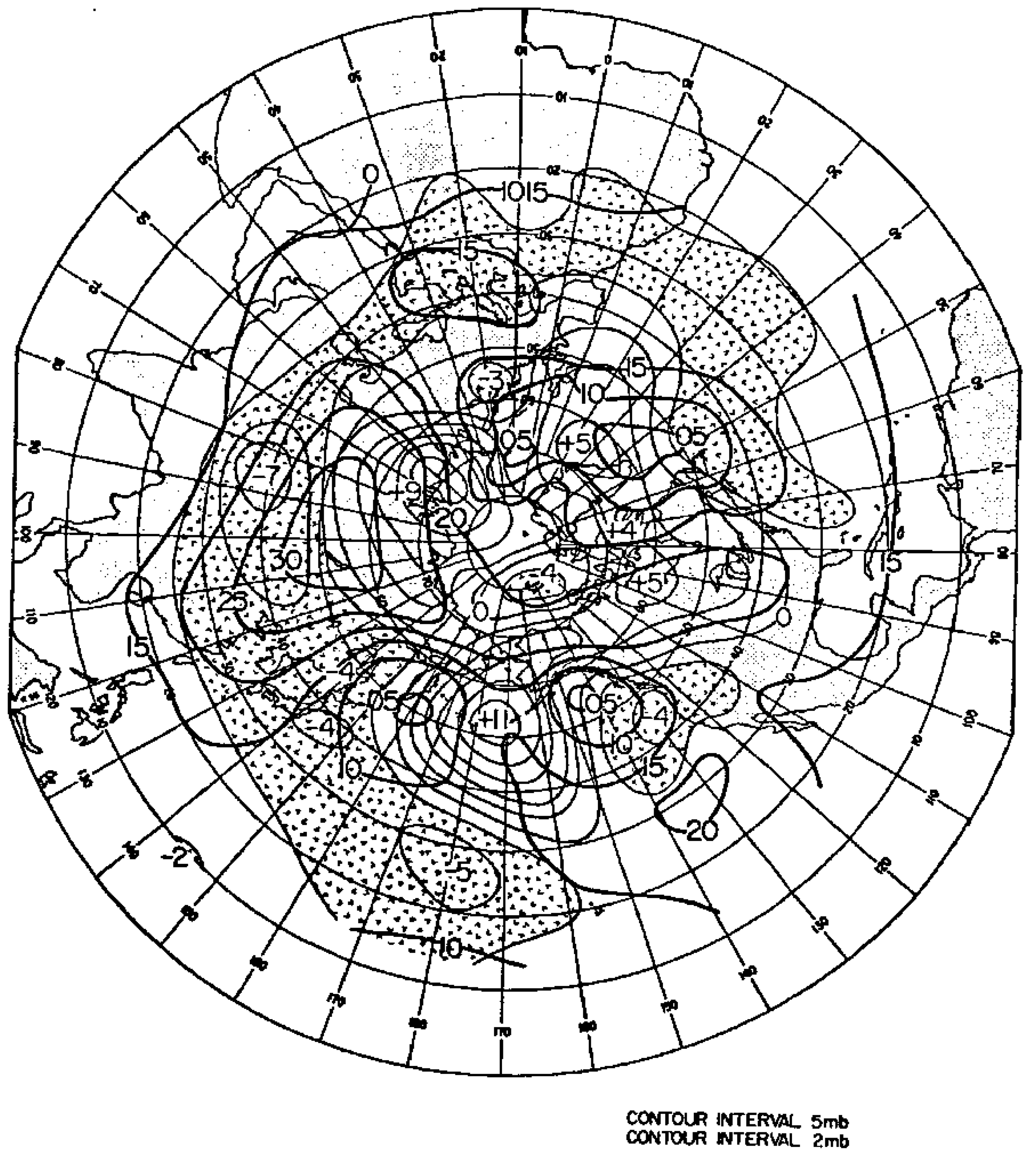

Figure 10b.--Mean sea level pressure, winter 1955-56 (Namias 1975).

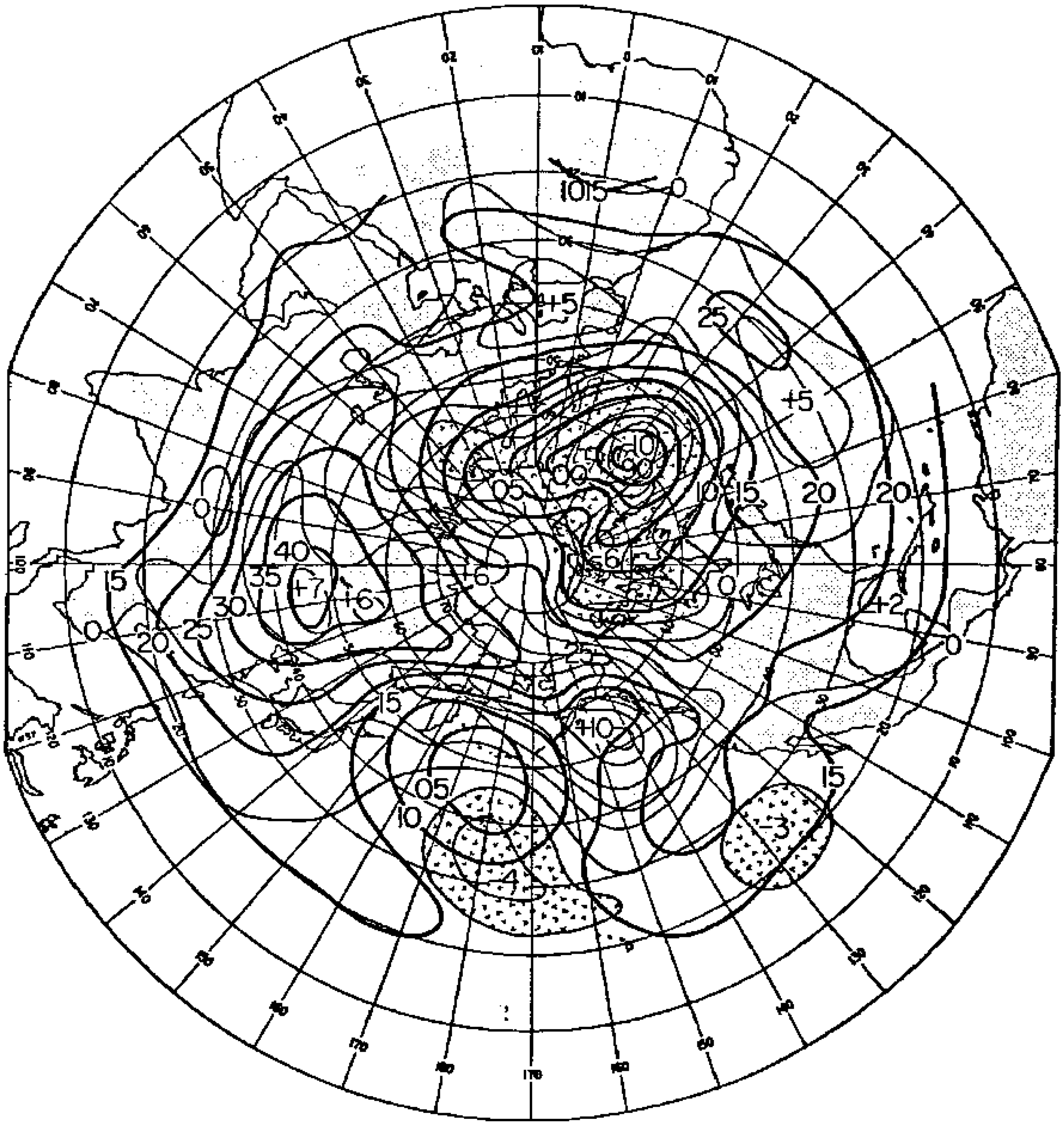

Figure 10c.--Mean sea level pressure, winter 1956-57 (Namias 1975).

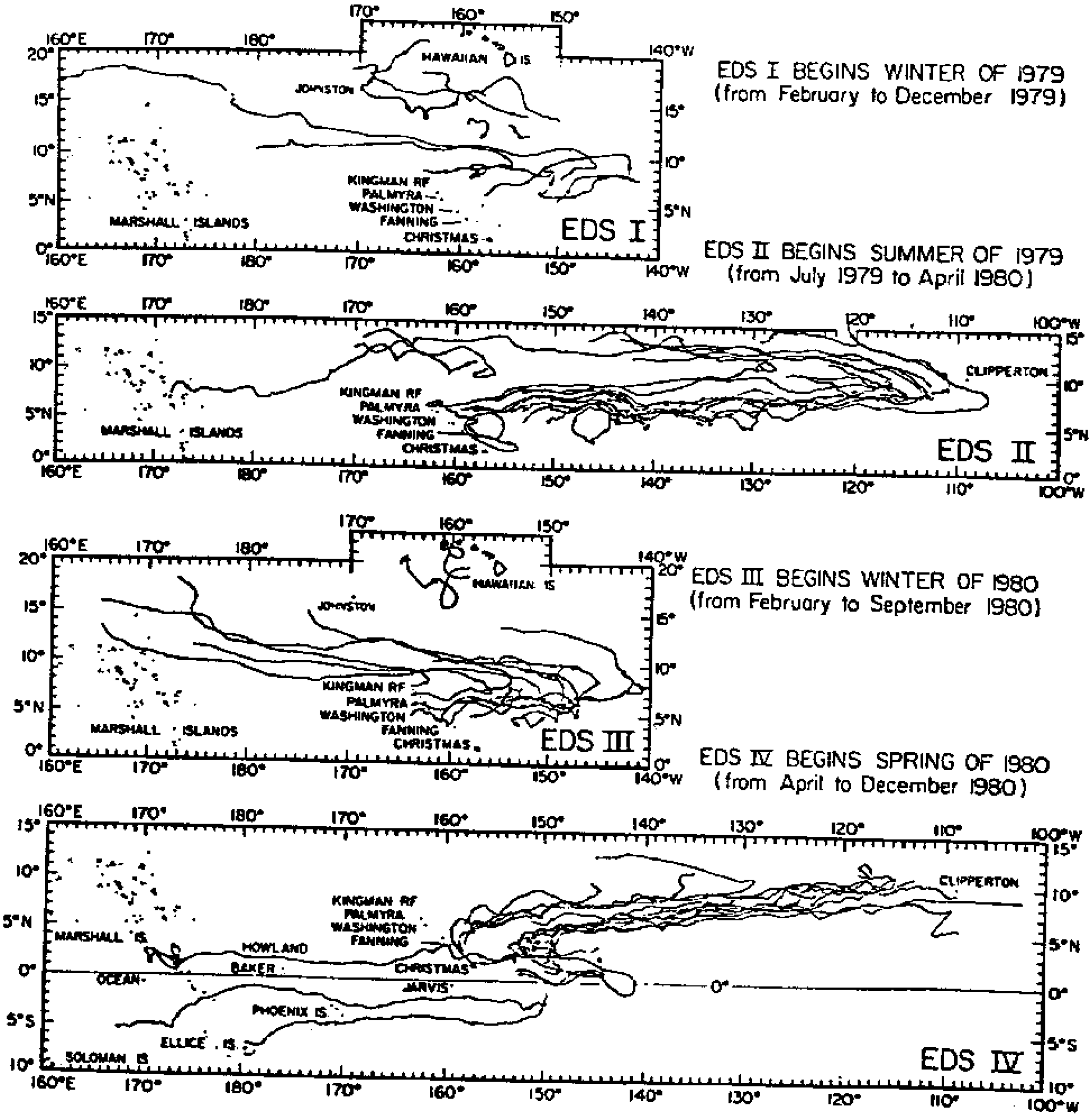

Figure 11.--Composite plots of the final trajectories obtained from four groups of satellite-tracked buoys deployed during the NORPAX Hawaii to Tahiti Shuttle Experiment, February 1979 to December 1980 (McNally pers. commun.).

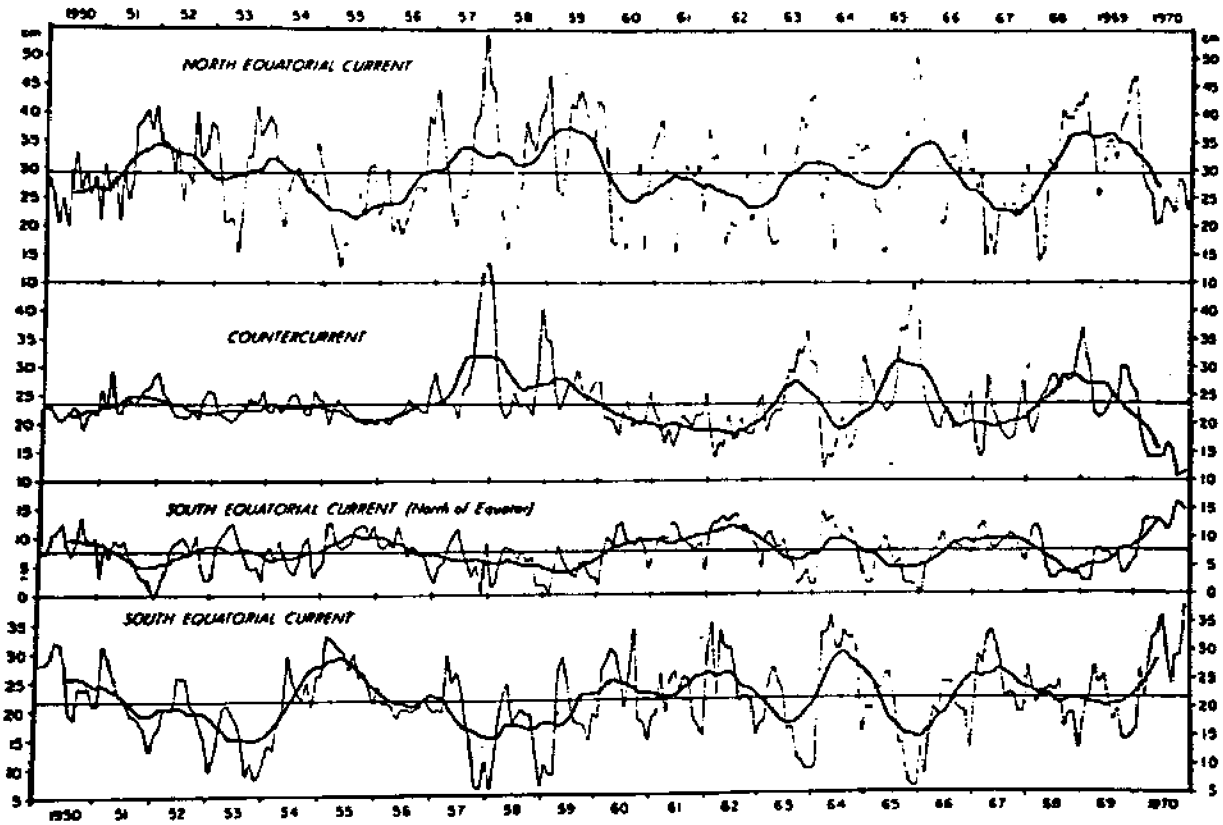

Figure 12.--Time series of sea level difference (in centimeters) across zonal currents of the western central equatorial Pacific, 1950-70 (Wyrtki 1974).

MORE ON SHIP DRIFT OBSERVATIONS

Before leaving the description of ocean currents, it should be pointed out that the first method used to map ocean currents, namely the ship-drift method, is by no means obsolete. Satellite navigation together with an accurate knowledge of ship speed and direction permits more frequent and reliable determinations of ship-drift than was possible during the days of celestial navigation. Figure 13 shows an example of ship-drift determinations made by NOAA Corps Officer Craig Nelson on NOAA ship Townsend Cromwell while traveling from Hawaii southeastward to the equatorial region. Although Officer Nelson had doubts about the accuracy of the ship's speed, a westward component of drift was determined in the North Equatorial Current, an eastward component of drift in the Equatorial Countercurrent, and again, a westward component of drift in the South Equatorial Current. Ship-drift data, from heavily traveled shipping lanes crossing major ocean currents, can provide valuable information about the temporal variability of current velocities.

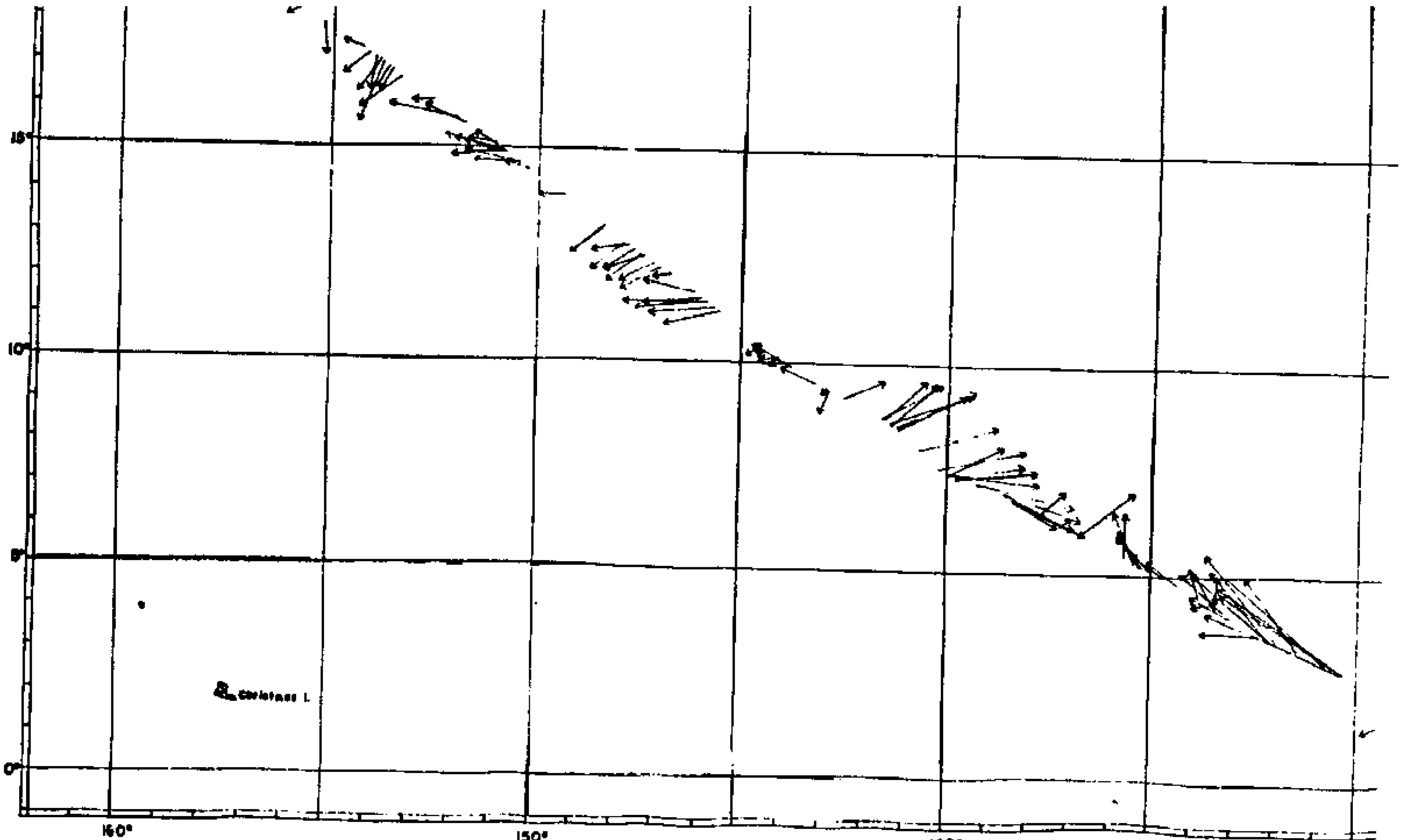

Figure 13.--Shift-drift vectors computed on the NOAA ship <u>Townsend Cromwell</u> using satellite navigation when traveling southeastward from Hawaii to the Equator (Nelson pers. commun.).

CONCLUSION

We have seen how the study of ocean currents has progressed from ship-drift observations to indirect, dynamic calculations and back again to direct measurements by current meters and Lagrangian drifters. During the last two decades, oceanographers have advanced from descriptions of average and steady state ocean currents to descriptions of their variability. Important advances have also been made in our understanding of the effects of atmospheric forcing on ocean currents. It is evident from the examples presented that the prediction of debris paths and destinations will depend not only on a knowledge of the general ocean circulation, but also, on an area-specific understanding of the variability of currents on time scales up to the interannual.

Complicating the prediction of debris paths is the fact that there are all kinds of debris. The satellite-tracked drifting buoy method of monitoring ocean currents provides a good indication of how debris will move in the ocean. Not all debris is as deeply anchored in the water with little exposure to the wind, however, as are the buoys. Debris can consist of plastic floats riding high on the water, partially submerged logs, or floats with fishing gear hanging deep in the water. Therefore, in addition to a knowledge of the water movement, the movement of the floating object induced by the drag of the wind must be considered when predicting debris paths. At this stage, I am happy to pass the problem on to the modeler.

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ON THE GENERAL CIRCULATION IN THE SUBARCTIC PACIFIC

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ABSTRACT

This work attempts to summarize the major features of surface circulation in the subarctic Pacific (from lat. 40°N to the Bering Strait). Effects of the density distribution (geostrophic flow) and wind drift are considered. The Subarctic Current is a slow, eastward drift between lat. 40° and 50°N; in winter speeds increase about fourfold as a result of strong eastward winds. Speeds in the swifter Kamchatka Current-Oyashio may also be enhanced by winter winds. The Alaskan Stream flows westward along the Alaska Peninsula and Aleutian Islands at peak speeds in excess of 100 cm/s, but it does not seem to have any large seasonal variation. Coastal currents off Oregon-Washington generally reverse with a reversal in the seasonal winds. Off southeast Alaska, the northward coastal currents are enhanced by winter winds. The coastal Kenai Current on the west side of the Gulf of Alaska increases in speed from about 25 to 100 cm/s in the fall as a result of a maximum in freshwater discharge. The Kuroshio and Alaskan Stream undergo occasional large interannual variations; the processes in neither system are completely understood, however. El Niño events also produce dramatic changes in water properties (and perhaps currents) along the eastern margin of the North Pacific.

The climatological map of near-surface flow can be used to provide estimates of the movement and transit time of material in the ocean. Off Oregon-Washington and southeast Alaska, winter storms commonly cause shoreward movement that is greater than the alongshore flow.

INTRODUCTION

The task of attempting to summarize the relevant features of the circulation of a large region of the ocean is a rather awesome one. The upper ocean is often rife with eddies and disturbed by large temporal changes, and it is difficult to obtain a firm grasp of the major features of flow for even a limited area from the results of a single survey of a few weeks. When one attempts to use data from many surveys over various seasons and many years, interpretation is subject to numerous sources of

In R. S. Shomura and H. O. Yoshida (editors), Proceedings of the Workshop on the Fate and Impact of Marine Debris, 26-29 November 1984, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 1985.

uncertainty and possible error. Furthermore, the fundamental nature of some of the methods used to infer flow has not in every case undergone rigorous verification. Finally, the presentations of circulations are often incomplete; for instance, effects of wind drift and wave transport are frequently ignored. With these caveats in mind, we will attempt to review the state of knowledge of the circulation of the North Pacific north of about lat. 40°N; our goal is to emphasize features that would have major effects on the drift of material.

First, we will examine the major types of motion that are generally important components of ocean currents. The climatological mean upper-ocean circulation in the subarctic Pacific is then shown and discussed. An examination of seasonal and interannual perturbations on the mean flow is also attempted. Finally, we highlight certain features of flow that may be especially relevant to the fate of debris in the ocean.

Types of Motion

To clarify much of the discussion to follow, some elementary concepts of the nature of the major kinds of ocean currents will be explained. Those that seem important to us in the context of this presentation are geostrophic flow, wind and wave drift, long waves, and tidal currents.

Geostrophic Flow

Geostrophic (or Earth-turned) flow results from a balance between the density or pressure gradient force and the deflecting force of the Earth's rotation. No actual statement is made about whether flow results from the density distribution or the density field results from the flow. In general though, we consider the density field to result from unequal cooling and heating, variable freshwater input, and the large-scale stress of the winds. The requirements for pure geostrophic flow are quite restrictive (a steady state, straight-line flow, no friction, and no change in flow along its path (McLellan 1965)), but many recent comparisons indicate that flow below the wind-mixed upper layer is generally at least quasi-geostrophic (within a few percent of an exact force balance). Hence, geostrophic flow calculations are a powerful tool, and they can be based on the very large data set of hydrocasts (conductivity-temperature-depth and Nansen bottle casts) built up over decades. Furthermore, the calculations often appear to be valid even in relatively shallow water (Schumacher and Kinder 1983), and intermediate reference levels (1,000 and 1,500 m) in the deep ocean in the northern Pacific seem to result in only slight deficiencies in speed (Reid and Arthur 1975). Much of the information presented below is based on use of the geostrophic relation.

Wind and Wave Drift

The direct action of wind stress on the sea surface produces currents; in addition, waves also form, and they in turn have a residual velocity in the direction of the wave train as a result of the fact that the particle orbits decrease in size with depth (Pond and Pickard 1978, for example). This wind drift (Ekman flow) and wave drift (Stokes drift) may result in appreciable speeds in the upper 50 m or so during times of strong winds. A schematic representation of the possible combined effects of geostrophic flow, wind drift, and wave drift is given in Figure 1. It appears that

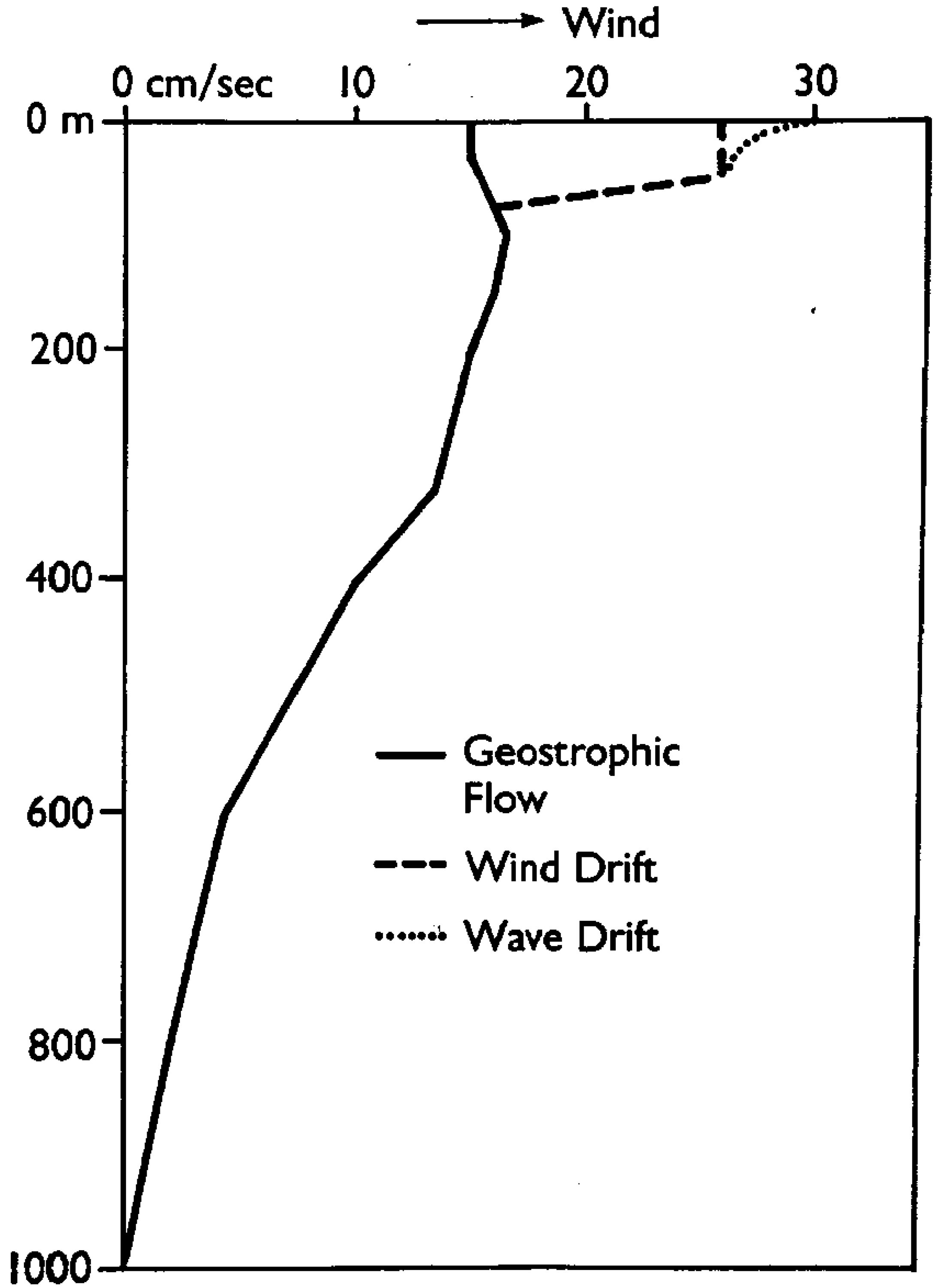

Figure 1.--Representative example of the combined effects of geostrophic flow, wind drift, and wave drift.

"Ekman spirals" (surface current 45° to the right of the wind, with velocity decreasing and turning clockwise with depth) seldom obtain in the real ocean, and the combined effects of wind and wave drift seem to produce a flow of nearly constant direction which does not diminish greatly until near the bottom of the mixed layer (James 1966; McNally 1981). Precise measurements of the exact behavior of wind and wave drift are very hard to make because of the difficulty of separating the components and eliminating the effects of other flows. McNally (1981) analyzed a large set of drifter data which suggests that the upper 30 m moved at about 1.5% of the wind speed at 20° to the right of the wind direction. This approximation is used here.

Long Waves

The long waves examined here are planetary waves and Kelvin waves. Other types of long waves exist but are, except for tidal currents discussed below, not believed to be of general importance to the problems to be dealt with. Although it may be an oversimplification, planetary waves may be thought of as highly curved ocean currents that result from interactions with bottom topography or from strong velocity shear. Some of the observed variability in thermal and density structure results from these features, especially in the subtropical gyre (Magaard 1983). Planetary waves seem to be prevalent in the Kuroshio but are not common features of the Alaskan Stream (Reed and Schumacher 1984). Since we cannot properly specify them and their effects on surface flow, they will not be dealt with further. Kelvin waves are long boundary waves (near a coastline or the Equator) that are often initiated by large changes in the wind (Voorhis et al. 1984). They are quite important along the Equator and appear to be a major factor in the initiation of El Nino events and their poleward spreading (Wyrtki 1975). Thus, some of the large interannual changes seen in the subarctic Pacific are linked to these waves.

Tidal Currents

Currents associated with the rise and fall of the tide are typically only ca. 2 cm/s in the deep ocean but can easily be 20 cm/s in water depths of 100 m (Dietrich 1963). Hence, they are of no importance to processes such as larval drift in the open ocean, but their relatively high velocities in shallow water make them a critical factor for the movement of material in the nearshore environment.

Climatological Mean Circulation

Figure 2 shows the paths of a number of drifting buoys from a study by McNally et al. (1983); the data are not examined in detail here, and the figure is only meant as an aid to orient the viewer to the larger-scale features of the North Pacific near-surface circulation. Note the Kuroshio and its eastward flow, which forms the northern boundary of the subtropical gyre, and the North Equatorial Current and the countercurrent to the south. The Subarctic Current and flow into the Gulf of Alaska are also shown. Figure 3 shows the tracks of drifters (Reed 1980) that were deployed in the Alaskan Stream but followed zones of recirculation south into the Subarctic Current and back into the Gulf of Alaska. One drifter moved into the coastal Kenai Current. We will concentrate below on features of the subarctic circulation.

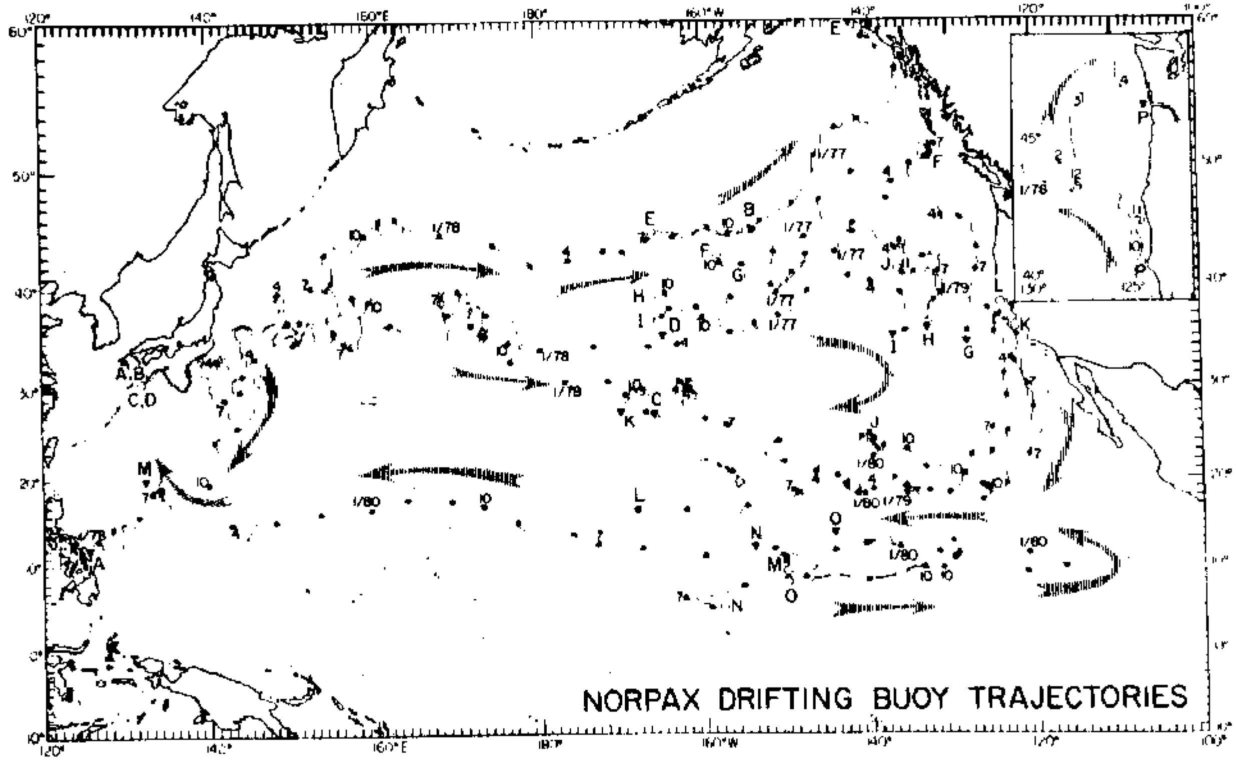

Figure 2.--Trajectories of drifting buoys in the North Pacific from McNally et al. (1983) during 1976-80. Solid circles indicate the first day of each month.

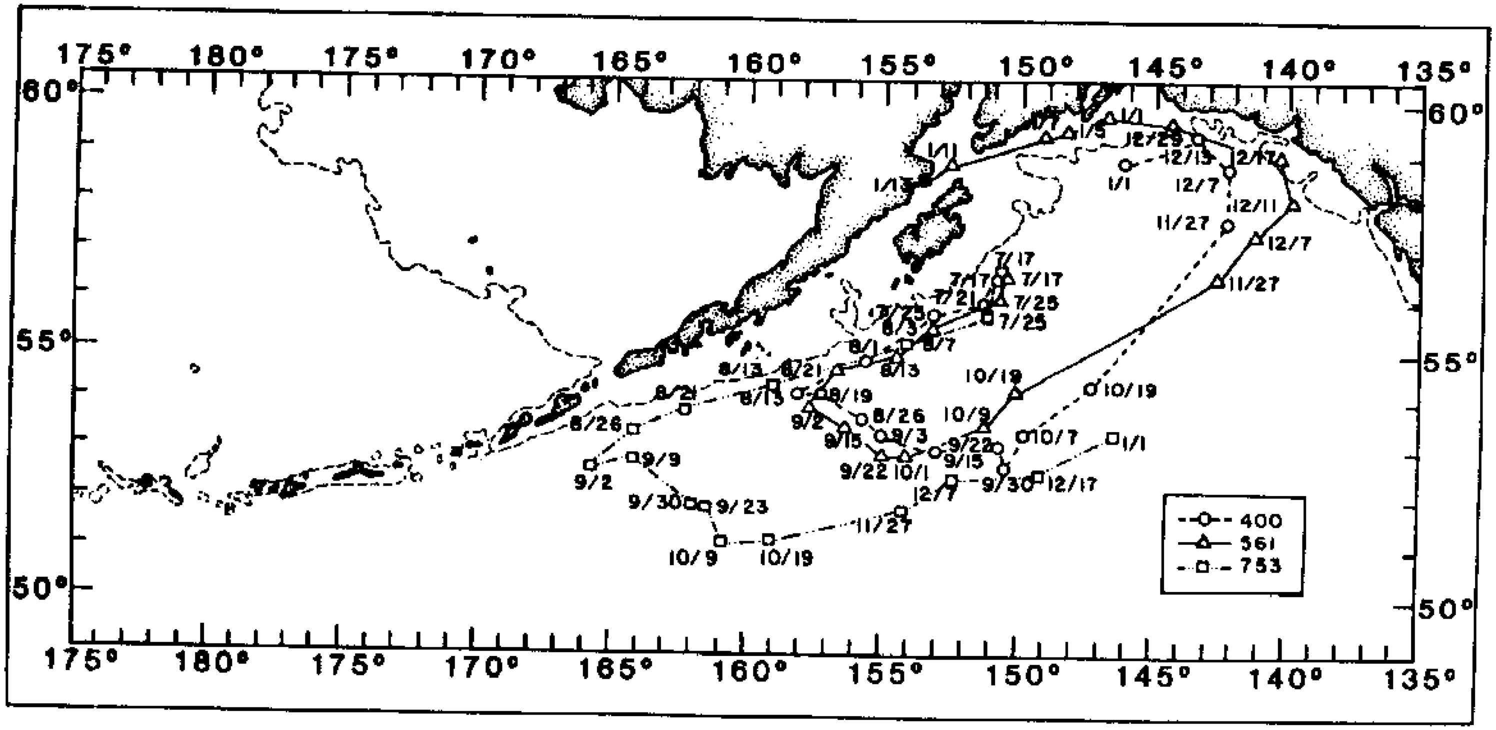

Figure 3.--Paths of drifting buoys indicating near-surface circulation around the Gulf of Alaska gyre (from Reed 1980), July 1978-January 1979.

Figure 4 is our attempt to present the climatological mean surface circulation of the subarctic Pacific. It is based on previous presentations of geostrophic flow (such as Dodimead et al. 1963; Reid and Arthur 1975; Reed 1984) and the results of drifting buoys and other direct current measurements (Reed 1980; Schumacher and Reed 1980; McNally 1981; McNally et al. 1983; Schumacher and Kinder 1983). Since the contribution of wind drift has been included, it should represent the expected total current better in some areas than geostrophic computations alone. The speed values shown on the figure are estimates of representative values; in the swifter currents, individual peak speeds would at times exceed those shown, but spatial averages across the flows would likely be smaller. In the broader, slower currents the values should be close to spatial averages. Certain features of coastal currents with known temporal variation are not shown but are discussed below.

The swiftest flow shown is in the Kuroshio, but peak speeds in the Alaskan Stream (Reed 1984) are at least half those off Japan. The Kuroshio extension retains appreciable speeds, but the mixture of this water and that from the Oyashio, which is known as the Subarctic Current, is much broader and slower. The Subarctic Current is probably more affected by wind drift than any other flow in this region; geostrophic speeds are usually <5 cm/s, but winds blow in the direction of this flow and considerably augment it, especially in winter (McNally et al. 1983). The Subarctic Current diverges off the U.S. west coast, typically off Vancouver Island, and a portion flows south as the California Current, which is generally opposed by the winter winds. (Inshore of the California Current, a northward flow, the Davidson Current, is usually present in winter.) The remainder of the Subarctic Current turns northward into the Gulf of Alaska; as this flow leaves the head of the Gulf of Alaska, it deepens, narrows, and intensifies. This westward outflow is known as the Alaskan Stream (Favorite 1967), and it continues westward along the Aleutian Islands until it enters the Bering Sea near long. 170°E. There is a separate coastal current inshore of the Alaskan Stream; this Kenai Current (Schumacher and Reed 1980; Royer 1981) extends from at least Prince William Sound, along the Alaska Peninsula, and through Unimak Pass into the Bering Sea. The weak extension of this flow in the Bering Sea closely parallels the 50-m isobath (Schumacher and Kinder 1983). The water entering the Bering Sea from the Alaskan Stream appears to flow mainly along the continental slope in the western part of the Bering Sea; the flow turns south off Kamchatka and forms the Oyashio, which reaches northern Japan.

Seasonal Variations

Knowledge of seasonal variations in currents in the subarctic has only come recently, mainly as a result of direct current measurements. Table 1 is our assessment of some of the likely seasonal effects; as more information is accumulated, this estimate will need to be revised. The two swiftest flows (the Kuroshio and Alaskan Stream) are not listed. Transport of the Kuroshio does appear to increase by 10-15% in summer (Blaha and Reed 1982), but interannual changes are much larger. It is not clear if the Alaskan Stream has a seasonal signal, but again obvious interannual changes sometimes occur (Reed 1984). The Subarctic Current (Table 1) clearly is strongest in winter (Reed 1980; McNally et al. 1983); the geostrophic flow is about 5 cm/s all year, but strong winter winds appreciably augment the

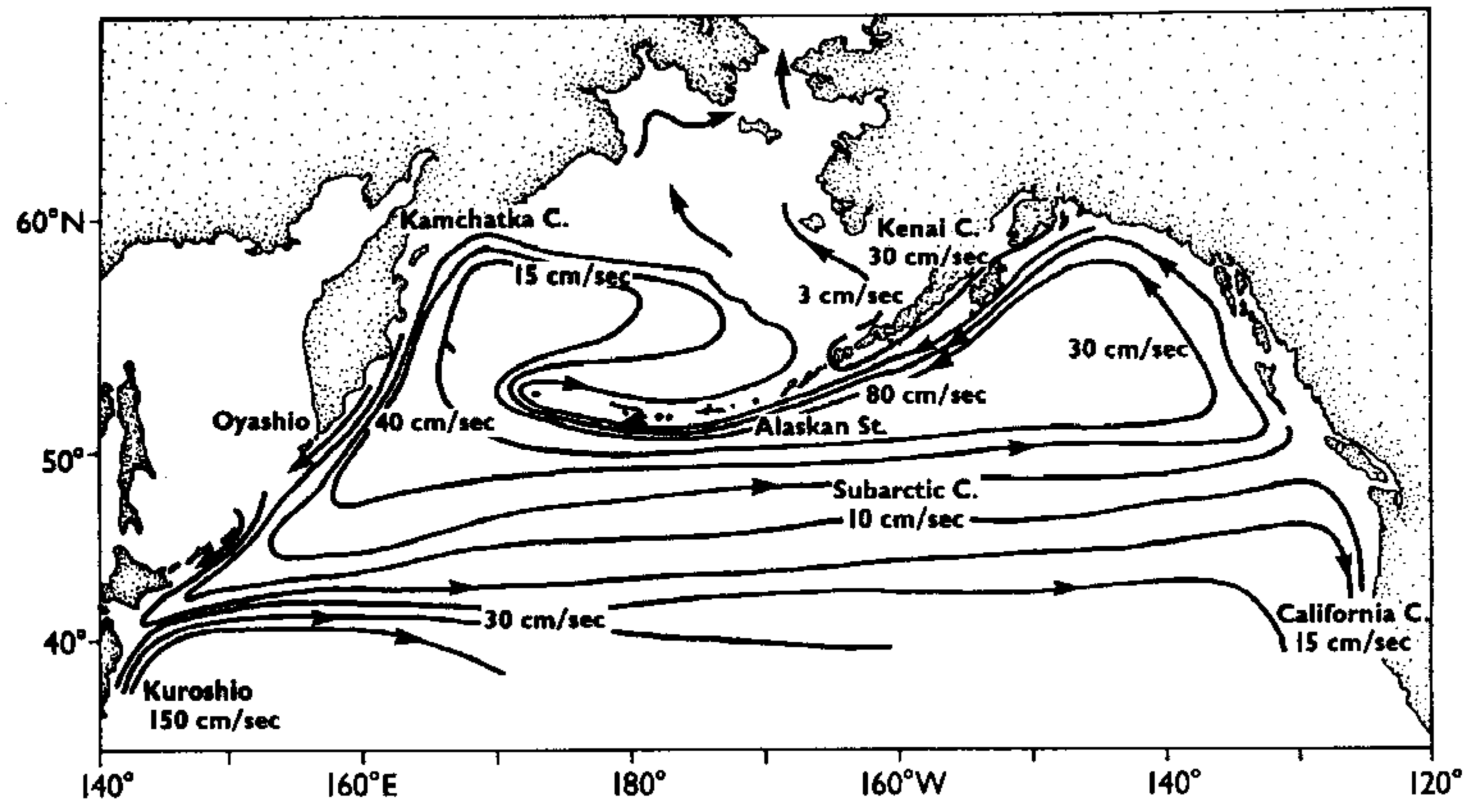

Figure 4.--Estimates of the climatological mean surface circulation in the subarctic Pacific.

Table 1.--Estimates of the seasonal variation in various surface current regimes in the subarctic Pacific.

Current or region	Time	Minimum flow speed (cm/s)	Direction	Time	Maximum flow speed (cm/s)	Direction
Subarctic Current (lat. 40°-50°N)	Summer	5	East	Winter	20	East
Kamchatka Current	Summer	30	Southward	Winter	50	Southward
Bering Sea (flow along 50-m isobath)	Summer	2	Variable	Winter	4	Variable
Kenai Current	Winter, spring, summer	25	Southwest	Fall	75	Southwest
Alaska, southeast coastal	Summer	10	Northward	Winter	20	Northward
Oregon-Washington coasts	Spring-summer	20	South	Winter	20	North

flow in the mixed layer. The Kamchatka Current probably has significant wind drift southward in winter. Reid (1973) concluded that this current has increased baroclinic structure and geostrophic flow in winter, but Ohtani (1970) casts doubt on this being a large-scale general feature of the flow.

The remainder of this section deals with coastal currents. In the eastern Bering Sea, the coastal flow along the 50-m isobath appears to have greater speeds in winter than summer (Schumacher and Kinder 1983), presumably through some action of the winds. In this and other areas of the shallow Bering Sea, intermittent ice melt in winter may also provide localized, occasional sources of buoyancy that enhance geostrophic flow. The Kenai Current undergoes a relatively large and rapid increase in speed in the fall (usually October); this change is not mainly produced by winds but is the result of a dramatic increase in freshwater drainage at this time (Schumacher and Reed 1980; Royer 1981). In the coastal waters of southeast Alaska, direct current measurements and sea level suggest an increase in northward speeds in winter (Lagerloef et al. 1981; Reed and Schumacher 1981), probably as a result of persistent winds from the south. Coastal currents off Oregon and Washington also seem to change seasonally;

flow is typically southward in spring and summer in conjunction with coastal upwelling, but a northward flow (the Davidson Current) exists in winter (Huyer and Smith 1983). Some of these changes probably result from local wind stress, but the large-scale winds and alongshore pressure gradient may also be important (Hickey 1981).

Interannual Variations

By interannual variations, we mean changes that occur intermittently; some of them may happen most often in one season, but they do not occur every year. The Kuroshio path undergoes large changes every few years; one mode is relatively straight flow along the coast of Japan, and the other is a large offshore meander (Taft 1972). Changes in speed and transport also seem to occur, but variations in relation to mechanisms may not have been completely resolved. Recent data (Reed 1984) have revealed an interannual change in speed and transport of the eastern part of the Alaskan Stream as shown in Figure 5. In February-March 1980 the source waters of the stream had all entered the head of the Gulf of Alaska, and peak speeds were about 100 cm/s. In August-September 1981 about half of the source water entered the stream between long. 150° and 165°W; peak speeds to the east were only about 50 cm/s, but values along the Aleutians were similar during the two cruises. It was suggested (Reed 1984) that this large-scale change, which is not entirely seasonal, resulted from the effects of differential vertical displacement of the pycnocline caused by an unusual distribution of wind-stress curl in the region of the inflowing source waters.

At least one other interannual event is of importance to the subarctic Pacific: the El Niño phenomenon. Marked changes in water temperature and sea level may occur all along the eastern margin of the Pacific and into the Gulf of Alaska (Enfield and Allen 1980), and these anomalies are presumably accompanied by some changes in currents. Cannon et al. (in press) concluded that since about 1920 the El Niño events of 1941, 1958, and 1982 have produced major changes as far north as the Gulf of Alaska; the large tropical El Niño of 1972 did not cause large anomalies north of California, however. Some of these changes appear to be caused by anomalous northward flow (Smith and Huyer 1983) associated with a long wave propagating from the Equator, but drifter tracks in winter 1982-83 suggest that the process was also aided by anomalously strong northward wind drift (T. C. Royer pers. commun.). The effects of El Niño events may be felt from southern California to the Gulf of Alaska, and even into the Bering Sea, for a distance of about 300 km off the coast, but elsewhere the effects seem to be much less marked. This process may affect the drift of material as a result of the anomalous currents produced.

Inferences on the Fate of Debris

For assessing the likely movement of material on the surface of the ocean, one would like an actual current forecast similar to weather forecasts. In the absence of such information, climatological information (Fig. 4) can be useful. For example, if an object entered the ocean off northern Japan, it should arrive off the U.S. west coast about 2 years later. If the object extended above the water, direct windage effects might appreciably lessen this time. As another example, assume that material entered the Kenai Current near long. 150°W. About 40 days later,

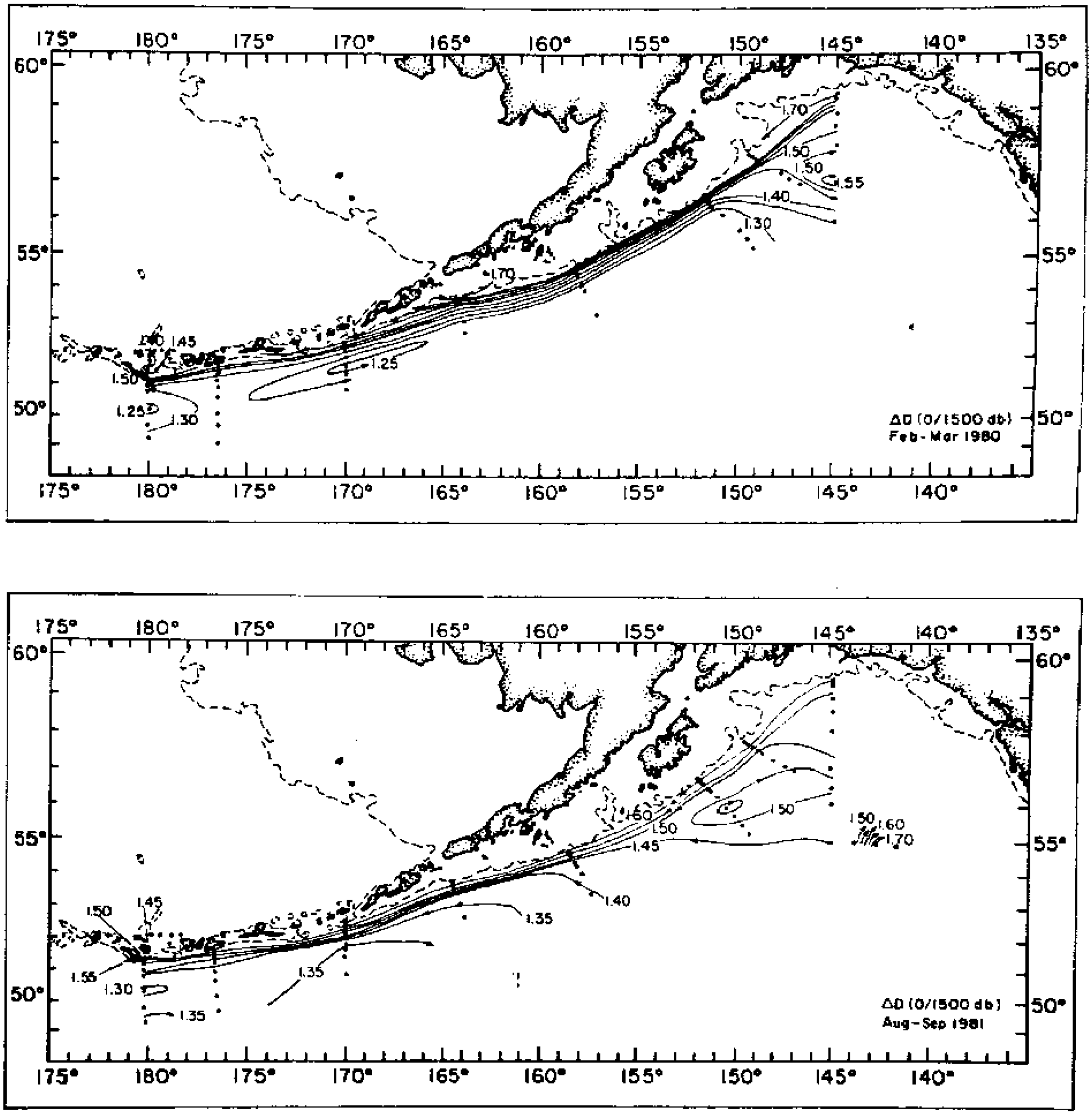

Figure 5.--Geopotential topography (in dyn m) of the sea surface, referred to 1,500 dB, February-March 1980 and August-September 1981 (from Reed 1984).

it should be near Unimak Pass at long. 165°W; during the fall velocity maximum, it may transit this distance in about 15 days.

When material enters the nearshore environment, climatological information should be used with considerable caution. Waters that normally move alongshore may be transported toward shore by a storm of brief duration. For example, this is apt to happen in winter off Oregon and Washington, where material is frequently driven onshore and litters the beaches. Water velocities associated with strong winds probably exceed 30 cm/s, which is greater than the typical alongshore velocities. Thus, material moving east in the southern part of the Subarctic Current may continue south in the California Current or be driven ashore, mainly depending on local weather conditions. Similar processes occur along the coast off southeast Alaska. Finally, tidal currents may play a role in coastal waters, where water displacements during half a tidal cycle are typically about 5 km (Dietrich 1963). Thus, material may be transported into bays or estuaries at times.

Currents that affect the drift of material are quite variable in space and time. One seldom has adequate information to make reliable diagnostic predictions of trajectories. Models are useful, however, because probability can supplement the limited deterministic information.

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OCEANOGRAPHIC FACTORS AFFECTING THE PREDICTABILITY OF DRIFTING OBJECTS AT SEA

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ABSTRACT

Movement within the oceans is turbulent. One of the obvious implications of this statement is that there is a random or uncertain character to the path that any particle may take. This suggests that, although the most probable or mean path of a floating object may be well defined by the most probable or mean currents, there is error or uncertainty that is associated with the predicted particle trajectories. This paper will discuss the relationships between oceanographic processes and this uncertainty.

The path of a floating object can be thought of as a Lagrangian trajectory. Its buoyancy imposes an important constraint and limits its motions to the special subset of two-dimensional movement. Two-dimensional surface motion (even random or turbulent) is subject to the kinematic constraints associated with the incompressibility of water. This means that any vertical motion of the upper layers of the ocean must be coupled to a corresponding convergence or divergence of the surface currents. Convergences act to collect or concentrate floating particles (antispreading or reduced uncertainty); whereas divergences will act to scatter and spread out floating particles. As a familiar example, the small-scale foam lines and "tide rips" seen in coastal waters represent strong collection or processes where the vertical water movement in the surface layer totally dominates diffusive or turbulent scattering processes. The significance of these processes on the predictability of future flotsam positions is discussed in this paper. A number of oceanographic processes can potentially contribute to the convergence or divergence of the surface currents. On the largest midocean scales the curl of the wind stress field and Rossby waves contribute to these processes. Both of these processes typically have strong signatures in the baroclinic temperature and salinity fields; the use of these signatures as factors in predicting trajectories is considered. On the smaller scale of the continental shelf, the effects of variable bathymetry can become important in the prediction problem. Even closer to shore, coastline configuration, freshwater runoff and tidal currents can all become important mechanisms. Each of these mechanisms is discussed.

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INTRODUCTION

For ages people have gone to beaches and found flotsam that has traveled possibly over truly global distances to arrive at some particular spot. Glass ball floats found along the Pacific coast of the U.S. are one example; driftwood found along the Arctic coast of Alaska is another. Anyone who has spent time at sea knows that drift can be puzzling, even on local scales. For example, where is the buoy that came loose during the night, or for that matter, what are the odds of successful recovery during a man overboard drill in rough seas? On even smaller scales, sewer outfalls deliver material into the ocean or into the marine environment with the absolute conviction that it will be lost and not accumulate in the vicinity at which it was injected into the system.

Mobility of the ocean surface is obvious to any observer. Mixing and moving are clearly operating over a wide range of time and length scales. Trajectory analysis is the intent to determine particle pathways which account for all of this movement and spreading. This type of analysis can be considered from a source point of view (i.e., something entered the water here, and one would like to know where it will be as time goes on), or from what is known as a receptor point of view (i.e., this is the spot where something was found, and I would like to know where it came from, and how long it took to get here). In either case it is necessary to know about the various scales of movement and spreading that are found in the ocean.

For the purposes of this paper, I will confine my attention to objects that are buoyant and thus constrained to move with at least some part of their structure at the surface of the ocean. I will also concentrate on trajectories of particles at sea and not consider the processes that affect beaching. I will attempt to go over some of the factors that control the movement of floating objects and the uncertainties surrounding the estimates of this movement.

The next section of this paper will discuss the ways we typically divide movements into currents on the one hand, and mixing or spreading terms on the other. In addition, I will discuss the typical oceanic relationships between advective and diffusive scales. The third section of this paper will cover scaling discussions for a number of oceanographic processes to estimate their influence on spreading, and thus the "findability" of objects adrift on the ocean surface. The final section of this paper will discuss mixed computational and tracking methods for use in trajectory analysis.

MEAN CURRENTS, TURBULENCE, AND UNCERTAINTY

What we think of as average or mean currents clearly depend on what time and space scales we wish to consider. In most cases, the choice is a compromise between what we would like to know and the amount of data that is available. For example, with only flotsam data, we could say that the average or mean currents seem to run from the North Pacific to the Oregon coast (because we find glass ball floats there), or that the coastal currents east of Point Barrow all run from the east (since the driftwood there has its origins in the valley of the Mackenzie), while the currents to the south and west of Point Barrow all run to the north through the Chukchi Sea (since all the driftwood there has its origin in the Yukon Valley). A little travel up and down the west coast of the U.S. clearly shows that the mean currents exhibit some variance since glass ball floats are widely distributed. Starting from these admittedly simple examples, we would like to consider a more quantitative way of looking at what we call the "mean currents" and its variance. We will then try and see if this quantitative information can be used to make some estimates about the ease of tracking or finding floating objects at sea.

A more or less traditional starting point for midocean current estimates is the geostrophic equations, and what is known as the "dynamic height method of current analysis" (Fomin 1964). When used with average seasonal data, these familiar techniques give the large-scale circulation patterns that are used in most marine atlases and provide the conventional wisdom about which way the water flows. Many of the results presented by authors in this conference are based on this type of analysis. Detailed measurements of water movements and density fields indicate that even when the geostrophic relationships are true, small imbalances can lead to time-dependent changes in the flow, and so-called quasi-geostrophic motions are observed (Pedlosky 1979). These quasi-geostrophic motions can be analyzed as Rossby waves and appear in the atmosphere as the familiar high-low patterns that are seen on weather maps. In the oceans, these are mesoscale eddies, rings, or thermal anomalies such as thought to be responsible for El Niño patterns. On still smaller scales, we find current variations associated with internal waves, windrows, or Langmuir cells, and this nesting of still smaller and smaller scales can go on ad infinitum. In practice, we must draw the line somewhere and make a pragmatic separation in what is really a continuum of scales of motion. In this separation we decide that scales above some certain level will be resolved, and these will be called "currents;" scales below that level will not be resolved and these will be called "turbulence" or "uncertainty." Obviously, one person's turbulence could be another person's currents, and often is. For this work, I will stick to traditional, midocean scales and consider currents to be geostrophically balanced.

Given geostrophic current patterns, what can we do about all the other variations and uncertainties that are left out of our definition? To really answer what they mean, we would have to know what they all mean, which is out of the question. Fortunately, there are some relatively simple models that we can use to represent these uncertainties in a statistical way. One of the easiest to understand and most useful was originally proposed by Einstein while he was working on studies of Brownian motion (Csanady 1973). This model is based on the idea of a random walk, i.e., that in each successive time step, an object will move in a random step, either north, south, east, or west with a probability of 25% for each option. Statistical analysis shows that after a number of such steps the distribution of possible positions will take on a two-dimensional, Gaussian shape, and if one were to repeat the experiment with a large number of cases, their cumulative distribution would look exactly like the classical solution to the diffusion equation, or the so-called distribution of variables equation (Sverdrup et al. 1942). This simple conceptual model then provides a framework which allows us to relate uncertainty to the effects seen in turbulence or large-scale eddy diffusion. In the ocean, numerous authors have matched distribution of variables with the distribution equations and evaluated effective eddy coefficients (Proudman 1953; Defant 1961). This will allow at least an order of magnitude estimate of what the oceanic levels of spreading should be. That is to say, from these coefficients we can go back to the random walk theory and calculate the random mean increase in particle separation and thus establish a relationship between the eddy coefficients, uncertainty, and the average spreading velocity for drifting particles.

To provide a more concrete example, Figures 1a, 1b, 1c, and 1d indicate the results of a series of random walk experiments superimposed on a 1-knot current. In each case, 10 particles were tracked over a period of 100 h, with increasing diffusion velocities (random step size) and correspondingly bigger advective eddy diffusion coefficients or uncertainty values. The values of diffusion coefficients shown here span typical midocean values that are obtained from tide distribution studies. On the low side (Fig. 1a) we see that with a diffusion coefficient of about 10^5, the corresponding spreading velocities are 0.08 of a knot, and most of the particles would be expected to lie within a circle 10 to 15 nmi after about 4 days of travel. On the high side (Fig. 1d), with a diffusion coefficient of about 5×10^6, there is an equivalent spreading velocity of about 0.5 knot, and the particles are likely to be scattered over a 40 to 50 nmi circle after 4 days of travel.

Before leaving our simple model for drift calculations we should point out that any floating object will be influenced by surface winds, as well as by the currents. The relative magnitude of this effect will depend on the exposed area and the relative subsurface drag. For the present work, we will consider this to be relatively unimportant with the reservation that in some special cases, the trajectory analysis would be quite wrong if these effects were not included.

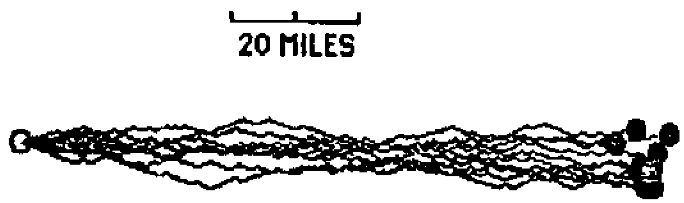
From what is presented in Figures 1a–1d, it is seen that even in relatively steady or nonturbulent, midocean regions, the uncertainty associated with the position of a drifting object is likely to increase to a number of miles over the space of a few days. Thus, if the aim is to find an object that is small or offers low visibility, then recovery or tracking will always be difficult. We will now consider a series of oceanographic processes that may counteract the potential spreading of objects and thus may improve the odds of predicting trajectory pathways.

OCEANOGRAPHIC PROCESSES

Any floating object must remain on the surface of the ocean. This constraint imposes an important coupling between the possible surface trajectory pathways that it could take and the vertical velocities in the upper layer of the ocean. Sustained vertical velocities (upwelling or downwelling) have often been identified with anomalous biological activity. They also clearly affect the spreading or concentration of surface waters and, consequently, anything that is floating in them. In the simple, conceptual model that was introduced in the last section one can look at some oceanographic processes that induce vertical velocity, downwelling in particlular, and estimate whether they might have a significant effect on the uncertainty of being able to track or locate objects at sea.

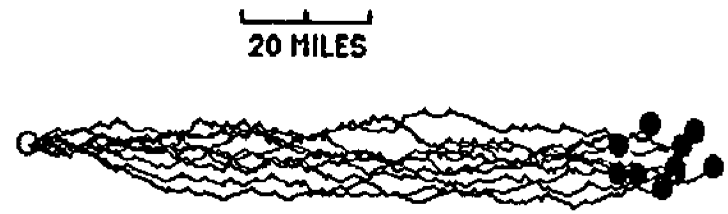
DISPLACEMENTS AFTER 100 HOURS
THE CURRENT SPEED IS 1 KNOT
DIFFUSION VELOCITY 0.08 KNOTS
DIFFUSION COEFFICIENT 0.132 X 10+6 CM SQ/SEC

Figure 1a.--Trajectories indicating the path taken by 10 different drifting objects.



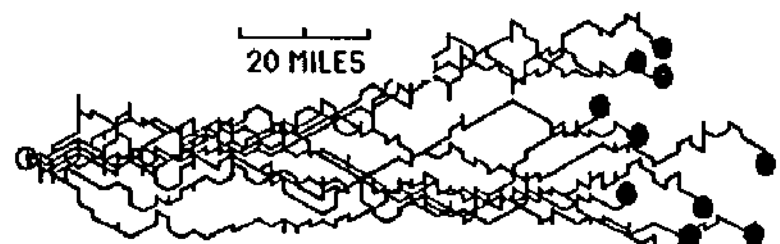
DISPLACEMENTS AFTER 100 HOURS
THE CURRENT SPEED IS 1 KNOT
DIFFUSION VELOCITY 0.17 KNOTS
DIFFUSION COEFFICIENT 0.529 X 10+6 CM SQ/SEC

Figure 1b.--Trajectories indicating the path taken by 10 different drifting objects.



DISPLACEMENTS AFTER 100 HOURS
THE CURRENT SPEED IS 1 KNOT
DIFFUSION VELOCITY 0.25 KNOTS
DIFFUSION COEFFICIENT 1.190 X 10+6 CM SQ/SEC

Figure 1c.--Trajectories indicating the path taken by 10 different drifting objects.



DISPLACEMENTS AFTER 100 HOURS
THE CURRENT SPEED IS 1 KNOT
DIFFUSION VELOCITY 0.50 KNOTS
DIFFUSION COEFFICIENT 4.761 X 10+6 CM SQ/SEC

Figure 1d.--Trajectories indicating the path taken by 10 different drifting objects.

On the largest oceanic scales, vertical velocity is associated with divergences or convergences of the Ekman transport, and this in turn is proportional to the curl of the wind stress. This is represented schematically in Figure 2 where the Ekman convergence tends to depress the thermocline. Major centers of Ekman convergence are associated with midocean gyres. Such places are known to have a tendency on large scales to accumulate floating material. This is clear from the concentrations of sargassum weed in the Sargasso Sea and relatively high concentrations of tarballs found on Bermuda beaches. To get a slightly more quantitative estimate of this effect, it can be seen that the vertical velocity estimates presented by Wyrtki (1961) and Munk (1966) for the bottom of the pycnocline in the Pacific were on the order of 10^{-5} cm/s and discussed in some detail by Overstreet and Rattray (1969). Using this and the geometry shown in Figure 2, a simple calculation shows that the resulting diffusion velocity would be negative, i.e., a convergence rather than a spreading, but that the magnitude of the term would be several orders of magnitude below the point where it would affect the distribution shown in Figure 1a. Thus, this scale of oceanic circulation would have no detectable effect on the spreading of objects at sea.

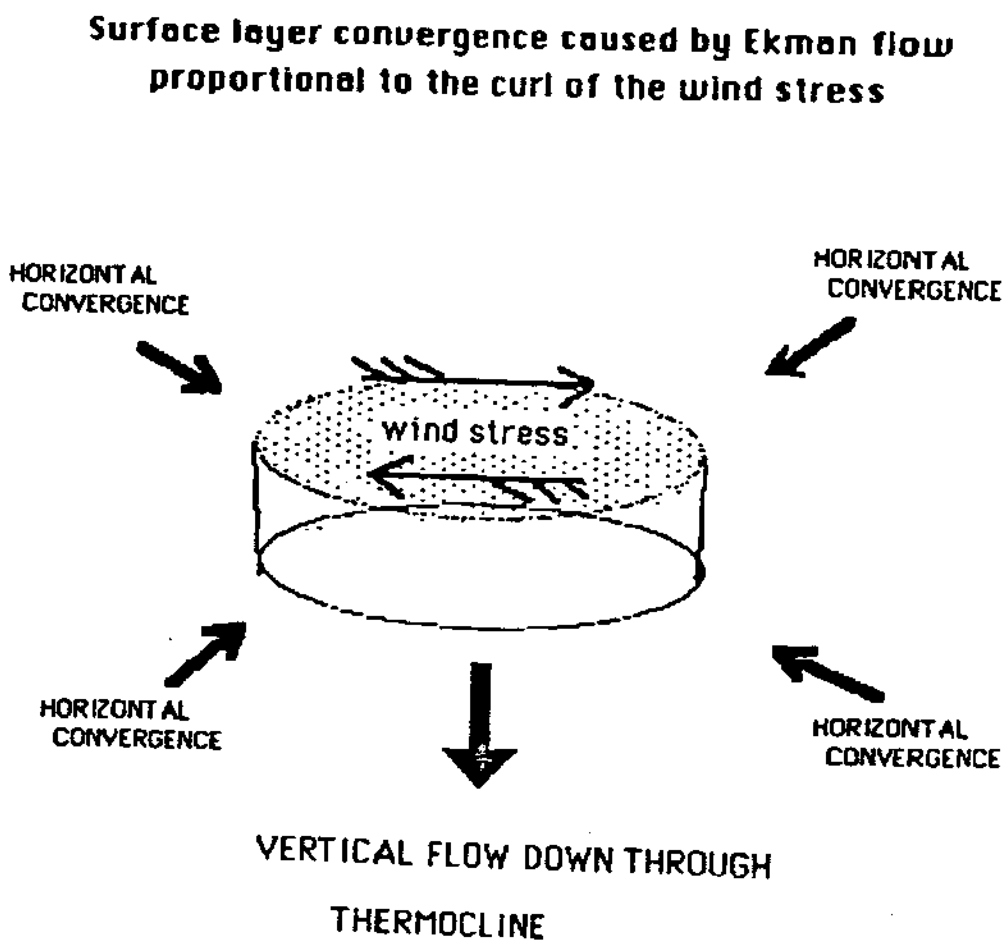


Figure 2.—Schematic representation of convergent Ekman layer as expected in a midocean gyre.

A second large-scale oceanic circulation feature that results in a convergence in the upper layer is the subarctic boundary region in the North Pacific. This permanent feature is well known to Pacific oceanographers and is described in some detail by Reed and Laird (1977). Quantitative estimates of the convergence velocities can be obtained from the work done by Roden (1970) (Fig. 3). From this, we can see that in the vicinity of lat. 40°N, a convergence in the surface currents is evident. Considering that the Ekman drift is confined to the top few tens of meters, this is equivalent to a convergence velocity on the order of 0.1 knot over a north-south line which extends for about 100 nmi. This is obviously a rough estimate, but it indicates that this process is of significant magnitude to affect the lower ranges of spreading we might expect in the open ocean, and several orders of magnitude more important than the convergence associated with the midocean gyres. For higher energy turbulence situations in the ocean, this process is still not likely to

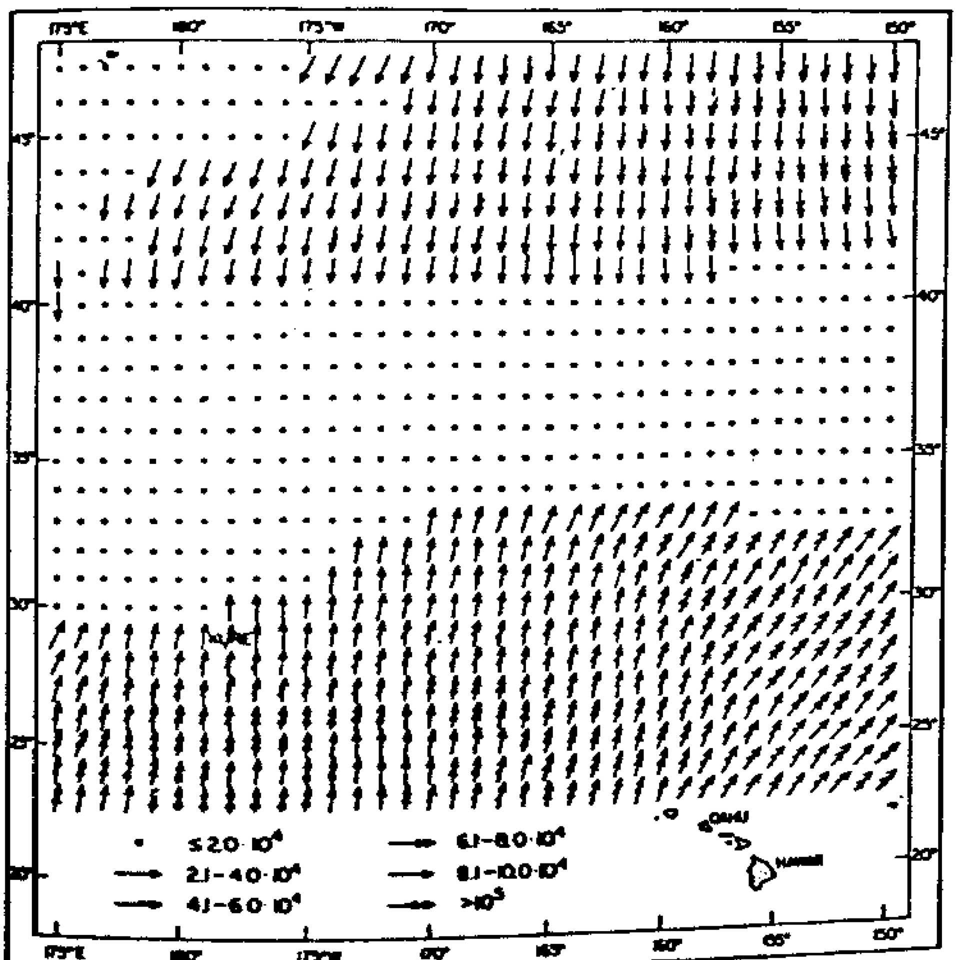


Figure 3.--Surface Ekman transports, in units of g cm^{-1} s^{-1}, in the central North Pacific. Arrows indicate the direction of transport in April 1968. (Reprinted from Roden 1970.)

significantly improve our ability to make trajectory estimates of drift positions beyond a few days.

The preceding two paragraphs discussed midocean processes. As one encounters the continental shelf, there are additional processes that can induce horizontal convergences that are strong enough to overcome the expected spreading velocities that are associated with typical turbulence estimates. The first such process has to do with bathymetry and the width of the shelf. Geostrophic flows tend to follow bathymetric contours for cases where the baroclinic adjustment is not accomplished such that a level of no-motion is established. A discussion of this process including relevant examples is presented by Galt (1980). Figure 4 indicates the surface circulation over the Fairweather Banks region of the Alaska Continental Shelf. Currents flowing north past Fairweather Banks encounter an abrupt narrowing of the shelf and the current is compressed closer to the shore. The convergent velocities in this case are nearly 0.25 knot. From our previous arguments, we see that these convergences are easily strong enough to make this a region where spreading tendencies would be suppressed, and consequently, the collection of flotsam is likely. Because of the complex shelf topography of the Alaskan coast, many examples of this type of bathymetrically induced collection points can be found.

The continental shelf is a region where freshwater coastal inputs mix with ocean waters of higher salinity to form fronts which provide other regions in which we can expect the possibility of significant convergences. Typically, relatively fresh water will float along the coastline and spread seaward, pushing a narrow mixing front ahead of it as it overrides the more dense seawater. This narrow mixing front is a collection zone that can often totally overcome spreading tendencies. As an example, an oil spill from the grounded tanker Alvenus in August 1984 encountered such a front produced by freshwater runoff from the Mississippi-Atchafalaya drainage basin. After moving nearly 30 nmi, the oil had only spread to a width of 10 m. This is obviously somewhat of an extreme case, but the tendency is general wherever there is significant freshwater coastal currents produced by localized runoff. Many such drainage systems are found in the northeast Pacific, including the winter circulation patterns from the Columbia River and a well-defined flow along the Alaskan Peninsula that has been described by Royer (1981).

In many shelf areas tidal flow can interact with bathymetry and produce horizontal currents. The convergences associated with these flows tend to be the strongest around the mouth of shallow submarine canyons or at the head of dredged channels. These can form the strongest convergences ever observed in the marine environment, and in such cases may totally dominate the horizontal spreading. In one study near the head of Monterey Canyon, drogues that were initially deployed over a several-mile area within a few hours ended up in an area some 10 m across (W. Broenkow pers. commun. 1974). In this case, the convergent velocities completely dominated the spreading velocities. In small harbors (e.g., Baltimore), actual maelstroms have been observed with a core pressure drop equivalent to 5 to 10 cm of water. Incoming tidal waves can underride less saline estuarine waters and produce strong convergence lines (so-called "riptides") which typically collect flotsam. These are commonly observed in most of the large estuaries around the northeast Pacific. By their

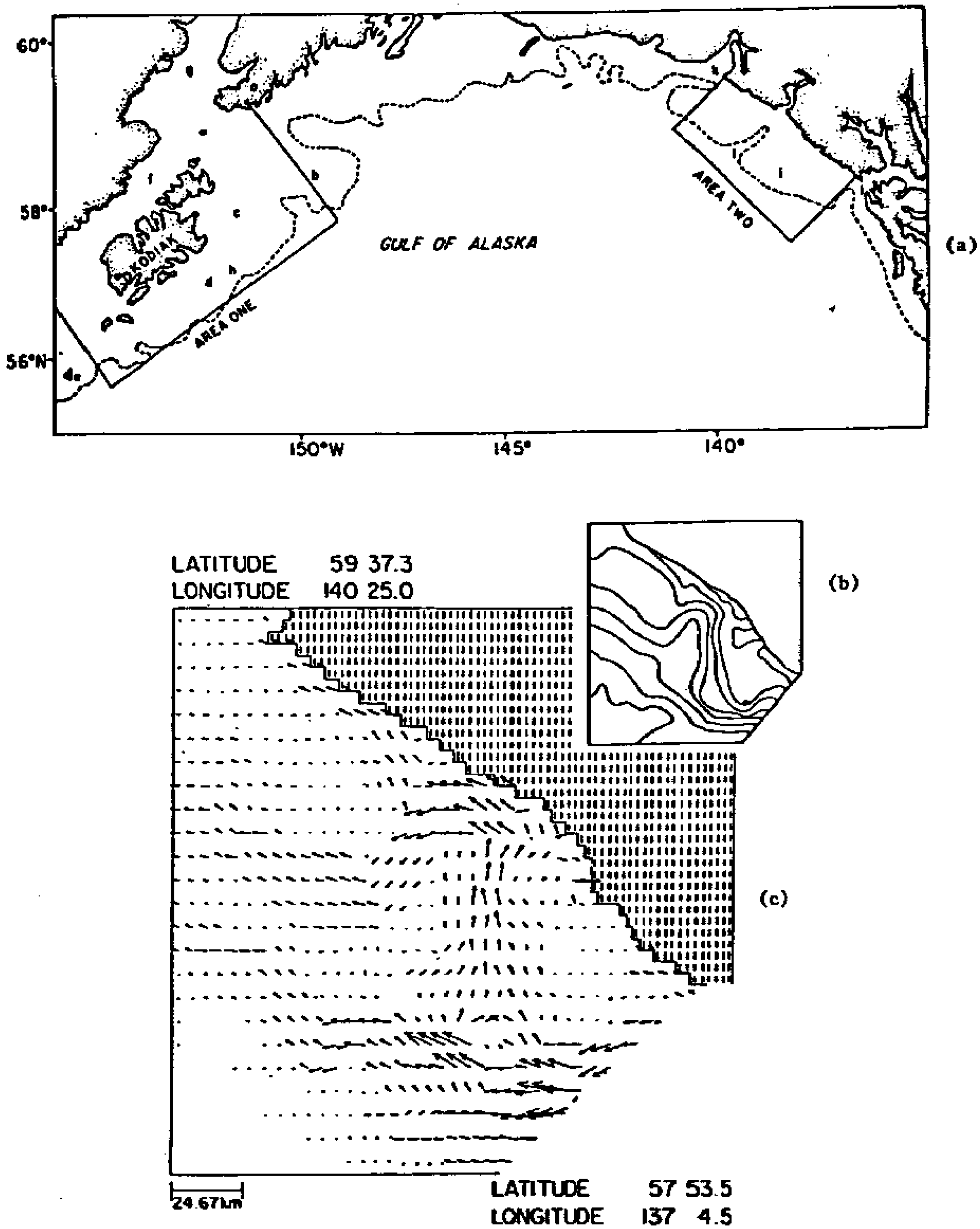


Figure 4.--(a) Area two indicates Fairweather Banks study region, (b) representation of surface elevation or geopotential contours over the Fairweather Banks study region, and (c) surface current pattern for Fairweather Banks study region.

nature, these intense processes can only be present over a part of a tidal cycle and only occur nearshore where large bathymetric variations are present.

SUMMARY AND CONCLUSIONS

Particle or flotsam trajectories can be calculated from water movements. In virtually all cases, the complete details of the water movement and the currents are pragmatically divided into a deterministic, known, and often considered steady portion, and an "everything else" term. The everything else term is usually assumed to have random properties and based on this, a simple statistical model can be developed that introduces the concept of spreading velocity that has the effect of increasing the uncertainty associated with predicting where a particle may end up. A number of oceanographic processes that result in surface convergence were discussed. For each of these cases, the tendency of the convergence velocity to counter the spreading velocity was quantitatively examined. For open-ocean processes, we find that the subtropical gyres have virtually no significant effect on spreading over length scales of hundreds of miles or a few days. The subarctic front in the North Pacific may marginally tend to reduce spreading tendencies, but concentrations of trajectories or flotsam distributions are unlikely. Over the continental shelf, bathymetric and baroclinic processes can lead to convergences that are typically the same order as the spreading velocities associated with characteristic estimates of ocean turbulence. As these are associated with topographic features and river runoff, they tend to be persistent features and may offer a rationale for developing flotsam search procedures, or at least improving the possibility of more accurate trajectories. Finally, small-scale features associated with tidal movement can produce locally strong convergences that will act as collection mechanisms for flotsam. These cases provide short-term guidance for developing flotsam recovery plans.

In all cases, particularly in open ocean regions, the prospects of recovering low-profile flotsam simply by going out and looking for it, are not good. The odds of recovery periods of a few days may be improved significantly if the flotsam's visibility can be enhanced either optically or electronically. This suggests that valuable or troublesome objects should be fitted with such devices as emergency locator transponders and strobes.

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TOWARD A POPULATION DYNAMICS OF MARINE DEBRIS

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ABSTRACT

Adopting a population dynamics viewpoint can provide a useful overview of the problem of marine debris. This paper outlines the information needed to establish an understanding of the population dynamics of marine debris, notes existing sources of data which could provide such information, points out potential gaps of information, and suggests experiments or sampling which could help fill those gaps. First, a typology of marine debris is needed; because the kinds of marine debris vary so widely, separate estimates of "birth" and "death" rates will be needed for each "species." Data on birth or generation rates of marine debris must include not only "species" and abundance, but location and seasonality. Mortality or degeneration rates of marine debris can be summarized with a survivorship curve. Although decay of the material is the only true death, for certain applications debris can be considered dead by being cast on a beach or by sinking to the ocean bottom. Fouling organisms may contribute to decreasing buoyancy and hence hasten the sinking of objects such as ropes and trawl netting. An important question is the choice of units to be used in a quantitative description of marine debris. The choice of units will depend on the type of debris, and meaningful units should have the property of independence. The choice of units will also reflect whether the impact of marine debris is being measured on fish stocks, fishing operations themselves, vessel navigation and safety, or marine bird and mammal populations.

INTRODUCTION

As the final formal presentation of this workshop, this paper will attempt to provide an overview of the technical aspects of the marine debris problem, especially as identified in the last few days, to note gaps in our information which need to be filled by future research, and to make some provocative comments which may stimulate thinking in the working group sessions which are the next phase of the workshop. As a conceptual framework for the discussion, I propose to talk about debris in terms of population dynamics, that is, to treat debris as a population of objects

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whose dynamics we wish to describe. As with a biological population, the main tasks are to determine how many new individuals are entering the population (through births and immigration) and how many individuals are leaving the population (through deaths and emigration), per unit time. From this information, the number of individuals of each kind of debris present at any time can be calculated.

Why should we be interested in the dynamics of marine debris? Certainly there are aesthetic reasons for objecting to the amount of junk in the sea. We should not ignore these reasons, since for the general public these reasons may be most important to mobilizing people to help, as the Oregon experience (Neilson 1985) has shown. There are also a number of more technical reasons to be interested in the amount and dynamics of debris. The papers in this workshop have emphasized the impact of debris on marine mammal, bird, and turtle populations. What deserves more emphasis is that there are strong reasons for fishermen and fishery scientists to be concerned about the amount of debris in the ocean. Debris can interfere with fishing operations by fouling nets or traps. When it fouls a ship's propeller, debris becomes a serious navigational hazard. And when lost gear continues to fish, it is an unreported source of mortality not taken into account in calculations and recommendations for management of the fishery resource.

Our perception of which kind of debris is of greatest interest and importance will depend on whether we are measuring the impact of debris on fish, seals, or ships. A drifting hawser might be a navigational hazard for a ship, but poses no danger to a seabird, while the plastic top of a six-pack of beer is more dangerous to a seabird than a ship. People with different interests may therefore have different perceptions of how serious the problem of marine debris is and what should be done to correct it.

Population Statics

The population dynamics of marine debris is a new scientific discipline. Before we can get to the dynamics, therefore, we must deal with some preliminary population statics. The first problem is to identify the different kinds of debris. Following our biological metaphor, we may call these different "species" of debris. Several papers in this workshop have presented "species lists," especially from the Pacific (Dahlberg 1985; Merrell 1985; Neilson 1985). The wide variety of debris means that the population dynamics may be different for each "species." Furthermore, we should keep in mind that new "species" may evolve in the future.

Estimates of standing stock sizes of marine debris may be given either as absolute or relative abundance. In this workshop, several papers have reported relative estimates of stock size, either from beach surveys (Merrell 1985) or as sightings from a ship (Dahlberg 1985; Jones and Ferrero 1985). Although an estimate of standing stock only describes the population at a particular point in time, a temporal series of snapshots of the population can provide clues to the dynamics of the population. Abundance can increase or decrease, and "species" composition can change. Usually the main problem with determining trends in abundance is the standardization problem: data have been taken at different times of day, under different weather conditions, from different heights above the ocean surface, from different beaches, and so on. A simple, standardized program of observation and sampling will therefore often give more useful results than a more elaborate, but inconsistent, program.

Jones and Ferrero (1985) have summarized clearly the problems with estimates of debris abundance made from ships. Some types of debris are much harder to see than others, size is very hard to estimate since large parts of some items are submerged, and in any case the sighting probabilities depend on sea state, buoyancy, color, and other factors. These are serious problems which must be overcome if sighting rates of debris are to be translated into estimates of absolute abundance. But shipboard sighting rates of debris can still be useful as relative abundance indicators. Programs of regular searching for marine debris could be expanded to include more vessels wherever such observations do not interfere with the normal mission of the ship. We should think about more passive and automatic means of collecting data. Perhaps high-resolution sonar could be used to detect large pieces of gear, or a simple grappling hook could be towed behind the ship. Collecting data in several different ways has the additional advantage that we can gain some insight into how some observations may be biased. For example, we could compare visual observation of debris from a ship with the amount caught on a hook during the same period. Or we could compare the amounts caught on several hooks towed at different depths.

We have to choose some units to describe the stocks of debris. Merrell (1985) reported the amount of debris on Alaskan beaches both as number per kilometer and as kilogram per kilometer and noted that number and weight did not always show the same trends. For debris items which are discrete and which come in similar sizes, the number of each "species" will be a suitable unit, but for others which come in variable sizes, the choice is not so easy. With fragments of nets, for example, we could use number, weight, linear measure, or surface area. What is the best unit to describe this population? Suitable units should express an equal impact and be independent of one another. If we choose numbers of net fragments as our unit, it implies that a 100-m net fragment has the same impact as a 10-m fragment. If we choose a linear measure, it implies that a 100-m net fragment is equal in its impact to ten 10-m fragments. Which is true for the impact on fish stocks? Which is true for the impact on marine mammals? This is an area for future investigation. Ideally, we would like to use a unit which is more closely related to the impact the debris is causing, such as the relative fishing powers of 10- and 100-m net fragments. This, however, requires a clearer mechanistic understanding of how drifting net fragments affect fish, mammal, and bird populations. For the present time, we will simply note that an appropriate choice of units to describe debris depends on (1) the type of debris, and (2) the target population--that is, whether the impact of debris is being measured on fishing operations, on vessel safety, or on fish, mammal, bird, or turtle populations.

Population Dynamics

Now we come to the dynamics of marine debris. Individual items of debris can enter the population through births or immigration and leave it through deaths or emigration. Let us leave aside the discussion of birth and death rates for just a moment and consider the migration of marine debris. Since debris cannot swim, we assume that a good approximation of migration routes can be calculated from a knowledge of ocean currents (Reed and Schumacher 1985; Seckel 1985). Individual items which are highly buoyant, such as styrofoam objects, might be influenced by wind more than currents. This makes the problem a bit more complicated, but since general wind patterns are well known and the relative contributions of wind and current can be estimated, this presents no fundamental problem. In general, then, the migration patterns of marine debris can be fairly well estimated for any "species" of interest from existing information on currents and winds. It is well to remember that much of our knowledge of surface currents comes from observation of scientific floating objects--drift bottles and buoys--so that knowledge should be quite applicable to floating debris.

The heart of population dynamics is the estimation of birth and death rates. We would like to be able to describe how many new nets are "born" each year in the ocean. We would like birth rates to be broken down by "species," location, season, and type of fishing operation. Now of course one of the basic differences between biological species and debris "species" is that biological individuals reproduce their own kind, while debris is produced as a result of man's activities. We therefore expect that for marine debris, in contrast to a biological population, there will be no relation between recruitment and standing stock. Instead, birth rates will be related to amount of fishing. Actually it is possible that this may not be strictly true and that there may be some stock-recruitment relationship for marine debris. If objects of debris interfere with fishing operations and cause other gear to be lost, then the stock is contributing to the recruitment of new individuals in the population. For example, a large ball of trawl netting may foul a gill net and cause it to break away or to be abandoned.

Like human births, we can divide births of marine debris into two kinds: planned and unplanned. The marine debris equivalent of planned parenthood is the deliberate dumping of trash or worn-out gear at sea. Unplanned parenthood is the accidental loss of gear. Data on accidental losses could be estimated by reports from fishermen or from observers on fishing boats (Low et al. 1985). If average rates of gear loss for various types of fishing operations could be calculated, they could then be applied to total fishing activity. Such estimates would be minimum estimates of birth rates since births due to deliberate dumping are not included. Certainly, we need more information on these deliberate births.

The estimation of mortality rates presents other problems. First of all we should consider the meaning of death for marine debris. The decay or disintegration of debris is certainly death, but effective death might occur before that. It depends on which group we are measuring the impact of debris. Debris which sinks is removed from the population as far as pelagic fishing operations are concerned, but not as far as benthic fishing operations are concerned. Debris cast ashore is removed from the population as far as vessel safety is concerned, but not as far as seals are concerned. This means that we will have to decide on what group we are measuring the impact of debris before the meaning of death is clear.

The decline in abundance over time in a population can be summarized with a survivorship curve. Figure 1 shows three general shapes that

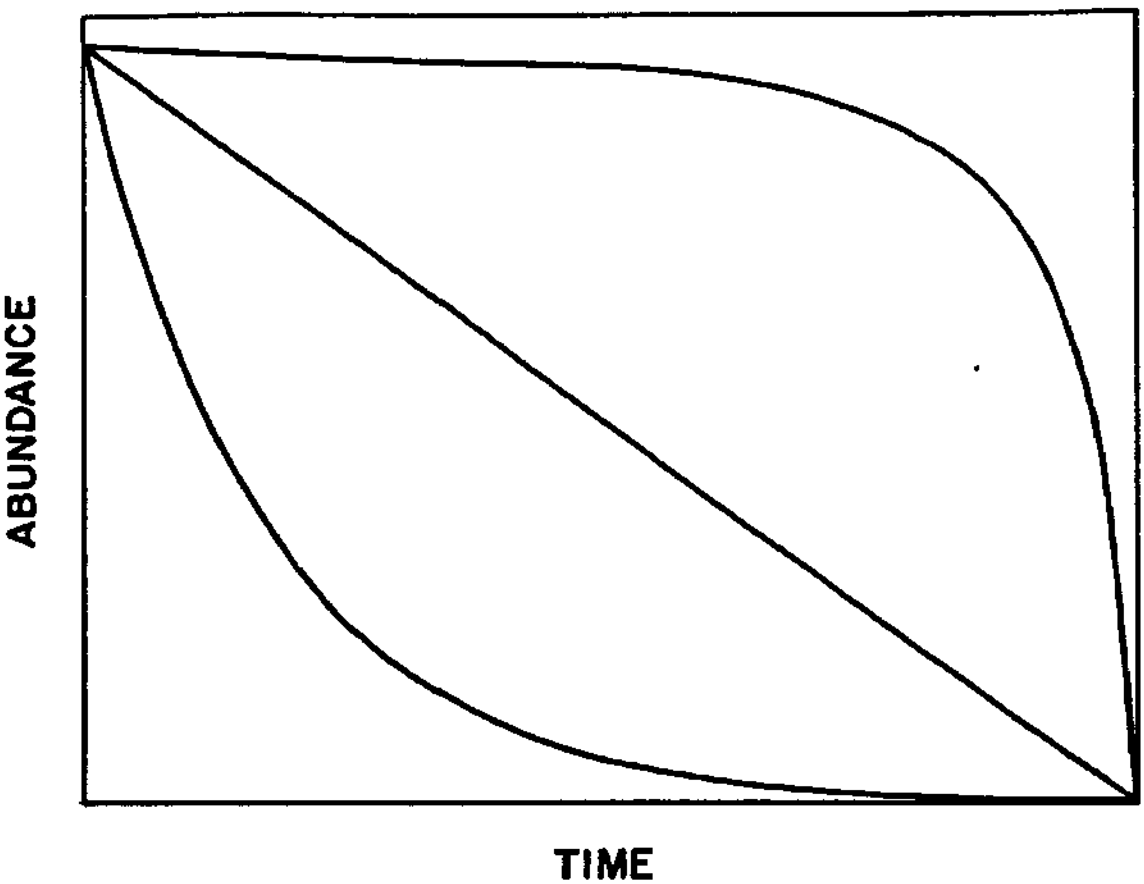

Figure 1.--Three general types of survivorship curves.

survivorship curves of marine debris might take. The top curve shows a population in which most individuals survive for most of the lifespan, then become "senescent" more or less simultaneously. In the middle curve, a constant number of individuals die in each unit of time, while in the lower curve, there is a constant rate of mortality per unit of time. Different "species" of debris will certainly have different survivorship curves. We need to establish the general shape of the survivorship curve for each "species" and to establish the time scale along the horizontal axis. Does it take days, months, or years for debris to die?

Another factor we need to consider is that although an individual item of debris may not die by disappearing from the ocean, it may change its condition in such a way that it becomes less effective. Carr et al. (1985) and High (1985) reported observations particularly directed at this important question. The impact of a lost gill net is quite different depending on whether the gill net is stretched open or tangled up. Even if a drifting net remains open its effectiveness must decline with time as it becomes fouled with algae, barnacles, and other organisms. Figure 2 shows some simple hypothetical possibilities of decline in effectiveness over time. The top curve shows a situation in which effectiveness remains high for a while, then declines rather rapidly. The middle figure shows a

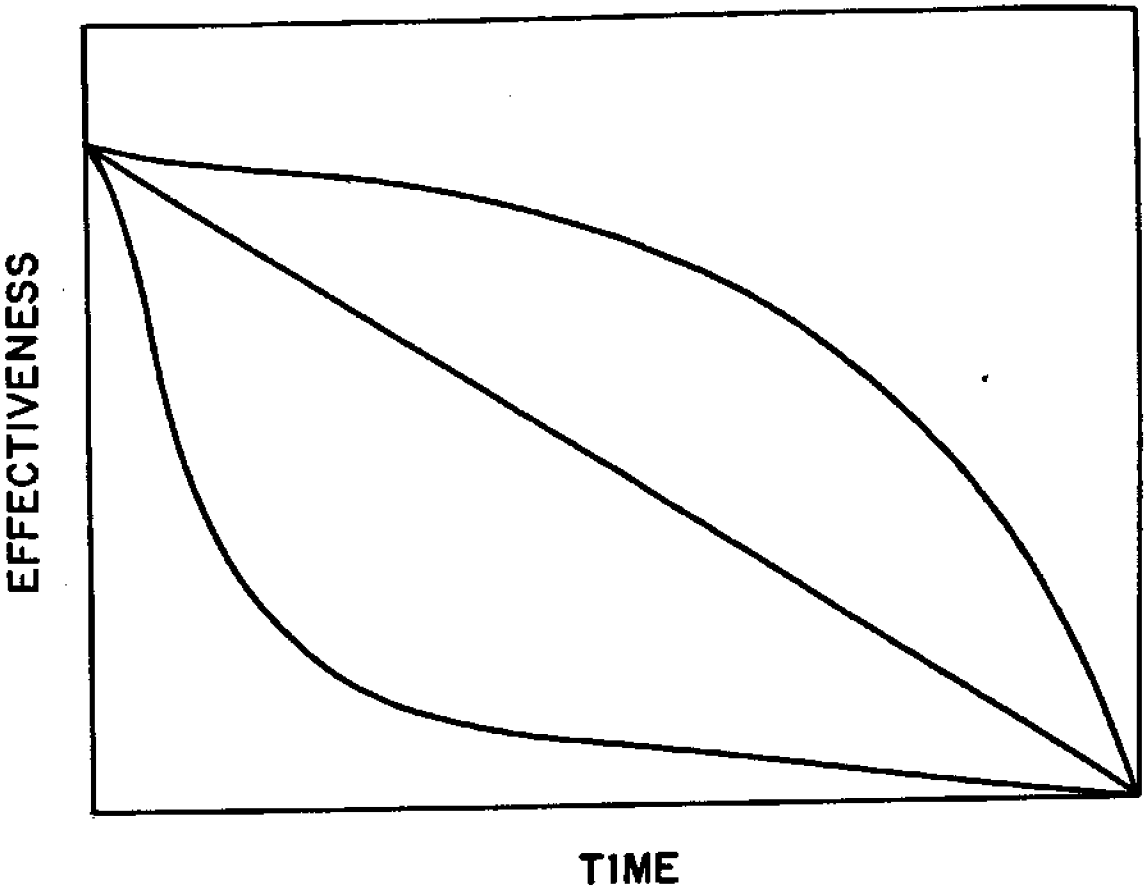

Figure 2.--Several possibilities for declining effectiveness of individual items of marine debris with time.

linear decrease in effectiveness with time, while the lower curve illustrates a situation in which there is an initial rapid decline followed by a longer period in which the debris continues to have an impact, though at a reduced level. As with survivorship, the important things we need to establish are the general shape of the effectiveness curve for each "species" of debris and the time scale on the horizontal axis.

The impact of a population of marine debris is a product of the effectiveness and survivorship curves. Figure 3 illustrates this idea. As a simple example, linear declines in relative effectiveness and in abundance with time are shown. Their product, however, which indicates the impact of this particular "species" of debris, is not linear. Putting it more formally, let q(t) be the average effectiveness (catchability coefficient in fisheries parlance) and n(t) the number of items of a particular debris "species," both functions of time. Then the total impact of (e.g., total number of fish caught by) this kind of debris is

$$\int_0^T q(t)\, n(t)\, dt \quad .$$

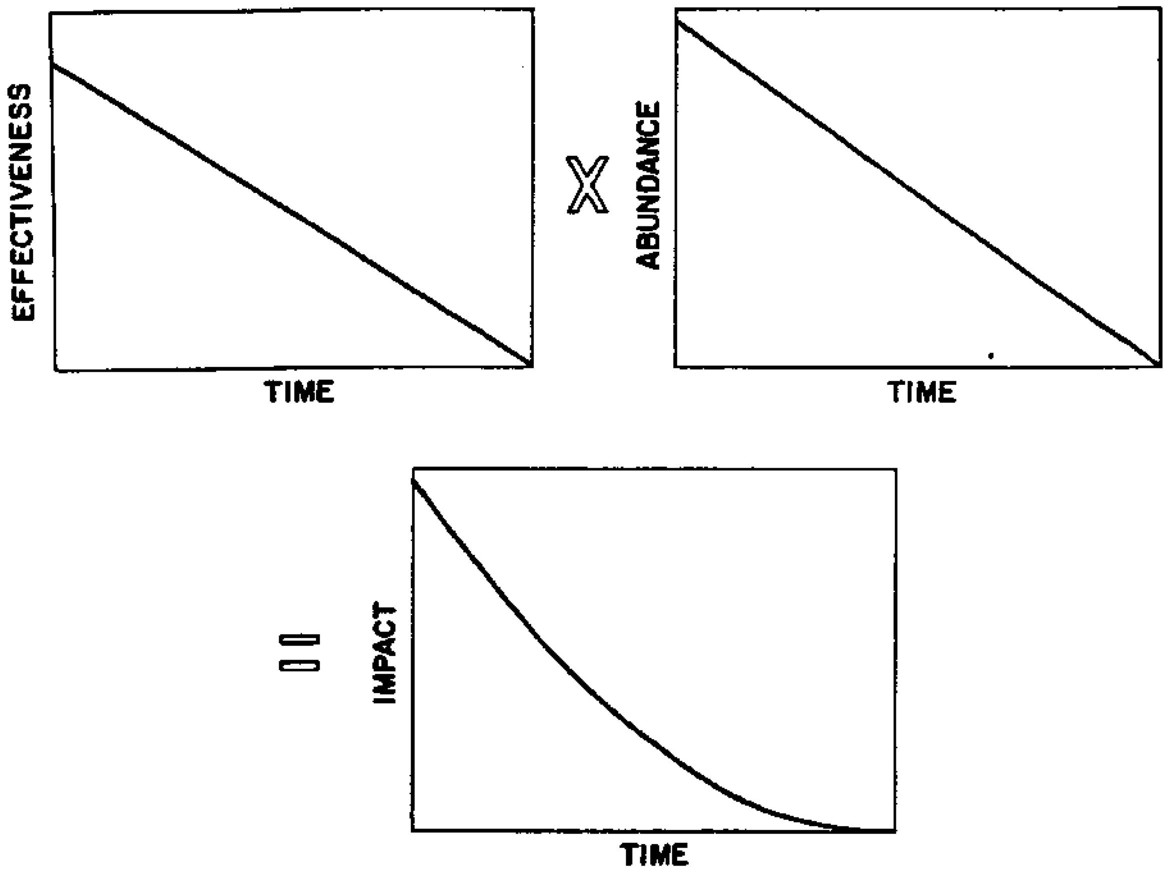

Figure 3.--Impact of a population of debris as a function of time. The impact is a product of the effectiveness and abundance functions.

There are three general causes of death: (1) deterioration of material as a result of exposure to seawater, sunlight, oxidation, biological agents, and the mechanical agitation of the ocean; (2) sinking by loss of buoyancy through water absorption and by fouling with marine organisms; and (3) stranding of material on the shore. What fraction of deaths is due to each of these three causes? At the present time even rough estimates do not seem to exist for floating marine debris.

The physical deterioration of rope and netting material could be estimated from the manufacturer's specifications; otherwise some simple experiments could show how long various materials might last. In general, we know that modern synthetic materials have a long life. In fact, it is the durability of these materials that is one of the fundamental causes of the debris problem. Given this long potential life, what does eventually happen to marine debris? If it does not deteriorate, and if it is not ingested by a marine organism, there are only two other ways it can die: either it sinks or it is cast up on a beach.

Loss of buoyancy can occur when an item of debris gradually absorbs water and also when marine organisms grow on it. The main organisms which could grow on floating debris and weigh it down are certain species of barnacles. Since the calcified barnacle shell is denser than water, a heavy growth of barnacles could cause an object which was originally slightly buoyant to become heavier than water and sink. How quickly this will happen depends on the original buoyancy of the object, and on the rate of settlement and growth of barnacles. Figure 4 illustrates this for three items of debris with different original buoyancies. The items of debris have positive buoyancies which decrease only slightly with time. The negative buoyancy of barnacles changes greatly with time, probably according to some S-shaped curve similar to the one shown. The first item of debris is so buoyant that barnacles will never cause it to sink. The second item of debris requires a heavy growth of barnacles to develop before it will sink, while the third item is only slightly buoyant and is quickly pulled down by the barnacles. The greatest unknowns are the rates of settlement and growth of the barnacles (and other organisms denser than seawater), but these could be established with some relatively straightfoward, though not necessarily easy or cheap, experiments.

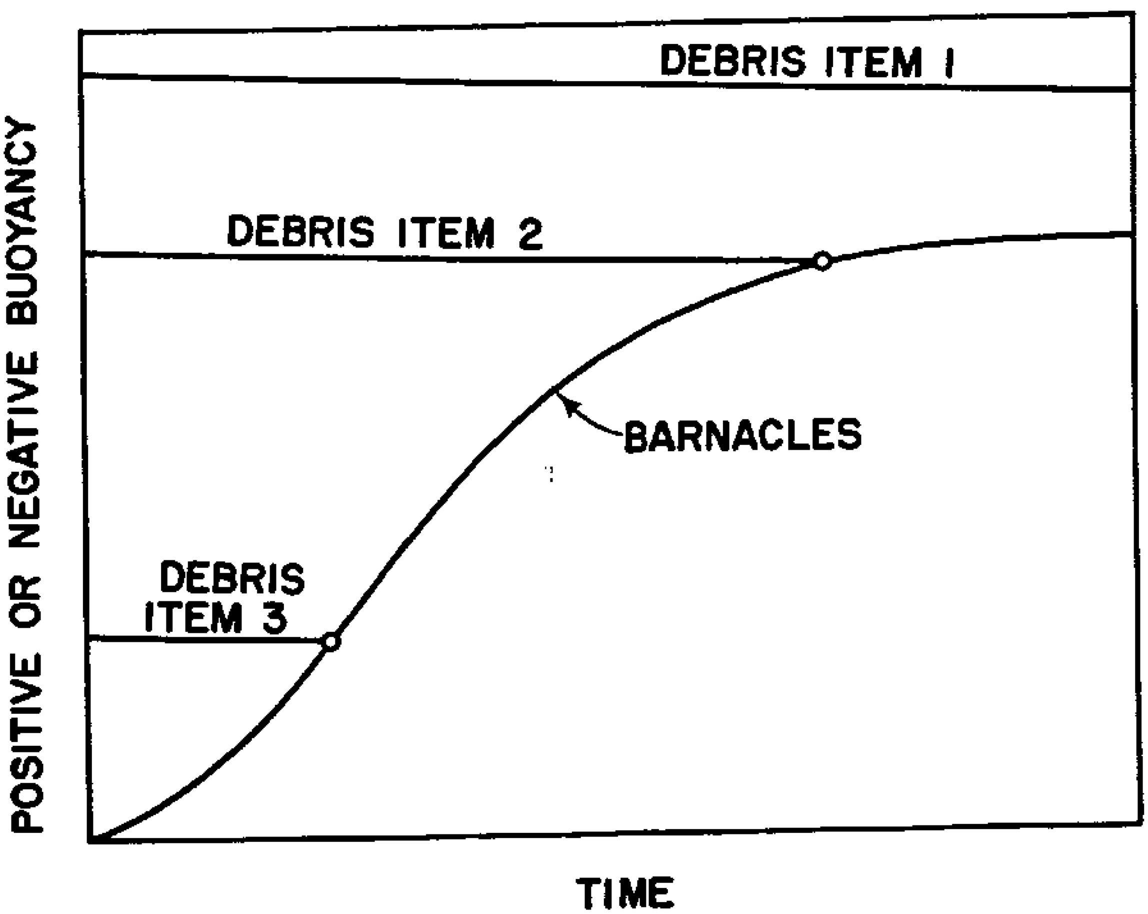

Figure 4.—Possible changes in buoyancy of items of debris with time due to the growth of barnacles or other organisms with density greater than that of seawater. In the examples shown, the growth of barnacles would cause debris items 3 and 2 to sink, but not item 1.

What happens after an object has begun sinking depends on several factors. Of course if the object is dense enough it will continue to sink to the bottom of the ocean. But if its density is close to that of seawater, the compressibility of the material relative to that of seawater is important. Material which is more compressible than seawater will continue to sink, even when the barnacles die and fall off deep in the ocean. On the other hand, material less compressible than seawater could sink to and remain at an intermediate depth.

The third possible fate of an item of marine debris is stranding on a shore. It is difficult to estimate how much material is eventually removed from the ocean in this way. Monitoring a beach and recording the amount of debris which accumulates may give a relative indication of abundance, but it does not tell us what fraction of a particular kind of debris ends up on a beach. Nearshore this fraction could be substantial. One possible approach in coastal waters is to attach sonic or radio tags to a sample of debris and monitor the fate of these tags. Such an experiment would also have to consider the possibility that some items of debris could be deposited on a beach, but later washed out again; these could be termed "born-again" debris. Away from the continental land masses, on the other hand, the probability of death due to deposit on a beach appears to be quite low. Since the oceans move in large circular gyres, and since surface waters tend to converge toward the centers of these gyres, a floating object, if it did not deteriorate or sink, could continue to go around and around. There is anecdotal evidence for some objects being afloat for many years.

SUMMARY AND CONCLUSIONS

This paper has provided a brief description of the marine debris problem, approached from a population dynamics viewpoint. This description addresses mainly the fate of marine debris. It concentrates on describing how much, when, and where. From this information, the impact of a given amount of debris on fishing operations or on vessel safety could be estimated by computing an encounter rate. To estimate the impact of this debris on populations of fish, birds, turtles, and mammals, however, would require more than a simple encounter rate. It would also require information on the behavior, physiology, and ecology of these animals, topics beyond the scope of marine debris population dynamics.

Attempts to reduce the amount of marine debris can be viewed as taking one of two basic approaches: to increase the death rates or to reduce the birth rates. Programs which remove debris from beaches or proposals to require certain rates of degradability in fishing gear are aimed at increasing death rates of debris. Programs which seek to reduce the amount of debris created, either through legal or financial incentives, are aimed at reducing birth rates. Either can be an effective means of population control. I hope we can find a suitable combination of these two approaches in the working group meetings which are next.

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THE OCEANIC CIRCULATION IN HAWAIIAN WATERS: FACTS, HYPOTHESES, AND PLANS FOR FURTHER INVESTIGATIONS (Abstract only)

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ABSTRACT

According to Robinson (Eddies in Marine Science, New York, 1983), "It is now well known that the mid-ocean flow is almost everywhere dominated by so-called synoptic or meso-scale eddies." This is even more true near major topographical features like the Hawaiian Ridge where, in addition to quasi-geostrophic motions (Rossby waves, synoptic eddies), barotropic and baroclinic tidal currents and currents associated with wind waves and surf, are of strong, and in some locations of dominating influence.

Examples of direct and indirect current observations will be presented. These observations illustrate how extremely difficult the predictions of the fate of marine debris in the Hawaiian waters is.

In view of the very limited knowledge that we have about the oceanic circulations in Hawaiian waters, a major research project, called "Hawaiian Ocean Experiment (HOE)," is planned for the period 1986-91. Background and plans of this comprehensive, interdisciplinary, cooperative oceanographic study of Hawaiian waters (to include the inhabited Hawaiian Islands and the Northwestern Hawaiian Islands) will be outlined.

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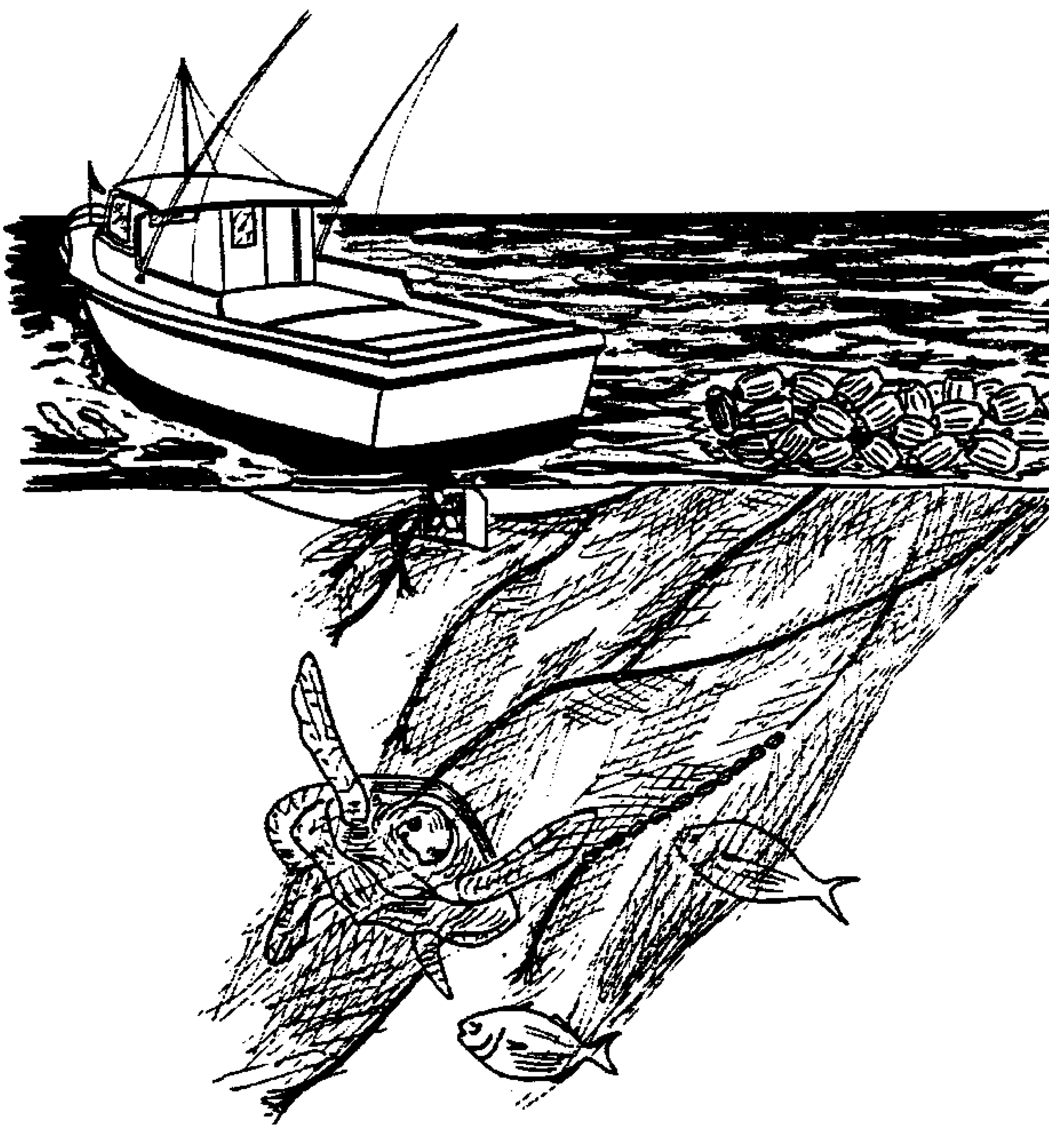
POSTER SESSION



PLASTIC POLLUTION AT SEA AND IN SEABIRDS OFF SOUTHERN AFRICA
(Poster presentation)

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ABSTRACT

Plastic objects were first recorded from seabird stomachs in the northwest Atlantic Ocean in 1962. Since then, this phenomenon has become increasingly widespread and abundant. Recently, plastic objects have been found in the stomachs of 22 seabird species from southern Africa and the African sector of the southern ocean, including birds restricted to the pack-ice. Three species, pintado petrel, *Daption capense*; blue petrel, *Halobaena caerulea*; and great shearwater, *Puffinus gravis*, have plastic objects in more than 90% of stomachs. In exceptional circumstances, ingested plastics make up 0.7% of body mass and completely fill the muscular stomach (gizzard). Although much has been hypothesized, the effects of these plastic objects are unknown.

Studies are under way in attempting to determine the spatial and temporal distribution of plastic pollution at sea and on the coasts of southern Africa using neuston trawls and beach surveys. The incidence of plastic ingestion by birds is being related to diet, foraging area, and behavior. The possible effects of ingested plastic objects on seabirds are being tested by physiological and energetic experiments on captive birds which will be fed differing amounts of plastic objects and compared with controls.

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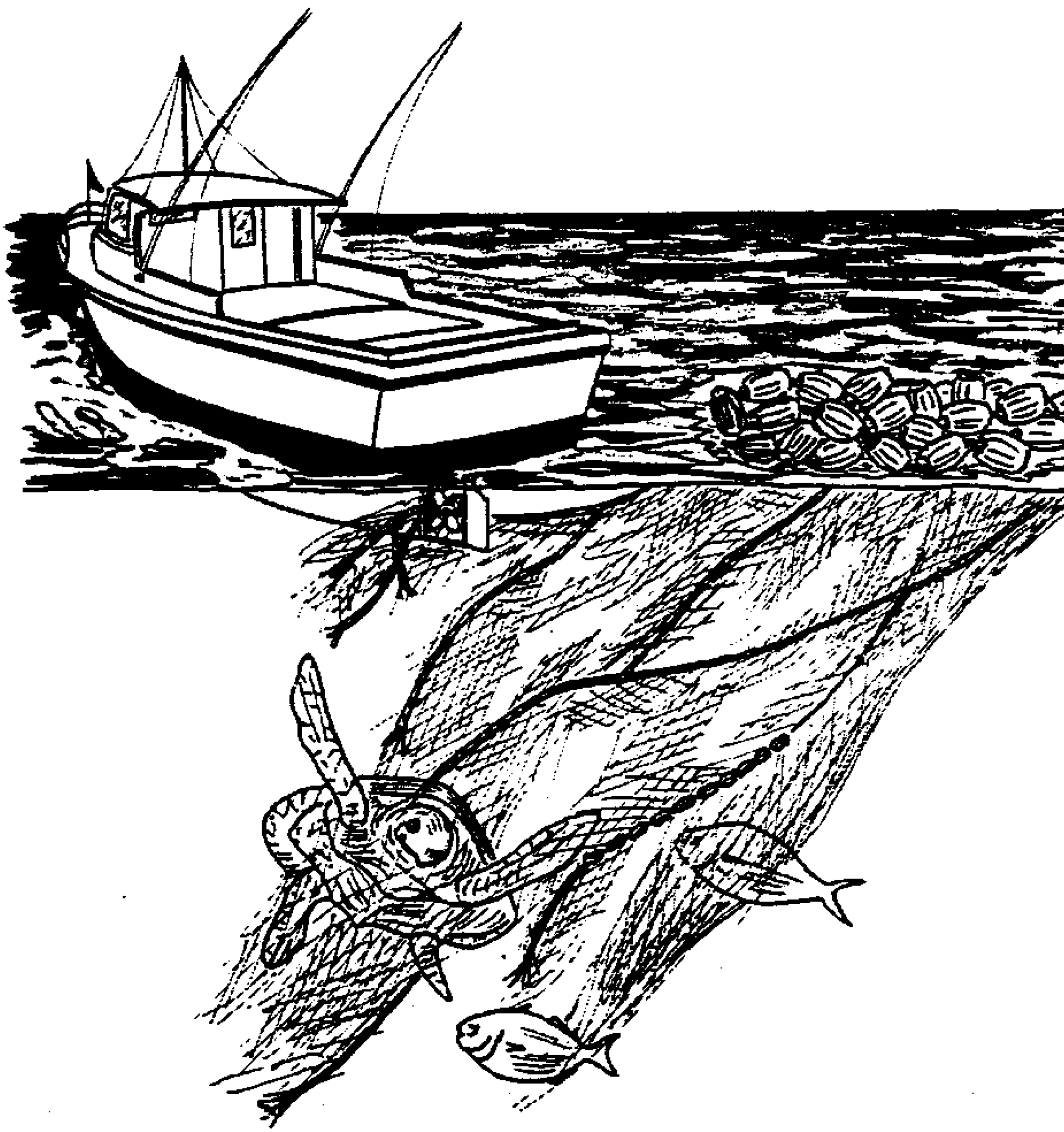
WORKING GROUP REPORTS



REPORT OF THE WORKING GROUP ON MARINE DEBRIS

(Dayton L. Alverson, Chairman)

1. Review the results of the Fate and Impact of Marine Debris (FIMD) workshop sessions and determine the extent and the nature of the marine resource interaction.

   The FIMD workshop provided ample evidence the debris of terrestrial and shipborne origin was widespread in the marine environment. A number of papers, mostly descriptive in character, suggests debris interacts with a wide variety of marine mammals, fish, turtles, birds, and invertebrates. The consequences and quantitative impacts of this interaction do not appear to be well understood nor documented for most observed interactions; however, substantial evidence of a qualitative character demonstrates that added mortality over those generated from natural causes is occurring for species of marine mammals, birds, fish, turtles, and shellfish. For the northern fur seals, the evidence of entanglement and increased mortality of young resulting from entanglement in large mesh trawl webbing is relatively strong, but there is a need to evaluate this hypothesis in terms of long-term availability of large mesh trawl nets and other factors such as disease. For many other species of mammals and fishes, invertebrates, seabirds, etc., evidence of death, wounds, feeding problems, etc., is apparent, but quantification of the impacts on the dynamics of impacted populations will require more study. Regardless, 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.

2. Determine if the workshop has missed any pertinent research efforts which address the marine debris problem and assess whether this information should be acquired to fully update the present state of knowledge.

   a. There is a body of data within the International North Pacific Fisheries Commission documents on net design and usage in the northeastern Pacific region. These data should be further explored to evaluate Charles W. Fowler's hypothesis that significant added mortality to young seals occurs as the result of entanglements.

   b. Most data presented on fishing effort reflected foreign information on U.S. fishing outside of state waters. Considerably more data are available on U.S. fishing effort in the eastern Pacific. The additional data would help to broaden our understanding of possible debris-marine resource and debris-human resource interaction.

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c. Information on fouling of fishing and recreational vessels as well as other waterborne traffic should be collected to understand the full scope of impacts of marine debris.

d. Historical data on entanglement should be further explored in detail with regard to fur seals to determine if specific sizes of mesh can be identified which generate the greatest potential mortality.

e. Fishermen groups and net manufacturers should be asked to assist in identifying specific types of nets and net components which are most involved in entanglement.

f. Additional information is needed on seabird entanglement and ingestion of plastic materials.

g. Incidentally caught organisms themselves can become marine debris when discarded at sea. Further studies are needed to quantify the amount of this type of debris generated and its impacts.

3. Determine if the present state of knowledge is adequate to identify possible mitigation.

Although the present state of the problem is adequate to demonstrate that debris-marine resources interactions are occurring and that many of these interactions are generating added mortality to species of marine life as well as endangering human life in many instances, the quantitative aspects of the problem in terms of the population dynamics of the animals involved and risk to humans are unknown. Similarly the source of some debris is not clear. Finally the cost of mitigation in terms of its value to problem resolution in some instances is unclear. There are, nevertheless, possible actions that should be explored to address the most obvious and dangerous problem areas. These include:

a. Education of the fishing community as to the extent of the problem, addressing the loss of marine mammals, fish, seabirds, sea turtles, and invertebrates and danger to human life.

b. Consideration of regulating mesh sizes of materials (e.g., nylon) used in the wings and body of trawls. The validity of the assumption that large mesh webbing causes entanglement problems needs confirmation. Could entanglement observations result from high survival of animals encountering this gear but high mortality be associated with the more common smaller mesh? This is not likely but the possibility should not be overlooked.

c. Regulation of the discharge of webbing and other harmful debris.

d. Development of charts of known snags to reduce net losses by fishing vessels.

e. Requirement for identification of fishing nets to identify source and areas lost.

f. Urging U.S. commitment to limit international waste disposal at sea.

g. Expanding public cleanup projects.

h. Requiring vegetable fiber hangings or escape panels on pots.

4. Determine which additional information is necessary to identify mangement actions which will alleviate the marine debris-marine resource interaction.

a. Further explore hypothesis regarding the added mortality caused from trawl webbing and plastic bands on fur seals and other potential sources of mortality, in particular disease, which might explain declining population sizes. Consider at sea verification of entanglement and death. Also study disease factors by reinstituting pelagic high seas studies. Expand beach studies in winter to verify entanglement deaths.

b. Expand study of wintering areas of birds.

c. Study fate of lost fishing nets through experimental design studies.

d. Investigate life of nets and breakdown processes after loss. Also develop a catalogue to help the public identify net components and materials.

e. Confirm sources of major debris and expand studies of their distribution in the marine environment.

f. Develop standardized beach survey methodology (see manual by Theodore R. Merrell, Jr.). Also study impacts of beach transport of debris and its effect on beach survey studies.

g. Collect information from fishing industry on derelict fishing nets and disablement of vessels by marine litter (see Auke Bay Laboratory format).

h. Expand use of submersibles in studies of lost gear on the seabed.

i. Enlist support of Korea, Japan, and Taiwan in a study of the scope of net losses, etc., from high seas gill net fisheries for squid. Also, request aid of international organizations (Food and Agriculture Organization of the United Nations and Intergovernmental Oceanographic Commission) in determining net losses at sea.

j. Consider a new international scientific forum to discuss the debris problem and other natural resource and environmental problems in the North Pacific region.

k. Evaluate the scope of the entanglement problem for marine mammals in other major world trawling areas. Do the same problems exist?

l. Considerations need to be given to the potential benefits of marine debris. There is evidence that some marine birds and fish benefit from marine debris.

m. Information should be obtained on the extent to which Asian fisheries contribute to floating and beach debris in the Bering Sea and the North Pacific.

n. Investigate current use and needs of plastic bands and potential design alterations which could alleviate associated problems.

REPORT OF THE WORKING GROUP ON IMPACTS OF DEBRIS ON RESOURCES

(Douglas G. Chapman, Chairman)

After reviewing some of the questions raised in background sessions, this group decided to deal first with general aspects and then to consider problems on a resource or species basis. For each of these, the Working Group attempted to: (1) define the problem and the problem material, (2) suggest information needed, (3) provide recommendations to obtain the information or to begin mitigation of the problem, and (4) note any other relevant points.

1. General.

   a. Information needed.

      (1) What is the fate of different gear types in different locales (and similar information for other debris, particularly bands)?

      (2) How long are the different types of debris likely to have an impact, that is, cause entanglement?

      (3) What are the rates of gear loss for fisheries, for which ghost fishing seems to be a problem?

   b. Recommendations relevant to mitigation.

      (1) Require net identification.

      (2) Develop a reference collection of debris, particularly nets.

      (3) Reduce sources of debris by educational programs.

      (4) Evaluate the costs and benefits of removal of debris from beaches on a periodic basis.

   c. Other comments.

      (1) To assist in scientific research to be undertaken on marine debris problems or mitigation, it is desirable to have clear definitions of the problem.

      (2) It needs to be recognized that marine debris can have positive benefits and these should be recognized and, if possible, assessed.

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Fur seals.

a. Problem.

For fur seals, it is clear that the problem of marine debris centers on (i) trawl net fragments and (ii) bands, usually of plastic. Seals entangled in trawl net fragments are impeded in swimming and diving and hence, have higher energy costs and lower feeding efficiency. They may also cause the seals to be more subject to predation. Bands around the seals' necks can cause lesions and ultimately death from suffocation.

b. Information needed.

(1) Confirmation of level of mortality that to date has been estimated by indirect methods.

(2) Studies as to whether fur seals become entangled with equal probability in netting of different mesh sizes.

(3) Determination as to whether the distribution of net debris at sea is the same (in regard to size, type, etc.) as is found on the beaches.

(4) Theoretical work or experimental studies should be carried out to relate drag of netting, etc., on entangled seals to their rate of survival.

c. Recommendations to obtain information or for mitigation.

(1) Radio tag and monitor entangled seals.

(2) Set up experiments utilizing marked net debris near rookery islands.

(3) Carry out additional beach and sea surveys; it may be necessary to survey at sea using several methods.

(4) Explore the possibility of obtaining insight into the problem or into mitigation through comparison of different pinnipeds.

d. Other points.

It was emphasized that although marine debris (trawl net fragments and bands) is at the moment the most plausible explanation of the recent fur seal population decline, other possible explanatory hypotheses should continue to be investigated.

Fisheries.

a. Problem.

Marine debris impacts fisheries through possible problems of vessel operations and through mortality on commercial fish of interest to the fishery. Lost or discarded gill nets or gill net fragments appear to be the primary problem for both of these impacts.

b. Information needed.

(1) Quantitative information is needed on the types of problems caused by net entanglement on fishing vessel operations as well as their frequency.

(2) Information is needed on the level of mortality of commercial fish stocks in ghost fishing gear.

c. Recommendations.

(1) Seek information from and cooperation with fishermen on the effects of marine debris on fishing vessel operations.

(2) If information on the amounts of ghost gear at sea and the longevity of impact were to become available, it would be possible to incorporate the mortality due to ghost gear into population dynamics models and thus, determine full impact.

(3) Studies should be undertaken on the costs and benefits as well as the possible options in making part or all of the net of biodegradable material.

4. Monk seals.

a. Problem.

Trawl net fragments are those debris items that have been found on monks seals and are perceived to be the main source of possible mortality. The rate of entanglement and, hence, of mortality is unknown but any loss is serious for this endangered species.

b. Information needs.

The information needs are much the same as those for the fur seal though it will be more difficult and less appropriate to carry out any experimental work on animals of this endangered species.

c. Recommendations.

(1) Carry out entanglement studies on captive animals.

(2) Clean up net debris on the beaches and in the lagoons of the islands and atolls inhabited by monk seals. This should be done on a continuing basis.

(3) Continue to monitor populations to determine the number of pups born and other population dynamics parameters but also, to determine the number of entangled seals and as possible, to remove the entangling material.

5. Birds.

a. Problem.

Marine debris impacts marine birds in two different ways, through entanglement and through ingestion. In regard to entanglement, lost and discarded gill net and gill net fragments are the prime cause, though it is believed that active fisheries represent a much more serious problem than ghost fishing. Plastic pellets are implicated as the cause of the ingestion problem.

b. Information needs.

(1) Population dynamics studies are needed of two or three species of birds that are most seriously involved in debris entanglement.

(2) The impacts of ingestion are not well understood and physiological studies and experiments are needed to determine such impacts.

(3) Ingestion of plastic pellets may involve a hydrocarbon contamination problem and studies need to be made to determine if this is so and what impact it might have.

c. Recommendations.

(1) Whatever steps are possible should be taken to seek elimination of dumping of effluent from manufacturing plants.

(2) As feasible, ocean surveys should be carried out to determine the level, distribution, and if possible, the source of plastic pellets. It was suggested that directed surveys are unlikely to be feasible but it may be possible to use platforms of opportunity.

6. Marine turtles.

a. Problem.

Although entanglement has been observed, ingestion of various types of marine debris, particularly plastic, seems to be the more serious potential problem.

b. Information needed.

(1) Similar to birds, the effects of plastic ingestion and the possibility of a hydrocarbon contamination effect are unclear. Hence studies are needed to determine if such effects exist and what their mortality implications would be at the individual level.

(2) Information is needed on the impact of such effects at the population level.

c. Recommendations.

(1) The stranding network in which stranded turtles are collected needs to be expanded and steps taken to assure that all stranded turtles are examined, as far as this is possible.

(2) Collection of turtles should be made for stomach analyses. Again this is most likely to be feasible from platforms of opportunity.

REPORT OF THE WORKING GROUP ON THE FATE OF MARINE DEBRIS

(James D. Schumacher, Chairman)

1. Research needs.

We believe that the extent, nature, and fate of debris are not well defined, although debris is clearly a problem throughout the world oceans. It is essential that research activities receive close international coordination.

a. More information is required on the quantity, type, distribution, and change with time of the amount of debris. The following strategies could address the problem of debris:

(1) Develop sampling devices for marine debris such as neuston nets with grappling hooks, and perhaps moored automatic collectors.

(2) Conduct beach surveys: expand present efforts in time and space, mark or remove debris so that the rate of accumulation can be estimated, and standardize reports from all nations.

(3) Do site-specific studies in the following environments:

(a) The eastern Bering Sea (Pribilof Islands) where there are low currents, large mammal populations, and extensive fishing efforts.

(b) Hawaiian Island waters, where there are endangered species and existing programs (monk seals) which would allow comparisons between beached and at-sea material.

(c) North-south sections along longitudes in the eastern and western Pacific (i.e., across convergence features and upstream and downstream).

(4) Conduct "ship of opportunity" surveys from the National Oceanic and Atmospheric Administration and other research vessels.

b. Examine the timing and rates of change of the threat potential of debris. How does debris change mechanically (e.g., nets become balls), chemically (buoyancy effects), and biologically (plant growth). Once beached, is debris no longer a problem; can it be returned to sea or be a problem on the beach itself? To what extent is benthic debris a threat to animals?

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c. Investigate the mechanisms of entanglement, ingestion, or wounding of individuals with marine debris. Obtain better estimates of the rates of death at sea caused by derelict gear and other debris. Evaluate the impact of entanglement and ingestion of marine debris on animal populations.

d. Examine the potential impact of demersal gill nets on marine fauna.

e. Examine historical records of monthly mean atmospheric pressure to determine the variability of surface currents. Evaluate the utility of using mean monthly atmospheric pressures as an index of the drift of marine debris.

f. Determine how activities will be coordinated to facilitate the exchange of ideas, data, and techniques amongst the international community.

2. The present state of knowledge suggests the following mitigating actions:

a. Enhance communications to:

(1) Change human attitudes toward the environment--the sea, even at its greatest depths, and beaches are not endless garbage pits. Encourage and facilitate the proper disposal of debris.

(2) Provide incentives to fishermen to cut packing bands and to return net fragments (e.g., nets continue to harvest fish, foul boats, and harm marine mammals and birds--The Oregon Experience).

b. Conduct materials research:

(1) Print "please cut" on bands, develop snap-off bands, and bands with biodegradable weak links.

(2) Can materials that may potentially become marine debris be made degradable?

(3) Can trawl net material be made negatively buoyant?

c. Continue to remove and quantify debris from monk seal habitat.

REPORT OF THE WORKING GROUP ON MANAGEMENT NEEDS

(Charles Karnella, Chairman)

The Working Group on Management Needs (Group), while recognizing that further research is indicated to quantify certain aspects of entanglement in and ingestion of debris, strongly believes that the data presented also indicate that a variety of management actions need be promptly undertaken as well. In recognition of this fact, the Group urges the National Oceanic and Atmospheric Administration and other relevant agencies take the following steps:

1. Program management.

   The immediate needs in this area are that:

   a. A person of appropriate stature with the National Marine Fisheries Service be appointed program coordinator; and

   b. A mechanism be established whereby overall program progress can be effectively reviewed at periodic intervals.

2. Public information and education.

   Recognizing that greater benefits are likely to be realized as a result of positive rather than negative incentives, Group participants urged that significant emphasis be placed upon public information and education and that steps specifically be taken to:

   a. Work with fisheries organizations and the fishery management councils to develop and carry out comprehensive information and education programs for foreign fishermen, working within the exclusive economic zone, and U.S. fishermen;

   b. Work with appropriate national and international organizations to undertake cooperative comprehensive information and education programs; and

   c. Work with relevant industries, such as has been done with elements of the plastics industry, on public education programs.

3. Technology.

   While recognizing the actions already taken by the National Marine Fisheries Service to establish a center for purposes of identifying debris and photographs of debris, the Group concluded that further needs indicated in this area are:

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a. A reference catalogue of netting materials be developed;

b. Actions be taken to develop and implement improved or alternative methods of fishing that will diminish the likelihood of gear loss;

c. Use be made of degradable materials and other gear alterations;

d. Efforts be undertaken to develop economically attractive methods for recycling plastics retained at sea;

e. Economical and effective systems be developed to mark gear through color coding or other means for retrieval and identification of source;

f. Systems be developed to facilitate and simplify means of retaining damaged gear onboard for onshore disposal; and

g. Modifications to plastic packing bands be developed to reduce entanglement problems.

4. Debris cleanup.

Group participants concluded that immediate steps to remove existing debris from the environment are clearly needed and concentrated efforts should be directed to reducing the rate at which new debris is deposited. The management steps recommended are:

a. To undertake cleanup programs to remove existing debris from shore areas and the water column;

b. To assign priority to areas where the density of debris is such that it affects endangered, threatened, or commercially valuable species;

c. To require that all potentially harmful debris be retained onboard vessels until proper disposal is possible;

d. To encourage the removal of debris from the environment and prevent the discarding of additional debris, positive incentives such as financial rewards for the return of discarded netting material should be considered as should possible negative incentives; and

e. To take such actions as may be necessary to assure the proper disposal of unwanted materials in a nonharmful manner.

5. Regulations.

Group participants, having considered presentations on the legal issues involved, concluded that the current state of our knowledge of the problems warrants immediate initiation of certain regulatory actions and exploration of a variety of other measures. The recommended steps are that:

a. Appropriate use be made of the several existing treaties, laws, and programs, including amendments where necessary, so as to minimize and as possible stop the deposition of harmful debris;

b. Other countries be requested to examine their domestic authorities for similar purposes as in "a" above.

c. Gear damage compensation programs be reviewed to lessen unnecessary contributions to lost net debris;

d. The Secretary of Commerce review his rulemaking authority under the Fishermen's Protective Act to help reduce gear loss;

e. The Magnuson Fishery Conservation and Management Act be reviewed to determine whether additional steps can be taken under its authority to reduce gear disposal at sea;

f. Consideration be given to amending the Magnuson Fishery Conservation and Management Act to include provisions for U.S. fishermen on gear disposal at sea and the reporting of abandoned gear comparable to those applicable to foreign fishermen;

g. Fishermen be advised that the purposeful disposal of fishing gear in the territorial sea is prohibited under the Clean Water Act;

h. The U.S. ratify optional Annex V of the Convention for the Prevention of Pollution from Ships and encourage other fishing nations to become signatories;

i. The U.S. consider "regional seas" agreements under the United Nations Environment Programs for waters adjacent to the U.S.;

j. Existing U.S. treaties, laws, and relevant programs (including those in "a" above) be reviewed to determine if they can be used to reduce debris, other than fishing debris, from land and water sources; and

k. Consideration be given to the development of a broad range of positive (financial) and negative (regulatory) incentives to reduce the deposition of debris in the marine environment.

6. Identification of problems and impacts.

The Group concluded that:

a. Existing data on the impacts on marine organisms of nonbiodegradable debris from foreign and domestic fisheries be analyzed to document the magnitude of this problem;

b. The rates of accumulation and disappearance of synthetic debris on selected beaches be monitored;

c. Information developed by stranding networks be monitored as an index of levels of entanglement;

d. A standardized program to monitor debris ingestion and entanglement on a regular long-term basis be developed and implemented;

e. A reporting program to monitor entanglement of vessels in lost or discarded fishing gear be undertaken; and

f. The impact of lost or discarded fishing gear and other marine debris on marine mammals, birds, turtles, fish, and human beings be monitored;

g. Assess on a continuing basis the type and quantity of debris loss in domestic and foreign fisheries, with emphasis on trawl and pelagic drift gill net fisheries of the North Pacific; and

h. Identify problems and impacts on certain fisheries; programs related to debris entanglement should be coordinated with programs related to incidental take.

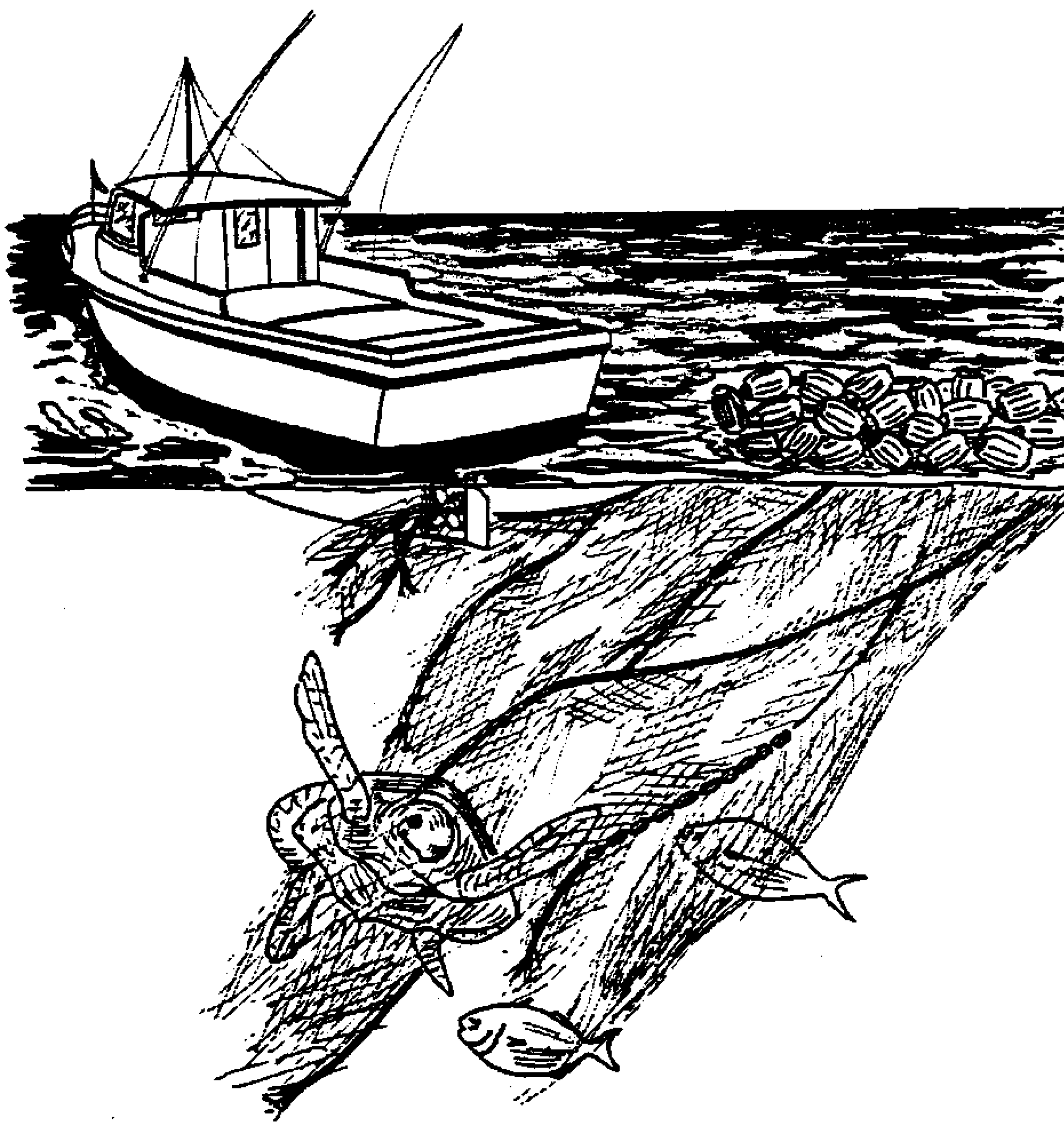
7. Disentanglement.

The Group believes that known methods for disentangling ships and animals should be widely disseminated to those likely to be in need and that efforts should be devoted to developing and publicizing improved techniques for gill net disentanglement.

8. Workshop results.

The Working Groups recommend that the papers, recommendations, and workshop proceedings be forwarded to other responsible agencies including the Departments of Commerce, Transportation, Interior, Defense, State, the Council on Environmental Quality, the Environmental Protection Agency, and appropriate congressional committees with a request that they address these issues.

APPENDICES



APPENDIX A

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APPENDIX B

AGENDA

1. Opening of the Workshop
2. Workshop Sessions
   a. Legal framework
   b. Session I - Source and quantification of marine debris
   c. Session II - Impacts of debris on resources
   d. Session III - Fate of marine debris
   e. Working Group Meetings
3. Special Session - Identifying management needs
4. Film showing
5. Plenary Session
6. Closing of the Workshop

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APPENDIX D

LIST OF TITLES--BACKGROUND PAPERS AND WORKING PAPERS

BACKGROUND PAPERS

N. Wallace
Bibliography on entanglement.

K. Middleton
Ghost gillnets haunt both fishermen and scientists.

R. J. Morris
Floating plastic debris in the Mediterranean.

M. J. Bean
United States and international authorities applicable to entanglement to marine mammals and other organisms in lost or discarded fishing gear and other.

N. Wallace
Solutions to debris entanglement or "Think of it as a big fishbowl."

B. Heneman
Records of pinniped entanglement in fishing gear at southeast Farallon Island.

C. Hammond
Derelict gill net reported to National Marine Fisheries Service, Alaska Region in 1983.

J. Grove
Plastic pollution in the Galapagos.

WORKING PAPERS

INTRODUCTION

M. Gosliner
Legal authorities pertinent to entanglement by marine debris.

SESSION I

R. N. Uchida
The types and estimated amounts of fish net deployed in the North Pacific.

Y. Gong
Distribution and migration of flying squid, _Ommastrephes bartrami_ (LeSueur), in the North Pacific.

L.-L. Low, R. E. Nelson, Jr., and R. E. Narita
Net loss from trawl fisheries off Alaska.

J. Neilson
The Oregon experience.

T. R. Merrell, Jr.
Fish nets and other plastic litter on Alaska beaches.

L. L. Jones and R. C. Ferrero
Observations of net debris and associated entanglements in the North Pacific Ocean and Bering Sea, 1978-84.

J. R. Henderson and M. B. Pillos
Accumulation of net fragments and other marine debris in the Northwestern Hawaiian Islands.

M. L. Dahlberg and R. H. Day
Observations of man-made objects on the surface of the North Pacific Ocean.

W. H. Lenarz
Theoretical first approximations of densities of discarded webbing in the eastern North Pacific Ocean and Bering Sea.

R. A. Fredin
Fishing effort by net fisheries in the North Pacific Ocean and Bering Sea since the 1950's.

K. Shima
Summary of Japanese net fisheries in the North Pacific Ocean.

T. F. Chen
High sea gill net fisheries of Taiwan.

SESSION II

N. Wallace
Debris entanglement in the marine environment: A review.

J. Scordino
Studies on fur seal entanglement, 1981-84, St. Paul Island, Alaska.

C. W. Fowler
An evaluation of the role of entanglement in the population dynamics of northern fur seals on the Pribilof Islands.

D. G. Calkins
Steller sea lion entanglement in marine debris.

B. S. Stewart and P. K. Yochem
Entanglement of pinnipeds in net and line fragments and other debris in the Southern California Bight.

J. R. Henderson
A review of Hawaiian monk seal entanglements in marine debris.

M. W. Cawthorn
Entanglement in and ingestion of plastic litter by marine mammals, sharks, and turtles in New Zealand waters.

R. H. Day, D. H. S. Wehle, and F. C. Coleman
Ingestion of plastic pollutants by marine birds.

G. H. Balazs
Impact of ocean debris on marine turtles: Entanglement and ingestion.

W. L. High
Some consequences of lost fishing gear.

H. A. Carr, E. H. Amaral, A. W. Hulbert, and R. Cooper
Underwater survey of simulated lost demersal and lost commercial gill nets off New England.

K. Yoshida and N. Baba
The problem on entanglement of fur seals in marine debris.

B. R. Mate
Incidents of marine mammal encounters with debris and fishing gear in Oregon.

SESSION III

G. R. Seckel
Currents of the tropical and subtropical North Pacific Ocean.

R. K. Reed and J. D. Schumacher
On the general circulation in the subarctic Pacific.

J. A. Galt
Oceanographic factors affecting the predictability of drifting objects at sea.

T. Gerrodette
Toward a population dynamics of marine debris.

L. Magaard
The oceanic circulation in Hawaiian waters: Facts, hypotheses, and plans for further investigations.

APPENDIX E

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