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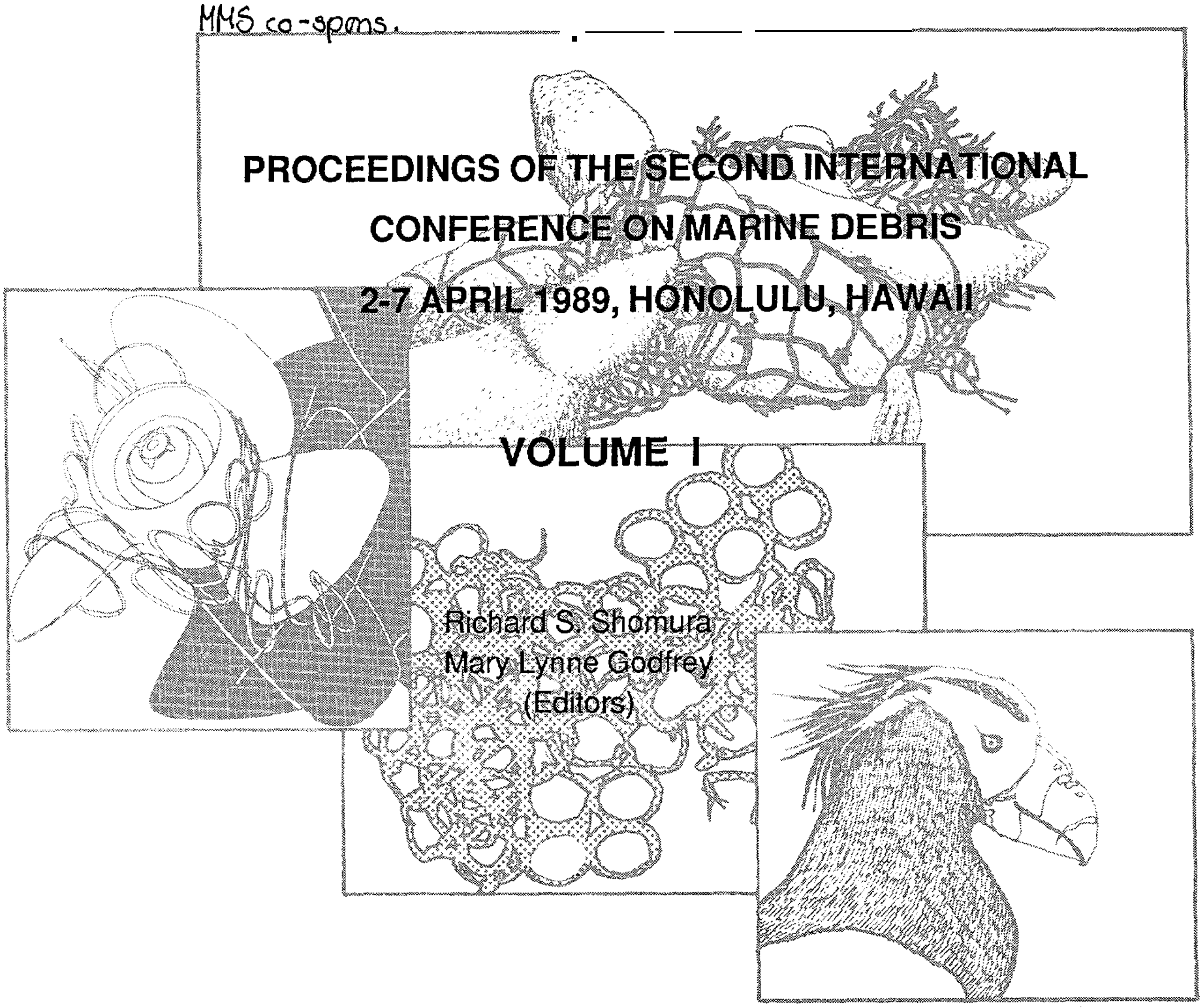

PROCEEDINGS OF THE SECOND INTERNATIONAL CONFERENCE ON MARINE DEBRIS

2-7 APRIL 1989, HONOLULU, HAWAII

VOLUME I

Richard S. Shomura
Mary Lynne Godfrey
(Editors)

NOAA-TM-NMFS-SWFSC-154

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center
University of Hawaii Sea Grant College Program

NOAA Technical Memorandum NMFS

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency which establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, the NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflect sound professional work and may be referenced in the formal scientific and technical literature.

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PROCEEDINGS OF THE SECOND INTERNATIONAL CONFERENCE ON MARINE DEBRIS 2-7 APRIL 1989, HONOLULU, HAWAII

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Sea Grant College Program, University of Hawaii
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U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service
U.S. Marine Mammal Commission
U.S. Minerals Management Service
U.S. National Oceanic and Atmospheric Administration
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NOAA-TM-NMFS-SWFSC-154

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John A. Knauss, Under Secretary for Oceans and Atmosphere
National Marine Fisheries Service
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PREFACE

The Second International Conference on Marine Debris is a sequel to the Workshop on the Fate and Impact of Marine Debris which was held in Honolulu, Hawaii, 26-29 November 1984. The workshop was the first meeting of its kind to address the issue of marine debris as an international problem, and focused primarily on the impact of debris on the living marine resources. This second meeting provides a status review of wider dimensions, including the source, impact, economics, technology, law and policy, and educational aspects of marine debris and its impact on society as well as on the resources of the sea. The details leading to this second meeting and the general conclusions drawn from this meeting are provided in the Executive Summary.

The size and scope of the Second International Conference on Marine Debris make it necessary to publish the proceedings in two volumes. The first volume includes the Executive Summary, the full text of 5 overview papers, and the full text of 40 papers presented in the technical sessions on sources (Session I), entanglement and ghost fishing (Session II), and ingestion (Session III). The second volume includes the text of 31 papers presented in the technical sessions on economics (Session IV), technology (Session V), law and policy (Session VI), and education (Session VII). Additionally, volume two includes the reports of the eight working groups (assessment, entanglement, ghost fishing, ingestion, economics, technology, law and policy, and education) and abstracts of the poster and video presentations. All technical papers were reviewed by one or more referees. Reference to several of the papers is by abstract only, the full text of these presentations not being submitted in time for publication or scheduled for publication elsewhere.

The Appendixes comprise the membership of the steering group, the agenda of the conference, and a list of conference participants.

The senior editor, who had the task of organizing this Second International Conference on Marine Debris, is indebted to many organizations and individuals for helping to make this conference a success. Special thanks are due the members of the steering group for their guidance and assistance in the technical aspects of the conference, and Ms. Christine Woolaway of the University of Hawaii Sea Grant College Program for her outstanding effort in working out the logistics and conference arrangements. Sponsors who provided financial and personnel support included (1) Canada Department of Fisheries and Oceans, (2) Council for Solid Waste Solutions, (3) Intergovernmental Oceanographic Commission (UNESCO), (4) National Coastal Resources Research and Development Institute (U.S.A.), (5) Pacific Rim Fishing Industries, (6) Sea Grant College Programs (Washington, D.C., and the University of Hawaii), (7) State University of New York (SUNY), Stony Brook, Marine Sciences Research Center's Waste Management Institute, (8) School of Ocean and Earth Science and Technology (University of Hawaii), (9) U.S. Environmental Protection Agency, (10) U.S. Fish and Wildlife Service, (11) U.S. Marine Mammal Commission, (12) U.S. Minerals Management Service, (13) U.S. National Oceanic and Atmospheric Administration (NOAA) (National Marine Fisheries Service Honolulu Laboratory), and (14) U.S. Navy.

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

Reference to trade names in the Proceedings of the Second International Conference on Marine Debris does not imply endorsement by the National Marine Fisheries Service, NOAA.

This proceedings is also a University of Hawaii Sea Grant College Program cooperative report, UNIHI-SEAGRANT-CR-91-02.

Finally, the editors owe the successful completion of these proceedings to two former employees of the Honolulu Laboratory, Ms. Louise Brewer and Ms. Elizabeth Young, who assumed the tremendous task of typing and checking the conference manuscripts.

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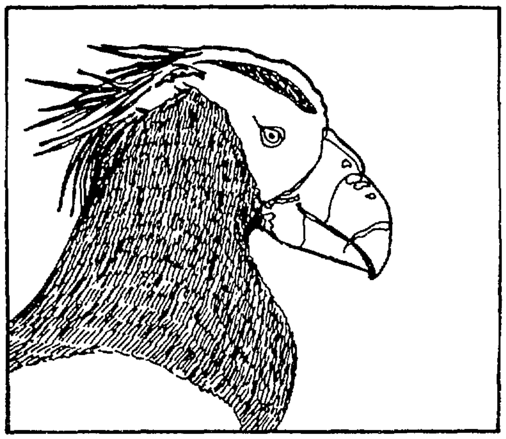
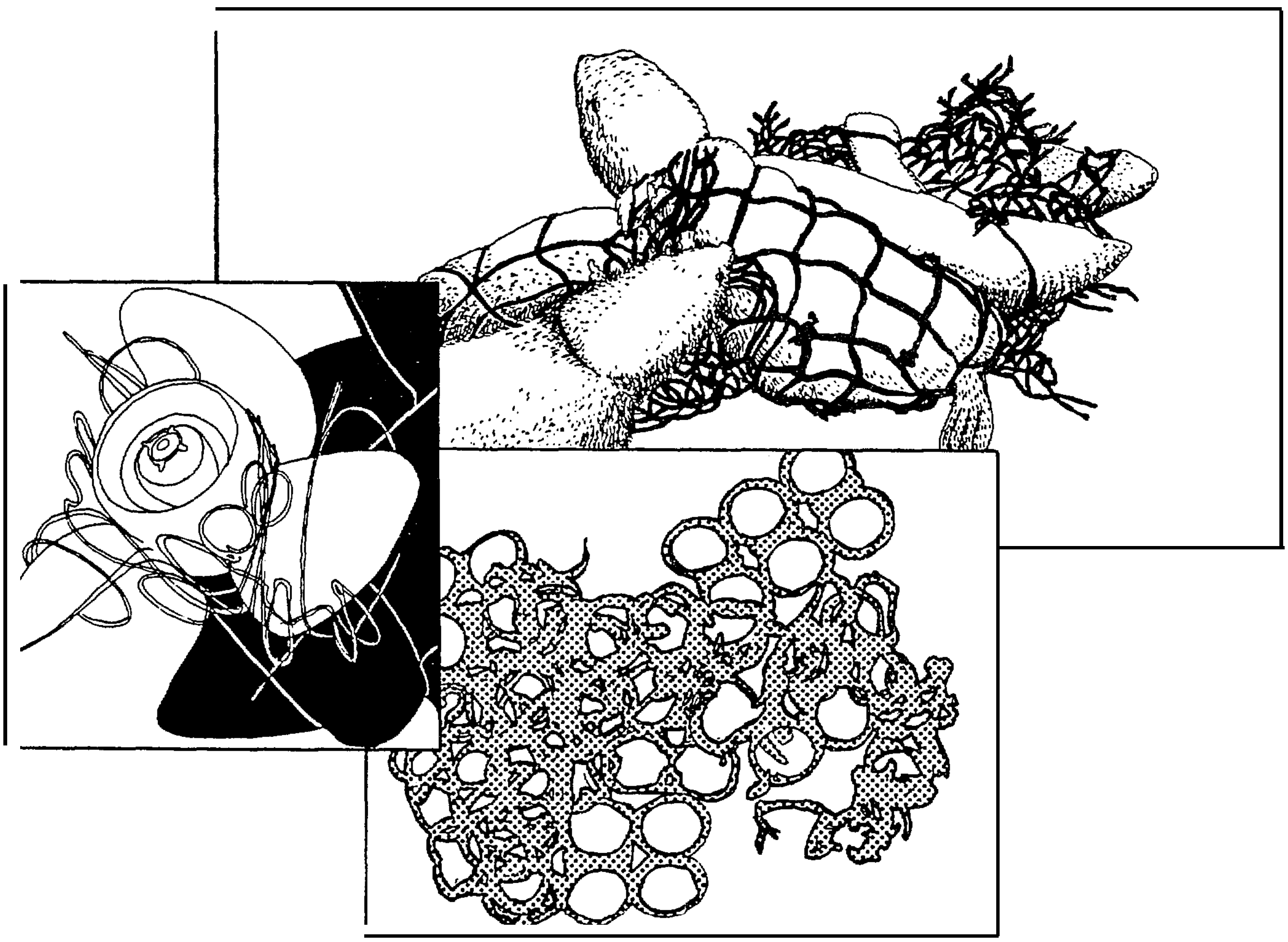


EXECUTIVE SUMMARY



EXECUTIVE SUMMARY

I. INTRODUCTION

Until 10 or 15 years ago, the presence of debris in ocean and coastal areas was not recognized as a significant marine pollution issue. By the early 1980's, however, it became apparent that the amount of debris accumulating at sea and on beaches was increasing dramatically. There was also a corresponding increase in the incidence of marine species being adversely affected by ocean debris. These included marine mammals, seabirds and commercially valuable species of fish killed and injured in lost or discarded fishing gear and other debris, as well as beach-cast turtles with their digestive tracts blocked by plastic items. Clearly, marine debris was becoming a widespread marine pollution problem that could no longer be ignored.

In November 1984, the National Marine Fisheries Service, at the recommendation and with the assistance of the Marine Mammal Commission, convened a Workshop on the Fate and Impact of Marine Debris. The workshop was the first meeting ever undertaken to comprehensively assess information on the amounts, distribution, sources, effects, and management needs pertaining to problems of trash and other human-related debris lost or discarded into the ocean.

Participants in that conference concluded that many marine organisms throughout the world were being affected adversely by persistent debris and that there was an urgent need to: (1) educate vessel operators, fishermen and the public on the problem; (2) stop or reduce the deliberate disposal of persistent materials; and (3) obtain better quantitative data to assess the impact of marine debris on living organisms.

As a result of the workshop findings, a number of programs were undertaken in the United States and elsewhere to address the problem of marine debris. In view of the progress being made, in December 1986, the Marine Mammal Commission recommended to the National Marine Fisheries Service that it initiate planning for a second conference to review the marine debris issue. The Service agreed with this recommendation and, in fiscal year 1988, provided funds to begin planning and organizing a conference. In March 1988 the Marine Entanglement Research Program established a steering group to organize an international workshop. The Second International Conference on Marine Debris took place 2-7 April 1989 at the Ala Moana Americana Hotel in Honolulu, Hawaii.

Objectives

The objectives of the conference, as defined by the steering group, were to:

- evaluate new information on the types, amounts, sources, fates, and distribution of marine debris in different ocean areas;

- evaluate what has been done in the North Pacific basin as a prototype for activities that might be usefully undertaken in other regions;

- identify and evaluate existing and potential methods for gathering data on and monitoring trends in the sources, types, fates, amounts and distribution of debris at sea and on beaches;

- identify and evaluate information on the nature and extent of marine debris-related impacts on species and populations of marine life, including seals, turtles, seabirds, crustaceans, and fish, in different ocean areas;

- identify and evaluate the impacts of marine debris on human health and the safety of ships at sea;

- identify and evaluate aesthetic and other impacts of marine debris on coastal environment;

- review and evaluate information on existing and potential technological and procedural ways to reduce or eliminate the problem of marine debris;

- assess the effectiveness and future role of programs to educate the public and promote awareness of the problem;

- evaluate international, intergovernmental, domestic, and informally constituted regional authorities that might be usefully drawn upon to strengthen cooperative efforts to address regional issue;

- describe programs necessary to assess the effectiveness of measures presently being taken to address various elements of the problem; and

- prepare a report summarizing the results of the conference and the steps that should be taken to address different aspects of the problem.

Workshop Organization

The conference opened Monday, 3 April, with a keynote address and a plenary session that set the stage for discussions during the remainder of the week. Overview papers presented during the plenary described the marine debris issue in six geographic areas: the North Pacific, the northwest Atlantic; the southwest Pacific; waters off southern Africa; the Antarctic; and the Caribbean. During the next 4 days, background and experience papers were presented on aspects of the marine debris problem. The subject areas of these technical sessions included: (1) amounts, types, distribution and sources of marine debris; (2) entanglement of marine life and ghost fishing; (3) ingestion by marine life; (4) economic impacts on vessels and shorelines; (5) solutions through technology; (6) solutions through law and policy; and (7) solutions through education. In some cases, these technical sessions ran concurrently. Beginning on Wednesday, 5 April, participants separated into eight working groups to discuss the results of the technical sessions and formulate recommendations on needed actions. The subject matter of the working groups mirrored those of the technical sessions except that entanglement and ghost fishing split into two working groups. At a final plenary session on Friday, 7 April, working group chairmen summarized the results of these deliberations for workshop participants as a whole. A conference summary was presented at the closing luncheon.

Sponsors and Participants

Sponsors of the workshop included: Canada Department of Fisheries and Oceans; Council for Solid Waste Solutions; Intergovernmental Oceanographic Commission (UNESCO); National Coastal Resources Research and Development Institute (U.S.A.); Pacific Rim Fishing Industries; Sea Grant Colleges--University of Hawaii; State University of New York at Stony Brook, Marine Sciences Research Center's Waste Management Institute; University of Hawaii, School of Ocean and Earth Science and Technology; U.S. Environmental Protection Agency; U.S. Fish and Wildlife Service; U.S. Marine Mammal Commission; U.S. Minerals Management Service; U.S. National Oceanic and Atmospheric Administration; and the U.S. Navy.

As at the 1984 conference, participants included representatives from these groups along with scientists from various disciplines, administration and management personnel from Federal and State offices, and representatives of the fishing industry, the academic community, conservation groups, and other public and private interests. Although participants were primarily from the United States, representatives from the Republic of Korea, Japan, New Zealand, Canada, Israel, The Netherlands, South Africa, and the United Kingdom were also present. This level of participation is indicative of the high degree of international interest in the problems of marine debris.

II. SUMMARY OF OVERVIEW SESSION
(chaired by Brian Boyle)

Several papers were presented addressing the marine debris situation in various parts of the world. Activities were reported under way to reduce the impact of marine debris on North Pacific seabirds and marine mammals . Effects of these actions are as yet unknown. Impacts of marine debris in the northwest Atlantic were also discussed, and it was concluded that aesthetic degradation of beaches and the cost of cleaning beaches appear to be the most serious effects of marine debris in the study area. Threat to marine life appears to be limited to sea turtles. Addressing accumulation, distribution, and environmental effects of plastic pollution in the southwest Pacific, it was noted that plastic debris of all kinds and in all sizes is widespread in this region, including shores of isolated and unpopulated islands. Ingestion of plastics has been recorded for at least 7 species of mammals, 26 seabird species, and 2 marine turtles species in the waters off southern Africa and the adjacent Southern Ocean. In addition, 5 marine mammal species and 13 seabird species have been found entangled in plastic debris. Steps are being taken by the Commission for the Conservation of Antarctic Marine Living Resources to monitor marine debris in the Antarctic. Assessment of petroleum hydrocarbons in the marine environment of the Caribbean was also discussed.

III. SUMMARY OF TECHNICAL SESSIONS

Session I: Amounts, Types, Distribution, and Sources of Marine Debris (chaired by Murray Gregory and Satsuki Matsumura)

Debris is found in all oceans in all parts of the world. Regional evaluations of the amounts, types, distributions, and sources of persistent debris are required to develop efficient strategies for its control. Such evaluations are also critical to the discovery of current and potential problems caused by marine debris'. This session included 22 papers, including several on concentrations of marine debris in the North Pacific/Bering Sea areas and others addressing the debris problems in the Gulf of Maine, New York Bight, the Outer Banks of North Carolina, a Texas barrier island, the east Mediterranean, the Israeli coast, and elsewhere. Papers also discussed the National Marine Debris Data Base and suggested guidelines for the design of beach debris surveys.

Session II: Entanglement of Marine Life (chaired by Charles Fowler)

The destruction of marine organisms through encounters with synthetic debris has been widely reported, and entanglement is the most common mechanism for this destruction. While the consequences of entanglement are obvious for individual animals, the implications for the status of the populations involved have been difficult to ascertain. Sixteen papers were presented on these topics, including ten on the northern fur seal and one each on Hawaiian monk seal, pinnipeds in the Southern California Bight, and marine mammals and sea turtles in the New York Bight. Presentations also addressed ghost fishing and the preliminary results of a study on the impact of the changing shape of derelict driftnets.

Session 111: Ingestion by Marine Life (chaired by Peter Lutz)

Ingestion of plastic bags, synthetic rope, plastic pellets, and other marine debris has been reported as the cause of death of individual sea turtles, seabirds, marine mammals, and fish. The extent to which such incidents occur is uncertain, and thus it is also uncertain whether such occurrences have negative impact on population levels. This session included 15 papers presenting the latest scientific findings on research on debris ingestion. Six papers addressed incidence and effects of ingestion by seabirds, four focused on ingestion of plastics by sea turtles, and others addressed ingestion by fishes and marine mammals.

Session IV: Economic Impacts on Vessels and Shorelines
(chaired by John Sutinen)

Netting, rope and sheeting discarded at sea can disable vessels, thus threatening human safety on the open water. Floating debris has a negative aesthetic impact on beaches and inshore waters and can pose a human health hazard. Coastal communities that depend on tourism can incur significant costs as a result of decreased tourist traffic and cleanup costs. An economic perspective on the problem of persistent marine debris addressed problems in enforcing regulations to prevent marine debris. A research agenda was proposed. One report described how the Japanese commercial fishing fleet suffered damages as a result of marine debris. Other papers addressed recent incidents of medical wastes washing up on U.S. Atlantic beaches and the New York State Marine Debris Program.

Session V: Solutions Through Technology (chaired by Bruce Perlson)

A vast range of useful applications of new and modified technology is available for reducing the marine debris problem. Areas ripe for advancement include: simplification of shipboard waste handling, control of land-based sources, port waste handling systems, plastics and other recycling systems, waste heat recovery; fishing gear loss and recovery, and controlled-lifetime plastics. There is apparently a changing attitude in the packaging industry toward the development of biodegradable plastics. A paper described results of studies of the weathering behavior of five types of plastic materials commonly found as marine debris, and another reported on a recently initiated project to encourage recycling of marine plastic debris. Other papers in this session addressed control and disposal of wastes aboard ships and the port's role in reducing marine debris by providing refuse reception facilities.

Session VI: Solutions Through Law and Policy (chaired by Timothy Keeney)

Solutions to the marine debris problem involve many disciplines, industries , institutions, and agencies of government. This session focused on models of public process that have dealt with fractionated leadership and authority structures in solving the marine debris and similar multidimensional problems. The U.S. Environmental Protection Agency's Interim National Coastal and Marine Policy, which is aimed at controlling medical wastes and other marine refuse, was described. Another paper discussed international and regional regulations to prevent and control pollution by ships and noted, for example, that a recent survey of the German Bight estimated that 95% of the 8.5 million pieces of debris dumped annually, come from ships. Five papers addressed aspects of MARPOL Annex V and its potential for reducing marine pollution, and the Marine Plastic Debris Action Plan adopted in the State of Washington was described.

Session VII: Solutions Through Education (chaired by Bernard Griswold)

Because a great deal of the persistent debris reaching the ocean is the result of actions by individuals, public education on impacts of debris and disposal alternatives is seen as an important factor in solving the problem. Papers in this session represented a wide range of educational programs and materials in place throughout the world, and one discussed how the plastics industry has responded to the problem of marine pollution, specifically to the presence of resin pellets in the marine environment. Efforts being carried out by TheTidy Britain Group to control marine litter were documented. Other authors discussed marine education and cleanup programs being implemented by the shipping industry, the U.S. Navy, various states and localities, and Japan. The final paper pointed out the need to consider and understand public attitudes and perceptions when designing an education program.

IV. SUMMARY OF WORKING GROUP MEETINGS

Working Group 1: Methods to Assess the Amounts and Types of Marine Debris (chaired by Christine Ribic)

The working group reviewed various methods currently being used to survey debris at sea, on beaches, on the sea floor, and emanating from land. Participants agreed that certain areas should be selected for concentrated study: on an international level, MARPOL special areas were suggested as appropriate; on national or regional levels, areas should be chosen to meet local areas of interest or management.

The group proposed methodologies to be used to determine amounts of debris . For nearshore, open ocean and sea bottom areas, platforms of opportunity, or dedicated surveys are appropriate. Beach surveys could be done using either designed programs or volunteer programs.

To improve accuracy and usefulness of strip transect surveys used to assess floating debris, the group recommended: using two or three observers instead of a single observer; calibration runs to estimate strip width; and experiments to investigate color and size biases. The working group further recommended that, when accurate distance measurements can be made, line transect methodology should be used. It also noted the possibility of using low-flying aircraft to survey nearshore areas.

As regards the magnitude of bottom debris, the group identified fishermen as a potential source of baseline information. It recommended that a survey form be developed to collect information from fishermen on debris tangled in their nets. One suggestion was made to classify all debris in one of four size categories ranging from "mega" (>2-3 dm) to "micro" (powdered or unseen in general).

The working group attempted to list certain debris types for purposes of recordkeeping, such as: nets (by type); other fishing gear; strapping bands (open/closed) (cut/not cut); granulated plastic (recycled plastic); particulate plastic; fragmented plastic; plastic bags; plastic containers (country of origin, age); Styrofoam; medical wastes; rope; entanglement remains (e.g., bones). The group recommended that other lists be reviewed to develop a common list that can be tailored to individual areas.

The working group agreed that the technique currently appropriate for assessment studies on a large scale was the beach survey. On a limited scale, dedicated surveys using visual observations and neuston tows in the nearshore areas (e.g. , bays, harbors) or limited ocean areas (e.g., off-shore dumping areas) could also be used for assessment. Techniques using aircraft are experimental and could probably be used for baseline studies. Bottom debris studies are currently in the baseline category. Development of techniques to study bottom debris is needed.

Most members of the working group agreed that a procedures manual should be compiled for use as a starting point for people interested in initiating marine debris studies.

Working Group 2: Entanglement of Marine Life (chaired by W. R. P. Bourne)

The working group found that there is accumulating anecdotal evidence that virtually all marine animals are occasionally entangled in debris, but that quantitative data are available for only a few species. Care is needed in the interpretation of available information because it is difficult to distinguish between the effects of marine debris and other factors such as oceanic fluctuations, disturbance of animals while breeding, the impact of fishing on both animals and their food supply, disease, and other forms of pollution.

The group found that entanglement of cetaceans appears to be infrequent, but even small numbers may represent a serious impact on the reduced population of North Atlantic right whales. Phocid seals are occasionally entangled in netting but the incidence is not high. One phocid seal for which the entanglement problem appears to be most significant is the endangered Hawaiian monk seal. Otariid seals appear to be among the marine species most prone to entanglement, young animals being particularly vulnerable. As regards marine turtles and seabirds, the group concluded that entanglement does occur but that there is little if any evidence of any impact on numbers when compared to other factors such as loss of habitat or incidental take in certain fisheries.

The working group concluded that, in view of the number of problems that require investigation and the wide area to be covered, there is need to establish an international organization to coordinate and standardize systematic collection and dissemination of information about the occurrence and impact of marine debris and possible conservation measures to mitigate its impact.

The group further recommended, among other things, that efforts be continued to monitor, remove, and destroy lost or discarded nets and other debris presenting a hazard to monk seals, marine turtles, and other wildlife in the Northwestern Hawaiian Islands; and that monitoring be continued on the numbers, survival, breeding success, and incidence of entanglement of northern fur seals. It also recommended the investigation of the impact of entanglement and other possible hazards on right whales in the northwest Atlantic and Kemp's ridley turtles in the Caribbean, and a review of the long-term evidence for the incidence of entanglement provided by bird-banding and beach surveys. Continued analysis of population level effects of entanglement through simulation modeling are to be encouraged.

Working Group 3: Ghost Fishing (chaired by Paul Breen)

The group concluded that ghost fishing is a potentially serious problem because of the very large volume of fishing gear now in use and the increasing use of nondegradable materials such as plastic, vinyl-coated wire, and fiberglass. Traps and gillnets were seen as the. primary cause of ghost fishing problems, with trawl and longline gear types presenting a lesser problem. The group concluded that mitigation of ghost fishing by traps is technologically simple, but that ghost fishing by nets may be more difficult to solve. It recommended that both time-failure devices and degradable meshes be developed and tested.

The group agreed upon a series of recommendations classified by priority. High priority was placed on the following four proposals:

1. Fishery agencies responsible for trap and tanglenet fisheries should conduct lost gear simulations to determine whether ghost fishing occurs and, if so, the rate at which target and nontarget species are killed. If ghost fishing is found to be a problem, the rates of gear loss should be estimated through logbook programs or questionnaires. Useful information might be obtained from surveys of manufacturers.

2. Where ghost fishing has been demonstrated or is suspected in a trap fishery, the fishery agency should decide what timed-failure mechanisms would be most appropriate to reduce the lifespan of traps and how soon timed failure should occur. Research under actual fishing conditions should then be conducted to determine the most appropriate regulation for timed failure.

3. Further studies with simulated lost pelagic gillnets should be conducted using nets larger than those studied to date and approximating commercial nets. These studies should examine whether ghost fishing takes place; if so, at what rate; and the rate at which the nets form a mass or otherwise cease to fish.

4. Direct observations should be made of lost pelagic gillnets to determine their shape and to determine the apparent rates at which ghost fishing for fish, birds, sea turtles, and marine mammals is taking place.

Working Group 4: Debris Ingestion by Marine Life (chaired by Louis Sileo)

The working group noted that studies to determine the prevalence of ingested plastics require monitoring. It recommended that future studies have statistically adequate sampling schemes designed to test hypotheses that the prevalence is increasing or decreasing in given areas, taxa, etc. The group found that, regardless of the species, the same three general pathophysiological effects were proposed: (1) mechanical blockages; (2) pseudosatiety or other impairment of a chick's ability to accept a full meal ; and (3) absorption of toxins from the plastic.

The working group placed priority on research on turtles, i.e., experimental feeding studies to determine how to interpret the lethality or other significance of ingested plastic and the range of pathophysiology in ingested plastic in turtles, along with continued monitoring of the prevalence of ingested plastic and its association with lesions. The group also recommended controlled experiments be carried out on birds to (1) determine if pseudosatiety does occur; (2) elucidate the duration of retention and erosion rates of ingested plastics; and (3) determine the toxicity of ingested plastics, The results of such studies will determine the need for long-term population studies.

Working Group 5: Economic Impacts of Marine Debris
(chaired by Kenneth McConnell)

The working group viewed the marine debris problem as an example of a situation where markets have failed to allocate resources efficiently, leading to the creation of nonmarket, or external, costs. The presence of an external cost indicates a problem that requires some form of public policy to solve. However, policies to reduce marine debris require people to change their behavior. Incentive schemes may be especially cost-effective in controlling debris when education and moral suasion fail. The working group proposed a list of projects to investigate the use of fees and incentives as part of the solution. These include: deposits on the return of nondegradable products, fees on the use of nondegradable materials , and incentives at the production level.

As regards compliance, the working group proposed investigating alternatives to the traditional approach of seeking compliance through persuasion. Policies combining punishment and reward and which partly subsidize the adoption of techniques are used elsewhere. For example, sewage treatment has been enhanced by Federal subsidies to construct waste treatment plants linked with the requirement that all households hook up. Methods of linking compliance to rules and regulations for handling marine debris can be linked to access to other beneficial programs.

Public campaigns to reduce pollution by moral suasion have been attempted for other forms of pollution. A study of such prior public campaigns would help understand their failures, which have been many, and their successes, which have been few.

As regards on-shore disposal, the working group proposed an investigation of the economic gains that can accrue to a particular region as a consequence of consolidating waste handling facilities.

On the matter of aesthetics, the working group noted that debris makes beaches less attractive and traps fish and wildlife. Each of these entails an aesthetic loss to some individuals. Currently, little' or nothing is known about the economic cost of either. The working group recommended two types of studies to help understand the magnitude of the economic costs of marine debris. These are a study of the economic costs of debris on a specific set of beaches and a study of the economic costs incurred when some individuals of a noncommercial species (e.g. , birds, mammals) are entangled in marine debris.

When vessels and their gear are impaired by contact with marine debris, there are two kinds of costs: the cost to repair or replace damaged gear and the opportunity cost of the vessel and gear when it is not in service. The working group suggested research to investigate the incidence of impairment and the magnitude of costs for one of the following industry groups: commercial fishing, shipping, or recreational boating.

The biggest impact of marine debris on fish stocks is the ghost fishing phenomenon, but there is also the possibility that consumers' perception of contamination of fish stocks by marine debris can influence the demand and price of selected fish products. Ghost fishing has an economic cost in terms of the lost resource. The working group suggested a joint project involving economists and biologists to study the impact of perceived contamination on the price of and demand for fish,

Working Group 6: Technological Solutions (chaired by William Gordon)

The working group recognized that further work is required to quantify the types and volumes of ship-generated debris, but felt strongly that technology/methodology currently exists to address management of the majority of the wastes generated at sea. Because a large measure of the ship-generated debris ultimately will be transported ashore, satisfactory resolution of much of the marine debris issue will require rational resolution to many of the terrestrial waste management issues and problems.

The group concluded that more information should be obtained about types, quantities, and distribution of the plastic materials that will be brought ashore under MARPOL regulations for disposal ashore, Such information should be disseminated throughout the plastics industry to encourage reuse of such material.

The working group recommended that development of new technologies be encouraged. For example, in the area of low technology burning, research is needed on the environmental impacts of air emissions, development of guidelines concerning materials separation and operations, and environmental implications of ash and methods of its disposal. Regarding incineration, research is needed on environmental impacts of air emissions and the environmental implications of ash and methods of disposal.

In the area of ship design, new designs should accommodate waste management strategies and new construction should include facilities and space accommodations for waste management.

Regarding policy, no single methodology or technology will ensure compliance with waste management regulations. The working group felt that, accordingly, no policy should be established which will prohibit technologies which have potential.

Working Group 7: Marine Debris Law and Policy
(chaired by David Nottingham)

The working group reviewed existing legal and institutional arrangements to curtail the disposal and loss of solid wastes into the marine environment. The group concluded that solutions to the problem of marine debris should be developed and implemented in concert with efforts to address broader solid waste management issues. The most pressing needs identified include: (1) expanding participation to relevant international agreements; (2) assuring that adequate port reception facilities are available at all ports and harbors to receive ship-generated garbage returned to shore; and (3) adopting national policies and programs, such as recycling and innovative packaging, to reduce quantities of generated solid waste.

The group identified two international agreements as being of greatest importance to the problem of marine debris: MARPOL Annex V and the London Dumping Convention (formally known as the International Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter). In addition, at least 10 regional conventions control various forms of pollution, including the disposal of plastics and other solid wastes into the marine environment. The working group concluded that these international conventions establish the prohibition of disposing of plastics and other solid materials into the sea as "customary international law."

The group recognized that control of land-based sources of marine debris is a difficult problem that must be addressed domestically by individual nations. For example, it recommended that governments encourage recycling programs to reduce the volume of material that becomes solid waste.

Regarding compliance and enforcement, the working group recommended that the International Maritime Organization and pertinent governments party to MARPOL Annex V develop incentives to encourage vessels owners and operators to comply with garbage disposal regulations, and that vessel owners and operators be encouraged to report ports and harbors that do not have required port reception facilities.

Working Group 8: Marine Debris Education (chaired by Kathy O'Hara)

Education has been identified as an important way to help reduce the marine debris problem and is particularly important because land-based sources of debris are primarily nonpoint. Ethics and behavior patterns of individuals both on land and at sea must be changed, and education is a known means for effecting such changes.

The working group was charged with assembling a comprehensive list of the types of educational materials currently in use. The group identified more than 100 different types of educational materials, including 21 brochures, 19 reports, fact sheets and special documents, 11 posters, 10 videos, 9 curriculums and guides for educators, 6 newsletters, and more than 30 other types of educational materials.

Marine debris education encompasses two key elements: the implementation of educational programs and the development of educational materials. With regard to the former, the working group recommended that marine debris education should be incorporated into three primary types of programs: (1) formal education in a structured academic setting; (2) informal education outside a formal academic setting but within structured educational events such as adult education classes and organized youth groups; and (3) general public awareness. Among the groups identified as target audiences for marine debris education, the working group concluded that five major groups are priority audiences: (1) general public, (2) media, (3) teachers and educators, (4) school children, and (5) all marine user groups.

A public awareness campaign is of utmost importance at present. Specific elements that should be addressed in developing this campaign include an initial assessment of human behavior and public perception of the marine debris problem. The working group felt that a comprehensive strategy to effectively use the media to disseminate information was paramount to the success of this campaign.

After reviewing the list of marine debris educational materials, the working group concluded that there is a wealth of materials currently available but there is a need to facilitate the dissemination of these materials to appropriate groups. In 1988, the National Oceanic and Atmospheric Administration's Marine Entanglement Research Program established two Marine Debris Information Offices, which respond to requests for information on marine debris. The working group suggested that the dissemination of educational materials would be facilitated if these offices were given increased visibility as a resource center along with sufficient quantities of educational materials to meet the demand.

Existing government distribution mechanisms should also be used to increase dissemination of materials, such as licensing and registration procedures for fishing and boating, the working group concluded. The group recognized the difficulty of disseminating educational materials on an international level due to the diversity of cultures and languages. However, it was suggested that specific international agencies, such as the United Nations Environment Programme, the Food and Agriculture Organization, and the International Maritime Organization, should be encouraged to facilitate information exchange.

Efforts should be made to include the marine debris issue on the agendas of international conferences and meetings that address the issues of marine pollution and education.

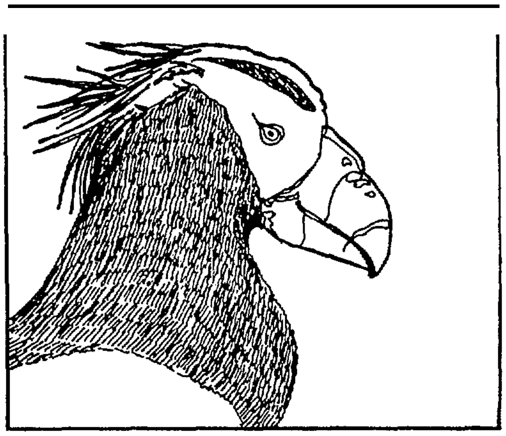
Appropriate means for evaluating the success of educational programs were discussed. The working group concluded that evaluation techniques could be conducted through long-term citizen monitoring of beach debris and monitoring the usage of shoreside refuse reception facilities. Formal surveys should be conducted, where possible, to assess changes in attitude and behavior.

It was agreed by all working group participants that the marine debris issue is part of the larger solid waste problem and therefore we should incorporate lessons learned from dealing with solid waste into marine debris educational materials and programs.

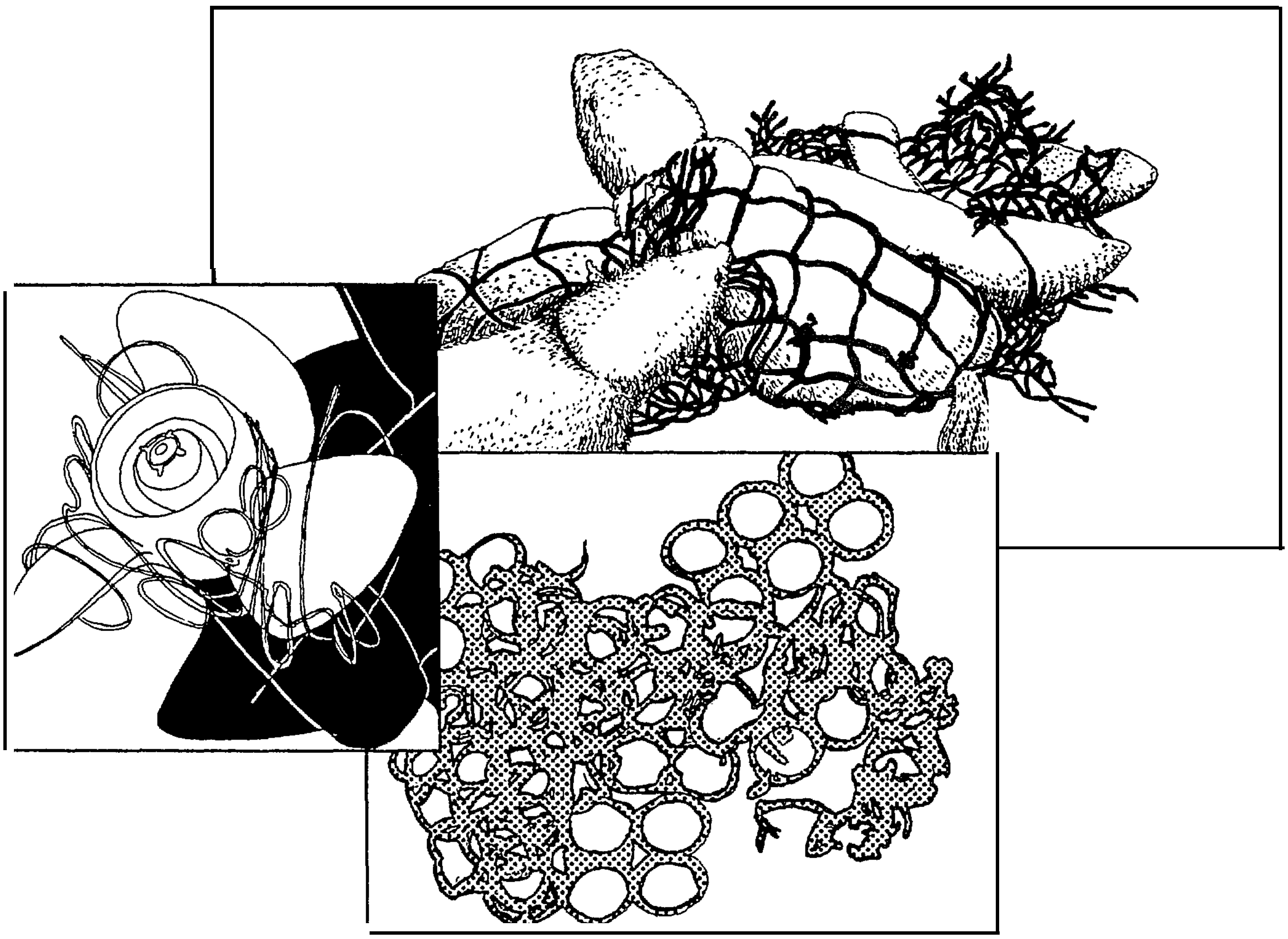
V. RECOMMENDATIONS

Conference participants set forth a number of priority recommendations. Examples of some of the primary recommendations are:

- broad international acceptance and implementation of the terms of MARPOL (73/78) Annex V, especially the provision of port reception facilities;
- recognition of the marine debris problem as a symptom of the worldwide solid waste disposal crisis;
- pursuance of technological and procedural solutions to the marine debris and solid waste problems while avoiding policies and regulations that may restrict solutions;
- expansion of marine debris and solid waste disposal education to people and institutions worldwide, recognizing regional and cultural differences in the perception of these problems;
- development of a set of standard methods for surveys of the amounts, types, and sources of marine debris;
- establishment of an international committee or organization to further collaborative research on the impacts of entanglement on living marine resources;
- design and implementation of baseline experiments to establish the lethal and sublethal impacts of persistent debris ingestion by sea turtles and seabirds;
- design and implementation of experiments to evaluate ghost fishing in gillnet and trap fisheries with high gear loss rates, developing mitigative measures as needed; and
- evaluation of the economic impacts of marine debris, both direct, as in vessel disablement and commercial fish loss, and indirect, as in aesthetic damage and solution costs.



OVERVIEW PAPERS



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

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ABSTRACT

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

INTRODUCTION

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

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

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

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

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

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

These findings prompted the workshop participants to make general recommendations for information collection to elucidate the sources, distribution, amounts, fates, and impacts of persistent marine debris. Studies of the biological impacts of entanglement and ingestion on North Pacific marine mammals, seabirds, and sea turtles were specifically identified. The development of sampling methodology for beach and sea surface debris--especially fishing gear--was recommended. In concluding that marine debris is a real problem for marine life and vessels, however poorly quantified, the workshop recommended education and mitigation efforts to be undertaken concurrently with the information collection activities. The mitigation efforts were to include regulation of the types of debris most hazardous to marine life, investigations of the use of biodegradable materials, net recycling, and the promotion of beach surveys and cleanups. Education efforts were recommended to advise user and interest groups of the nature and scope of the marine debris problem. The target groups were to include fishing and plastics industries, merchant carriers, the military, appropriate international organizations, and the public.

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

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

RESEARCH AND MONITORING ACTIVITIES

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

Biological Research

Northern Fur Seal Entanglement

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

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

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

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

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

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

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

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

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

Northern Sea Lions

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

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

The November survey was conducted to census fur seal and sea lion pups hauled out or stranded in the Aleutian Islands after weaning. This survey covered nine known haul-out locations and possible stranding sites but found no entangled fur seal or sea lion pups.

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

Hawaiian Monk Seals

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

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

Seablrds

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

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

The other two studies of seabird ingestion of plastics involved the Laysan albatross population at. Midway. Sampling of Laysan albatross chicks to determine diet, growth, and general health was initiated in 1987 to measure the relationship between plastic ingestion and growth, and plastic ingestion and mortality. This study continued in 1989, as the variability in the amounts of plastic fed by parent albatrosses to their chicks has been higher than expected. Chicks in 1987 had on average nine times more plastic in their diet than did 1988 chicks. Preliminary indications are that plastic ingestion may not contribute in any obvious way to chick mortality; its impacts on growth, however, may be detectable (Sileo, Sievert, and Samuel 1990; Sileo, Sievert, Samuel, and Fefer 1990).

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

Cetaceans

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

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

Sea Turtles

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

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

Debris Sources and Amounts

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

Methods

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

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

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

Debris Surveys

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

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

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

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

To date, there have been no coordinated ship/beach debris surveys to evaluate the relationship between amounts and types of floating and stranded debris in any region of the North Pacific. Johnson and Merrell (1988) report on time series of beach debris surveys from selected beaches in Alaska, where they cleaned sections of beach and also tagged large debris items . From this work they have been able to estimate the rate of deposition of entangling materials on certain Alaska beaches, At Yakutat, the deposition rate of trawl nets was estimated at seven nets/km/year. As a result of his debris tagging work, Johnson discovered that large net debris may be buried, uncovered, and moved along the beach by severe winter storms. Investigations into the dynamics of beached debris are continuing in Alaska and are further reported in Johnson (1990).

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

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

In an attempt to elucidate the sources of net fragments in the North Pacific and the Bering Sea, a study of NMFS Foreign Fishery Observer Program data was conducted (Berger and Armistead 1987). The records from 1,068 observer cruises in 1982-84 in the U.S. exclusive economic zone (EEZ) provided data from every month of the year. The amounts of net discarded, lost, retrieved, or seen floating were recorded, as were net-mending activities and fishing operations. In 1982, 1983, and 1984, respectively, 14, 31, and 17% of the net pieces discarded were in the mesh size range to entangle fur seals. During this period, a total of 1,551 pieces of net were brought up in trawls and most were discarded back into the ocean. In 1983, foreign joint venture operations lost 70 trawl nets or large portions of nets. In 1984, this number increased to 90 nets. Foreign fishing in the U.S. EEZ has been almost completely displaced since 1984, but it is not known if the loss and discard rate of nets and net fragments has changed. Under the U.S. domestic law implementing MARPOL Annex V, it is illegal to discard net fragments, and one would therefore expect the amount of net input into the U.S. EEZ in the North Pacific to decrease in the coming years.

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

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

MITIGATION

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

Legal and Administrative Actions

On 30 December 1988, the terms of optional Annex V of the International Convention for the Prevention of Pollution from Ships as modified by the Protocol of 1978 (MARPOL 73/78) entitled "Regulation for the Prevention of Pollution by Garbage from Ships" entered into force for 35 nations representing slightly over 50% of the world's registered shipping tonnage. The MARPOL Annex V prohibits the discharge of plastic from ships into the ocean and sets distance-from-shore limitations for the discharge of other types of ship's garbage. Table 1 summarizes the discharge requirements of Annex V. Ships are defined under MARPOL 73/78 as all surface and subsurface craft as well as all fixed and floating platforms regardless of size. Annex V also identifies five special areas in which all discharge of garbage is prohibited. There are no special areas in the Pacific Ocean.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Mitigation Technology and Procedures

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

Shipboard Waste Handling

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

In 1986, NMFS contracted for a review of shipboard waste handling options. The report (Parker et al. 1987) produced a table showing the applicability of various waste disposal methods for various types of ships. Limited data on waste generation rates, ship configurations, and procedure capacities required some assumptions to be used in developing the table. The most general findings in this study were that:

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

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

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

Degradable Plastics

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

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

Fishing Gear Marking

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

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

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

It remains to be seen whether future improvements in fishing technology and procedures will actually reduce gear losses and increase recovery rates or merely enable greater risks to be taken. This issue will be given increased attention in the United States in coming years.

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

Recycling

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

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

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

MARINE DEBRIS EDUCATION

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

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

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

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

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

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

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

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

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

In an attempt to ensure the widest possible understanding of the requirements of MARPOL Annex V and to build the basis for compliance, NMFS has contracted for the development and implementation of a shipping and cruise lines industry education program (Wallace 1990). This activity is directed at all vessels and vessel operators plying U.S. waters, regardless of nationality. Products from this work will include model shipboard waste management plans, summaries of the U.S. regulations implementing MARPOL Annex V, and packets of information on the impacts of marine debris. Delivery of these materials will be through corporate offices, union offices, and associations of shipowners and officers.

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

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

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

CONCLUSIONS

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

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

Research

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

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

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

Mitigation

Marine debris mitigation is proceeding apace. Laws are being passed, attitudes are changing, and industries are getting the message. The relationship between marine debris and the overall solid waste crisis is the real key here. The marine problem will not be completely solved until the land-based disposal problem is solved. Broad public concern for the ocean and coastal environment has allowed a start to be made; there can be no turning back. The timetable for control depends on the rate of development and implementation of rational solid waste disposal practice. For the near future, two areas of emphasis are evident. First, the remaining North Pacific Rim nations must accede to MARPOL and ratify Annex V. Second, the focus for the next several years must be on technology, policy, processes, regulation, enforcement, and education to fully implement MARPOL Annex V. On land, appropriate combinations of source reduction, recycling, incineration, substitution, and use of landfills must be sought. Within 2 to 5 years, control of persistent waste discharge into the ocean could be fully institutionalized around the North Pacific Rim. This endeavor assumes increased international cooperation in the provision of port reception facilities, in enforcement, and in promoting responsible waste management by all maritime nations.

Education

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

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

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

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

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OVERVIEW: MARINE DEBRIS IN THE NORTHWEST ATLANTIC OCEAN

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ABSTRACT

This review emphasizes recent developments (since the author's 1988 report) in regard to marine debris sources, types, amounts, and distribution, effects, and mitigation, on the Atlantic coasts of Canada and the United States.

INTRODUCTION

A substantial body of information about sources, types, amounts, and effects of marine debris exists for the northwest Atlantic Ocean, most of which is summarized in a report (Heneman 1988) distributed to participants at this conference. This presentation includes general observations based on that report but emphasizes new developments.

For our purposes, the northwest Atlantic reaches from the Atlantic coast east to midocean and south to, and including, the North Equatorial and Antilles Currents. Its western watershed, which includes the St. Lawrence and many lesser rivers, drains the most densely populated and industrialized areas of the United States and Canada.

SOURCES, TYPES, AMOUNTS, AND DISTRIBUTION

In contrast to areas of the world where a few sources account for most marine debris, the northwest Atlantic is plagued by a great variety of major debris sources. Merchant shipping, commercial fishing vessels, cruise ships, recreational boats, and naval vessels may be the largest sources, although MARPOL Annex V should cause these to diminish in importance. At the same time, inadequate storm drain and sewage treatment systems in the United States and Canada are known to dump large amounts of floatable into the marine environment, especially in periods of high rainfall; coastal landfills commonly "leak" debris into nearby waters; the plastics industry in the northeastern United States appears to have been a major source of plastic resin pellets; and beachgoers are an important source of litter. As we have seen with medical wastes for the past two summers, relatively small amounts of illegally dumped materials can have major effects. Virtually every kind of debris source that has been

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identified anywhere in the world is a contributor somewhere in the northwest Atlantic. This variety of major sources obviously complicates efforts to reduce amounts of marine debris and to mitigate its effects.

It is more difficult to generalize about where debris occurs in the northwest Atlantic than in a trade wind area such as the Caribbean. The North Atlantic gyre concentrates floating debris in the Sargasso Sea and on the beaches of Bermuda. Along the gyre's southern periphery, trade winds deposit large amounts of debris from the Antilles Current onto Atlantic-facing beaches in the Bahamas. Farther north, local sources and local wind and current conditions are more important factors influencing the distribution of debris on the United States and Canadian coasts.

There is little information on trends in amounts of marine debris. Wilber (pers. commun.) points out that his data and Carpenter and Smith's (1972) data for the northern Sargasso Sea indicate a 1,000% increase in the density of plastic pieces and a 200-400% increase in plastic pellets in a period of about 15 years.

There is little recent information to report from Canada on sources, amounts, and distribution of debris. Canada's Ocean Policy of 1987 includes commitments to deal with plastic debris and lost and abandoned fishing gear, but little has been done to implement the policy. Growing public concern may be leading to a change, however. Last summer, for example, the Nova Scotia Department of the Environment conducted one of Canada's first beach cleanups. An opinion survey at the same time found increasing indignation about litter on beaches.

EFFECTS

The best-known and most serious effects of marine debris along the northwest Atlantic coast are aesthetic and economic; the summer of 1988 provided another well-documented example of that when tourist-dependent coastal economies lost tens of millions of dollars to beach closures in the New York area. This is not a new problem, however; the first major incident of this sort was in the summer of 1976, when sewage and debris closed Long Island beaches and the Governor of New York declared a disaster.

Other effects, such as damage to vessels and harm to wildlife, are either minor or are poorly documented. At the Workshop on the Fate and Impact of Marine Debris (FIMD) in 1984, participants agreed that the effects of debris on sea turtles and of derelict nets and traps on fish and shellfish deserved greater attention (Shomura and Yoshida 1985). That is especially true for the northwest Atlantic, where these subjects may represent the most important information gaps.

ACTION AND MITIGATION

Two new programs in the United States are collecting information on types, sources, and amounts of debris. The Marine Entanglement Research Program and the U.S. National Park Service are sponsoring regular data collection at eight national seashores, including four on the Atlantic coast: Cape Cod, Assateague Island, Cape Hatteras, and Cape Canaveral.

The U.S. Environmental Protection Agency (EPA) has funded at least 1 year of a National Marine Debris Data Base, in which the Center for Marine Conservation is computerizing data from all the 1988 statewide volunteer beach cleanups. Over time, these two programs may provide a means of monitoring the success of Annex V and other mitigation measures.

On the Atlantic coast of the United States, mitigation efforts such as education and public awareness campaigns have focused on implementation of Annex V. The Marine Entanglement Research Program has funded several projects through the Center for Marine Conservation, including:

- a Marine Debris Information Office located in Washington, D.C. to respond to information requests from the Atlantic and Gulf coasts. It provides educational materials to marine user groups, industry, educators, policy makers, and the general public;
- separate public service advertisement campaigns aimed at the commercial fishing, shipping, and plastics industries, and recreational boaters and fishermen;
- a review of marine debris information for the general public, "A Citizen's Guide to Plastics in the Ocean."

The Society of the Plastics Industry helped fund the Citizen's Guide, public service announcements for television, and other marine debris educational materials produced by the Center for Marine Conservation.

Another Center for Marine Conservation project, this one in Florida and funded by the National Marine Fisheries Service Saltonstall-Kennedy program, endeavors to show that education is a cost-effective method of persuading commercial and recreational fishermen to comply with Annex V.

There have been continuing and expanding efforts to remove debris from the marine environment. For instance, most coastal states have had annual beach cleanups in recent years. The Army Corps of Engineers, the EPA, the U.S. Coast Guard, and New York and New Jersey state agencies recently announced that they have begun a cooperative program in the New York area. They will try to locate concentrations of floating debris by helicopter and use Army Corps vessels to collect it.

Canada's Department of Fisheries and Oceans convened a workshop in Halifax, Nova Scotia, 17-18 May 1989. The workshop provided an opportunity for organizations and individuals from the private sector to advise the government on the development of an action plan on marine debris (Buxton 1989; DPA 1989).

As for mitigation efforts, Canada has placed itself in an unusual position. Although Canada is a signatory to the London Dumping Convention, it is not a signatory to MARPOL, much less to Annex V. For some years, the Canada Shipping Act has prohibited the disposal of any garbage or trash from vessels within 200 nmi of Canada's Atlantic and Pacific coasts, a provision that is stricter than Annex V. Unlike Annex V, however, the act does not restrict ocean disposal by Canadian vessels beyond 200 nmi, and it does not require ports to provide reception facilities.

Recent amendments to the Canada Shipping Act take a half step forward by permitting Canadian agencies to impose stricter regulations that would bring Canada into conformity with Annex V. But the agencies have not yet decided to actually adopt any new restrictions. Furthermore, there seems to be little enforcement of existing regulations and no educational programs to encourage compliance.

CONCLUSION

Although the Atlantic coast of the United States has the same marine debris problems, more or less, as other coastal areas of the country and the world, its problems receive more attention than is warranted simply by its geography. United States policy makers are concentrated in Washington, D.C. National, and to some extent international, opinion shapers are concentrated in New York City. As a result, events in that part of the world become more important.

To mention two examples: The cover story in Time magazine for 1 August 1988 is titled "Our Filthy Seas." That same week, Newsweek's cover story was "Don't Go Near the Water--Our Polluted Oceans." An issue has truly arrived on the national agenda when it makes the covers of these two magazines the same week, when it is a regular fixture on network news, and when it is an issue in a presidential campaign, as it was in 1988. The fact is, the response to marine debris problems on the Atlantic coast will continue to have a disproportionate influence on how the rest of the United States responds to its marine debris problems.

It has become abundantly clear since the 1984 FIMD workshop that the ultimate solutions to marine debris problems on the U.S. Atlantic coast are inextricably bound to solutions to the impending crisis in solid waste disposal on land. All of the elements that can contribute to reducing amounts and effects of marine debris--source reduction, recycling, degradability, changing societal attitudes towards waste--are vital in the larger arena of land disposal. That fact should inform much of our effort in regard to the marine debris subset of the problem.

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PLASTICS: ACCUMULATION, DISTRIBUTION, AND ENVIRONMENTAL EFFECTS OF MESO-, MACRO-, AND MEGALITTER IN SURFACE WATERS AND ON SHORES OF THE SOUTHWEST PACIFIC

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ABSTRACT

Plastic debris of all kinds and in all sizes is widespread in the southwest Pacific. Densities of virgin nibs exceed 1,000 km^{-2} in surface waters north of New Zealand and in nearshore waters adjacent to manufacturing centers. There is a latitudinal gadient of densities, with numbers falling to less than 20 km^{-2} south of New Zealand. On shorelines, greatest numbers (>>100,000 m^{-1} of beach length) are found near large cities, although a similar latitudinal gradient shows with very low numbers from around southern New Zealand (l-5 m^{-1}) and none from the subantarctic islands. In general, numbers of nibs on shores of eastern Australia are much less than they are on New Zealand shores. Significant numbers (.>1,000 m^{-1}) have been found as local concentrations on some trade wind-facing beaches of all Pacific islands so far examined.

Distribution of these nibs, together with that of other plastic and persistent synthetic litter, is influenced by surface current patterns and prevailing wind regimes, with greatest concentrations being noted on windward and downdrift shores, in windrows, and (tentatively) along oceanic fronts.

Larger, fabricated plastic items have been seen on the shores of all isolated and unpopulated islands so far visited around the region. Where identifiable, sources frequently lie in distant water fishing activities. On populated islands, many of which lack adequate facilities for domestic waste and garbage disposal, there is a buildup of locally sourced litter along shores. Not only is this litter aesthetically distasteful, some materials (e.g. , syringes) are hygienically unacceptable. The problem is an ever-growing one and needs addressing in appropriate forums. The environmental implications of this plastic pollution are many, with the most important involving entanglement and ingestion. The longer term significance of hazardous and persistent chemical residues, originally present in plastics as additives and released in minor amounts during degradation,

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is difficult to assess. Pelagic plastics also provide an important hard substrate for an encrusting biota that includes a hermatypic coral, bryozoans, coralline and filamentous algae, hydroids, barnacles, and some foraminifers, and are a largely unrecognized vector in their wider distribution.

From surface crazing and other evidence of aging such as chalkiness and embrittlement, it is inferred that degradation rates decrease progressively from lower to higher latitudes.

INTRODUCTION

It is generally accepted that surface waters of the South Pacific Ocean (Fig. 1) are relatively free from man-made pollutants, other than in the nearshore zone of more heavily populated islands (Mates 1981). Recent reviews have tended to emphasize localized incidents involving point-sources of sewage and industrial effluents (e.g. , Suva Harbor, Fiji: Brodie and Morrison 1984), and toxic chemicals and pesticides (Cook Islands: Hambuechen 1973; and Tonga: Brodie and Morrison 1984; Morrison and Brodie 1985), although wider political concern has been expressed over the prospect of seabed disposal and dumping or storage of nuclear waste in the expanses of the region (Branch 1984; Carew-Reid 1988). The area lies remote from tanker routes (Waldichuk 1977) and major shipping lanes, and pelagic tar balls so common to more frequently traversed waters are rarely encountered (Butler et al. , 1973, p. 24; Bourne 1976; Gregory 1977, unpubl. data; Oostdam 1984; Lee pers. commun.). The problems of marine oil pollution become more evident passing westward into southeast Asian waters (Bilal 1985). However, the island countries of the southwest Pacific have a long and commonly expressed concern over contingency planning for pollution from oil spills (Hayes 1981; Dahl and Baumgart 1983; Hayes and Kay 1986) .

Plastics and other persistent synthetic materials are today a significant contaminant of both open ocean and nearshore waters, particularly those adjacent to the industrial North. The sources and environmental problems they create are many and varied (Gregory 1978, 1983; Laist 1987; Pruter 1987). Plastic artifacts as well as casual litter and solid domestic wastes have long been an acknowledged, although seldom seriously addressed, problem on several Pacific islands (Anonymous 1976; Connor 1976; Efi 1976). On Tonga, for example, plastics and cigarette and candy wrappers have been identified as ". . . the second most common form of litter and the second largest waste item for disposal" (Chesher 1984, p. 38). In all instances known to this author, the importance of local sources has been noted, with little recognition that some material may have been adrift for a time before stranding. The observations of Sachet (1955) on the wide dispersal of exotic pumice on Pacific atolls, as well as those of Bligh (1792) on coconut husks, are evidence that, over the vastness of the Pacific, floating materials can drift far from their places of origin. Drift pumice, often with an encrusting biota, is common on beaches of eastern Australia (Table 1). Similarly, in the Southern Ocean there is evidence of floating debris such as logs, pumice, and man-made artifacts being rapidly dispersed in circumpolar fashion by the strong West Wind

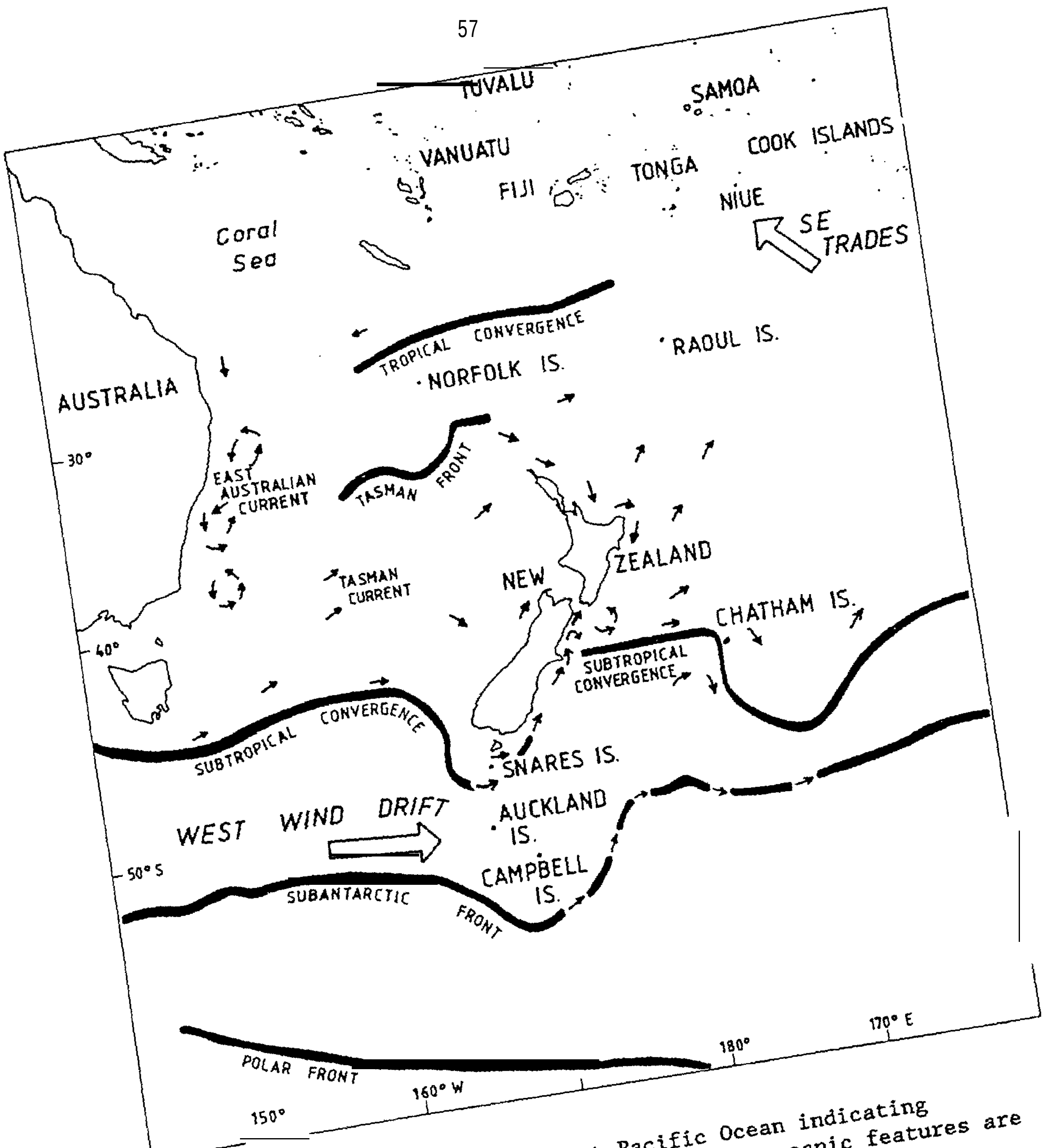


Figure 1.--Map of the southwest Pacific Ocean indicating principal places mentioned in text. Major oceanic features are also illustrated.

d general oceanic circulation (Barber et al. 1959; Drift Current ... Gregory et al. 1984; Smith 1985; Gregory 1987, p. 1990; ... et al 1988). Lutjeharms .

Waters around New Z... although ... islands are by any criteria relatively unpolluted, ... semienclosed estuaries and harbors in the vicinity of larger urban centers give increasing ... for concern (Ridgway and Glasby 1984). Plastics and other persistent synthetic compounds,

Table 1.--Numbers of virgin plastic granules and drift pumice on selected beaches of eastern Australia (arranged from north to south). The quantities of granules are local maximums expressed in number per linear meter of shore, following the approach of Gregory (1978); p = present in low numbers ($<1\ m^{-1}$). Drift pumice: * = abundant, + = present.

Location	Plastic granules	Drift pumice
Tasmania		
Hobart to Bicheno	nil	nil
Victoria		
Portsea, Sorrento, Rosebud	P	nil
Mordialbo	>1,000	nil
St. Kilda	>500	nil
Altona	100	nil
New South Wales		
Narooma	nil	+
Batemans Bay	nil	*
Kioloa	nil	*
Jervois Bay	P	nil
Shoalhaven	>5	*
Stanwell Park	>50	*
Botany Bay	>>2,000	+
Bondi	>10	+
Manly	P	nil
Narrabeen	>20	nil
Port Macquarrie	P	*
Coffs Harbor	nil	*
Queensland		
Gold Coast	P	*
Brisbane (Red Cliffs)	nil	+
Bargara (Bundaberg)	5	*
Keppel Sands (Rockhampton)	5	*
Sarina	nil	*
Mackay	P	*
Townsville	nil	*

particularly those arising from packaging, are a significantly visible but minor part of the local waste stream (Ministry for the Environment 1987; Plastics Institute of New Zealand 1988). The environmental hazards and threats to local wildlife are varied and have been reviewed by a number of authors (Gregory 1977, 1978, 1987, 1990; Gregory et al. 1984; Cawthorn 1985, 1987; Mattlin and Cawthorn 1986; Dawson and Slooten 1987; Murray 1988).

Gregory (1977, 1978) initially recorded small virgin plastic resin granules and pellets in surprisingly high quantities on the New Zealand coast and mapped their distribution (Fig. 2). It was noted that greatest numbers occurred near metropolitan centers, suggesting that the distribution was caused by dispersal from local sources (Fig. 2), although some evidence indicated possible drift from eastern Australia waters (Gregory 1978). Changes in the composition of litter stranding on a remote northern New Zealand beach over an 8-year period have been recorded by Hayward (1984). Ever-increasing fishing activities add further to the seaborne litter load on even the most isolated shores (e.g., Auckland and Campbell Islands, Cawthorn 1985; Gregory 1987, 1990).

This paper reviews in detail the nature, characteristics, quantities, distribution and sources of pelagic plastics around the southwest Pacific region. It is based largely on the author's published studies from New Zealand and its offshore, subantarctic islands. However, the opportunity has been taken to include a corpus of previously unpublished data gathered from eastern Australia, several Pacific islands, and adjacent waters during opportunistic surveys over a number of years. The environmental consequences of this plastics pollution are evaluated and some conclusions reached on how they could be addressed.

PLASTIC MESOLITTER

In the category of plastic mesolitter I include the small, ovoidal-to-rounded and rod-shaped virgin plastic granules or nibs of polyethylene and polystyrene resins that are the raw materials or feedstock of plastic fabricators worldwide. The granules are mostly <5 mm across, are colorless to translucent or transparent, and have been described in detail previously (Gregory 1978, 1983). Intensely colored dye-carrying granules (yellow, blue, green, red, black, white) are never as common as the colorless ones. In addition, there are occasional sharply angular and jagged plastic chips of comparable size produced through granulation of larger items for recycling. These chips are variously colored but rarely transparent or translucent. Small, often flaky, fragments coming from the degradation and disintegration of larger plastic objects also fall into this category. The fragmenting and fracturing processes appear to be mostly embrittlement through oxidative aging and photodegradation rather than physical or mechanical weathering.

Gregory (1977, 1978) described the distribution of virgin plastic granules on New Zealand shores (Fig. 2). Large numbers, often >10,000 m^{-1} of beach length and in one instance >>100,000 m^{-1}, were recorded near some of the larger metropolitan and industrial areas where plastics fabricators are located (Fig. 2). Away from these regions numbers decreased, but they were persistently and surprisingly high at some remote localities (e.g. , to >150 m^{-1} near North Cape; and to 50 m^{-1} near East Cape). Only around the southernmost part of South Island were they consistently very rare or absent. For the mid-1970's it was estimated that at least 1,000 metric tons of these granules were stranded on the shores of New Zealand (Gregory 1978).

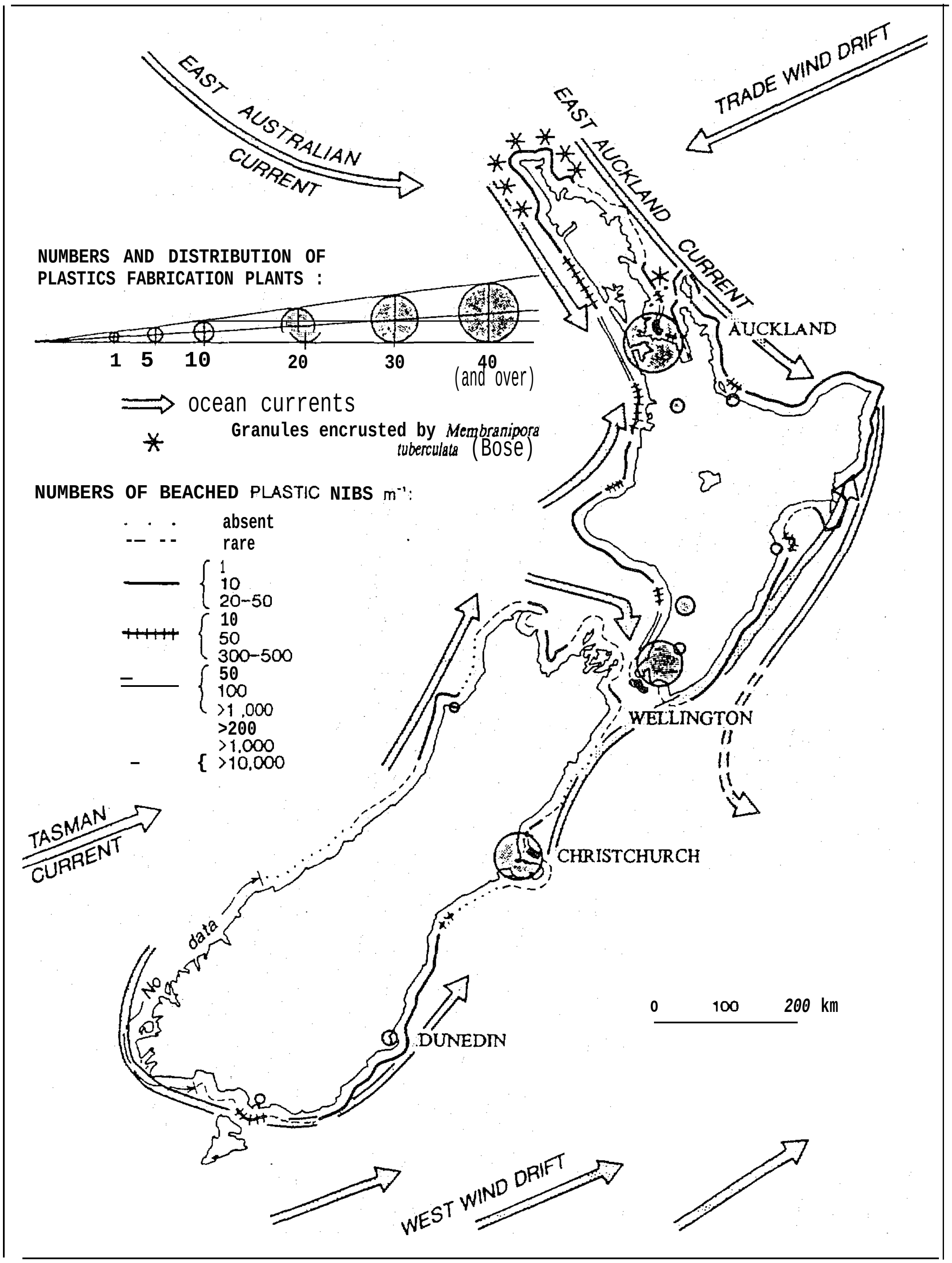


Figure 2. --Distribution of virgin plastic granules on New Zealand shores based on a 1972-78 survey. Three values given for each distribution line indicate abundance levels at which pellets were (i) reasonably consistent (lowest value, top of list), (ii) commonly encountered (middle value), and (iii) locally concentrated (greatest value). Data are from Gregory (1978). Local New Zealand sources of virgin plastic granules are after Bullen (1968); the surface currents and prevailing winds that spread them around and along the coast are after Brodie (1960).

Virgin plastic granules have been encountered on the shores of eastern Australia from Batemans Bay in New South Wales north to Townsville in Queensland (Table 1). They are also present around Melbourne and Adelaide. None have been noted on eastern Tasmanian shores northward from Hobart. Occurrences are sporadic, and numbers seldom reach those recorded from New Zealand. On remote beaches numbers are generally <1 m^{-1}, and in many instances a lengthy search is required to turn up any granules at all. It is only at a few isolated localities around Sydney (>2,000 m^{-1}) and Melbourne (>1,000 m^{-1}) that quantities ever approach those frequently recorded near Auckland.

No virgin plastic granules have been found so far on any of New Zealand's subantarctic islands (e.g., Campbell, Auckland, Snares, Antipodes, and Bounty) (Gregory 1987), although they are not uncommon on Chatham Island (to >100 m^{-1}, Gregory 1978). The granules, however, have been found on all subtropical and tropical southwest Pacific islands that were systematically searched by this author during visits over the past few years (Table 2, Figs. 3-8). In several instances the numbers are unexpectedly high for such remote, nonindustrialized places (e.g., Tonga, >>1,000 m^{-1}).

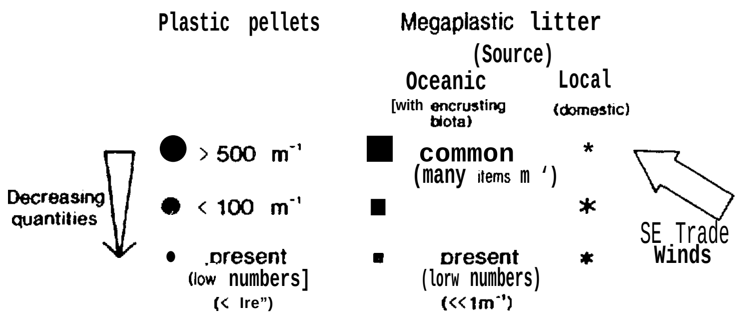
The angular granules produced for recycling are never common away from the industrial centers of Australia and New Zealand, and have not been encountered on the shores of those Pacific islands so far examined.

The numbers of plastic granules and larger plastic items afloat in surface waters of the New Zealand sector of the Southern Ocean have been determined from over 50 neuston tow stations (Gregory et al. 1984; Gregory 1987, 1990). The numerous reports of Southern Ocean feeding seabirds ingesting plastic granules and other artifacts (Bourne and Imber 1982; Furness 1983; Randall et al. 1983; Brown et al. 1986; Skira 1986; Gregory 1987, 1990; Harper and Fowler 1987; Ryan 1987a) indicate these materials have circumpolar dispersal. Brief and sporadic surveys of pelagic plastic have been undertaken from research vessels on passage between New Plymouth and Norfolk Island, Tauranga and Raoul Island, and the Hauraki Gulf to Wellington by way of East Cape as well as around Auckland Harbor and its approaches. At this time data are inadequate to draw unequivocal conclusions. The data strongly suggest, however, that densities in surface waters to the north of New Zealand probably (and often substantially) exceed 1,000 km-z (Fig. 9). Indeed, fresh granules stranding along the most recent swash line (by inference over one tidal cycle--February 1988) on Raoul Island at 5-10 m^{-1} suggest that densities approaching 10,000 km^{-2} may occur sporadically! Variation in numbers between stations is very large. There is apparently a strong latitudinal gradient in the areal density of floating granules (Fig. 9). In higher latitudes between the Subtropical Convergence and the Subantarctic Front, granules occur in numbers that may barely reach 20 km-z (Gregory et al. 1984; Gregory 1987, 1990). Densities farther south and in the region of seasonal pack ice are negligible. In some nearshore waters much higher densities are commonplace (e.g., >10,000 km-z in Hauraki Gulf; >20,000 km-z in Auckland Harbor; >40,000 km^{-2} in Cook Strait approaches to Wellington Harbor) (Gregory 1990, unpubl. data). For comparison, densities elsewhere have been 1,500-3,600 km^{-2} for the Cape Basin region of the South Atlantic lying west of southern Africa (Morris 1980), and 3,640 km-z from over 1,000 neuston trawl stations

Table 2.--Virgin plastic granule numbers on representative southwest Pacific island shores. Numbers given are local maximums expressed in number per linear meter of shore, following Gregory (1978); p = present in low numbers ($<1\ m^{-1}$). For locations see Figures 3-8.

Location	Number
Norfolk Island	
Emily Bay	ca. 100
Raoul Island	
North Beach	>50
Denham Bay	nil
Fiji, Viti Levu	
Lautoka	P
Singatoka	P
Korolevu	<5
Deuba	>>100
Suva	>5(?)
Fiji, Vanua Mbalavu	
East	24
West	P
Tonga, Tongatapu	
Anahulu Beach	100
Laulea Beach	>>1,000
Oholei Beach	< 5 0
Keleti Beach	nil
Fahina Beach	nil
Western Samoa, Upolu Island	
Apia	P
Vaiala Beach	nil
Malaeia Beach	20(?)
Cook Islands, Rarotonga	
Ngatangiia Harbor	>500
Raringaru Stream	>>10
Akapuao Stream	do(?)
Totokoitu Stream	P
Papua Stream	10
Rarotongan Hotel	1-<10

KEY: Figures **3-8**



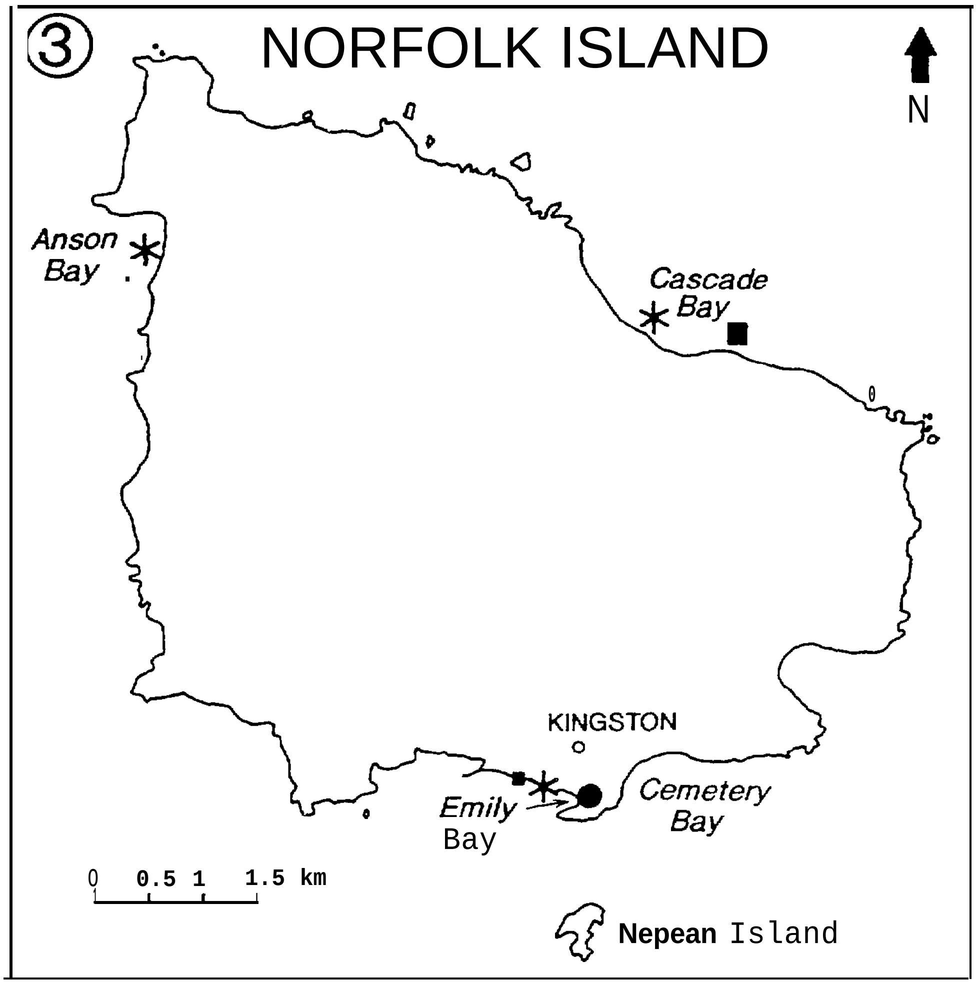


Figure 3. --Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Norfolk.

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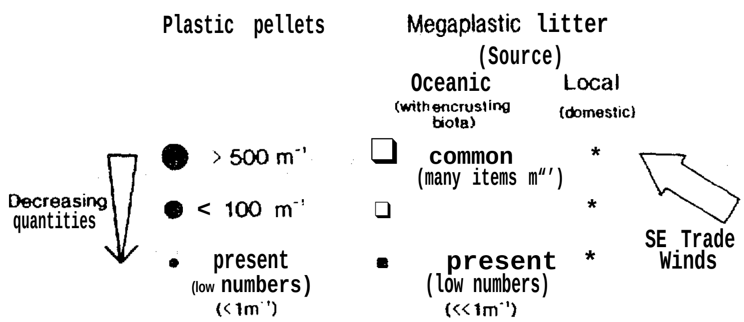

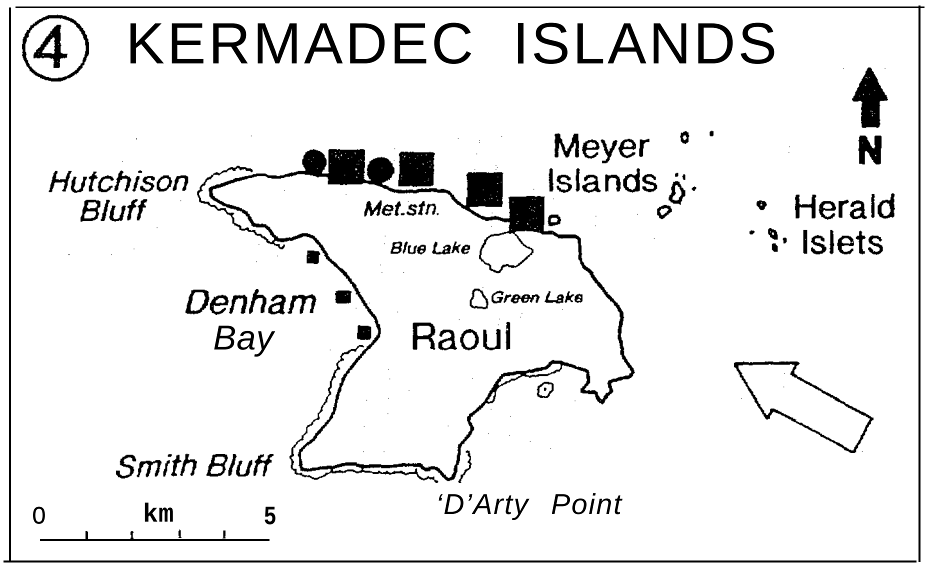

Figure 4. - -Virgin plastic granules , oceanic and locally generated megalitter on southwest Pacific island shores. Raoul.

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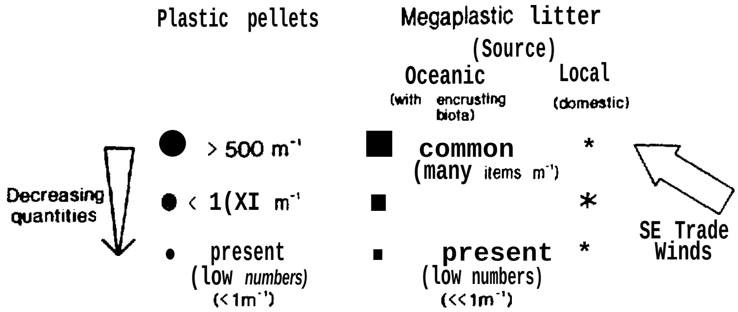

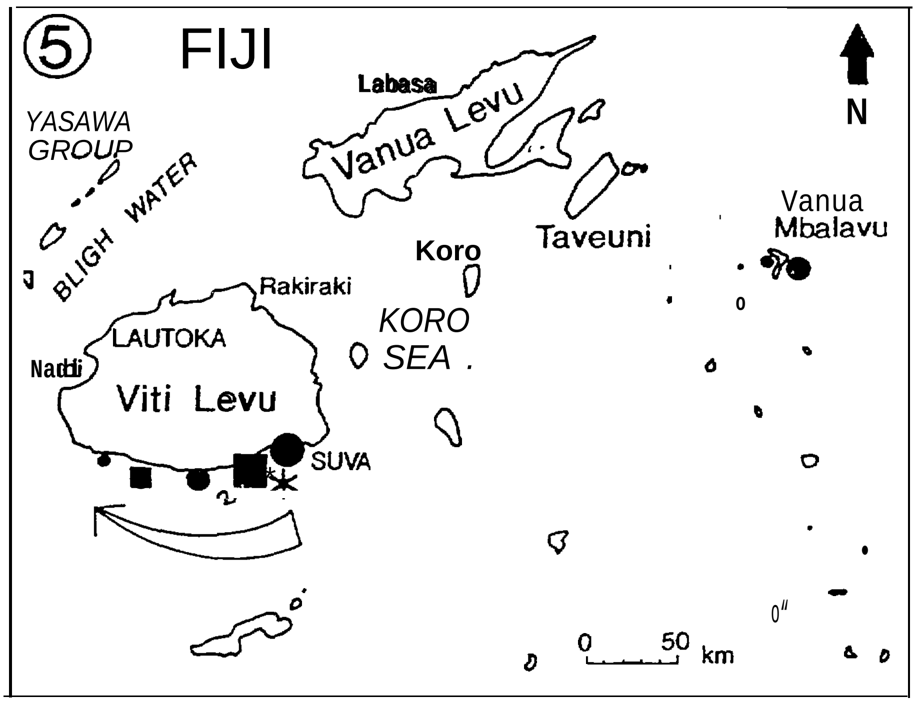

Figure 5. --Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Fiji.

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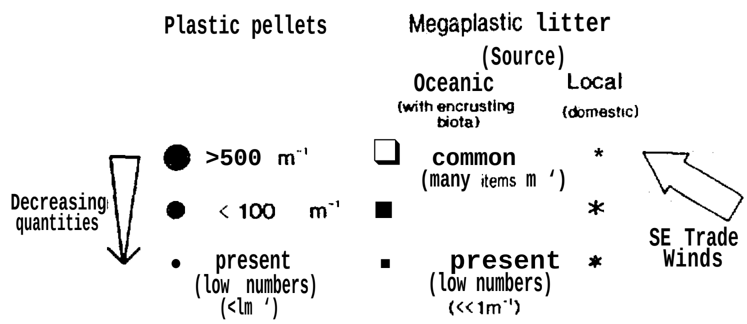


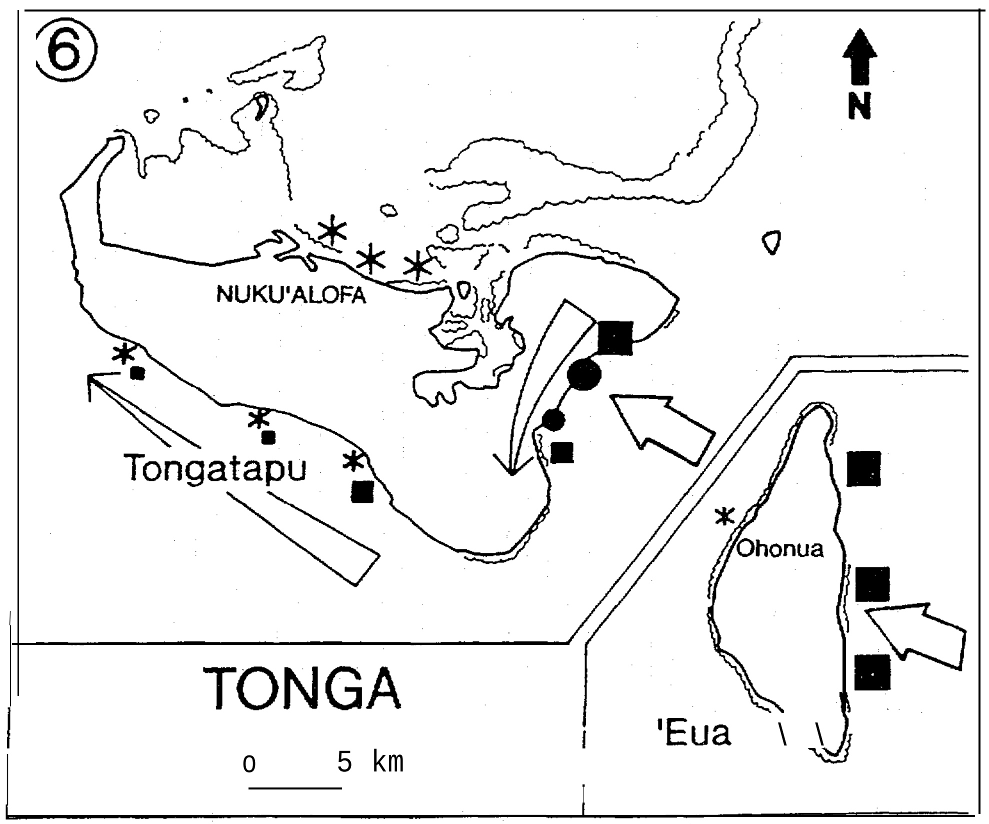
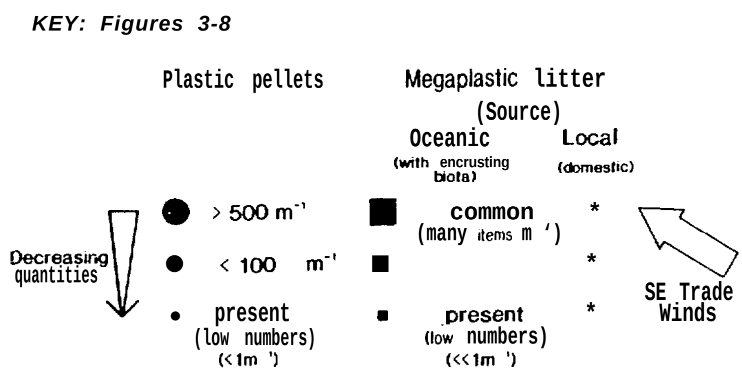


Figure 6. --Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Tonga.



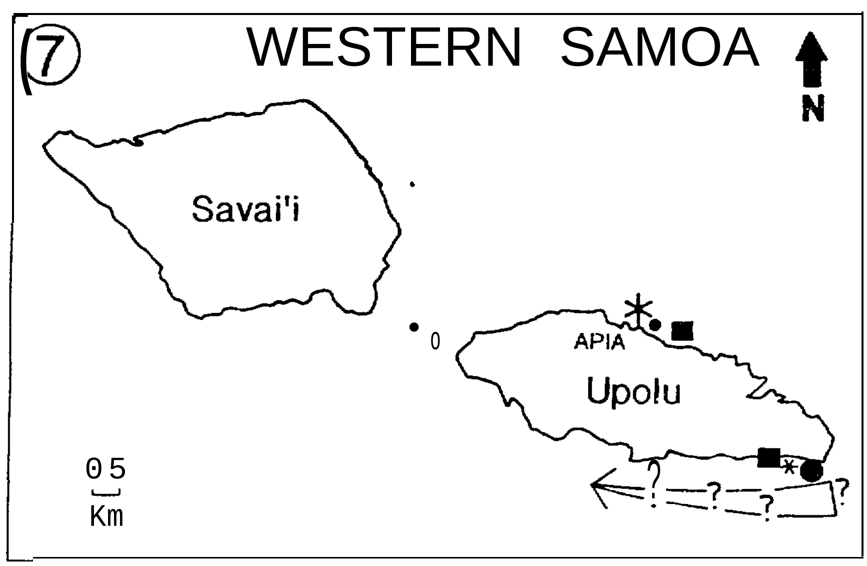


Figure 7.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Western Samoa.

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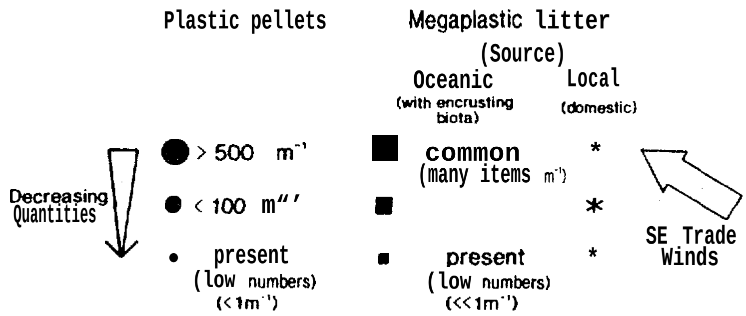

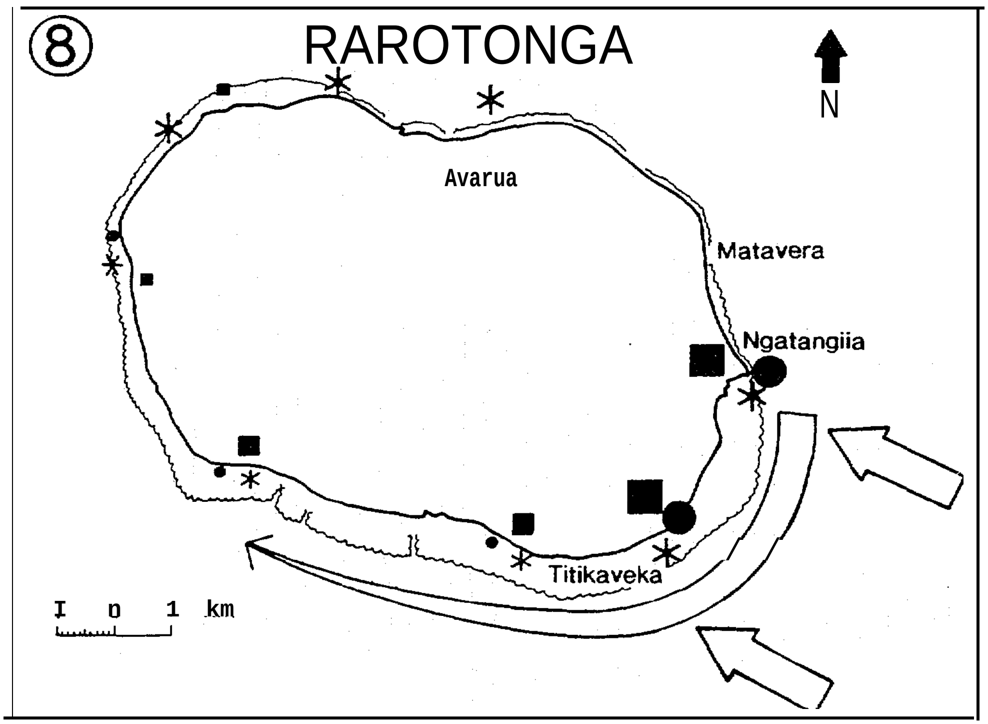

Figure 8. --Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Rarotonga.

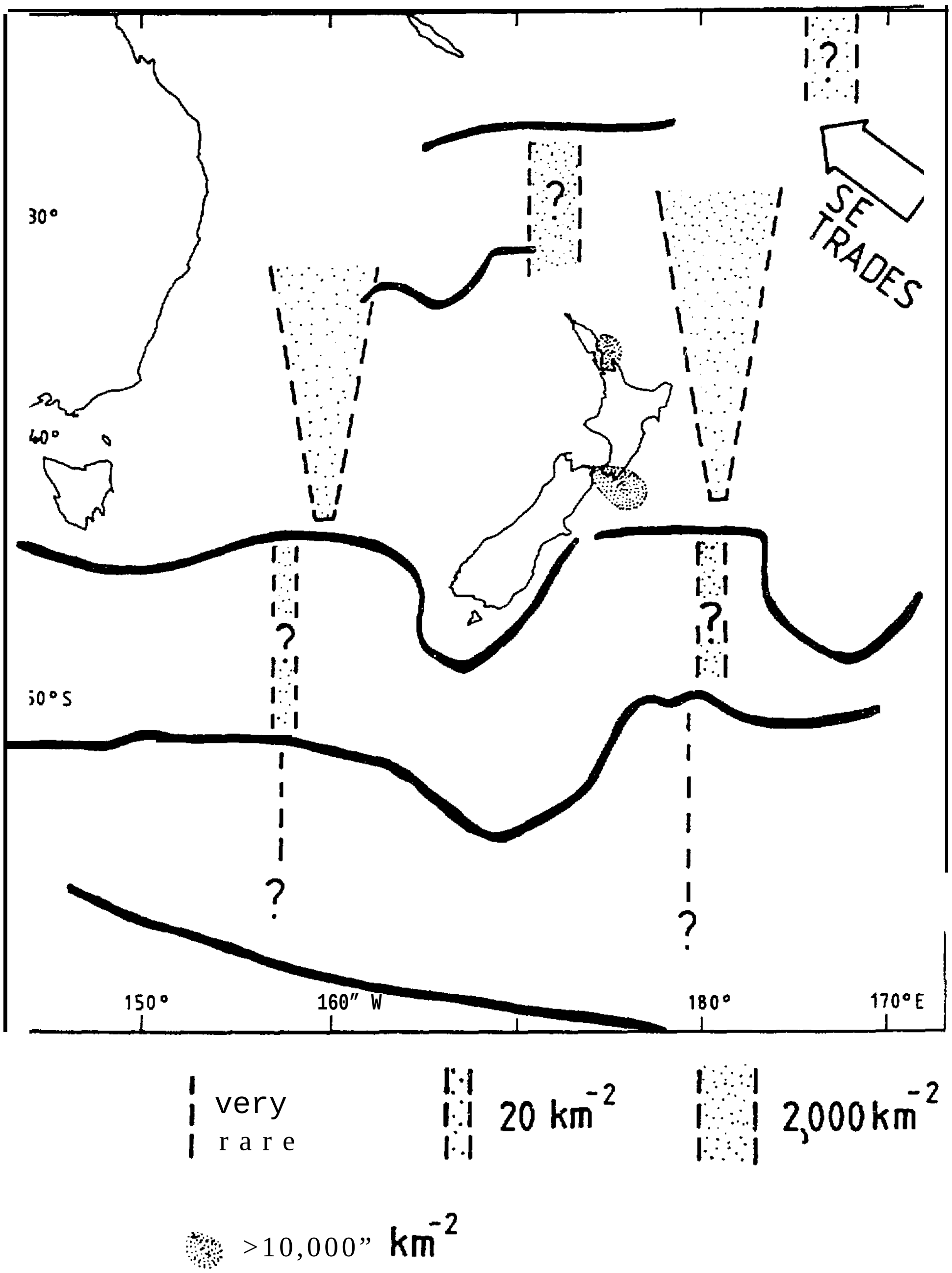

Figure 9. --Regional distribution of pelagic plastic granules across the southwest Pacific is influenced by oceanic fronts and wind and surface current patterns. Based on Gregory et al. (1984); Gregory (1987, 1990), and unpublished data.

for waters in the Agulhas Current up to 100 nmi offshore from Cape Province (Ryan 1988). On the other hand, densities in surface waters of the northern Sargasso Sea include >10,000 pieces of plastic and 1,500 pellets km-z (Wilber 1987). Elsewhere around the eastern North Atlantic, densities of polluting plastic are lower, with only 700 pieces km^{-2} and 80 pellets km^{-2} being reported from waters north of the Gulf Stream (Wilber 1987).

PLASTIC MACRO- AND MEGALITTER

In the categories of plastic macro- and megalitter I include large manufactured items and artifacts fabricated from plastics and other persistent synthetic materials and the products of their fragmentation and disintegration, following the approach of McCoy (1988). Megalitter is of a size enabling visual identification of floating items by a shipboard observer (generally decimeters or larger), while macrolitter is mostly smaller items and fragmented material, larger than the previously described granules and readily seen with the naked eye during shoreline surveys. Typical examples of the former are fishing floats, containers, crates, bottles and their tops, netting, lines, hawsers, strapping bands, plastic sheeting and bags, foamed items, and confectionery wrappings. Only some of these items are readily degradable.

Significant quantities of macro- and megalitter have been seen on all shores examined to date (Tables 2 and 3, Figs. 3-8, 10-13). The amounts are highly variable, but even on uninhabited islands and the otherwise remotest of places discarded plastic is present. In a survey of New Zealand's subantarctic islands, Gregory (1987, Appendix 1) itemized a great diversity of plastic material and noted that the quantity of macrolitter was surprisingly small considering the abundance of megalitter items (Fig. 10). A similar diversity of seaborne megalitter becomes stranded on islands of the southwest Pacific. As an example, Raoul Island in the Kermadec Group some 500 km northeast of New Zealand (Fig. 1), has <10 permanent residents at a weather station, and yet large quantities of macro- and megalitter are stranded on the beaches (Table 3).

In late 1988 New Zealand's Department of Conservation, with cooperation from the Wildtrack Programme produced by the Natural History Unit of TVNZ (Television New Zealand), initiated a nationwide survey of plastic litter on beaches. Most participants are students who complete a standard record card (Fig. 14). Preliminary reviews of some 50 returns coming from widely separated places, both remote and near population centers of the North and South Islands, confirm casual observations that considerable quantities of plastic macro- and megalitter accumulate on these shores. It is surprising to note that few returns identified the small resin granules, even at places where they are reasonably common. Those items most frequently recorded were fragments of foamed and hard plastic, plastic bags and sheeting, strapping bands, bottles, and bottle tops. The following selected examples illustrate the magnitude of contamination:

74 bottles on 860 m of beach--Ohope, Bay of Plenty

426 bottles and 82 bags on 2 km of beach--Mohaka, Hawkes Bay

32 bags on 500 m of beach--Petone, Wellington Harbor

2,817 bottle tops (from repeated surveys: 4 August, 14 and 19 September 1988)--Oreti, Southland

200 packing straps on <200 m of beach--Mokomoko Inlet, Southland

Table 3.--Simplified catalogue of plastic megalitter and other artifacts found on a 3-km stretch of beach on the northern coast of Raoul Island, southwest Pacific.

Type of litter	Number
Fish boxes and crates	10
Fishery floats	26
Bottles and containers (detergent, cosmetics, etc).	40
Hawser, rope	
Long (ea. ±10 m)	10
Short (<10 m)	5
Netting (trawl) and rigid mesh	5
Foamed material (Styrofoam)	
Small (<2 cm)	>30
Moderate (>2 to <15 cm)	>10
Large (>15 cm)	>20
Sheeting	10
Strapping bands	>20
Footware (jandals/thongs)	20
Miscellaneous	>10

Repeated surveys (1974, 1978, 1981, and 1982) at Kawerua, a remote beach on the exposed west coast of Northland, showed a gradual decrease in numbers of plastic bags and an increase in bottles and total plastic items, probably reflecting changes in types of packaging over that period (Hayward 1984). Comparable trends in plastic megalitter accompanying changing patterns in offshore fishing activities have been noted for the subantarctic islands and mainland New Zealand shores (Cawthorn 1985).

SOURCES AND DISTRIBUTION

From the approach of Ryan (1987b), it is appropriate to identify three categories of plastic debris on shores throughout the region.

1. Material having a local onshore source.

2. Material originating from nearby fishing and shipping activities.

3. Material that has drifted from afar and that can be considered oceanic.

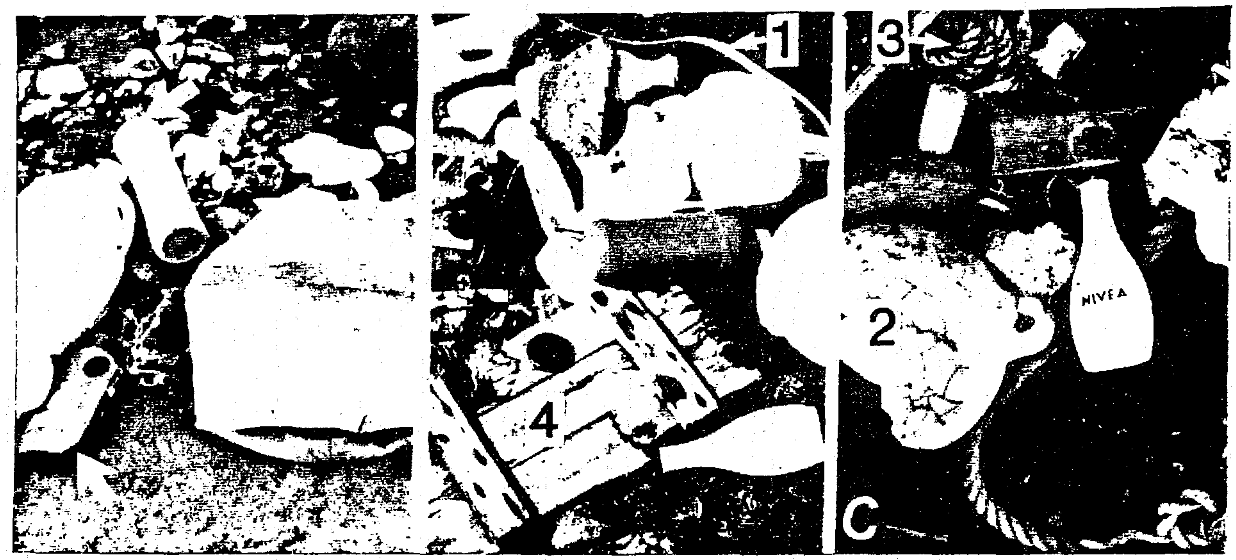

Figure 10.--Representative plastic items washed up on New Zealand's subantarctic islands: North West Bay, Campbell Island (A) and Derry Castle Reef, Auckland Islands (B and C). The large crushed container in (A) is of French origin and the two smaller items (arrow) are of United Kingdom manufacture. Note the polypropylene strapping (l), incipient crazing on the inside of broken high-density plastic fishing floats (2), cordage (3), and parts of wooden packing crates (4) in B and C.

Figure 11. --Representative locally generated and oceanic plastic litter assembled from combing 100 m of beach at Makara, west coast near Wellington, New Zealand. Some of this collection has clearly come from fishing activities. (Photograph taken by M. Cochrane.)

Figure 12. --Plastic sandal heavily encrusted with bryozoans, coralline algae, and clumps of the pink foraminiferan, *Homotrema rubra* (arrow). (Collected by K. A. Rodgers on Tuvalu.)

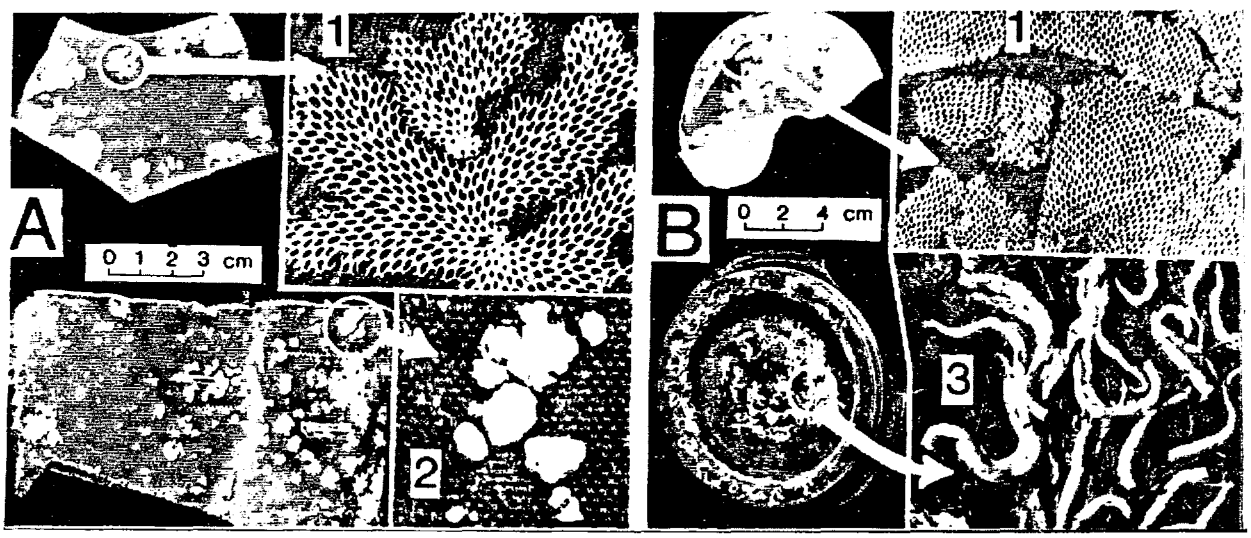

Figure 13. --Encrusted oceanic plastic *items* from Rarotonga (A) and Raoul Island (B). Note the bryozoans (l), coralline algae (2), and calcareous annelid tubes (3).

For the New Zealand coast and inshore waters, Gregory (1978) identified industrial centers as the principal sources (Fig. 2) of plastic meso-litter (mostly granules). This litter was material that was accidentally spilled in wharf and other cargo handling areas and at processing plants, and reached the sea through sewage and storm drainage systems as well as natural waterways. Subsequent dispersal was effected by coastal currents (Fig. 2). On populated islands (e.g., Tonga, Rarotonga), as on New Zealand shores, it is possible to separate plastic megalitter into two populations. One is probably of local (or domestic) origin, and the other comes from offshore sources and may have been adrift for some time. Casual visitors as well as indiscriminate and uncontrolled garbage dumping are responsible

BEACH CLEAN UP& SURVEY 'RECORD CARD

Date:_____ General Location: (eg Bethells Beach, Auckland) ____________

Exact Site on beach ____________

Approx. size of area:___metres long by ___metres wide

Character of area (circle one): rock, sand, mud, gravel, other (specify) ____________

Name of surveyor or organisation: ____________

Contact address and tel. no: ____________

An easy way to record the material you pick up is by counting in groups of five like this:
Bottles 𝍸 II Total [7]

HARD PLASTICS	Total	GLASS	Total
Bottles, containers		Bottles	
Tops		Light bulbs and tubes	
6-pack yokes		Broken fragments	
Buckets		ALUMINIUM	
Toys/combs		Cans, cartons	
Fragments		Foil/trays/wrapping	
Other		Other	
FOAM PLASTICS		TIN/STEEL	
Trays/cups/packaging		Tins/cans	
Fishing floats		Drums	
Foam fragments		Wire	
Other		Bottle tops	
PLASTIC SHEET AND FIBRES		Other	
Plastic sheets		PAPER	
Plastic & cellophane bags		CARDBOARD	
Fishing nets		TIMBER (leave driftwood on beach)	
Fishing lines (approx. length in metres)		CLOTH ITEMS	
		RUBBER ITEMS	
Other rope/cord (approx length in metres))		FOREIGN DEBRIS (describe overleaf)	
Packing tape/strapping - cut		ENTANGLED/STRANDED ANIMALS (describe overleaf)	
Packing tape/strapping - uncut			

ESTIMATE OF TOTAL VOLUME OF RUBBISH COLLECTED FROM YOUR AREA ____________

THANK YOU FOR COMPLETING THIS SURVEY CARD. PLEASE RETURN IT TO YOUR BEACH CO-ORDINATOR, OR YOUR LOCAL DEPARTMEW OF CONSERVATION OFFICE, OR POST TO ANNIE WHEELER, MARINE DEBRIS NETWORK, C/O DEPARTMENT OF CONSERVATION, P O BOX 8 NEWTON, AUCKLAND.

DETAILS OF ENTANGLED/STRANDED ANIMALS

Identify bird or animal ____________

Cause of injury or death ____________ If the creature is still alive, seek help from your beach co-ordinator, or local RSPCA, DOC office or Forest and Bird. Take photographs.

DETAILS OF FOREIGN DEBRIS

Describe item and the country you think it is from ____________

WHERE DO YOU THINK MOST OF THE RUBBISH YOU HAVE COLLECTED HAS COME FROM? (ie fishing boats, picnickers, household rubbish, foreign boats etc)

____

The NZ Marine Debris Network is a coalition of conservation groups who are concerned about the issue of marine debris and coastal pollution and its effect on wildlife. The Network includes representatives from the Department of Conservation, Greenpeace, Royal Forest and Bird Protection Society, University of Auckland, RSPCA, and the World Society for the Protection of Animals.

One of the aims of the Network is to co-ordinate the efforts of the many groups and individuals thoughout the country who are involved in beach clean ups and to carry out a survey of the debris collected off New Zealand beaches. This information can then be used to determine the main types and sources of the debris that litters our beaches. It will contribute to a national marine debris data base, and will help develop solutions to marine debris pollution.

Your participation in this beach clean up is an important contribution to an on-going nationwide effort.

GUIDELINES FOR COLLECTORS

1. Carry out your beach clean-up and survey at low tide.
2. Make sure you have warm clothing, and sun protection if necessary.
3. Wearing rubber or gardening gloves can be a good idea.
4. Before you start: make sure you've got your record card and board, pen and rubbish collection bags.
5. Take something to drink and perhaps a snack.
6. Work in small groups, so some of you can be picking up and sorting the rubbish into categories for recycling (see below) while one person is recording the details on the survey record card.
7. Know who your beach co-ordinator is and where to find them. Be clear about what area you are meant to be surveying.
8. Know where the rubbish collection point is.
9. Report any entangled animals to your co-ordinator and take photos if possible.
10. Give your record card back to your co-ordinator or post to the address on the other side of this form.
11. MAKE SURE YOU SEPARATE YOUR RUBBISH INTO DIFFERENT BAGS WITH 1. PLASTICS. 2 GLASS, 3. PAPER, 4. ALUMINIUM CIJ'IS. 5. TINS; AS ALL THIS MATERIAL IS GOING TO BE RECYCLED.

Figure 14. -- Standard record card used in New Zealand coastal plastic pollution surveys.

for much of the former; some must also come from vessels operating in local waters. The most unsavory items found during the course of these surveys were soiled (disposable) baby diapers, syringes, and discarded pesticide or agricultural chemical containers. Litter coming from distant offshore sources is considered oceanic. It is characteristically embrittled and sports an encrusting biota (see below) .

Around the subantarctic islands, plastic macro- and megalitter concentrate on west- facing (i.e. , windward) shores, whereas little reaches their eastern (leeward) coasts (Gregory 1987) . The dominating influence here is the strong West Wind Drift Current of the Southern Ocean (Lutjeharms et al. 1988) . The same pattern is repeated on southwest Pacific island shores. Here, however, it is the eastern shores --those facing into the southeasterly trade winds --onto which plastic meso-, macro-, and megalitter are herded (Figs. 3-8). Further, in several instances, it is possible to identify crude decreases in quantities of plastics in the downdrift direction (e.g., Viti Levu, Tongatapu, and Rarotonga; Figs. 5, 6, and 8). The encrusting biota (see below) of many megalitter items suggest they have been afloat for some time. These are part of the global oceanic population of pelagic litter. Plastic granules on Australian, New Zealand, and Fiji shores can have their major origins in local suppliers and manufacturers.

Norfolk, Raoul, Vanua Mbalavu, Tongatapu, and Rarotonga have no local sources for virgin plastic granules, and lie upwind from regional ones. Nibs on these shores must have come from the same global oceanic population of pelagic plastics and are dispersed by the southeast trade winds. A possible source exists in French Polynesia, which lies upwind, but I have no data for this region.

Although plastic macro- and megalitter on eastern Australian shores have not been surveyed, quantities of this litter and the resin granules appear to be much lower than at equivalent sites in New Zealand. This difference probably reflects coastal current and broad oceanic circulation patterns as well as persistent winds that blow offshore or parallel to the coast over this region. On the other hand, drift pumice is quite common on these shores, as it is on the shores of many Pacific islands (Sachet 1955). Much of the plastic litter on popular recreational beaches of Australia, New Zealand, and larger southwest Pacific islands comes from casual visitors and day trippers; it is dominated by food and confectionery wrappings and drink bottles. This material is seldom conspicuous on isolated shores. From these remote places, there is evidence that much plastic debris comes from fishing-related or other shipping activities (Cawthorn 1985, 1987; Mattlin and Cawthorn 1986; Gregory 1987, 1990).

Attention has already been drawn to the accumulation of plastic debris on the windward shores of several southwest Pacific islands. The materials involved are mostly of oceanic origin and also from fisheries-related and shipping activities, and their quantities on west- and north-facing (leeward) shores are minimal. The principal urban population centers of Tongatapu, Rarotonga, and Upolu (Western Samoa) are all situated on north-facing coasts along which much locally generated plastic has spread.

Plastic items, categorized by country of origin (when possible), are summarized in Table 4 for New Zealand's subantarctic islands and for subtropical Raoul Island. Some items are truly oceanic (e.g., an Argentinean fishing float reaching the Snares), but most appear related to regional fishing activities. South Korean, Taiwanese, and Japanese vessels are common in these waters, so the dominance of Asian-sourced artifacts is not unexpected. The Russians also have a considerable presence, but one that is not reflected in the seaborne litter. Personal experience on a Russian research vessel reveals that they generate very little plastic, and discarded paper and cardboard packaging are incinerated.

The regional distribution of dispersed pelagic or oceanic plastics is schematically summarized in Figure 9. It has been inferred (Gregory et al. 1984; Gregory 1990) that major oceanic fronts such as the Polar, Subantarctic, Subtropical, and Tropical Fronts, and eddies from the East Australian Current have important influences on the distribution and abundance of litter. They act as barriers arresting the spread of material, and along these barriers the material is also concentrated and carried. For example, Bourne and Clarke (1984) noted an accumulation of garbage in the Humbolt Front off Valparaiso, Chile. Observations in the Hauraki Gulf, northern New Zealand, show that densities of plastic granules taken in tows made along windrows may exceed 10,000 km^{-2}, whereas densities in tows transverse to the windrows may be as few as 1,000 km-z (Gregory, unpubl. data).

Table 4.--Summary of numbers of plastic items having identifiable countries of origin.

Country of origin	Subantarctic islands	Raoul Island
Asia	11	5
United Kingdom	5	1
New Zealand	4	6
Australia	3	2
Spain	2	--
Bulgaria	1	--
France	1	--
Norway	1	--
U.S.S.R.	1	1
Argentina	1	--

ENCRUSTING BIOTA

Plastics and other synthetic litter afloat on surface waters of the ocean are an important and expanding, although little studied, ecological niche for a pseudoplanktic biota of the kind commonly present on *Sargassum* (Winston 1982; Butler et al. 1983). Gregory (1978) noted that granules from beaches of northernmost New Zealand were sometimes encrusted by the bryozoan *Membranipora tuberculata*. This is a tropical species and has also been found on drift plastics from Australia, Norfolk and Raoul Islands, and Fiji, Rarotonga, and Tongatapu. It was inferred that there had been eastward dispersal across the north Tasman Sea by way of eddies in the East Australian Current (Gregory 1978). Other encrusting taxa identified during past and present studies include further bryozoan species awaiting identification, coralline algae, calcareous annelids, barnacles, a hermatypic coral, and the pink foraminiferan *Homotrema rubra* (Figs. 12, 13). Encrusters are less common on artifacts from the subantarctic, where only goose barnacles (*Lepas* spp.) and the annelid *Spirorbis* have been recognized.

It is evident that pelagic plastic litter may be an important vector in the transoceanic and regional dispersal of a varied biota and may increase the chances of migration to distant shores, including isolated islands, as contemplated by Ryan (1987b).

DISCUSSION

The general environmental problems of the southwest Pacific region, with its limited financial and natural resources, have received wide attention (e.g., Chan 1973; Salvat 1979; Izrael et al. 1981; Dahl and Carew-Reid 1985; Carew-Reid 1988). Plastics are an unnecessary additional contaminant to the region, and the environmental implications to be drawn are those that have been identified elsewhere (Laist 1987) and need no further elaboration. For animals these implications include death or debilitation through entanglement; blockage of the intestinal tract through ingestion, leading to starvation and death; ulceration of delicate tissues by jagged plastic fragments; and reduction in quality of life and reproductive performance. In addition, large items can be hazards to shipping. The aesthetic concerns expressed about plastic pollution also must be acknowledged. Unsightly accumulations of locally generated or oceanic plastics on beaches could be to the detriment of tourism (Prasad 1987). Soiled diapers, used syringes, and medicinal and pesticide containers stranded or abandoned on beaches will discourage even the most hardy of tourists.

The oceanic problem can be addressed through MARPOL and the London Dumping Convention. The local problem needs to be approached with cultural delicacy, for traditional practice and attitudes towards refuse disposal are in many ways rather casual (Anonymous 1976). Educational efforts, directed primarily at the young (Bryant 1988), will need to draw on and develop from traditional Pacific ways.

The very attributes that mankind finds desirable in plastics--lightness, strength, manufacturing adaptability, flexibility, inertness, resistance to degradational processes, transparency, and prolonged shelf life in packaging--are also the reasons they are today a globally important marine pollutant (Andrady 1988; Johnson 1988).

It is difficult to estimate the rate at which plastics disappear or are adsorbed into the environment (Gerrodette 1985). And while the breakdown of plastic compounds in itself may create few problems, the effects of released additives such as antioxidants, retardants, and biocides have never been assessed, only speculated about (Gregory 1978). Locally generated litter is likely to be fresh in appearance, while much of the oceanic and offshore-generated plastic litter stranding on these tropical and subtropical Pacific shores is chalky, crazed, and embrittled, all evidence of oxidative aging and photodegradation. Whether this occurs while it is afloat or after it is stranded on the shore has not been established. Circumstantial evidence suggests that aging is more rapid once artifacts are stranded high and dry on a beach (Gregory 1983). On the New Zealand coast, the extent of degradation apparently decreases southwards, although a detailed survey to confirm this claim has not been undertaken. Similarly, the proportion of degraded virgin granules is much greater on the tropical shores than it is on temperate ones (Table 5) (Gregory 1983, table 1). On high-latitude subantarctic shores, crazing is less evident and much breakdown occurs through mechanical abrasion and battering (Gregory 1987).

The extent of crazing and embrittlement of plastic granules (Table 5) and megalitter items observed on Raoul, Rarotonga, and Tonga suggest that a survival time of 5 years (Gregory 1983) may be overly generous. Evidence indicates that plastics degrade more rapidly in the Australian and New Zealand region than they do in equivalent Northern Hemisphere latitudes, although contrary to popular belief, the reason is not necessarily related to higher ultraviolet values (Sharman 1987). Controlled experiments and observations on rates of plastic degradation around the world are needed if we are to understand adequately the population dynamics of pelagic plastics

Table 5. --Relative numbers (in percentages) of fresh, slightly degraded, and highly degraded plastic granules from selected localities.

Locality	Number	Fresh	Slightly degraded	Highly degraded
		Increasing degradation ———>		
Fiji	163	18	45	37
Raoul	25	24	52	24
Rarotonga	70	19	41	40
Tonga	60	20	30	50
Auckland, New Zealand	216	79	13	8
Botany Bay, Australia	73	53	40	7

and to establish whether an equilibrium state between accumulation (strandings) and losses in environmental sinks (disappearance from view) has been already reached.

CONCLUSIONS

Although pollution by plastics of the southwest Pacific marine environment has not yet reached the magnitude evident in waters adjacent to more heavily populated, industrialized, and fished regions of the Northern Hemisphere, it is a developing problem and cause for concern.

Increased fishing activities across the region, and in particular drift gillnetting, are likely to escalate presently identified problems.

Regional distribution and dispersal are influenced by proximity to sources, oceanic current and circulation patterns, and prevailing winds. Oceanic fronts may have a key role in defining boundaries to zones with broadly similar areal densities of pelagic plastics.

Population dynamics of pelagic plastics across the southwest Pacific as well as globally are not well understood, and more information is needed on the “sinks” of this material.

There is need to educate the public about the environmental problems arising from the indiscriminate disposal of plastics and other persistent synthetic compounds.

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THE MARINE PLASTIC DEBRIS PROBLEM OFF SOUTHERN AFRICA: TYPES OF DEBRIS, THEIR ENVIRONMENTAL EFFECTS, AND CONTROL MEASURES

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ABSTRACT

Plastic debris is a global marine pollutant which is inflicting ever-increasing environmental and financial costs. In the seas off southern Africa and the adjacent Southern Ocean, entanglement has been recorded for at least 5 species of marine mammals, 13 seabird species, 2 turtles, and 6 shark species. Plastic ingestion has been recorded from 7 marine mammal species, 36 seabird species, 2 marine turtle species, and 7 shark species. The incidence in invertebrate taxa is not known. At present, entanglement does not pose a threat to the survival of any populations off southern Africa, but the recent introduction of a driftnet fishery *to* the South Atlantic and Indian Oceans and the suffering frequently associated with entanglement are causes for concern. By contrast, ingestion of plastic particles may adversely affect almost the entire population of species that do not regurgitate indigestible objects, with large, accumulated plastic loads reducing feeding efficiency or obstructing the digestive tract. Off southern Africa, generalist, surface-feeding, pelagic taxa such as certain procellariiform seabirds (petrels and albatrosses) and juvenile marine turtles are at risk from plastic ingestion. The incidence of ingested plastic in some species exceeds 90% of the population. The major financial cost of marine plastic debris is the reduced aesthetic appeal of coastal areas, which adversely affects the tourist industry. In South Africa alone, approximately R1O million is spent annually on cleaning beaches, where plastic makes up more than 90% of all stranded debris.

To address the problem of marine debris requires knowledge of the sources of various pollutants. Beach surveys readily assess the most abundant types of plastic debris, and from these data their sources can be inferred. Disposable packaging accounts for more than half the large plastic objects on southern African beaches, with most of the remainder composed of fishing gear. Sheet plastic (bags and wrappings) is the most abundant single type of plastic. Among small particles, virgin industrial pellets and fragments of other products predominate.

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Using these findings to assign culpability and to elicit assistance, four approaches are being used to tackle the problem of marine plastic debris off southern Africa: education, product substitution, recycling, and legislation. As a short-term measure, specific types of artifacts responsible for most entanglements (e.g. , hi-cone six-pack yokes, packing straps) and ingestion (e.g. , virgin pellets, plastic bags) have been targeted for action. These approaches to control marine plastic pollution are discussed in relation to the highly diverse socioeconomic conditions prevailing in southern Africa.

INTRODUCTION

Much concern recently has been focused on the problems associated with anthropogenic marine debris, particularly as regards plastic (Shomura and Yoshida 1985; Laist 1987; Wolfe 1987). A variety of approaches has been adopted to tackle these problems, but have concentrated on maritime legislation (e.g., Bean 1987; Lentz 1987) and on awareness campaigns in developed, first world communities (e.g., Neilson 1985). Other than international maritime legislation, there have been few attempts to tackle the growth of marine debris arising from third-world communities. The southern African region comprises virtually the entire socioeconomic spectrum, and is to a large extent isolated from the world's major manufacturing centers. It is thus a useful area for examining the efficacy of various measures taken to limit persistent debris production. This paper reviews the occurrence of anthropogenic marine debris off southern Africa and in adjacent oceanic areas, and summarizes the known environmental effects of debris. The approaches used to identify the sources of marine debris and to control the amount of litter entering the sea are discussed.

THE SEAS OFF SOUTHERN AFRICA

Southern Africa has an unindented coastline, with few large bays or inlets (Fig. 1). Strong wave action is characteristic of much of the coast, with sandy beaches comprising almost 70% of the coastline. The continental shelf is narrow (<50 km wide) off the east coast, moderately broad (up to 150 km wide) off the west coast, and is most extensive off the south coast, where the Agulhas Bank extends more than 200 km offshore.

There are two main current systems. The cool (10°-16°C) Benguela Current flows north along the west coast, and is characterized by localized upwelling of cold, nutrient-rich bottom water when surface waters are advected offshore (Shannon 1985). The warm (22°-28°C) Agulhas Current flows south, close inshore along the east coast until it reaches the Agulhas Bank, where it moves offshore. South of the subcontinent, the Agulhas Current retroflects to flow eastward in oceanic waters to the north of the Subtropical Convergence (Lutjeharms 1981). However, large (500-km diameter) eddies formed at the retroflection zone frequently transport Agulhas Current water into the South Atlantic (Lutjeharms 1988; Lutjeharms and Valentine 1988). Elsewhere to the south of the subcontinent, the predominant surface flows are eastward, associated with the West Wind Drift (Lutjeharms et al. 1988).

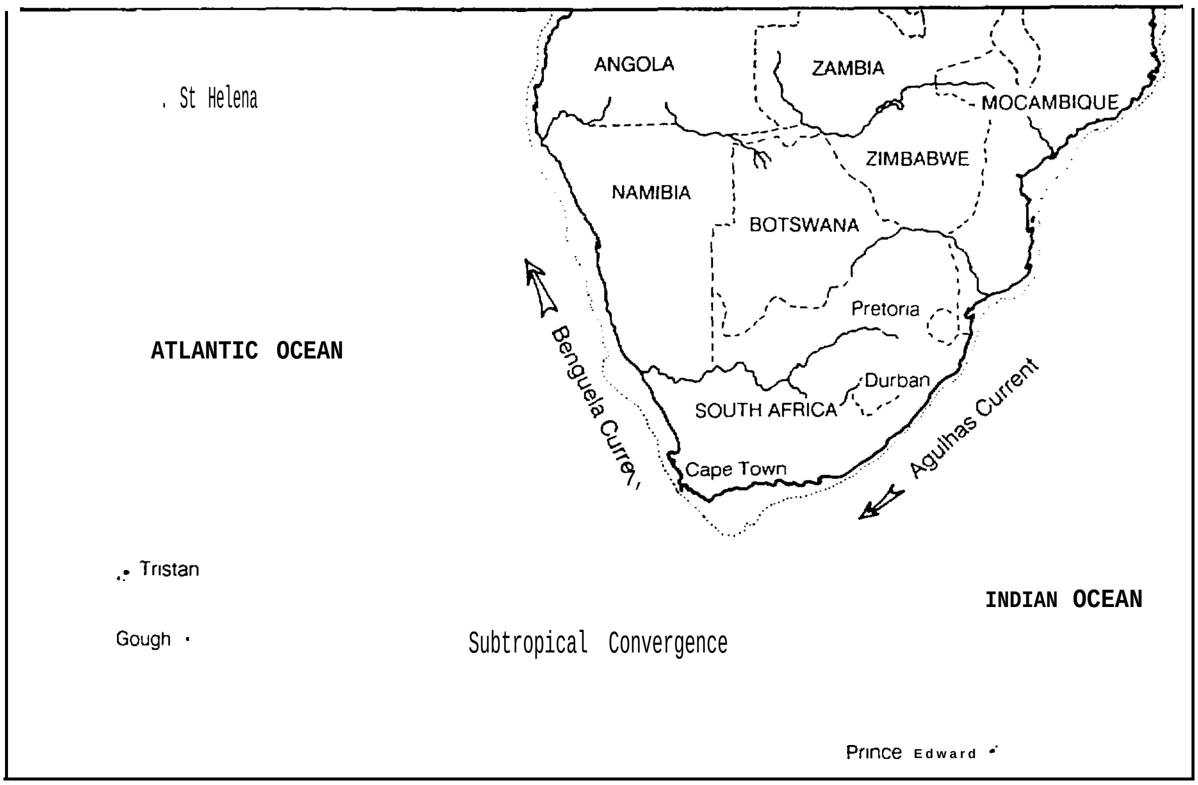


Figure 1. --The southern African region and adjacent oceans. The stippled line indicates the approximate edge of the continental shelf.

Most merchant ships in the area travel around southern Africa following the Cape sea route between Europe-North America and the Persian Gulf-Southeast Asia. This route runs close inshore along the south and east coasts of southern Africa, only moving offshore off the west coast. There is relatively little transoceanic merchant trade to either South America or Australia.

Commercial fisheries off southern Africa are concentrated on the broad continental shelves off the south and west coasts, where there are extensive demersal (bottom trawl) and pelagic (purse seine) fisheries (Crawford et al. 1987). There is a limited prawn fishery off the east coast, and a longline tuna fishery in oceanic waters. Gillnets were little used in the region until 1989, when oriental vessels started using driftnets more extensively in both the South Atlantic and South Indian Oceans (Ryan and Cooper in press).

THE DISTRIBUTION OF PLASTICS AND OTHER DEBRIS AT SEA

Little has been recorded of the distribution and abundance of plastic and other debris at sea off southern Africa. The abundance, distribution, and movements of tar balls at sea have been documented for two regions off the southern African coast, with a view towards identifying coastal areas vulnerable to oil pollution (Shannon et al. 1983). The abundance of small plastic particles (<10 mm diameter) also has been estimated from surface neuston trawls. Morris (1980) reported densities ranging between 1,300 and 3,600 virgin industrial pellets km-z in oceanic waters of the Cape Basin west of Cape Town.

The density of plastic debris in coastal waters off the southwestern Cape averaged 3,640 particles km-z, derived from over 1,200 neuston trawls conducted at monthly intervals during 1977-78 (Ryan 1988a). Seasonal patterns of distribution and abundance were related to probable source areas and transport at sea. However, the highly clustered dispersion of particles, presumably due to fine-scale convergence zones, resulted in great variances in debris abundance estimates (range 0-445,000 particles km-z), largely as a consequence of the relatively small sampling area (190 m^2 per trawl). Foamed plastics and fragments of manufactured articles were the most abundant types of particles, but virgin industrial pellets accounted for most of the mass (mean 42.4 g km-z; Ryan 1988a). It appears that at least a significant proportion of the debris arises from local sources, with concentrations inshore and close to harbors (Ryan 1988a, cf. Morris 1980). However, there is also evidence that the Agulhas Current is an important debris vector (Ryan 1988a).

A small number of neuston trawls (39) in oceanic waters south of southern Africa in the Agulhas retroflection area collected only *two* plastic particles, both fragments of manufactured articles (P. G. Ryan unpubl. data). This gives a density estimate for the area of only 50 particles km^{-2}, similar to the density in the Southern Ocean south of New Zealand (Gregory et al. 1984).

Ryan (1988a) found that the density of large (>100 mm diameter) objects counted from a low-flying plane was an order of magnitude greater 10 km from the shore (19.6 objects km-z) than 50 km offshore (1.6 km-z) in the area between Cape Town and Saldanha Bay, where the merchant shipping lane runs close inshore. This offshore gradient is likely to be less marked farther north off the west coast where the continental shelf is broader (hence fishing grounds more extensive) and the shipping lane runs farther offshore. In oceanic waters south of the subcontinent, in the region of the Agulhas retroflection, ship-based counts provided density estimates of between 0.04 and 0.09 large objects km^{-2} (P. G. Ryan unpubl. data).

These data refer only to floating debris. Virtually nothing is known about debris on the seabed off southern Africa. Debris comprised of materials denser than seawater presumably does not disperse far from source areas. Such items occasionally are caught in bottom trawls off the west coast (B. Rose pers. commun. ; pers. observ.). Floating debris can also sink if it supports sufficient sessile organisms or entangles enough animals to increase the density above that of seawater. Such objects have a much greater dispersal capability than do plastics that are denser than seawater.

IMPACTS OF MARINE DEBRIS

Marine debris has both environmental impacts and financial costs. The major financial burden results from the reduced aesthetic appeal of polluted marine systems. Beaches are important for the >R2,000 million per annum tourist industry in southern Africa, and their appeal is reduced when they are littered with stranded debris. In South Africa alone some R10 million is spent annually on cleaning litter off beaches.

Apart from the accumulation of unsightly debris, the main environmental impact associated with marine debris is animal mortality through entanglement in and ingestion of debris. In addition, it has been suggested that anthropogenic debris is having some ecological effect by increasing the amount of available substratum onto which sessile organisms can settle (Carpenter and Smith 1972; Winston 1982), and it is possible that debris has increased the rate of propagule dispersal to islands (Ryan 1987b) . However, the significance of the latter two impacts has not been determined.

Entanglement off Southern Africa

Entanglement involves animals becoming enmeshed in objects that impede movement, causing drowning, starvation, or reduced fitness, or restrict growth, cutting deep wounds into growing animals. This typically involves fairly large pieces of debris, and the apparent suffering associated with entanglement engenders considerable public concern.

Representatives of five marine vertebrate classes are known to have become entangled in debris off southern Africa (Table 1); there are no data for invertebrate groups. Most records are from coastal waters (where there are most observers), but a few entangled seals and birds have been found at subantarctic islands. Overall, the incidence of entanglement is fairly low, with only one species, the great white shark, *Carcharodon carcharias*, having more than 1% of individuals examined entangled in debris, There may be some cause for concern along the south coast, where 14% of stranded birds are entangled in debris (n = 97), with 28% of the vulnerable jackass penguin, *Spheniscus demersus*, entangled (n = 32, P. G. Ryan unpubl. data).

However, interpretation of the incidence of entanglement is complicated by different sampling techniques. For example, recoveries of banded crested terns, *Sterna bergii*, in southern Africa indicate that 14.2% (n = 267) of birds are captured after being entangled in debris, whereas only 2.2% (n = 46) of stranded birds were found entangled (x^2 = 5.23, P < 0.05; Fitzpatrick Institute unpubl. data). And yet it is to be expected that the proportion of entanglement among stranded animals is higher than that among the general population, although the exact relationship is unclear. Also, it is not possible to infer the consequences of a given level of entanglement on population trends. Northern fur seal, *Callorhinus ursinus*, numbers have been decreasing apparently at least partly as a result of a 0.4% frequency of entanglement (Fowler 1987). A similar entanglement frequency has been recorded at some Cape fur seal,

Table 1. --A summary of the known incidence of entanglement of marine animals in plastic objects and other debris off southern Africa, excluding the by-catch of nontarget species during fishing operations (including shark exclusion nets). Based on Shaughnessy (1980), Balazs (1985), and (unpubl. data) from G. Avery, P. B. Best, N. Rice, G. J. B. Ross, and the Natal Sharks Board.

Taxon	Type of debris	Frequency of occurrence
Cetaceans	Ropes, nets	Three plus species, apparently infrequent.
Seals	Ropes, nets, line 92% Packing straps 6% O-rings 2% Wire <1%	Cape fur seals 0.12%, but 0.6% in one colony. Two records at subantarctic islands.
Birds	Nets, rope, line 89% Plastic bags 11%, Six-pack yokes	Thirteen species, 0.6% of stranded animals but up to 14% locally.
Turtles	Rope	Two species.
Fish	All packing straps	Six species of sharks, 0.2% of shark-net catch, incidence ranges 0-1.4%.

Arctocephalus pusillus, colonies (Shaughnessy 1980), and yet this species' population is increasing by 3.7% per year (David 1987).

The types of objects causing entanglement off southern Africa vary among taxa (Table 1). However, most items are either fishing gear (rope, netting, and fishing line) or disposable packaging (primarily plastic packing straps and plastic bags). Only one item was not made of plastic; a single seal was found with a piece of wire caught around its neck (Shaughnessy 1980).

These data on entanglement ignore the incidental catch of animals during commercial fishing operations. Some birds and mammals are caught in demersal trawls (e.g., Ryan and Moloney 1987) and by the longline fishery (e.g., Ryan and Rose 1988), but for at least these taxa the fishery by-catch is relatively small (cf. Tull et al. 1972; Piatt and Nettleship 1987), due largely to the limited use of gillnets. The impact of the recent expansion of oriental driftnet fisheries in oceanic waters of the South Atlantic and South Indian Oceans needs urgent investigation. The killing of seabirds for food by fishermen is an ongoing problem (Cooper 1977; Ryan and Rose 1988).

Table 2.--A summary of the known incidence of marine animals ingesting plastic objects and other debris off southern Africa. Based on Hughes (1973), Ryan (1987a), and unpubl. data from P. B. Best, J. H. M. David, G. J. B. Ross, and the Natal Sharks Board.

Taxon	Type of debris	Frequency of occurrence
Cetaceans	Plastic bags 8 Plastic bottles 1 Packing strap 1	Seven species, 3.0% of stranded animals.
Seals	--	No records.
Birds	Virgin plastic pellets 56% Plastic user fragments 43% Wood, tar balls, paint, glass, and aluminium foil 1%	Thirty-six species, incidence ranges 0-92% with 10 species >50% and 4 species >80%.
Turtles	Plastic bags 75% Virgin plastic pellets 25% Glass 1 piece	Two species, 11.1% of stranded animals.
Fish	Plastic bags 82% Plastic bottles 12% Nets and line 6%	Seven species of shark, 0.3% of shark-net catch, incidence ranges 0-6%.

Debris Ingestion off Southern Africa

The effects of debris ingestion are seldom as dramatic as those of entanglement, but ingested debris can cause death or debilitation by obstructing the digestive tract (e.g., Balazs 1985; Fry et al. 1987) or reducing meal size and the urge to eat (e.g., Ryan 1988b). Ingested plastic may also be a source of toxic chemicals (e.g., Ryan et al. 1988).

Ingestion of marine debris has been recorded for four vertebrate classes off southern Africa (Table 2); there are no data for invertebrate groups. Debris ingestion is much more prevalent than is entanglement, affecting over 90% of individuals of blue petrels, *Halobaena caerulea*, and great shearwaters, *Puffinus gravis*, breeding at oceanic islands (Ryan 1987a). The incidence of debris ingestion among southern African seabirds is among the highest in the world, largely due to the predominance of generalist, surface-feeding procellariiform seabirds (petrels, storm-petrels, shearwaters, and albatrosses) that do not frequently regurgitate indigestible objects and thus accumulate ingested plastic (Ryan 1987a, 1988c). The present incidence of debris ingestion by turtles may be greater than the 11% indicated in Table 2, because there are no observations subsequent to 1973. Debris ingestion by birds has increased since the late 1970's off southern Africa (Ryan 1988c).

Ingestion of debris off southern Africa by large proportions of populations of birds and turtles in particular is cause for concern. Almost all debris ingested is plastic that floats in seawater (Table 2). The few nonfloating debris items found in animals apparently are eaten ashore (e.g., gulls at refuse dumps, giant petrels at their breeding islands). Although the types of objects ingested are influenced by an animal's size (e.g., Ryan 1987a), two types of plastic objects make up the majority of ingested debris: virgin industrial pellets and plastic bags (Table 2). Reducing the abundance of these items at sea is the only long-term solution to the problem of debris ingestion.

TACKLING THE MARINE DEBRIS PROBLEM

Marine debris is extremely heterogeneous in terms of both the size and composition of artifacts and the wide range of their sources. This diversity makes the control of marine debris problematic. Examining the various impacts of marine debris highlights the types of debris responsible for most environmental problems. Off southern Africa these are discarded fishing gear, various types of plastic packaging (notably bags and packing straps) , and small plastic particles (chiefly virgin industrial pellets). These types of debris warrant most attention, but the implementation of effective measures to reduce the amount of debris entering the sea requires knowledge of the sources of marine debris. It is evident that the general source of discarded fishing gear is the various fishing industries, providing a ready target for action. However, the sources of packaging and, to a lesser extent, industrial pellets are highly diffuse, complicating the assessment of culpability.

Using Beach Surveys to Identify Debris Sources

Beach surveys offer the simplest and most practical way to assess the relative abundance of various types of marine debris and to identify their probable sources (e.g., Merrell 1980; Vauk and Schrey 1987). However, one problem with stranded debris surveys is controlling for the selective removal of debris by beachcombers (see Ryan 1987b). Surveys at uninhabited islands avoid this problem. Figure 2 shows the numerical dominance of plastic articles and the much faster growth in amount of plastic debris compared with other debris types at Inaccessible Island in the Tristan group, central South Atlantic Ocean. Most of the debris identifiable as to country of origin derives from South America, and the proportion has been increasing: 32% in 1984, 36% in 1987, and 48% in 1988. Given the limited merchant trade across the South Atlantic, it is likely that much of the plastic debris reaching Inaccessible Island has drifted more than 3,000 km from South America (Ryan and Watkins 1988).

This contrasts with the situation on southern African beaches, where most identifiable debris derives from local sources. A survey of stranded debris at 50 sandy beaches between Cape Town and the Transkei was undertaken during June 1984. All large (>20 mm) articles within representative 50-m stretches of beach were collected (P. G. Ryan unpubl. data). Plastic made up more than 90% of stranded debris, and was recorded at all beaches sampled. Disposable packaging (e.g., bags, bottles; Fig. 3) comprised more

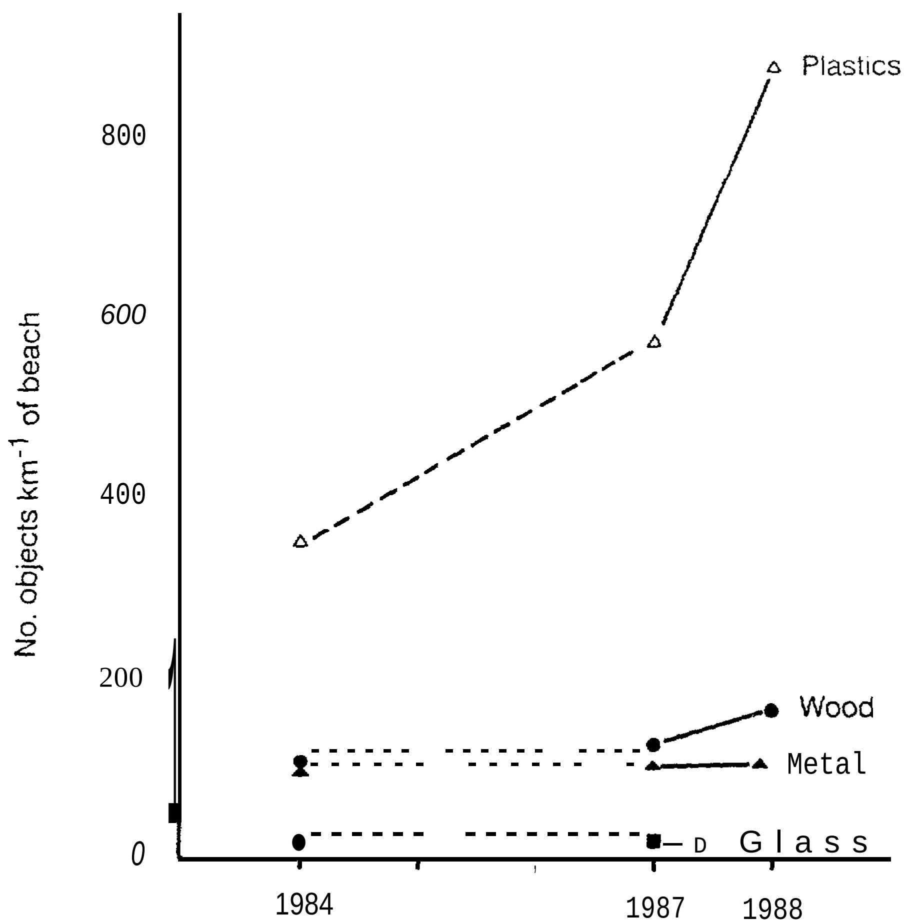
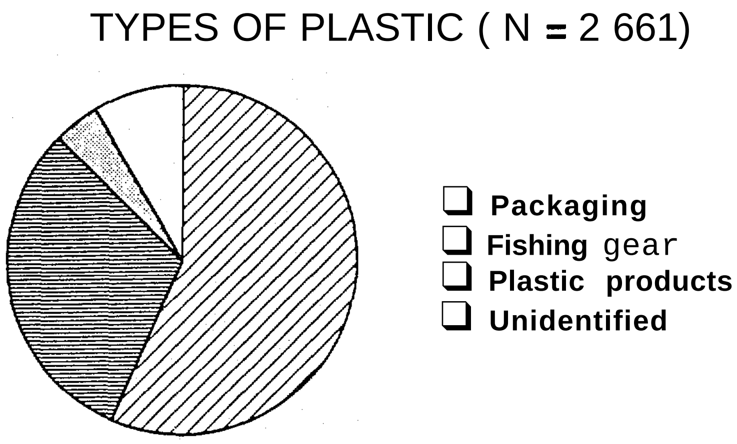


Figure 2, --The densities of various types of stranded debris at uninhabited Inaccessible Island during 1984 (Ryan 1987a), 1987 (Ryan and Watkins 1988), and 1988 (P. G. Ryan unpubl. data). Dashed lines between 1984 and 1987 indicate the lack of samples during this period.

than half of all plastic articles (57%), with fishing gear (netting, ropes, monofilament line, floats, traps, and fish boxes) making up most of the remainder (31%; Fig. 3). Almost half of the packaging was sheet plastic (bags and wrappings constituting 47% of packaging; Fig. 3), whereas polypropylene rope made up most of the fishing gear (85%).

The relative proportions of packaging and fishing gear among stranded plastic debris varied with distance from human settlements. Beaches in urban areas had a much greater proportion of packaging than either rural or island beaches (Fig, 4). This indicates that dumping of garbage from ships is not the only source of debris; urban areas in coastal South Africa also contribute significantly to marine debris loads (although selective removal of fishery-related products by beachcombers may contribute to the



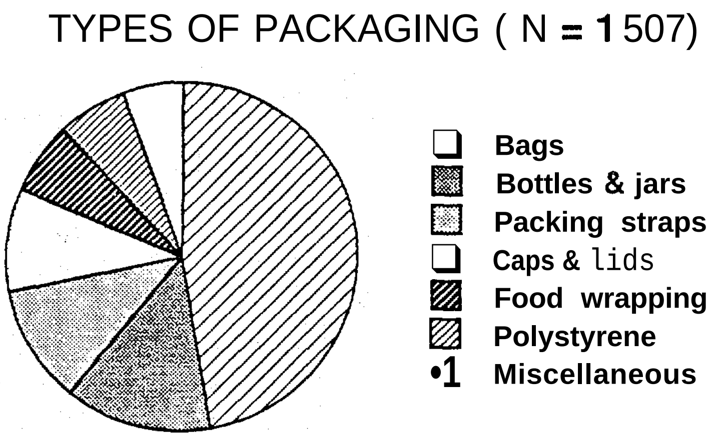


Figure 3. --The proportions (by number) of various functional groups of plastic articles found stranded on 50 South African beaches during June 1984.

differences). This is evident to anyone examining storm-water outlets draining urban areas, and concurs with current thinking that land-based sources may be more important contributors of debris to the marine environment than are vessels (Bean 1987, but see Pruter 1987; Wirka 1988). The mean density of packaging at urban beaches in South Africa (0.66 articles m^{-1} of beach) was greater than that at rural beaches (0.53 m^{-1}), although variances were great.

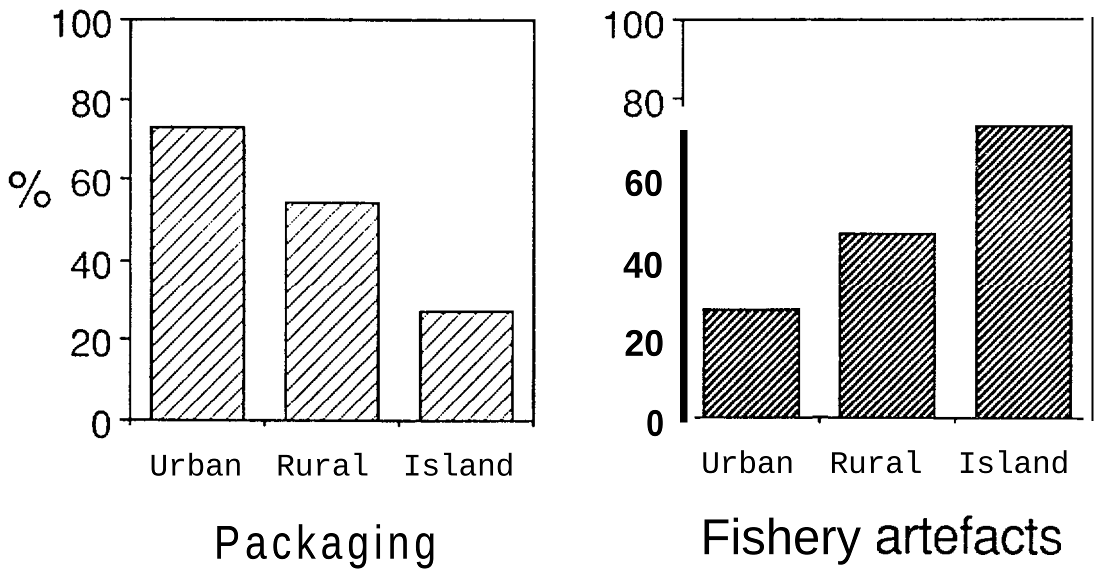


Figure 4. --The relative proportions (by number) of packaging and fishing gear stranded at urban (n = 26) and rural (n - 24) beaches in South Africa, compared with the situation at oceanic islands.

Virgin industrial pellets and fragments of plastic articles also are widespread and abundant on southern African beaches, with exceptional densities of up to 43,350 particles per meter of beach (88% industrial pellets, P. G. Ryan unpubl. data). Determining the origin of these items is more difficult than determining the origin of larger articles. However, at least some industrial pellets derive from local sources, where poor handling practices result in spillages, with transport to the sea in wastewater (pers. observ.).

Measures to Control Marine Debris in Southern Africa

The diverse nature of marine debris requires a multilevel approach to mitigating the problem. Four basic control tools are available: education, product substitution, recycling, and legislation. However, not all of these approaches are appropriate to tackle the different facets of the marine debris problem.

Ship-Based Sources

Ships are responsible for fishing gear (with the exception of monofilament-line and other wastes from shore-based anglers) and a proportion of general refuse (packaging and other operational wastes). This source of debris has received more attention than have land-based sources (e.g., Dixon and Dixon 1981; Horsman 1982; Low et al. 1985; Pruter 1987), and is the subject of several international conventions (e.g., Lentz 1987). South Africa has agreed in principal to sign Annex V of the International

Convention for the Prevention of Pollution from Ships (MARPOL), which came into force at the end of 1988 and prohibits the dumping of all plastic products at sea. This will be a major advance, and South Africa's ratification of Annex V warrants expediting. Priority should also be given to Namibia, which became independent in 1989, acceding to MARPOL.

However, there are problems associated with enforcing Annex V of MARPOL (e.g., Bean 1987) which necessitate that its implementation in South Africa be coupled with an intensive education campaign aimed at all mariners. A representation to this effect has been made to the South African committee working on incorporating Annex V into national legislation (Dolphin Action and Protection Group 1989). In the interim, favorable responses have been received from several merchant lines and the South African Navy in response to requests to reduce the amount of debris dumped at sea (Dolphin Action and Protection Group 1988a, 1988b, 1989).

One problem area not covered by Annex V of MARPOL is the accidental loss of fishing gear at sea. There is no simple solution to this problem, The dumping at sea of damaged nets and other persistent debris by fishing vessels has officially been outlawed in South Africa since 1986 (Dolphin Action and Protection Group 1988a). However, captains of commercial fishing vessels currently are paid bonuses based on the cleanliness of vessels returning *to* port. This is perceived by the industry as being responsible for considerable dumping at sea, an action that could be avoided by linking bonuses to the amount of persistent debris returned to shore.

Land-Based Sources

There are two main types of marine debris derived from land-based sources: virgin industrial pellets and the diverse array of manufactured articles , principally disposable objects such as packaging and convenience items (Bean 1987). The loss of industrial pellets into the environment is limited to the plastics industry, which in southern Africa is a fairly small target for control measures. There is only one polymer producer in southern Africa (linked to the oil-from-coal plant at Secunda in the Transvaal), and almost all converters (manufacturers that convert industrial plastics into user products) are based in South Africa (Fig. 5). The industry has been apprised of the problem and is sympathetic. The recent large increases in the price of virgin pellets apparently have resulted in improved handling practices leading to reduced losses, but this needs verifying, and, if necessary, supporting with punitive legislation against accidental spillages.

A more intractable problem is that of general refuse being washed or blown into the sea. This type of debris derives from such a variety of sources that there is no simple target for control measures (Pruter 1987). Ultimately, the only solution is to educate the public to dispose of refuse correctly. There are ongoing antilittering campaigns in most southern African states, but these are proving insufficient to the task. The problem is complicated by the difficulty of communicating to a broad cultural and economic spectrum simultaneously. South Africa has the potentially disastrous combination of a burgeoning third-world population shopping in first-world supermarkets for products wrapped in first-world packaging,

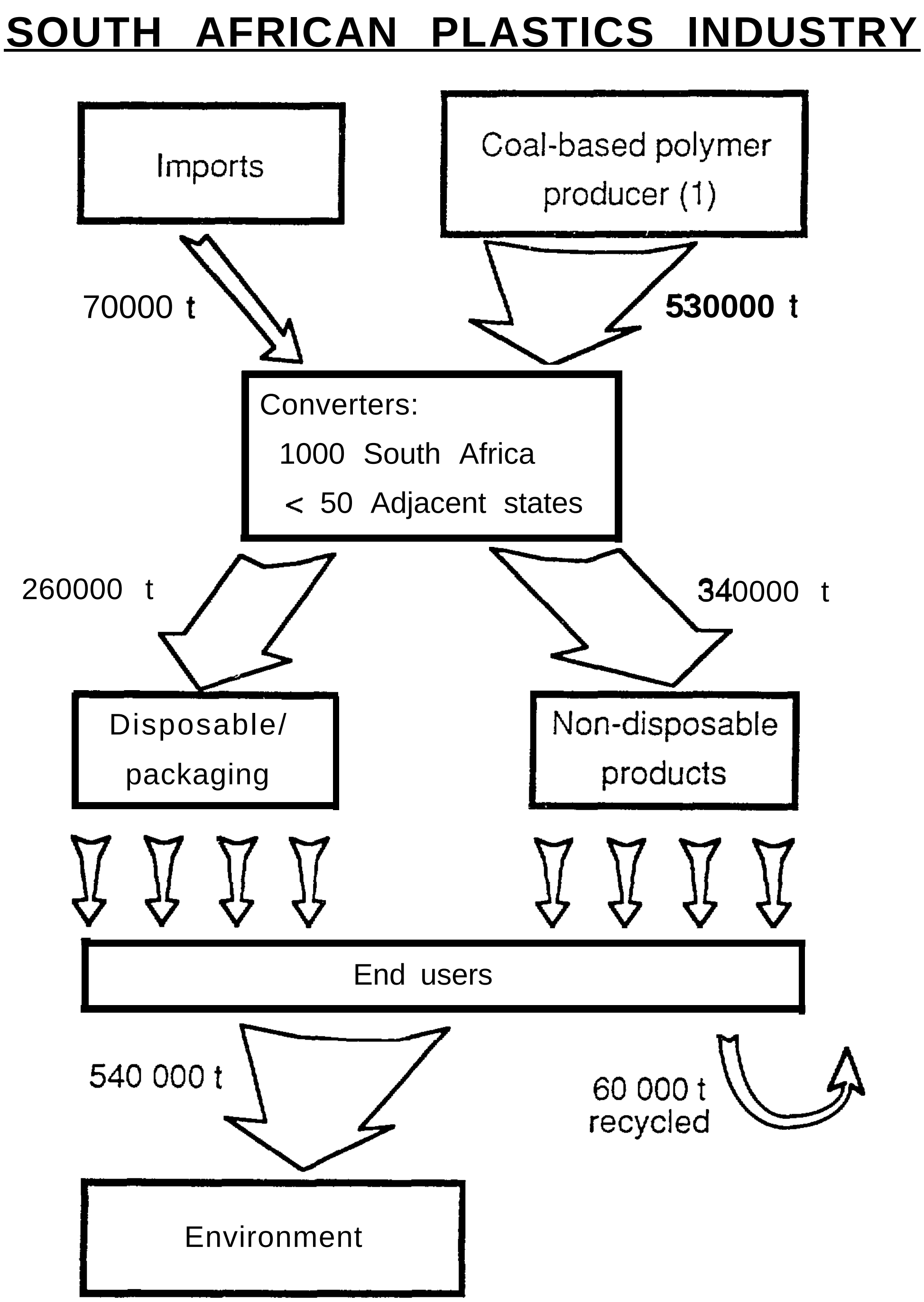


Figure 5.- -The status of the South African plastics industry during 1988, showing the magnitude (metric tons) of flows between producers, users, and the environment (derived from data from the Plastics Federation of South Africa).

mostly plastic. Some 20% of South Africans live adjacent to urban areas in informal settlements where adequate waste disposal facilities are lacking. The same problem occurs in neighboring states such as Botswana and Namibia as a result of the large number of products imported from South Africa.

To counter these problems, attempts are being made to reduce the amount of plastic used in disposable applications (260,000 tonnes in South Africa in 1988, Fig. 5). This "source-reduction" approach (Wirka 1988) can be successful, judging by the small amount of litter found in Zimbabwe, where strict currency exchange regulations limit the use of plastics and almost all containers are returnable on a deposit basis. However, there is considerable industry resistance to such changes, despite support for a reduction in superfluous and environmentally damaging packaging by consumer bodies. Concerted public pressure is needed to stem the growth of plastics in disposable applications (Wirka 1988). At present, product substitution is preferred to the use of degradable plastics, which have attendant problems (e.g., Taylor 1979; Wirka 1988).

Almost 10% of South Africa's annual plastic production was recycled during 1988 (including factory scrap; Fig. 5), a greater proportion than that recycled in the United States (l%; Wirka 1988). One mixed-plastics recycling plant producing a wood substitute has recently been established in Cape Town, and there are several primary recycling operations throughout South Africa. However, there is much scope for further recycling, and incentives to return used plastics for recycling are likely to prove successful in limiting littering. There are problems associated with recycling plastics in southern Africa. The relatively small volume of material and the widely scattered markets render many recycling operations uneconomic. Also, in most areas of southern Africa, solid waste disposal using landfill sites remains by far the cheapest disposal technique, although groundwater contamination by leachates from landfills is a potential problem.

Legislation in South Africa is starting to address the problem of inadequate waste disposal. The recently promulgated Environmental Conservation Bill provides for heavy fines and, in some cases, jail sentences for littering and other disposal contravention. However, it is hoped that voluntary meaures taken by the business sector will obviate the need for further legislation. Awareness campaigns focusing public concern have had considerable success in promoting the use of more environmentally friendly products and practices (e.g., the phasing out of six-pack yokes and shrink-wrapped packaging for bricks, and the printing of warning labels on a variety of disposable plastic products; Dolphin Action and Protection Group 1989), but many problems remain to be solved. It is only through the whole-hearted support of the entire community that the marine debris problem can be diminished.

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INTERNATIONAL EFFORTS TO CONTROL MARINE DEBRIS IN THE ANTARCTIC

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ABSTRACT

Since much of the Antarctic, including the surrounding seas, remains in a relatively pristine state, the monitoring of environmental changes in this area often provides early warning of hazardous global phenomena, e.g. , the stratospheric depletion of ozone. Reacting to a U.S. initiative, members of the Commission for the Conservation of Antarctic Marine Living Resources have taken steps to monitor the potential problem of marine debris, particularly from fishing operations. The Commission is joining with the Scientific Committee for Antarctic Research in establishing a program to monitor the effect of plastic pollution and entanglement on marine animals. The initiatives undertaken to establish monitoring programs for marine debris, the results to date, the reasons for their success and future needs in the Antarctic are discussed in this review.

INTRODUCTION

The 1984 Workshop on the Fate and Impact of Marine Debris provided ample warning that marine debris of terrestrial and shipborne origin was widespread in the marine environment and was apparently capable of contributing substantially to increased mortality of marine life (Shomura and Yoshida 1985). Of particular concern was the implication of debris arising from fishing operations (including lost or discarded net fragments, plastic packing bands, lines, and rope) in the harmful entanglement of substantial numbers of animals from many North Pacific populations of pinnipeds: northern fur seal, *Callorhinus ursinus* (Scordino 1985); Steller sea lion, *Eumetopias jubatus* (Calkins 1985); northern elephant seal, *Mirounga* augustirostris, California sea lion, *Zalophus californianus*, and harbor seal, *Phoca vitulina richardsi* (Stewart and Yochem 1985); and Hawaiian monk seal, *Monachus schuainslandi* (Henderson 1985). Fowler's (1985 1987) analyses of the substantial database for northern fur seals even suggested that the mortality of fur seals due to entanglement may be contributing significantly to declining trends (4-8% per year since the mid-to-late 1970's) of the population on the Pribilof Islands.

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

To begin addressing the uncertainties surrounding the marine debris problem while mitigating the known impacts, the 1984 workshop recommended, among other things, that educational efforts be undertaken to advise user and interest groups of the nature and scope of the issue. It was thought appropriate to include relevant international groups in this educational approach. The 1984 workshop also agreed that additional efforts should be undertaken to establish the severity of the debris problem in areas other than the North Pacific. Consequently, the stage was set for aggressive initiatives at several international forums to determine if the marine debris problem was occurring in other ocean basins.

Given the apparent adverse impact of marine debris, especially from fishing operations, upon North Pacific pinniped populations, it seemed reasonable to focus attention upon the Antarctic, where large populations of pinnipeds also occurred. In response to the establishment of a substantial international trawl fishery in the Antarctic during the 1970's, the Convention and Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) had come into force in 1982. The United States was a founding member of CCAMLR and brought the marine debris issue to the Commission's attention at its third annual meeting, in September 1984, 4 months after the convening of the marine debris-workshop.

U.S. ANTARCTIC INITIATIVES

Organization and Mandate of CCAMLR

The CCAMLR is a unique international agreement which implements an ecosystem approach to the conservation and management of marine living resources found in the Antarctic, The CCAMLR convention area includes the marine area south of the Antarctic Convergence, the boundary between lat. 48° and 60"s which separates cold Antarctic waters from warmer subantarctic waters (Fig. 1). The area south of this boundary is considered the Antarctic marine ecosystem. The convention applies to "the populations of finfish, mollusks, crustaceans, and all other species of living organisms, including birds, found south of the Antarctic Convergence" (Anonymous 1988a) .

The CCAMLR currently comprises 20 member nations, and an additional 4 nations have acceded to the convention but have not yet been accorded membership (Anonymous 1988a). The major operational units which undertake the convention's responsibilities (Fig. 2) are the Commission for the Conservation of Antarctic Marine Living Resources (the "Commission") and the Scientific Committee for the Conservation of Antarctic Marine Living Resources (the "Scientific Committee"). The work of these bodies is facilitated by a permanent secretariat which resides at CCAMLR headquarters in Hobart, Tasmania, Australia.

The convention mandates a management regime which ensures that harvesting of Antarctic species, such as finfish and krill, is conducted in a manner that considers ecological relationships among dependent and related species. Article II of the convention specifically requires the Commission *to* follow four basic principles of conservation (Sherman and Ryan 1988):

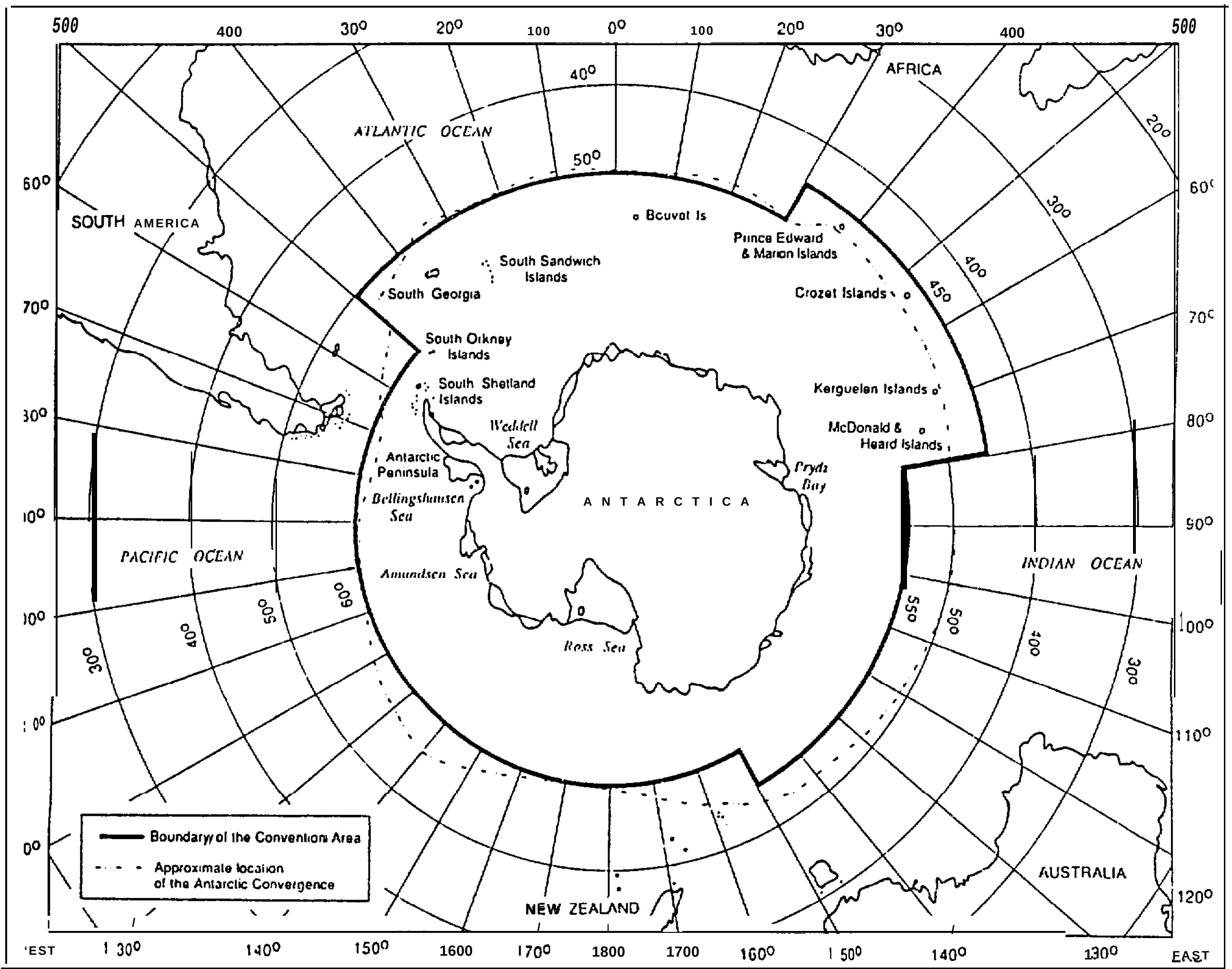

Figure 1. --Boundary of the area under the jurisdiction of the Convention for the Conservation of Antarctic Marine Living Resources (Anonymous 1988a).

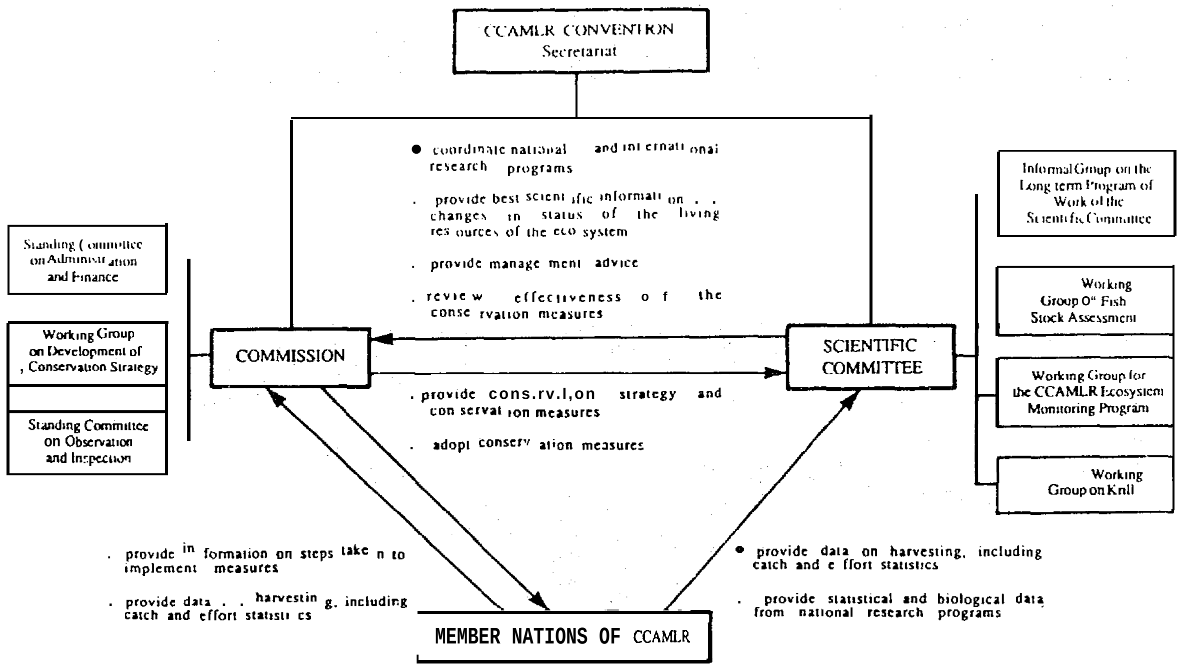

Figure 2..--Organizational structure of the Convention for the Conservation of Antarctic Marine Living Resources (after Sherman and Ryan 1988).

1. To prevent any harvested population from falling below the level that ensures the greatest net annual increment to stable recruitment;

2. to maintain the ecological relationships between harvested, dependent, and related populations of Antarctic marine living resources;

3. to restore depleted populations; and

4. to prevent or minimize the risk of changes in the Antarctic marine ecosystem that are not potentially reversible over two or three decades.

It was within this ecosystem context that the United States was able to raise the marine debris issue. In particular, the fourth principle gave rise to a powerful argument that the Commission must act to prevent irreversible changes in the Antarctic marine ecosystem which might arise from harvesting activities, including the loss or disposal of debris resulting from those activities. At least the Commission found itself compelled to give the issue due consideration when the United States introduced it at the 1984 annual meeting.

U.S. Proposals and CCAMLR Response

1984 Initiative

In 1984, the U.S. delegation submitted and the Commission considered a paper entitled "Assessment and avoidance of incidental mortality of Antarctic marine living resources." This document indicated that, while there did not seem to be any problem with entanglement of animals in lost or discarded fishing gear and other marine debris in the convention area, there was growing evidence in other areas, e.g., the North Pacific, that significant numbers of nontarget marine organisms were being caught and killed in such debris, as well as being caught and killed incidentally during certain fishing operations. The Commission agreed with these conclusions, and asked its members to undertake steps to study and assess the possible sources, fates, and effects of marine debris in the convention area, including (Anonymous 1984):

- reviewing and reporting on past encounters with marine debris at sea or at coastal research stations;
- reporting on the nature of problems arising from debris such as fouled propellers or entangled animals, and
- periodically surveying beaches at research stations or other areas to ascertain the types, quantities, and sources of debris accumulating there.

The Commission also agreed that members should report on the number of birds, marine mammals, and other nontarget species taken incidentally during fishing operations. Moreover, members were asked to inform their nationals of international and national laws prohibiting or restricting the disposal of netting and other potentially hazardous materials at sea and to report on measures taken to assess, avoid, and mitigate incidental mortality of Antarctic marine life. Finally, it was agreed to include this item on the agenda for the 1985 meeting and to consider the desirability of marking fishing gear for identification purposes, as well as restricting the use of gillnets in the convention area.

In 1985, the Commission received formal reports from four members, including the United States, on steps taken in response to the basic monitoring program established in 1984. A number of oral reports were received as well, and the United States submitted a preliminary report of the proceedings of the 1984 Workshop on the Fate and Impact of Marine Debris. Based upon this information, the Commission again concluded that there was no evidence that significant quantities of fishing gear, binding material, or other hazardous debris had been or were being lost or discarded in the convention area (Anonymous 1985). However, given the compelling evidence for such debris in other ocean areas, including areas adjacent to the convention area, and of the extent of its harmful effects to marine life and of its hazards to navigation, the Commission agreed to continue its monitoring program.

The Commission further agreed that members should continue studying the feasibility and desirability of marking fishing gear and of maintaining inventories of such material brought into the convention area. However, given that there were no substantial gillnet operations in the area at the time, the Commission concluded that prohibiting the use of gillnets as a preventative measure could interfere unnecessarily with the Commission objective of assuring the rational use of resources, The Commission did agree to keep the matter under review.

1986 Initiative

At the 1986 meeting, the Commission received reports from members on monitoring results and the United States submitted a paper proposing additional steps for ensuring that accidental and incidental mortality of marine life did not become a problem in the convention area. While the information provided continued to indicate that incidental and accidental mortality of living marine resources did not appear to be a problem, the Commission recognized that such mortalities, including those resulting from entanglement in or ingestion of marine debris, could interfere with efforts to achieve the objectives of the convention (Anonymous 1986). As a consequence, the Commission agreed to new measures to reduce or prevent the at-sea discarding of fishing and other hazardous debris:

- Members would take steps to ratify and implement both optional Annex V of the 1978 Protocol to the International Convention for the Prevention of pollution from Ships (MARPOL) and the International Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention); and

- the secretariat would prepare drafts of an information brochure to advise fishermen, researchers, and others working in the convention area of the hazards of marine debris; and of a placard for displaying on ships which listed the "do's and don'ts" for storing, handling, and discarding refuse.

The Commission agreed to continue its monitoring provisions and the collection of incidental catch data. Moreover, it agreed to undertake three new monitoring steps (Anonymous 1986):

1. recording and reporting fishing gear lost in the convention area;

2. if feasible, collecting and safely disposing of marine debris encountered; and

3. collecting samples of marine debris along with pertinent data, including species and numbers of entangled marine animals, for archival by the secretariat.

At the 1987 meeting, progress on all agreed monitoring measures was reviewed, and the Commission closely examined the information on lost or discarded fishing gear obtained from national reviews of such data and from beach surveys in the convention area. Although several members observed no marine debris or entanglement problems, others reported sightings of debris consisting of fishing buoys, gas bottles, plastic containers, trawl net fragments, and plastic packing bands (Anonymous 1987). Moreover, two fur seals, *Arctocephalus gazella*, were seen entangled in derelict fishing nets and a third in longline gear. The Commission agreed not only to continue all elements of the monitoring program, including new steps agreed upon in 1986, but also to establish the issue of incidental/accidental mortality of Antarctic marine living resources as a standing item on the agenda for subsequent annual meetings.

The Commission also reviewed in 1987 the secretariat's drafts of an information brochure and a placard for display on vessels operating in the convention area. The secretariat was authorized to publish the agreed texts and members were urged to give these the widest possible circulation. Moreover, given that Annex V to the MARPOL Convention would prohibit or control the disposal of debris arising from fishing operations in the convention area, members were again specifically urged to ratify and implement this international measure.

In 1988, the Commission received further reports from members regarding loss of trawl cod ends and sightings of other derelict debris, including net fragments and packing bands. Moreover, five fur seals, *A. gazella*, were seen entangled in derelict fishing gear and two adult male fur seals died after becoming entangled in trammel nets (Anonymous 1988b). The Commission agreed to continue all elements of its monitoring program but noted that the reporting of incidental mortality as recommended in 1986 had been inadequate so far.

Also in 1988, the secretariat published and distributed the information brochure and placard for display on the ships of all member nations. As requested by the Commission, the U.S. has made these available to scientists and others working in the Antarctic and to the operators of vessels entering the convention area, including the National Science Foundation, the U.S. Coast Guard, and the National Oceanic and Atmospheric Administration.

FUTURE NEEDS AND ACTIVITIES

Improving Monitoring Efforts

The assumption is often made that much of the Antarctic, including the surrounding seas, remains unsullied by human activities. Consequently, if significant environmental changes are observed there, it is often presumed that these may be resulting from significant environmental perturbations occurring elsewhere on the globe, e.g., the stratospheric depletion of ozone resulting from the production and use of chlorofluorocarbon compounds in the Northern Hemisphere (Anonymous 1988e). The evidence reviewed so far by the Commission would tend to indicate that the marine debris problem in the Antarctic is minimal. That is, it would appear that the levels of debris discarded by vessels in the convention area or the amount brought in by circulation or by other means from other ocean basins have not yet been sufficient to generate major problems for Antarctic marine life.

However, recent information suggests that the level of CCAMLR's monitoring efforts to date may not have been sufficient to ascertain the levels and consequences of marine debris effectively. The Bird Biology Subcommittee of the International Council of Scientific Unions, Scientific Committee for Antarctic Research (SCAR) concluded that a high proportion of Antarctic seabirds had ingested plastic particles, that the incidence was increasing in at least some species in the Southern Ocean and that the problem was particularly acute for procellariform species which accumulate rather than excrete plastics (Anonymous 1988d). Van Franeker and Bell (1988) and Ainley et al. (1990) suggested that the source of the ingested plastic is from wintering areas outside the Antarctic. The SCAR Group of Specialists on Seals also noted that entanglements of Antarctic fur seals in discarded fishing gear had been reported from several areas around the Antarctic, including South Georgia, the South Shetland, Crozet, Marion, Heard, and Bouvet Islands (Anonymous 1988c). Consequently, one might conclude that CCAMLR has so far been seeing only the tip of the marine debris iceberg.

Taking note of CCAMLR's early monitoring initiatives in this area, both SCAR groups requested the Commission's assistance in examining the problem further. The SCAR's Bird Biology Subcommittee requested that CCAMLR consider initiating programs to monitor the level and effects of plastic pollution in subantarctic and Antarctic seabirds, considering both ingestion of plastic particles and entanglement. The SCAR Group of Specialists on Seals also requested that CCAMLR seek detailed information on the frequency of occurrence and nature of entanglement events involving seals in order to identify the causes of entanglement and trends in the frequency and extent of such entanglement over time (Anonymous 1988b).

At its 1988 meeting, however, the Commission noted that its monitoring program had three shortcomings relevant to SCAR's requests (Anonymous 1988b):

1. It did not address the problem of ingestion of plastics.

2. It did not specifically provide for quantitative and detailed reports of entanglement when fishing operations were not directly involved.

3. It may not provide adequately detailed information on incidental mortality during fishing operations to enable assessment of the problem or to monitor changes quantitatively.

To see if these shortcomings could be rectified so that assistance might be given to SCAR, the Commission authorized the chairman of the Scientific Committee to open a dialogue with the relevant SCAR groups (Anonymous 1988b). In particular SCAR's advice was sought (and provided at the 1989 meeting (Anonymous 1989)) on how the levels and effects of ingestion of plastics by Antarctic seabirds could be monitored, how quantitative surveys could be conducted to determine the incidence, causes, and effects of marine mammal entanglements, and how the CCAMLR system of reporting incidental mortality might be improved in order to precisely determine the incidence, causes, and effects of such mortality. This new interaction between the Commission and SCAR should pave the way for greatly improving CCAMLR's pioneering efforts to monitor the marine debris problem.

Improving the Coordination of Efforts

The CCAMLR's exhortations on behalf of MARPOL apparently paid off, since Annex V came into force in December 1988 (Anonymous 1988e). It is now illegal for ships registered in the 35 ratifying nations, including the United States, to dump plastic debris such as that arising from fishing operations into the sea.

To become even more effective in controlling the marine debris problem in the Antarctic, it would seem desirable for the Commission to begin coordinating its actions with the International Maritime Organization (IMO). The IMO is the specialized agency of the United Nations which oversees implementation of MARPOL and the London Dumping Convention. This possible coordination, along with the pending cooperation between the Commission and SCAR, points out a growing need for an effective coordinating mechanism on this and other Antarctic issues.

In fact there has been a continuing debate among the Antarctic Treaty consultative parties (ATCP's) regarding the need for an Antarctic Treaty secretariat (Kimball 1987). The ATCP's favoring such a secretariat point to the increasing variety and complexity of issues being dealt with which require more numerous and more frequent communications within and between instruments of the Antarctic Treaty system, including CCAMLR, as well as with other relevant international organizations and elements of the outside world. The growing number of players becoming involved in dealing effectively with the issue of marine debris in the Antarctic (CCAMLR, SCAR, and IMO) may well provide another argument in favor of a secretariat.

DISCUSSION

Despite possible shortcomings and problems, it would appear that substantial progress has been made in trying to deal with the issue of marine debris in the Antarctic. The CCAMLR's monitoring program has evolved quite rapidly since the United States introduced the issue in 1984. Although the program is, perhaps, not yet as quantitative as some scientists would wish, the Commission is at least in a very good position to ascertain and evaluate trends in levels of debris and entanglements of marine life.

Under the convention, the Commission must take all of its decisions by consensus, which has led at times to a lowest-common-denominator-syndrome and resulted in somewhat ineffectual measures. So, the progress made with respect to marine debris might seem all the more remarkable unless one considered it in the light of the unique nature of the convention itself. The CCAMLR not only requires an ecosystem approach to the conservation and management of living marine resources but also sets forth the principle that the Commission must act to prevent or minimize irreversible changes to that ecosystem. More than anything, these unique provisions probably account for the success achieved on the issue.

The philosophy behind CCAMLR provides great flexibility and a basis for dealing with many kinds of marine conservation issues, not just those dealing with the use of resources. This is a powerful tool, and the convention should be taken seriously as a model for all future resource use conventions and agreements in other ocean areas.

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COOPERATIVE RESEARCH ON PETROLEUM POLLUTION IN THE CARIBBEAN: THE CARIPOL PROGRAM

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ABSTRACT

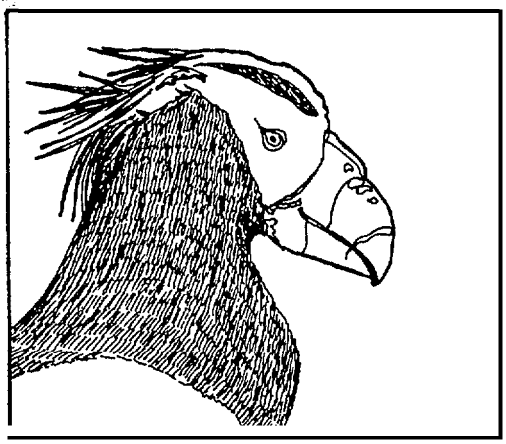
The CARIPOL program is a cooperative regional effort to assess the state of pollution of the marine environment in the Caribbean and adjacent regions. In its initial phase, CARIPOL has concentrated on the assessment of petroleum pollution through the monitoring of three easily determined variables: the occurrence of tar aggregates on beaches, of floating tar at sea, and of dissolved or dispersed petroleum hydrocarbons. A data base of greater than 7,000, 680, and 1,460 data points, respectively, for the three variables has been accumulated through submissions from 14 countries in the region.

Tar on beaches is a serious problem in the region, especially in the Windward islands, the Cayman islands, and the archipelago of Aruba, Curacao, and Bonaire where loads of up to 1 kg of tar/m of beach front have been reported. Other affected areas include the ease coast of Florida, the Yucantan peninsula, and Campeche Sound. The occurrence of floating tar has been closely correlated with tanker traffic in areas such as the south coast of Puerto Rico and the Straits of Florida. Dissolved and dispersed petroleum hydrocarbons reach critical levels only in enclosed waters such as bags and harbors subject to intense maritime traffic or industrial petroleum sites.

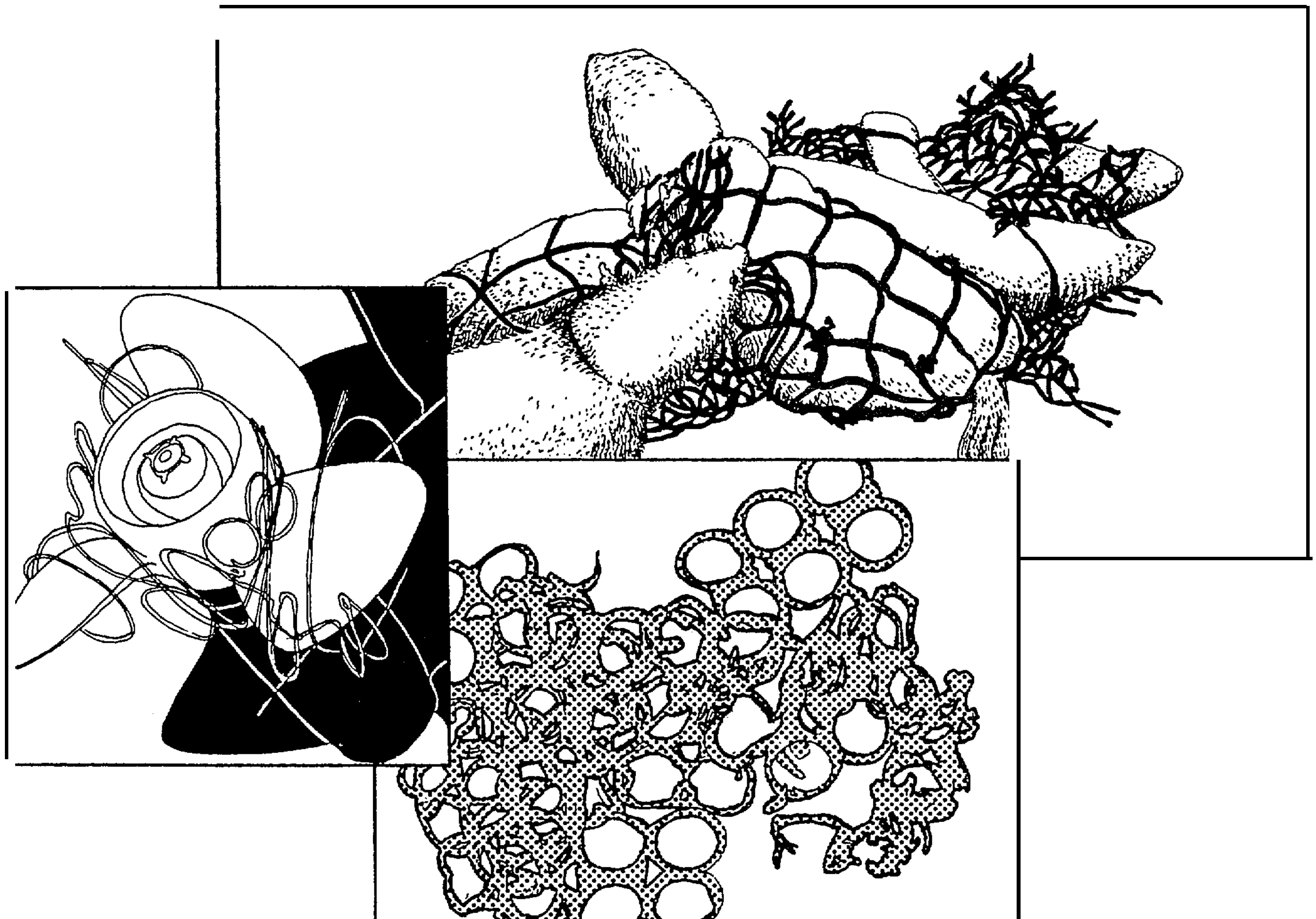
The CARIPOL program has now embarked upon a second phase to assess the accumulation of petroleum hydrocarbons in sediments and organisms. Initial results indicate that although these compounds are rapidly degraded when released to the water, they may persist for extended periods upon reaching marine sediments.

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

SESSION I



AMOUNTS, TYPES, DISTRIBUTION, AND SOURCES OF MARINE DEBRIS



QUANTITATIVE ESTIMATES OF GARBAGE GENERATION AND DISPOSAL IN THE U.S. MARITIME SECTORS BEFORE AND AFTER MARPOL ANNEX V

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ABSTRACT

Annex V of MARPOL 73/78 is regarded as an important instrument for reducing the amounts of plastics and other debris discarded into the ocean. Estimates of the aggregate quantities of garbage discarded are outdated, however, and represent only order of magnitude efforts. In this paper, the authors present updated estimates of the amounts of plastics and other debris generated in the U.S. maritime sectors.

The analysis covers both public and private sectors, including merchant marine vessels active in U.S. trade; commercial fishing vessels; recreational boats; research and industrial vessels; U.S. Navy, Coast Guard, and Army ships; and vessels and structures associated with offshore oil and gas operations . Current disposal practices as well as disposal practices under Annex V are analyzed and used to develop estimates of how the disposition of garbage generated at sea, i.e., the amounts dumped overboard, brought back to shore for disposal, and incinerated, will change under the new regulations .

INTRODUCTION

Two questions which underlie the debate over the U.S. ratification of MARPOL Annex V are: (1) How much garbage is being dumped overboard from vessels? and (2) What effect would the specific restrictions contained in Annex V have on the overall marine debris problem? Throughout the numerous congressional hearings which led up to U.S. ratification, only one source of aggregate data, a 1975 study by the National Academy of Sciences (NAS), was identified which addressed these questions. That study, however, examined the entire world fleet and included sources of debris which will not be regulated by Annex V (Table 1). It also made no attempt to account for actual disposal practices, reporting instead on the quantities of garbage "potentially" dumped (NAS 1975).

The present study utilizes current information for the U.S. maritime sectors to develop current and more comprehensive estimates of garbage

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Table 1. --Global marine litter estimates (National Academy of Science 1975).

Garbage types and sources	Ton/year	Percent
Sources regulated under MARPOL Annex V		
Crew-related wastes		
Merchant marine	11,000	1.8
Passenger vessels	2,800	0.4
Commercial fishing	34,000	5.4
Recreational boats	10,300	1.6
Military	7,400	1.2
Oil drilling and platforms	400	0.1
Commercial wastes		
Merchant cargo wastes or dunnage	560,000	89.5
Annex V subtotal	625,900	100.0
Sources not regulated under MARPOL Annex V		
Fishing gear loss	100	1.0
Loss due to catastrophe'	10,000	99.0
Non-Annex V subtotal	10,000	1000.0
Total	636,000	100.0

'Includes debris from shipwrecks or marine storms.

quantities. The main components of the model are: vessel populations, entrances to U.S. ports, crew sizes, garbage generation factors, and plastics as a percent of total garbage. It also fills a gap left in previous studies by addressing historical shipboard disposal practices and changes in practice expected to result from implementation of Annex V. It must be noted, however, that few direct measurements of garbage generation and disposal practices exist. The methodological improvements offered in this study are based on updated data where they exist, and on substantial anecdotal information collected throughout the course of broader regulatory studies of MARPOL Annex V (Eastern Research Group (ERG) 1988a, 1988b).

The study first reviews information related to the sources, types, and quantities of garbage generated in the various maritime sectors. Data on per capita garbage generation, crew size, voyage length, and annual ship utilization factors are used to derive estimates of per voyage, per vessel, and annual aggregate garbage quantities generated. Estimates are made for the following sectors:

- Merchant shipping.
- Commercial fishing.

- Commercial passenger vessels.
- Recreational boating.
- Offshore oil and gas operations.
- Research and other miscellaneous vessels.
- U.S. Navy, Coast Guard, Army, and other government vessels.

An analysis of historical garbage disposal practices in these sectors is used to estimate the pre-Annex V garbage quantities dumped overboard, brought back to shore for disposal, or burned in marine incinerators. Under MARPOL Annex V, ships may be forced to alter their current disposal practices. An analysis of options available for compliance with Annex V is used to derive the post-Annex V disposition of vessel garbage.

GARBAGE ESTIMATION PARAMETERS

This section reviews the types and quantities of garbage generated in the maritime sectors. This information is combined with data on vessel populations, crew sizes, and voyage lengths from the supporting statistical section to produce estimates of the per voyage, per vessel, and aggregate annual garbage quantities generated.

Types of Garbage Generated

Several types of garbage are generated by vessels operating at sea. In this study, "domestic" garbage refers to general garbage such as galley refuse (food wastes, food packaging materials) and garbage from the hotel areas of the vessel (discarded items such as smoking materials and packaging, shampoo bottles, and razors). Wastes associated with normal ship operations, such as rags and containers, are also included. Some vessels generate an additional amount of "commercial" waste. Examples include cargo dunnage, spent fishing gear, and disposable or single-use oceanographic research instruments. These are discussed separately.

Domestic Wastes

Several sources of information on the quantities of garbage generated by ships are available. A series of studies done for the Intergovernmental Maritime Consultative Organization, the predecessor to the International Maritime Organization (IMO), are judged to represent the best available estimates (IMO 1987). These rates, representing per capita daily quantities, were reported as follows:

- Harbor vessels--1.0 kg (2.2 lb).
- Inland and coastal vessels--1.5 kg (3.3 lb).
- Oceangoing cargo vessels--2.0 kg (4.4 lb).
- Oceangoing cruise vessels--2.4 kg (5.3 lb).

As shown, the rates vary depending upon the type of vessel and where the vessel operates.

These rates appear consistent with those obtained elsewhere. The U.S. Navy, for example, examined garbage generation aboard naval ships in 1971 (Naval Ship Engineering Center 1971) and again in 1988 (L. Koss and Lt. Mullenhard, U.S. Navy, pers. commun. 1988), and reported estimates of 1.39 and 1.43 kg/person/day (3.05 and 3.15 lb), respectively. On land, the U.S. Environmental Protection Agency (EPA) estimates that each person generates an average of 1.82 kg (4.0 lb) of garbage per day (National Solid Waste Management Association (NSWMA) n.d.). Thus, the rates from the IMO studies appear consistent with those obtained elsewhere.

In this study, the IMO rates for oceangoing cargo and cruise vessels are applied respectively to cargo and passenger vessels which operate over the open ocean. The IMO rate for inland and coastal vessels is applied to crafts which travel inland or along the coastline.

Commercial Wastes

Several classes of vessels generate wastes associated with their commercial activities. These wastes are distinct from any operational wastes generated through normal vessel repair and maintenance activities, which are included under the category of domestic wastes.

Commercial cargo wastes or dunnage.--The term "dunnage" covers materials such as timber, plywood, pallets, rope, and plastic sheeting used to protect, separate, and secure cargo carried in break-bulk form. In the study (NAS 1975), these types of cargo wastes dominated the aggregate waste quantity estimates (Table 1). Since the mid-1970's, however, the trend towards containerization, and changes in cargo handling methods, are believed to have greatly reduced the amount of dunnage used. Cargo carried by containerships or other types of intermodal ships (barge carriers, roll-on/roll-off) is generally unloaded for transshipment in port without being disturbed. According to officials of the American Institute of Merchant Shipping, therefore, the "vast majority" of cargo ships now produce no dunnage waste (J. Cox, American Institute of Merchant Shipping, pers. commun. 1988).

The quantities and types of dunnage still used in general cargo trade vary, and depend upon the type of cargo being carried. Break-bulk shipments of food products, for example, use mainly cardboard for separation and protection of the cargo. For a highly explosive shipment of ammunition, however, extensive wooden encasements are constructed *to* protect against movement of the cargo. In such cases, tens of thousands of board feet of lumber may be used. Palletized cargoes may be shrink-wrapped and secured with steel or plastic strapping, but these are not normally removed prior to final delivery at the customer's facilities. Lumber and plywood are the most common materials used.

Marine terminal operators familiar with the loading and unloading of break-bulk ships indicate that very little plastic waste is generated. One reported use for plastic is to capture leaks of moisture or hydraulic fluids in the vessel's cargo hatches. This plastic would likely be removed when the vessel is being unloaded. As indicated, plastic shrink-wrap is used with palletized cargo, but this is generally not removed either on board the ship or in port.

Estimates of per-vessel and aggregate dunnage quantities are difficult to make based upon the limited data. The study (NAS 1975) estimated that general cargo ships generate up to 285 tons of dunnage per year. This estimate contrasts significantly with information provided by marine terminal operators and shipping interests. Due largely to the trend towards containerization of cargo, there appears to be much less dunnage used today. Relying on current reports, this study assumes that two-thirds of the general cargo vessels entering U.S. ports generate dunnage in the form of lumber, one third generate only cardboard; and that 10%-generate plastic waste. The quantities used are estimated as follows:

- Lumber--48.6 m^3 (approximately 20,000 board ft) per vessel entrance.
- Cardboard--23.6 m^3 (30 yd^3) per vessel entrance.
- Plastic--assumed to be generated by only 1 of every 10 break-bulk ships entering U.S. ports, in minimal quantities of 0.12 m^3 (4.0 ft^3) per entrance.

As the estimates presented later will show, under these assumptions the amount of waste generated by general cargo ships represents only a small proportion of the total garbage volume regulated by Annex V. Furthermore, overall estimates of plastics are not particularly sensitive to assumptions regarding dunnage volumes.

Fishing gear wastes.--Commercial fishing activity also contributes to the problem of marine debris, and to plastics in particular. Whether trawl gear, set nets, or lines are being used, occasional fouling of equipment, such as the tearing or twisting of nets and lines, will occur. During repair, portions of nets, excess line, floats, and other gear wastes may be generated. All such materials are nowadays made of synthetics, and are prohibited from disposal under Annex V. In addition to these items, substantial quantities of fishing gear are also lost accidentally. Annex V, however, does not cover this category of debris, hence no estimates are made here.

Limited information is available on the amounts of gear waste generated. The Foreign Fisheries Observer Program, National Marine Fisheries Service (NMFS) has monitored fishing gear repair operations on board foreign vessels active in Alaskan waters. Berger and Armistead (1987) analyzed data from this program and found that fishing gear repair operations took place about once every 4.9 days. The U.S. vessels active in the same fisheries report a similar incidence of gear repair (J. Gnagey, Alaska Trawl Fisheries, pers. commun. 1988; Z. Grader, Pacific Coast Federation of Fishermen's Associations, pers. commun. 1988). Discarded webbing was found to be typically small, with only 21.2% of pieces deemed to be "of a mesh size or area thought most likely to entangle marine mammals" (Berger and Armistead 1987). Some 57.9% of discarded pieces consisted of "primarily loose strands of twine or pieces with a mesh size of less than 100 mm."

Working with these data, the amount of gear waste generated over a typical cruise is estimated to be relatively small. Assuming that (1) the average piece of webbing produced during net repair is 1 m^2, (2) webbing is composed of 15 mm diameter twine (Uchida 1985) , and (3) the incidence of net repair and discard is twice per week, than the volume of waste generated over even a 30-day fishing expedition would amount to just over 0.12 m^3 (4 ft^3) of net material (ERG estimates).

Evidence suggests that 'these estimates from the Alaskan fisheries may represent an upper bound on the frequency and amount of fishing gear waste discarded. Beach surveys have found the concentration of fishing gear waste off the Alaskan islands to be among the highest noted anywhere (e.g. , Merrell 1985). Discussions with fishery representatives elsewhere in the United States have indicated that net repair operations while at sea are relatively less common. Moreover, net fragments and floats in other fisheries are reported to be retained on board for use in repair operations, rather than discarded. Spare nets may also be carried in order to avoid at-sea repairs completely (ERG 1988a, 1988b). In this study, it is assumed that the average volume of fishing gear. waste generated in all U.S. fisheries is half of that calculated for Alaska. An estimate of 0.03 m^3 (1 ft^3) of gear waste per week at sea is assumed.

Nongear fishing wastes. --Certain fisheries produce additional quantities of wastes due to their use of specialized fishing techniques. These include longline fishing, which uses packaged bait (B. Alverson, Longliner Vessel Owners Association, pers. commun. 1988), and the herring fishery, which utilizes quantities of packaged salt (J. Kaelin, Associated Fisheries of Maine, pers. commun. 1988). Longline bait is sold frozen, with packages wrapped in plastic, packed in cardboard boxes, and secured with plastic strapping. Chemical light or Cyalume sticks are also used to attract fish, These sticks, about the size of a pencil, are themselves made of plastic. Salt used in the herring fishery comes in large plastic bags.

Available estimates of marine waste disposal do not address this source of waste. The Center for Environmental Education (CEE) reports that longline gear is used in at least five different fisheries (CEE 1986), and that longline vessels can bait up to 5,000 hooks per day. In order to capture the additional wastes produced by vessels in these fisheries, it is assumed in this study that they generate twice the normal volume of fishing gear waste.

Research vessel wastes. --Research vessels may generate additional plastic wastes in the form of packing materials from research instruments brought on board, and from disposable measuring instruments used in monitoring oceanic experiments. Based on discussions with representatives at various research institutions, an additional 0.12 m^3 (4 ft^3) of plastic waste per voyage is assumed.

Dry Versus Wet Garbage

The nature of the MARPOL Annex V regulations makes it necessary to estimate separately the amounts of "wet" garbage (food waste) and "dry" garbage generated. Many vessels are expected to separate plastics from their dry garbage and then dispose of the remainder while in areas where no Annex V restrictions apply. Some, however, may have to retain all dry garbage for onshore disposal (and even wet garbage, in some cases) depending on whether they operate in Annex V "special areas" or in coastal waters. (Special areas currently include the Mediterranean Sea, Baltic Sea, Red Sea, Black Sea, and Persian Gulf Areas; Table 2.)

The dry garbage component of the overall solid waste stream is estimated based on the recent U.S. Navy study (Koss and Mullenhard, pers. commun. 1988). In this study, dry garbage accounted for 59.4% of domestic waste by weight, while wet garbage accounted for 40.6%. These percentages are similar to those found in the earlier, more extensive Navy studies, where the dry garbage component was estimated at 43.6%.

Plastics as a Percentage of Total Wastes

Annex V places a complete prohibition on the overboard disposal of plastics. Estimates of the percentage of the overall vessel waste stream accounted for by plastics are needed in order to develop projections of the quantity of garbage that may be brought back to shore for disposal.

The EPA estimates that plastics represent 6.5% (by weight) of all household and commercial solid waste on land (NSWMA n.d.). The relevance of this estimate to vessel operations is uncertain, however, because of likely differences in the types of waste generated at sea. In the national EPA estimate, paper and paperboard waste makes up 42% of the total, and yard waste accounts for another 16%. Garbage generated at sea is likely to contain much less paper waste and no yard waste. Under these assumptions, plastics would represent a larger share of the waste stream at sea than it would on land. At the same time, though, national estimates would include discards of durable plastic objects and industrial plastic waste, very little of which is generated at sea.

Studies done by the U.S. Navy in 1971 (Naval Ship Engineering Center 1971) and 1988 (Koss and Mullenhard, pers. commun. 1988) represent the only direct estimates of plastic wastes based on actual operating experience. In 1971, plastics were found to account for only 0.3% of total garbage by weight. This study covered numerous vessels and was used by the NAS in their estimates (NAS 1975). In 1988, however, the Navy found that the plastics share of total garbage weight had risen to 6.7%--an apparent twentyfold increase. It must be noted that the more recent study is based on an analysis of a single Navy vessel operating over a short (32-h) cruise. Thus, the figures may not be representative.

In reviewing the data from the Navy studies, the question of potential differences in plastics usage between Navy and other vessels arises. Navy vessels carry extensive electronic equipment on board which may be wrapped in plastic "bubble" wrap and other cushioning materials. This source of

Table 2.--Summary of MARPOL Annex V restrictions (International Maritime Organization 1987).

Garbage type	All vessels: Outside special areas[a]	All vessels: Within special areas[a]	Offshore platforms and associated vessels[b]
Plastics	Disposal prohibited	Disposal prohibited	Disposal prohibited
Floating dunnage, lining and packing materials	>25 nmi from land	Disposal prohibited	Disposal prohibited
Paper, rags, glass, etc., not ground	>12 nmi from land	Disposal prohibited	Disposal prohibited
Paper, rags, glass, etc., ground[c]	>3 nmi from land	Disposal prohibited	Disposal prohibited
Food waste, not ground	>12 nmi from land	Disposal prohibited	Disposal prohibited
Food waste, ground[c]	>3 nmi from land	>12 nmi from land	>12 nmi from land
Mixed refuse types	(d)	(d)	(d)

[a]Annex V special areas include the Mediterranean, Baltic, Red, and Black Seas, and the Persian Gulf Areas.

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

[c]Ground waste must be able to pass through a screen with mesh size *no* larger than 25 mm (0.1 in).

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

plastics is not generally present on board other types of vessels. Second, considerably more at-sea repair occurs on board Navy ships than aboard merchant marine or fishing vessels. Tools and replacement parts may be packaged in plastic, and parts themselves may be plastic. Wire and cable have plastic insulation. On the other hand, due to the large crew sizes, food supplies on board Navy vessels are generally purchased in bulk. The reduced packaging associated with this bulk purchasing would suggest smaller plastic generation rate. Navy vessels may, therefore, generate more plastics from operational sources, but less from galley refuse.

In the absence of any conclusive evidence on the amount of plastics contained in the ship's waste stream, the results from the most recent Navy study (Koss and Mullenhard, pers. commun. 1988) have been used. This study indicates that plastics represent 6.7% of all wet and dry solid waste, and 11.3% of dry solid waste, by weight. Additional studies of this nature relative to shipping and other maritime sectors would certainly be welcome.

Garbage Densities

Further analysis of garbage generation patterns requires estimates of the density of garbage. These are needed in order to convert the weight of a given accumulation of garbage to volume terms. At sea, it may be the volume of garbage, rather than its weight, that figures in decisions regarding disposal options.

Table 3 shows estimates of garbage density for shipboard types of garbage. It will be noted that no sources of data specific to plastics were identified. Studies done for the State of New York by Franklin Associates (V. Sellers, Franklin Associates, pers. commun. 1988) found that 1,000 kg (2,200 lb) of uncompressed plastic soda containers had an average volume of 20.8 m^3 (325 ft^3), suggesting a density of 48.1 kg/m^3 (3.07 lb/ft^3). Navy officials, however, have suggested that a much lower density of 15.4 kg/m^3 (1 lb/ft^3) is appropriate (Koss and Mullenhard, pers. commun. 1988). This would imply that plastics used on board ship weigh one-third as much as much as empty soda bottles--an apparently generous volume estimate. In the absence of any data specific to ships, however, the Navy's estimate of 15.4 kg/m^3 (1 lb/ft^3) is incorporated. Again, this estimate is the more generous of those available in terms of estimating the volume of plastics generated on board.

Table 3.--Estimates of density for shipboard-generated garbage.

Source of estimate and garbage type	Density	
	kg/m^3	lb/ft^3
Society of Naval Architects and Marine Engineers (1982):		
Dry rubbish	100.0	6.3
Dry garbage	120.0	7.5
Refuse, 70% wet	640.0	40.0
Food waste	400 to 1,000	25.0 to 68.8
Gassan (1978):		
Hotel solids	277.0	17.2

Table 4 summarizes the numerous estimates and assumptions used in calculating garbage weights and volumes. The reader should note that densities are calculated for each of the different components of mixed garbage. Any conversions from garbage weight to volume made in this study must be considered, therefore, in the context of the density values used.

GARBAGE HANDLING AND DISPOSAL PRACTICES BEFORE AND AFTER MARPOL ANNEX V

This section summarizes the more substantial review of garbage handling and disposal practices contained in ERG (1988b). Estimates of the percentage of vessels using each of the various garbage handling and disposal methods, both historically and under Annex V, are used to evaluate the disposition of the aggregate garbage quantities under pre- and post-Annex V assumptions.

Pre-Annex V Garbage Handling and Disposal Practices

The historical methods employed by shipboard crews to dispose of garbage provide a basis for determining the current disposition of the garbage generated on board, i.e., how much is discarded overboard, how much brought back to shore for disposal, and how much is burned in onboard incinerators.

In most sectors, garbage handling practices vary depending on where the ship operates. Over deep-sea routes, garbage is typically collected throughout the ship and discharged daily. Closer to shore, crews are more likely to retain garbage for onshore disposal. The historical practice of ocean dumping while out at sea has been confirmed in most sectors. A representative of the American Institute of Merchant Shipping, for instance, states that: "Generally aboard merchant vessels on the high seas, waste generated as a result of vessel operations and deck maintenance is disposed of directly overboard" (Corrado 1986).

The predominance of ocean disposal is also indicated by statistics kept by the Department of Agriculture's Animal and Plant Health Inspection Service (APHIS). This agency requires ships entering the United States from foreign ports to incinerate, sterilize, or otherwise sanitize any garbage prior to disposing of it on shore. The APHIS inspection records for fiscal year 1986, for example, show that only 2.5% of vessels entering the United States from foreign ports off-loaded any garbage (A. Langston, U.S. Department, of Agriculture, pers. commun. 1988).

Most commercial fishing groups also acknowledge that garbage dumping has traditionally been the most widely used means of getting rid of any trash which accumulates.

The use of garbage handling equipment such as grinders, compactors, or incinerators has not been widespread in the maritime sectors. Only some newer ships are equipped with such equipment, Until now, overboard disposal while well out at sea has been the most convenient and inexpensive method available. Based on discussions with operators in the merchant

Table 4.- -Assumptions and estimates used in garbage generation calculations.

Domestic garbage generation rates (International Maritime Organization 1987)

Vessel category	Per capita per day kg	Per capita per day lb
Oceangoing	2.0	4.4
Coastal	1.5	3.3
Inland/harbor	1.0	2.2
Passenger cruise	2.4	5.3

Fishing waste generations rates (Eastern Research Group estimates)

Vessel category	Per vessel per day			
	m′	kg	ft^3	lb
Normal vessels	0.004	0.064	0.140	0.140
Longliners, etc.	0.008	0.127	0.280	0.280

Domestic waste components, by weight (Koss and Mullenhard, pers. commun. 1988)

Garbage type	As percent of all garbage by weight	As percent of dry garbage by weight
Wet (food waste)	40.6	--
Dry (nonfood waste)	59.4	100.0
Plastic	6.7	11.3
Glass	4.1	6.9
Metal	13.0	21.9
Rubber	0.3	0.5
Paper, other	35.2	59.3

Garbage density (Society of Naval Architects and Marine Engineers 1982), except for plastic density, which was suggested by Navy personnel

Garbage type	kg/m^3	m^3/kg	lb/ft^3	ft^3/lb
Total garbage	174.2	0.006	10.89	0.10
Dry garbage	100.0	0.010	6.30	0.16
Food waste	640.0	0.002	40.00	0.03
Plastics	16.0	0.063	1.00	1.00

marine, commercial fishing, and government sectors, it is assumed here that for most ships, overboard disposal is the predominant method used.

Vessels which spend more time operating close to shore are less likely to rely on overboard disposal. There are several possible reasons for this: Laws and regulations may already prohibit dumping in such areas; vessels are away from port for shorter periods and thereby generate less garbage; or operators may be conscious about dumping close to shore. Several categories of vessels have been identified as using alternative disposal means. These include segments of the coastal trade fleet, tug and towboat operators, recreational boaters, offshore oil and gas operations, some industrial and research vessels, and some Coast Guard vessels.

Post-Annex V Garbage Handling and Disposal Practices

Under MARPOL Annex V, vessel operators may have to implement changes in garbage handling procedures in order to achieve compliance with the requirements of the regulations. The actions taken by an individual operator will depend upon a number of factors, including (1) where the vessel operates and the specific restrictions of Annex V which apply in those areas, (2) the quantities and types of garbage generated by each vessei, and (3) the cost and noncost factors which influence the selection of compliance methods.

Each vessel owner or operator will evaluate his operations relative to the requirements of MARPOL Annex V. Table 2 presented a summary of the restrictions introduced by Annex V for the various types of garbage. Disposal of plastics is prohibited everywhere, and disposal of other types of wastes is restricted for vessels operating near shore. Vessels operating in special areas are prohibited from disposing of anything except food wastes , and then only beyond 12 mi from shore. A separate set of rules apply to offshore oil and gas operations.

Alternative compliance options have been analyzed in terms of their relative costs and conveniences in the regulatory analysis prepared for the Coast Guard (ERG 1988b). Among the compliance methods examined were: substitution of plastics, storage of garbage for onshore disposal, use of compactors to reduce garbage volumes, with subsequent disposal on shore, and installation of onboard garbage incinerators. The model used for comparing these alternatives took into account all of the relevant costs associated with each option, including the volumes and types of garbage generated; equipment, installation, and operating costs; the opportunity costs of current garbage handling and disposal procedures (i.e. , not paying crews to dump garbage); and costs associated with off-loading and disposing of garbage in port.

The *cost* comparison model shows that for most vessels, onboard separation and storage of plastic garbage, with eventual disposal in port, is the least costly alternative (see ERG 1988b). As the garbage generation tables below will show, the quantities of plastics generated by most vessels would not present extreme storage difficulties. Where garbage volumes may cause inconveniences or storage problems, compactors can be used to reduce the volumes.

Several factors not captured by the cost. comparison may steer vessel operators towards more costly compliance methods. If, for whatever reason, vessels anticipate the accumulation of large quantities of garbage on board, they may consider methods that reduce or eliminate this burden, even if it increases their costs. Operators may be concerned about situations where onshore garbage disposal would not be possible for extended periods of time, due to delays or the inability to obtain removal service in port. Finally, the cost comparisons do not consider issues caused by operations in special areas, where additional restrictions on the disposal of garbage will apply.

When both the cost and noncost issues are considered, most smaller vessels are still projected to choose separation and storage of garbage which they will no longer be able to dump overboard. Extensive use of onboard garbage compaction equipment is forecast, however, for larger commercial fishing vessels and for a majority of domestic trade merchant ships. Such equipment will be used to reduce the volume of garbage retained on board and to facilitate handling and disposal in port. Equipment manufacturers indicate that equipment suitable for onboard use can achieve a compaction ratio of between 500 and 1,000%, although for pure plastics the ratio is lower unless the material is first shredded. Only ships in the merchant shipping foreign trade category and some larger research and passenger ships are expected to select onboard incinerators. In the case of foreign trade vessels, the decision to invest in incinerators will not be based simply on economics, as incinerators represent the most expensive means of compliance, but rather upon the increased convenience afforded to the vessel. Time spent in port is extremely costly, thus incinerators may be viewed as "insurance" against the possibility of being delayed due to difficulties in obtaining garbage disposal services. It must be noted, however, that current or future air pollution standards for marine incinerators could greatly increase the cost of this option.

Special mention should be made of the solution expected to be adopted by U.S. Navy ships. As shown below, the Navy has particular garbage disposal problems due to the large number of crewmen on board. According to the most recent reports, Navy ships are expected to be outfitted with thermal extrusion equipment specially designed for shipboard application. This technology will enable Navy crews to melt down all plastics generated on board and extrude them into a storable form.

Pre- and Post-Annex V Garbage Disposition

Table 5 presents estimates of the pre- and post-Annex V distribution of vessels in the merchant shipping sector according to the garbage handling and disposal practices used. The distributions reflect ERG conclusions from the review of disposal practices and options described above. Similar distributions have been developed for each of the maritime sectors under study, but are not shown here.

Aggregate quantities of domestic garbage derived in the supporting statistical section are shown in the first column of Table 6 below. The table shows the pre- and post-Annex V disposition of these garbage

Table 5.--Current garbage handling and disposal practices and projected practices under MARPOL Annex V merchant shipping sector (Eastern Research Group estimates).

Merchant shipping	Current compliance rate (%)	Current compliance choices (%)					Annex V compliance choices (%)		
		Dump	Store	Compact	Incinerate		Store[a]	Compact	Incinerate
Foreign trade									
U.S. vessels									
Atlantic/Gulf/Pacific ports	5	95	0	0	5		5	70	25
Noncontiguous ports	5	95	0	0	5		5	70	25
Foreign vessels									
Atlantic/Gulf/Pacific ports	5	95	0	0	5		5	70	25
Noncontiguous ports	5	95	0	0	5		5	70	25
Noncontiguous trade	5	95	0	0	5		5	80	15
Great Lakes vessels									
1,000 GT and over	100	0	25	50	25		25	50	25
Under 1,000 GT	100	0	25	50	25		25	50	25
Military Sealift Command charter	5	95	0	0	5		5	75	20
Temporarily inactive vessels	5	95	0	0	5		5	75	20
Coastal shipping									
Ships									
1,000 GT and over	25	60	40	0	0		10	75	15
Under 1,000 GT	5	95	5	0	0		15	75	10
Tow/tugboats									
Large (inspected)	20	80	20	0	0		50	45	5
Small	20	80	20	0	0		60	40	0

[a]Refers to storage of all garbage that vessels would not be permitted to dump. Assumes other garbage will be dumped where allowed under Annex V.

Table 6.--Final disposition of vessel-generated domestic waste, aggregated sector totals (annual quantities) (GT = gross tons; MT = metric tons).

Maritime sector	Total generated annually (MT)	Pre-Annex V: Off-loaded in port (MT)	Pre-Annex V: Off-loaded in port (m^3)[a]	Pre-Annex V: Incinerated at sea (MT)	Pre-Annex V: Incinerated at sea (m^3)[a]	Pre-Annex V: Dumped overboard (MT)	Pre-Annex V: Dumped overboard (m^3)[a]
Merchant shipping	30,949	3,302	39,794	1,148	14,971	26,499	349,304
Commercial passenger vessels	258,074	232,121	3,026,799	638	8,322	25,315	330,095
Commercial fishing	233,177	0	0	0	0	233,177	3,040,564
Recreational boating	636,055	424,036	5,529,325	0	0	212,018	2,764,662
Offshore oil and gas operations	16,710	10,733	139,958	0	0	5,977	18,656
Miscellaneous vessel classes	1,637	5	60	0	0	1,633	20,778
U.S. Navy	57,596	0	0	0	0	57,596	751,040
U.S. Coast Guard	4,317	1,452	28,786	0	0	2,864	8,941
U.S. Army	490	0	0	0	0	490	6,388
NOAA	317	7	165	88	1,146	222	2,463
Total	1,239,322	671,656	8,764,887	1,874	24,439	565,791	7,292,892

Table 6.--Continued.

Maritime sector	Post-Annex V[b]							
	Off-loaded in port				Incinerated at sea		Dumped overboard	
	Plastics		Other					
	(MT)	(m^3)[a]	(MT)	(m^3)[a]	(MT)	(m^3)[a]	(MT)	(m^3)[a]
Merchant shipping	1,626	311,353	2,737	6,255	4,381	57,132	22,204	103,685
Commercial passenger vessels	22,490	2,304,400	233,340	1,060,557	1,117	14,564	1,128	5,265
Commercial fishing	15,373	1,352,768	0	0	3,723	48,542	214,081	999,660
Recreational boating	39,848	4,975,109	554,892	2,771,045	0	0	41,315	128,964
Offshore oil and gas operations	398	49,740	5,547	72,799	0	0	0	0
Miscellaneous vessel classes	109	5,372	0	0	306	3,986	1,223	5,709
U.S. Naw	3,859	2,409,124	0	0	0	0	53,737	250,929
U.S. Coast Guard	289	126,913	765	2,604	0	0	3,262	10,183
U.S. Army	33	9,143	0	0	0	0	199	621
NOAA	11	331	0	0	148	1,926	158	737
Total	84,037	11,544,253	797,282	3,913,261	9,674	126,150	337,306	1,505,752

[a]Weight-to-volume conversions reflect (1) the densities of the various types of garbage (see Table 4), (2) the composition of the vessel waste stream, and (3) the degree to which compaction equipment is used in each sector.

[b]Assumes full compliance with Annex V requirements.

quantities. Both the weight and volume of garbage are indicated. Weight-to-volume conversions reflect assumptions about the types of garbage generated and the use of compaction *to* reduce garbage volume. This table shows aggregated sector totals only. A set of more detailed disposition tables is found in the Appendix.

The first columns of Table 6 indicate the current disposition of vessel-generated domestic garbage. The relative quantities of garbage currently brought back to shore, incinerated, or dumped overboard vary from sector to sector. A small amount of at-sea incineration occurs in portions of the merchant shipping and cruise ship sectors as well as on some National Oceanic and Atmospheric Administration (NOAA) research vessels. The percentage of domestic garbage brought back to shore for disposal is relatively high in the commercial passenger and recreational boating sector. Of the 1.2 million metric tons (MT) generated in all of the sectors, however, 566,000 MT or 45% by weight is still dumped overboard.

Under Annex V, some increased use of marine incinerators will occur, but the percentage of domestic garbage disposed of via incineration at sea will remain below 1%. All plastics, with the exception of that destroyed in incinerators, will be returned to shore for disposal. The current methodology predicts that 84,037 MT of plastics will be brought ashore for disposal. This will account for only 9.5% of all garbage brought ashore on a tonnage basis. Because of its low density, however, in volume terms plastics will represent close to 75% of the waste. Restrictions on the disposal of other types of garbage for vessels operating close to shore or in special areas will also increase the quantity of nonplastics brought ashore. Overall, the net increase in plastics and nonplastics brought ashore under Annex V will be 209,663 MT.

SUPPORTING STATISTICAL ANALYSIS OF MARITIME SECTORS SUBJECT TO COAST GUARD ENFORCEMENT OF MARPOL ANNEX V REGULATIONS

This section provides supporting data on the populations of ships covered in this study and used to generate the estimates of aggregate garbage generation shown in Table 6. Seven separate maritime sectors are identified as falling under the jurisdiction of the Coast Guard under MARPOL Annex V. These sectors are: merchant shipping, commercial fishing, commercial passenger vessels, recreational boating, offshore oil and gas operations, research and other miscellaneous vessels, and vessels operated by the U.S. Government. Each of these is profiled below in terms of the number and types of ships, onboard employment, and the frequency and duration of voyages. This information is then combined with data from earlier sections to derive per voyage, per vessel, and aggregate annual garbage quantity estimates for each of the sectors.

Merchant Shipping

Merchant vessels are those ships involved in the waterborne transport of cargo and passengers over established transoceanic, coastwise, intercoastal, and inland water routes. Under the provisions of the Jones Act, domestic waterborne commerce (cargoes moving between U.S. ports) is reserved exclusively for U.S. vessels. The U.S. import and export trade, however, is dominated by foreign vessels. The foreign and domestic trade sectors are discussed separately below.

Foreign Trade Vessels

According to the U.S. Maritime Administration (MARAD), the U.S. oceangoing merchant fleet numbers approximately 823 vessels of 1,000 gross tons (GT) and over. Of these, however, some 391 are inactive. Of the 432 active U.S. vessels, 122 or 28% are active in foreign trade. Another 54 vessels are active in Marine Sealift Command (MSC) operations, and will have voyage patterns comparable to foreign trade ships (see Table 7).

In addition to the vessels covered by MARAD, the Coast Guard's Marine Safety Information System (MSIS) data base shows there to be 43 vessels under 1,000 GT that are certificated for operation over open ocean routes. Thus, a total of 219 U.S.-flagged vessels operate over foreign trade routes.

The MARAD reports show that foreign-flagged vessels dominate the foreign trade sector, accounting for 95.6% of all U.S. import and export trade by tonnage (MARAD 1987b). The number of foreign vessels involved is commensurate. Data from the Coast Guard indicate that in 1987 a total of 6,751 foreign vessels, representing 110 different shipping nations, were inspected at U.S. ports (Coast Guard 1987b).

We assumed that vessels without incinerators will off-load all garbage in their final foreign port of call prior to setting sail for the United States. Under this assumption, vessels will retain on board all garbage they are prevented from dumping, and seek to off-load it upon return to the United States.

In order to estimate how much garbage is generated by these ships while en route to the United States, we examined data from the U.S. Customs Bureau's AE-975 file, Vessel Entrances and Clearances (U.S. Bureau of the Census 1987). This data base includes information on the final foreign port of call of vessels arriving at U.S. ports.

Four months of data (January, April, July, and October) were examined and used to derive annual estimates. In 1987, U.S. vessels made a total of 3,969 entrances to U.S. ports, while an estimated 33,087 entrances were made by foreign vessels. Table 8 shows a breakdown of these entrances by U.S. coastal area and foreign region of origin. Along the Atlantic and Gulf coasts, the largest number of entrances, 55 and 40%, respectively, were recorded by vessels clearing Customs from Caribbean ports. Entrances at Pacific coast ports were dominated by vessels arriving from Pacific Rim countries (46.6%) and from Pacific Canadian ports (28.8%).

A weighted average voyage length for foreign trade vessels arriving at U.S. ports was developed by calculating typical voyage lengths for each of the U.S.-foreign region pairings from Table 8. The estimated voyage lengths are based upon representative voyages from each foreign region to the U.S. coast and an assumed vessel speed of approximately 500 nmi per

Table 7.--Deployment status of U.S. flag merchant fleet, vessels 1,000 gross tons (GT) and over (U.S. Maritime Administration (MARAD), Merchant Marine Data Sheet, 1 March 1987).

Deployment status	Passenger/ combination		General cargo		Intermodel vessels		Bulk carriers		Tankers		Total	
	No.	Dwt	No.	Dwt	No.	Dwt	No.	Dwt	No,	Dwt	No.	Dwt
Active vessels												
Privately owned	2	15	36	531	112	2,694	22	934	192	11,772	364	15,946
Oceangoing												
U.S. foreign trade	--	--	26	380	69	1,703	13	684	14	806	122	3,573
Foreign-to-foreign	--	--	--	--	4	72	--	--	8	571	12	643
Domestic trade	2	15	1	18	20	358	7	188	146	9,671	176	10,250
Coastal	--	--	--	--	1	17	5	133	97	4,062	103	4,212
Noncontiguous	2	15	1	18	19	341	2	55	49	5,609	73	6,038
Military Sealift Command charter	--	--	9	133	19	561	2	62	24	724	54	1,480
Great Lakes[a]	--	--	--	--	--	--	55	1,819	3	20	58	1,840
Government-owned	4	32	3	26	--	--	--	--	1	17	8	75
BB charter and other custody	4	32	3	26	--	--	--	--	1	17	8	75
Subtotal--active fleet	6	47	39	557	112	2,694	22	934	193	11,789	372	16,021
Inactive vessels												
Privately owned	6	59	13	164	35	1,124	39	937	33	3,040	126	5,324
Oceangoing	6	59	13	164	35	1,124	4	336	33	3,040	91	4,723
Temporarily inactive	--	--	3	43	1	33	1	63	2	131	7	270
Laid up	6	59	7	82	32	1,085	3	273	29	2,841	77	4,340
Laid up (MARAD custody)	--	--	3	39	2	6	--	--	2	68	7	113
Great Lakes	--	--	--	--	--	--	35	601	--	--	35	601

Table 7. --Continued.

Deployment status	Passenger/ combination		General cargo		Intermodel vessels		Bulk carriers		Tankers		Total	
	No.	Dwt	No.	Dwt	No.	Dwt	No.	Dwt	No.	Dwt	No.	Dwt
Government-owned (MARAD)	24	183	184	2,102	28	761	--	--	21	623	257	3,669
National defense												
Reserve fleet	21	166	184	2,102	23	593	--	--	18	401	246	3,262
Ready research force (RRF)	1	9	53	661	17	438	--	--	8	141	79	1,249
Other reserve	6	57	122	1,356	6	155	--	--	9	244	143	1,812
Special programs	1	5	3	28	--	--	--	--	--	.-	4	33
Nonretention	13	95	6	57	--	--	--	--	1	16	20	168
In processing for RRF	--	--	--	..	4	152	--	--	--	--	4	152
Other government-owned	3	17	--	--	1	16	--	--	3	222	7	255
Subtotal--Inactive fleet	30	242	197	2,266	63	1,885	39	937	54	3,663	383	8,993
Total--Active and inactive	36	289	236	2,823	175	4,579	61	1,871	247	15,452	755	25,014

[1] Includes ships normally active but laid up due to the winter freeze.

Table 8.--Entrances to U.S. ports by U.S. and foreign vessels, and estimated days at sea by U.S. coastal area, 1987 (U.S. Bureau of the Census 1987; Eastern Research Group estimates).

U.S. coastal area	Vessel origin	Estimated number of entrances: Foreign vessels	U.S. vessels	Total vessels	Estimated voyage length″ (days)
Atlantic	Caribbean	5,895	954	6,849	3
	Scandinavia and N. Europe	1,497	204	1,701	9
	Canada--Atlantic	963	3	966	3
	Mediterranean	765	45	810	9
	W. coast S. America	612	27	639	9
	E. coast S. America	465	36	501	8
	Pacific Rim	282	3	285	15
	W. coast Africa	267	9	276	11
	Australasia	126	--	126	17
	Indonesia and India	123	--	123	16
	Middle East	78	6	84	12
	E. coast Africa	39	9	48	16
	Canada--Great Lakes	39	--	39	4
	Total	11,151	1,296	12,447	
	Weighted average voyage length	5.7	4.6		
Gulf	Caribbean	3,264	474	3,738	3
	W. coast S. America	1,794	249	2,043	6
	Scandinavia and N. Europe	1,212	51	1,263	10
	Mediterranean	645	42	687	10
	Pacific Rim	435	9	444	13
	W. coast Africa	327	27	354	15
	E. coast S. America	267	15	282	8
	Canada--Atlantic	282	--	282	6
	Australasia	99	--	99	14
	Indonesia and India	72	3	75	13
	Middle East	63	3	66	12
	E. coast Africa	27	9	36	10
	Canada--Great Lakes	33	--	33	7
	Canada--Pacific	3	--	3	7
	Total	8,523	882	9,405	
	Weighted average voyage length	6.7	5.3		
Pacific	Pacific Rim	3,285	306	3,591	11
	Canada--Pacific	1,650	567	2,217	3
	Caribbean	708	195	903	10
	W. coast S. America	321	138	459	15

Table 8. --Continued.

Us. coastal area	Vessel origin	Estimated number of entrances: Foreign vessels	Us. vessels	Total vessels	Estimated voyage length[a] (days)
	Australasia	174	3	177	11
	Indonesia and India	150	15	165	15
	Scandinavia and N. Europe	120	3	123	15
	E. coast Africa	51	--	51	11
	Mediterranean	12	--	12	18
	Total	6,471	1,227	7,698	
	Weighted average voyage length	9.2	7.7		
Great Lakes	Canada--Great Lakes	1,716	156	1,872	1
	Scandinavia and N. Europe	96	9	105	10
	Mediterranean	27	--	27	10
	W. coast Africa	12	--	12	11
	Pacific Rim	6	--	6	16
	Middle East	3	--	3	13
	Total	1,860	165	2,025	
	Weighted average voyage length	1.7	1.5		
Noncontiguous areas (includes Alaska, Hawaii Puerto Rico, and Virgin Islands	Caribbean	3,891	354	4,245	(b)
	Pacific Rim	426	6	432	(b)
	W. coast S. America	195	27	222	(b)
	E. coast S. America	135	3	138	(b)
	Scandinavia and N. Europe	93	--	93	(b)
	Australasia	84	--	84	(b)
	Indonesia and India	75	6	81	(b)
	W. coast Africa	60	3	63	(b)
	Canada--Atlantic	54	--	54	(b)
	E. coast Africa	42	--	42	(b)
	Mediterranean	18	--	18	(b)
	Canada--Pacific	6	--	6	(b)
	Middle East	3	--	3	(b)
	Total	5,082	399	5,481	(b)

[a]The percentage of entrances from each vessel origin is used to derive the weighted average voyage lengths for each coastal area.

[b]Voyage lengths for entrances to noncontiguous ports are estimated as follows: Hawaii- -6 days (60% of entrances are from Japan), Puerto Rico and the Virgin Islands --1 day (majority of entrances are from Caribbean countries) .

As indicated above, the Jones Act excludes foreign vessels from competing for U.S. domestic trade. Consequently, all domestic trade moves aboard U.S. vessels. In 1987, the fleet of U.S.-flagged domestic trade vessels included the following:

- 176 vessels of 1,000 GT and over (MARAD 1987a). Of these, 103 or 59% are active in "coastal" trade or trade between ports in the contiguous United States (see Table 7). All but six of these are tankers. The remaining 73 vessels operate in "noncontiguous" trade or trade between the contiguous U.S. states and the noncontiguous states and properties. Included in this total are 49 tankers and 19 intermodal vessels, as well as 2 U.S. cruise ships (described in the next section);

- 12 freighters and 14 tankers under 1,000 GT designated for coastwise travel (Coast Guard 1987b);

- 14 freighters and 43 tankers designated for lakes, bays, and sounds operation (Coast Guard 1987b);

- 9 freighters and 6 tankers designated for river operation (Coast Guard 1987b); and

- ca. 5,000 tug and towboats (U.S. Army Corps of Engineers 1987), which operate predominantly over the inland waterways.

Great Lakes ships may operate in either domestic or foreign (United States-Canada) trade. No breakdown is reported for these ships based on trade status, hence they are analyzed in terms of the number of ships and annual operating ratios, rather than number of entrances. (Operating ratios or utilization rates refer to the percentage of days annually on which the ship is engaged in trading activities.) In 1987, there were estimated to be 58 active Great Lakes ships of 1,000 GT or over (MARAD 1987a) and 7 of under 1,000 GT (Coast Guard 1987b).

Domestic trade vessels operate exclusively within U.S. waters, and will hence be under Coast Guard jurisdiction whenever they are operating. One exception is noncontiguous vessels which may exit U.S. waters en route from the continental United States. The approach to estimating garbage quantities in the domestic sector is, therefore, somewhat different. Whereas the annual garbage quantities generated by foreign trade vessels are estimated based upon the number of voyages, in this case it is the number of ships, the crew size, and the annual ship utilization rate which are the determinants.

Crews aboard domestic trade ships also average 20-25 men. Large oceangoing tugs carry up to 10 men, while smaller tugs and motor barges carry 6-man crews.

Domestic ships over 1,000 GT are estimated to have average voyage lengths of 5 days, while those under 1,000 GT average 4 days. Trips of large tugboats are also assumed to average 4 days, while small tugs are estimated to average 2 days at sea.

All vessels in the merchant marine sector, with the exception of Great Lakes ships, are assumed to operate with 90% utilization rates. Due to the winter freeze-up, Great Lakes ships are limited to approximately 50% utilization.

Garbage Generation Estimates

Domestic garbage. --In Table 9 below, estimates of the amount and types of garbage generated over typical voyages are shown for each of the merchant shipping categories. The table shows both weight and volume estimates, and indicates that the greatest accumulation would occur on foreign trade and large domestic trade ships. Over a 7-day voyage these ships are estimated to generate 330 kg or 2.2 m^3 of garbage, of which only 22 kg is plastics. One cubic meter represents approximately 8-9 large 113.5 liter (30-gal) garbage bags.

Cargo wastes. --Table 10 presents estimates of the number of entrances to U.S. ports by U.S. and foreign general cargo vessels, and of the quantities and types of dunnage generated by such ships. In the Customs data base, dry cargo ships account for 56.1% of entrances by U.S. ships and 74.4% of entrances by foreign ships (Bureau of the Census 1987). The MARAD data indicate that 28 of the 101 dry cargo ships in the U.S. foreign trade fleet (27.7%) are general cargo-type ships (MARAD 1987a). Applying this percentage to the number of dry cargo entrances, it is estimated that U.S. and foreign break-bulk ships enter U.S. ports 617 (0.277 x 0.561 x 3,969 entrances) and 6,819 (0.277 x 0.744 x 33,087 entrances) times annually. These entrances are seen in Table 10 to generate potentially close to 20,000 m^3 of waste lumber, 3,815 m^3 of cardboard, and 2,981 m^3 of plastic.

Commercial Passenger Vessels

The category of commercial passenger vessels encompasses all for-hire passenger-carrying vessels, including cruise ships, ferries and excursion vessels, and charter boats.

Cruise Ships

The cruise ship category includes domestic ships which operate exclusively within U.S. waters and foreign ships which sail from U.S. ports on international voyages. The Customs data base identifies approximately 80 foreign cruise ships which operate regularly out of U.S. ports. In 1986, these vessels recorded an estimated 3,324 entrances to U.S. ports (see Table 11). A high proportion of these entrances (45%) was recorded by vessels entering the Miami and Tampa port districts from the Bahama Islands. Other origin and destination combinations which account for large numbers of entrances include Canada/Alaska, Mexico/Los Angeles, Mexico/Miami, and Bermuda/New York. Puerto Rico and the Virgin Islands also receive numerous cruise ships, which arrive primarily from other Caribbean or South American ports.

Based upon the predominance of short-haul trips represented by these data, an average voyage duration of 1 day (24 h) is assumed for cruise

Table 9. --Derivation of per voyage, per vessel, and annual domestic garbage quantities generated merchant shipping (Eastern Research Group estimates) (GT - gross tons, MT - metric tons).

Merchant shipping	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Foreign trade																	
U.S. vessels																	
Atlantic/Gulf/Pacific	7	25	165	2.0	330	2	196	2	22	1	90	50	16, 425	NA	3,405	1,124	7,326
Noncontiguous/fOreign	2	25	53	2.0	105	1	62	1	7	0	90	156	16,425	NA	399	42	273
Foreign vessels																	
Atlantic/Gulf/Pacific	7	25	173	2.0	345	2	205	2	23	1	90	48	16,625	NA	26,145	9,020	58.809
Noncontiguous/Crest Lakes	2	25	60	2.0	120	1	71	1	8	1	90	137	16,425	NA	6,942	833	5,431
Noncontiguous trade (U.S. - -domestic)	7	25	175	2.0	350	2	208	2	23	1	90	47	16, 425	71	NA	1,166	7,603
Great Lakes (domestic and foreign trade)																	
1,000 CT and over	2	25	53	1.5	79	1	47	0	5	0	50	07	6,844	58	NA	397	2,588
Uncle r 1,000 GT	2	25	53	1.5	79	1	47	0	5	0	50	87	6,846	7	NA	48	312
United States																	
Military Sealift charter	7	25	175	2.0	350	2	2oa	2	23	1	90	47	16,425	54	NA	887	5,783
Temporarily inactive vessels	7	25	175	2.0	350	2	208	2	23	1	90	47	16,425	7	NA	115	750
Coastal shipping																	
Ships																	
1,000 CT and over	5	25	125	1.5	188	1	111	1	13	1	90	66	12,319	103	NA	1,269	8,273
Under 1,000 GT	4	25	100	1,5	150	1	89	1	10	1	90	82	12,319	98	NA	1,207	7,871
Tow/tugboats																	
Large (Inspected)	4	10	40	1.5	60	0	36	0	4	0	90	82	4,928	12	NA	59	386
Small	2	6	12	1.5	18	0	11	0	1	0	90	164	2,957	5,000	NA	14,783	96,380
Total garbage per year																30,949	201,785

[a] Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b] Total garbage weight per year is equal to the product of either (1) per vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrances-
[c] Refers to the percentage Of days annually operating in U.S. waters.

Table 10. --Estimates of annual quantities of cargo waste (dunnage) currently dumped and quantities dumped under MARPOL Annex V (Eastern Research Group estimates).

Basis of estimate	Us. vessels	Foreign vessels
Number of entrances to U.S. ports per year	3,969	33,087
Dry cargo as percentage of all. entrances	56.1%	74.4%
Dry cargo entrances	2,227	24,617
General cargo as percentage of all dry cargo ships	27.7%	27.7%
General cargo entrances	617	6,819
Dunnage generated per clearance from U.S. port		
Lumber		
Quantity (m^3)	48.6	48.6
Percent of entrances	66.7%	66.7%
Cardboard		
Quantity (m^3)	23.6	23.6
Percent of entrances	33.3%	33.3%
Plastic		
Quantity (m^3)	0.12	0.12
Percent of entrances	10.0%	10.0%
Total dunnage quantities generated per year		
Lumber (m^3)	19,983.4	220,930.2
Cardboard (m^3)	130,979	130,979
Plastic (m^3)	7.20	7.20
Incidence of dumping	50. 0%	50.0%
Total dunnage quantities dumped in U.S. waters per year		
Current practice		
Lumber (m^3)	9,991.7	110,465.1
Cardboard (m^3)	1,768,214	1,768,214
Plastic (m^3)	3.602	3.602
Under MARPOL Annex V		
Lumber (m^3)	9,991.7	110,465.1
Cardboard (m^3)	1,768,214	1,768,214
Plastic (m^3)	0.00	0.00

Table 11. --Cruise ships entering U.S. ports (Bureau of the Census 1987; Eastern Research Group estimates).

Vessel origin	U.S. port of entrance	Estimated number of entrances (1987)	Percent of total
Bahamas	Miami	1,232	37.1
Bahamas	Tampa	276	8.3
Canada (Pacific coast)	Anchorage	244	7.3
Mexico (Pacific coast)	Los Angeles	228	6.9
Mexico (Gulf coast)	Miami	168	5.1
Bermuda	New York	152	4.6
French West Indies	Virgin Islands	116	3.5
Leeward/Windward Islands	Virgin Islands	84	2.5
Netherlands Antilles	Virgin Islands	80	2.4
French West Indies	San Juan, Puerto Rico	72	2.2
Netherlands Antilles	Miami	72	2.2
Haiti	Miami	56	1.7
Netherland Antilles	San Juan, Puerto Rico	56	1.7
Bahamas	San Juan, Puerto Rico	52	1.6
Haiti	San Juan, Puerto Rico	44	1.3
Jamaica	Miami	44	1.3
Dominican Republic	Virgin Islands	40	1.2
Dominican Republic	San Juan, Puerto Rico	32	1.0
Venezuela	San Juan, Puerto Rico	32	1.0
All other origins	All other destinations	244	7.3
Total		3,324	100.0

ships arriving in the United States. While examples of much longer voyages may be found within the data, short voyages are much more typical.

Foreign cruise ships entered U.S. ports with an average passenger complement of 786. Crew-to-passenger ratios are approximately 1:2 (J. Ruers, International Committee of Passenger Liners, pers. commun. 1988), hence an average of approximately 1,000 persons are assumed to be on board such ships.

Coast Guard data indicate that approximately two dozen U.S.-flagged vessels are used in domestic cruise operations (L. Stanton, Coast Guard, pers. commun. 1988). These include two large vessels of over 1,000 GT which operate in the Hawaiian interisland trade as well as several smaller vessels active on coastal routes along both the east and west coasts. Average time between ports is estimated at 1 day, as the vessels are usually in port each night. Such vessels are estimated to carry an average of 200 passengers and crew members (E. Scharfe, Director, Small passenger Vessel Association, pers. commun. 1988) during typical cruises.

Other Passenger-Carrying Vessels

Additional categories of passenger-carrying vessels include ferries and charter fishing and pleasure vessels, of which there are a large number. In 1987, the Coast Guard's MSIS data base contained some 49 U.S.-flagged passenger vessels of 1,000 GT and over, and 4,774 vessels under 1,000 GT.

Among the larger passenger vessels, four are ocean-designated and include the two Hawaiian cruise ships discussed above as well as two converted hospital ships that are part of the MSC. These are covered in the merchant vessel data. Ten larger passenger vessels operate with river designations (e.g., Mississippi River cruises), while the remaining 34 are designated for operation in lakes, bays, and sounds. These vessels offer ferrying services and excursion or sightseeing cruises of short duration. Thus, a total of 44 additional large ferries and riverboats operate domestically. They are assumed to carry up to 1,000 passengers on voyages averaging 1 day in duration.

Approximately 75% of the 4,774 passenger-carrying vessels under 1,000 GT are charter fishing boats, with ferries, yachts, and other small boats accounting for the remaining 25% (Stanton pers. commun. 1988) . Charter fishing boats are assumed to carry an average of 20 persons, while ferries and other commercial passenger vessels are assumed tc carry 200 people. Voyage lengths of 1 day or less are assumed for all vessels in this category.

Large cruise ships generate substantial quantities of garbage even on overnight voyages. Table 12 indicates that 1,000 passengers on a luxury cruise will generate over 2 MT of garbage each day. Smaller ships carrying 200 passengers may generate close to 500 kg per day.

Commercial Fishing

United States Vessels

Fishing vessels may be classified according to whether they operate in" onshore, offshore, or inland fisheries. Onshore fishing, defined as fishing which takes place within 12 nmi from shore, is conducted by smaller boats making primarily day-long trips. Data sources distinguish between fishing boats, which are under 5 net tons in size, and fishing vessels, which include all craft of 5 net tons or more (see Table 13).

Boats under 5 net tons generally do not exceed 7.6 m (25 ft) in length (T. Willis, Coast Guard Documentation Branch, pers. commun. 1988), and are not eligible for Coast Guard documentation. Normally, therefore, they do not operate at significant distances from shore. For convenience, all fishing boats (i.e., <5 net tons) are assumed to operate in the onshore fisheries. The NMFS estimates there to be approximately 105,500 boats active in the U.S. fisheries (NMFS 1987). These are assumed to carry an average of three crew members, and to return to port each night.

Table 12.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated commercial passenger vessels (Eastern Research Group estimates) (GT - gross tons, MT - metric tons).

Commercial passenger ships	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	(m³)	Dry garbage (kg)	(m³)	Plastic garbage (kg)	(m³)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	(m³)
Cruise ships																	
U.S. vessels																	
>1,000 GT	1	1,000	1,000	2.4	2,400	16	1,426	14	161	10	90	329	788,400	2	NA	1,577	10,281
Under 1,000 GT	1	200	200	2.4	480	3	285	3	32	2	90	329	157,680	24	NA	3,784	24,6?3
Foreign vessels	1	1,00	1,000	2.4	2,400	16	1,426	14	161	10	90	NA	NA	NA	3,324	7,978	52,013
Excursion vessels	1	200	200	2.4	480	2	285	3	32	2	90	329	157,680	1,194	NA	188,270	1,227,495
Charter boats	1	20	20	2.4	48	0	29	0	3	0	90	329	15,768	3,581	NA	56,465	368,148
Total garbage per year																258,074	1,682,608

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal to the product of either (1) per vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrances.
[c]Refers to the parentage of clays annually operating in U.S. waters.

Table 13. --Employment and craft in the U.S. commercial fisheries ([U.S.] National Marine Fisheries Service 1987).

Size	Number
Vessel >5 tons	24,300
Motor boats	104,000
Other boats	1,500
Total craft	129,800
Fishermen	238,800

While some larger craft also operate close to shore, fishing vessels (5 net tons and over) are assumed to operate beyond 12 nmi from shore. These vessels are capable of longer voyages, and are frequently equipped with sophisticated navigational and fish locating equipment. They also have greater onboard storage and processing capacity.

The NMFS estimates that in 1986 there were 24,300 fishing vessels of 5 net tons or more in the United States. While these may range up to 1,000 GT and over in size, relatively few are this large. Table 14 indicates that over 60% of fishing vessels are both smaller than 25 net tons in size, and <15.2 m (50 ft) in length.

Inland fishing *covers* commercial activity taking place on the inland waterways. At present, small commercial fisheries operate on the Great Lakes and along the Mississippi River (S. Koplin, NMFS, Statistics Branch, pers. commun. 1988), and account for only a small percentage of the national catch. States bordering the Great Lakes, for example, accounted for only 1.7% of the 1987 U.S. commercial catch (NMFS 1987). As boats active in the inland fisheries will be contained within the data presented above, the craft involved will be assumed to operate in a fashion similar to those in the saltwater fisheries. Assumptions regarding crew sizes and voyage lengths of fishing vessels are shown in Table 15, which derives the per voyage, per vessel, and aggregate annual garbage quantities.

Foreign Fishing Vessels

Foreign fishing vessels granted access to fishing stocks within the U.S. exclusive economic zone (EEZ) will also be expected to comply with MARPOL Annex V. While some restrictions on vessel discharges already apply, the requirements do not address specifically the problem of garbage dumping.

In the recent past, foreign fishing activity in U.S. waters has centered around the eastern Bering Sea and Aleutian Islands areas, where

Table 14.--Documented U.S. fishing vessels,[a] by length and gross tonnage (U.S. Coast Guard, Marine Safety Information System 20 April 1986; [U.S.] National Marine Fisheries Service 1987).

	Vessel length				
Gross tonnage	<15.2 m (<50 ft)	15.2-19.8 m (50-65 ft)	19.8-24.1 m (65-79 ft)	>24.1 m (>79 ft)	Total
Less than 25	14,703	112	2	2	14,815
25-49	2,774	1,152	33	--	3,959
50-99	340	1,511	1,107	45	3,003
100-199	18	117	1,418	674	2,227
200-299	--	--	--	69	69
300-399	--	--	--	32	32
400-499	--	--	--	49	49
500-599	--	--	--	45	45
600-699	--	--	--	15	15
700-799	--	--	--	10	10
800-899	--	--	--	10	10
900-999	--	--	--	23	23
1,000-1,999	--	--	--	34	34
2,000-2,999	--	--	--	2	2
3,000-3,999	--	--	--	2	2
4,000-4,999	--	--	--	2	2
More than 5,000	--	--	--	--	--
Total	17,835	2,891	2,560	1,015	24,300

[a]Vessels are defined as craft of 5 net tons or over.

the most significant target species has been Alaskan pollock. The country most active in this fishery is Japan. Other fisheries with considerable foreign participation include the Pacific whiting and Atlantic mackerel fisheries.

Direct access to U.S. fishing stocks by foreign vessels has been cut back considerably in recent years. At present, foreign access is obtained primarily through joint venture permits (J. Kelley, NMFS, Office of Fishery Conservation and Management, pers. commun. 1989). Under joint venture agreements, U.S. vessels deliver their catch to large foreign motherships or other factory trawlers, which process the fish at sea.

Data on the number of foreign fishing vessel permits issued in 1987, by type of vessel, flag of vessel, and fishery, were requested from the NMFS, but were not available in time for this report. In general, though, activity by foreign fishing vessels within U.S. waters has been decreasing in recent years with the "Americanization" of the U.S. EEZ. Direct fishing

Table 15.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: commercial fishing (Eastern Research Group estimates) (GT = gross tons, MT - metric tons).

Commercial fishing	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Undocumented	1	3	3	1.5	5	0	3	0	0	0	66	241	1,084	105,500	NA	114,367	745,660
Documented																	
5-25 GT	7	7	49	2.0	98	1	58	1	7	0	66	34	3,373	14,815	NA	49,965	325,766
25-300 CT	15	15	225	2.0	450	3	267	3	30	2	66	16	7,227	9,258	NA	66,908	436,229
300-1,000 GT	15	15	225	2.0	450	3	267	3	30	2	66	16	7,227	188	NA	1,359	8,858
Over 1,000 GT	30	30	900	2.0	1,800	12	1,069	11	121	8	66	8	14,454	40	NA	578	3,770
Foreign vessels[b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0
Total garbage per year																233,177	1,520,282

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.

[b]Total garbage weight per year is equal to the produce of either (1) per vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrances.

[c]Refers to the percentage of days annually operating in U.S. waters.

by foreign vessels has been almost completely phased out, while joint ventures between U.S. catcher vessels and foreign processing vessels are declining. More and more, foreign access to U.S. fishery products will be in the form of exported products processed on U.S. soil. According to a report to the Alaska Department of Environmental Conservation, "it is generally assumed that there will be little, if any, joint venture activity in the North Pacific EEZ by 1991" (Pacific Associates 1988).

Garbage Generation Estimates

Domestic garbage---Table 15 shows the derivation of the per voyage and annual domestic waste estimates. The largest ships may generate up to 1,800 kg of garbage overall per voyage. Of this amount, however, they would likely have to retain only the plastics. Small fishing boats are estimated to generate only 4.5 kg of total garbage per day at sea.

Commercial wastes.--As indicated, it is assumed that most fishing craft will generate an additional 0.028 m^3 (1.0 ft^3) of plastic gear waste per week (0.004 m^3 (0.14 ft^3) per day). Longliners and boats in the herring fisheries are assumed to generate twice this amount. Such vessels are assumed to represent 5% of all vessels in the 5-25 and 25-300 GT categories. Table 16 shows the estimated quantities of fishing wastes generated annually.

Recreational Boating

All recreational boats operating over the navigable waters of the United States are also required to comply with Annex V. Potentially, therefore, most of the approximately 14 million recreational boats in the United States might be included in an analysis of Annex V. For this study, we limit the analysis to numbered boats in coastal states or in states bordering the Great Lakes. Still, some 7.3 million recreational boats fit this criterion (see Table 17).

The majority of recreational boats are used on inland waters or, when used in the ocean, within 3 nmi from shore. When operating in these waters, boaters are prohibited from disposing of any garbage overboard. Beyond 3 nmi from shore, limited dumping may occur.

In order to identify those boats prohibited from any overboard disposal, several assumptions were made. First, only boats registered in coastal states are assumed to operate in the ocean. Secondly, only larger boats are assumed to operate beyond 3 nmi from shore. Within coastal and Great Lakes states, the size breakdown of the registered boating fleet is as follows:

- 56.3% are under 4.9 m (16 ft) long,
- 39.6% are between 4.9 and 7.9 m (16 and 26 ft) in length, and
- 3.7% are greater than 7.9 m (26 ft) in length (see Table 17).

Table 16.--Estimates of annual quantities of plastic fishing gear wastes generated in the U.S. fisheries (Eastern Research Group estimates) (GT - gross tons, MT = metric tons).

		Annual quantities of fishing waste generated			
		Vessels generating normal quantities		Vessels generating additional quantities	
Vessel category	Number of vessels	(MT)	(m^3)	(MT)	(m^3)
Undocumented	105,500	1,779	131,781	0	0
Documented					
5-25 GT	14,815	216	12,570	23	1,323
25-300 GT	9,258	135	7,855	14	827
300-1,000 GT	188	3	160	0	0
Over 1,000 GT	40	1	34	0	0
Foreign vessels	NA	NA	NA	NA	NA
Total	129,801	2,133	152,400	37	2,150

[a]Vessels using trawls, set nets, or pots. Plastic waste in these fisheries is essentially gear-related.
[b]Vessels active in bait fisheries (i.e., longlining) or herring fisheries which generate additional quantities of plastic waste in the form of bait wrappings or salt bags.

According to the Boat Owner's Association of the U.S. (BOATUS), recreational boats under 4.9 m (16 ft) in length "are most likely confined to inland lakes, rivers, and bays," and of those over 4.9 m (1.6 ft), only 10% are estimated to venture beyond 3 nmi from shore (Schwartz 1987). Based on this, approximately 219,000 boats are estimated to operate in areas where some overboard disposal of garbage is permitted. The remaining 13.1 million operate in areas where no garbage disposal may occur.

Garbage Generation

Voyage lengths and onboard complements for recreational boats of various sizes are shown in Table 18, which derives the per voyage and annual garbage quantities generated.

Offshore Oil and Gas Operations

Offshore oil and gas operations such as exploratory drilling, development drilling, and oil and gas production from offshore platforms are also covered by MARPOL Annex V. The restrictions which apply to such operations are different from those applicable to commercial and recreational vessels. Under Annex V, ocean disposal of all types of garbage, with the exception of ground food wastes, is prohibited. For operations located within 12 nmi from shore, even the disposal of ground food wastes is prohibited.

Table 17, --Recreational boats in coastal and Great Lakes states (U.S. Coast Guard 1987a).

Region	Class and size					
	Class A <4.9 m (<16 ft)	Class 1 4.9-7.9 m (16-26 ft)	Class 2 7.9-12.2 m (26-40 ft)	Class 3 12.2-19.8 m (40-65 ft)	Class 4 >19.8 m (>65 ft)	Total
Coastal states						
Number	2,548,709	1,955,105	212,458	22,754	1,806	4,740,832
Percent of total	53.8	41.2	4.5	0.5	0.0	100.0
Great Lakes states						
Number	1,540,340	916,301	55,846	4,540	232	2,517,259
Percent of total	60.7	37.2	1.9	0.3	0.0	100.0
Coastal and Great Lakes						
Number	4,089,049	2,871,406	268,304	27,294	2,038	7,258,091
Percent of total	56.3	39.6	3.7	0.4	0.0	100.0

Table 18. --Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: recreational boats (Eastern Research Group estimates) (GT = gross tons, MT = metric tons).

Recreational boats	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	(m^3)	Dry garbage (kg)	(m^3)	Plastic garbage (kg)	(m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	(m^3)
Coastal states																	
Under 4.9 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	2,548,709	NA	22?,267	1,455,671
6.9-7.9 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	1,955,105	NA	171,267	1,116,640
7.9-12.2 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	212,438	NA	18,611	121,343
12.2-19.8 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	22,754	NA	1,993	12,996
Over 19.8 m	2	6	12	1.5	18	0	11	0	1	0	6	11	197	1,906	NA	356	2,321
Subtotal																415,495	2,708,971
Great Lakes states																	
Under 4.9 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	1,540,340	NA	134,934	879,751
4.9-7.9 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	916,301	NA	80,266	523,337
7.9-12.2 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	56,105	NA	4,915	32,044
12.2-19.8 m	1	4	4	1.0	4	0	2	0	0	0	6	22	88	4,540	NA	398	2,593
Over 19.8 m	2	6	12	1.5	18	0	11	0	1	0	6	11	97	232	NA	46	298
Subtotal																220,560	1,438,022
Total garbage per year																636,055	4,146,994

[a] Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.

[b] Total garbage weight per year is equal to the product of either (1) per vessel population, or (2) garbage quantity per voyage and the number of entrances.

[c] Refers to the percentage of days annually operating in U. S. waters.

Mobile Offshore Drilling Units

Data from the Department of the Interior's Minerals Management Service (MMS) for February 1988 showed there to be 124 mobile offshore drilling units (MODU's) active in U.S. Federal waters (L. M. Tracey, Department of the Interior, Minerals Management Services, pers. commun. 1988). All but one of these were reported to be operating beyond 12 nmi from shore. Approximately 78 MODU's were active in state waters (J. Dees, Ocean & Oil Weekly, Houston, TX, pers. commun. 1988). State waters extend out to 3 nmi from shore, except off Florida and Texas, where the state-federal boundary occurs at 3 leagues or approximately 10.35 nmi. All activity in state waters is subject to the complete ban on disposal within 12 nmi of shore, while MODU's in Federal waters would be able to dispose of ground food wastes. The MMS data indicate that MODU's in Federal waters have an average of 40 beds. This figure has been used as an estimate of the number of men aboard MODU's on a 24-h basis. Active MODU's are assumed to operate at 100% utilization.

Platforms

Approximately 3,500 production platform "complexes," consisting of one or more platforms in a single location, actively operate in U.S. Federal waters. Of these, however, only 779 are manned. A total of 124 manned platforms are situated within 12 nmi from shore, while the remaining 655 are located beyond 12 nmi. Dees (pers. commun. 1988) estimates that a maximum of 40 additional manned platforms are active in state waters.

The MMS data indicate that platform complexes have an average of 15 beds each.

Offshore Service Vessels

Service vessels employed in petroleum support activities are also covered by Annex V prohibitions. This category includes supply ships, tugs, anchor-handling vessels, crew ships, and research and survey vessels. Coast Guard data indicate that there are 484 offshore service vessels (OSV's) operating in the Federal Outer Continental Shelf region. Most crew and supply ships fall in the 50-200 dwt range. These are assumed to carry crews of five persons, and to make trips lasting an average of 1 day.

No data are available to indicate how many OSV'S operate in state waters. Assuming the same ratio of structures (MODU's and platforms) to OSV's exists in state waters as in Federal waters, it is estimated that there are 63 additional OSV'S active in state waters (484 ÷ 903) x 118).

Garbage Generation

Garbage quantities for the offshore oil and gas sector are calculated in Table 19 on a per day, rather than a per voyage basis, since the structures are stationary and relatively permanent. Currently, all garbage with the exception of food wastes is required by the MMS to be transported to shore for disposal.

Table 19.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: offshore oil and gas (Eastern Research Group estimates) (GT - gross tons, MT - metric tons).

Offshore oil and gas operations	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	(m³)	Dry garbage (kg)	(m³)	Plastic garbage (kg)	(m³)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	(m³)
Mobile offshore drilling units																	
Within 12 nmi	1	40	40	2.0	80	1	48	0	5	0	100	365	29,200	74	NA	2,161	14,098
Outside 12 nmi	1	40	40	2.0	80	1	48	0	5	0	100	365	29,200	123	NA	3,592	23,417
Offshore oil and gas production platforms																	
Within 12 nmi	1	15	15	2.0	30	0	18	0	2	0	100	365	10,950	655	NA	7,172	46,762
Outside 12 nmi	1	15	15	2.0	30	0	18	0	2	0	100	365	10,950	655	NA	7,172	46,762
Offshore service vessels	1	5	5	2.0	10	0	6	0	1	0	100	365	3,650	545	NA	1,989	12,970
Total garbage per year																16,710	108,915

[a] Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.

[b] Total garbage weight per year is equal to the product of either (1) per vessel population, or (2) garbage quantity per voyage and the number of entrances.

[c] Refers to the percentage of days annually operating in U.S. waters.

Research and Other Miscellaneous Vessels

Several categories of miscellaneous vessels have also been included in this analysis. These include vessels operated by universities and other oceanographic research institutions, maritime academy training ships, and various "industrial" vessels such as dredges and cable-laying ships.

Research Vessels

Numerous universities as well as private and nonprofit groups (e.g., Greenpeace, the Cousteau Foundation), operate oceanographic research vessels. The Coast Guard's MSIS data base indicates that in 1987 there were 26 vessels actively involved in oceanographic research (Coast Guard 1987b) .

A 1978 profile of the world's oceanographic research fleet indicated that a typical research cruise might involve 20-25 crew members and 10-20 scientists (Trillo 1978; cited in Parker et al. 1987). These estimates were deemed appropriate by individuals connected with two major oceanographic research institutes, the Woods Hole Oceanographic Institute (J. Colburn, Woods Hole Oceanographic Institute, pers. commun. 1988) and the Scripps Institution of Oceanography (G. Schorr, Associate Director, Scripps Institution of Oceanography, La Jolla, CA, pers. commun. 1987).

School Training Vessels

Seven maritime academies in the United States operate a total of 14 ships used for training (Coast Guard 1987b). Seven of these are ocean-designated, six are authorized for coastwise travel, and one carries a Great Lakes designation. Only five of the vessels are greater than 1,000 GT in size.

Training ships of 1,000 GT or over are estimated to carry 150 men, while those under 1,000 GT are estimated to carry a crew of 50. Voyage lengths are estimated at 15 and 7 days, respectively. These estimates are based on discussions with officials at the Massachusetts Maritime Academy, who are familiar with the sizes and operations of vessels used at their and other maritime academies (D. Kan, Massachusetts Maritime Academy, Buzzard's Bay, MA, pers. commun. 1987).

Industrial Vessels

The category of industrial vessels comprises an assortment of vessel types including dredges, cable-laying ships, and drilling ships. Their common characteristic is that they carry crews who perform functions other than operating the vessel. The Coast Guard's MSIS data base indicates that in 1987 there were a total of 85 such vessels. Of these, 57 were greater than 1,000 GT, while 22 were under 1,000 GT. Furthermore, 69 were ocean-designated, while 17 were designated for coastal operation only.

While it is difficult to generalize about these vessels as a group, voyage lengths and crew complements on board have been approximated.

Oceangoing industrial vessels of 1,000 GT or over are estimated to carry an average of 30 persons on board and have voyage lengths averaging 15 days. Coastal vessels of 1,000 GT are also assumed to carry crews of 30 men, but are at sea for an average of 7 days. Both oceangoing and coastal vessels under 1,000 GT are estimated to carry 15 persons and to operate over 7-day voyages .

Garbage Generation

Domestic garbage .--Estimates of garbage generation in these sectors are shown in Table 20. School training ships and research vessels over 1,000 GT generate substantial quantities of garbage and plastics. Large research vessels, for example, may generate over 10 m^3 of plastics from domestic sources alone. This would be sufficient to fill an average commercial garbage dumpster.

Research vessel wastes.--The additional quantities of plastics associated with oceanographic research wastes are derived in Table 21.

U.S. Navy

Data from the Jane's Fighting Ships (1,986) indicate that the U.S. Navy fleet currently numbers approximately 679 active vessels (see Table 22). Normal operational cycles for Navy vessels involve one 6-month tour of duty outside of U.S. waters every 18 months (D. Steigman, Jane's Publishing CO., pers. commun. 1988). Consequently, at any given time approximately one-third of the Navy fleet is operating outside of U.S. waters.

Crew complements on board Navy vessels range from 25 men up to as many as 5,000 on board the largest aircraft carriers. Where a range of crew sizes was reported, crew complements shown in Table 22 represent the average. Utilization factors while in U.S. waters range from 20 to 75%, depending on the vessel's strategic importance and its re-fit cycle (Mullenhard, pers. commun. 1988). Steigman (pers. commun. 1988) provided separate estimates of operating ratios for each class of Navy vessel, which are used to derive garbage quantity estimates for these ships while in U.S. waters.

Garbage Generation

Because of the large crew sizes and extended periods at sea, several categories of Navy ships are seen in Table 23 to generate extremeiy large quantities of wastes. Aircraft carriers with 5,000 men aboard, for example, could generate as much as 200 MT of garbage over a 20-day cruise. Several other categories of ships may generate 10 to 20 MT as well. Clearly, the Navy has particular garbage handling problems.

U.S. Coast Guard

The Coast Guard operates a large fleet of vessels, ranging from small harbor patrol boats to a pair of 121.9-m (400-ft) icebreakers. Table 24 provides a summary of the Coast Guard's fleet and indicates the number of

Table 20.- -Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: miscellaneous vessel categories (Eastern Research Group estimates) (GT - gross tons, MT - metric tons).

Miscellaneous vessels	Voyage length (days)	Crew size	Person days per voyage	Per capita generation race (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
School training																	
1,000 CT and over	15	150	2,250	2.0	4,500	29	2,673	26	302	19	35	9	38,325	5	NA	192	1,249
Under 1,000 CT																	
Ocean	7	50	350	2.0	700	5	416	4	47	3	35	18	12,775	2	NA	26	167
Coastal	7	50	350	1.5	525	3	312	3	35	2	35	18	9,581	5	NA	48	312
Industrial vessels																	
1,000 GT and over																	
Ocean	15	30	450	2.0	900	6	535	5	60	4	75	18	16,425	52	NA	854	5,569
Coastal	7	30	210	1.5	315	2	187	2	21	1	75	39	12,319	11	NA	136	883
Under 1,000 CT																	
Ocean	7	15	105	2.0	210	1	125	1	14	1	75	39	8,213	17	NA	140	910
Coastal	7	15	105	1.5	158	1	94	1	11	1	75	39	6,159	5	NA	31	201
Research vessels																	
Inspected																	
1,000 CT and over	25	50	1,250	2.0	2,500	16	1,485	15	168	10	35	5	12,775	2	NA	26	167
300-1,000 GT	15	50	750	1.5	1,125	7	668	7	75	5	35	9	9,581	15	NA	144	937
Uninspected																	
Under 300 GT	10	25	250	1.5	375	2	223	2	25	2	35	13	4,791	9	NA	43	281
Total garbage per year																1,637	10,676

[a]Dry garbage is calculated as 59.4$ of total garbage by weight. Plastic garbage is 6.73 of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal co the product of either (1) per vessel population, or (2) garbage quantity per voyage and the number of entrances
[c]Refers to the percentage of daya annually operating in U.S. waters.

Table 21. --Estimates of annual quantities of additional plastic wastes generated by oceanographic research vessels (Eastern Research Group estimates) (GT = gross tons).

Vessel category	Number of vessels	Voyage length (days)	Voyages per year[a]	Additional waste per year (m^3)
Private vessels				
1,000 GT and over	2	25	5	1.17
300-1,000 GT	15	10	13	22.78
Under 300 GT	9	10	13	13.67
National Oceanic and Atmospheric Administration vessels				
Large deepwater vessels	4	25	5	2.34
Small coastal vessels	20	10	13	30.37
Total	50			70.32

[a]Annual vessel utilization of 35% is assumed.

vessels in each class, the crew complement, and typical voyage durations, This table is based upon discussions with Coast Guard operations personnel.

Coast Guard vessels are assumed to operate entirely within U.S. waters. Utilization factors for Coast Guard vessels are similar to those of Navy ships, and are assumed to average 50%.

Garbage Generation

Several categories of Coast Guard cutters as well as the large polar icebreakers are estimated to generate substantial quantities of garbage over representative voyages. The relevant quantities are shown in Table 25.

U.S. Army

The U.S. Army reports a fleet of approximately 580 crafts (G. Danish, U.S. Army, pers. commun. 1988). Of these, only a small number are "sea deployable." As shown in Table 26, these include four logistic support vessels approximately 91.4 m (300 ft) in length, 35 utility class landing craft capable of extended trips at sea, and 10 large oceangoing tugs.

The rest of the Army's fleet is made up of approximately 490 "ship-to-beach" craft of various types, used mainly for shuttling troops and supplies to and from larger vessels anchored offshore. In addition, the

Table 22.--U.S. Navy vessels by type and status (Jane's Fighting Ships 1986; Navy League of the United States 1987).

Vessel type	Active	Building/ reactivating conversion	Approximate onboard complement	*Estimated manpower total
Strategic missile submarines	38	5	150	5,700
Attack submarines	101	15	140	14,140
Aircraft carriers	13	3	5,000	65,000
Battleships	2	2	1,500	3,000
Cruisers	31	13	500	15,500
Destroyers	68	1	350	23,800
Frigates	100	4	300	30,000
Light forces	7	0	25	175
Light amphibious warfare ships	57	7	700-2,800	99,750
Mine warfare ships	3	6	70	210
Auxiliary ships	79	3	100-1,000	35,550
Military Sealift Command	72	18	25-120	5,220
Ready reserve force	73	0	40-1,200	45,260
Naval reserve	35	0	NA	NA
Total	679	77		343,305

'Where crew complements vary within a class, the arithmetic mean of the range is used. Total estimated complement is derived by dividing average complement by the number of active vessels.

Army maintains 15 small harbor tugs and about 25 small outboard motor-powered J boats.

These craft are used only intermittently during peacetime in logistics exercises. A utilization rate of 35% is assumed for all vessels.

Garbage Generation

The largest Army ships, the logistic support vessels, carrying 40 persons on board for up to 30 days, may generate close to 2 MT of garbage and 10 m^3 of plastics alone. Other vessel classes generate considerably smaller quantities of garbage.

National Oceanic and Atmospheric Administration
Research Vessels

The NOAA operates a fleet of approximately two dozen vessels which are engaged in atmospheric and oceanographic research (B. Cunningham, Office of NOAA Corps, NOAA, pers. commun. 1988). These vessels range in size from 250 to 4,000 GT. Smaller vessels are estimated to carry approximately 10 persons on board, and to remain at sea for periods of approximately 1 week.

Table 23. --Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: U.S. Navy vessels (Eastern Research Group estimates) (GT - gross tons, MT - metric tons).

U.S. Navy vessels	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m')	Plastic garbage (kg)	Plastic garbage (m^s)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No, of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Strategic missile submarines	3	150	450	2.0	900	6	535	5	60	4	3	3	2,973	3a	NA	113	737
Attack submarines	7	140	980	2.0	1,960	13	1,164	12	131	8	6	3	6,624	101	NA	669	4,362
Aircraft carriers	20	5,000	100,000	2.0	200,000	1,304	118,800	1,1?7	13,400	837	22	4	811,111	13	NA	10,544,	68,748
Battleship	20	1,500	30,000	2.0	60,000	391	35,640	353	4,020	251	33	4	243,333	2	NA	487	3,173
Cruisers	20	500	10,000	2.0	20,000	130	11,880	118	1,340	84	22	4	81,111	31	NA	2,514	16,394
Destroyers	20	350	7,000	2.0	14,000	91	8,316	82	938	59	22	4	56,778	68	NA	3,861	25,172
Frigates	20	300	6,000	2.0	12,000	78	7,128	71	804	50	22	4	48,667	100	NA	4,867	31,730
Light forces	15	25	375	2.0	750	5	446	.4	50	3	22	5	4,056	7	NA	28	185
Light amphibious warfare ships	5	1,750	8,750	2.0	17,500	114	10,395	103	1,173	73	22	16	283,889	57	NA	16,182	105,502
Mine warfare ships	15	70	1,050	2.0	2,100	14	1,247	12	141	9	22	5	11,356	3	NA	34	222
Auxiliary ships	15	500	7,500	2.0	15,000	98	8,910	88	1,005	63	22	5	81,111	79	NA	6,408	41,778
Military Sealift Command	15	75	1,125	2.0	2,250	15	1,337	13	151	9	22	5	12,167	72	NA	876	5,711
Ready reserve force	15	620	9,300	2.0	18,600	121	11,048	109	1,246	78	33	8	150,867	73	NA	11,013	71,805
Naval reserve	15	620	9,300	2.0	18,600	121	11,048	109	1,246	18	0	0	0	35	NA	0	0
Total garbage per year																57,596	375,520

[a]Dry garbage is calculated as 59.4$ of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal to the product Of either (1) per vessel population, or (2) garbage quantity per voyage and the number of entrancea.
[c]Refers to the percentage of days annually operating in U.S. waters.

Table 24. --U.S. Coast Guard fleet by type and status (Jane's Fighting Ships 1986; Navy League of the United States 1987).

Vessel type	Active	Reserve	Uncle r construction	Approximate complement
Cutters, high endurance	15	--	--	171
Cutters, medium endurance	34	--	7	82
Icebreakers	6	--	--	161
Icebreaking tugs	8	--	1	17
Surface effect craft	3	--	--	18
Large patrol craft	83	--	8	11
Training cutter	1	--	--	245
Buoy tenders, seagoing	28	--	--	53
Buoy tenders, coastal	12	--	--	20
Buoy tenders, inland	6	--	--	20
Buoy tenders, river	18	--	--	20
Construction tenders, inland	17	--	--	20
Harbor tugs, medium	4	--	--	10
Harbor tugs, small	14	--	--	10
Total	249	--	16	--

Larger vessels make voyages of up to 1 month and typically carry some 20 officers, 55 to 60 crewmen, and up to 30 scientists.

Approximately half of these vessels operate out of the NOAA base in Seattle, while the other half are stationed in Newport News. Other bases maintained by NOAA include Woods Hole, Miami, Pascagoula, and San Diego, as well as one each in Alaska and Hawaii.

Garbage Generation

The largest NOAA ships may generate as much as 4 MT of garbage over a typical 20-day voyage, and close to 20 m^3 of plastics from domestic sources alone , as shown in Table 27.

Wastes associated with the research activities of these ships are derived along with those of private research vessels in Table 21.

Other Government Vessels

Other Federal *Government* agencies such as the Customs Bureau and the U.S. Army Corps of Engineers, as well as numerous state and local government departments and agencies, may operate modest fleets of boats. No large craft, however, are estimated to be operated by agencies other than those discussed above. Smaller boats are included in the data presented in the section on recreational boats, but are not separately analyzed here.

Table 25.--Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: U.S. Coast Guard vessels (Eastern Research Group estimates) (GT - gross tons, MT = metric tons).

U.S. Coast Guard vessels	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	Total garbage (m^3)	Dry garbage (kg)	Dry garbage (m^3)	Plastic garbage (kg)	Plastic garbage (m^3)	Annual ship utili-zation rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	Total garbage per year[b] (m^3)
Icebreakers																	
Polar class 121.9 m	90	140	12,600	2.0	25,200	164	14,969	148	1,688	105	50	2	51,100	2	NA	102	666
Mackinaw class 73.2 m	6	75	450	2.0	900	6	535	5	60	4	50	30	27,375	1	NA	27	178
Bay class 42.7 m	6	17	102	2.0	204	1	121	1	14	1	50	30	6,205	9	NA	56	364
High endurance cutters																	
115.2 m	60	156	9,360	2.0	18,720	122	11,120	110	1,254	78	50	3	56,940	12	NA	683	4,455
82.3 m	60	109	6,560	2.0	13,080	85	7,710	77	87'5	55	50	3	39,785	10	NA	398	2,594
Medium endurance cutters																	
66.0 m	30	71	2,130	2.0	4,260	28	2,530	25	285	18	50	6	25,915	16	NA	415	2,703
61.9 -64,9 m	30	75	2,250	2.0	4,500	29	2,673	26	302	19	50	6	27,375	10	NA	274	1,785
Patrol boats																	
33.5 m	10	16	160	2.0	320	2	190	2	21	1	50	18	5,640	23	NA	134	876
29.0 m	3	13	39	1.5	59	0	35	0	4	0	50	61	3,559	15	NA	53	348
25.0 m	2	10	20	1.5	30	0	18	0	2	0	50	91	2,738	15	NA	41	268
Buoy tenders																	
Seagoing	5	50	250	1.5	375	2	223	2	25	2	50	37	13,688	27	NA	370	2,409
Coastal	4	32	128	1.5	192	1	114	1	13	1	50	46	8,760	12	NA	105	"685
River	5	18	90	1.0	90	1	53	1	6	0	50	37	3,285	18	NA	59	386
Inland	3	14	42	1.0	42	0	25	0	3	0	50	61	2,555	6	NA	15	100
Construction	5	8	40	1.0	40	0	24	0	3	0	50	37	1,460	16	NA	23	L52
Harbor tugs																	
Medium	1	4	4	1.0	4	0	2	0	0	0	50	183	730	4	NA	3	19
Small	1	4	4	1.0	4	0	2	0	0	0	50	183	730	2,120	NA	1,548	10,090
Search and rescue <19.8 m	1	4	4	1.0	4	0	2	0	0	0	50	183	730	2,120	NA	1,548	10,090
TotaL garbage per year																4,317	28,146

[a]Dry garbage is calculated as 59.4$ of total garbage by weight. Plastic garbage is 6.73 of dry garbage by weight. See Table 4.

[b]Total garbage weight per year is equal to the product of either (1) per vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrances.

'Refers to the percentage of dsya annually operacing in U.S. waters.

Table 26. --Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: U.S. Army vessels (Eastern Research Group estimates) (GT - gross tons; MT - metric tons).

U.S. Army vessels	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	(m³)	Dry garbage (kg)	(m³)	Plastic garbage (kg)	(m³)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	(m^3)
Logistic support vessels	30	40	1,200	2.0	2,600	16	1,426	14	161	10	35	4	10,220	4	NA	41	267
Lending craft, utility class 2000	20	10	200	2.0	400	3	238	2	27	2	35	6	2,555	35	NA	89	583
Large oceangoing tugs	20	8	160	2.0	320	2	190	2	21	1	35	6	2,044	10	NA	20	133
Other small lending craft	2	5	10	1.0	10	0	6	0	1	0	35	64	639	491	NA	314	2,045
Smal 1 harbor tugs	2	5	10	1.0	10	0	6	0	1	0	35	64	639	15	NA	10	62
J -boats	2	5	10	1.0	10	0	6	0	1	0	35	64	639	25	NA	16	104
Total garbage per year																490	3,194

[a]Dry garbage is calculated as 59.4* Of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal to the product of either (1) per vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrances.
[c]Refers to the percentage of days annually operating in U.S. waters.

Table 27. --Derivation of per voyage, per vessel, and annual domestic garbage quantities generated: National Oceanic and Atmospheric Administration (NOAA) research vessels (MT = metric tons, NA - not applicable). (Source: Eastern Research Group estimates.)

NOAA research vessels	Voyage length (days)	Crew size	Person days per voyage	Per capita generation rate (kg/day)	Domestic garbage generation per voyage[a]: Total garbage (kg)	(m³)	Dry garbage (kg)	(m³)	Plastic garbage (kg)	(m³)	Annual ship utilization rate[c] (%)	Voyages per year	Garbage per year per vessel (kg)	No. of vessels	No. of entrances	Total garbage per year[b] (MT)	(m^3)
Large deepwater vessels	20	110	2,200	2.0	4,400	29	2,614	26	295	18	35%	6	28,105	10	NA	281	1,832
Coastal research vessels	5	10	50	2.0	100	1	59	1	7	0	35%	26	2,555	14	NA	36	233
Total garbage per year																317	2,066

[a]Dry garbage is calculated as 59.4% of total garbage by weight. Plastic garbage is 6.7% of dry garbage by weight. See Table 4.
[b]Total garbage weight per year is equal to the product of either (1) par vessel annual garbage quantity and the vessel population, or (2) garbage quantity per voyage and the number of entrancea.
[c]Ref era to the percentage of daye annually operating in U.S. waters.

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APPENDIX

Detailed Garbage Generation Tables for 10 Maritime Sectors

(ERG estimates)

Appendix Table I.--Final disposition Of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (GT - gross tons, MT = metric tons). Merchant shipping.

Merchant shipping	Total MT generated	Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off -loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port				Incinerated at sea		Dumped overboard	
								Plastics		Other					
		MT	m^3	MT	m^3	MT	m^3	HT	m^3	MT	m^3	MT	m^3	MT	m^3
Foreign trade															
U.S. vessels															
Atlantic/Gulf/Pacific	1,124	0	0	56	733	1,067	13,919	46	1,659	0	0	323	4,212	75'4	3,523
Noncont iguous	42	0	0	2	27	40	519	2	54	0	0	12	157	28	131
Foreign vessels															
Atlantic/Gulf/Pacif ic	9,020	0	0	451	5,881	8,569	111,738	370	11,708	0	0	2,593	33,815	6,057	28,282
Noncontiguous/Great Lakes	833	0	0	42	543	791	10,319	34	1,081	0	0	239	3,123	559	2,612
Noncontiguous trade (U. S.)	1,166	0	0	58	760	1,108	14,446	55	1,705	0	0	224	2,927	886	.4,139
Great Lakes vessels															
1,000 GT and over	397	298	970	99	1,294	0	0	7	3,014	93	147	99	1,294	198	927
Under 1,000 GT	48	36	117	12	156	0	0	1	364	11	18	12	156	24	112
Military Sealift charter (U. S.)	887	0	0	44	578	843	10,987	39	1,224	0	0	213	2,776	635	2,965
Temp. inactive vessels (U.S.)	115	0	0	6	75	109	1,424	5	159	0	0	28	360	82	384
Coastal shipping															
Ships															
1,000 GT and over	1,269	0	0	317	4,136	952	12,409	12	429	0	0	460	5,998	797	3,723
Under 1,000 GT	1,207	0	0	60	787	1,147	14,955	61	2,542	0	0	175	2,283	971	4,535
Tow/tugboats															
Large (inspected)	59	12	154	0	0	47	632	4	1,035	10	22	2	31	42	198
Small	14,783	2,957	38,552	0	0	11,826	157,955	990	286,579	2,623	6,068	0	0	11,169	52,154
Total	30,949	3,302	39,794	L, 148	14,971	26,499	349,304	1,626	311,353	2,737	6,255	4,381	57,132	22,20'4	103,685

● Assumes full compliance with Annex V requirements.

Appendix Table 2. --Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (GT - gross tons, MT = metric tons). Commercial passenger ships.

Commercial passenger ships	Total MT generated	Before MARPOL Annex V: Off-loaded in port		Incinerated at sea		Dumped overboard		After MARPOL Annex V*: Off-loaded in port: Plastics		Off-loaded in port: Other		Incinerated at sea		Dumped overboard	
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Cruise ships															
U.S. vessels															
>1,000 GT	1,577	1,577	20,561	0	0	0	0	106	13,191	1,471	6,870	0	0	0	0
Under 1,000 CT	3,784	3,595	46,879	0	0	189	2,467	25.4	31,025	3,531	16,157	0	0	0	0
Foreign vessels	7,978	5,744	74,899	638	8,322	1,596	20,805	5,733	267,957	0	0	1,117	14,564	1,128	5,265
Excursion vessels	188,270	178,856	2,332,241	0	0	9,413	122,750	12,614	1,543,483	175,656	803,829	0	0	0	0
Charter boats	56,465	42, 349	552,219	0	0	14,116	184,073	3,783	448,765	52,682	233,701	0	0	0	0
Total	58,0742	232,121	3,026,799	638	8,322	25,315	330,095	22,490	2,304,400	233,340	1,060,557	1,117	14,564	1,128	5,265

* Assumes full compliance with Annex V requirements.

Appendix Table 3.- -Final disposition of vessel-generated gargage before and after MARPOL Annex V (annual quantities) (GT - gross tons, MT - metric tons). Commercial fishing.

Commercial fishing	Total MT generated	Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off -loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port: Plastics		Off-loaded in port: Other		Incinerated at sea		Dumped overboard	
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	IIT	m^3	UT	❑ '	MT	m^3
Undocumented	114,367	0	0	0	0	114,367	1,491,320	7,663	880,206	0	0	0	0	106,705	498,263
Documented															
5-25 GT	49,965	0	0	0	0	49,965	651,532	3,348	317,669	0	0	0	0	46,617	217,682
25-300 GT	66,908	0	0	0	0	66,908	872,457	4,259	151,126	0	0	3,345	43,623	59,304	276,921
300-1,000 CT	1,359	0	0	0	0	1,359	17,717	77	3,092	0	0	204	2,658	1,077	5,031
Over 1.000 GT	578	0	0	0	0	578	7,539	27	677	0	0	173	2,262	378	1,763
Foreign vessels[b]	NA	NA	NA	N A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total for sector	233.177	0	0	0	0	233,177	3,040,566	15,373	1,352.768	0	0	3,723	48,542	214,081	999,660

“Assumes full compliance with Annex V requirements.
[b]Data unavailable in time for this report. See Section 2.3 for discussion.

Appendix Table 4. --Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT = metric tons). **Recreational boating.**

Recreational boating	Total MT generated	Before MARPOL Annex V: Off-loaded in port		Incinerated at sea		Dumped overboard		After Annex V[a]: Off-loaded in port: Plastics		Other		Incinerated at sea		Dumped overboard	
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Coastal states															
Under 4.9 m	223,267	148,845	1,940,895	0	0	74,422	910,447	14,959	1,867,751	208,308	972,704	0	0	0	0
4.9-7.9 m	171,267	114,178	1,488,853	0	0	57,089	744,427	10,327	1,289,470	43,813	746,158	0	0	17,127	53,461
7.9-12.2 m	18,611	12,408	161,791	0	0	6,204	80,896	1,122	140,125	15,628	81.084	0	0	1,861	5,809
12.2 -19. B m	1,993	1,329	17,328	0	0	664	8,664	120	15,007	1,674	8,684	0	0	199	622
Over 19,8 m	356	237	3,094	0	0	119	1,547	19	2,219	269	1,509	0	0	68	211
Subtotal	415,495	276,996	3,611,961	0	0	138,698	1,905,981	26,548	3,314, S73	369,692	1,810,140	0	0	19,255	60,103
Great Lakes states															
Under 4.9 m	134,934	89,956	1,173,001	0	0	44,978	586,500	8,137	1,015,916	113,304	587,865	0	0	13,493	42,119
4.9-7.9 m	80,268	53,512	697,782	0	0	26,756	348,891	4,840	606,337	67,401	349,703	0	0	8,027	25,055
7.9-12.2 m	4,915	3,277	42,725	0	0	1,638	21,363	296	37,004	4,127	21,412	0	0	491	1,534
12.2 -19.8 m	398	265	3,.457	0	0	133	1,729	24	2,994	334	1,733	0	0	40	124
Over 19.8 m	46	30	398	0	0	15	199	2	285	35	194	0	0	9	27
Subtotal	220,560	1.47,040	1,917,363	0	0	73,520	958,682	13,299	1,660,537	185,200	960,906	0	0	22,060	68,860
Total for sector	636,055	42.4,036	5,529,325	0	0	212,018	2,764,662	39,848	4,975,109	554,892	2,771,045	0	0	41,315	128,964

[a]Assumes full compliance with Annex V requirements.

Appendix Table 5.- -Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT - metric tons). Offshore oil and gas operations.

Offshore oil and gas operations	Total MT generated	Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off - loaded in port		Incinerated at sea		Oumped overboard		Off - loaded in port				Incinerated at sea		Dumped overboard	
								Plastics		Other					
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Mobile offshore drilling units (MODU's)															
- within 12 nmi	2,161	1,284	16,737	0	0	877	2,738	145	18,076	2,016	9,414	0	0	0	0
- outside 12 nmi	3,592	2,133	27,819	0	0	1,458	4,552	0	0	0	15,647	0	O	0	0
Offshore oil and gas production platforms															
- within 12 nmi	1,796	1,067	13,910	0	0	729	2,276	120	15,023	1,675	7,824	0	0	0	0
- outside 12 nmi	7,172	4,260	55,553	0	0	2,912	9,090	0	0	0	31,247	0	0	0	0
Offshore service vessels (OSV's)	1,989	1,989	25,939	0	0	0	0	133	16,6'41	1,856	8,667	0	0	0	0
Total for sector	16,710	10,733	139,958	0	0	5,977	18,656	398	49,740	5,547	72,799	0	0	0	0

[a]Assumes full compliance with Annex V requirements.
[b]The MODU's, platforms, and OSV's are assumed to currently off -load all dry garbage in accordance with MMS and EPA requirements, hence only food wastes are shown as being dumped.

Appendix Table 6.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (GT - gross tons, MT - metric tons). Miscellaneous vessels.

		Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off-loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port: Plastics		Off-loaded in port: Other		Incinerated at sea		Dumped overboard	
Miscellaneous vessels	Total MT generated	MT	m^3	MT	m^3	UT	m^3	MT	m^3	MT	m^3	UT	m^3	MT	m^3
School training															
1,000 GT and over	192	0	0	0	0	192	2,499	9	224	0	0	57	750	125	584
Under 1,000 GT															
Ocean	26	0	0	0	0	26	333	1	51	0	0	5	67	19	89
Coastal	48	0	0	0	0	48	625	3	96	0	0	10	125	36	167
Industrial vessels															
1,000 GT and over															
Ocean	854	3	37	0	0	851	10,780	60	3,255	0	0	128	1,665	667	3,112
Coastal	136	0	6	0	0	135	1,710	10	516	0	0	20	264	106	494
Under 1,000 GT															
Ocean	140	0	6	0	0	139	1,762	10	625	0	0	14	181	116	541
Coastal	31	0	1	0	0	31	389	2	138	0	0	3	40	26	119
Research vessels															
Inspected															
1,000 GT and over	26	0	L	0	0	25	322	2	45	0	0	13	166	11	51
300-1,000 GT	144	0	6	0	0	143	1,814	10	324	0	0	43	560	91	423
Uninspected															
Under 300 GT	43	0	2	0	0	43	544	3	97	0	0	13	168	27	127
Total for sector	1,637	5	60	0	0	1,633	20,778	109	5,372	0	0	306	3,986	1,223	5,709

[a] Assumes full compliance with Annex V requirements.

Appendix Table 7.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT - metric tons). U.S. Navy.

U.S. Navy vessels	Total MT generated	Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off-loaded in port		[incinerated at sea		Bumped overboard		Off-loaded in port: Plastics		Off-loaded in port: Other		Incinerated at sea		Dumped overboard	
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Strategic missile submarines	113	0	0	0	0	113	1,473	8	4,725	0	0	0	0	105	492
Attack submarines	669	0	0	0	0	669	8,724	45	27,984	0	0	0	0	624	2,915
Aircraft carriers	10,544	0	0	0	0	10,544	137,497	706	441,051	0	0	0	0	9,838	45,939
Battleships	487	0	0	0	0	487	6,346	33	20,356	0	0	0	0	454	2,120
Cruisers	2,514	0	0	0	0	2,514	32,788	168	105,174	0	0	0	0	2,346	10,955
Destroyers	3,861	0	0	0	0	3,861	50,345	259	161,492	0	0	0	0	3,602	16,821
Frigates	4,867	0	0	0	0	4,867	63, 460	326	203,562	0	0	0	0	4,541	21,203
Light forces	28	0	0	0	0	28	370	2	1,187	0	0	0	0	26	124
Light amphibious warfare ships	16,182	0	0	0	0	16,182	211,005	1,084	676,843	0	0	0	0	5,097	70,498
Mine warfare ships	34	0	0	0	0	34	444	2	1,425	0	0	0	0	32	148
Auxiliary ships	6,408	0	0	0	0	6,408	83,556	429	268,023	0	0	0	0	5,978	27,917
Military Sealift Command	876	0	0	0	0	876	11,423	59	36,641	0	0	0	0	817	3,816
Ready reserve force	11,013	0	0	0	0	11,013	143,610	738	460,660	0	0	0	0	0,275	47,981
Naval reserve	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	57,596	0	0	0	0	57,596	751,040	3,859	2,409,124	0	0	0	0	53,737	250,929

[a]Assumes full compliance with Annex V requirements.

Appendix Table 8.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT -metric tons). U.S. Coast Guard.

		Before MARPOL Annex V						After MARPOL Annex V[1]							
		Off-loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port				Incinerated at sea		Dumped overboard	
								Plastics		Other					
U.S. Coast Guard vessels	Total MT generated	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Icebreakers															
Polar class 400 ft	102	0	0	0	0	102	319	1	4,275	0	0	0	0	95	298
Mackinaw class 240 ft	27	16	322	0	0	11	35	2	1,145	9	29	0	0	17	53
Bay class 140 ft	56	33	657	0	0	23	71	4	.467	17	59	0	0	35	108
High endurance cutters															
378 ft	683	0	0	0	0	683	2,133	46	28,580	0	0	0	0	638	1,990
270 ft	398	0	0	0	0	398	1,242	27	16,641	0	0	0	0	371	1,159
Medium endurance cutters															
210 ft	415	0	0	0	0	415	1,294	28	17,343	0	o	0	0	387	1,208
203-213 ft	274	0	0	0	0	274	855	18	11,450	0	,0	0	0	255	797
Patrol boats															
110 ft	134	80	1,581	0	0	55	170	9	5,618	42	143	0	0	83	260
95 ft	53	32	628	0	0	22	68	4	2,233	17	57	0	0	33	103
82 ft	41	24	483	0	0	17	52	3	1,718	13	44	0	0	25	79
Buoy tenders															
Seagoing	370	220	4,351	0	0	150	468	25	15,458	116	394	0	0	229	715
Coastal	105	62	1,238	0	0	43	133	7	4,397	33	112	0	0	65	203
River	59	35	696	0	0	24	75	4	2,473	19	63	0	0	37	114
Inland	15	9	180	0	0	6	19	1	641	5	16	0	0	10	30
Construction	23	14	275	0	0	9	30	2	977	7	25	0	0	14	45
Harbor tugs															
Medium	3	2	34	0	0	1	4	0	122	1	3	0	0	2	6
Small	10	6	120	0	0	4	13	1	427	3	11	0	0	6	20
Search and rescue boats <65 ft	1,548	919	18.219	0	0	628	1,961	104	12,947	484	1,648	0	0	959	2,995
Total	4,317	1,452	28,786	0	0	2,864	8,941	289	126,913	765	2,604	0	0	3,262	10,183

[1]Assumes full compliance with Annex V requirements.

Appendix Table 9.- -Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT - metric tons). U.S. Army.

U.S. Army vessels	Total MT generated	Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off - loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port				Incinerated at sea		Dumped overboard	
								Plastics		Other					
		MT	m^3	MT	m^3	MT	m^3	UT	m^3	MT	m^3	MT	m^3	MT	m^3
Logistic support vessels	41	0	0	0	0	41	533	3	1,710	0	0	0	0	17	52
Landing craft, utility class 2	89	0	0	0	0	89	1,166	6	3,740	0	0	0	0	36	113
Large oceangoing tugs	20	0	0	0	0	20	267	1	855	0	0	0	0	8	26
Other landing craft	314	0	0	0	0	314	4,090	21	2,624	0	0	0	0	127	397
Small harbor tugs	10	0	0	0	0	10	125	1	80	0	0	0	0	4	12
J -boats	16	0	0	0	0	16	208	1	134	0	0	0	0	6	20
Total	490	0	0	0	0	490	6,388	33	9,143	0	0	0	0	199	621

[a]Assumes full compliance with Annex V requirements.

Appendix Table 10.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT - metric tons). National Oceanic and Atmospheric Administration (NOAA) research vessels.

		Before MARPOL Annex V						After MARPOL Annex V*							
		Off-loaded in port		Incinerated at sea		Dumped overboard		Off-Loaded in port: Plastics		Off-Loaded in port: Other		Incinerated at sea		Dumped overboard	
NOAA research vessels	Total MT generated	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Large deepwater vessels	281	6	141	84	1,099	191	2,144	9	235	0	0	141	1,832	131	612
Coastal research vessels	36	1	24	4	47	31	319	2	96	0	0	7	93	27	125
Total	317	7	165	88	1,146	222	2,463	11	331	0	0	148	1,926	158	737

*Assumes full compliance with Annex V requirements.

Appendix Table Il.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT - metric tons). Summary table.

Sector	Total MT generated	Before MARPOL Annex V						After MARPOL Annex V“							
		Off -loaded in port		Incinerated at sea		Oumped overboard		Off-loaded in port				Incinerated at sea		Dumped overboard	
								Plastics		Other					
		MT	*3	MT	m^3	MT	m^3	UT	m^3	MT	m^3	MT	m^3	MT	m^3
Merchant shipping	30,949	3,302	39,794	1, 148	14,971	26,499	349,304	1,626	311,353	2,737	6,255	4,381	57,132	22,204	103,685
Commercial passenger ships	258,074	232,121	3,026,799	638	8,322	25,315	330,095	22,490	2,304,400	233,360	1,060,557	1,117	14,564	1,128	5,265
Commercial fishing	233,177	0	0	0	0	233,177	3 ,040, 564	15,373	1,352,768	0	0	3,723	48,542	21 4,081	999,660
Recreational boating	636,055	424,036	5,529,325	0	0	212,018	2,764,662	39,848	4,975,109	554,892	2,771,045	0	0	41,315	128,964
Offshore oil and gas operations	16,710	10,733	139,958	0	0	5,977	18,656	398	49,740	5,547	72,799	0	0	0	0
Miscellaneous vessels	1,637	5	60	0	0	1,633	20,778	109	5,372	0	0	306	3,986	1,223	5,709
U.S. Navy	57,596	O	0	0	0	57,596	751,040	3,859	2,609,124	0	0	0	0	53,737	250,929
U.S. Coast Guard	4,317	1,452	28,786	0	0	2,864	8,941	289	126,913	765	2,604	0	0	3,262	10,183
U.S. Army	490	0	0	0	0	490	6,388	33	9,143	0	0	0	0	199	621
National Oceanic and Atmospheric Administration research vessels	317	7	165	88	1,146	222	2,463	11	331	0	0	148	1,926	158	737
Total	1,239,322	671,656	8,764,887	1,874	24,439	565,791	7,292,892	84,037	11,544,253	797,282	3,913,261	9,674	126,150	337,306	1,505,752

‘Assumes full compliance with Annex V requirements.

THE QUANTITATIVE DISTRIBUTION AND CHARACTERISTICS OF MARINE DEBRIS IN THE NORTH PACIFIC OCEAN, 1984-88

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ABSTRACT

The distribution, abundance, and characteristics of marine debris in the North Pacific, Bering Sea, and Japan Sea were studied during the 5-year period 1984-88 using standardized observations at 181 daily transect stations encompassing approximately 21,420 km of observations, for a total of 1,070 km² of sampling. The most abundant debris type was plastic, which composed 89.3% of the total 2,127 debris items seen on transect; other debris items consisted of glass (3.3%), wood (3.2%), paper/fiber (2.4%), metal (0.5%), rubber (0.2%), and unidentified debris objects (1.0%). The most abundant plastic type was fragments (34.2%); other main plastic types were Styrofoam objects (22.5%), sheets and bags (18.2%), gillnet floats (5.0%), polypropylene line (3.1%), miscellaneous floats (2.8%), and miscellaneous/unidentified plastic objects (12.3%). Gillnet fragments, trawl net fragments, unidentified net fragments, and uncut plastic strapping, which were minor components of the plastic debris, were recorded a total of 46 times, primarily between lat. 37° and 44°N, in and near the Subarctic Front. The distribution and characteristics of the 6 general debris types are presented, as well as the distribution and characteristics of the 11 main plastic types. The highest densities of marine debris generally occurred in Japan Sea and nearshore Japan Water, Transitional Water, and Subtropical Water. Densities of most types of marine debris generally were low in Subarctic Water and Bering Sea Water. Heterogeneous geographic input, currents, and winds are important in locally concentrating marine debris.

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

INTRODUCTION

Marine debris, especially plastic debris, increasingly is recognized as a national and international pollution problem (Shomura and Yoshida 1985; Wolfe 1987). Debris presents problems on beaches, where it is aesthetically displeasing, is expensive (and probably impossible) to remove, causes unnecessary mortality of coastal wildlife, and (in the case of some medical, military, and industrial wastes) is potentially toxic. Debris also can cause problems at sea, where it can damage vessels, entangle marine animals, and result in the deaths of some animals that mistake it for food. Although the general nature of the marine debris problem is understood, the actual magnitude of the problem is unknown, because much of the information about it is anecdotal. For instance, we know that the northern fur seal, *Callorhinus ursinus*, become entangled and die in derelict fishing nets at sea, but estimates of the abundance of derelict nets at sea are highly uncertain (Pruter 1987). Consequently, estimates of both the true mortality rate of fur seals due to entanglement and the true effects of this mortality on fur seal populations also are uncertain (but see Fowler 1982, 1985, 1987).

During the last two decades, several workers have systematically observed floating debris and lost plastic nets in the North Pacific Ocean (Venrick et al. 1973; DeGange and Newby 1980; Dahlberg and Day 1985; Jones and Ferrero 1985; Yoshida and Baba 1985; Baba et al. 1986; Day and Shaw 1987; Mio and Takehama 1987; Yagi and Nomura 1987) and stranded debris on coastal beaches (Merrell 1980, 1984). These studies have shown that marine debris is distributed widely, is of several types, and is distributed by surface currents and winds.

The objective of this study was to improve our knowledge of the quantitative distribution and characteristics of marine debris in the North Pacific Ocean. Specifically, we wanted to: (1) describe the quantitative distributions of the six main types of marine debris; (2) describe the comparative at-sea densities of the main debris types; (3) describe the mean dimensions of the main debris types; (4) describe the quantitative distributions of the 11 main types of plastic debris; (5) describe the frequencies of colors of the main plastic types; and (6) examine the effects of input, currents, and winds on the quantitative distribution of ❑arine debris. Because of the extensive geographic coverage of the work, this study constitutes the first complete analysis and the most detailed synoptic picture of marine debris anywhere in the world ocean.

METHODS

We collected data on the density (number per square kilometer), types, sizes, and colors of marine debris at 181 debris transect stations in the Bering and Japan Seas and the North Pacific Ocean north of Hawaii. At each station, we counted, identified, and estimated the two largest dimensions (at least 2.5 x 2.5 cm) of marine debris within 50 m of one side of a ship moving forward at a known rate of speed for a known period of time (Dahlberg and Day 1985; Day and Shaw 1987). The only types of debris that were sampled as far as we could see from either side of a moving ship were gillnet fragments, trawl net fragments, unidentified net fragments, and uncut pieces of plastic strapping. This paper includes some published data from 38 stations in 1984 (Dahlberg and Day 1985) and 49 stations in 1985 (Day and Shaw 1987); the data from the other 94 stations are from 1986 to 1988 and have been combined with the 1984-85 data for a broader overview of patterns in the North Pacific.

The sampling surveyed approximately 21,425 km of ocean, for a total of approximately 1,073 km^2 of sampling (Fig. 1). The total effort consisted of 854 h 47 min (854:47) of sampling at 152 of the stations during which observation conditions were recorded. Effort by observation condition was: poor 21:50 (2.6% of the total effort of known conditions); fair 163:30 (19.1%); moderate 253:00 (29.6%); good 320:17 (37.5%); and very good 96:10 (11.3%). We decreased sampling effort when conditions were less than moderate (21.7% of total effort during known conditions) and sampled extensively when conditions were moderate to very good (78% of total effort during known conditions). Sampling was not conducted during periods when high waves could affect sightability of debris.

General debris types were standardized and consisted of glass, metal, paper/fiber, plastic, rubber, wood, or miscellaneous/unidentified debris. Plastic debris types also were standardized: fragment, Styrofoam (which may include foamed plastics of other chemical composition), polypropylene line fragment (which may include synthetic lines of other chemical composition) , gillnet float, miscellaneous float, gillnet fragment, trawl net fragment, unidentified net fragment, uncut plastic strapping, sheet/bag, and miscellaneous/unidentified plastic debris. The two largest dimensions of pieces of debris were estimated in centimeters. Pieces of plastic debris were identified to the same standardized colors that were used for neuston plastic (Day et al. 1990): black/gray, blue, brown, green, orange, red/pink, tan, transparent, white, yellow, and mixed/unidentified colors.

Data were compiled as the density ($number/km^2$) of total marine debris, of each general type of marine debris, and of each type of plastic debris at each station. We stratified the density data into five oceanographic water mass strata: Bering Sea Water, Subarctic Water (north of the Subarctic Front or north of approximately lat. 42°N), Subtropical Water (south of the Subtropical Front or south of approximately lat. 31°N), Japan Sea/nearshore Japan Water (west of approximately long. 150°E), and Transitional Water (Subarctic Front, Transition Zone, and Subtropical Front). We then subjected the stratified density data (total density, the 6 general debris types, and the 11 plastic debris types) to Kruskal-Wallis tests (Conover 1980; Zar 1984). For each data set, we tested the hypothesis:

HO: The density does not vary among water masses.

When test results were significant, we conducted multiple comparison tests (Conover 1980) to determine which water masses were significantly different.

The size data were combined into 10-cm size classes for sizes up to 100 cm; larger debris items were combined into size classes 101-200 cm,

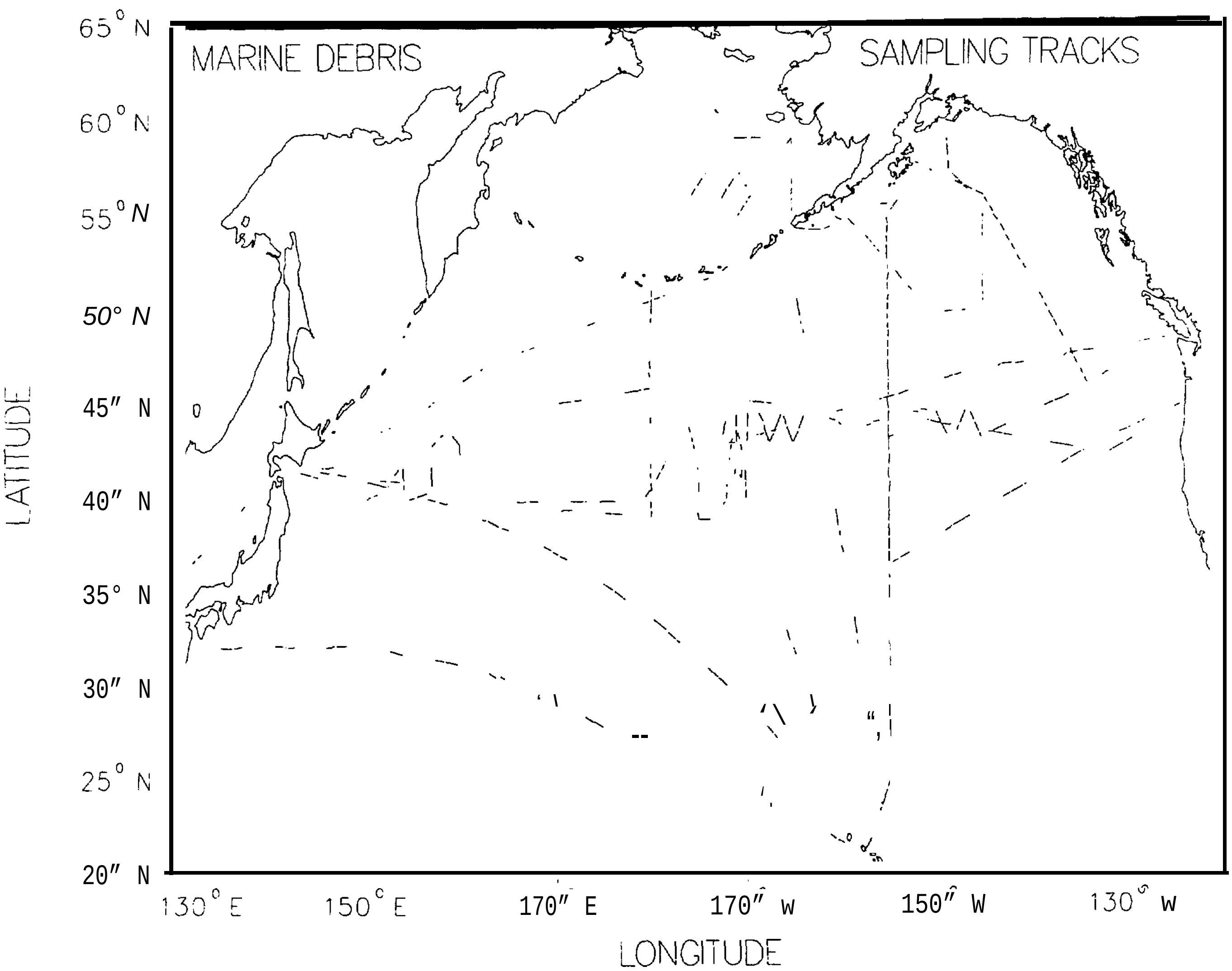

Figure 1. --Cruise tracks for marine debris sampling, 1984-88.

>200 cm, or unknown. The size data were compiled for each of the six general-debris types but not for the individual plastic types. The color data were compiled as frequencies of each color of plastic; subsequently, these frequencies were divided by the total number of plastic items to determine percentages of each color type.

RESULTS

Total Debris

We recorded 2,127 debris objects on the 181 debris transects. Plastic was the most common general type of debris, being recorded 1,899 times (89.3% of the total number of debris objects). Glass was next in frequency (72 objects; 3.3%), followed by 68 wood objects (3.2%), 53 paper/fiber objects (2.4%), 10 metal objects (0.5%), and 4 rubber objects (0.2%). Miscellaneous/unidentified marine debris was recorded 22 times (1.0%).

Marine debris was widespread in occurrence, but occurred in greatest densities in the Japan Sea and off the eastern coast of Japan; it also was common along the Subarctic Front and in southern Transitional Water (Fig. 2). Lowest densities were in the central Alaska Gyre, in the Bering Sea, and in the vicinity of the Hawaiian Islands. The highest density of total marine debris was 36.7 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea. Densities of total marine debris differed significantly among water masses ($H = 66.735$; $n = 181$; $df = 4$; $p < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Transitional Water - Subtropical Water > Subarctic Water - Bering Sea Water.

Glass Debris

Glass objects were recorded 72 times. Glass containers of various types (miscellaneous bottle, sake bottle, jar, beer bottle, and Japanese whisky bottle, in decreasing order of frequency) were recorded 54 times (75.0% of total glass); bottles were the most abundant, being recorded 42 times (58%). The second main class of glass objects was light bulbs (11 objects; 15.3%), which were represented (in decreasing order) by incandescent bulbs, fluorescent bulbs, and floodlights. The remaining seven (9.7%) glass objects consisted of glass fishing floats (glass balls). The mean dimensions of glass debris were 17.9 x 33.7 cm ($n = 34$ objects of known dimensions).

Glass debris was widespread south of the Subarctic Water, occurring in greatest densities in southern Transitional Water, in the Japan Sea, and off eastern Japan; it was uncommon in Subarctic Water and absent in the Bering Sea (Fig. 3). The highest density was 1.3 pieces/km^2 at lat. 30°34'N, long. 173"10'W in Subtropical Water northwest of the Hawaiian Islands. Densities of glass differed significantly among water masses ($H = 34.744$; $n= 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons tests were confusing, however, in that those water masses with the largest difference in mean ranks were not significantly different, whereas water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Transitional Water > Subarctic Water, the two with the largest sample sizes (49 and 99, respectively) . We suspect that other water masses were different but that sample sizes in most were too small for the multiple comparisons test to find significant differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Subtropical Water, Transitional Water, Subarctic Water, and Bering Sea Water.

Metal Debris

Metal objects were recorded 10 times. Metal cans of various sizes were the most common metal debris, being recorded eight times (80% of total metal) . The remaining two metal objects were a 208.2 L (55-gal) drum and a metal trawl float (10% each). The mean dimensions of metal debris were 41.5 x 64.5 cm ($n = 5$ objects of known dimensions).

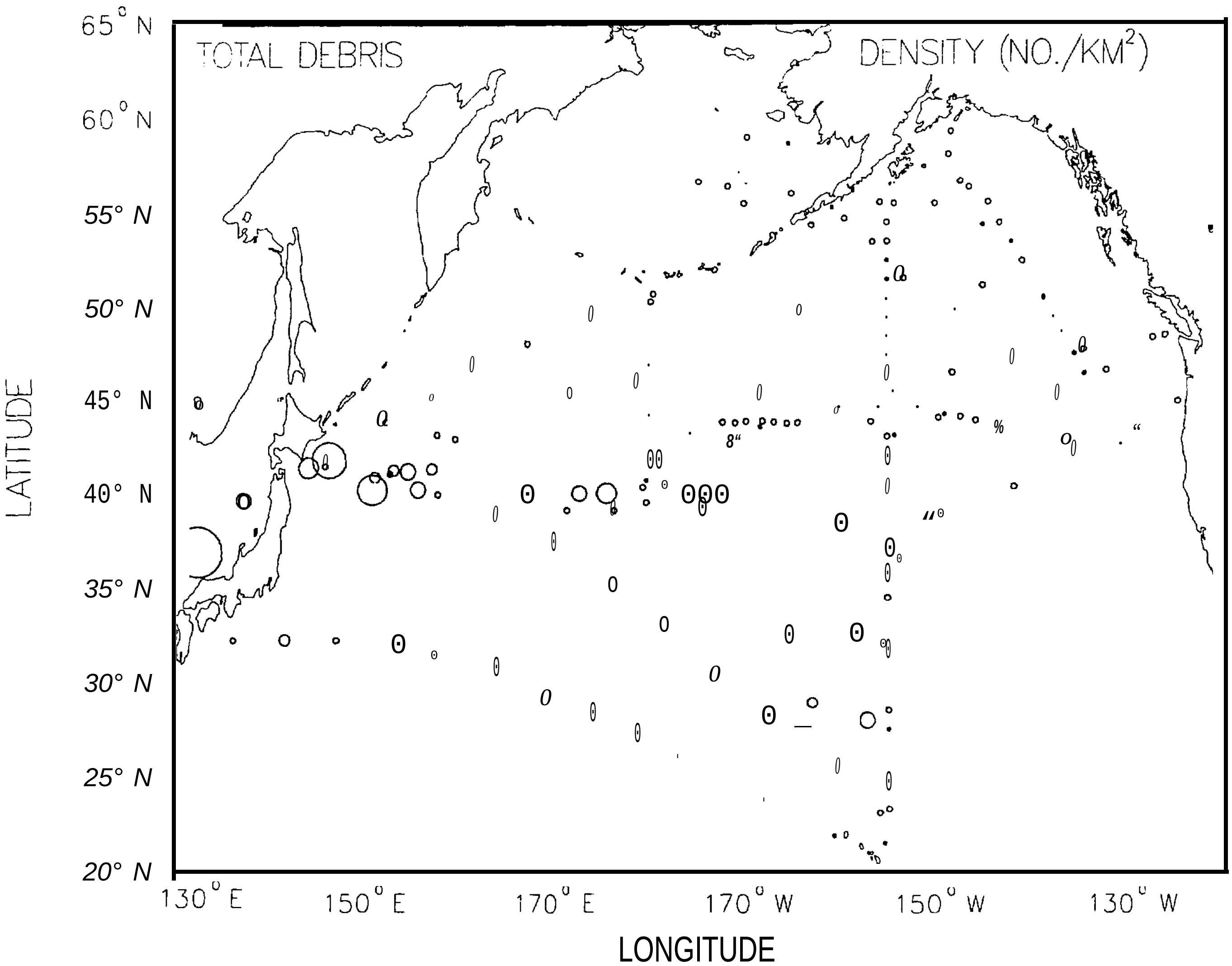

Figure 2. --Densities of total marine debris, 1984-88. Solid black circles indicate stations at which debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 36.7 pieces/km^2.

Metal debris was sporadic in occurrence and almost certainly originated from ships. The main areas of occurrence were the Japan Sea and off eastern Japan, with other records in the northern Gulf of Alaska and the eastern subarctic Pacific (Fig. 4). The highest density was 0.5 piece/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea. Densities of metal debris appeared to differ significantly among water masses ($H = 10.106$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons, however, indicated that none of the water masses were significantly different; we suspect that densities were too low overall for the multiple comparisons to find significant differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Transitional Water, Subarctic Water, and none in Subtropical and Bering Sea Waters.

Table 1.--Densities (number/km^2) of general types of marine debris in five water masses of the North Pacific, 1984-88.

Parameter	Bering Sea Water		Subarctic Water		Transitional Water		Subtropical Water		Japan Sea and nearshore Japan Water	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
n	7		99		69		18		8	
Distance sampled (km)	872.6		11,010.5		6,072.0		2,408.0		1,061.9	
Area sampled (km^2)	43.7		551.7		303.6		120.4		53.1	
Total density	0.3	0.3	0.4	0.6	3.6	3.8	2.4	3.5	11.5	12.8
Glass	0.0	0.0	<0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.2
Metal	0.0	0.0	<0.1	<0.1	<0.1	<0.1	0.0	0.0	0.1	0.2
Paper/fiber	<0.1	0.1	<0.1	0.1	0.1	0.2	<0.1	0.1	0.1	0.8
Plastic	0.2	0.2	0.3	0.4	3.3	3.7	2.1	3.1	10.5	11.7
Rubber	0.0	0.0	0.0	0.0	<0.1	<0,1	0.0	0.0	0.1	0.1
Wood	<0.1	<0.1	0.1	0.3	<0.1	0.1	<0.1	0.1	0.2	0.2
Miscellaneous/ unidentified	<0.1	0.1	<0.1	<0.1	0.1	0.1	<0,1	0.1	0.0	0.0

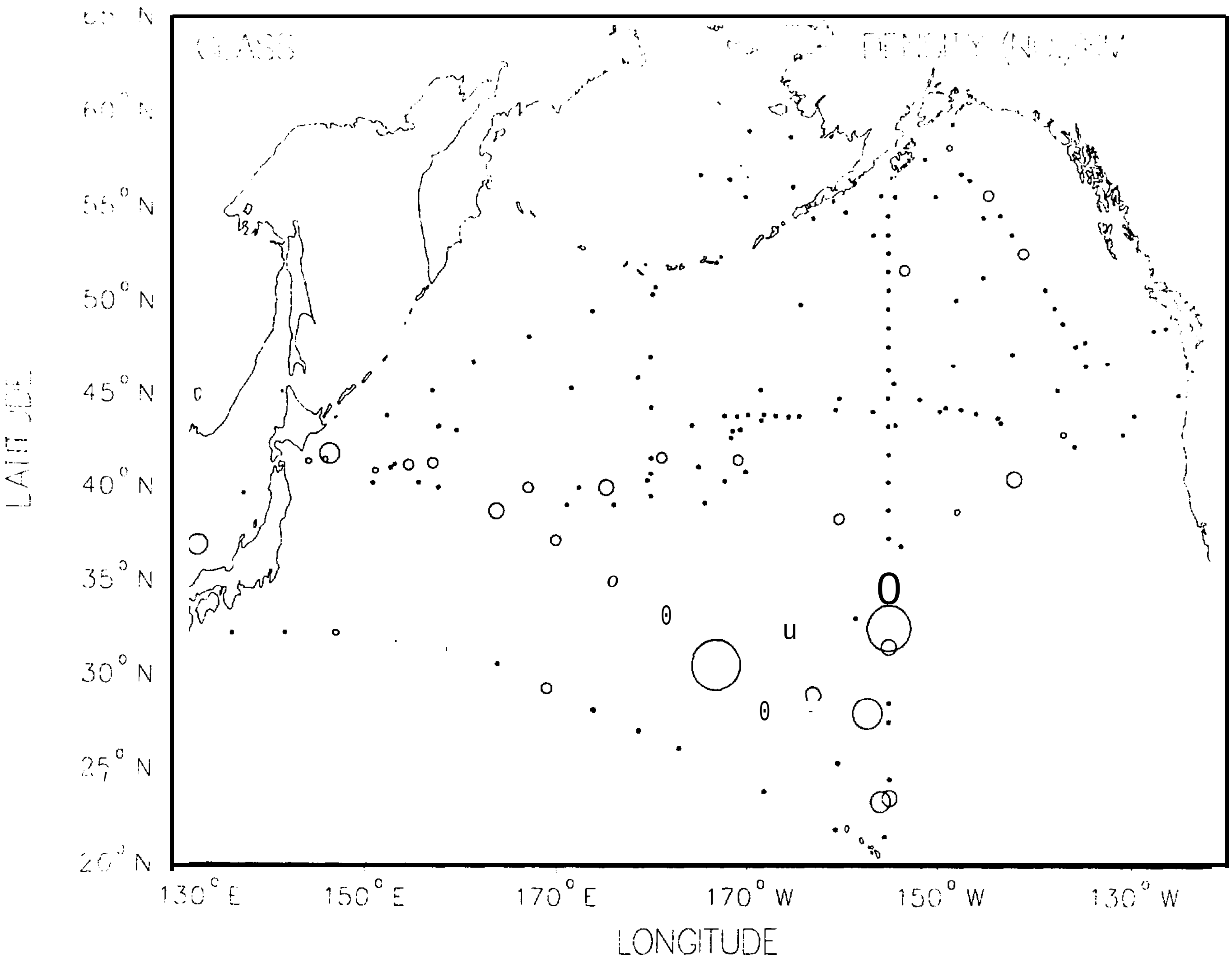

Figure 3. --Densities of glass debris, 1984-88. Solid black circles indicate stations at which glass debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 1.3 pieces/km².

Paper/Fiber Debris

Paper/fiber objects were recorded 53 times. Paperlike objects were the most common, being recorded 34 times (66.0% of total paper/fiber); of these, cardboard (fragments, boxes, sheets, and tubes) was recorded 19 times (35.8%), and paper (fragments, towels, cups, magazines, and cigarette packs) was recorded 16 times (30.2%). Hemp line was recorded 11 times (20.8%); it consisted of fragments of hemp deck lines from ships and of 1

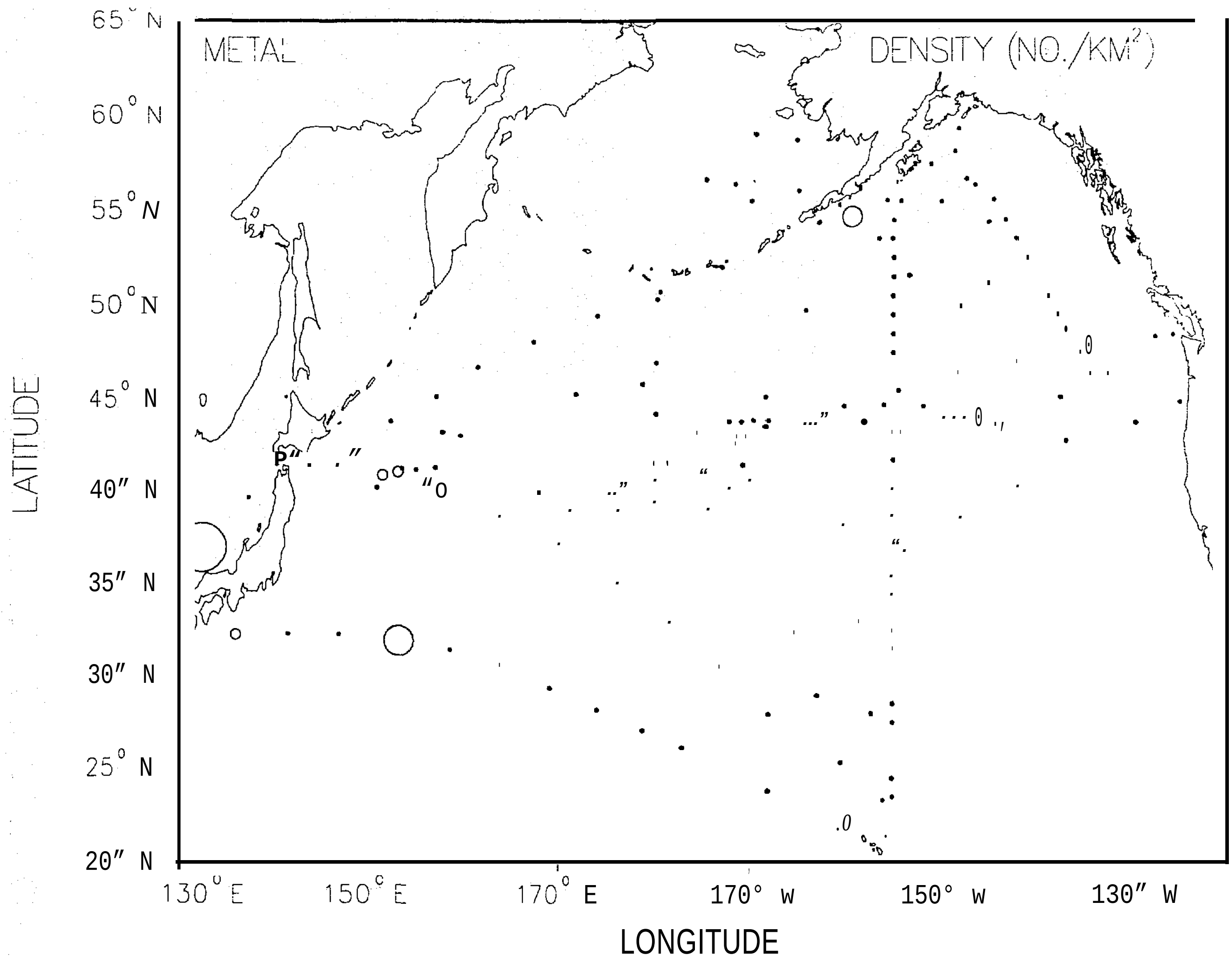

Figure 4.- -Densities of metal debris, 1984-88. Solid black circles indicate stations at which metal debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 0.5 piece/km^2.

piece of twine. Woven debris was the least common kind of paper/fiber, being recorded seven times (13.2%); this category included cloth fragments and bags, canvas fragments and bags, and one carpet fragment. The mean dimensions of paper/fiber objects were 23.1 x 75.6 cm (n - 42 objects of known dimensions); the mean dimensions excluding objects >200 cm long were only 23.1 x 50.6 cm (n = 42 and *n* = 39, respectively), however.

Because paper decomposes rapidly at sea, paper\fiber debris occurred primarily near shore (e.g., the Japan Sea, off eastern Japan, the Bering

Sea) or in areas that are fished heavily (e.g., southeastern Bering Sea, flying squid fishery near the Subarctic Front east of Japan), where numerous fishing boats provide constant input of paper debris; most of the records of this debris type in southern Transitional Water and northern Subtropical Water are of hemp deck lines (Fig. 5). The highest density was 2.3 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea. Densities of paper/fiber differed significantly among water masses (H - 38.676; n = 181; df = 4; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water > Transitional Water = Subtropical Water = Subarctic Water = Bering Sea Water.

Rubber Debris

Rubber objects were recorded only four times, the least of all general debris types. All four (100%) objects were rubber gloves, which frequently are used on fishing boats. The mean dimensions of rubber objects were 15.5 × 25.5 cm (n = 3 objects of known dimensions).

Rubber debris was recorded at only three stations: at lat. 32°15'N, long. 141°36'E in Transitional Water east of Japan; at lat. 36°55'N, long. 132°30'E in the Japan Sea; and at lat. 27°59'N, long. 157°13'W in Subtropical Water north of the Hawaiian Islands. The highest density was 0.3 piece/km^2 in the Japan Sea. Densities of rubber appeared to differ significantly among water masses (H = 28.715; n = 181; df = 4; $P < 0.05$; Table 1). Multiple comparisons, however, found no significant differences; we suspect that densities were too low overall for the multiple comparisons to find differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Transitional Water, and none in Subtropical, Subarctic, and Bering Sea Waters.

Wood Debris

Wood objects were recorded 68 times. Sawed or milled wood objects were the most common (63 objects; 92.6% of total wood); this category consisted (in decreasing order of frequency) of boards, sawed logs (for shipping to sawmills), dock pilings, and large timbers or blocks that frequently are used as dunnage on ships. Bamboo objects (3; 4.4%) were next in abundance and consisted of flagpoles (for marking the ends of drift gillnets) and fragments. Finally, fabricated objects (2; 2.9%) were represented by one wooden pallet and what appeared to be a wooden ladder. The mean dimensions were 23.5 x 183.0 cm (n = 62 objects of known dimensions); the mean dimensions excluding objects >200 cm long were 23.5 x 78.8 cm (n = 62 and n = 45, respectively), however.

Wood debris occurred primarily near shore, probably because of its tendency to become waterlogged and sink with time. The highest densities were in the northern Gulf of Alaska, where harvested logs were common in the Alaska Coastal Current and farther offshore, in the Japan Sea and off the eastern shore of Japan; little wood debris was recorded far from shore, however (Fig. 6). The highest density was 2.8 pieces/km^2 at lat. 59°47'N, long. 148°17'W near the coast of the northern Gulf of Alaska. Densities of wood differed significantly among water masses (H = 19.830; n = 181; df = 4; $P < 0.05$; Table 1). Multiple comparisons indicated that densities

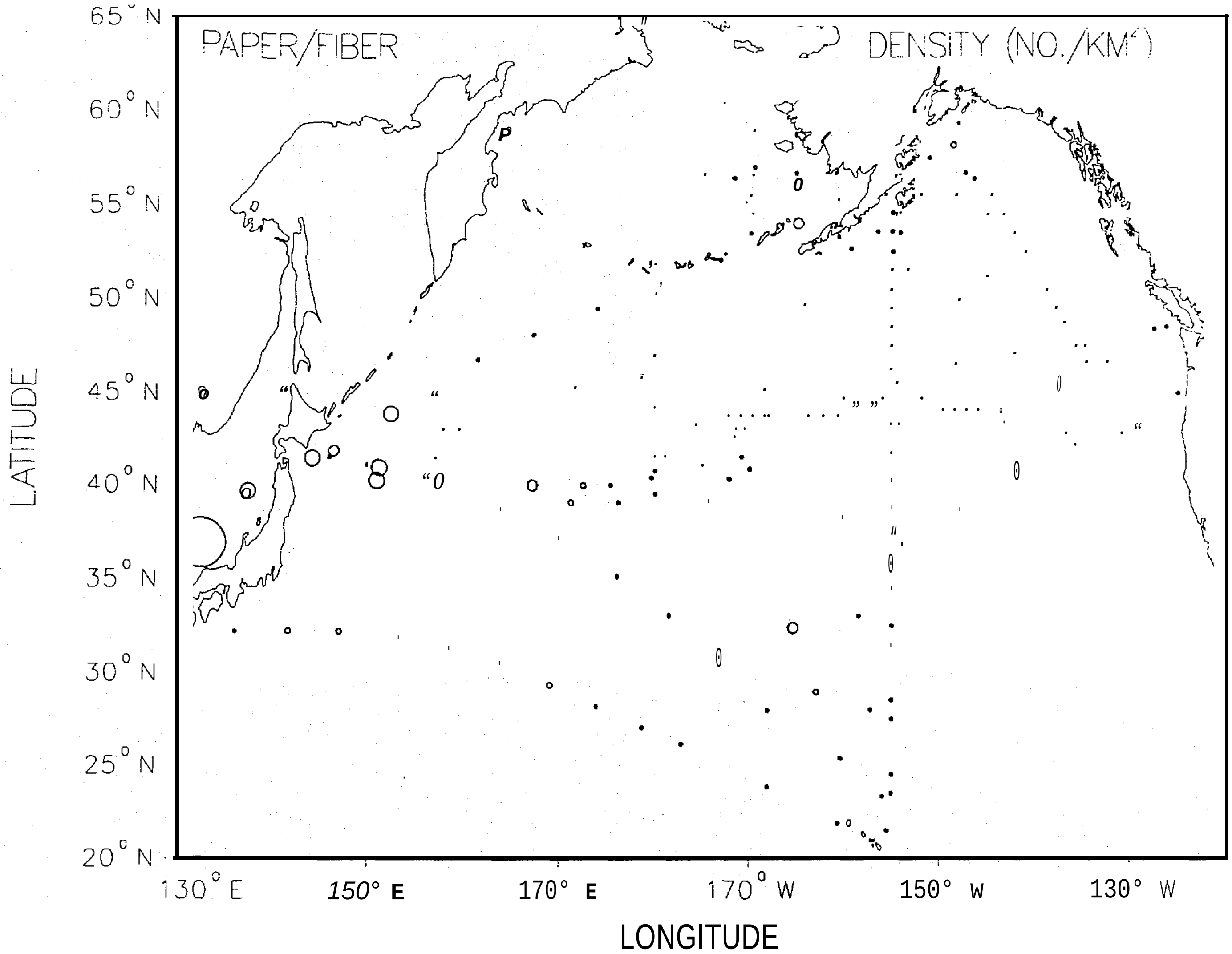

Figure 5. --Densities of paper/fiber debris, 1984-88. Solid black circles indicate stations at which paper/fiber debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 2.3 pieces/km².

were: Japan Sea/nearshore Japan Water > Subarctic Water = Subtropical Water = Transitional Water = Bering Sea Water.

Plastic Debris

Types of Plastic Debris

Of the 1,899 plastic debris objects recorded on transect, fragments were the most common type (649 objects). Styrofoam was next in abundance

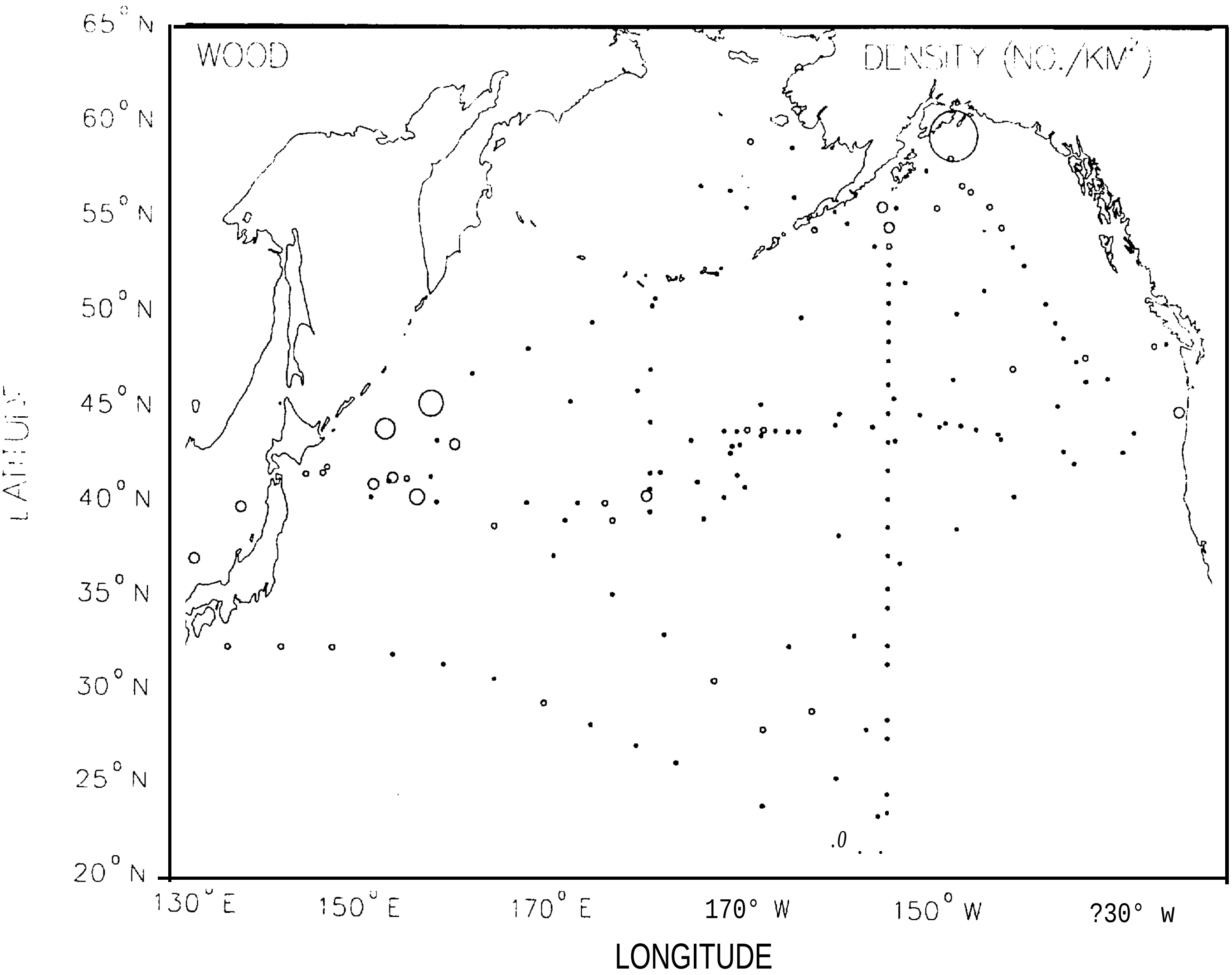

Figure 6.- -Densities of wood debris, 1984-88. Solid black circles indicate stations at which wood debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 2.8 pieces/km^2.

(428 objects), followed by 346 sheets/bags, 95 gillnet floats, 59 polypropylene line fragments, 54 miscellaneous floats, 12 gillnet fragments (plus 8 seen off transect), 11 trawl net fragments (plus 3 seen off transect), 8 uncut plastic straps, and 3 unidentified net fragments (plus 1 seen off transect). Miscellaneous/unidentified plastic debris was recorded 234 times. The mean dimensions of plastic objects were 13.3 x 24.3 cm (n = 1,569 objects of known dimensions); the mean dimensions excluding objects >200 cm were 11.7 x 19.1 cm (n = 1,564 and n = 1,557, respectively).

As might be expected from its abundance overall, plastic debris was the most widespread of all debris types (Fig. 7). The highest densities were in the Japan Sea and off the eastern coast of Japan, with lower densities in the Subarctic Front east of Japan and in southern Transitional Water; the lowest densities were near the Hawaiian Islands, in Subarctic Water (especially in the Alaska Gyre), and in the Bering Sea. The highest density of total plastic debris was 32.6 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea; local densities here were so high that Day was unable to census all marine debris, so he stopped sampling here. The only other high densities of plastic debris were 23.8 pieces/km^2 at lat. 41°50'N, long. 146°12'E and 18.2 pieces/km^2 at lat. 40°15'N, long. 150°46'E, both off the eastern coast of Japan. Densities of plastic differed significantly among water masses ($H = 74.168$; $n = 181$; $df = 4$; $P < 0.05$; Table l.). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Subtropical Water = Transitional Water > Subarctic Water - Bering Sea Water.

Fragments were irregular pieces of plastic (other than the specific categories discussed here) that apparently had been broken from other, larger pieces. They were the most abundant plastic type, being recorded 649 times (34.2% of total plastic). Fragments occurred in highest densities off eastern Japan and in the Japan Sea, with lower densities in northern Subtropical Water near the Subtropical Front; in contrast, they were uncommon in Subarctic Water and the Bering Sea (Fig. 8). The highest density was 18.9 pieces/km^2 at lat. 41°50'N, long. 146°12'E off the eastern coast of Japan. The density of plastic fragments differed significantly among water masses ($H = 62.887$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Transitional Water > Subtropical Water = Subarctic Water = Bering Sea Water.

Styrofoam included all objects made of foamed polystyrene, including fragments, sheets, boxes or other containers, and fishing floats; based on observed colors and textures, we believe that none of this debris consisted of other types of foamed plastics (e.g. , polyurethane). Styrofoam objects were recorded 428 times (22.5% of total plastic), making them second in abundance of all plastic types. As was seen for neuston plastic (Day et al. 1990), Styrofoam debris also is a "nearshore Japan/transitional species," with few records in Subarctic Water or the Bering Sea (Fig. 9). The highest density was 4.9 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea. The density of Styrofoam differed significantly among water masses ($H = 58.655$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan' Water - Transitional Water = Subtropical Water > Subarctic Water - Bering Sea Water.

Polypropylene line is used more commonly than are other synthetic lines and largely has replaced hemp line on ships; consequently, we categorized all lines that appeared to be synthetic as polypropylene. Debris of this type consisted of intact lines and line fragments. Polypropylene lines were recorded 59 times (3.1% of total plastic). These lines were absent in the Bering Sea, were recorded in Subarctic Water only three times, and peaked in abundance in and around the Subarctic Front, in

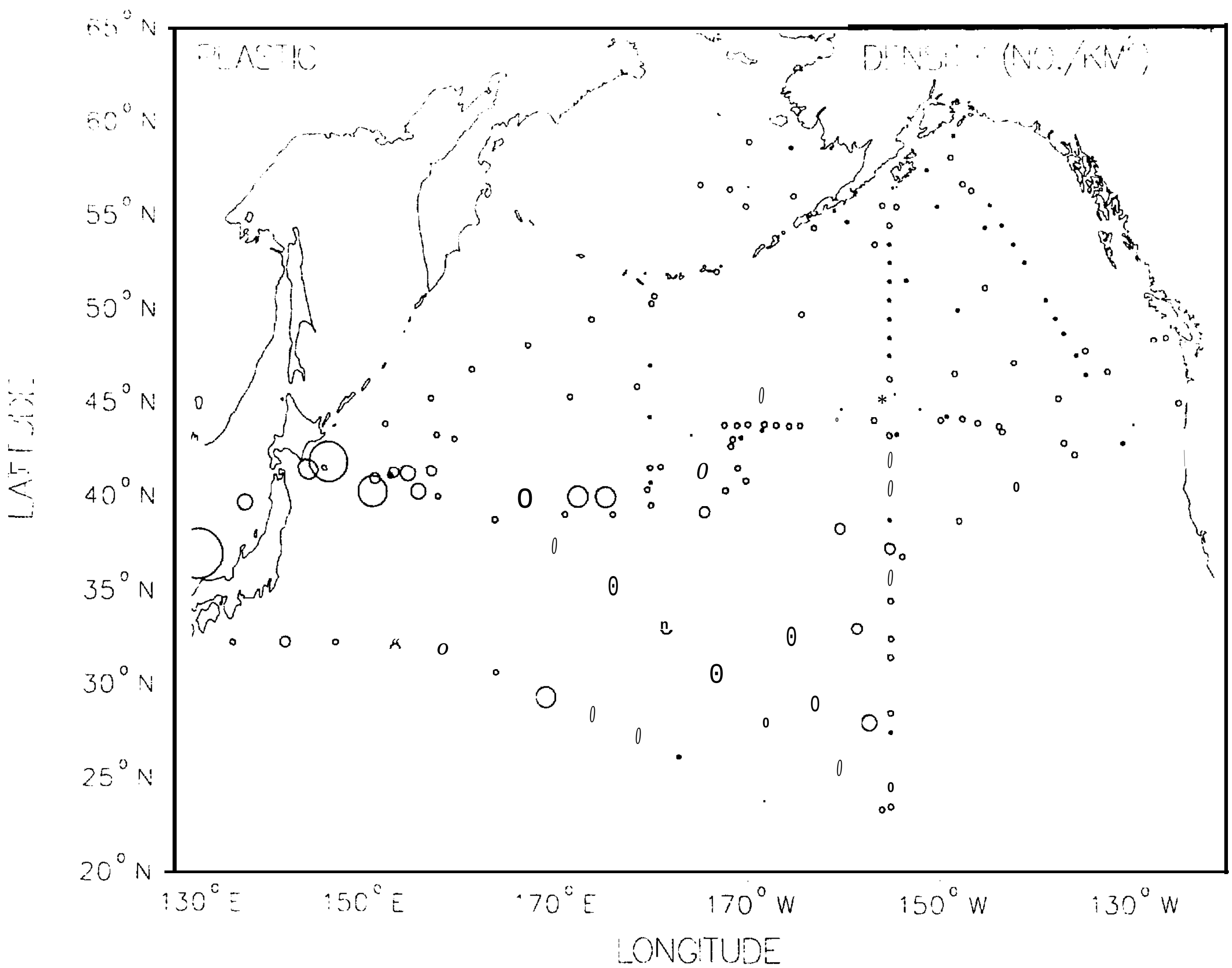

Figure 7.--Densities of plastic debris, 1984-88. Solid black circles indicate stations at which plastic debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 32.6 pieces/km².

the Japan Sea, and in and near the Subtropical Front (Fig. 10). The highest density was 1.2 pieces/km² at lat. 40°00'N, long. 175°17'E near the Subarctic Front in the central Pacific. Densities of polypropylene line differed significantly among water masses (H - 27.068; n = 181; df = 4; $P < 0.05$; Table 2). Multiple comparisons were confusing, however, in that those water masses with the largest difference in mean ranks were not significantly different, whereas water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Transitional Water > Subarctic Water, the two

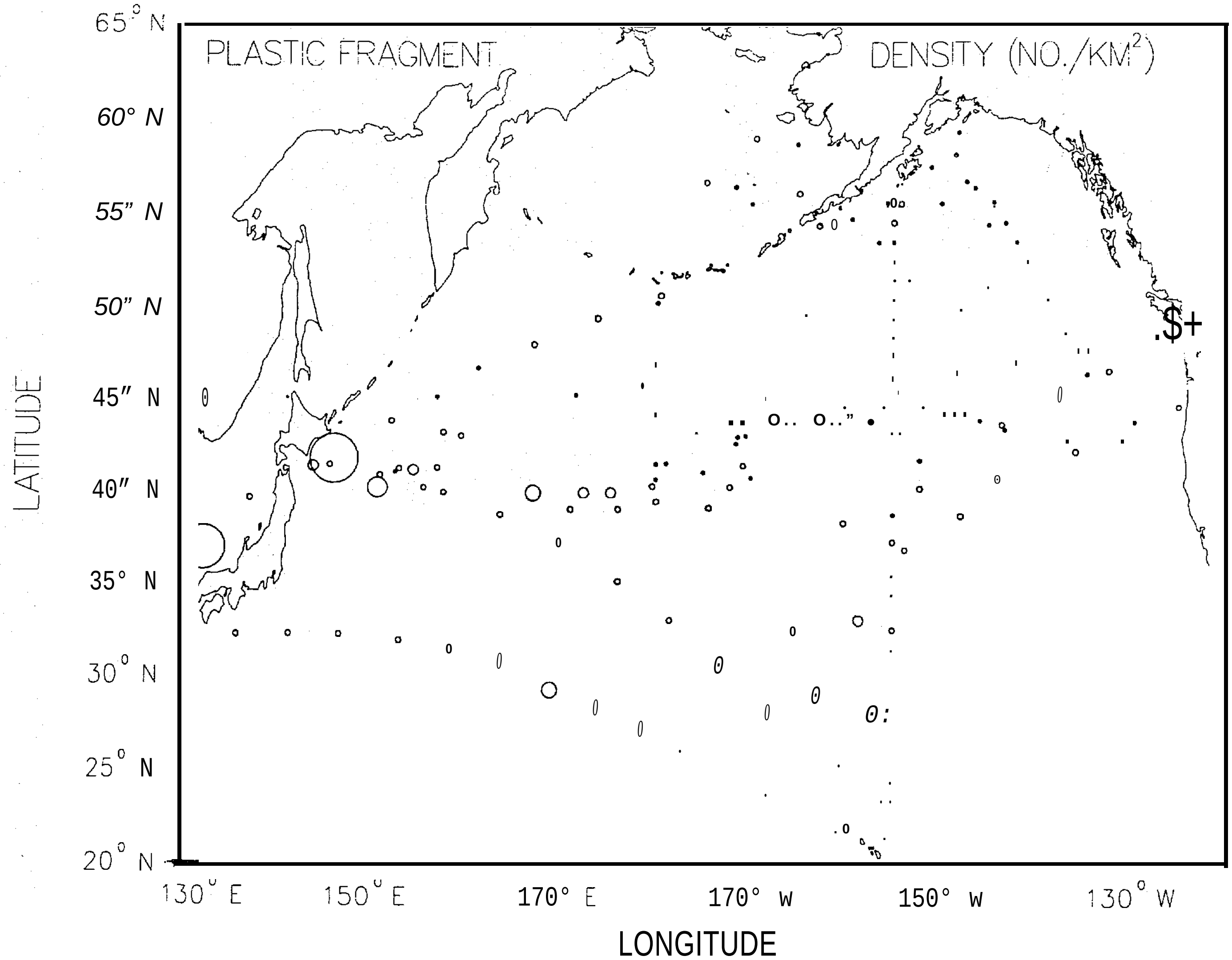

Figure 8. --Densities of plastic fragments, 1984-88. Solid black circles indicate stations at which plastic fragments was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 18.9 pieces/km².

with the largest sample sizes (49 and 99, respectively). We suspect that other water masses were different but that sample sizes in most were too small for the multiple comparisons to show significant differences. The pattern of mean ranks (in descending order) was: Transitional Water, Subtropical Water, Japan Sea/nearshore Japan Water, Subarctic Water, and Bering Sea Water.

Table 2. --Densities (number/km^2) of types of plastic debris in five water masses of the North Pacific, 1985-88.

Parameter	Bering Sea Water Mean	Bering Sea Water SD	Subarctic Water Mean	Subarctic Water SD	Transitional Water Mean	Transitional Water SD	Subtropical Water Mean	Subtropical Water SD	Japan Sea and nearshore Japan Water Mean	Japan Sea and nearshore Japan Water SD
n	7		99		49		18		8	
Fragment	0.1	0.1	0.1	0.2	0.9	1.3	0.8	1.4	5.3	7.6
Styrofoam	<0.1	0.1	0.1	0.1	0.7	0.8	0.4	0.8	2.1	1.7
Polypropylene line	0.0	0,0	<0.1	<0.1	0.1	0.2	0.1	0.2	0.2	0.4
Gillnet float	0.0	0.0	<0.1	0.1	0.2	0.2	0.2	0.3	0.1	0.1
Miscellaneous float	0.0	0.0	<0.1	<0.1	0.1	0.1	0.1	0.1	0,1	0.2
Gillnet fragment	0.0	0.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.0	0.0
Trawl net fragment	0.0	0.0	<0.1	<0.1	<0.1	0.1	0.1	<0.1	00	0.0
Unidentified net fragment	0.0	0,0	0.0	0.0	<0.1	<0.1	0.0	0.0	0.0	0.0
Uncut strapping	0.0	0.0	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.1
Sheet/bag	<0.1	<0.1	<0.1	0.1	0.8	1.3	0.1	0,2	2.1	2.8
Miscellaneous/ unidentified	0.1	0.1	<0.1	0.1	0.5	0.5	0.3	0.4	0.6	0.5

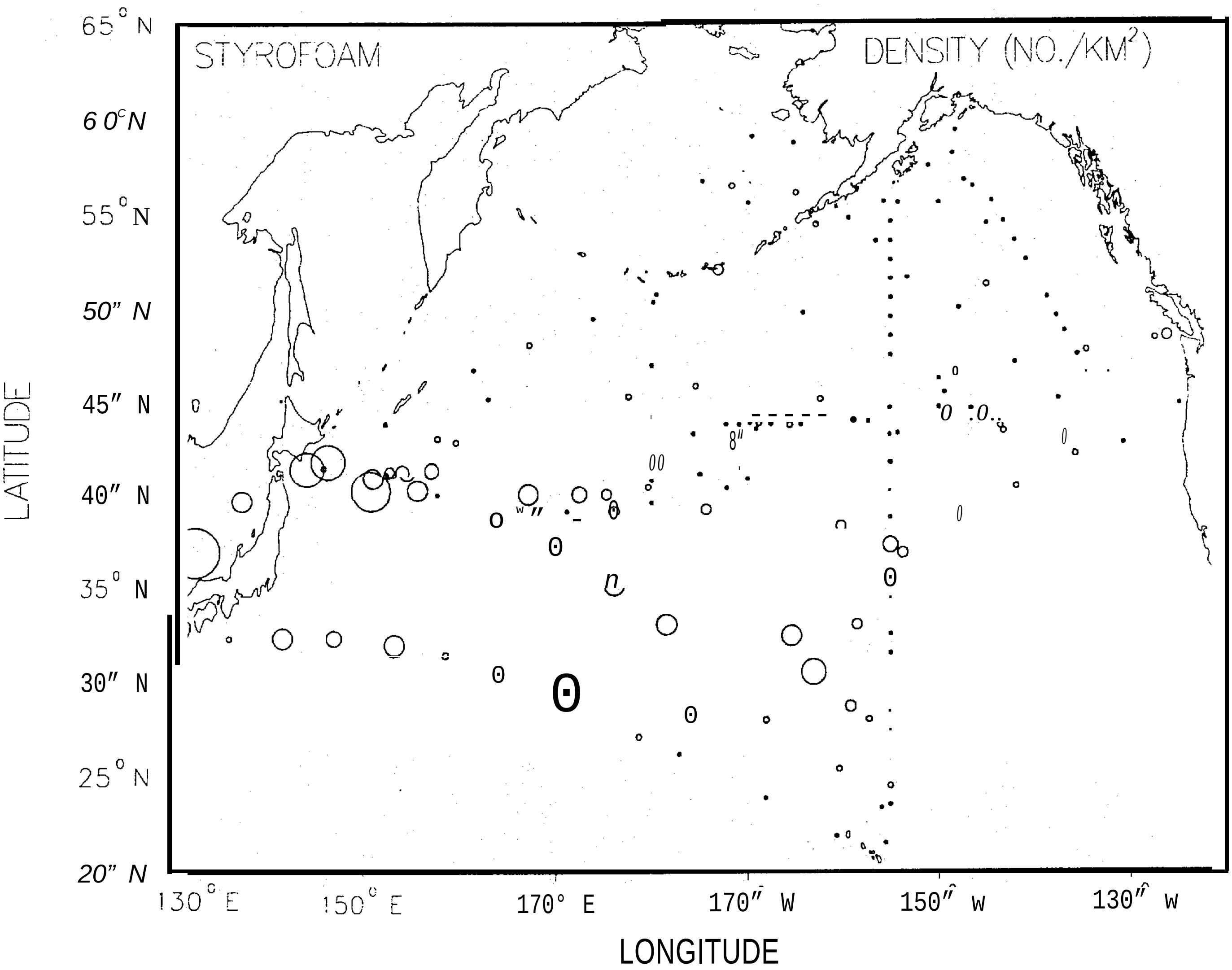

Figure 9. --Densities of Styrofoam, 1984-88. Solid black circles indicate stations at which Styrofoam was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 4.9 pieces/km^2.

Floats include gillnet floats, trawl net floats, longline floats, crab pot buoys, and large boat bumpers made out of plastic other than Styrofoam. They primarily represent various types of fishing floats.

Gillnet floats were widely distributed and were common, being recorded 95 times (5.0% of total plastic). They were especially common in and around the Subarctic Front (center of the major gillnet fishery for squid--see below), in southern Transitional Water, and in and near the Subtropical

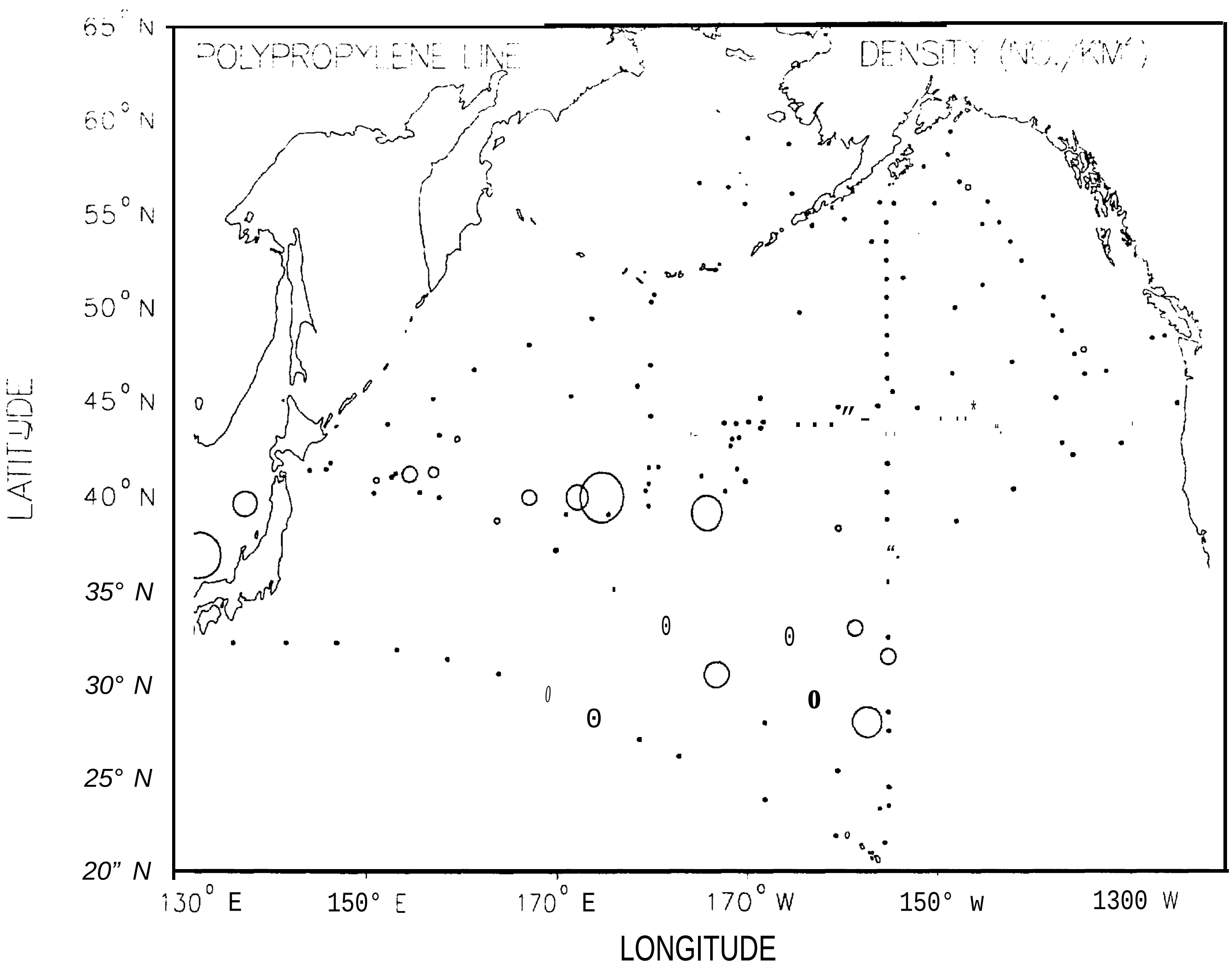

Figure 10. - -Densities of polypropylene line, 1984-88. Solid black circles indicate stations at which polypropylene line was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 1.2 pieces/km².

Front; the only place they were absent was in the Bering Sea, probably because of the limited sampling there (Fig. 11). The highest density was 0.8 piece/km² at lat. 40°15'N, long. 150°46'E near the Subarctic Front east of Japan and at lat. 27°59'N, long. 157°13'W in Subtropical Water north of Hawaii. Densities of gillnet floats differed significantly among water masses (H - 28.690; n - 181; df = 4; $P < 0.05$; Table 2). Multiple comparisons again were confusing, however, in that those water masses with the largest difference in mean ranks were not significantly different, whereas

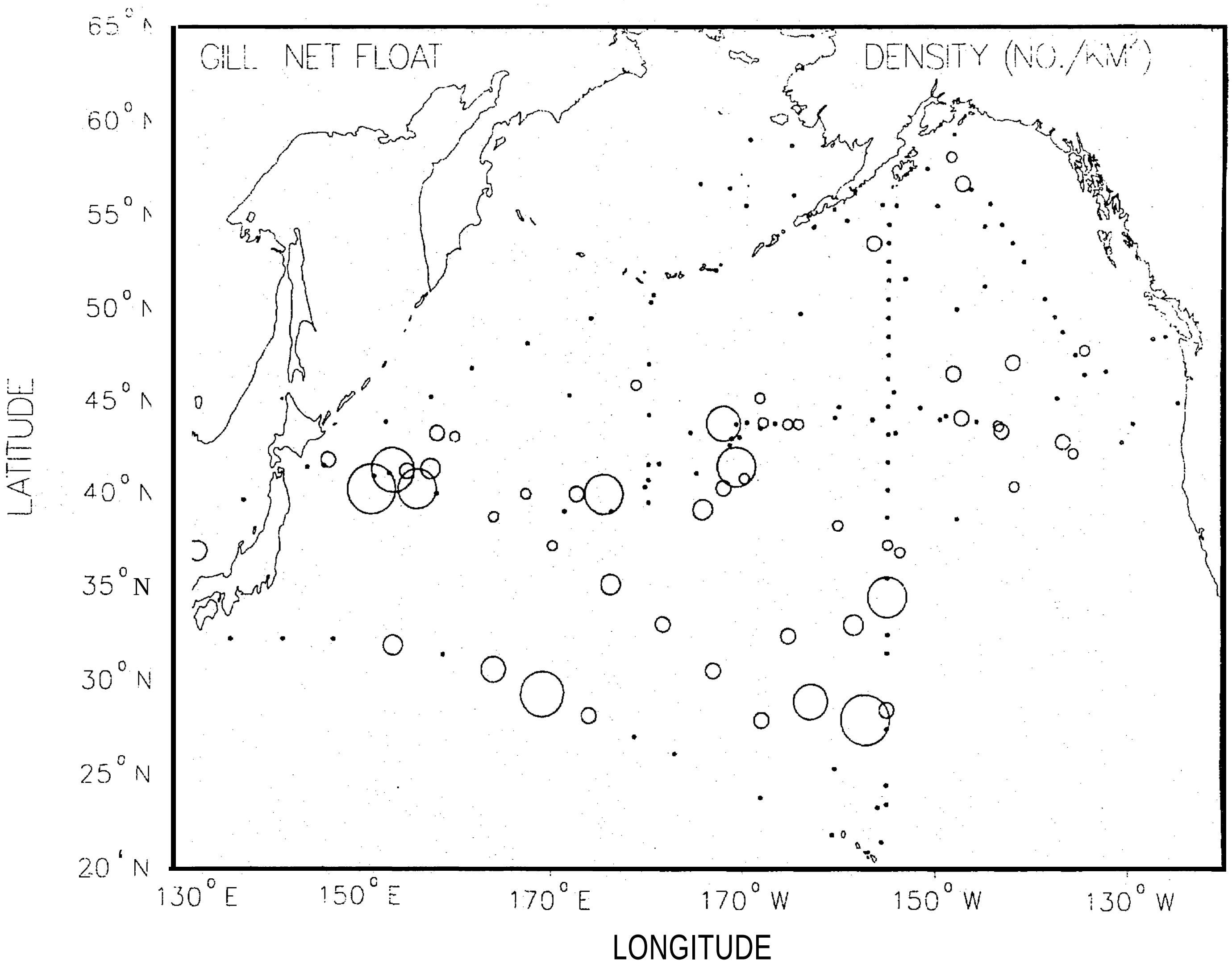

Figure Il.--Densities of plastic gillnet floats, 1984-88, Solid black circles indicate stations at which gillnet floats were not recorded. Sizes of hollow circles indicate relative densities. The highest density was 0.8 piece/km².

water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Transitional Water > Subarctic Water, the two with the largest sample sizes (49 and 99, respectively). Again, we suspect that other water masses were different, but that sample sizes in most were too small for the multiple comparisons to show significant differences. The pattern of mean ranks (in descending order) was: Transitional Water, Subtropical Water, Japan Sea/nearshore Japan Water, Subarctic Water, and Bering Sea Water.

Miscellaneous floats also were widespread at sea. These floats were concentrated in southern Transitional Water and Subtropical Water, with records scattered everywhere but the Bering Sea, again probably because of the limited sampling there (Fig. 12). These floats were rare in Subarctic Water as a whole, however. The highest density was 0.6 piece/km^2 at lat. 33°01′N, long. 158°31′W in Transitional Water north of Hawaii. Densities of miscellaneous floats differed significantly among water masses ($H = 29.842$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons again were confusing, in that those water masses with the largest difference in mean ranks were not significantly different, whereas water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Subtropical Water > Subarctic Water; one of these water masses had a moderate sample size and the other had a large sample size (18 and 99, respectively). We again suspect that other water masses were different, but that sample sizes in most were too small for the multiple comparisons to show significant differences . The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Subtropical Water, Transitional Water, Subarctic Water, and Bering Sea Water.

Although they were recorded only 34 times on transect and another 12 times off transect, net fragments and uncut packing straps are important components of marine debris, for they are thought to cause excessive mortality of some marine animals such as northern fur seals (Fowler 1982, 1985, 1987). These four plastic types were not distributed evenly in the North Pacific, but instead were concentrated between lat. 37° and 44°N (Fig. 13).

Gillnet fragments were recorded on transect 12 times and off transect 8 times; they were seen between lat. 25°37′ and 45°15′N, with the most (3) seen at lat. 38°-390 and 42°-43°N (Fig. 13). The highest density was 0.7 piece/km^2 in Subtropical Water northwest of the Hawaiian Islands. Densities of gillnet fragments differed significantly among water masses ($H = 14.732$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons, however, did not find significant differences. We suspect that densities were too low overall for the multiple comparisons to find significant differences . The pattern of mean ranks (in descending order) was: Subtropical Water, Transitional Water, Subarctic Water, and none in Japan Sea/nearshore Japan Water and Bering Sea Water.

Trawl net fragments were recorded on transect 11 times and off transect 3 times; they were seen between lat. 30°21′ and 44°07′N, with the most (3) seen at lat. 40°-41″ and 41-42°N (Fig. 13). The highest density was 0.2 piece/km^2, recorded at four stations near the Subarctic Front in the central and western North Pacific. Densities of trawl net fragments differed significantly among water masses ($H = 10.629$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons did not find significant differences, however, and we suspect that densities were too low overall for the multiple comparisons to find significant differences. The pattern of mean ranks (in descending order) was: Transitional Water, Subtropical Water, Subarctic Water, and none in Japan Sea/nearshore Japan Water and Bering Sea Water.

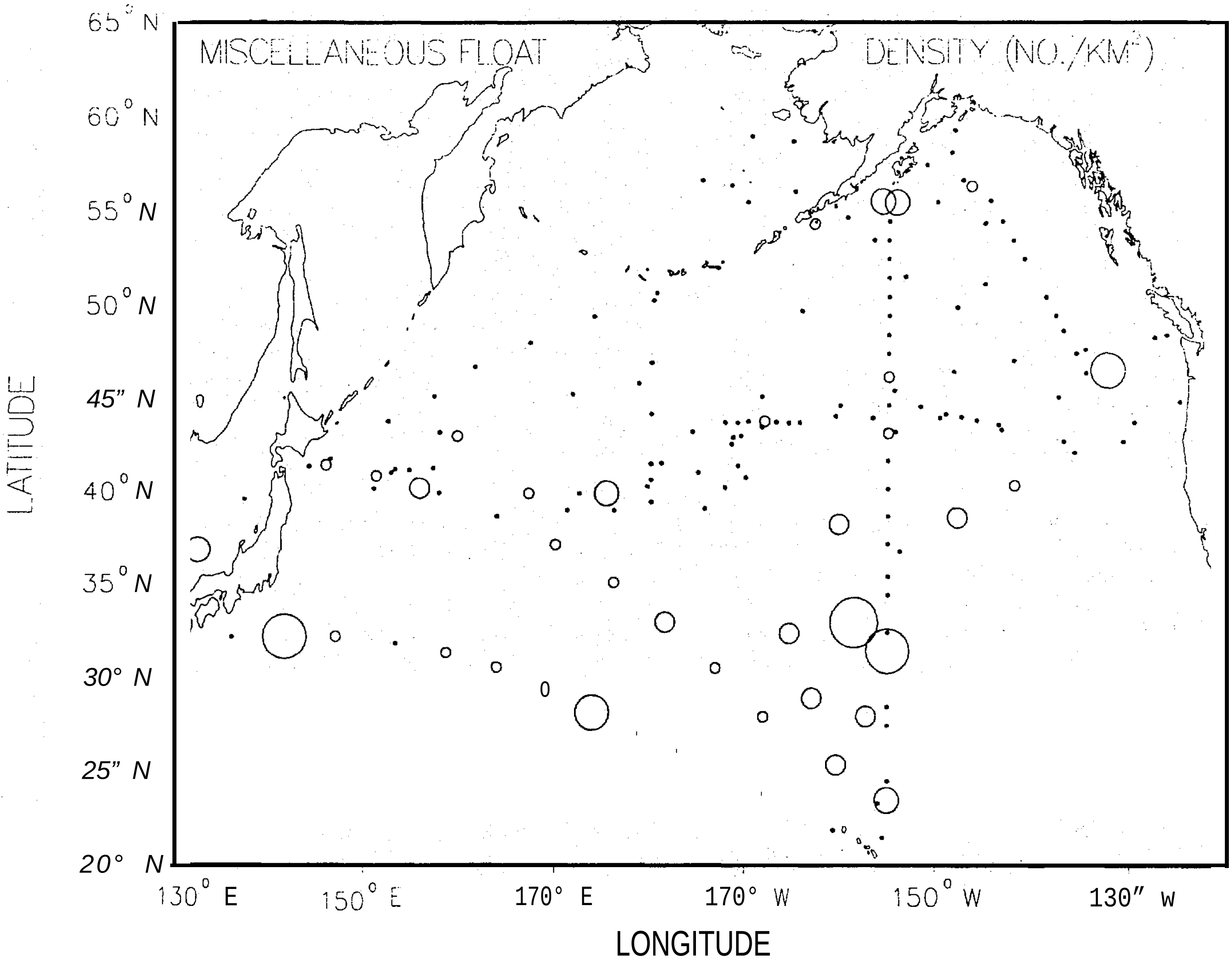

Figure 12. --Densities of miscellaneous **plastic floats, 1984-88. Solid** black circles indicate stations at which miscellaneous plastic floats were not recorded. Sizes of hollow circles indicate relative densities. The highest density was 0.6 piece/km².

Unidentified net fragments were recorded on transect three times and off transect once; they were seen between lat. 33°07′ and 43°35′N, with the most (two) seen at lat. 33°-34°N (Fig. 13). The estimated mesh size of these nets was 4 x 4 cm. The highest density was 0.3 piece/km² at lat. 33°01′N, long. 158°31′W in Transitional Water north of Hawaii. Densities of unidentified net fragments did not differ significantly among water masses ($H = 5.418$; $n = 181$; $df = 4$; $P > 0.05$; Table 2), probably because they were so low overall.

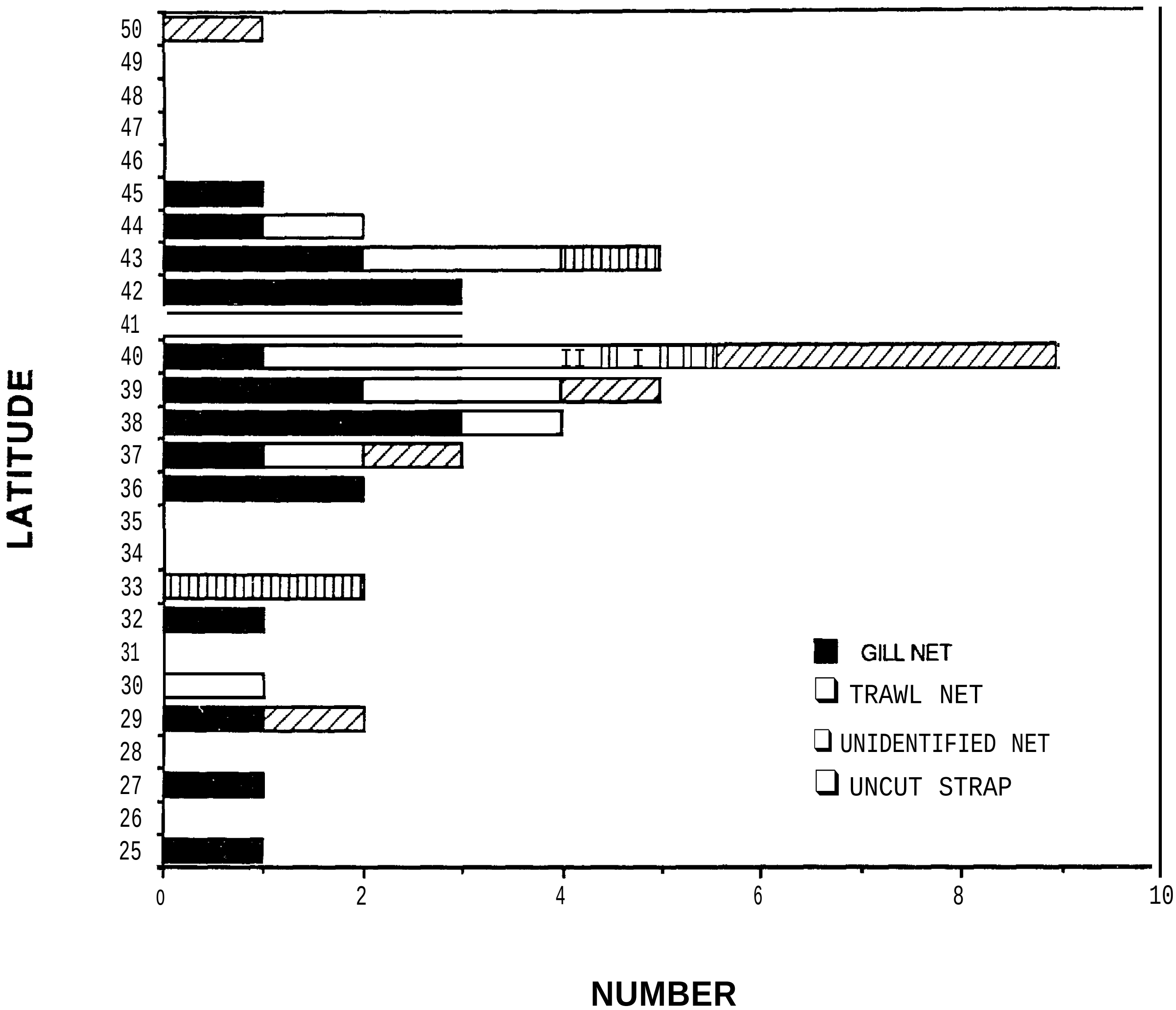

Figure 13. --Numbers of nets and uncut plastic strapping seen, by 1° blocks of latitude, 1984-88.

Uncut straps were recorded eight times, all on transect; they were seen between lat. 29°33′ and 50°03′N, with the most (four) seen at lat. 40°-41°N (Fig. 13). The highest density was 0.3 piece/km^2 at lat. 36°55′N, long. 132°30′E in the Japan Sea. Densities of uncut straps did not differ significantly among water masses ($H = 5.462$; n - 181; df - 4; $P > 0.05$; Table 2), probably because they were so low overall.

Sheets and bags, which are a pollution problem because they are eaten by and entangle sea turtles (Balazs 1985; Carr 1987), were recorded 346 times (18.2% of total plastic). Sheets and bags occurred in highest densities in the Japan Sea, off the eastern coast of Japan, and along the Subarctic Front east of Japan; this debris type was common in Transitional Water and was essentially absent from Subarctic Water and the Bering Sea (Fig. 14). The highest density was 7.9 pieces/km^2 at lat. 36°55′N, long. 132°30′E in the Japan Sea. Densities of sheets/bags differed significantly among water masses ($H = 61.202$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Transitional Water > Subtropical Water = Subarctic Water = Bering Sea Water.

Miscellaneous/unidentified plastic consisted of both fabricated objects and truly unidentified pieces; the latter objects occurred when we encountered such high local densities that we were unable to record all details on individual plastic objects, One hundred fifty-seven containers of various kinds constituted 67.1% of this category and included bottles, jars, squeeze tubes, boxes, bowls, cups, pans, beer or soda cases, woven bags, and buckets. The remaining 77 objects were a diverse assortment of screens, sponges, lids, mats, bottle caps, sandals, trays, rings, shoe liners, shovels, pipes, toys, paddles, poles, baseball caps, handles, helmets, and unidentified plastic debris. The highest density was 1.3 pieces/km^2 at lat. 35″1O′N, long. 176°01′E in Transitional Water in the central North Pacific, at lat. 40°15′N, long. 150°46′E near the Subarctic Front off eastern Japan, and at lat. 36°55′N, long. 132°30′E in the Japan Sea.

Colors of Plastic Debris

Plastic debris was recorded in all 10 of the standardized colors, plus miscellaneous/mixed colors (Fig. 15). White was by far the most common color, being recorded 922 times (48.6% of total plastic). The color tan was second in abundance (187; 9.9%), followed by transparent (124; 6.5%), blue (119; 6.3%), and yellow (86; 4.5%). The colors green (35; 1.8%), brown (32; 1.7%), red/pink (28; 1.5%), black/gray (25; 1.3%), and orange (17; 0.9%) were rare in occurrence. Finally, miscellaneous/mixed plastic was recorded 323 times (17.0% of total plastic), primarily in cases when local densities were too high for us to record all data on individual pieces of debris.

Frequencies of some colors of debris plastic differed strongly from those frequencies of neuston plastic (Fig. 15). The greatest difference was in transparent plastic, whose frequency in marine debris was <25% of that in neuston plastic. Similarly, the frequency of black and gray plastic in marine debris was <50% of that in neuston plastic. In

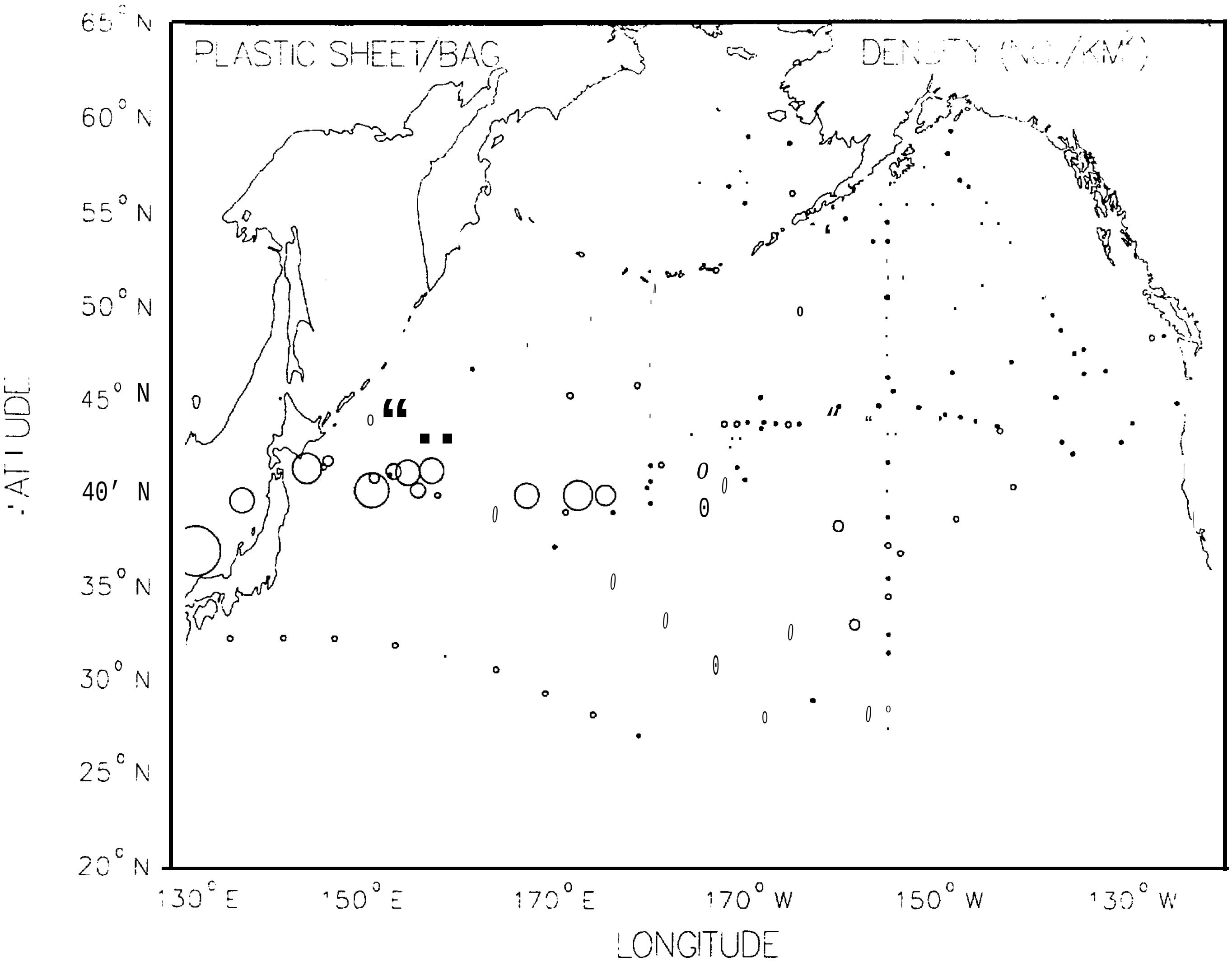

Figure 14. --Densities of plastic sheets and bags, 1984-88. Solid black circles indicate stations at which plastic sheets and bags were not recorded. Sizes of hollow circles indicate relative densities. The highest density was 7.9 pieces/km².

contrast, the frequency of white plastic was nearly 33% higher, that of tan plastic was nearly four times higher, and that of yellow plastic was nearly four times higher in marine debris than in neuston plastic. Frequencies of the other colors were relatively similar comparing the two types of plastic.

DISCUSSION

We believe that the present distribution of marine debris is controlled largely by four main phenomena: (1) the heterogeneous geographic

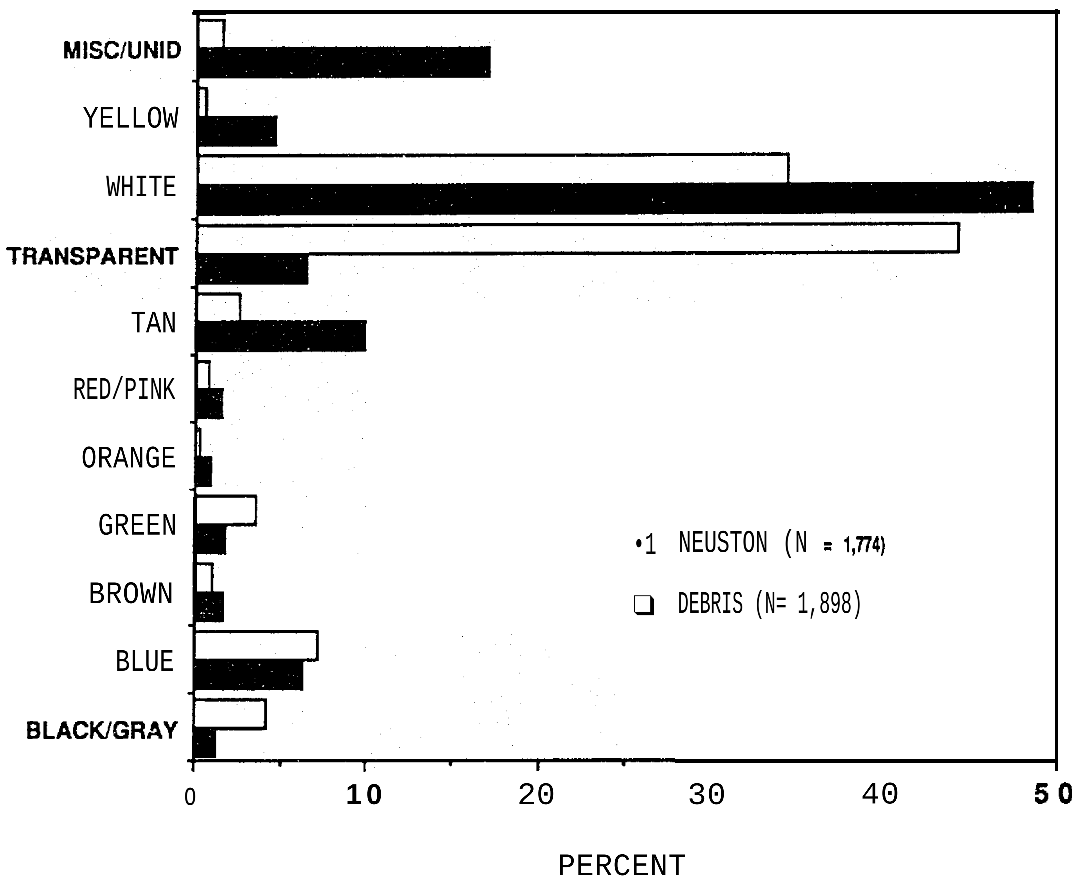

Figure 15. --Frequencies of colors of plastic debris, 1984-88, compared with frequencies of colors of neuston plastic, 1985-88 (the latter data from Day et al. 1990),

input of debris, (2) the subsequent redistribution of that debris by currents and winds, (3) the decomposition of the debris at sea, and (4) the beaching of the debris. The data that we report on here strongly suggest that these factors interact to yield the distributions that we observed. In the absence of precise" data on rates of input, transport, and degradation, however, our conclusions about factors controlling marine debris in the North Pacific must be considered tentative.

It is clear that there is heterogeneous geographic input of marine debris, with much originating in the far western Pacific. This conclusion is supported strongly by the high densities in and around the Japan Sea and nearshore Japan, where the highest densities of both marine debris and neuston plastic (Day et al. 1990) in the North Pacific were recorded. Debris was most abundant in Tokyo Bay (which had far more debris than Day has ever seen elsewhere in the North Pacific--it was too abundant for him to sample) and in localized areas in the Japan Sea. It is unclear to us how much of this debris comes from ships and how much comes from the land. At the other extreme were the Bering Sea and Gulf of Alaska, where low human populations probably provide little input of marine debris.

In Transitional Water to the east of Japan, the importance of transport compared to direct input from ships is difficult to evaluate. The area between lat. 35° and 45°N and from the eastern coast of Japan to long. 145°W is the site of a large pelagic fishery for neon flying squid, *Ommastrephes bartrami*. At the height of the fishery (May-December), approximately 700 gillnetting ships from Japan, Korea, and Taiwan participate (Fredin 1985), as well as an unknown number of small jigging ships. This fishery undoubtedly contributes to marine debris in the area, although its contribution relative to transport is unknown. In contrast, debris entering the ocean around Japan and Korea is moved eastward by the Subarctic Current (in Subarctic Water) and in the Kuroshio (Kawai 1972; Favorite et al. 1976; Nagata et al. 1986) into the same area. In addition to this general eastward movement, Ekman (wind) stress tends to move surface waters from the Subarctic and the Subtropic into the Transitional Water mass as a whole (Roden 1970). As a result, densities of debris in Transitional Water generally are high, but the relative importance of the two sources (i.e., local input and transport into the area) is unclear. Further, the generally convergent nature of surface water in the North Pacific Central Gyre (Masuzawa 1972) should result in high densities there also.

Surprisingly, there are differences among the distributions of types of debris. For example, Styrofoam debris clearly is a “nearshore Japan/transitional/subtropical species” (Fig. 9); neuston Styrofoam also is most abundant around Japan (Day et al. 1990). This localized distribution of Styrofoam may be a consequence of its weak, crumbly texture, which can lead to rapid disintegration; hence, it probably cannot survive long enough to be transported offshore in large quantities. Further, Styrofoam sinks when crushed and waterlogged. Thus , it may be observed only in places where input rates are high. In addition, plastic sheets and bags also seem to be “transitional” (Fig. 14), placing them directly in the range of most of the world’s sea turtle species, which readily ingest this type of plastic debris (Balazs 1985). The reason for this distribution of sheets and bags is not known.

The comparison of frequencies of colors of neuston plastic and debris plastic (Fig. 15) suggests a bias in our sampling. Colors chat do not contrast strongly with seawater (black/gray, transparent) are underrepresented in debris in comparison with neuston plastic. Although some bias in the color frequency data for neuston plastic probably results *from* color-selective ingestion of neuston plastic by seabirds (Day et al. 1985), we believe that the difficulty in observing low-contrast debris is the major cause of the differences in Figure 15. Although there is bias in the debris sighting data, however, densities of debris plastic and neuston plastic are strongly correlated (Day and Shaw 1987). Hence, although absolute estimates of at-sea densities of marine debris plastic are affected by these sighting biases, the debris data presented here provide important information about relative abundances in various parts of the ocean.

Although Fowler (1982, 1985, 1987) claimed that entanglement in lost netting and other marine debris is the major source of mortality of northern fur seals, we find that the data on at-sea densities of lost net fragments are inadequate to determine quantitatively its true importance. We have seen fur seals entangled in net fragments only twice, both in the flying squid fishery and both during fall 198'7. The first record was of a fur seal with a trawl net fragment caught over its head at lat. 44°07'N, long. 156°23'W; there were raw, open cuts on the face and gums, although this animal did not appear to be hurt in any way and swam playfully with another unentangled fur seal. The second record was of an immature female fur seal completely entangled in a gillnet fragment at lat. 43°15'N, long. 145°11'W, along with the partially eaten remains of what appeared to be a salmon shark, *Lamnaditropis*, and a yellowtail, *Seriola lalanda*. Thus , sightings of entangled fur seals in derelict net fragments at sea are quite rare, making it difficult to assess the frequency of entanglement. On the other hand, our extensive experience at sea in the North Pacific suggests to us that the probability of entanglement and subsequent mortality of fur seals is higher in nets that actively are fishing for flying squid than in net fragments. The flying squid fishery deploys approximately 3,000,000 km of drift gillnets annually and is concentrated approximately in the zone lat. 39°-460N (Day unpubl. data). Further, many of the deployments of research nets observed by Day in this area resulted in fur seals' feeding from the nets, climbing on and swimming around the nets, and occasionally becoming caught in the nets. (Most escaped unharmed, however.) Given the high number of entanglements of fur seals in actively fishing gillnets that we have observed, the nearly 60,000 vessel-nights of net deployments in a year, the large amounts of those nets that are fished, and the low number of entanglements in lost net fragments that we have observed in over 21,000 km of observations at sea, we suggest here that the mortality of fur seals from actively fishing nets should be assessed quantitatively and compared to estimates of mortality from derelict nets.

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DISTRIBUTION AND DENSITY OF FLOATING OBJECTS IN THE NORTH PACIFIC BASED ON 1987 SIGHTING SURVEY

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ABSTRACT

A sighting survey has been conducted in the North Pacific since 1986 to understand the distribution of floating objects there . The survey was conducted on board various types of vessels , including a fisheries research vessel, patrol vessels, training vessels, and commercial freighters, a total of 32 vessels with a distance surveyed of 165,288 nmi.

A total of 46,706 floating objects were recorded in 1987. Of these, fishing net debris accounted for 0.7%, other fishing gears 5.9%, Styrofoam 14.0%, and other petrochemical products 18.3%. The remainder included drifting logs or lumber 7.9%, floating seaweed 42.7%, and other 10.5%.

Density of the objects was generally high in the coastal waters , but high density was also observed in areas between lat. 25° and 30°N, and long. 170° and 130°W. It is assumed that" floating objects transported from various areas by ocean currents accumulated here. A belt-shaped low-density area was observed between lat. 45° and 50"N.

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

INTRODUCTION

A total of 32 vessels, vessels which belong to the Fisheries Agency of the Government of Japan, training ships of fishery high schools and universities , and cargo transport ships, participated in a sighting survey of floating objects in the North Pacific (Table 1). The total distance for which the sightings were conducted was 165,228 nmi, and 46,706 items of marine debris were sighted during the cruises.

This survey has been repeated continuously since 1986, with the objectives of defining patterns of marine debris, clarifying the conditions of distribution, and determining the actual volume of various types of debris floating in the sea. Although the areas surveyed extended to the Sea of Japan, Yellow Sea, South Pacific Ocean, and Gulf of Mexico, this report concentrates on the North Pacific and its adjacent waters.

METHODS

Methods of sighting and items of observation were the same as in the previous year (Mio and Takehama 1987), except for the addition of the size of debris items observed. Size is described as follows. We measured with the eye the length of the longest piece of marine debris and recorded that S = <50, M - 50-200, and L = >200 cm.

RESULTS

Outline of Results

The distribution pattern of the cruising distance for the surveys (henceforth referred to as effort) shows that effort was high in Japanese waters and in the western Pacific, and low in the eastern and southern Pacific (Fig. 1). By season, 57.7% of the entire effort was expended during the 4 months from June to September. In the other months, excluding December, 4 to 8% of the effort was expended.

Looking at marine debris by kind (Table 2), 310 pieces of fishing net were recovered, 0.7% of all marine debris found (gillnet 0.2%, trawl net 0.1%, and unidentified net 0.4%). The proportion of fishing gears other than nets was somewhat larger (5.9%) and accounted for 15.3% of the total petrochemicals (fishing nets, other fishing gears, Styrofoam, and other plastic debris). Styrofoam accounted for 36% of all petrochemicals and for 14% of all marine debris, being the most abundant single material. Sheets and bags made of nylon and vinyl, and other plastic debris represented by containers for detergent and drinking water, accounted for 18.3% of the total marine debris and for 47.0% of the total petrochemicals. The number of their sightings was large, and they were quantitatively the major item of marine debris. Among biodegradable marine debris, pieces of wood and drifting logs accounted for 7.9%, and floating seaweed accounted for 42.7%. Other consisted mainly of glass products and empty cans, and accounted for 10.5%,

Table 1.--Vessels engaged in marine debris sighting survey in 1987.

Name of vessel	Gross tonnage	Horsepower	Area of survey[a]	Cruising distance (nmi)	Number of debris pieces sighted
Kotaka Maru	47	235	J	648.9	2,319
Tankai Maru	157	900	J	2,758.8	296
Hokko Maru	466	1,800	J P	9,435.1	971
Wakataka Maru	170	540	J	3,618.9	1,325
Soyo Maru	494	1,600	J	6,286.1	3,221
Yoko Maru	499	1,600	J	5,363.6	1,341
Mizuho Maru	150	900	J	4,979.2	3,094
Shunyo Maru	393	2,600	J	7,156.6	1,340
Shoyo Maru	1,362	2,000	J P	14,857.4	2,798
Kaiyo Maru	2,644	3,800	J P	9,940.2	179
Wakatake Maru	427	1,500	J P	4,166.7	259
Shin Riasu Maru	471	1,400	J P	12,194.9	910
Wakasio Maru	199	900	J	1,285.3	448
Hoyo Maru No. 12	284	1,000	J P	4,134.4	663
Kanki Maru No. 58	96	470	J P	4,337.7	229
Hokuho Maru	441	1,300	J P	7,281.7	654
Shirafuji Maru	138	1,000	J	386.0	876
Osyoro Maru	1,779	3,200	J P	4,018.5	166
Hoksei Maru	893	2,100	J P	4,057.2	236
Tansu Maru	444	1,500	J	1,561.9	779
Omi Maru	417	1,300	J P	4,485.1	107
Shirahagi Maru	366	2,600	J P	6,903.4	305
Toko Maru	1,513	8,000	J P	12,845.6	343
Hakuryu Maru	517	2,500	J P	4,086.7	230
coop	2,445	3,800	J	1,237.6	52
Sunbelt Dexie	11,447	14,000	J P	5,366.6	15,387
Nichiyo Maru	995	3,000	J P	1,176.7	4,673
Kumamoto Maru	380	1,600	J	3,599.2	598
Riasu Haru No. 1	476	1,100	J P	11,732.4	251
Hoyo Maru No. 78	300	440	J P	5,294.1	885
Taisei Maru No. 55	*350*	3,400	J P	725.2	449
Tosi Maru No. 15	*730*	3,600	J	3,803.5	1,974

[a]J = Japanese waters north of lat. 20°N and west of long. 160°E;
P = Pacific area other than Japanese waters.

Effects of Environmental Conditions

In order to study the effects of luminous intensity and waves on the sighting survey, the numbers of sightings by wind force and by time of day were examined comparatively for eight vessels which had conducted surveys for a fairly long time in the area where the effort expended was largest (lat. 40° to 45″N and long. 140° to 150°E).

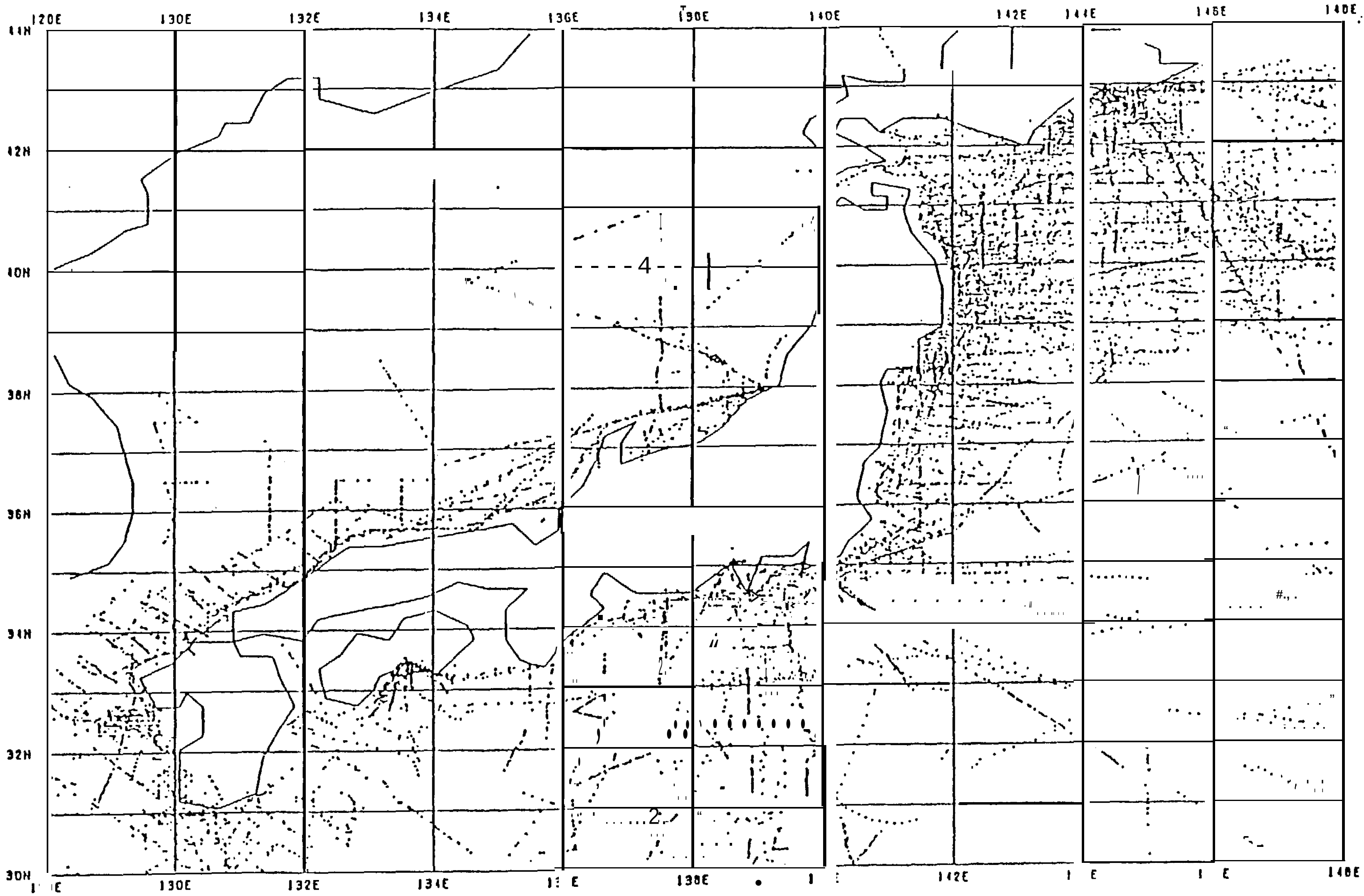

Figure 1A.--Tracks of vessels engaged in marine debris sighting survey in 1987, coastal waters of Japan.

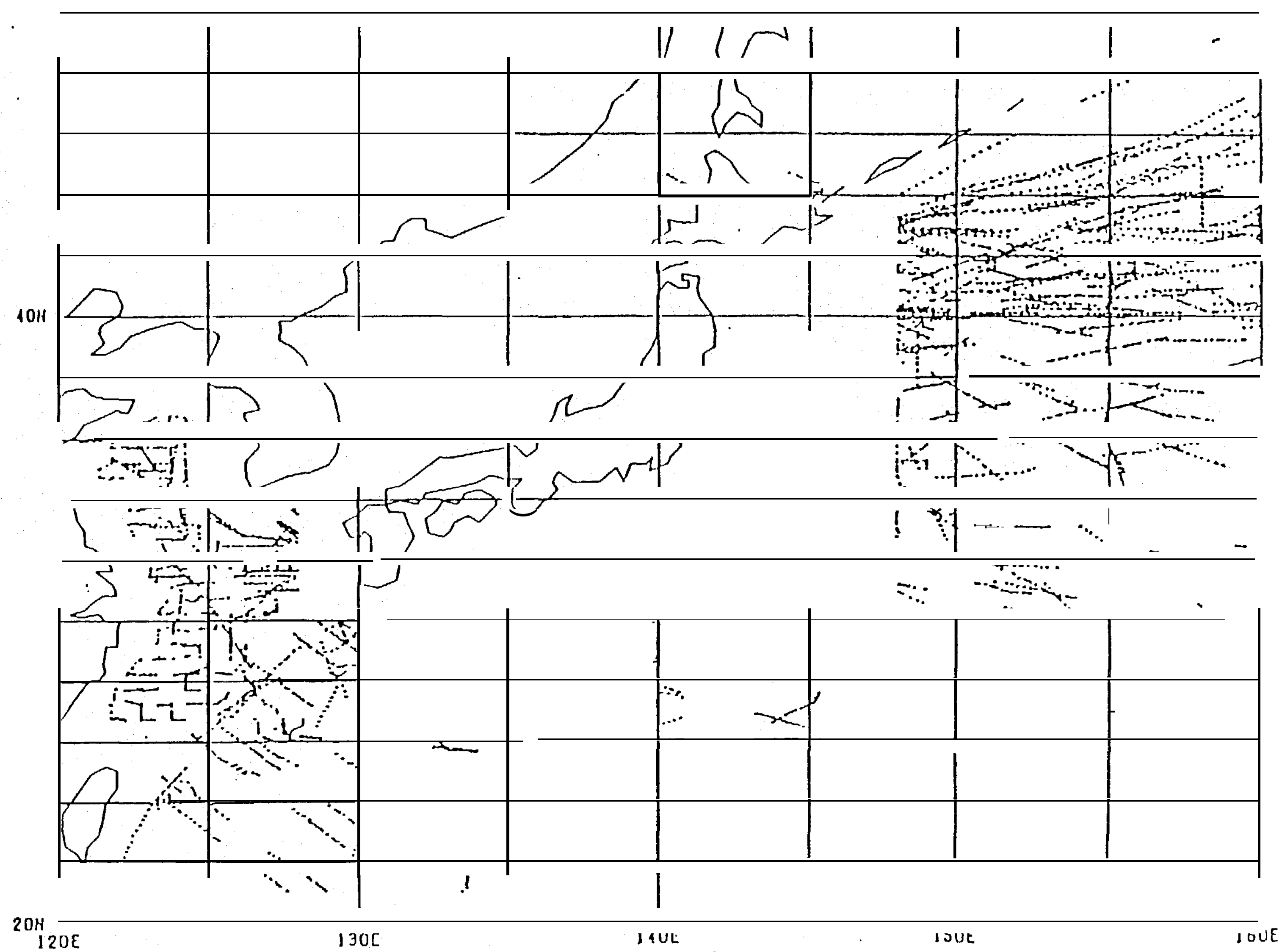

Figure 1B.--Tracks of vessels engaged in marine debris sighting survey in 1987 neighboring waters of Japan.

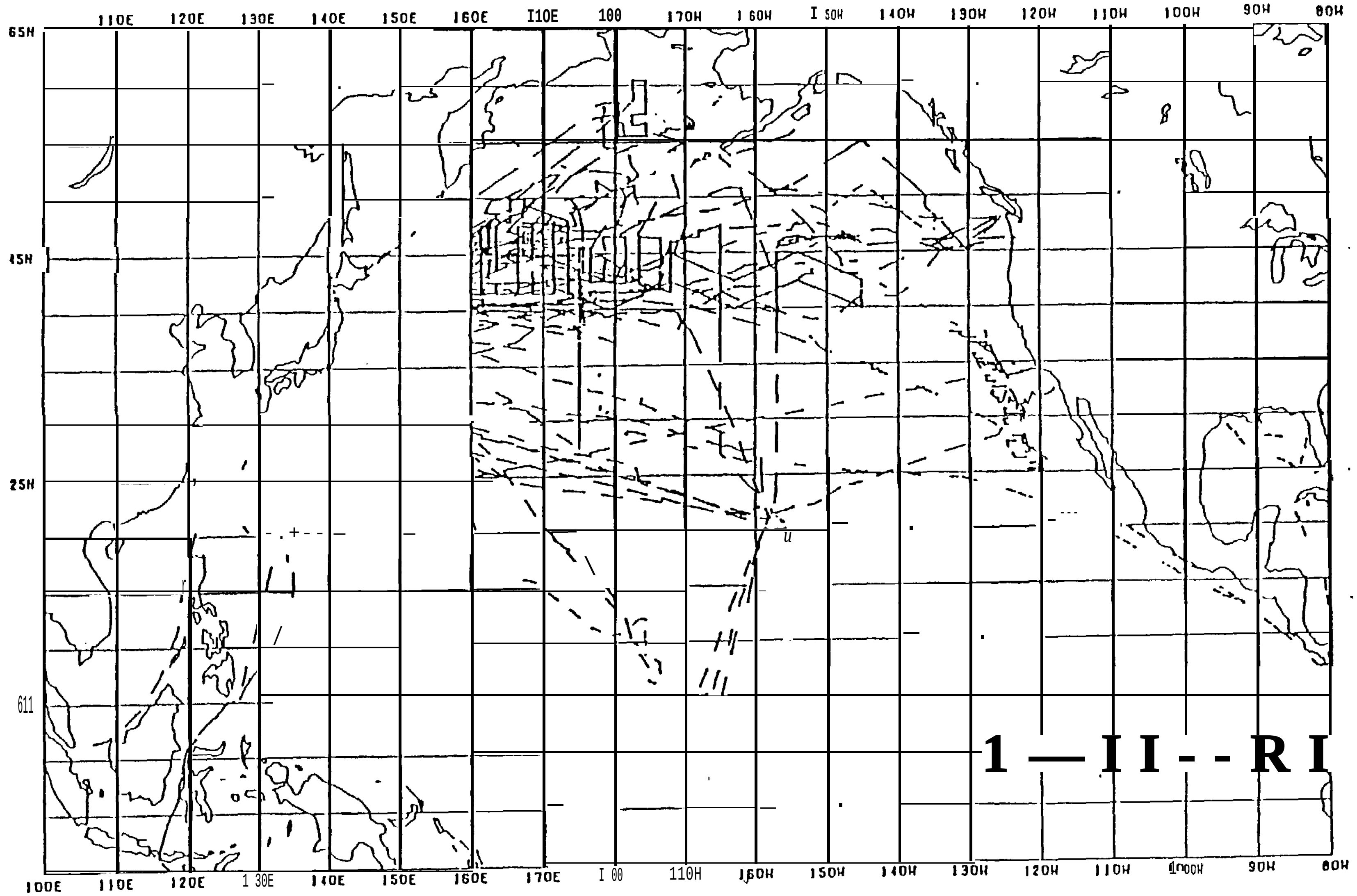

Figure 1c. -Tracks of vessels engaged in marine debris sighting survey in 1987, Pacific high seas area.

Table 2. --Number of debris items sighted, by month and type of debris.

Month	Cruising distance (nmi)	Type of debris: Fishing net			Other fishing gear	Styrofoam	Other plastic debris	Wood	Floating seaweed	Others	Total
		Unknown	Trawl	Gill							
January	7,857.3	--	--	--	18	30	12	192	169	151	582
February	7,832,1	4	--	2	38	128	85	34	32	31	354
March	8,813.8	2	--	.-	104	415	115	88	709	394	1,827
April	6,819.6	4	2	5	134	360	208	207	884	62	1,875
May	11,181.7	4	2	2	169	334	131	90	257	221	1,210
June	28,435.9	13	14	7	313	752	1,020	1,172	2,192	833	6,617
July	31,323.2	23	5	6	344	724	95a	314	1,601	296	4,266
August	20,184.3	19	8	9	315	873	'799	295	781	309	3,408
September	18,743.9	44	25	14	567	1,136	1,500	507	4,951	627	9,371
October	13,030.9	31	3	19	282	1,162	2,761	612	7,987	1,784	14,641
November	9,840,1	27	1	13	459	541	901	141	374	162	2,619
December	1,225.2	2	--	.-	31	97	59	20	14	13	236
Total	165,287.9	173	60	77	2,774	6,552	8,544	3,672	19,951	4,893	46,706

Wind Force

The evidence suggests that the number of debris items sighted per unit of effort (100 nmi) is inversely related to wind force (Beaufort scale) . The maximum sightings occurred at wind force class 1 and sightings decreased as the wind force increased (Fig. 2).

Only five vessels conducted sightings surveys in wind force class 1. This effort was extremely small compared to the effort in wind force classes 2 to 5, and was only 11% of wind force class 3, which had the largest effort. Wind force which showed maximum effort varied by vessel; in the case of *Shoyo Maru*, wind force exceeding class 6 showed maximum effort. Although as a general trend the number of sightings decreased as wind force increased, the number of sightings also varied by type of vessel and kind of marine debris,

Luminous Intensity

Time of day was used as an index of luminous intensity, and data from the same time of day were compared for sighting of marine debris (Fig. 3). Using the average value of the same eight vessels, the number of sightings decreased after 1200 (time of the maximum value); the rate of decrease remained within 60%, except at 1700. Five vessels showed the maximum value between 1200 and 1400, but for the *Hokko Maru* the maximum value was obtained at 1700, and for the *Shoyo Maru* the maximum value was obtained at 0600. These findings suggest that the number of sightings by time were related to many elements, and no clear trend by time was recognized. It is considered that there was no time of day at which it was extremely difficult to find marine debris.

Sighting Rate by Distance

In this survey, we usually observed at close range from the stern the distances and angles each debris items sighted. The distance at right angles to the track of the vessel (right angle distance) was measured, and marine debris was collected by category (Fig. 4). The number of sightings decreased as the right angle distance increased, and the number of sightings per 10 m accounted for <5% when the distance exceeded 100 m. Therefore, in estimating the number of sightings, the sighting width of 200 m, 100 m on each side of the track, was also estimated.

The relationship between right angle distance and the number of sightings of marine debris indicated a distribution with the maximum value of 10 to 20 m except for pieces of wood and drifting logs. Since the position of the marine debris never changed and never showed any movement against the vessel, it was easier to spot marine debris that was closer to the observers. If an observer could stop and scan the sea completely, the number of sightings would likely be in proportion to the distance. However, when sightings are conducted from a moving vessel it is not always possible to find marine debris close to the observer. As the vessel is sailing, the closer the debris is to the observer, the shorter the time in which it remains in the observer's visual field. Also it is not possible

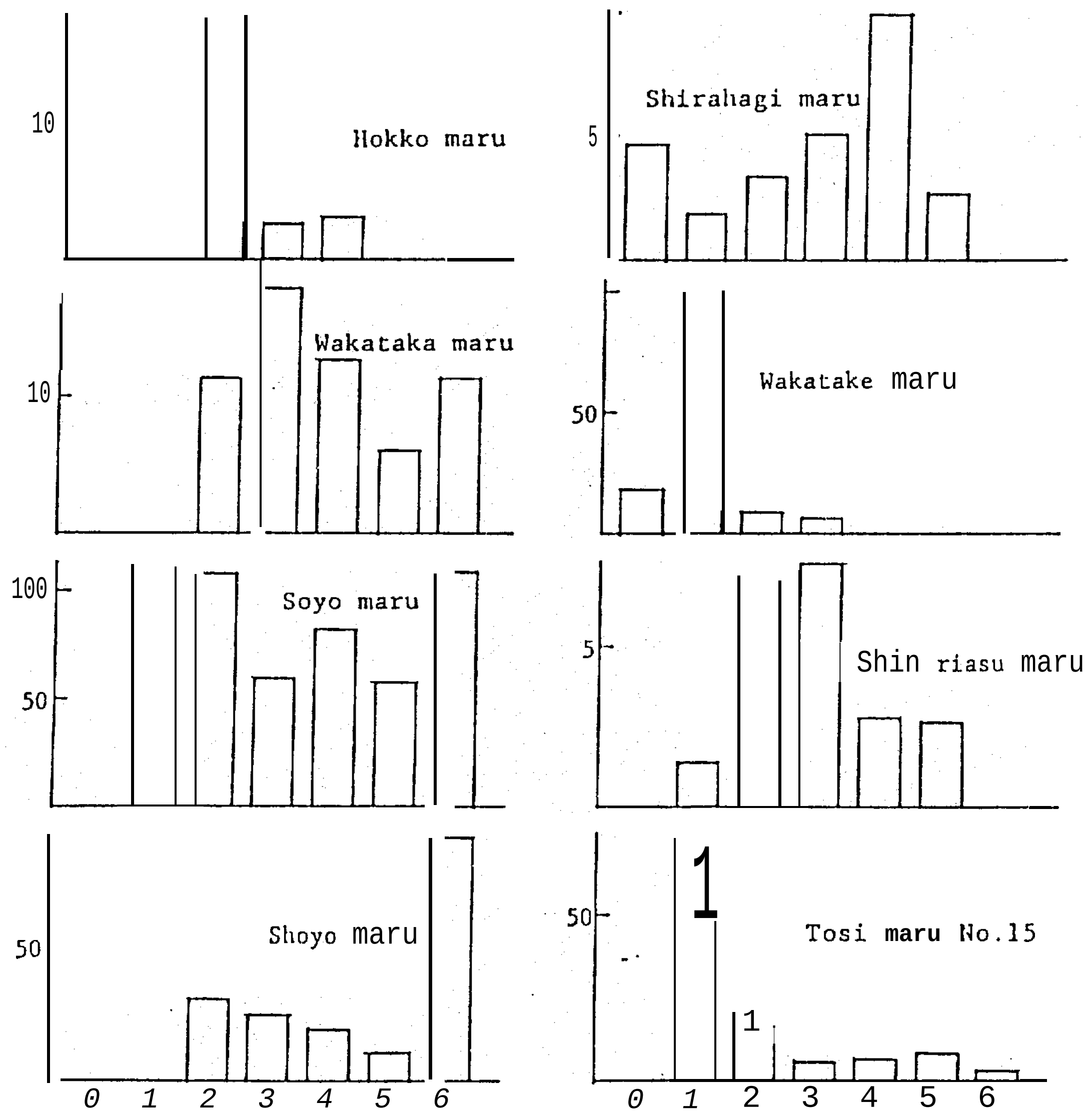

Figure 2. --Number of marine debris pieces sighted per 100 nmi in terms of wind force (Beaufort scale) for each vessel.

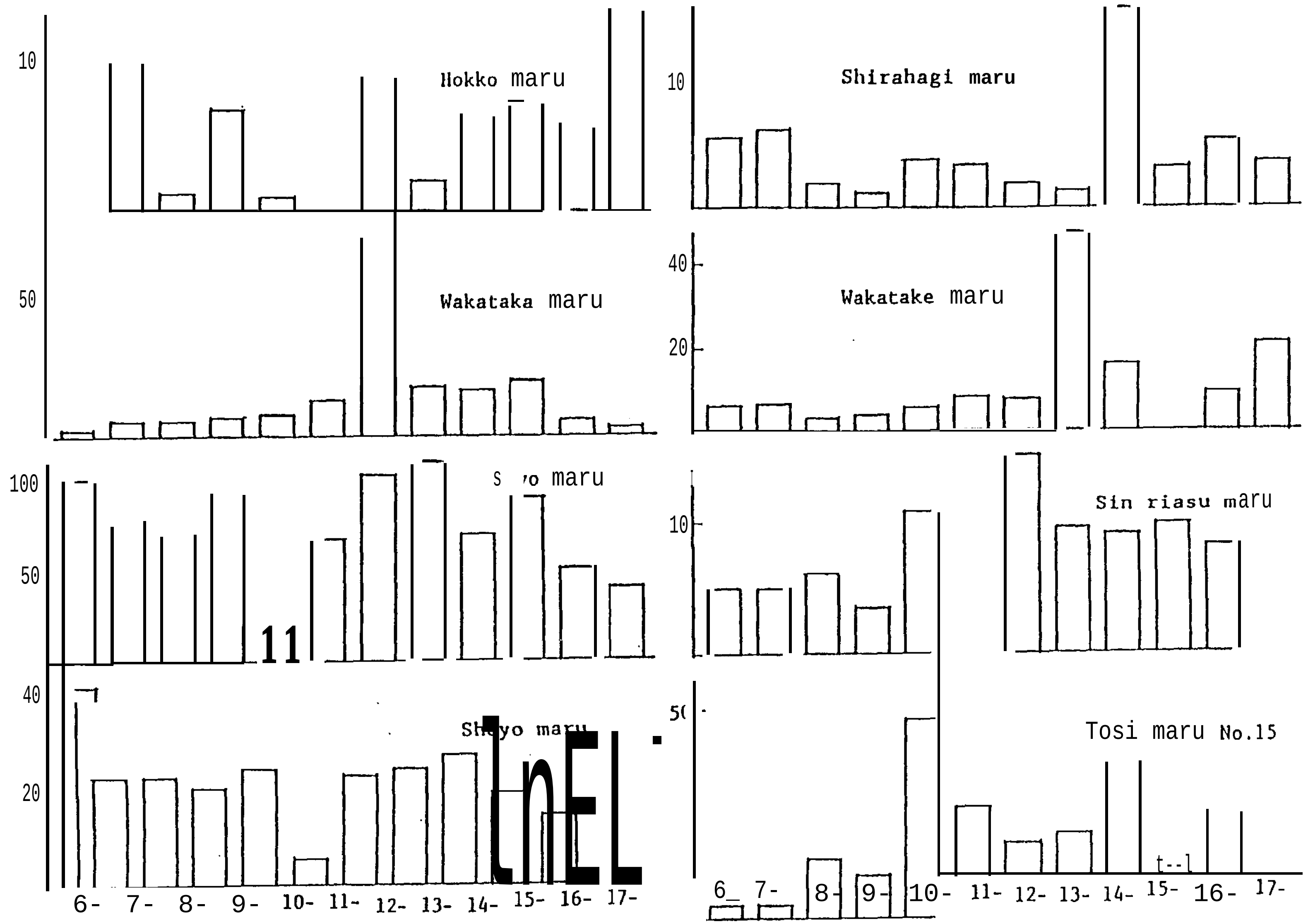

Figure 3. --Number of marine debris pieces sighted in terms of time of observation for each vessel.

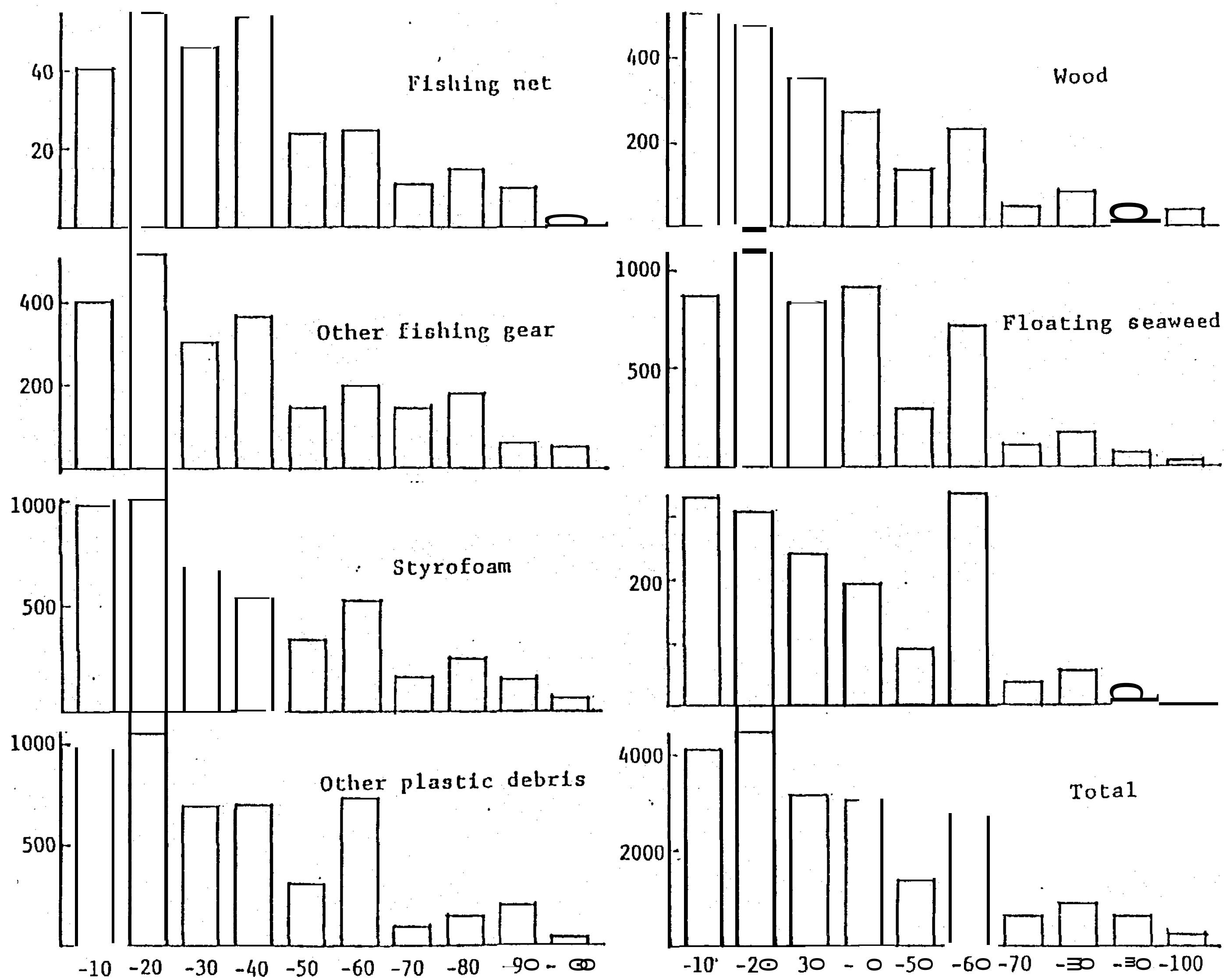

Figure 4.--Number of marine debris pieces sighted in terms of right angle distance (in meters) by type of debris.

to find marine debris on the sea when it is hidden behind the vessel. It is thought that there is a preferred distance for finding marine debris when the sighting is conducted from a fixed position. This was determined by the fact that in comparison with the sightings in Japanese waters and those in the Pacific Ocean, the number of sightings at a distance of 10 to 20 m tended to be larger than the number of sightings at a distance of O to 10 m.

Vessels conducting surveys in the Pacific Ocean were larger in size and had higher speeds than vessels conducting surveys in Japanese waters only. For the above two reasons, it is considered to be more difficult to observe the surface of the sea that is closer to the vessel. In addition, a decrease in the number of sightings in the range of O to 10 m was also caused by errors which arose from rounding to the nearest whole number when the angles sighted were reported. That is, as an angle was measured with the eye, the article which was recognized in the range of 0° to 5° was mostly reported as at 5°. If a distance sighted exceeded 115 m, marine debris was located from 10 to 20 m in right angle distance. For the optimum distance sighted in the relationship between right angle distance and number of sightings, it is necessary to collect more data and to continue further studies. In this report, the effective width was calculated from the assumption that the sighting probability on the path is 1.

Distribution Density of Marine Debris

Relationship between right angle distance (Y) and sighting rate (g(Y)) is shown in the following curvilinear equation:

$$g(Y) = 1 - \mathrm{Exp}\ (-(Y/A)''(l-B)).$$

The coefficients of each type of marine debris are shown in Table 3.

The number of individual items per unit area for each type of marine debris was calculated by blocks (5° of latitude by 10° of longitude) on the basis of the following equation (Seber 1982):

$$N = \frac{nf(0)}{2L}.$$

- N = Number of individuals per unit area.
- n = Number sighted.
- L = Steaming distance.
- f(o) = I/effective width.

Figure 5 shows the number of individual items per unit area by block obtained in this manner, and by the type of marine debris.

Table 3. --Coefficients of each type of marine debris.

Type of marine debris	A	B	f(o)'
Fishing net	46,099	4,178	0.01752
Other fishing gear	39,623	3,627	0.01923
Styrofoam	41,598	3,969	0.01891
Other petrochemical products	46,366	4,613	0.01779
Pieces of wood and drifting logs	38,330	4,165	0.02060
Floating seaweed	47,890	5,679	0.01797
Other	31,485	3,565	0.02331
Total debris	38,162	3,430	0.01951

DISCUSSION

Distribution of Effort

A glance at the distribution of effort by block tells its own story: The blocks where effort was expended abundantly were concentrated in Japanese waters (Fig. 6). There were three blocks in which the survey distance exceeded 10,000 nmi, and the blocks which exceeded 3,000 nmi were also restricted to Japanese waters and adjacent areas. Next to the Japanese waters and adjacent areas, the offshore area of California, the southern area of the Alaska Peninsula, and the Northwestern Hawaiian Islands were also areas in which a large amount of effort was expended. However, the former two areas were also completely surveyed, one by the *Kaiyo Maru* only and the other by the *Toko Maru* and the *Shin Riasu Maru,* respectively, and the survey season was biased. As the Northwestern Hawaiian Islands are in the path of vessels which come and go from Honolulu, the area of survey is restricted.

Furthermore, glancing at numbers sighted by block, even blocks of other plastic debris, which has the most abundant sightings, the blocks in which 50 or more petrochemical items were found were only 18.4% of the total number of blocks in which petrochemicals were found. In order to obtain reliable density of marine debris, ideally speaking, it is necessary to conduct surveys evenly throughout the blocks in each season. As we mentioned before, in the present surveys, effort is frequently biased by season and by block, and the number of reliable blocks are extremely few. However, we calculated tentative density using the results of sightings as they were obtained.

Distribution of Marine Debris by Type

There were only 310 individual sightings of fishing nets, and reliable results were not obtained. However, the blocks in which sighting density was high were from lat. 25° to 40°N and long. 170° to 130°W, and in that area the density increased toward the east. Sighting density was next highest in Japanese waters and the East China Sea, but was only 2% of the block in which the density was the highest. In waters of lat. 45° to 50°N,

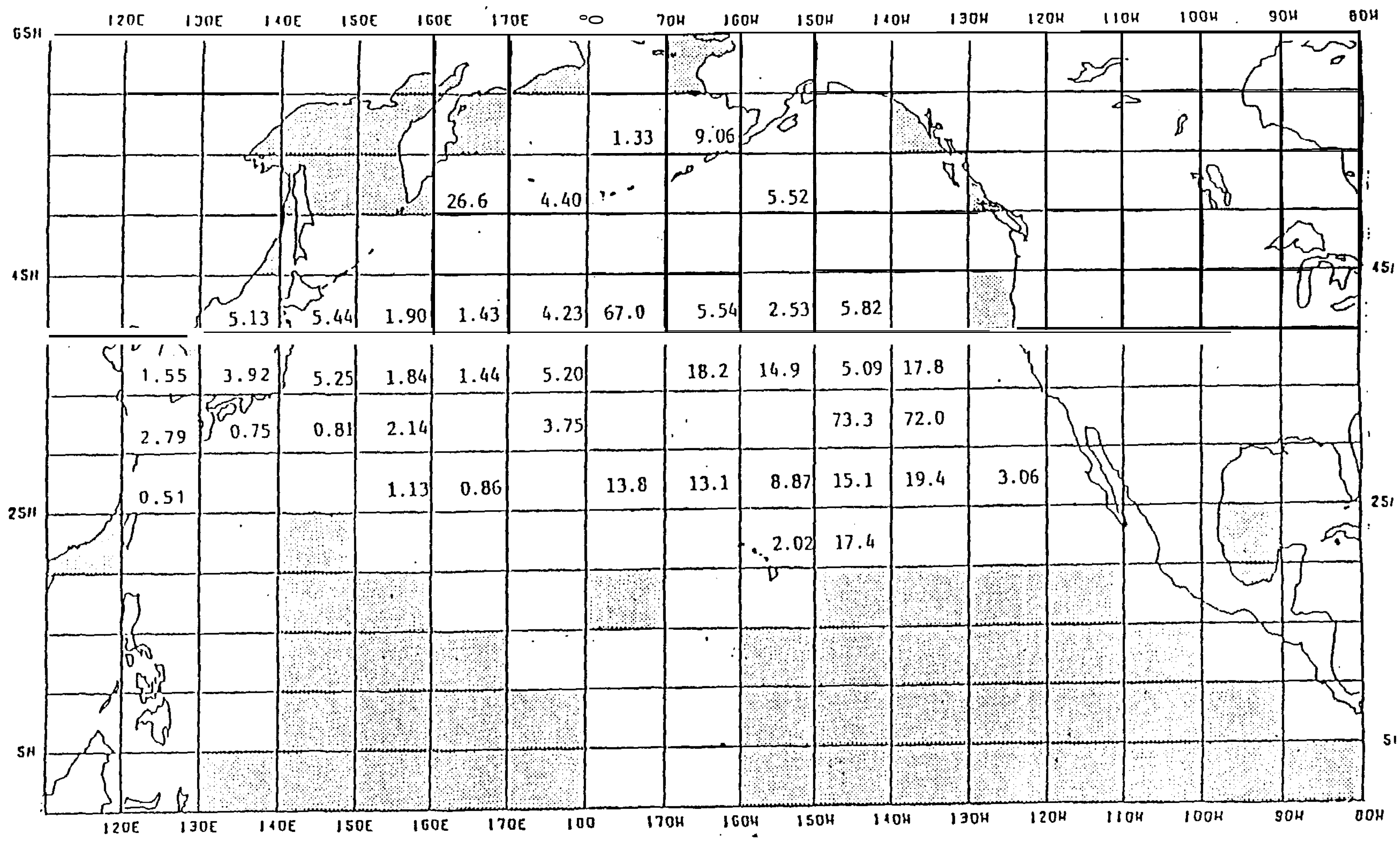

Figure 5A --Estimated density distribution of fishing net debris in 1987
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

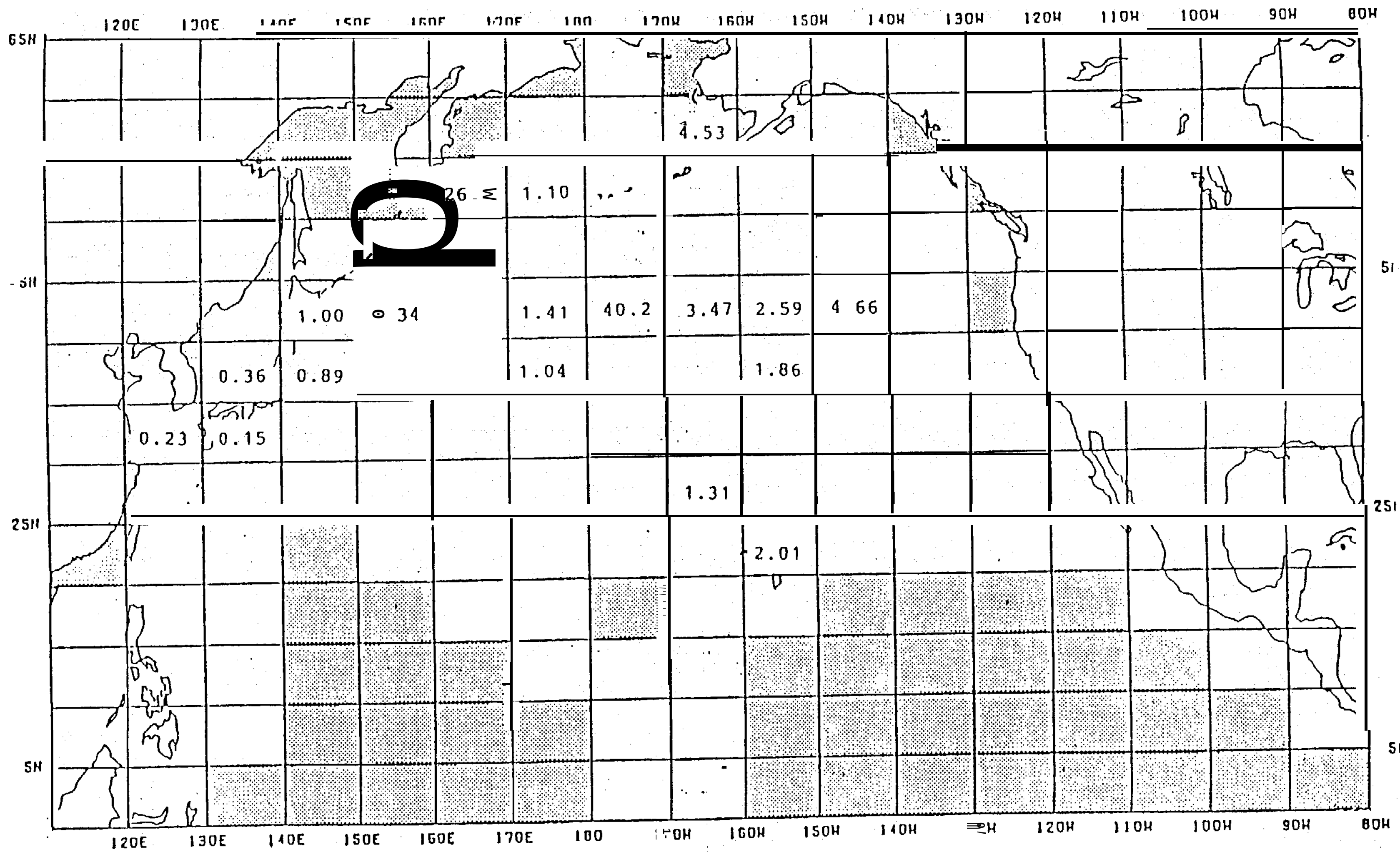

Figure 5B -Estimated density distribution of trawl net debris in 1987.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

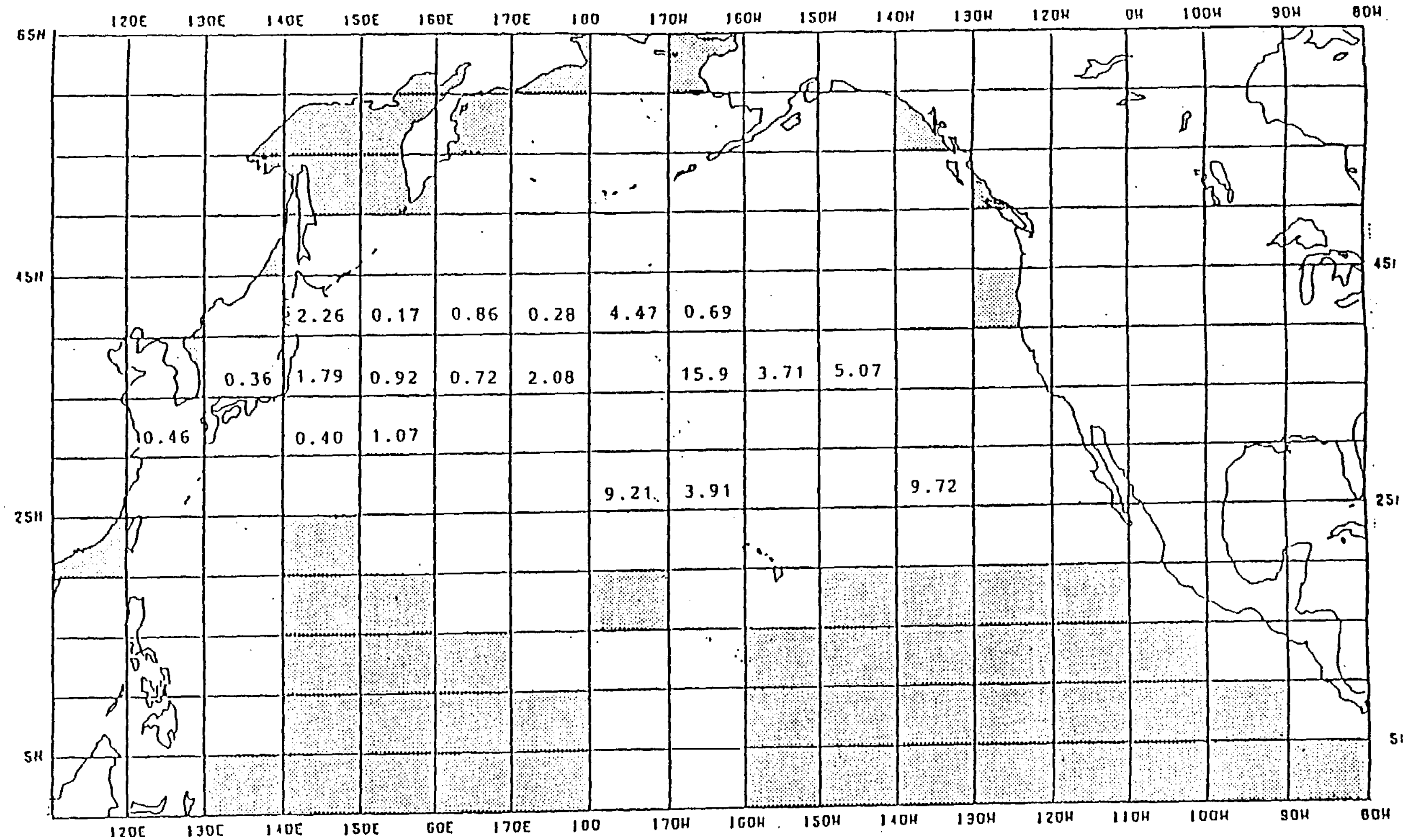

Figure 5< --Estimated density distribution of drift net debris in 19∃7
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

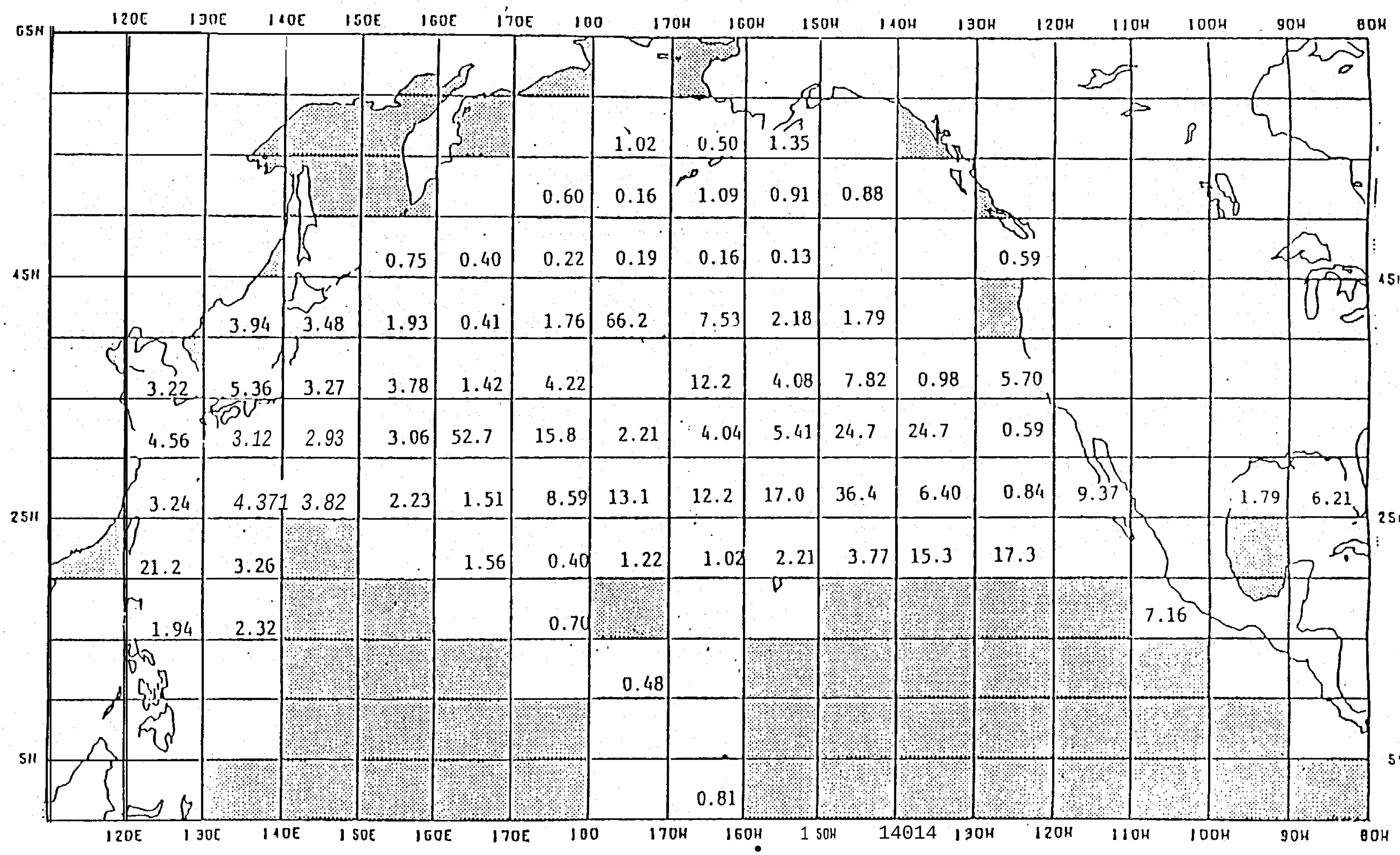

Figure 5D. --Estimated density distribution of other fishing gear debris in 1987.
Unit: number of debris pieces × 10-′ per 1 nmi^2.

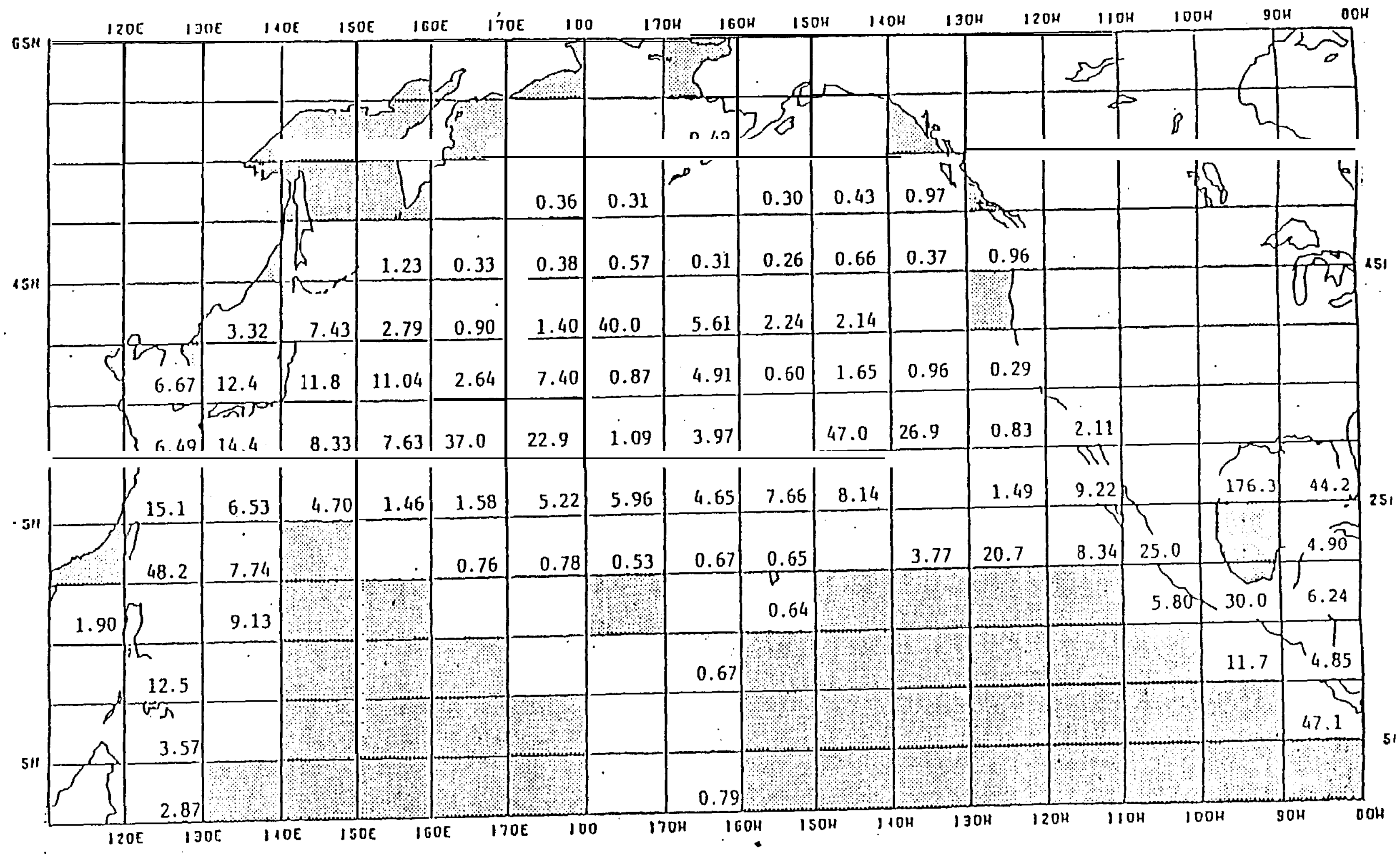

Figure 5E --Estimated dens ty distribution of Styrofoam debris io 1987
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

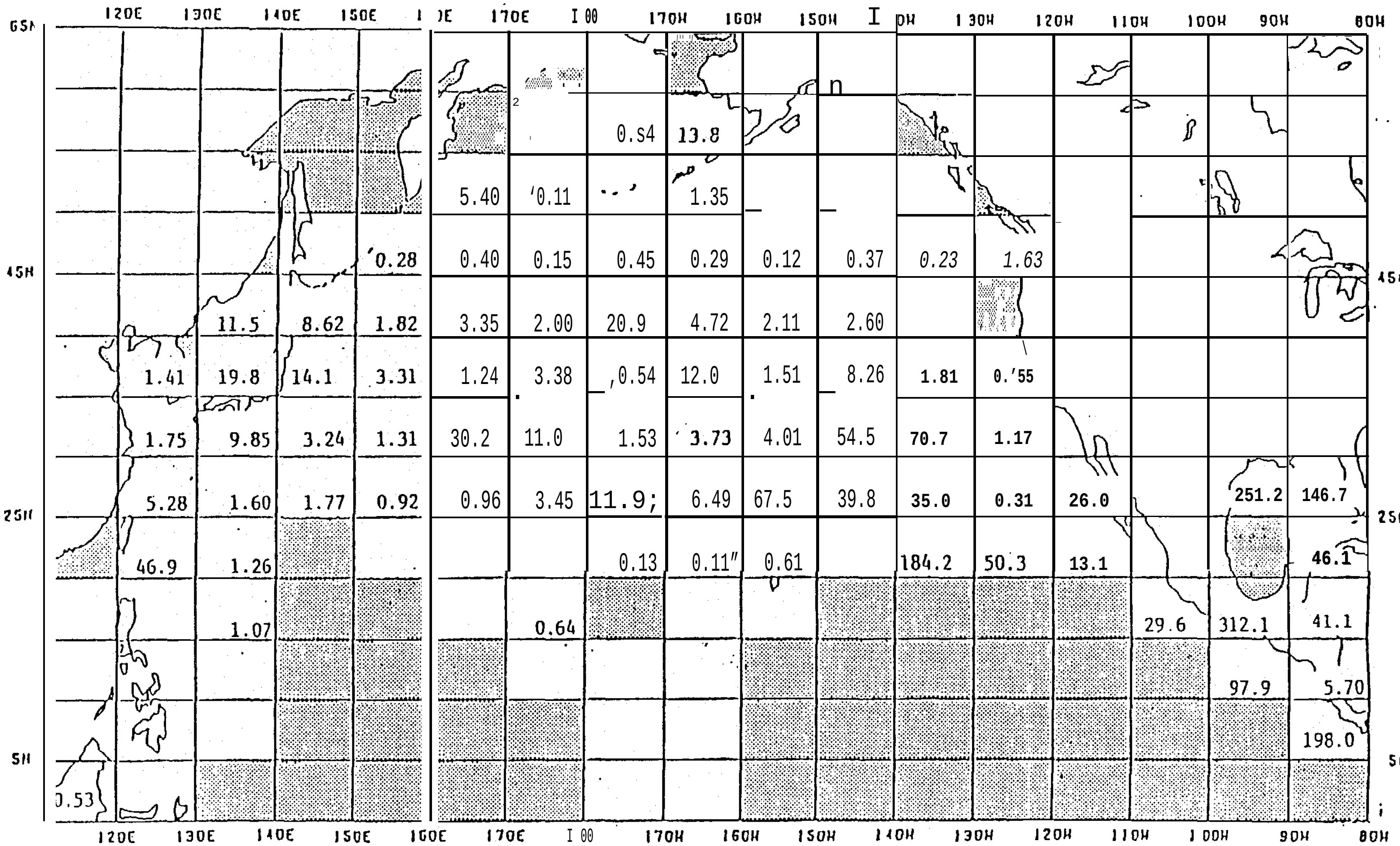

Figure 5F. --Estimated density distribution of other plastic debris in 1987.
Unit: number of debris pieces x 10^{-1} per 1 nmi^2.

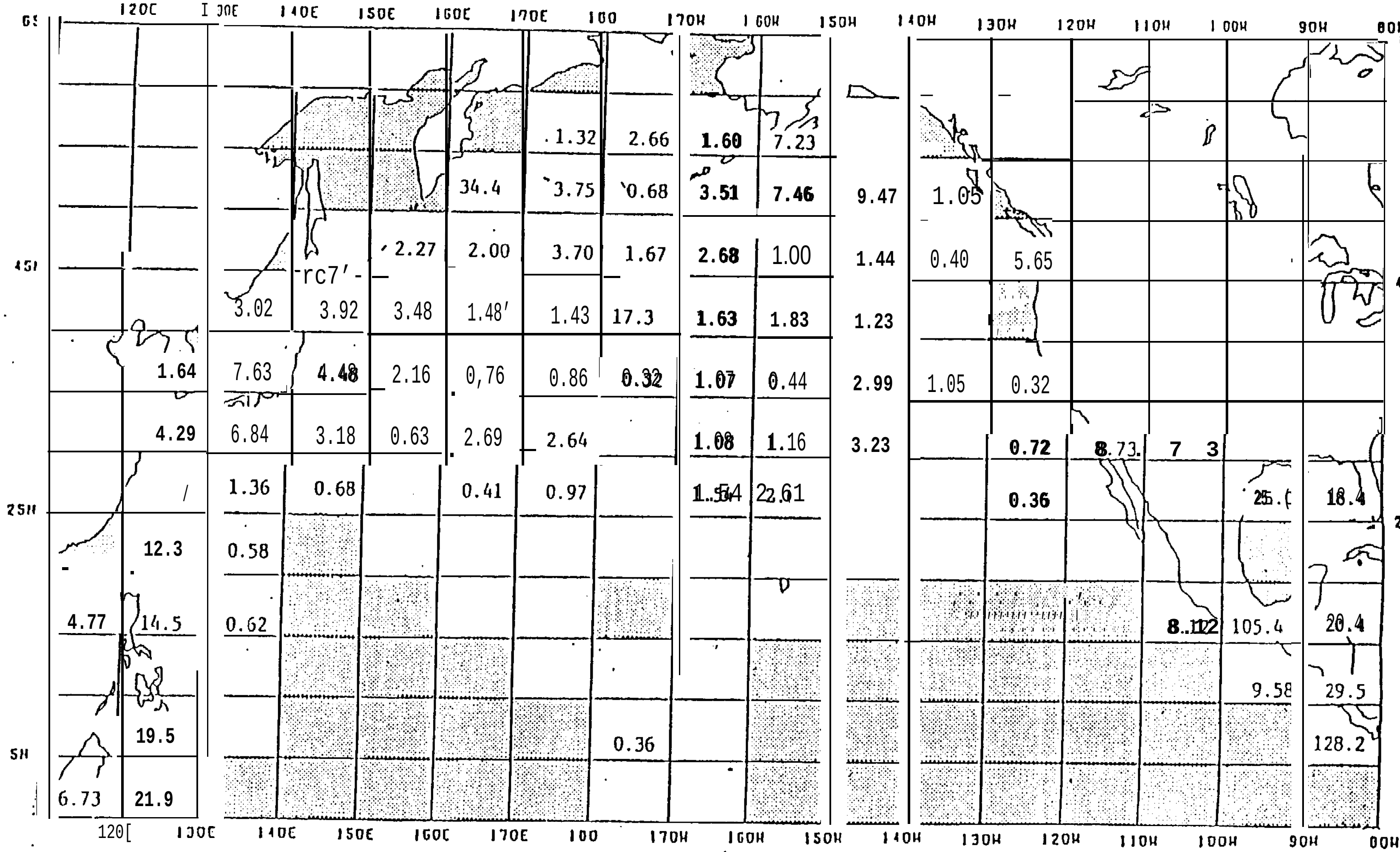

Figure 5G. --Estimated density distribution of wood debris in 1987.
Unit: number of debris pieces X 10^{-1} per 1 nmi^2.

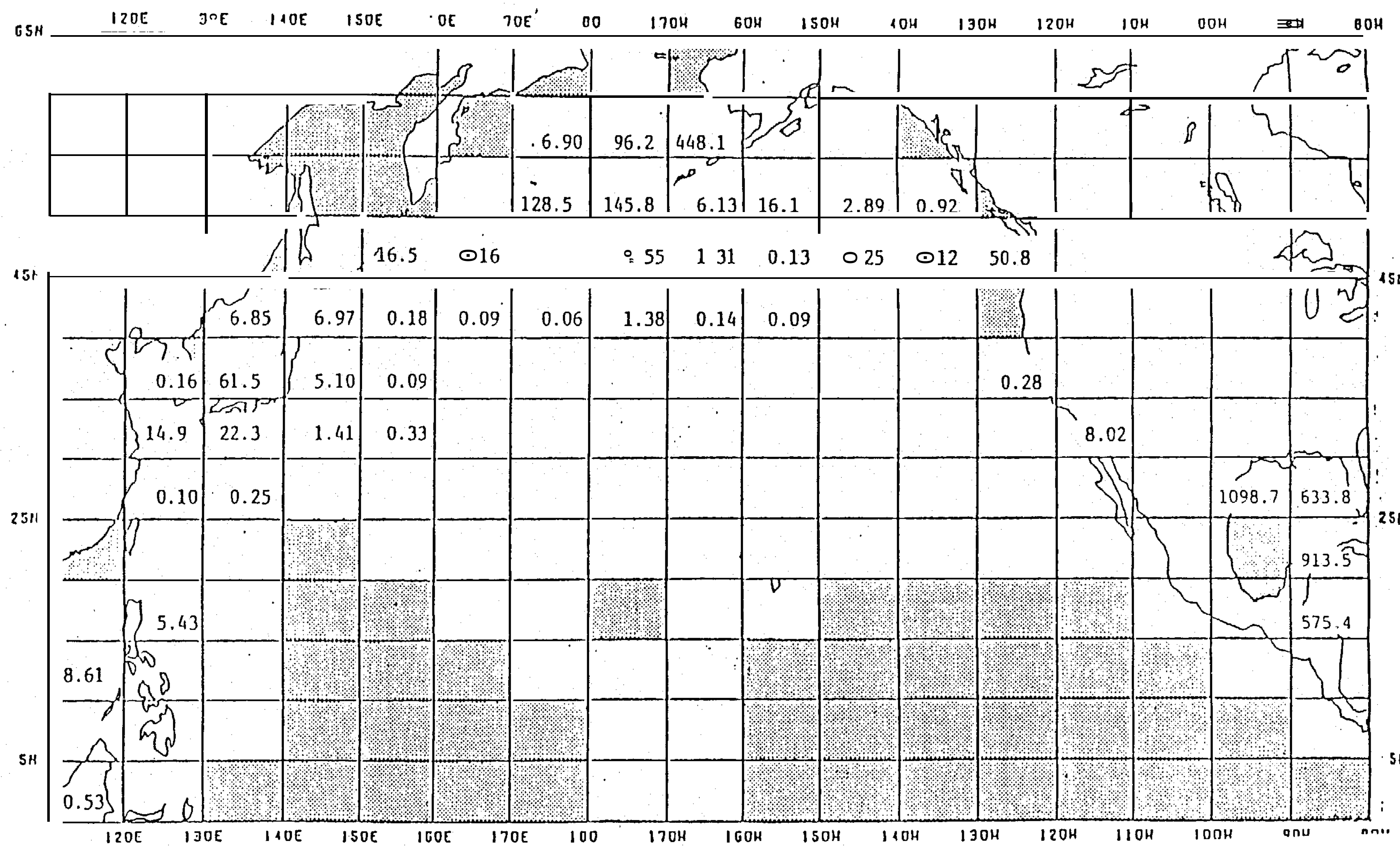

Figure 5ᵡ --Estimated density distribution of floating seaweed debris in 19∃7.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

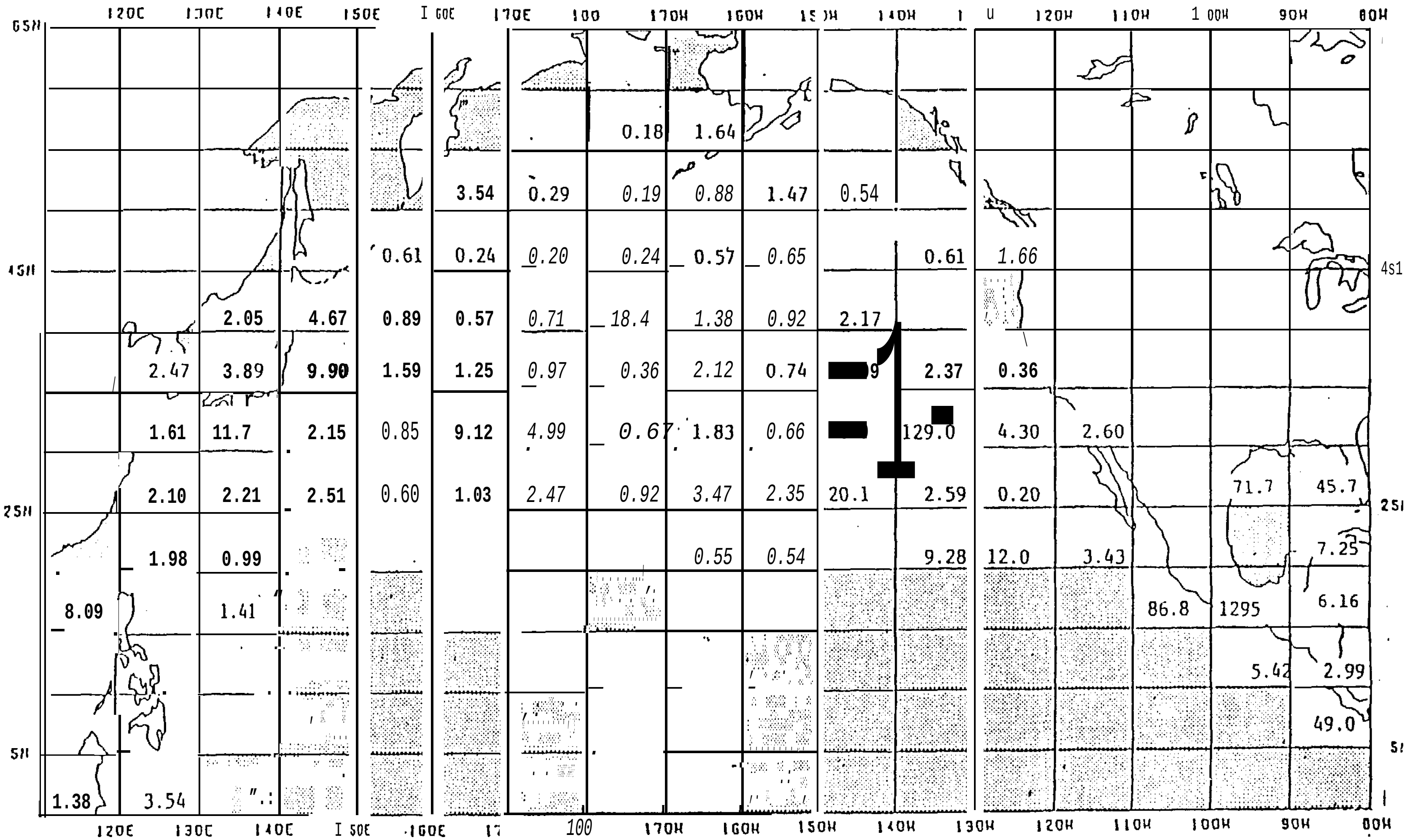

Figure 51. --Estimated density distribution of other marine debris in 1987.
Unit: number of debris pieces x 10^{-1} per 1 nmi^2.

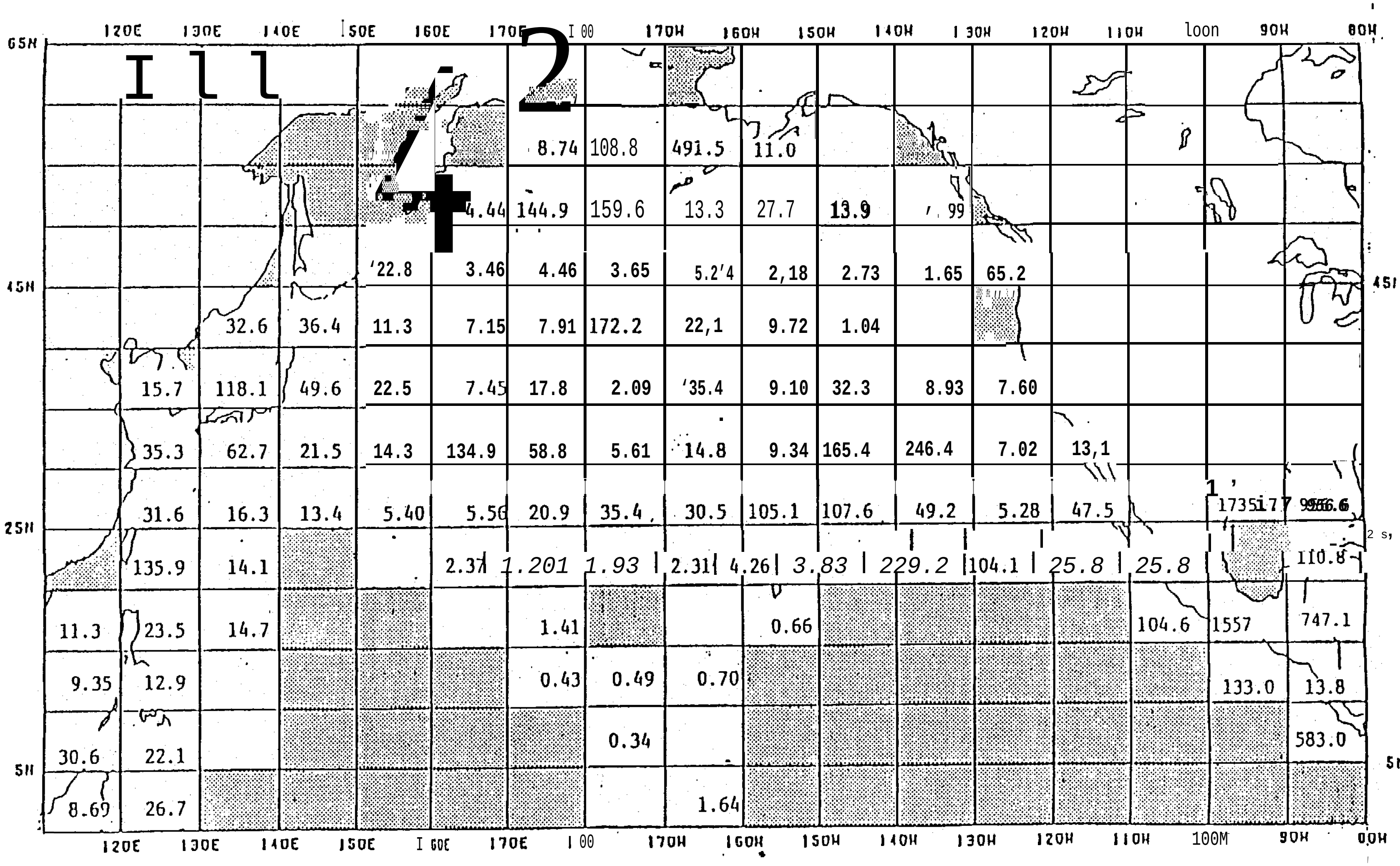

Figure 5J. --Estimated density distribution of total marine debris in 1987.
Unit: number of debris pieces x 10^{-1} per 1 nmi^2.

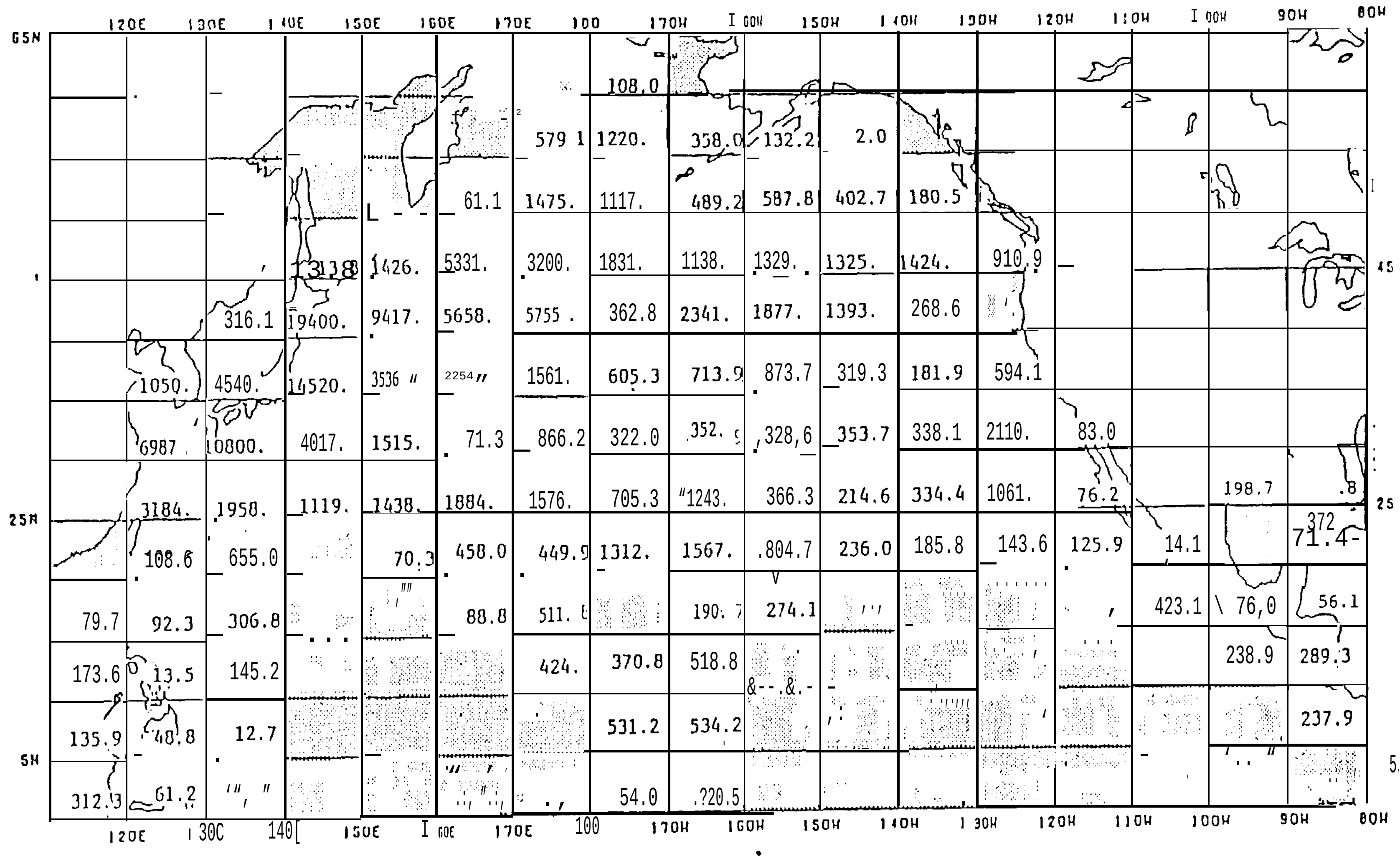

Figure 6.- -Surveyed cruising distance in each 5° x 10° area in 1987, Unit: nautical mile.

fishing nets were not found at all. The distribution split to both south and north with this area in between, and it was thought that fishing nets found in the south were transported by currents moving from west to east. There were many unidentified fishing nets, and characteristics by kind of fishing net were not clearly recognizable. In waters north of lat. 50°N, only trawl nets were identified.

The numbers of other fishing gear sighted were greater than the number of fishing nets, and other fishing gear was found in 70.1% of all the areas surveyed. Although a distribution pattern of other fishing gear was similar to that of fishing nets, the blocks in which density was high inclined toward the south.

A great number of Styrofoam pieces were sighted. The range of distribution was widest, Styrofoam items being found in 77.8% of the blocks in the area surveyed. The distribution pattern was different for petrochemical articles other than Styrofoam, and the areas in which density was high were found in waters off Japan, at lat. 25° to 35°N and long. 170°W, lat. 25° to 35°N and long. 160°E to 140°W, in the Gulf of Mexico, and in the coastal areas of Central America. Areas which showed a comparatively high density were scattered widely. To explain the difference in this distribution pattern, petrochemical articles except Styrofoam are transported mainly by ocean currents, while Styrofoam items are floating on the surface of the sea and are thought to be strongly influenced by wind.

Other plastic debris was sighted in the greatest numbers (8,544 items), and the number of blocks sighted was the same as for other fishing gears. The distribution pattern was also similar. Six blocks in which the density was highest were concentrated in the range of lat. 20° to 35°N and long. 160°E to 130°W, followed by blocks in Japanese waters. In addition, an area in which the density was extremely high was in the Gulf of Mexico as well as the coastal areas of Central America.

For pieces of wood and drifting logs, densities were high in the coastal areas, suggesting that pieces of wood and drifting logs come primarily from the rivers and coastal areas. Floating seaweed showed this trend remarkably, and beyond three coastal blocks it was not found at all.

Blocks of highest density of combined petrochemical articles were seen in the coastal areas of Central America, followed by blocks of high density concentrated in waters of lat. 20° to 35°N and long. 150° to 130°W. Although the number of blocks was small, there were also those that showed high density in waters of lat. 25° to 35"N and long. 170°E to 170°W. Furthermore, densities of marine debris that were <2% of the highest density block, could be found in Japanese waters and the East China Sea, but a considerably high density was shown in the wide range. As another distinctive phenomenon, density was low in any blocks in waters of lat. 45" to 50°N, and the North Pacific Ocean and the Bering Sea are separated by this area. It is believed that marine debris seldom passes from one of these areas to the other.

Figures used in the above determinations were the numbers of individual items sighted. When considering the effects of marine debris,

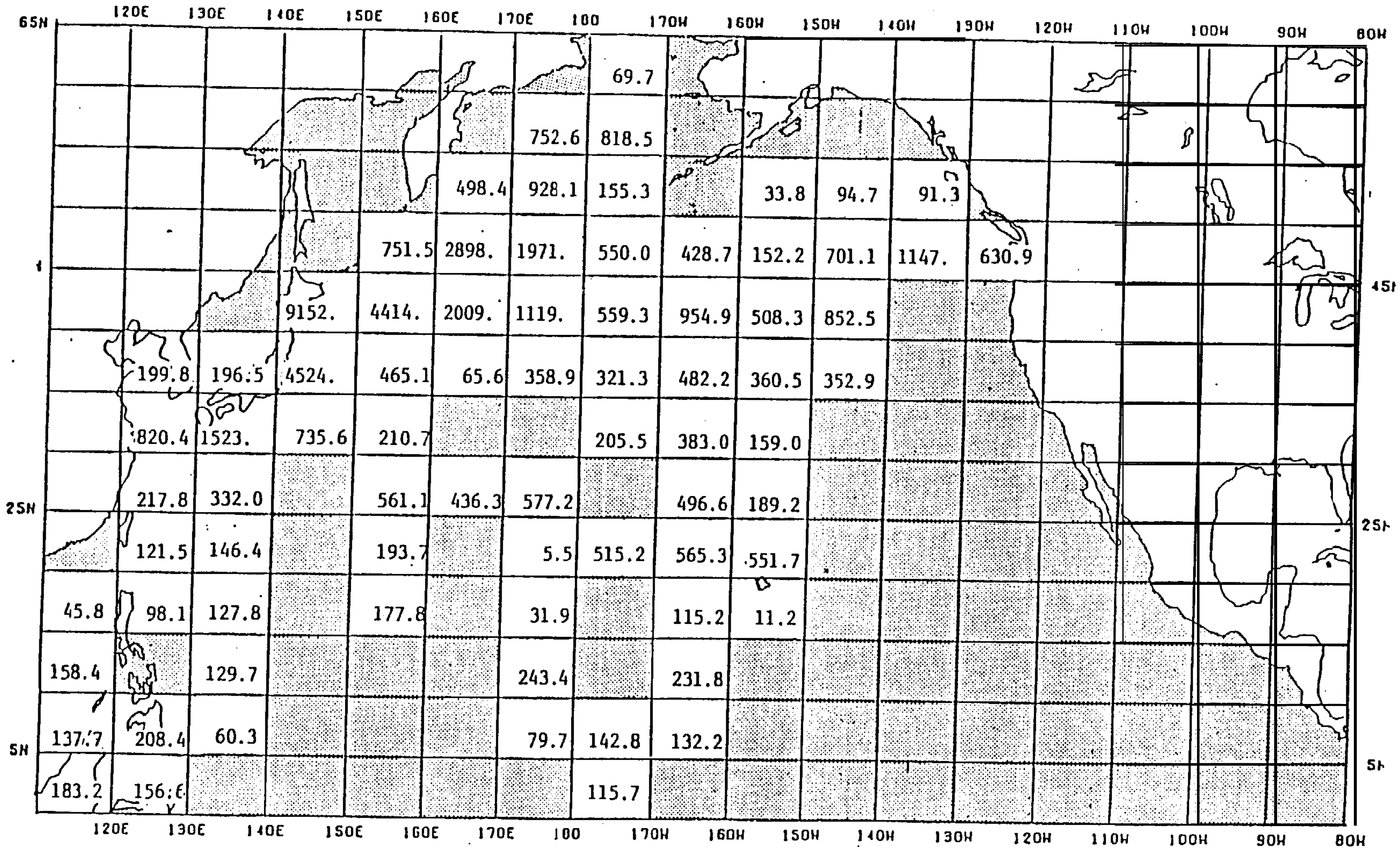

Figure 7.--Surveyed cruising distance in each 5° × 10° area in 1986 Unit: nautical mile.

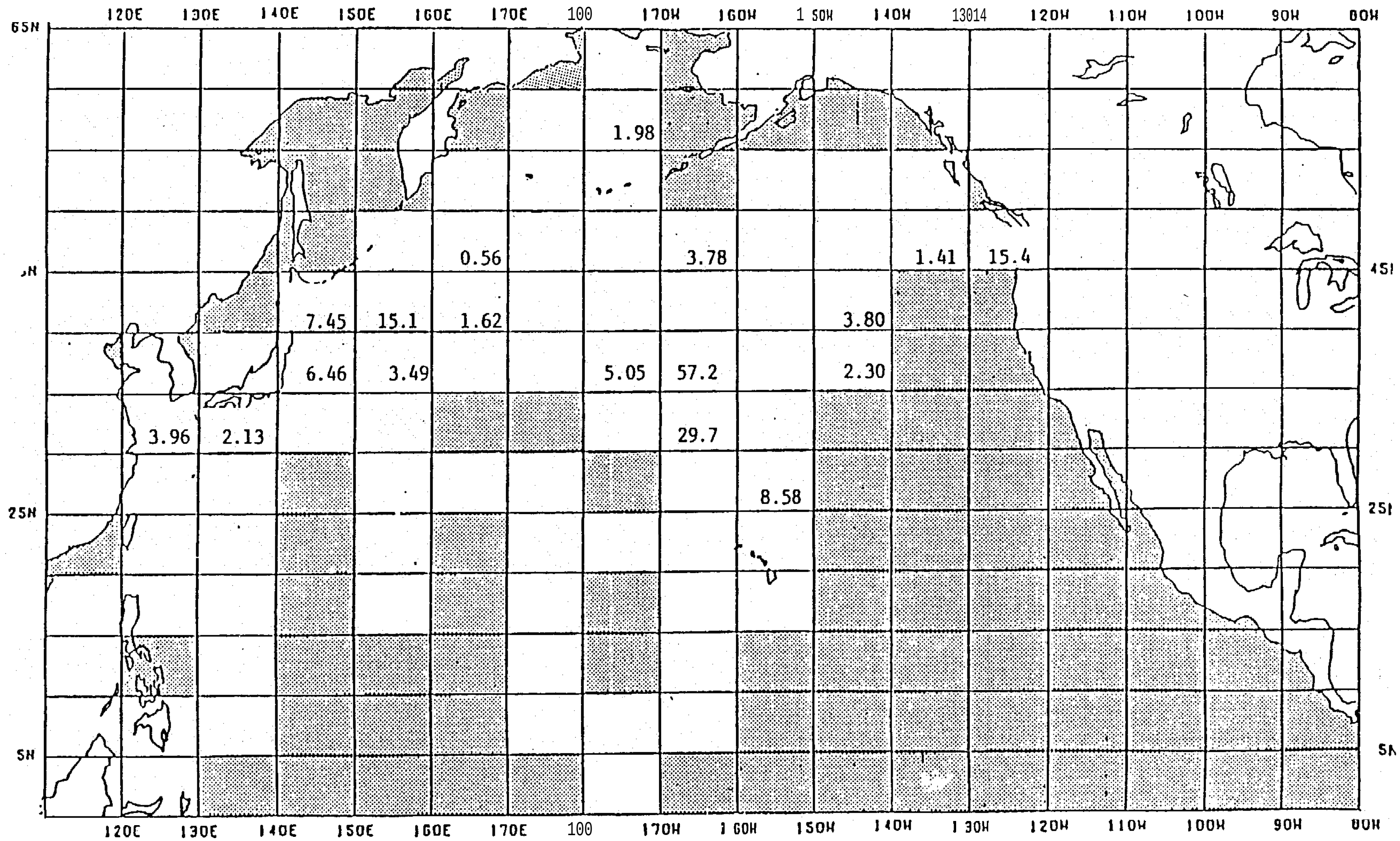

Figure 8A. --Estimated density distribution of fishing net debris in 1986.
Unit: number of debris pieces x 10^{-1} per 1 nmi^2.

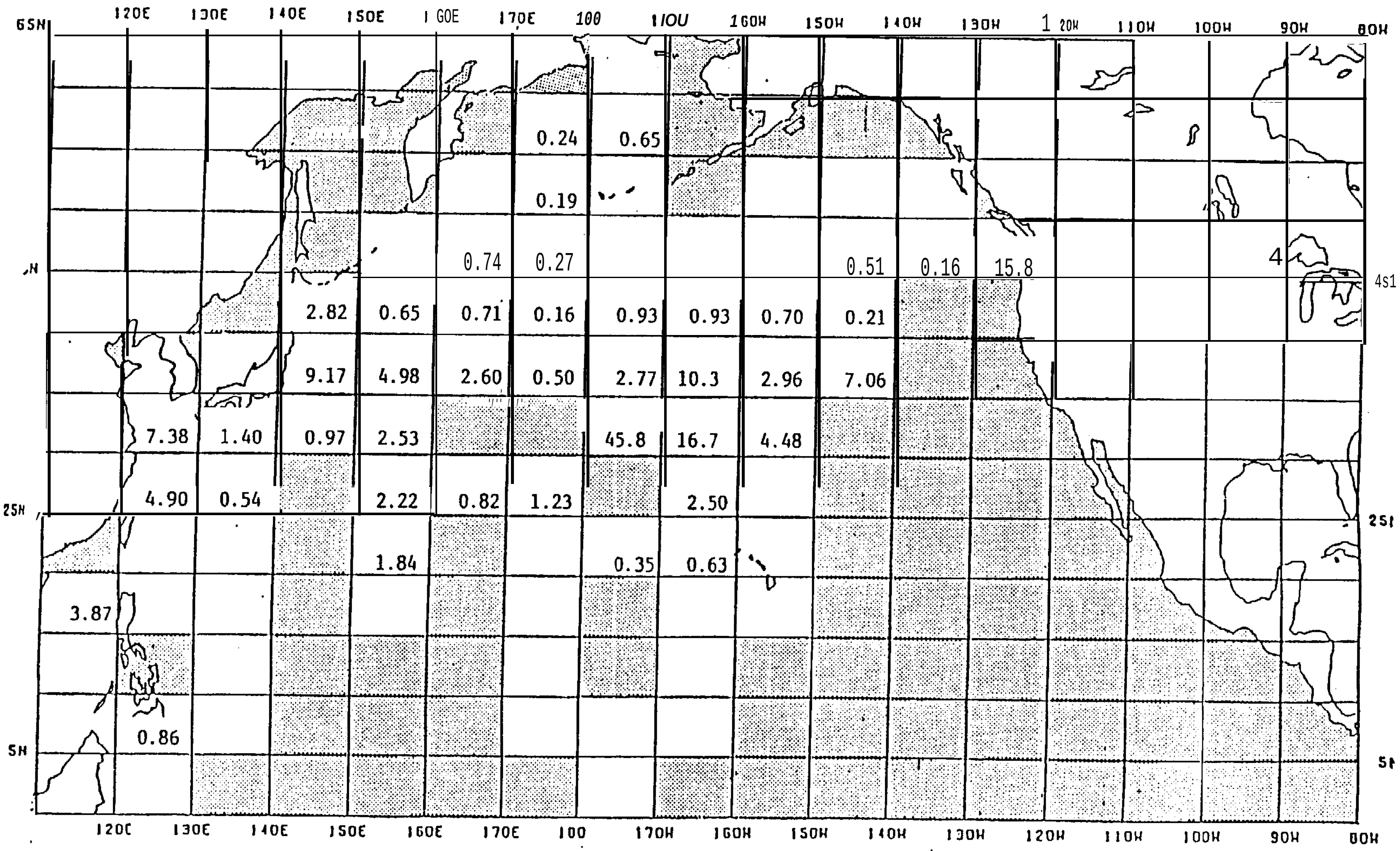

Figure 8B. --Estimated density distribution of other fishing gear debris in 1986. Unit: number of debris pieces x 10^{-1} per 1 nmi^2.

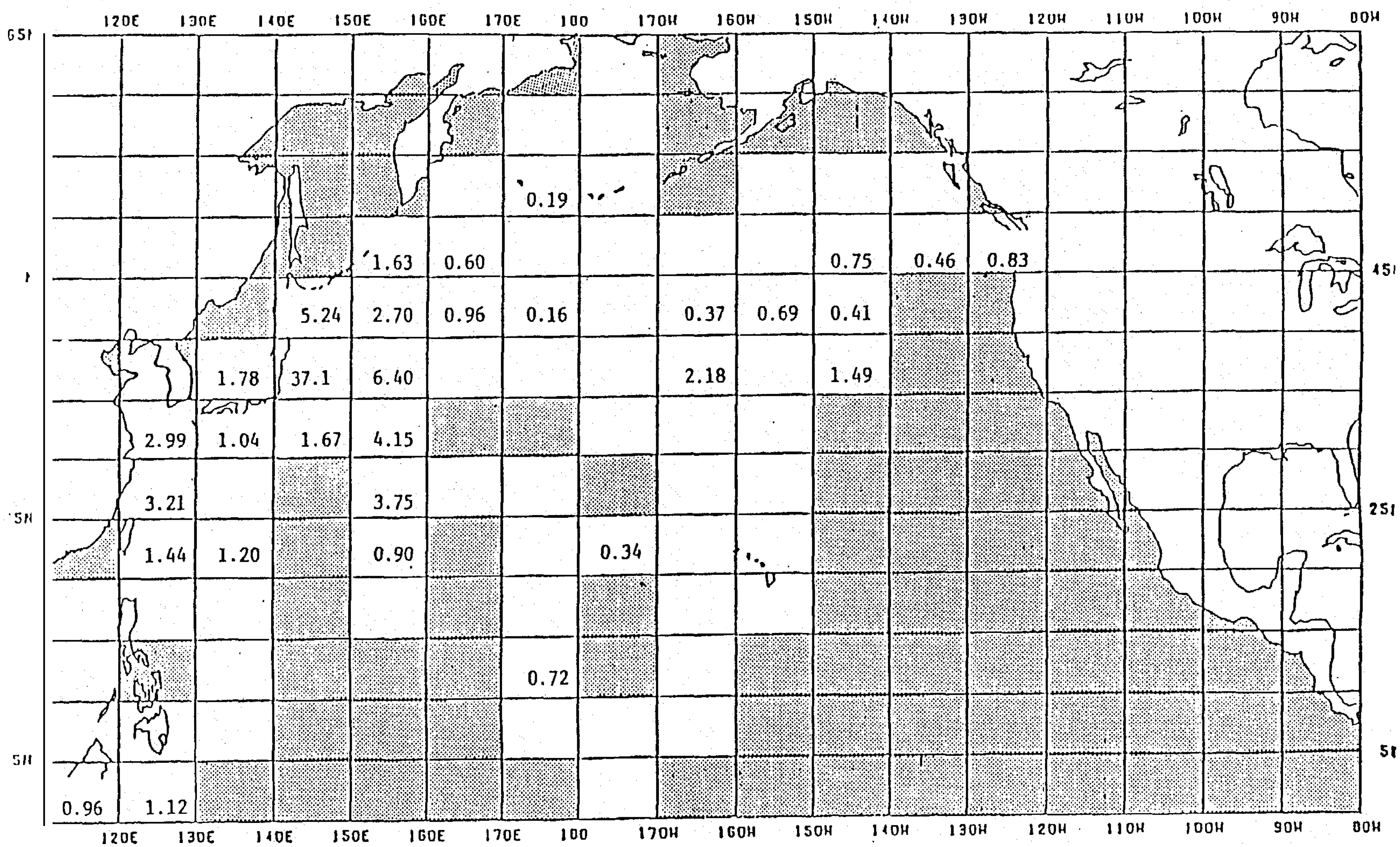

Figure 8C. --Estimated density distribution of Styrofoam debris in 1986.
Unit: number of debris pieces x 10^{-1} per 1 nmi^2.

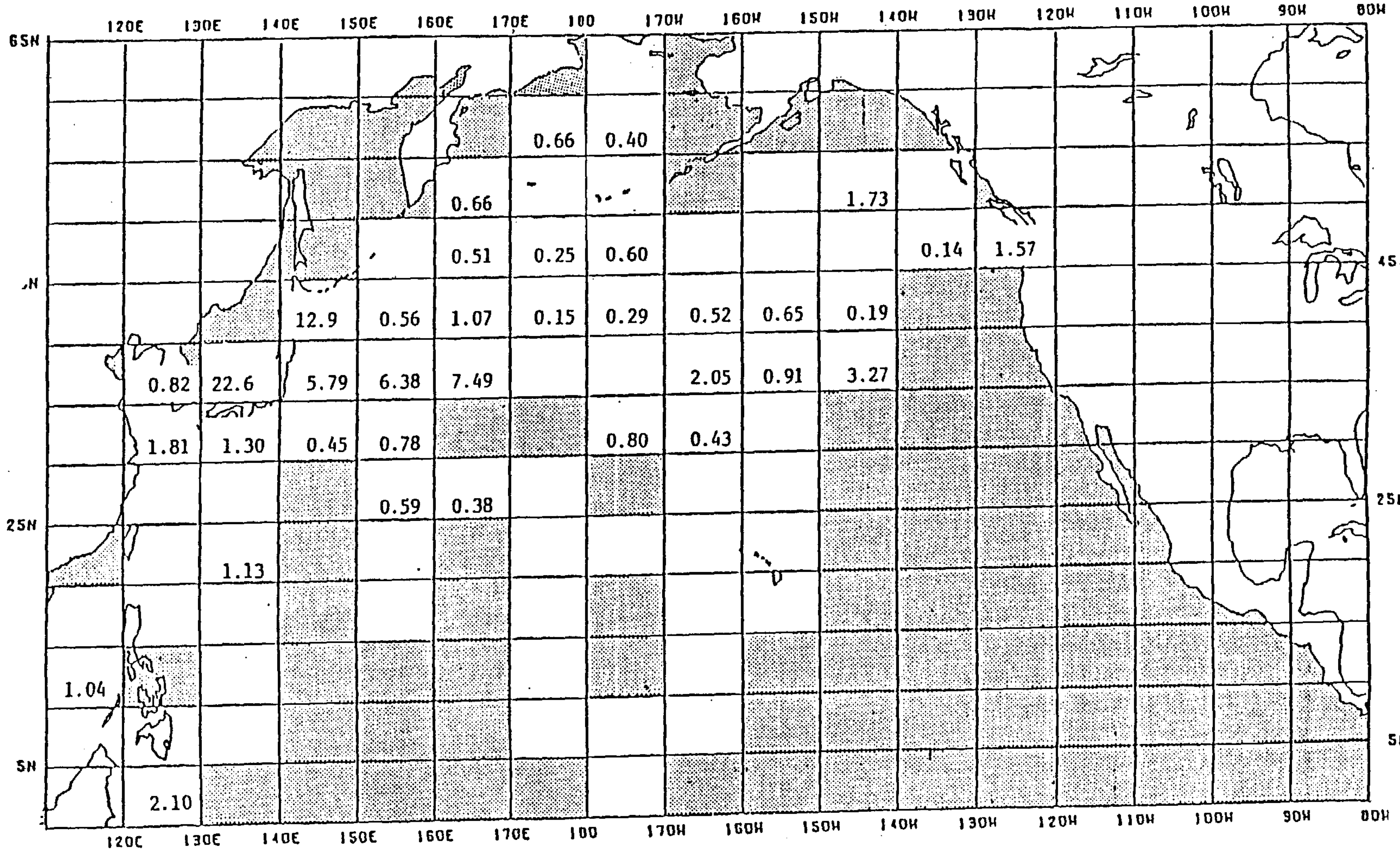

Figure 8D.--Estimated density distribution of other plastic debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

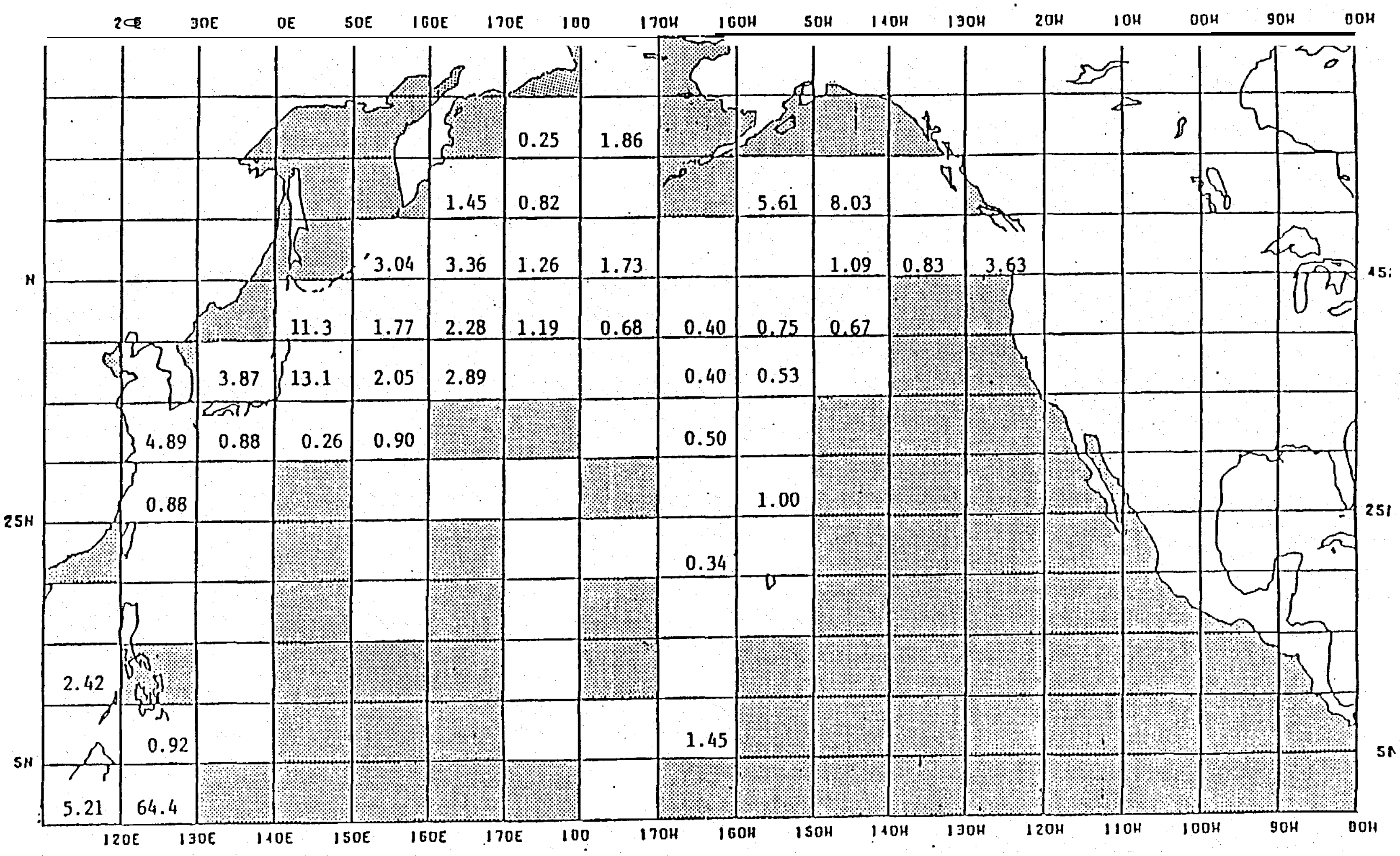

Figure 8E.--Estimated density distribution of wood debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

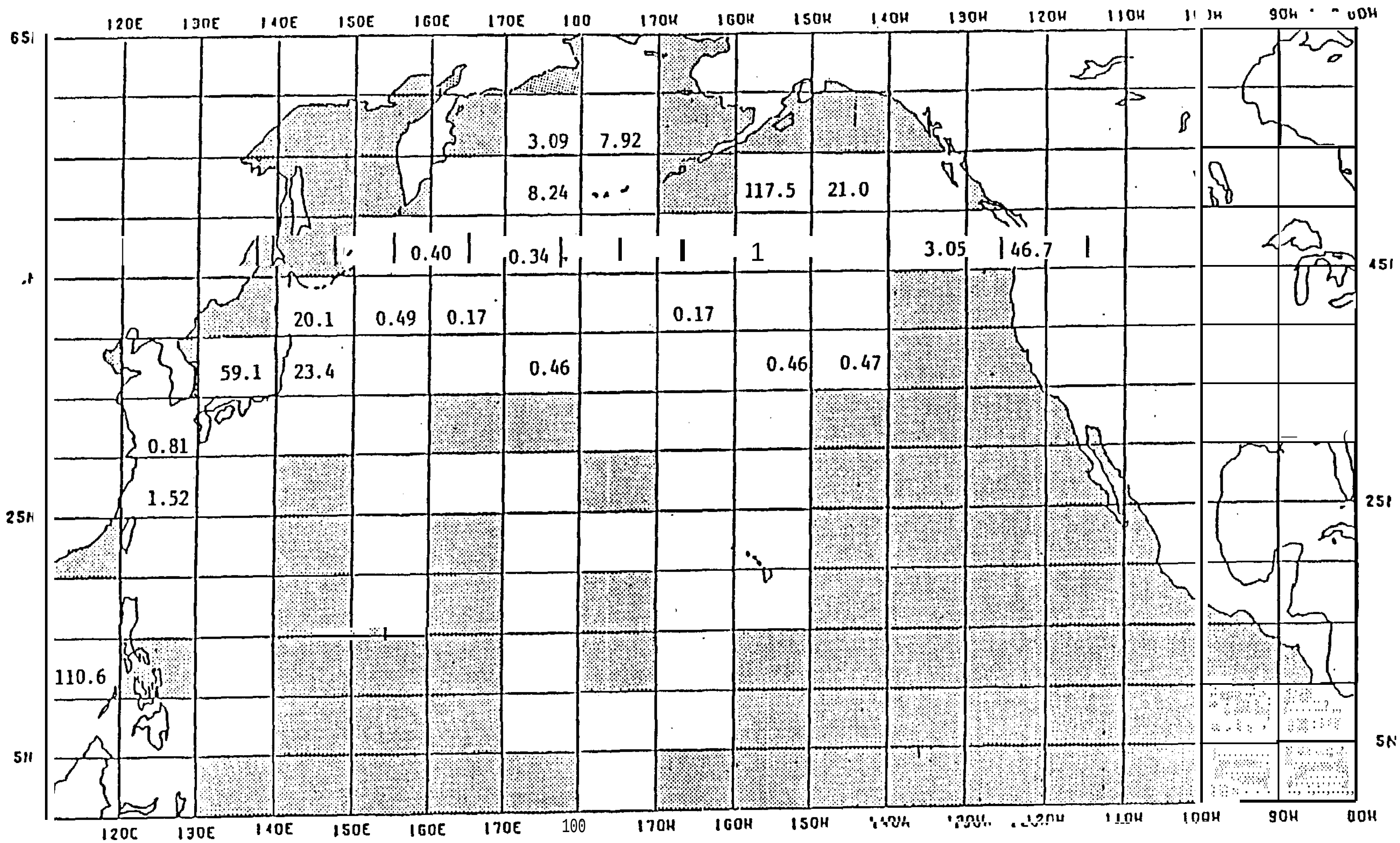

Figure 8F.--Estimated density distribution of floating seaweed debris in 1986.
Unit: number of debris pieces X 10^{-1} per 1 nmi^2.

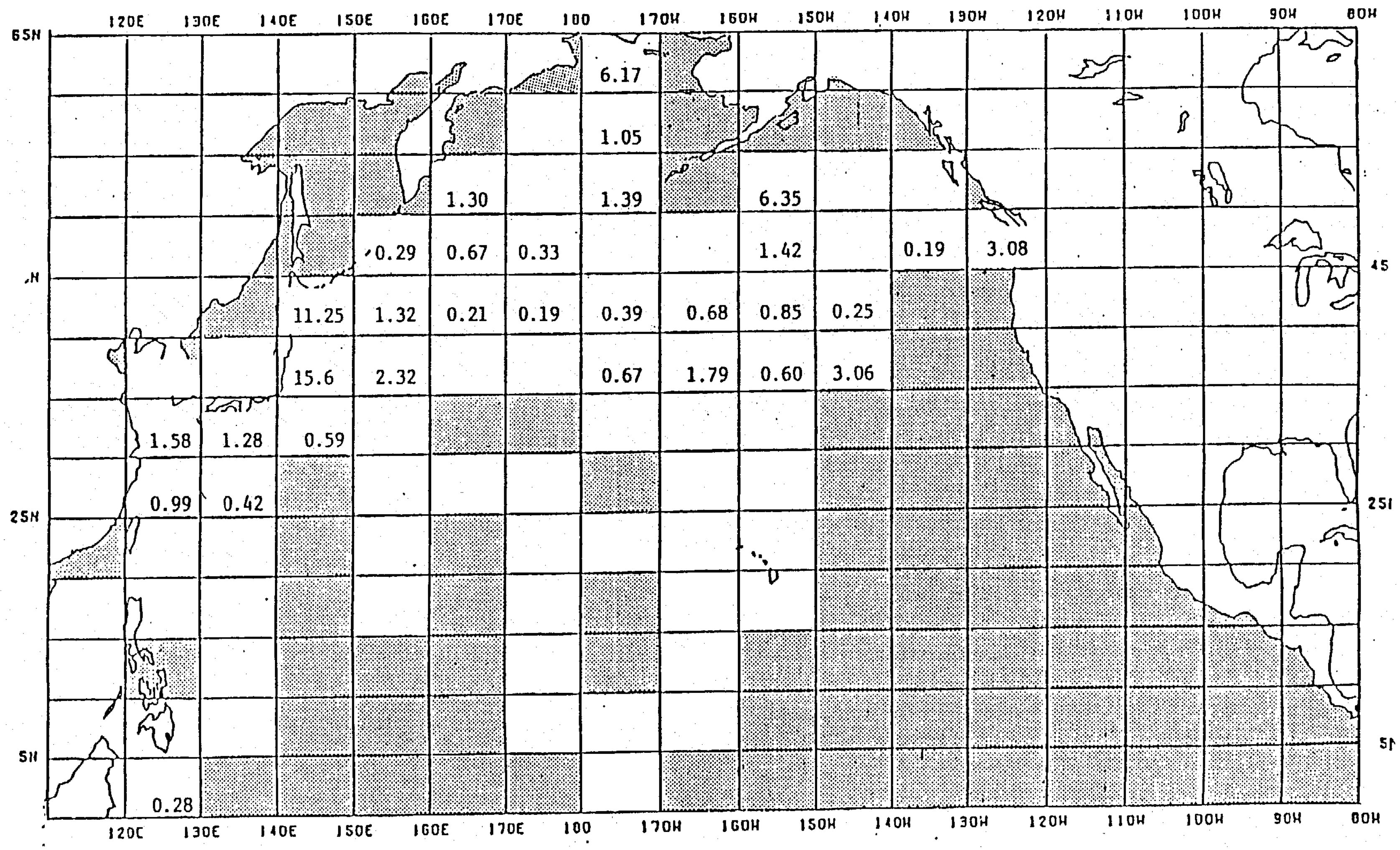

Figure 8G --Estimated density distribution of other marine debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

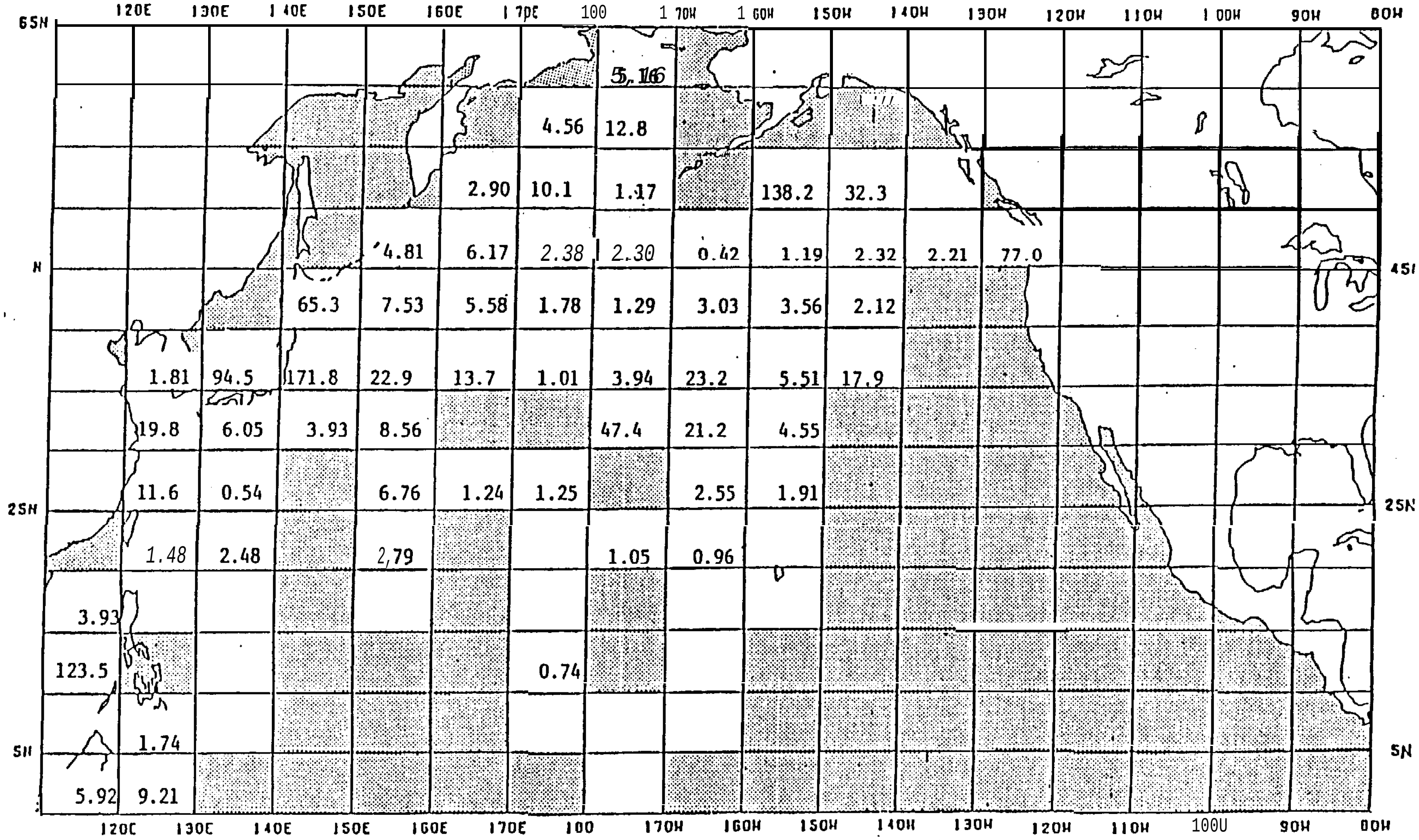

Figure 8H.--Estimated density distribution of total marine debris in 1986.
Unit: number of debris pieces x 10-′ per 1 nmi^2.

not only the number of individual items, but also their volume are important elements. However, it is quite difficult to measure with the eye the volume of things having various shapes. Therefore, in the survey we set these very rough size criteria and recorded the sizes of marine debris. Judging from the results by type of marine debris, "small" showed an extremely high rate, except in fishing net, pieces of wood, and drifting logs . In particular, "small" accounted for >90% of other plastic debris and Styrofoam, which were also great in actual volume. Although the number of items of this type of marine debris was great, it is believed that there was no greater difference in quantity than in number between this marine debris and other marine debris. More than half of the "large" items were fishing nets; the number was small, but the volume of each item was large. It is necessary to obtain more information on size in future surveys. It is believed that pieces of wood, drifting logs, and floating seaweed, which occur naturally, constitute the bulk of marine debris because of their large quantity and relatively large size.

These distribution patterns were almost the same as those obtained from the experimental sighting surveys conducted in 1986 (Figs. 7 and 8). It is necessary to study relationships between movement and accumulation of marine debris and ocean currents as well as to collect more data in the future. Furthermore, in order to' understand yearly changes, it is also necessary to intensify the surveys in the North Pacific Ocean and adjacent areas and to establish methods of monitoring.

Yagi and Nomura (1988) reported on yearly changes in the density of marine debris based on sighting surveys conducted by the *Ryofu Maru* of the Meteorological Agency twice in winter and summer during 1976-86 using observations lines fixed between the Equator and lat. 34"N along long. 137°E. The survey results are said to be valuable for examining the yearly changes in marine debris using the same blocks at fixed periods each year, although observation blocks were limited in number. The survey results showed that the number of marine debris pieces sighted by unit distance more than doubled from when the survey was first launched. In particular, plastic sheet fragments have shown a marked increase in recent years.

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THE QUANTITATIVE DISTRIBUTION AND CHARACTERISTICS OF NEUSTON PLASTIC IN THE NORTH PACIFIC OCEAN, 1985-88

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ABSTRACT

The distribution, abundance, and characteristics of neuston plastic in the North Pacific, Bering Sea, and Japan Sea were studied during the 4-year period 1985-88 at 203 neuston stations encompassing ca. 91,000 m^2 of sampling. The highest total density of neuston plastic was 316,800 pieces/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan. The highest total concentration of neuston plastic was 3,491.8 g/km^2 at lat. 40°00'N, long. 171°30'E near the Subarctic Front in the central North Pacific. Main types of neuston plastic were miscellaneous line fragments (21.7% of all stations), Styrofoam (12.8%), polypropylene line fragments (7.4%), miscellaneous or unidentified plastic (7.4%), and raw pellets (5.9%). Plastic fragments were recorded at 52.2% of all stations and at 88.3% of those stations with plastic. The highest densities (number per square kilometer) and concentrations (gram per square kilometer) of neuston plastic occurred in Japan Sea/nearshore Japan Water, in Transitional Water, and in Subtropical Water. Densities of neuston plastic in Subarctic Water and Bering Sea Water were low. Heterogeneous geographic input and currents and winds are important in distributing and concentrating neuston plastic. Microscale convergence appear to be important mechanisms that locally concentrate neuston plastic, increasing the probability of its entering food chains.

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

INTRODUCTION

Marine debris, especially plastic debris, increasingly is recognized as a national and international pollution problem (Shomura and Yoshida 1985; Wolfe 1987). Plastic enters the ocean in many forms and many sizes. In addition to plastic objects associated with ships (e.g., lines, nets, floats), virtually every kind of plastic packaging and plastic object used on land may be discarded or lost to the sea. Some plastics are denser than seawater and thus sink, but some are buoyant enough to float, either because of trapped gas or because of low specific gravity. At sea, plastic objects undergo mechanical breakdown or fragmentation, leading to progressively smaller pieces of floating plastic. The size fraction of plastic debris caught in nets designed to catch surface plankton (hereafter referred to as neuston plastic) is of interest for several reasons. First, small plastic objects are more abundant than are the larger ones from which they are formed. Second, collection of plastic in nets is an objective process that provides unbiased estimates of densities. Finally, objects in this size range can be mistaken for food items, with possibly important ecological consequences (Day 1980; Day et al. 1985).

Several workers have investigated the distribution of neuston plastic in the North Pacific (Wong et al. 1974; Shaw 1977; Shaw and Mapes 1979; Day et al. 1985; Day and Shaw 1987). These studies have shown that neuston plastic is widespread, is most.abundant in the central and western North Pacific, and is distributed by currents and winds.

The goal of this study was to improve our knowledge of the quantitative distribution and characteristics of neuston plastic in the North Pacific Ocean. Specifically, we wanted to: (1) describe the quantitative distributions of the main types of neuston plastic, (2) compare the at-sea densities of the main neuston types, (3) describe the frequencies of colors of neuston plastic, and (4) examine the importance of currents and winds in affecting the quantitative distribution of neuston plastic. Because of the extensive geographic coverage of the work, this study provides one of the most detailed synoptic pictures of neuston plastic anywhere in the world ocean.

METHODS

We collected data on the density, concentration, and types of neuston plastic $\geq$0.500 mm in size at 203 neuston stations in the North Pacific Ocean north of lat. 21°N (i.e., Hawaii) and in the Bering and Japan Seas. At each station, a 1.3-m ring net (during 1985) or a Sameoto (Sameoto and Jaroszynski 1969) neuston sampler (1986-88) with a 0.500-MM mesh net was used to collect neuston samples. Following Day and Shaw (1987), the area of ocean's surface sampled was calculated by multiplying the width of the net opening (0.5 m for the Sameoto sampler; see Day and Shaw 1987 for information on the ring net) by the distance the ship traveled in 10 min of sampling at a known speed, corrected for the time that the net was not fishing. Samples were washed from the net and either were sorted on the ship or were preserved in formalin and sorted later in the laboratory. Although areas sampled varied among stations, we ignored these differences among stations in the analyses. Data from 1985 that already were published (32 stations, Day and Shaw 1987) were included here because that number is small compared with the 171 stations for which the data have not been published.

During sorting, individual pieces of plastic were counted and identified as one of six standardized types: pellet, fragment, Styrofoam (which may include foamed plastics of other chemical composition), polypropylene line (which may include synthetic line of other chemical composition), miscellaneous or unidentified line, and miscellaneous or unidentified plastic. These pieces of plastic also were identified as 1 of 11 standardized colors: black/gray, blue, brown, green, orange, red/pink, tan, transparent, white, yellow, and mixed or unidentified. The samples then were placed in preweighed vials and were air-dried before being weighed to the nearest 0.001 g.

Data were compiled as the total density (number per square kilometer) and total concentration (mass per square kilometer) of neuston plastic at each station and as the density of each general type of plastic at each station. The color data were compiled as the numbers and frequencies of occurrence of each color at each station and were tabulated as total frequencies of each color. For data analysis, each station was stratified geographically into one of five water masses: Bering Sea Water, Subarctic Water (north of the Subarctic Front, or north of ca. lat. 42°N), Subtropical Water (south of the Subtropical Front, or south of ca. lat. 31°N), Japan Sea/nearshore Japan Water (the latter area consisting of water east of Japan and west of lat. 150°E), and Transitional Water (that between Subarctic Water and Subtropical Water, and including the Subarctic Frontal Zone, the Transition Zone, and the Subtropical Front).

The stratified data on total density, total concentration, and densities of each type of neuston plastic were analyzed with a Kruskal-Wallis test (Conover 1980; Zar 1984). For each data set, we tested the hypothesis:

HO: The density (or concentration) does not differ among water masses.

When test results were significant, we conducted multiple comparisons tests (Conover 1980) to determine which water masses were different. We also calculated means and standard deviations of each data set in each water mass . The color data were compiled as frequencies of each color of plastic. Subsequently, these frequencies were divided by the total number of plastic items to determine percentages of each color type.

RESULTS

Neuston plastic was recorded at 120 stations (59.1% of total stations) ; the total number of pieces recorded was 1,774. The two water masses in which plastic occurred at 100% of the stations were Subtropical Water (n - 2 stations) and Japan Sea/nearshore Japan Water (n - 11 stations) . Neuston plastic also was common in Transitional Water, where it occurred at 56 (93.3%) of 60 stations, and in Subarctic Water, where it occurred at 46 (71.9%) of 64 stations. Finally, it was uncommon in Bering Sea Water, where it occurred at only 5 (7.6%) of 66 stations.

Total Density

Total densities of neuston plastic were highest in the Japan Sea, in nearshore water east of Japan, and in Transitional Water and the Subarctic Front; total densities generally were very low in Subarctic Water (especially in the center of the Alaska Gyre) and in the Bering Sea (Fig. 1). The highest total density of neuston plastic was 316,800 pieces/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan. Other stations with high total densities were 221,000 pieces/km^2 at lat. 38°55'N, long. 135°58'E in the Japan Sea; 217,300 pieces/km^2 at lat. 37°58'N, long. 52°00'E near the Subarctic Front east of Japan; and 202,700 pieces/km^2 at lat. 40°00'N, long. 174°30'E near the Subarctic Front in the central North Pacific. Total densities differed significantly among water masses (H - 1221.482; n = 203; df - 4; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water - Subtropical Water - Transitional Water > Subarctic Water > Bering Sea Water.

Concentration

Total concentrations of neuston plastic generally were 10W, with high concentrations recorded at only four stations in Transitional Water, at two stations in nearshore water east of Japan, and at one station in Subarctic Water; total concentrations at the other stations with plastic generally were <10% of the highest concentration (Fig. 2). The highest total concentration was 3,941.8 g/km^2 at lat. 40°00'N, long. 171°30'E near the Subarctic Front in the central North Pacific. Other concentrations >1,000 g/km^2 were 3,007.9 g\km^2 at lat. 37°58'N, long. 152°00'E near the Subarctic Front east of Japan, 1,979.1 g/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan, and 1,048.5 g/km^2 at lat. 28"20'N, long. 162°20'W in Subtropical Water north of the Hawaiian Islands. Total concentrations differed among water masses (H = 120.604; n = 203; df = 4; $P < 0.05$; Table 1). Multiple comparisons indicated that concentrations were: Subtropical Water = Japan Sea/nearshore Japan Water = Transitional Water > Subarctic Water > Bering Sea Water. The similarity in patterns between total densities and total concentrations is understandable, considering the strong correlation between these two parameters (Spearman's R = 0.905; Z - 12.861; n = 203; $P < 0.05$; Conover 1980; Zar 1984). The Pearson's product-moment correlation between these parameters was not as high, however (r 0.544; n = 203; $P < 0.05$).

Pellets

In the plastics industry, plastic resins commonly are manufactured as cylindrical pellets a few millimeters in size. Later, these pellets are melted and molded into finished products. Pellets were uncommon, being recorded only 12 times (5.9% of total stations and 10.0% of stations with plastic). Pellets were absent in the Bering and Japan Seas, were recorded only once in Subarctic Water, and were recorded primarily in Transitional

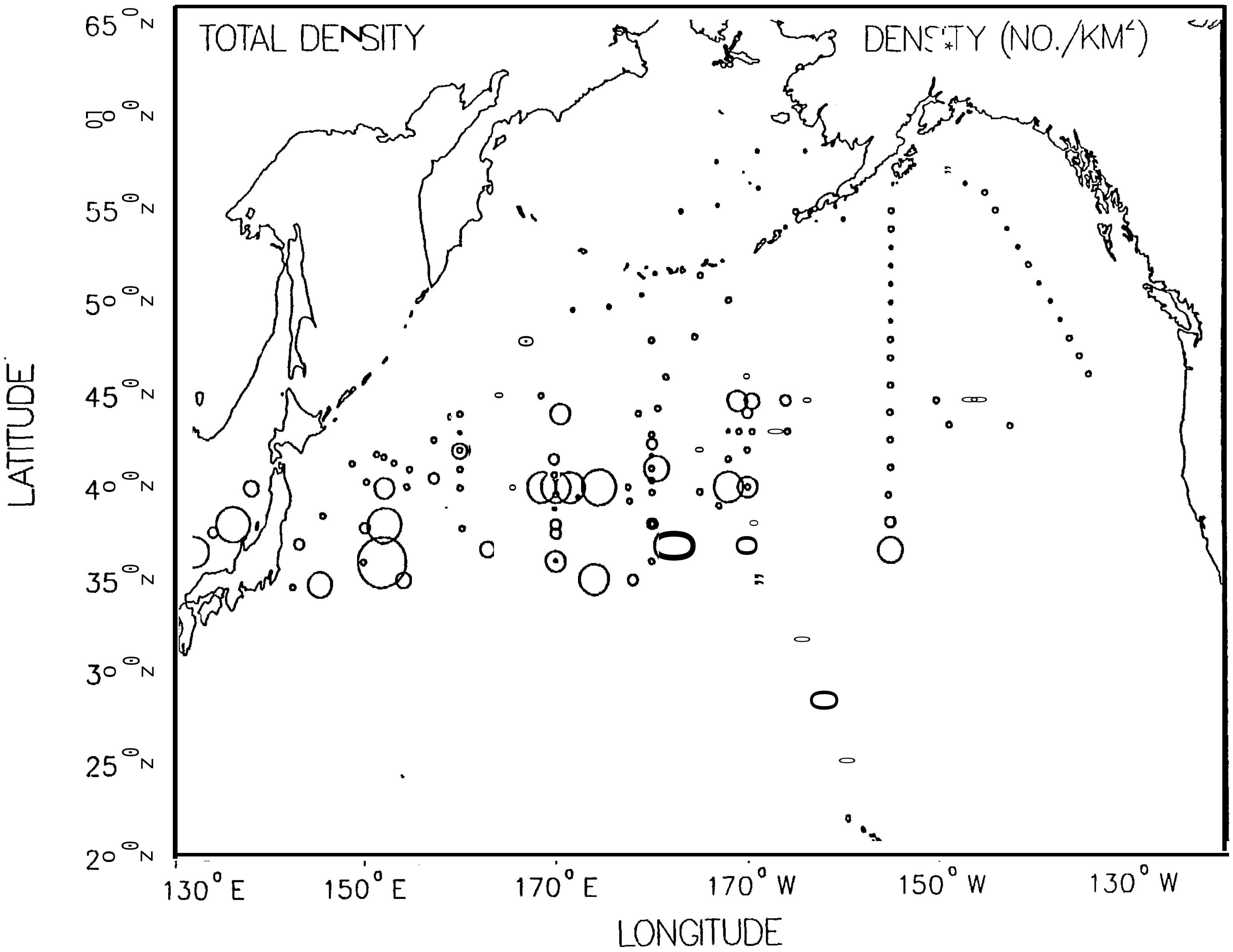

Figure 1.--Total densities of neuston plastic, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 316,800 pieces/km^2.

Table 1. --Densities (number per square kilometer) and concentrations (grams per square kilometer) of neuston plastic in five water masses of the North Pacific, 1985-88.

Parameter	Bering Sea Water		Subarctic Water		Transitional Water		Subtropical Water		Japan Sea and nearshore Japan Water	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Number	66		64		60		2		11	
Area sampled (m*)	35,906		28,662		22,154		541		3.824	
Total concentration	1.0	4.2	61.4	225.5	291.6	714.4	535.1	726.1	128.2	172.2
Total density	100	600	12,800	*22,300*	57,900	72,800	61,000	74,000	74,700	73,800
Pellet	0	0	<100	300	300	800	3,300	4,600	500	1,200
Fragment	0	0	9,600	20,300	52,700	69,200	57,700	69,400	46,100	40,000
Styrofoam	0	0	400	1,300	1,100	3,200	0	0	26,200	37,200
Polypropylene line	100	400	400	1,500	500	1,500	0	0	0	0
Miscellaneous line/thread	100	300	2,600	6,900	2,300	4,600	0	0	1,900	3,300
Miscellaneous/unidentified	100	500	100	500	1,000	3,100	0	0	0	0

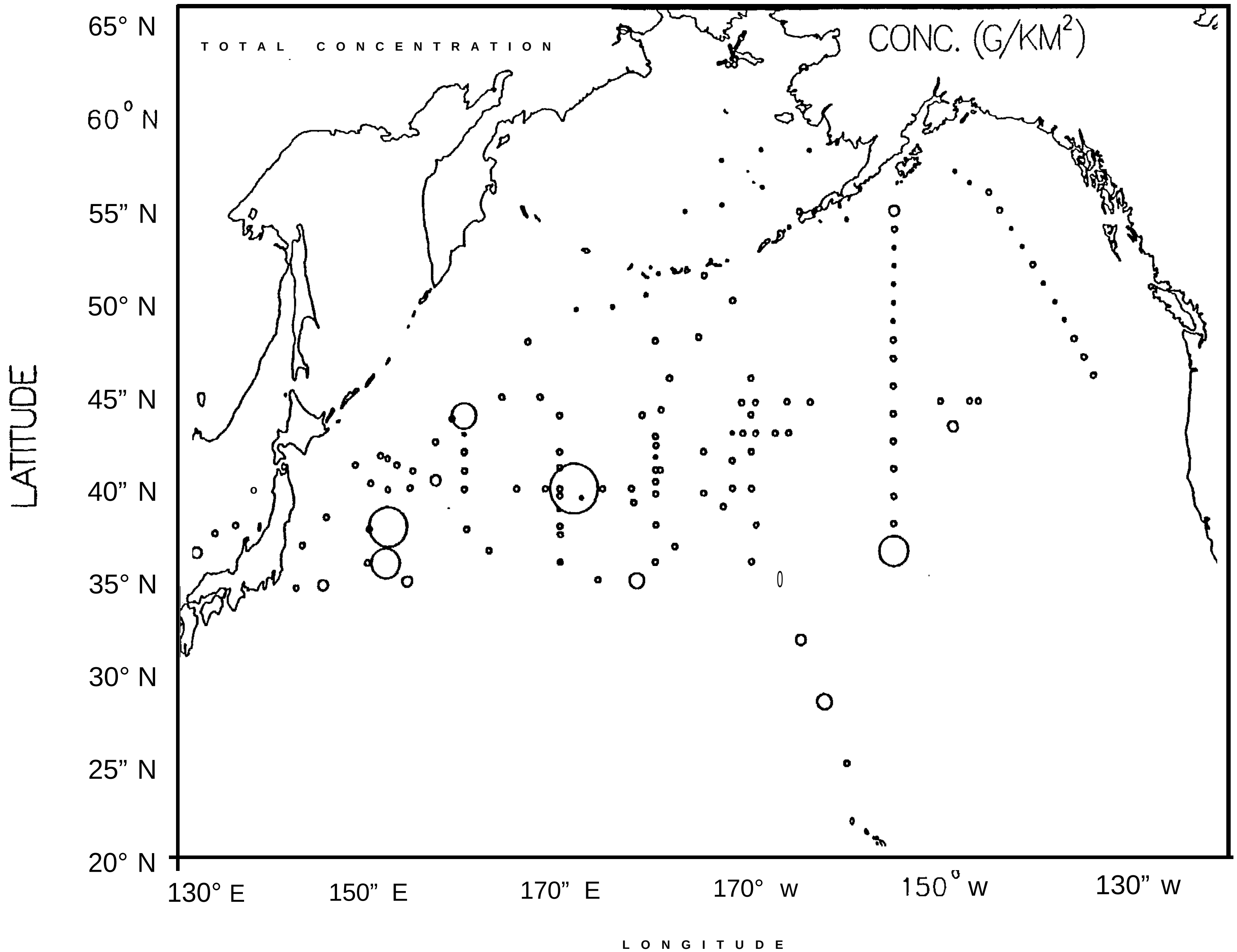

Figure 2, --Total concentrations of neuston plastic, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest concentration was 3,941.8 g/km^2.

Water and in nearshore water east of Japan (Fig. 3). The highest density was 6,500 pieces/km^2 at lat. 28°20'N, long. 162°20'W in Subtropical Water north of the Hawaiian Islands. The density of pellets differed among water masses (H - 22.996; n = 203; df - 4; P < 0.05; Table 1). Multiple comparisons were confusing, however, in that none of the individual water masses were significantly different. We suspect that the significant result was an artifact of the presence of pellets at both of the two stations in Subtropical Water. Consequently, the mean rank in this water mass was much higher than those in the other water masses, although the small sample size made it impossible to prove that significant differences actually existed.

Fragments

Fragments are small pieces of plastic broken from larger pieces (excluding Styrofoam). This category included primarily chips and pieces of sheets. Fragments were common, being recorded at 106 stations (52.2% of total stations and 88.3% of all stations with plastic). Fragments were common except in the Bering Sea and occurred in highest densities in nearshore water east of Japan and in and around the Subarctic Front; densities were lower in the Japan Sea and Subtropical Water and were much lower in Subarctic Water (Fig. 4). The highest density was 288,000 pieces/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan. Other stations with high densities of fragments were 202,700 pieces/km^2 at lat. 40°00'N, long. 174°30'E near the Subarctic Front in the central North Pacific; and 199,000 pieces/km^2 at lat. 37°58'N, long. 152°00'E near the Subarctic Front east of Japan. The density of fragments differed significantly among water masses (H - 113.587; n = 203; df = 4; P < 0.05; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water - Subtropical Water = Transitional Water > Subarctic Water > Bering Sea Water.

Styrofoam

This category included all pieces of pieces of foamed plastic; based on observed color and texture, we believe that all of this plastic was polystyrene . Styrofoam was uncommon, being recorded only 26 times (12.8% of total stations and 21.7% of stations with plastic). It was recorded in all locations except the Bering Sea and Subtropical Water, and occurred in highest densities in the Japan Sea and nearshore water east of Japan. It was a "transitional/nearshore Japan species," being recorded outside of this area only five times (Fig. 5). The highest density was 99,500 pieces/km^2 at lat. 36°37'N, long. 131°54'E in the Japan Sea. Other stations with high densities were 82,200 pieces/km^2 at lat. 38°55'N, long. 135°58'E in the Japan Sea; and 65,400 pieces/km^2 at lat. 34"49'N, long. 144°55'E off the eastern coast of Japan. Densities of Styrofoam differed significantly among water masses (H = 52.967; n - 203; df = 4; P < 0.05; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water > Transitional Water = Subarctic Water = Subtropical Water.

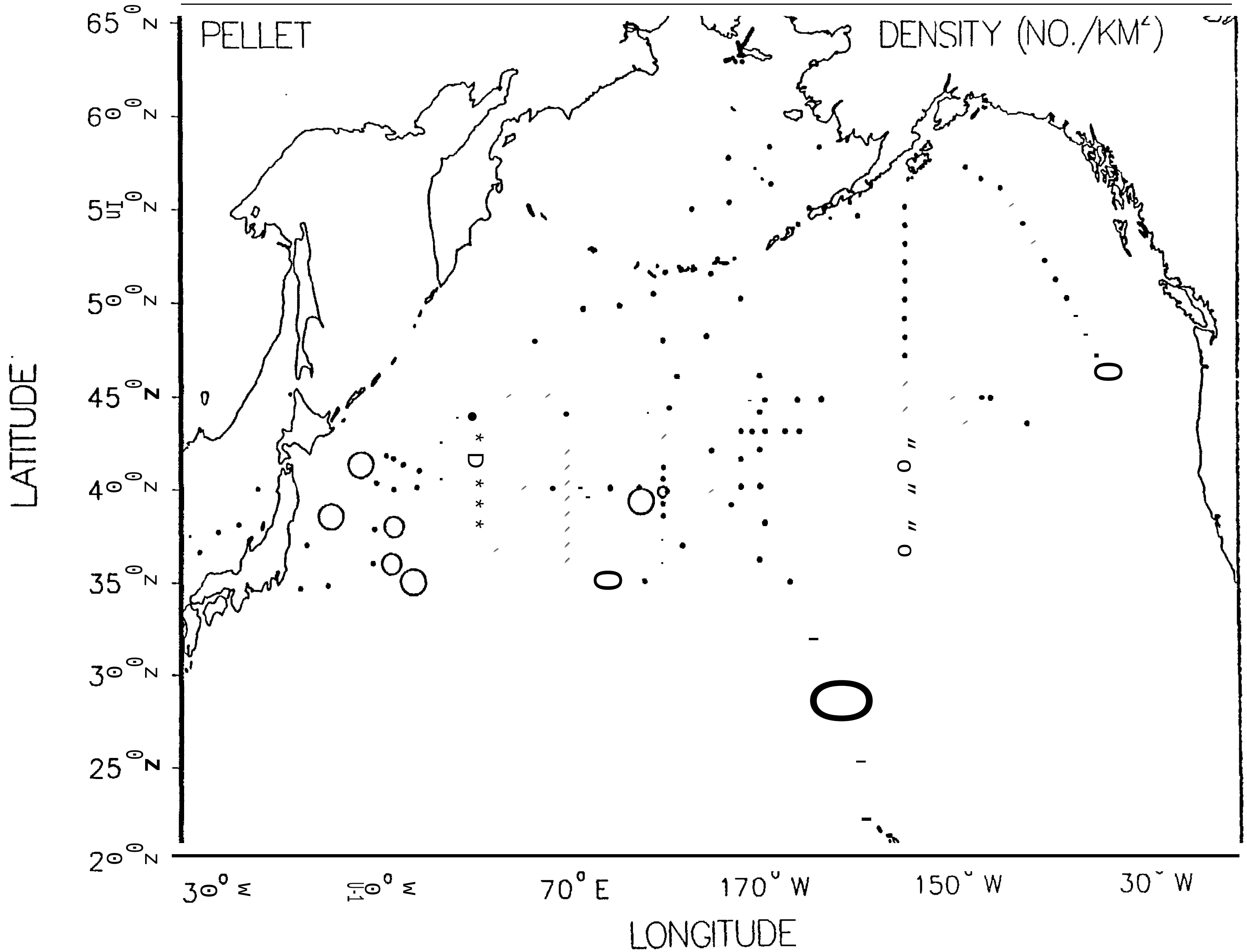

Figure 3.--Densities of pellets, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 6,500 pieces/km^2.

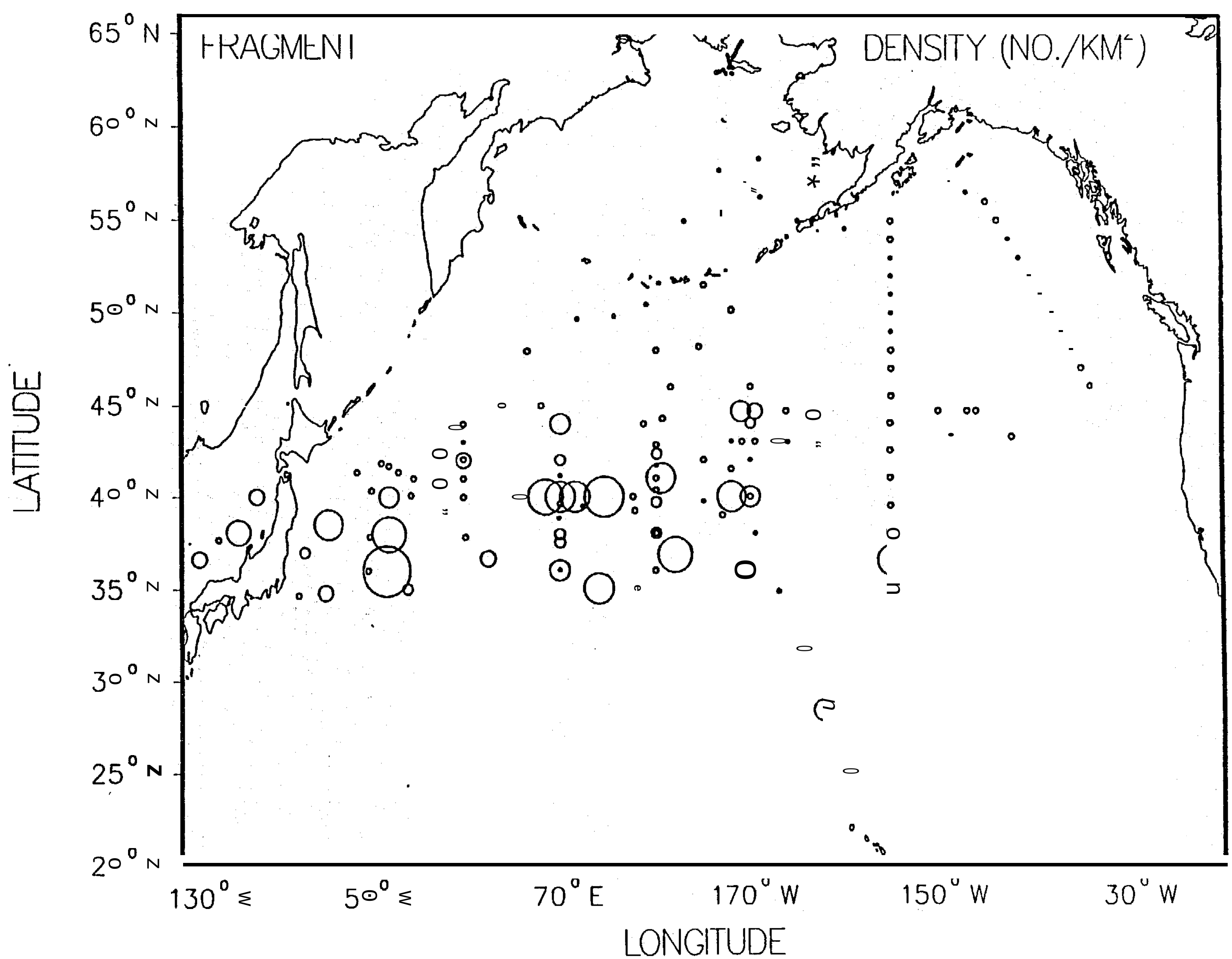

Figure 4.--Densities of fragments, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 288,000 pieces/km^2.

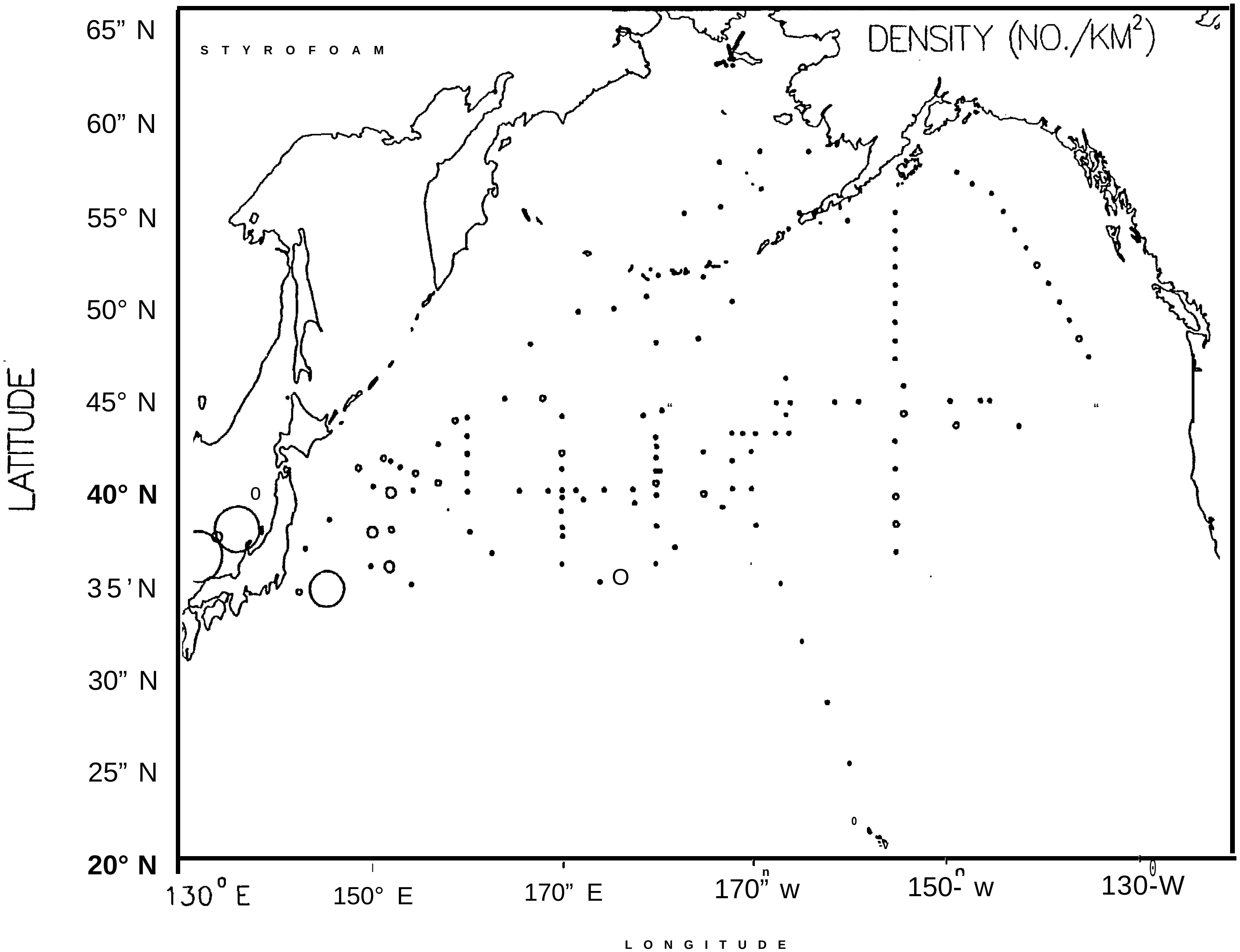

Figure 5. --Densities of Styrofoam, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 99,500 pieces/km^2.

Polypropylene Line Fragments

Polypropylene line fragments are small, woven pieces of large synthetic lines that are used as deck lines on fishing boats and cargo ships, Polypropylene is the most commonly used plastic for these applications. These line fragments were uncommon, being recorded 15 times (7.4% of total stations and 12.5% of stations with plastic). Polypropylene line fragments occurred primarily in and near the Subarctic Front and in Transitional Water; they were absent in the Japan Sea and in Subtropical Water (Fig. 6). The highest density was 8,400 pieces/km^2 at lat. 41°09'N, long. 170°00'E near the Subarctic Front in the central North Pacific. We failed to reject the null hypothesis that the density of polypropylene line fragments did not differ significantly among water masses ($H = 3.597$; $n = 203$; $df = 4$; $P > 0.05$; Table 1), probably because densities were low everywhere.

Miscellaneous Lines/Threads

Miscellaneous lines and threads included unidentified woven line fragments and (especially) monofilament lines that were from either gillnets or monofilament fishing line. We do not know what type of plastic they were, but they probably were not nylon, as it does not float (Carpenter 1976). Miscellaneous lines/threads were somewhat common, being recorded 44 times (21.7% of total stations and 36.7% of stations with plastic). They were recorded in all but Subtropical Water, with the highest densities occurring east of Japan and near the Subarctic Front (Fig. 7); they possibly may be fragments of line used by squid jiggers, which fish in this area. The highest density was 40,500 pieces/km^2 at lat. 47°59'N, long. 166°41'E in western Subarctic Water. Densities of miscellaneous lines/threads differed significantly among water masses (H - 24.607; $n = 203$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons were confusing, however, in that those water masses with the largest difference in mean ranks were not significantly different, whereas water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Transitional Water > Bering Sea Water, two with large sample sizes (60 and 66, respectively). We suspect that other water masses were different but that sample sizes in most were too small for the multiple comparisons to show significant differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Transitional Water, Subarctic Water, Bering Sea Water, and Subtropical Water.

Colors of Neuston Plastic

Most neuston plastic was transparent. This color was recorded 785 times (44.3% of the total 1,774 pieces and 44.9% of plastic of identified color) . White plastic also was abundant, being recorded 610 times (34.4% of the total and 34.9% of plastic of identified color), followed by blue (128 pieces; 7.2% of the total and 7.3% of plastic of identified color), black/gray (74 pieces; 4.2% and 4.2%), green (62 pieces; 3.5% and 3.5%), and tan (45; 2.5% and 2.6%). The colors brown (17 pieces; 1.0% and 1.0%), red/pink (13 pieces; 0.7% and 0.7%), yellow (8 pieces; 0.5% and 0.5%), and orange (5 pieces; 0.3% and 0.3%) were rare in occurrence. Miscellaneous or unidentified colors occurred 27 times (1.5%).

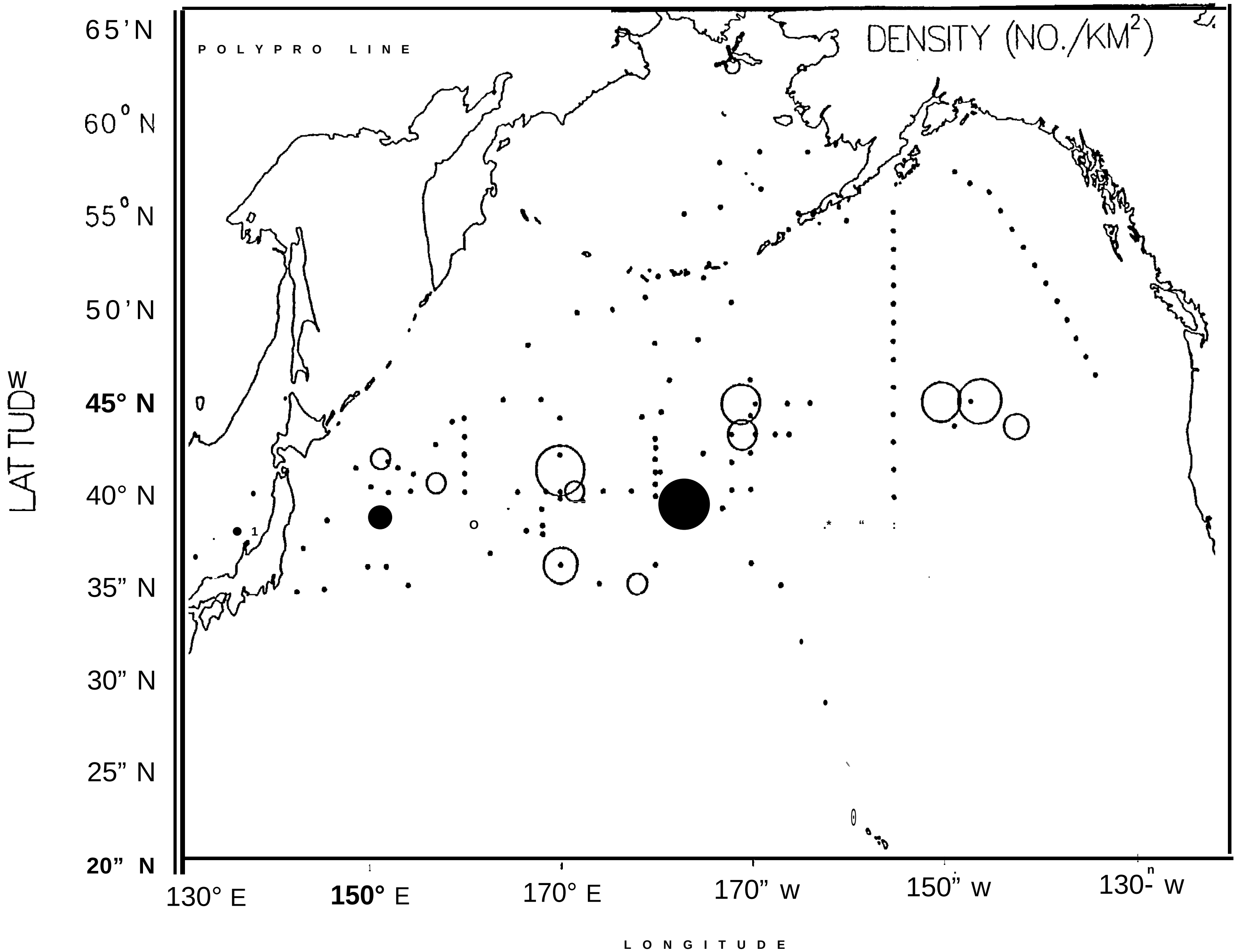

Figure 6. --Densities of polypropylene line fragments, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 8,400 pieces/km^2.

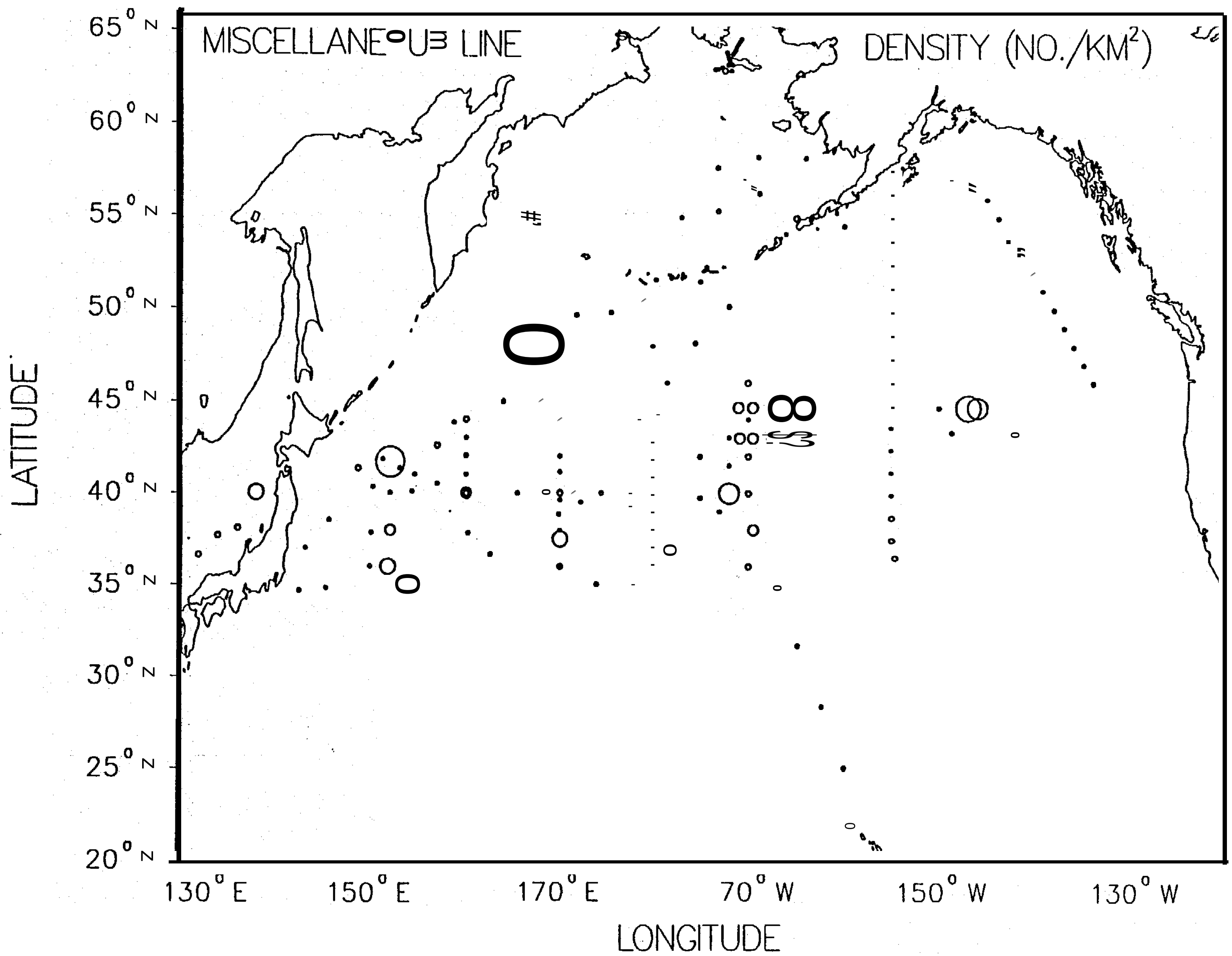

Figure 7.--Densities of miscellaneous lines/threads, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 40,500 pieces/km^2.

DISCUSSION

The distribution of neuston plastic results from two main phenomena, heterogeneous geographic input of plastic and subsequent redistribution by currents and winds. In addition, a phenomenon of unknown importance is the in situ decomposition of plastic in the ocean.

It appears that there is heterogeneous geographic input of neuston plastic, with much of it originating in the western Pacific. This conclusion is indicated by the high densities in and around the Japan Sea and nearshore Japan, where the highest densities of both neuston plastic and marine debris (Day et al. 1990) were recorded. The most polluted water in this area were Tokyo Bay (which had far more plastic than Day has ever seen elsewhere in the Pacific--he was unable to sample there) and localized areas in the Japan Sea. At the other extreme was the poorly populated Bering Sea area, where low rates of input probably occur. The low human population around much of the Gulf of Alaska probably contributes to the low densities there, also.

After entering the ocean, however, neuston plastic is redistributed by currents and winds. For example, plastic entering the ocean in Japan is moved eastward by the Subarctic Current (in Subarctic Water) and the Kuroshio (in Transitional Water, Kawai 1972; Favorite et al. 1976; Nagata et al. 1986). In this way, the plastic is transported from high-density areas to low-density areas. In addition to this eastward movement, Ekman stress from winds tends to move surface waters from the subarctic and the subtropics toward the Transitional Water mass as a whole (see Roden 1970: fig. 5). Because of the convergent nature of this Ekman flow, densities tend to be high in Transitional Water. In addition, the generally convergent nature of water in the North Pacific Central Gyre (Masuzawa 1972) should result in high densities there also.

One point that is not entirely clear is the cause of the low densities of neuston plastic in Subarctic Water. Part of the reason for these low densities is the apparently low input from shipping in this area: densities of both neuston plastic and marine debris in this area are low, suggesting little input from ships. The role of the divergent Alaska Gyre in helping to maintain these low densities is unclear, however. For example, neuston plastic tends to concentrate near the edges of the subarctic water mass, with little occurring in its center (Fig. 1), as would be expected for an upwelling gyre. On the other hand, the rate of vertical advection (in the low hundreds of meters/year, with downwelling occurring much of the year; T. C. Royer, Institute of Marine Sciences, University of Alaska, Fairbanks, Alaska, pers. commun.) is much lower than the rate of lateral advection (ea. 3,000 km/year at a speed of 15 cm/see; Favorite et al. 1976), which should result in upwelling having little effect on the distribution of neuston plastic in this gyre.

A third factor, and one of unknown importance, is the in situ decomposition of larger marine debris plastic into small neuston plastic. As discussed by Day and Shaw (1987), the small percentage of raw plastic pellets and the high correlation between abundances of debris plastic and neuston plastic suggested that in situ decomposition was occurring. Although the present study did not test this hypothesis, we believe that the in situ decomposition of plastic can be important. The large pool of debris plastic and neuston plastic (particularly fragments) in Transitional Water probably is resident for a long period of time and appears to be decomposing there. For example, our impression was that transparent neuston plastic in this area tended to be opaque on the surface, to have more surface crazing (Gregory 1978, 1983), and to be more brittle than did most from Subarctic Water, where it tended to be more transparent on the surface and more pliable. The same phenomenon was true for much of the marine debris plastic in Transitional Water, where it was heavily bleached and heavily encrusted, suggesting long residence time. In reality, however, chemical weathering (leaching of plasticizers from the plastic matrix, causing the remaining plastic to be brittle and more susceptible to mechanical weathering), thermal weathering (increasing the rate of chemical weathering) , and solar weathering (from strong sunlight) probably are most important in the in situ production of fragments of neuston plastic in Transitional and Subtropical Waters, whereas mechanical weathering (from rough seas) probably is most important in stormier Subarctic Waters. Finally, thermal (i.e., freezing) and mechanical weathering probably are most important in "the stormy, cool Bering Sea, which is ice-covered in winter.

Frequencies of colors of neuston plastic in the North Pacific differed from frequencies of colors of neuston plastic ingested by seabirds (Day et al. 1985). For example, white, yellow, tan, and brown neuston plastic (light colors) represented only 40.0% of total identified neuston plastic in the ocean, whereas it represented 85.0% of neuston plastic ingested by seabirds. One of the largest differences was in tan plastic, which composed only 2.6% of the identified neuston plastic in the ocean but 55.1% of the neuston plastic eaten by seabirds. The largest difference was in transparent plastic, which represented 44.9% of the identified neuston plastic in the ocean but was not found in seabirds. Transparent plastic is not eaten by birds, probably because of difficulty in seeing it at sea (Day et al. 1985).

Neuston plastic can enter food chains when it is mistaken for prey (Day et al. 1985), especially where it becomes concentrated near important, localized prey. For example, there appeared to be a relationship between high densities of neuston plastic and high densities of water-striders, *Halobates* sericeus (Insects: Gerridae) in Transitional and Subtropical Waters. These marine insects live at the surface of the ocean and are eaten by at least nine species of tropical seabirds that breed in the Hawaiian Islands and feed in these water masses. Water-striders are especially important prey of blue-gray noddies, *Procelsterna cerulea*, Bulwer's petrels, *Bulweria bulwerii*, and Benin petrels, *Pterodroma hypoleuca*, with the latter two species also containing significant amounts of neuston plastic (Harrison et al. 1983; Cheng et al. 1984). We suspect that these insects are moved slowly into microscale convergence at the same time that plastic and other organisms are. For example, the density of water-striders was 136,000/km^2 at one station where the density of neuston plastic was 113,300 pieces/km^2; the highest density of water-striders was ca. 250,000/km^2 (Day unpubl. data). Given the co-occurrence of water-striders and neuston plastic in some tropical seabirds, we suggest that many of these birds are feeding in these microscale convergence, where they are picking up water-striders, other plankters, and neuston plastic. Indeed, Day has seen surface-feeding planktivorous seabirds (phalaropes and storm-petrels) feeding in large numbers in microscale convergence in the Oyashio-Kuroshio Confluence. These convergence contained visible lines of kelp wrack, plastic, and other marine debris.

Another group that ingests neuston plastic as well as planktonic prey in coastal and oceanic microscale convergence is sea turtles (Carr 1987). Young turtles apparently feed in these convergence during the first year or more at sea, when they drift with the currents and hence act much like neuston plastic. (During this period they also may become entangled in marine debris plastic.) Later, as they become older, these turtles both ingest larger pieces of marine debris plastic and become entangled in marine debris plastic (Balazs 1985).

Microscale convergence may be found in many areas of the world ocean (e.g., Owen 1981; Bourne and Clark 1984), and they may occur in areas different from the general areas of concentration discussed above. From our experience, microscale convergence concentrating neuston plastic are near lat. 28°-29°N north of Hawaii; in and near the Subarctic Front as microscale ephemeral convergence; in the complex Oyashio-Kuroshio Confluence east of Japan (including the ephemeral, mobile warm-core and cold-core rings; Nagata et al. 1986); at scattered locations in the Japan Sea; and probably in and around the Subtropical Front (i.e., around lat. 30°-32°N).

Perhaps the most impressive microscale convergence are in and around the Subarctic Front. Here, dynamic instabilities in surface layers (Roden 1970) create numerous ephemeral convergence in the zone lat. 37°-42°N and in the Oyashio-Kuroshio Confluence east of Japan. This juxtaposition of high biological productivity, physical complexity, large numbers of seabirds that ingest neuston plastic, and large amounts of neuston plastic increases the possibility of ingestion of that plastic.

ACKNOWLEDGMENTS

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MOVEMENTS OF FLOATING DEBRIS IN THE NORTH PACIFIC

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ABSTRACT

A net fragments tracking experiment and numerical simulations using surface current data set (SCUDS) data were conducted to estimate movements of floating debris in the North Pacific.

Six driftnet sets (40 tans each) were placed in the area lat. 39°N, long. 155°E. Locations of the net sets and sea surface temperatures were collected and transmitted every day using the Argos system. Data were taken about six times a day for 4 months. At termination of the net drifting experiment, the net sets with buoys were retrieved and new Argos buoys with curtain drogues were released at the points of retrieval to continue the surface current tracking.

The buoys moved predominantly eastward, although each track line was complicated, particularly in areas near the Oyashio Front. It is considered that the movements of the nets were mainly due to surface currents and that direct influence from wind was negligible, because the underwater portion was very large (a driftnet 2,000 m long although it had formed a mass) compared with the above-water portion of the buoy. Average speed was estimated based on the buoy movements and ranged from 10 km/day to 20 km/day. Movements of floating debris in the North Pacific were simulated using a computer model based on SCUDS.

Results showed the existence of two large-scale eddies in the eastern and western parts of the mid-Pacific, and floating debris are through to accumulate in these areas.

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INTRODUCTION

North Pacific currents are found in a great circle ranging from the Kuroshio through the Kuroshio Extension and the North Pacific Current to the California Current and the North Equatorial Current in the south. In the vicinity of these currents are the Oyashio, Alaska, Aleutian, and other currents.

Floating debris (excluding Styrofoam, which is mostly above the surface) moves along these currents. Movements change depending on large and small vortexes in the water and are difficult to generalize, but we can estimate average movements on the basis of surface currents.

Marine features of the North Pacific are outlined by Favorite et al. (1976). The northwestern part of the North Pacific is characterized by the Kuroshio Extension and the Oyashio. The distribution of water masses in summer is greatly affected by the southerly intrusion of cold water masses and the strength of the Aleutian Current, both of which vary from year to year, as reported by Hiramatsu (1987, 1988).

Tests using driftnets were conducted to estimate movements of floating of floating debris. Driftnets were set in the Oyashio waters in May 1988 and were recovered after about 4 months of drifting. The Argos system was used for tracking the nets and analyzing their drift routes. We have also illustrated overall currents on a computer display using the surface current data sets (SCUDS), which covers ship drift data from about 4 million ship observations over the past 40 years.

CURRENT OBSERVATIONS USING ARGOS BUOYS

Method

Six driftnets were set by the first survey ship in order to observe changes in net shapes and movements in the northwestern part of the North Pacific. Each net was equipped with an Argos buoy at one tip and a radio buoy at the other. Nets were set in waters at lat. 39°N, long. 155°E and were arranged in the shape of a star, with five nets set in a 37-km (20-mi) radius from a key net.

Each net was 2,000 m (40 tans) long. Their fluid resistance in the water was so large that the early movements of each net were presumed to indicate an average current over a distance of 2,000 m. Ten days later, the shapes of several nets had changed greatly. Some nets were either folded or "balled up." They became masses with a maximum length of roughly 50 m (Mio et al. 1990).

They were still large enough to resist winds, and buoy tracks accurately indicated the movements of nets in the sea currents. There was a thermometer inside each buoy case. The buoy was metallic and had no heat-resistant structure. Therefore, each thermometer was able to indicate surface water temperatures. Styrofoam was used as a floater at the upper part of each buoy. It reduced heat flow from sunlight. Even if the buoy was exposed to strong sunlight, the thermometer's deviation from surface water temperature would have been very small.

Argos buoys were set on 5 and 6 May 1988. Three of the six buoys suspended transmission during drifting because of mechanical troubles, but the second survey ship recovered three of the four trouble-hit Argos buoys 4 months later by tracking radio buoys. The second survey ship recovered the nets and released three Argos buoys with curtain drogues for further observation of currents.

Results and Analysis

Tracks of buoys from May to September are illustrated in Figure 1.

Buoy 4783, which moved the greatest distance eastward in the 4 months, reach long. 180°. The slowest-moving buoy (4782) came as far as long. 162°E. An average speed of the maximum eastward movement was about 20 km/day. Any buoy movement was not straight but very complex depending on inertial forces and tides. The theoretically calculated inertial cycle at lat. 40°N is about 19 h, and it matched these observations. Figures 2-4 indicate the track of buoy 4789, which is zoomed gradually. Figure 4, where vertical and horizontal scales are almost the same, shows that the floating debris moved north to northeast at an average speed of 7 cm/sec while making a clockwise motion. The radius of the circular motion was about 1.6 km, and the flow speed was 10-50 cm/sec. Driftnets, which were set at roughly the same place, followed very different tracks, hinting at a large diffusion coefficient in the waters. One hundred days after setting, the maximum east-west distance between tracks was 1,637 km and the maximum

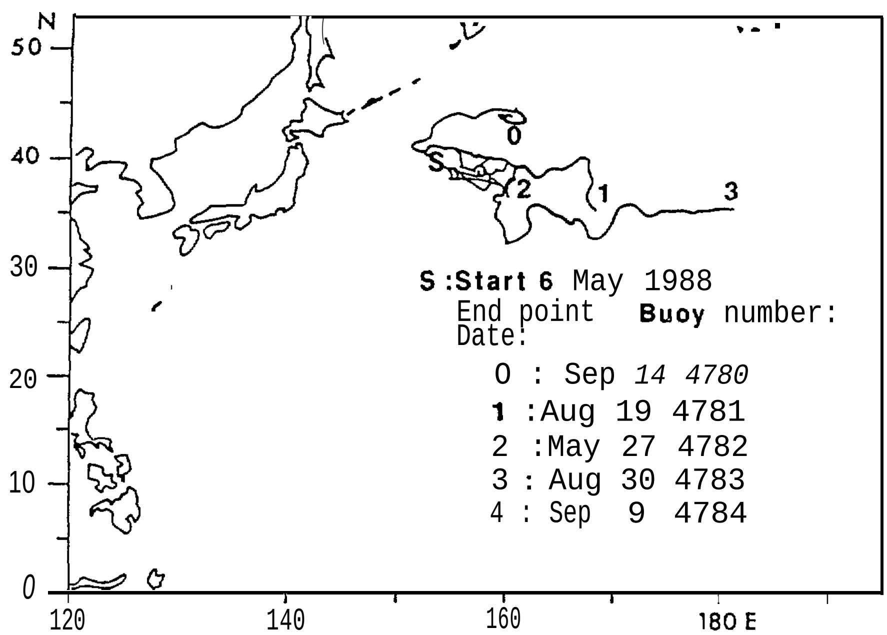

Figure 1. --Trajectories of drifting buoys.

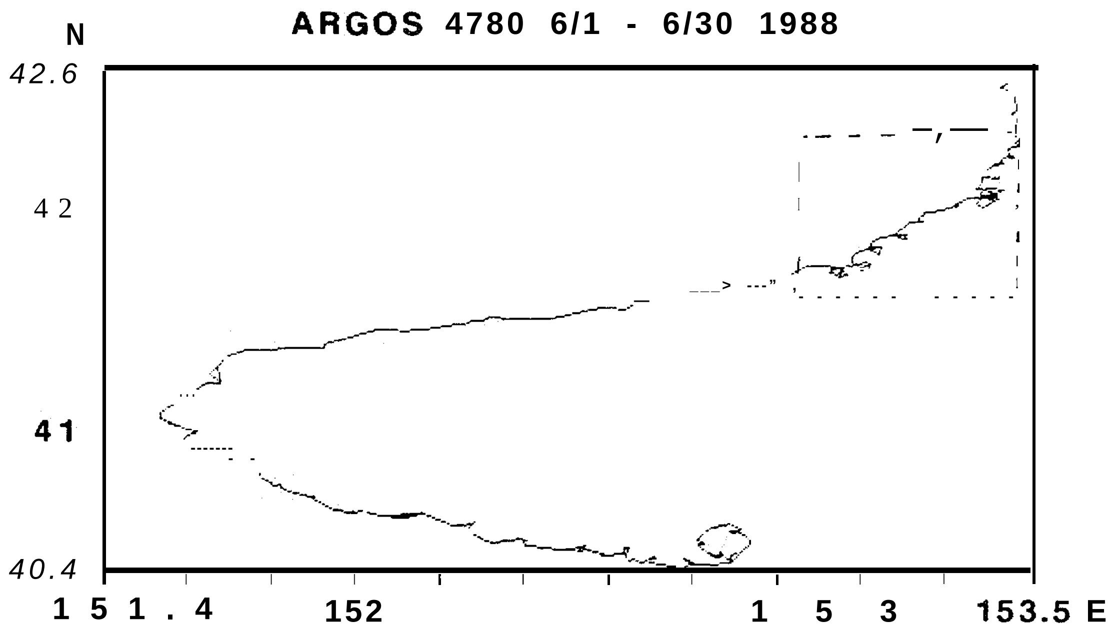

Figure 2. --Western part of buoy 4780 trajectory.

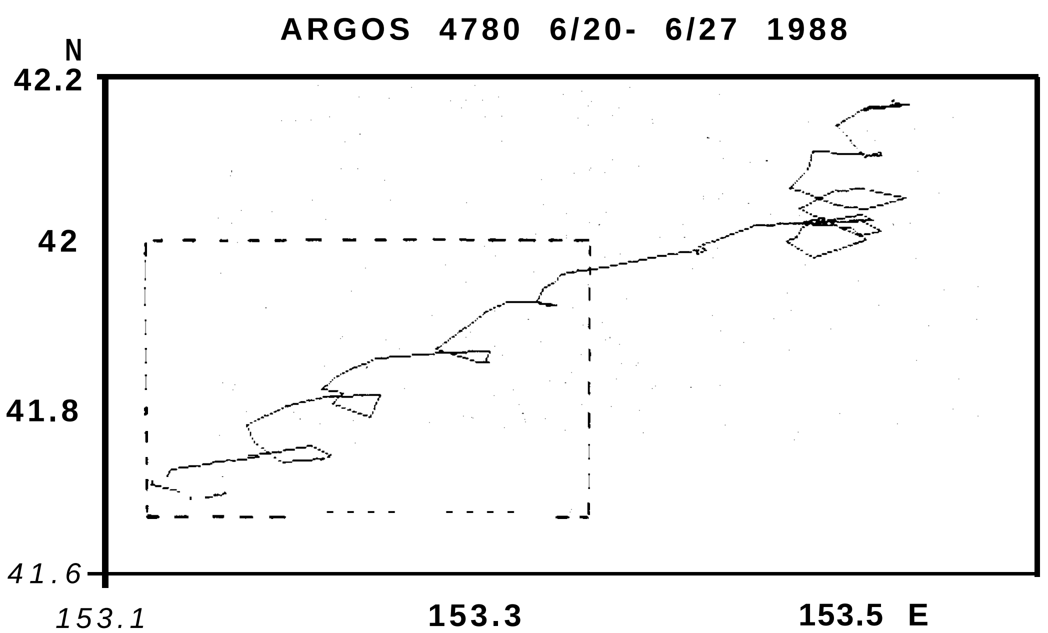

Figure 3. --Part of buoy 4780 trajectory, enlarged from Figure 2.

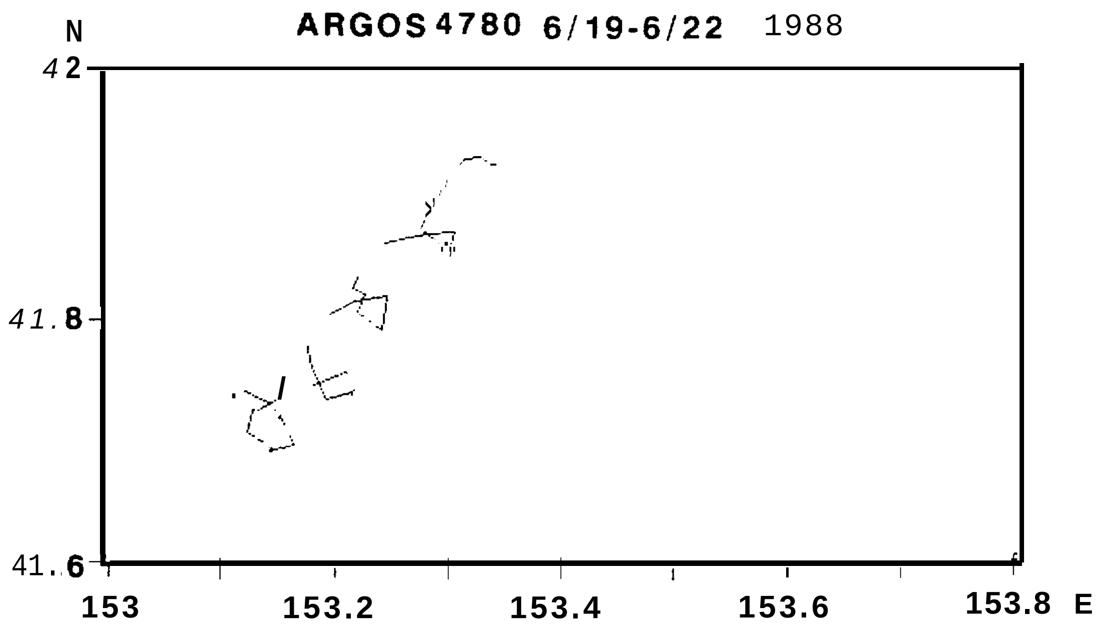

Figure 4. --Inertia circle of buoy 4780, enlarged from Figure 3.

north-south distance was 1,021 km. The large diffusion indicates a need to incorporate a large plus or minus deviation in forecasting the movement of any object in the water on the basis of the generally known currents. The large diffusion coefficient gives evidence of great turbulence in the waters.

Data from thermometers on the buoys are shown in Figure 5. Any buoy with a large net cannot be expected to go through a water mass or across the front of a mass. Short-term changes in the water temperature, especially sudden declines, may be attributable to vertical mixing of waters.

The water temperature rose gradually during the observation period between May and September. Any sudden rise in the temperature may be attributed to a combination of strong sunlight and calm water, which can cause an increase in just the surface water temperature. It may also be ascribed to surface water which was heated by the sun and flowed into the vicinity of a buoy.

Driftnets remained at a depth of 10 m. Warm surface waters which are frequently seen in the northern part of the North Pacific in summer are usually limited to 1 or 2 m in depth.

The surface water temperature changes are seen frequently in infrared heat pictures taken by satellites and have some adverse effect on analysis of water masses, which depends on surface temperature.

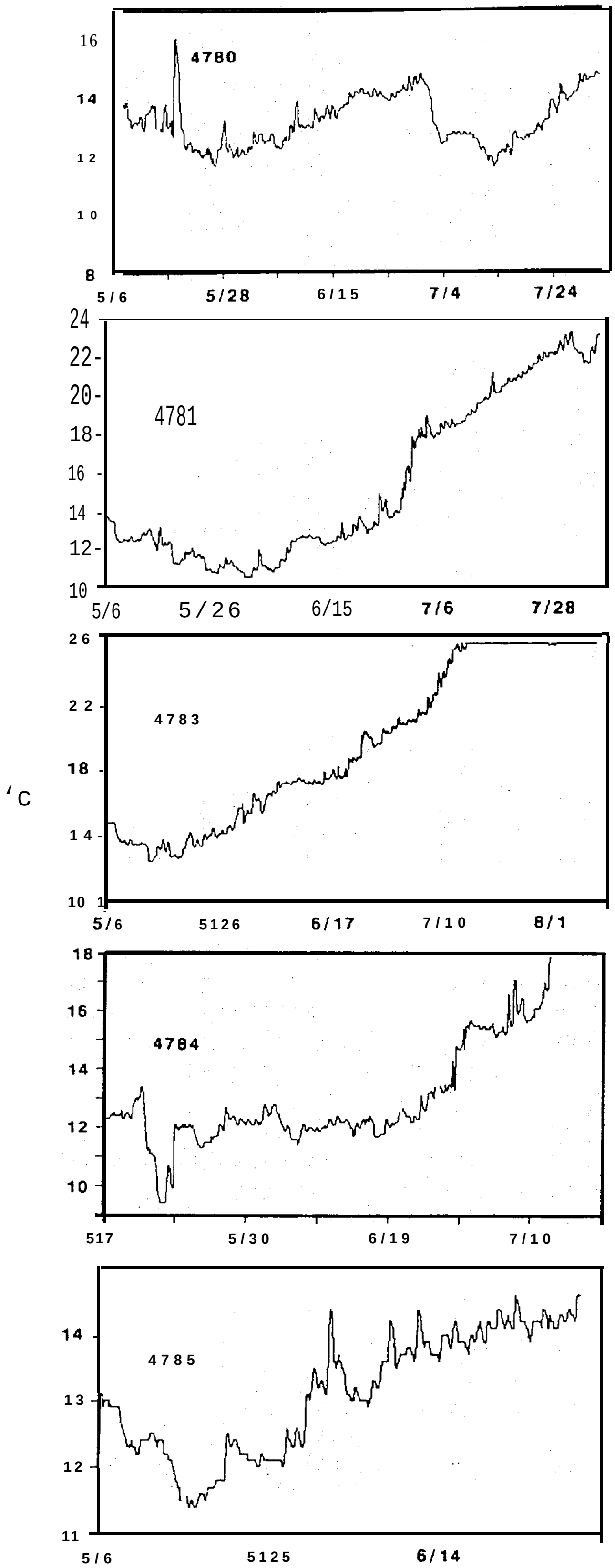

Figure 5.- -Daily changes in buoy temperatures (May-August 1988).

SIMULATION OF FLOATING DEBRIS MOVEKENT AND DEBRIS DENSITY USING SHIP DRIFT DATA

If the speeds of all sea currents in time and space are available, the track of floating debris like the buoy on currents such as those discussed in the previous section can be simulated. Based on a specific speed at an initial point, we can determine a point debris would reach within a given period of time. Another current speed at the arrival point can be used to estimate how fast and where the debris would move further. Repeating such estimates can lead to a possible track which floating debris would follow.

In this section, we try to solve the Lagrangean equation and simulate a buoy track on the basis of given sea current speeds. We have used the ship drift data released by Meehl (1982). The currents in any time and space can be obtained by interpolating these data. We have compared the simulated results with findings from buoy drift observations by Kirwan et al. (1978) and sightings of floating debris observed by the Fisheries Agency, the Government of Japan (Mio et al. 1990) in order to analyze the mechanism for the gathering of objects.

Our simulation results successfully matched the findings from Kirwan's observation in both time and space. The model may be available for the simulation of buoy movement.

Thus , in the following, we will. discuss where buoys set in waters around Japan move and where a number of buoys set all over the Earth would gather.

Drifting in the Western North Pacific

Assume that buoys are initially dropped at lat. 30°N, long. 140°W near Torishima Island in the western part of the North Pacific. The results show how the buoy track changes depending on the season.

Spring

Figure 6(a) shows the track of a buoy set on 1 April. The buoy immediately begins to move eastward and reaches the international dateline in 6 months . However, the buoy remains around lat. 30°N, long. 150°W for nearly 2 years while its track loops. This is because it is dragged into a vortex in the eastern part of the North Pacific (Meehl 1982, fig. 2). Floating debris can remain in the water for a long time. If floating debris such as waste were dumped evenly all over the Pacific, it would tend to gather in the vortex waters.

Summer

Figure 6(b) shows the track of a buoy set on 1 July. It also moves eastward, but its speed is far faster than that of the spring buoy. It reaches the international dateline in about 4 months. Since the speed of currents at long. 140°E is fastest in autumn, the buoy set in summer is eventually moved by these fast currents. Later, it is dragged into the vortex in the eastern Pacific and remains just north of Hawaii.

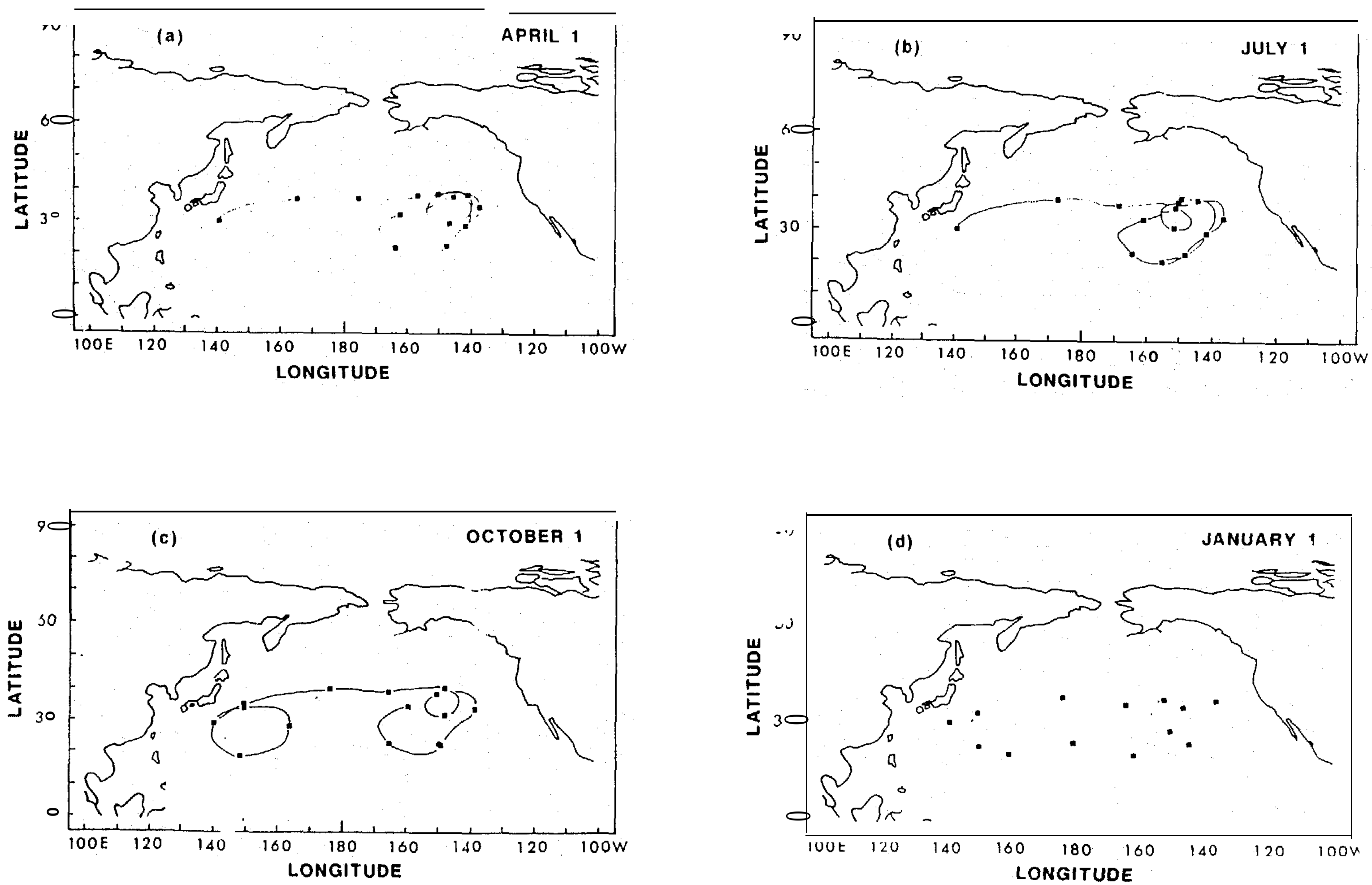

Figure 6.--Simulated tracks of buoys which were set at lat. 30°N, long. 140°E in the western North Pacific in (a) spring (1 April), (b) summer (1 July), (c) autumn (1 October), and (d) winter (1 January). Each buoy took 3 months to move from one mark to another.

Autumn

The track in Figure 6(c) is for a buoy set 1 October. Unlike the above tracks, this one loops around lat. 30°N, long. 150°E before extending eastward. The Kuroshio Extension weakens, and a vortex and a southward current around lat. 30°N, long. 150°E appear in winter. A buoy dropped in autumn is dragged into this winter current. The loop indicates that floating debris stays in the water for a long time.

Winter

Figure 6(d) shows the track of a buoy put into the water on 1 January. Like the track of a buoy set in autumn, the winter buoy track includes a small loop in the western Pacific.

All of the above tracks loop in the eastern part of the North Pacific. This indicates that floating debris remains in the water for a long time and tends to gather there.

Drifting in the Eastern North Pacific

Figure 7(a,b,c) shows the tracks of buoys put into the water on 1 May. The three drop sites are lat. 50°N, long. 140°W; lat. 40°N, long. 130°W; and lat. 30°N, long. 120°W, respectively. The buoy in Figure 7(a) is set in the region of the Alaskan current system. It moves westward, traveling south of the Aleutian Islands around the Alaskan gyre and western subarctic gyre. After turning south it is picked up by the North Pacific current system and moves eastward as in Figure 6.

The buoy which is set at lat. 40°N (Fig. 7b) is carried westward by the North Equatorial Current system after remaining in the vicinity of lat. 30°N for nearly 2 years. The buoy set at lat. 30°N (Fig. 7c) immediately begins to move westward.

Debris Density

We calculated many tracks in the Pacific from starting points evenly distributed in space and time to find where buoys would gather. We tried to find not the place where a buoy dropped at a certain point would go, but the place where buoys would gather intrinsically due to currents, irrespective of setting points or time.

We simulated tracks for 7,755 buoys. Dropping points were chosen randomly so that the number of initial buoys would be the same for *every* unit area. The setting density was five buoys for every 3.09×10^{11} m^2 of ocean; buoy setting continued for 4 years. To scatter drop times evenly, they were chosen on the basis of random numbers. Presuming a lifespan of 2 years, we simulated a track for each buoy for 2 years.

Figure 8 indicates the debris density in January after 4 years of setting. In the sea, you see some points to which buoys were carried by currents. In the North Pacific, which is our area of concern, debris is

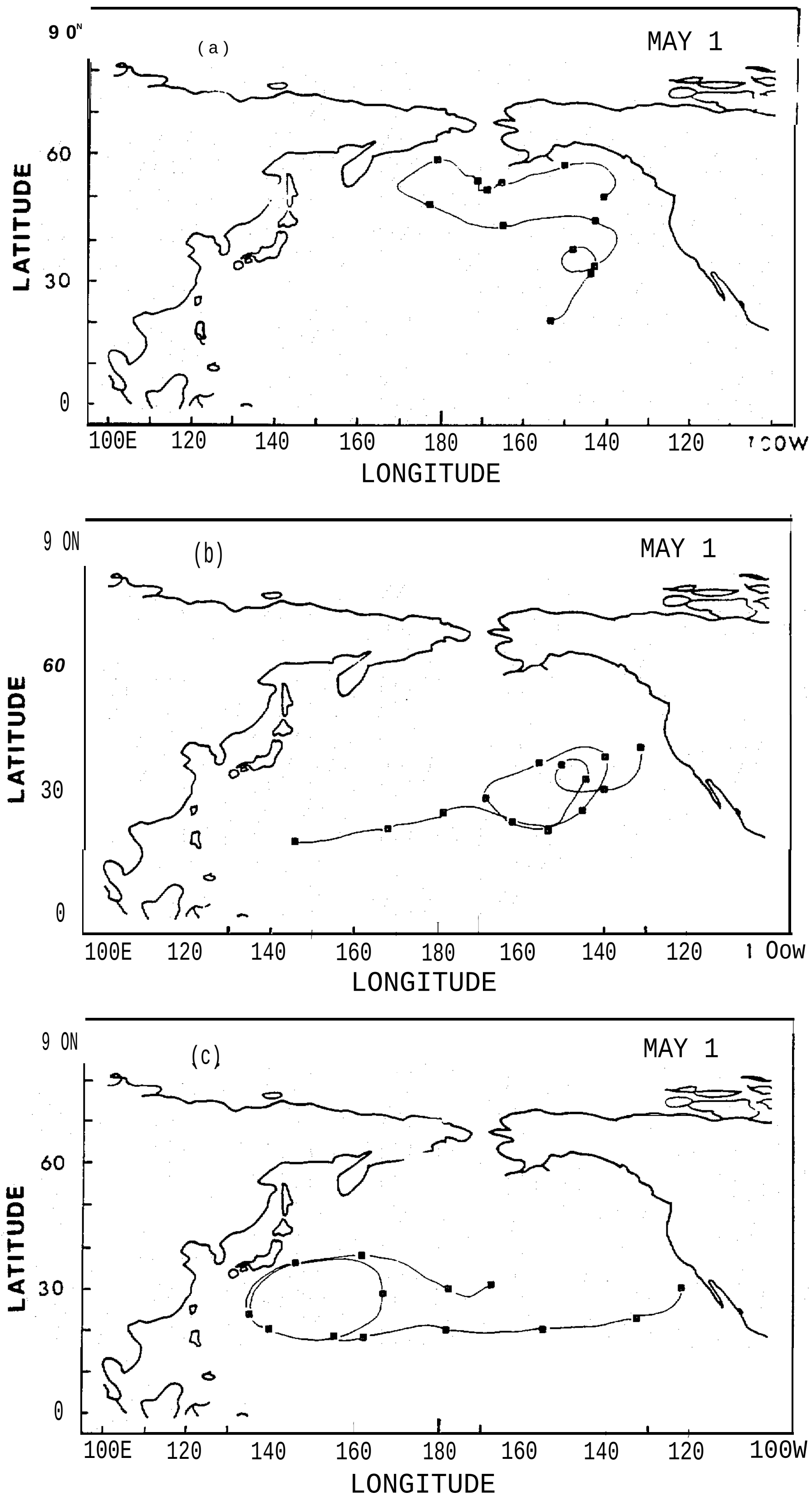

Figure 7. - -Simulated tracks of buoys which were set at (a) lat. 50°N, long. 140°W; (b) lat. 40°N, long. 130°W, and (c) lat. 30°N, long. 120°W in the eastern part of the North Pacific on 1 May.

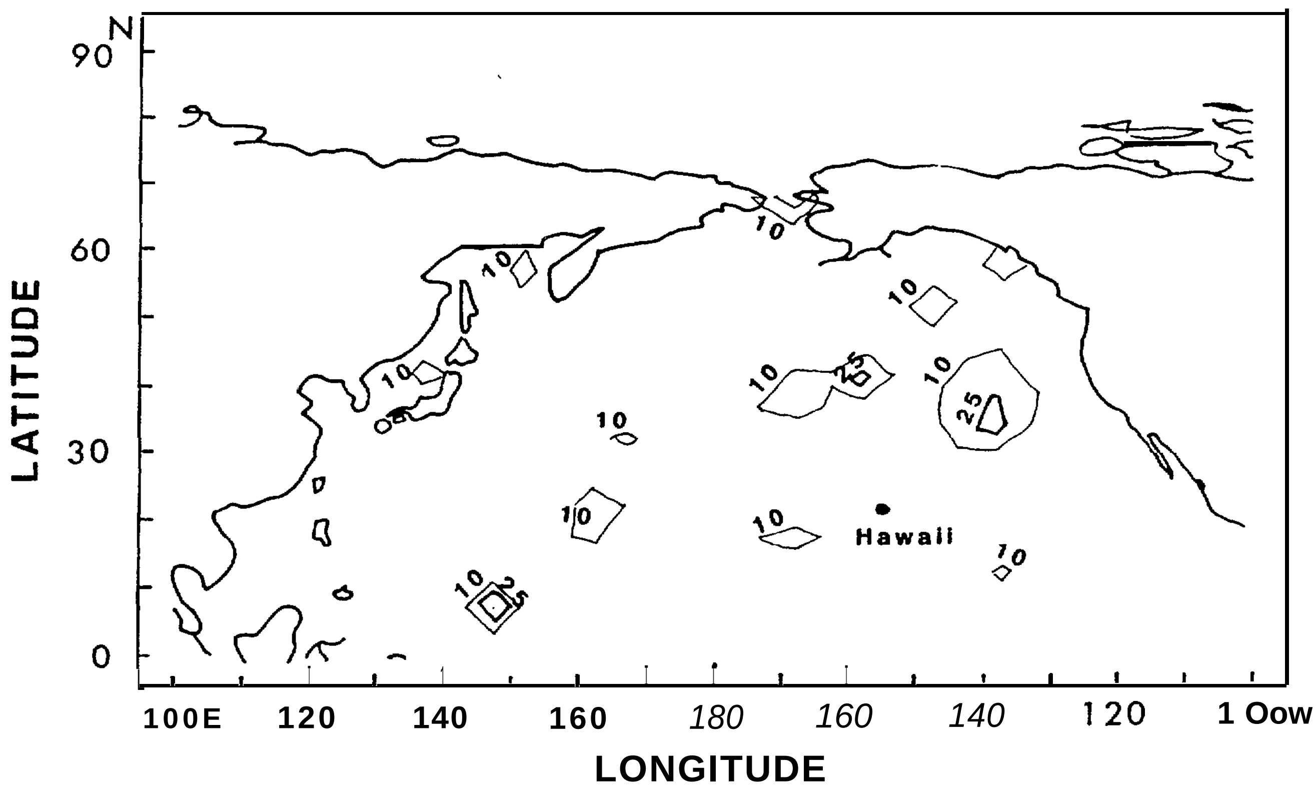

Figure 8.--Floating debris density in the North Pacific on 15 January. Contour line shows the number of buoys in unit area. Original density was give at every place.

seen to gather in the eastern part. The gathering points are to the north of Hawaii, which agrees with sighting observations of Mio et al. (1990). However, note that the gathering points shift seasonally. In the Northern Hemisphere, winds in areas of high atmospheric pressure circle to the right and sea surface currents deviate from the wind direction by 20° to 30°, as pointed out by McNally (1981). So we know that a high concentration of debris could be seen in the center of the North Pacific area of high atmospheric pressure.

CONCLUSION

The results of drift buoy observations matched fairly well those of the simulation based on ship drift data in waters like the Kuroshio Extension where the current is strong. Debris getting into the currents may cross the North Pacific in about 1 year.

There are no marked currents in waters around the Ogasawara Islands and northwest of Hawaii in any season. Figures for drift tracks and for distribution of floating debris point to those waters as locations where floating debris can gather.

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TYPE, SOURCE, AND ABUNDANCE OF TRAWL-CAUGHT MARINE DEBRIS OFF OREGON, IN THE EASTERN BERING SEA, AND IN NORTON SOUND IN 1988

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ABSTRACT

In 1988, National Marine Fisheries Service scientists collected information on type, source, and abundance of marine debris caught during annual bottom trawl surveys off Oregon, in the eastern Bering Sea, and in Norton Sound. Numbers of individual debris items caught were tallied by haul. When possible, the nationality of origin was determined. Animals entangled or associated with debris items were noted. Debris items were categorized by material (e.g. , plastic, glass) and use (e.g., galley wastes, fishing equipment). Effort in square kilometers trawled was calculated for each haul from distance fished and average net width measurements. Average catch-per-unit-effort (CPUE) in numbers of items per square kilometer was calculated for individual debris items, major categories, and total debris by area and for combined areas.

Of the 696 hauls surveyed, 70 were off Oregon, 541 in the eastern Bering Sea, and 85 in Norton Sound. Marine debris was most abundant off Oregon, occurring in 70% of the hauls and averaging 149.6 items/km^2. In the eastern Bering Sea, 23% of the hauls caught marine debris, for an average of 7.5 items/km^2. Norton Sound had the least amount of debris. It occurred in 7% of the hauls and averaged 1.9 items/km^2. Galley wastes dominated debris in Oregon (64% of the total CPUE) and in the eastern Bering Sea (40% of the total CPUE), followed by engineering/processing wastes. Fishing equipment debris was abundant in the eastern Bering Sea (1.86 items/km^2) and off Oregon (1.69 items/km^2), but was not found in Norton Sound. Plastic debris was found in all three areas, but was most abundant in the eastern Bering Sea. Debris of foreign origin accounted for 70% of the total CPUE of all debris found in the eastern Bering Sea; however, domestic debris dominated off Oregon (88% of the total CPUE) and in Norton Sound (100% of the total CPUE).

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

INTRODUCTION

Marine debris, particularly plastic debris, has been identified as a potential threat to the marine environment world wide (Pruter 1987). To determine the magnitude of the problem, scientists must document the effects and abundance of different types of debris in the marine environment. Educators need to know the probable sources of marine debris in order to direct information campaigns at the proper audiences.

Prior to 1985, the majority of information about marine debris was anecdotal. Few studies presented scientific evidence on the abundance of marine debris or its effects on the marine environment. Recently, studies have reported on the effects of marine debris on marine mammals (Fowler 1988), marine birds (Day et al. 1985), marine turtles (Balazs 1985), and other marine wildlife (Pruter 1987).

While several studies have attempted to estimate the abundance of debris in the marine environment from at-sea disposal rates (Horseman 1982), few studies have addressed the abundance of marine debris using systematic methods. Quantitative surveys of marine debris deposited on beaches in Alaska have been conducted since 1980 (Merrell 1980; Johnson 1988). At-sea surveys have quantified floating debris in the North Pacific since 1977 (Shaw 1977; Dixon and Dixon 1983; Yagi and Nomura 1988). Berger and Armistead (1987) reported the number of pieces of net material caught in trawl nets deployed by foreign fishing vessels in the exclusive economic zone off Alaska between 1982 and 1984.

This study presents baseline information on the type, probable source, and abundance of marine debris caught on the seabed during bottom trawl surveys off Oregon, in the eastern Bering Sea, and in Norton Sound off Alaska during 1988.

METHODS

Survey Areas and Sampling Design

Marine debris was sampled by National Marine Fisheries Service (NMFS) scientists from bottom trawl hauls conducted during 1988 off the coast of Oregon in November-December, in the eastern Bering Sea from May to August, and in Norton Sound during August. A total of 696 hauls were completed covering 33.1 km^2 over a combined survey area of 907,851 km^2 (Table 1).

Seventy hauls were conducted between 45 and 110 km off the coast of Oregon between lat. 44° and 45″30′N and from 100 to 675 m deep (Fig. 1). The survey area off Oregon encompassed 7,230 km^2, of which 2.7 km^2 was actually covered by bottom trawls (Table 1).

In the eastern Bering Sea, 541 hauls were conducted from the 20 m isobath on the Alaskan coastline out to the *500* m isobath on the continental slope and north from the Alaska Peninsula to Saint Lawrence Island. Stations were sampled at the centers of 37 x 37 km (20 x 20 nmi) grids. The survey area encompassed an area of 858,941 km^2, of which 26.2 km^2 was

Table 1.--Survey area (square kilometers) and sampling density for marine debris during the NMFS bottom trawl survey off Oregon, in the eastern Bering Sea, and in Norton Sound, 1988.

	Effort					
Area	Area encompassed by survey (km^2)	Area covered by trawls (km^2)	Percent area sampled	Total number of hauls	Number of hauls with debris	Percent hauls with debris
Oregon	7,230	2.7	0.037%	70	49	70%
Eastern Bering Sea	858,941	26.2	0.003%	541	122	23%
Norton Sound	41,680	4.2	0.010%	85	6	7%
Total	907,851	33.1	0.004%	696	177	25%

actually covered by trawl hauls. Because of differences in sampling density, the eastern Bering Sea survey area was divided into four subareas. The four subareas for analysis were the north-south shelf and slope (Fig. 2).

Eighty-five hauls were conducted in Norton Sound between the 7 and 20 m isobaths (Fig. 2). The Norton Sound survey area encompassed 41,680 km^2 and a total of 4.2 km^2 was actually surveyed.

Trawls were towed on the bottom for approximately 0.5 h at each station at a towing speed of about 5.6 km/h (3 kn). For each haul, location, depth, and distance fished were recorded. The effective path width of the trawl net on the bottom was estimated using a sonar measuring device on a subset of hauls during each survey.

Catches of 1 metric ton or less were entirely sampled. Larger catches were weighed and subsampled, and numbers of marine debris items extrapolated to the total catch. Marine debris items in the catch or subsample were sorted by type of material: plastics, glass, rubber, metal, wood, paper, cloth, and other. Debris items were also described as accurately as possible, such as “plastic strapping band” or “metal beverage can.” The number of each of the items caught was recorded on a tally sheet and the vessel, cruise, and haul number indicated. When possible, the U.S. or foreign original of an item was indicated and the percent of all items from U.S., foreign, and unknown sources indicated on each haul tally sheet. The number of entangled animals was recorded by species and debris item. A complete description of NMFS sampling procedures is provided by Wakabayashi et al. (1985).

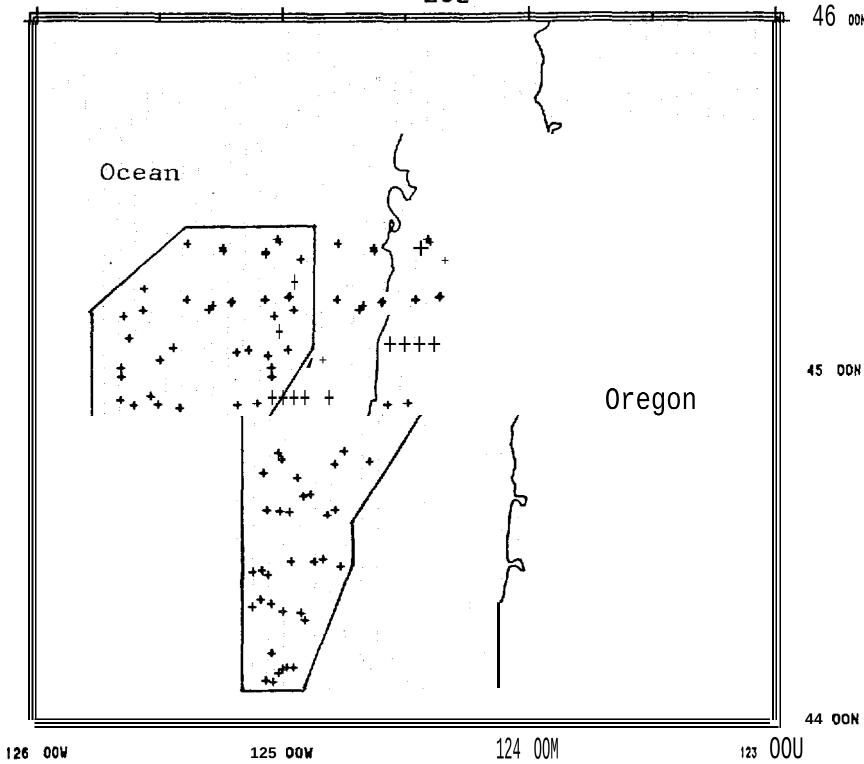

Figure 1.--Area surveyed and station locations sampled for marine debris during the National Marine Fisheries Service bottom trawl survey off Oregon, 1988.

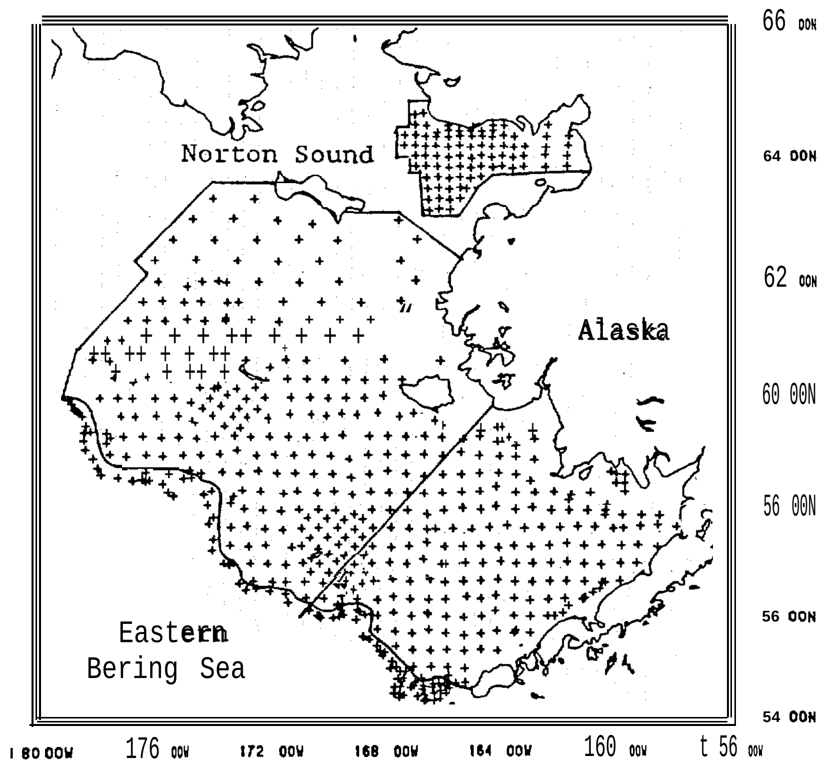

Figure 2.--Area surveyed and station locations sampled for marine debris during the National Marine Fisheries Service bottom trawl survey in the eastern Bering Sea and Norton Sound, 1988.

Vessels and Fishing Gear

The survey off the coast of Oregon was conducted aboard the 64.6 m NOAA ship Miller *Freeman* using two nets, a modified Nor'eastern trawl and a poly-Nor'eastern trawl. The mean effective path width of the poly-Nor'eastern trawl was estimated to be 14.7 m and the modified Nor'eastern 16.4 m. The eastern Bering Sea survey was conducted using three vessels: the *Miller Freeman,* the 30.5 m RV *Alaska,* and the 37.5 m MV *Homing Star.* Two nets were used during the survey, the eastern trawl, with an estimated mean effective path width of 17.0 m, and the modified Nor'eastern trawl used on the Oregon survey. The Miller *Freeman* conducted the Norton Sound survey with the eastern trawl used in the eastern Bering Sea survey. The eastern trawl had 10.2 cm (4 in) mesh in the wings and body, 8.9 cm (3.5 in) mesh in the cod end, and a 3.2 cm (1.25 in) cod end liner. The modified and poly-Nor'eastern had construction similar to the eastern trawl except for 12.7 cm (5 in) mesh in the wings and body.

Data Analysis

It was assumed all debris 6.5 cm^2 (1 in^2) and larger lying on the surface of the bottom and within the mean effective path width of each net was caught with equal efficiency by each net. This assumption may not necessarily be valid for all hauls, since different nets and different towing conditions can affect the ability of the net to catch objects on the bottom. However, since the NMFS has standardized fishing gear and methods used during most of its annual resource assessment surveys, results obtained from the 1988 surveys should be comparable to future surveys using the same gear and techniques. A second assumption was that scientists identified all of the marine debris caught in each haul.

Marine debris items were grouped by use and by material of composition. Use categories included galley waste, personal use waste (e.g. , deodorant tubes, gloves, lighters), fishing gear, engineering and fish processing waste, and other unidentified use waste. Material categories included plastic, glass, rubber, metal, wood, paper, and other. Numbers of items caught were summed by use and material categories by haul and by combinations of the two categories, such as plastic galley waste or metal engineering and processing waste.

The effort expended in each haul was calculated in square kilometers by multiplying the distance fished in each haul by the effective path width of the net. The numbers of individual and grouped marine debris items caught in each haul were divided by the effort to give catch-per-unit-effort (CPUE) in numbers of items per square kilometer for each haul. Mean CPUE per haul was calculated for the entire survey area off Oregon and in Norton Sound and for individual subareas in the eastern Bering Sea using the following formulas:

For an individual haul, CPUE - catch in numbers per unit effort in square kilometers.

For the entire survey area,

$$\text{Mean CPUE} - \frac{\Sigma(\text{CPUE})}{N}$$

$$\text{Variance} = \frac{\Sigma((\text{CPUE} - \text{mean CPUE})^2)}{(N * (N-1))}$$

where Σ = summation for all hauls in the area,

N = the number of hauls in the area.

In the eastern Bering Sea the mean CPUE and variance for the combined subareas were weighted by the area of each subarea in square kilometers using the formulas:

$$\text{Overall mean CPUE} = \frac{\Sigma(A * \text{mean CPUE})}{Z(A)}$$

$$\text{Variance} = \frac{\Sigma(A^2 * \text{variance (mean CPUE)})}{X(A)^2}$$

where Σ = summation for all subareas,

A = subarea weighting factor.

South shelf = 299,115 km^2
North shelf = 520,618 km^2
South slope = 17,544 km^2
North slope - 21,660 km^2

Estimates of CPUE for material and use categories and for total debris items were calculated independently and therefore sums of individual categories do not necessarily equal totals. A more complete description of the standard NMFS methods of calculating CPUE is given in Wakabayashi et al. (1985) .

Estimates of the total number of items of debris on the bottom of each area during the 1988 surveys were calculated using an area-swept method (Wakabayashi et al. 1985). Mean CPUE and estimates of numbers of items present in each area are presented as baseline estimates for subsequent comparisons within areas and for all areas combined and were not meant to provide statistically significant comparisons between areas. The percent of debris items by use and material categories is presented for each area and for all areas combined.

RESULTS

Oregon

Of the three areas surveyed, the area off Oregon had the highest concentration of marine debris with 149.6 items/km² (Table 2, Fig. 3). A total of 399 debris items were caught in 49 out of the 70 hauls completed (Table 1). Within use categories, the mean CPUE of galley waste was 89.4 items/km², accounting for 64% of the CPUE of all debris items caught, followed by engineering and processing waste (27%), personal use waste (6%), other use waste (2%), and fishing equipment (1%). Of material categories, the mean CPUE of metal debris was 54.08 items/km² and represented 36% of the mean CPUE of all debris caught, followed by plastics (26%) (Fig. 4), glass (19%), rubber (8%), cloth (6%), wood (3%), and paper (1%) (Table 3).

Of the 399 debris items caught off Oregon, 149 or 37% were identified as of either U.S. or foreign origin. Debris of U.S. origin made up 88% of the mean CPUE of debris of identifiable national origin caught off Oregon, 100% of the CPUE for engineering and processing waste and fishing equipment (Table 4). Foreign debris was represented in the CPUE as galley waste (15%) and personal use items (11%). By material category, U.S. debris caught off Oregon dominated all categories except rubber debris, where foreign debris was 54% of the CPUE of identified items (Table 5).

No animals entangled in marine debris were found in the survey off Oregon. Anemones were attached to a glass bottle and starfish were observed on a piece of plastic rope.

Eastern Bering Sea

The mean CPUE of all debris items caught in the eastern Bering Sea was 7.52 items/km² (Table 2, Fig. 5). Out of the 541 hauls completed, 122 hauls contained a total of 255 marine debris items (Table 1). Galley waste CPUE was 3.15 items/km² or 40% of the mean total CPUE, followed by fishing equipment (24%), engineering and processing waste (24%), and personal use waste (12%). By material category, plastic dominated the total mean CPUE with 4.4 items/km² (51%) (Fig. 6), followed by metal debris (27%), rubber debris (9%), cloth debris (5%), glass debris (4%), and wood debris (1%) (Table 3).

Of the 255 debris items caught in the eastern Bering Sea, U.S. or foreign origin was identified for 60 items. Foreign debris dominated the identified items, accounting for 70% of the mean CPUE (Table 4). Foreign debris was 76% of the CPUE of identified galley waste and 93% of the personal use waste CPUE. Debris of U.S. origin was greatest in fishing equipment waste (67% of CPUE) and engineering and processing waste (64% of CPUE). Foreign debris made up most of the plastic (76% of CPUE), metal (57% of CPUE), rubber (100% of CPUE), and glass debris (84% of CPUE) (Table 5). The U.S. debris accounted for 100% of the CPUE of identified paper and other material debris.

Table 2. --Catch-per-unit-effort (CPUE) (number per square kilometer) by use category and area for marine debris caught during the National Marine Fisheries Service bottom trawl survey, 1988 (CI = confidence interval).

Use category	Oregon		Eastern Bering Sea		Norton Sound		All areas	
	Number/km^2 (95% CI N = 70)	Percent of area total CPUE	Number/km^2 (95% CI N = 70)	Percent of area total CPUE	Number/km^2 (95% CI N = 70)	Percent of area total CPUE	Number/km^2 (95% CI N - 70)	Percent of area total CPUE
Galley wastes	89.40 (57.2-121.6)	64%	3.15 (2.1-7.2)	40%	0.70 (0.0-1.7)	36%	5.12 (2.7-7.6)	51%
Engineering and processing	37.87 (18.3-57.4)	27%	1.84 (1.0-2.6)	23%	0.73 (0.0-1.8)	38%	2.10 (1.3-2.8)	21%
Fishing equipment	1.69 (0.0-3.4)	1%	1.86 (1.1-2.6)	24%	0.00 --	0%	1.80 (1.1-2,5)	18%
Personal use items	8.92 (0-18.9)	6%	0.91 (0.0-1.9)	12%	0.51 (0.0-1.2)	26%	0.96 (0.0-1.9)	10%
Other debris	2.55 (0,0-6.6)	2%	0.08 (0.0-0.2)	1%	0.00 --	0%	0.05 (0.0-0.1)	<1%
Total	149.60 (97.9-201.3)	100%	7.52 (6.7-14.4)	100%	1.94 (0,3-3.6)	100%	11.26 (7.6-14.9)	100%

Note: Individual and total debris categories were calculated separately and thus are not necessarily additive.

Table 3. --Catch-per-unit-effort (CPUE) (number per square kilometer) by debris material category and area for marine debris caught during the National Marine Fisheries Service bottom trawl survey, 1988 (CI - confidence interval).

	Oregon		Eastern Bering Sea		Norton Sound		All areas	
Debris category	Number/km* (95% CI N - 70)	Percent of area total CPUE	Number/km^2 (95% CI N = 70)	Percent of area total CPUE	Number/km^2 (95% CI N - 70)	Percent of area total CPUE	Number/km* (95% CI N - 70)	Percent of area total CPUE
Plastic	39.05 (20.7-57.4)	26%	4.40 (4.9-7.8)	51%	0.24 (0.0-0.7)	12%	6.37 (5.0-7.7)	57%
Metal	54.08 (29.6-78.6)	36%	2.33 (0.0-4.8)	27%	0.96 (0.0-2.3)	49%	2.68 (0.3-5.0)	24%
Rubber	12.10 (0.3-23.9)	8%	0.80 (0.0-1.8)	9%	0.26 (0,0-0.8)	13%	0.87 (0,0-1.8)	8%
Glass	28.66 (16.4-40.9)	19%	0.38 (0.1-0.6)	4%	0.00 --	0%	0.59 (0.3-0.8)	5%
Cloth	9.61 (3.6-15.6)	6%	0.41 (0.1-0.7)	5%	0.48 (0,0-1.2)	25%	0,49 (0.2-0.8)	4%
Wood	4.24 (0.0-8.9)	3%	0.11 (0.0-0.2)	1%	0.00 --	0%	0.14 (0.0-0.3)	1%
Paper	1.34 (0.0-2.7)	1%	0.13 (0.0-0.3)	2%	0.00 ..	0%	0.13 (0.0-0.3)	1%
Other	0.54 (0.0-6.4)	<1%	0.00 .-	0%	0.00 ..	0%	>0.01 (0.0-0.1)	<1%
Total	149.60 (97.9-201.3)	100%	7.52 (6.7-14.4)	100%	1.94 (0.3-3.6)	100%	11.26 (7.6-14.9)	100%

Note: Individual and total debris categories were calculated separately and thus are not necessarily additive,

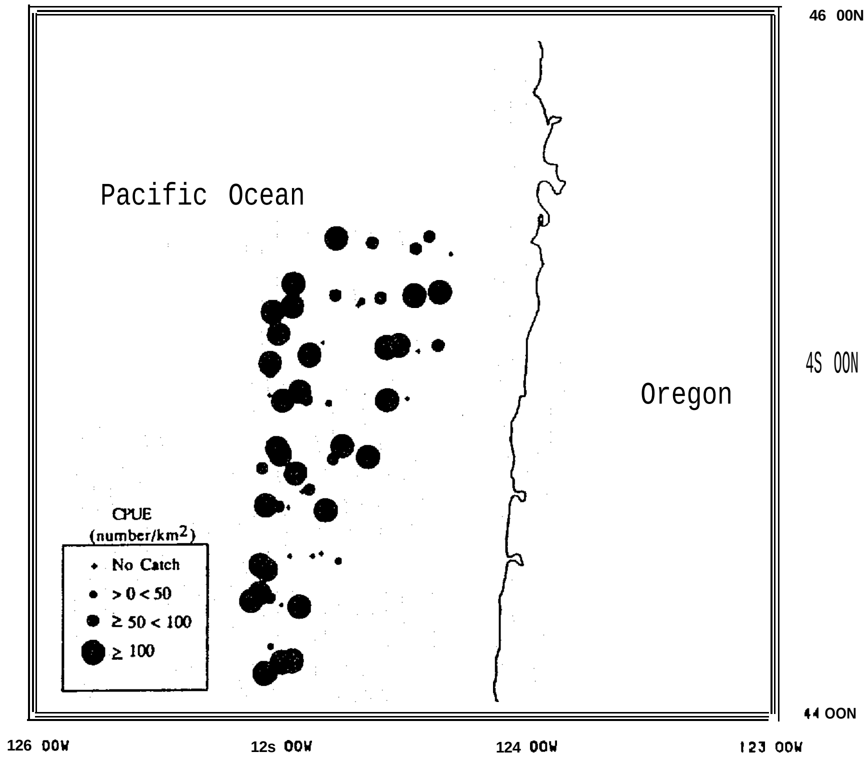

Figure 3.- -Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of all marine debris caught during the National Marine Fisheries Service bottom trawl survey off Oregon, 1988.

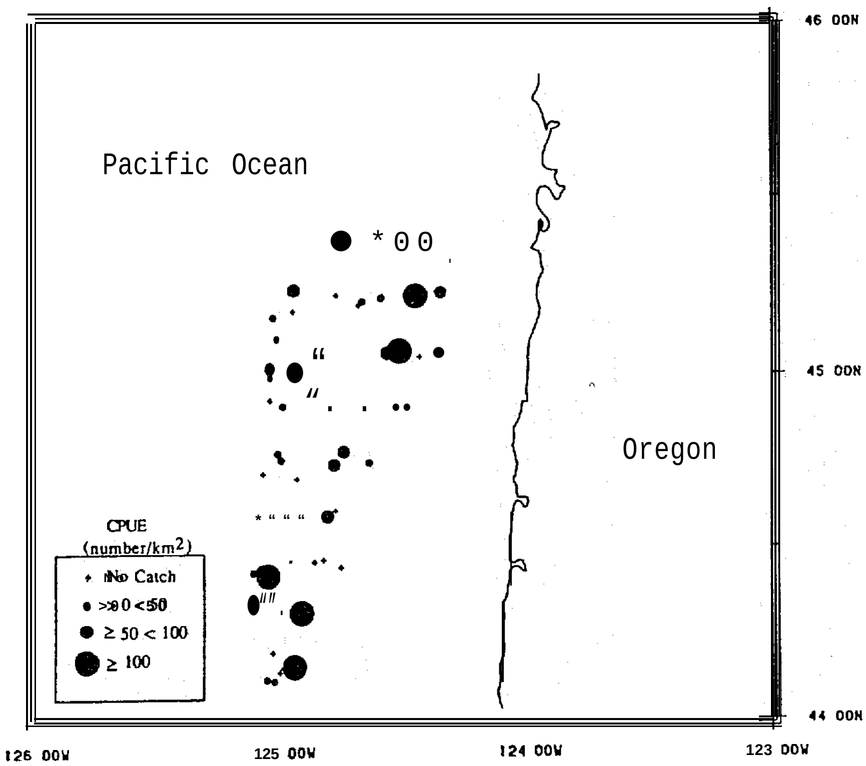

Figure 4, --Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of plastic marine debris caught during the National Marine Fisheries Service bottom trawl survey off Oregon, 1988.

Table 4. --Percent of catch-per-unit-effort (number per square kilometer) by foreign or domestic (U.S.) origin, use category, and area for marine debris caught during the National Marine Fisheries Service bottom trawl survey, 1988.

	Oregon		Eastern Bering Sea		Norton Sound		All areas	
Use category	U.S.	Foreign	U.S.	Foreign	U.S.	Foreign	U.S.	Foreign
Galley wastes	85%	15%	24%	76%	0%	0%	37%	63%
Engineering and processing	100%	0%	64%	36%	100%	0%	75%	25%
Fishing equipment	100%	0%	67%	33%	0%	0%	66%	34%
Personal use items	89%	11%	7%	93%	0%	0%	24%	76%
Other debris	100%	0%	100%	0%	0%	0%	100%	0%
Percent by area	88%	12%	30%	70%	100%	0%	42%	58%

Table 5. --Percent of catch-per-unit-effort (number per square kilometer) by foreign or domestic (U.S.) origin, material category, and area for marine debris caught during the National Marine Fisheries Service bottom trawl survey, 1988.

	Oregon		Eastern Bering Sea		Norton Sound		All areas	
Debris material	Us.	Foreign	U.S.	Foreign	U.S.	Foreign	U.S.	Foreign
Plastic	100%	0%	24%	76%	0%	0%	33%	67%
Metal	85%	15%	43%	57%	100%	0%	55%	45%
Rubber	46%	54%	0%	100%	0%	0%	4%	96%
Glass	81%	19%	16%	84%	0%	0%	37%	63%
Cloth	0%	0%	0%	0%	0%	0%	0%	0%
Wood	100%	0%	0%	0%	0%	0%	100%	0%
Paper	100%	0%	100%	0%	0%	0%	100%	0%
Other	100%	0%	100%	0%	0%	0%	100%	0%
Percent by area	88%	12%	30%	70%	100%	0%	43%	57%

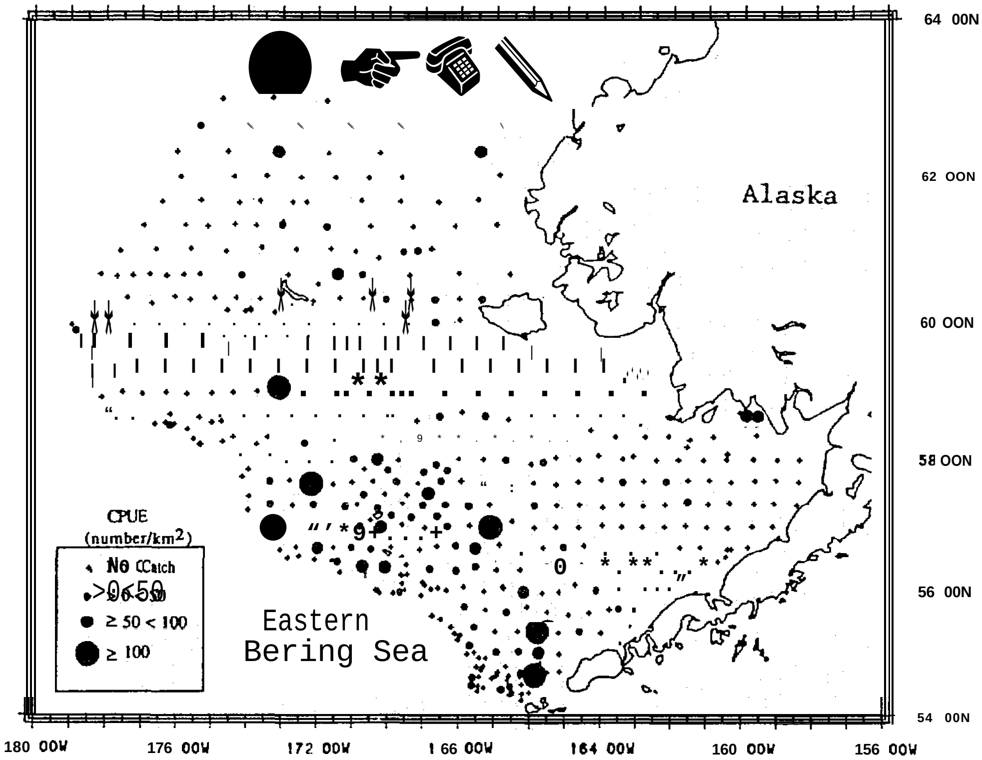

Figure 5.- -Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of all marine debris caught during the National Marine Fisheries Service bottom trawl survey in the eastern Bering Sea, 1988.

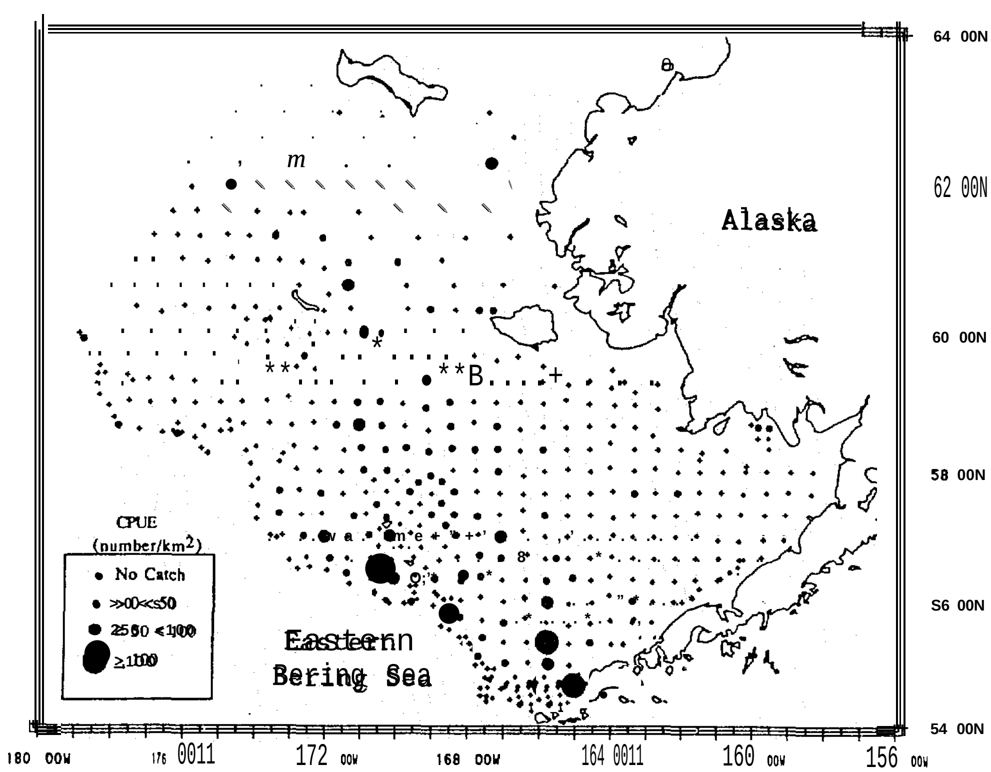

Figure 6.- -Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of plastic marine debris caught during the National Marine Fisheries Service bottom trawl survey in the eastern Bering Sea, 1988.

A Tanner crab, *Chionoecetes opilio*, and an unidentified hermit crab, Paguridae, entangled in separate pieces of plastic trawl web twine, were caught during the eastern Bering Sea survey. Numerous invertebrates including mussels, anemones, octopus, barnacles, unidentified tunicates, and starfish were associated with plastic sheeting, plastic rope, glass bottles, and a rubber shoe. Fish eggs were found attached to plastic sheeting.

Norton Sound

Of the three areas surveyed, Norton Sound had the lowest concentration of marine debris, with 1.94 items/km^2 (Table 2, Fig. 7). Eight items of debris were found in 6 of the 85 hauls completed. Galley waste had a mean CPUE of 0.73 items/km^2 or 38% of the total debris mean CPUE followed by engineering and processing waste (36%), and personal use waste (26%). No fishing equipment waste was found in Norton Sound. Metal debris accounted for 49% of the total debris mean CPUE, cloth debris 25%, rubber debris 13%, and plastic debris 12% of the total debris mean CPUE (Fig. 8).

Out of the eight debris items caught in Norton Sound, a single debris item, a metal piece of railroad track, was identified as being of U.S. origin.

No animals were found entangled or associated with marine debris in Norton Sound.

All Areas Combined

Out of a total of 696 trawl hauls examined for marine debris in the 3 areas, 177 (25%) had a total of 662 marine debris items identified in the catch. For the 3 areas combined, the mean CPUE of all debris items, weighted by surface area, was 11.3 items/km^2 (Table 2). Galley waste accounted for 51% of the mean CPUE of all debris items, followed by engineering and processing waste (21%), fishing equipment waste (18%), and personal use waste (10%). Over all areas surveyed, plastic was the most abundant debris material, caught with a mean CPUE of 6.37 items/km^2 (57% of the mean total CPUE), followed by metal debris (24%), rubber (8%), glass (5%), cloth (4%), and wood and paper (1% of the mean total CPUE) (Table 3).

Of the 210 debris items identified to national origin in the 3 areas, 58% of the mean total CPUE was foreign (Table 4). Foreign debris dominated galley waste (63%) and personal use waste (76%). The U.S. debris accounted for 75% of the mean CPUE of identified engineering and processing waste and 66% of identified fishing equipment waste mean CPUE. Foreign debris accounted for 67% of the mean CPUE of identified plastic debris, 96% of rubber debris, and 63% of the mean CPUE of identified glass debris (Table 5). The U.S. debris dominated identified debris made of metal (55% of mean CPUE) and accounted for all of the identified wood and paper debris caught in the three areas. Plastic represented the largest percentage of CPUE of galley waste (46%), engineering and processing waste (48%), and fishing equipment waste (92%) (Table 6). Rubber debris made up most of the CPUE of personal use waste (77%). A complete list of the individual marine debris items found during the survey is found in Tables 7 through 9.

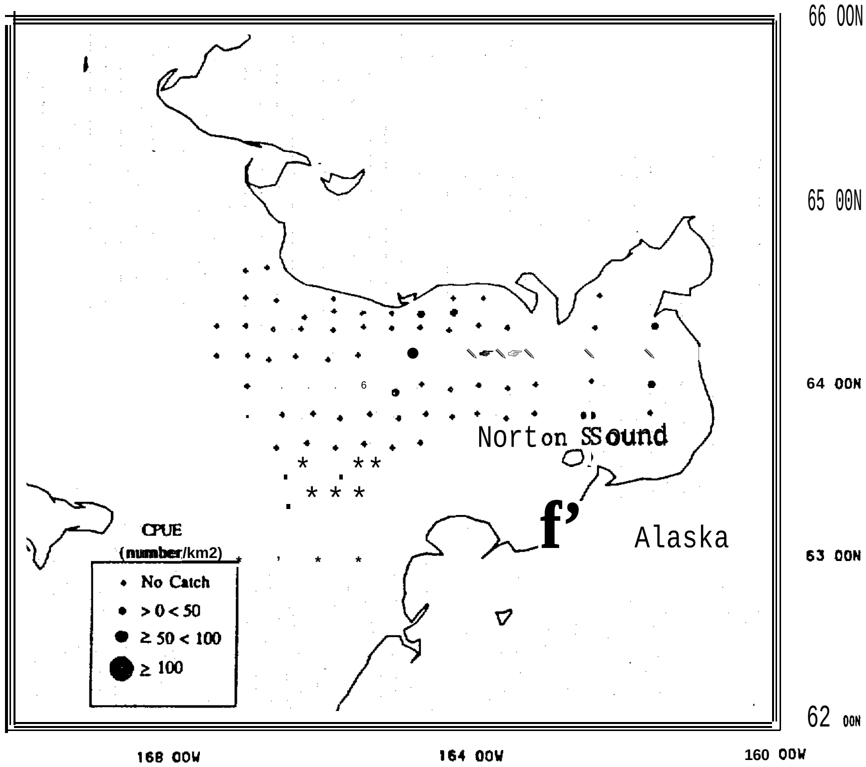

Figure 7. --Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of plastic marine debris caught during the National Marine Fisheries Service bottom trawl survey in the Norton Sound, 1988.

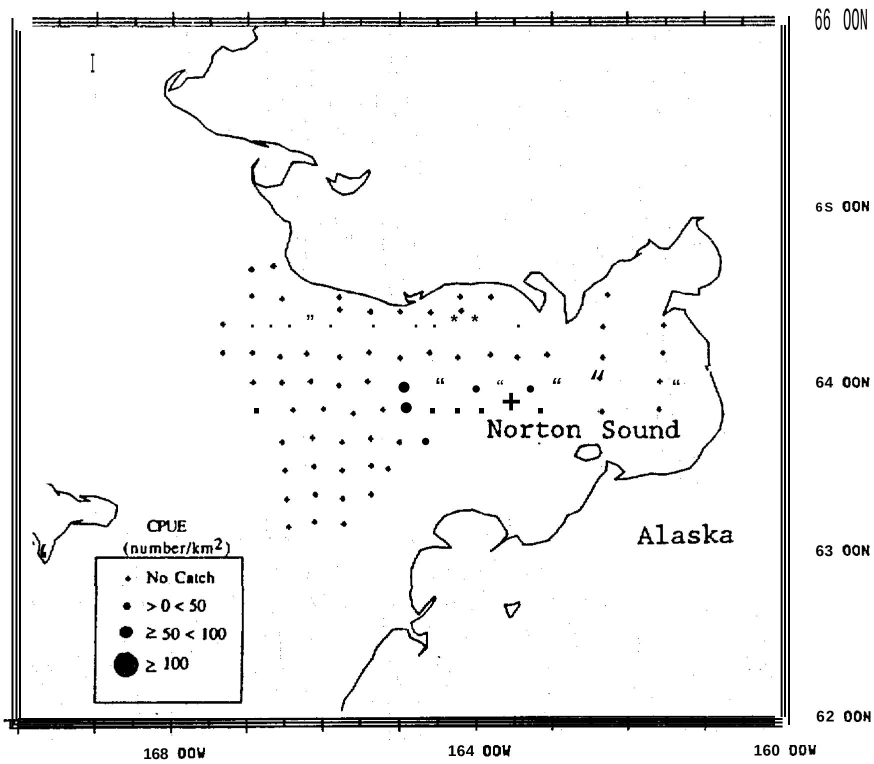

Figure 8. --Relative density (catch-per-unit-effort (CPUE) in number per square kilometer) of all marine debris caught during the National Marine Fisheries Service bottom trawl survey in the Norton Sound, 1988.

Table 6.--Percent of catch-per-unit-effort (number per square kilometer) by debris material and use categories for marine debris caught during the National Marine Fisheries Service bottom trawl survey off Oregon, in the eastern Bering Sea, and in Norton Sound, 1988.

	Use category					
Debris	Galley wastes	Engineering and processing	Fishing equipment	Personal use	Other	Percent by material category
Plastic	45.8%	47.5%	91.8%	9.9%	65.4%	56.6%
Metal	42.9%	16.9%	6.1%	0.0%	30.8%	23.8%
Rubber	0.0%	6.1%	0.0%	77.4%	3.8%	7.7%
Glass	10.7%	0.0%	2.1%	0.0%	0.0%	5.2%
Cloth	0.0%	20.3%	0.0%	7.0%	0.0%	4.3%
Wood	0.0%	6.5%	0.0%	0.0%	0.0%	1.2%
Paper	0.5%	2.5%	0.0%	5.6%	0.0%	1.2%
Other	0.0%	0.2%	0.0%	0.0%	0.0%	<1%
Percent by use category	51.3%	20.8%	17.8%	9.6%	0.5%	100.0%

DISCUSSION

The three areas surveyed provide an interesting comparison of the abundance and type of marine debris found on the bottom in areas with different amounts and types of vessel use. The area off Oregon is used extensively by cargo vessels, U.S. and U.S.-foreign joint venture commercial fishing operations, and recreational boaters and fishermen. In 1985, the latest year for which data are available, approximately 1,740 commercial fishing vessels operated off the coast of Oregon (Korson and Thomson 1987) and the U.S. Coast Guard reported 143,373 commercial and recreational vessels in Oregon with Coast Guard identification numbers (Coast Guard 1986). The area surveyed off Oregon is located on one of the major north-south west coast cargo shipping lanes, with frequent vessel traffic observed during the survey (T. Dark, Alaska Fisheries Science Center, Seattle, Wash., pers. commun. 1989).

In the eastern Bering Sea, some nonfishery tug, barge, and cargo vessel operations exist, but vessel traffic is predominantly associated with the commercial fishing industry. Harvesting vessels, domestic and foreign processing vessels, and a wide variety of support vessels operate in the eastern Bering Sea each year. In 1985, the Alaska Department of Fish and Game (1986) estimated that 1,729 domestic commercial fishing vessels operated in the eastern Bering Sea, and the NMFS estimated that 254 254 foreign vessels fished or processed seafood in the eastern Bering

Table 7.--Description, material and use category, number caught, catch-per-unit-effort (CPUE) (number per square kilometer), and swept-area estimate of the number of debris items in the survey area for marine debris caught off Oregon during the National Marine Fisheries Service bottom trawl survey, 1988 (CI - confidence interval).

		Catch			Swept-area estimate	
Use category	Item	Number caught	Mean CPUE km^2	CPUE variance	Estimated number	95% CI
			Plastic			
Galley waste	Bags	39	14.31	11.2468	103,277	54,946-151.607
	Bottles	2	0.51	0.1290	3,702	0-8,896
	Lids, caps	4	1.71	1.4426	12,325	0-29,634
	Six-pack ring	1	0.25	0.0624	1,803	0-5,405
	Vegetable sack	1	0.90	0.8185	6,529	0-19,567
	Other	2	0.72	0.2909	5,170	0-12,943
Fishing equipment	Fishing line	2	0.88	0.4228	6,347	0-15,718
	Fishing net	1	0.27	0.0732	1,952	0-5,850
	Rope	21	9.45	12.9024	68,218	0-119,983
Personal use	Lighter	1	0.27	0.0717	1,932	0-5,790
	Deodorant tube	15	4.02	16.1272	28,981	0-86,855
Engineering and processing	Sheeting	8	2.36	2.8377	17,058	0-41,339
	Strapping band	9	2.92	1.2100	21,102	0-36,955
	Duct tape	1	0.22	0.0494	1,605	0-4,809
Other	Clay pigeon	1	0.25	0.0601	1,770	0-5,303
			Glass			
Galley waste	Bottle	65	25.92	32.4534	187,265	105,167-269,364
	Pieces	2	0.75	0.3088	5,447	0-13,456
	Fruit jar	4	1.95	3.0305	14,082	0-39,170
			Rubber			
Personal use	Gloves	6	2.47	0.1049	17,798	3,035-32,561
	Shoe	1	0.86	0.4123	6,211	0-15,465
Engineering and processing	Tar	10	5.05	0.2546	36,411	0-109,125
	Gasket	3	0.79	0.3292	5,666	0-13,935
	Paint	4	1.80	2.4378	13,012	0-35,513
	Sheeting	2	0.87	0.4358	6,287	0-15,801
Other	Misc. pieces	1	0.27	0.0702	1,913	0-5,732

Table 8. --Continued.

Use category	Item	Catch: Number caught	Catch: Mean CPUE km²	Catch: CPUE variance	Swept-area estimate: Estimated number	Swept-area estimate: 95% CI
			Metal			
Galley waste	Beverage can	33	1.55	1.4860	1,328,689	0-3,401,783
	Lids, caps	1	0.05	0.0029	45,914	0-136,821
	Container	7	0.26	0.0188	223,756	0-457,004
	Tinfoil	1	0.05	0.0026	43,827	0-130,601
	Cook pot	1	0.03	0.0012	29,301	0-87,316
Fishing equipment	Crab trap	3	0.11	0.0050	94,090	0-214,290
Engineering and processing	Pieces	3	0.17	0.0280	143,604	0-427,928
	Wire	9	0.10	0.0054	89,238	0-214,176
			Paper			
Galley waste	Bag	1	0.03	0.0008	24,249	0-72,261
Personal use	Piece	1	0.05	0.0024	41,663	0-124,152
Engineering and processing	Carton	1	0.05	0.0027	44,404	0-132,320
			Wood			
Engineering and processing	Pieces	2	0.04	0.0014	37,988	0-101,750
	Paint brush	1	0.03	0.0010	27,047	0-80,599
	Other	1	0.03	0.0010	27,196	0-81,044
			Cloth			
Personal use	Pants	1	0.06	0.0034	49,995	0-148,982
Engineering and processing	Pieces	6	0.25	0.0120	217,809	31,675-403,944
	Tarp	1	0.05	0.0026	43,544	0-129,759
	Bag	1	0.05	0.0024	41,663	0-124,152

[a]XBT - Expendable bathythermograph.

Table 9.--Description, material and use category, number caught, catch-per-unit-effort (CPUE) (number per square kilometer), and swept-area estimate of the number of debris items in the survey area for marine debris caught in Norton Sound during the National Marine Fisheries Service bottom trawl survey, 1988 (CI = confidence interval).

Category			Catch			Swept-area estimate	
Material	Use	Item	Number caught	Mean CPUE No./km^2	CPUE variance	Estimated number	95% CI
Plastic	Galley waste	Bag	1	0.24	0.0559	9,857	0-29,493
Rubber	Personal use	Shoe	1	0.26	0.0664	10,741	0-32,138
Metal	Galley waste	Beverage can	2	0.46	0.2128	19,228	0-57,530
	Engineering and processing	Railroad track	.2	0.50	0.2516	20,906	0-62,557
Cloth	Engineering and processing	Pieces and rags	1	0.23	0.0539	9,674	0-28,947
	Personal use	Dress	1	0.25	0.0629	10,453	0-31,275

Sea-Aleutian Islands area (Berger et al. 1988). There are few, if any, recreational boaters operating in the eastern Bering Sea and the major cargo transit routes lie south of the Aleutian Islands.

Norton Sound has the least amount of vessel traffic of the three areas surveyed. Tug and barge traffic to Nome, Alaska, occurs during the spring and summer. A fleet of about a dozen vessels conducts a commercial red king crab fishery in the survey area for approximately 1 week each year (Alaska Department of Fish and Game 1986). During the winter, most of Norton Sound is covered by ice.

The estimated abundance of marine debris in the three areas surveyed differed by nearly two orders of magnitude, from 1.94 items/km^2 in Norton Sound to 149.60 items/km^2 off Oregon. The higher concentration of marine debris off Oregon is probably related to the extensive vessel operations in this area. Most of the marine debris off Oregon was galley waste, 89.4 items/km^2 (64%), and engineering and processing waste, 37.87 items/km^2 (27%), which are associated with the operation of most types of vessels. Fishing equipment waste abundance off Oregon, 1.69 items/km^2, was quite similar to that found in the eastern Bering Sea, 1.84 items/km^2. It is interesting to note that the numbers of commercial fishing vessels operating off Oregon and in the eastern Bering Sea were also similar, 1,740 and 1,983, respectively. The abundance of galley waste and engineering and processing debris caught in the eastern Bering Sea may represent the average amount resulting from commercial fishing operations and minimal cargo traffic. The higher abundance of galley waste and engineering and processing waste found off Oregon may be due to the added input of cargo vessel and recreational boater debris.

RECOMMENDATIONS

- *Collect* marine debris data from all annual NMFS bottom trawl surveys.

- Develop a standardized data collection protocol, data base system, analysis methodology, and reporting format.

- Provide similar marine debris data forms to commercial trawl fishermen.

- Encourage foreign governments to conduct similar bottom trawl marine debris surveys.

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ESTIMATING THE DENSITY OF FLOATING MARINE DEBRIS: DESIGN CONSIDERATIONS

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ABSTRACT

We calculated sample sizes needed to estimate the density of surface marine debris potentially injurious to marine mammal and bird populations in the Gulf of Alaska and the Bering Sea as well as sample sizes needed to specifically estimate floating nets. Using published estimates of debris density, we developed alternative sample size requirements that depended on the accuracy required based on the coefficient of variation of the density. The survey technique used was visual sighting of debris using strip transect methodology. In general, large numbers of transects are needed in order to get estimates even with large coefficients of variation. Sparsity of data and nonstandard definition of transects contribute to the problems in estimating required sample sizes.

INTRODUCTION

The problems of marine debris and its impacts on marine mammals and on human activity in the oceans have been reviewed and discussed extensively by Shomura and Yoshida (1985). There has been interest in estimating the amount of floating marine debris using visual assessment. This technique has been used by many researchers (Venrick et al. 1973; Suzuoki and Shirakawa 1979; Dahlberg and Day 1985; Jones and Ferrero 1985; Yoshida and Baba 1985a, 1985b, 1988; Baba et al. 1986; Ignell and Dahlberg 1986; Day and Shaw 1987; McCoy 1988; Mio and Takehama 1988; Yagi and Nomura 1988). The purpose of this paper is to investigate survey design to estimate the density of surface marine debris in the Gulf of Alaska and Bering Sea.

We considered the design of two surveys. The first was to estimate density for all potentially harmful floating debris that could be visually assessed (specifically nets, fragmented plastic pieces, and strapping bands). Each type of debris was assumed to be equally important. The second design was for estimating the density of floating nets only.

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METHODS

The strip transect was the method used for visually assessing the density of floating objects. This method was chosen because of its widespread use (references cited above). The transects have a fixed width and the assumption is that all objects within that width are seen. The method of Burnham et al. (1980) was used to estimate sample size. This method is nonparametric because it does not make an assumption about the distribution of the debris. Estimation of sample size is based on achieving a certain coefficient of variation for the density of objects.

We used the conservative estimate for total transect length:

$$L - (3 \cdot L1)/(cv(D)^2 \cdot n1)$$

where L1 (total length of transects) and n1 (total number of objects seen) come from a pilot study, and cv(D) is the coefficient of variation (Burnham et al. 1980).

We used previously published papers on the Gulf of Alaska and the Bering Sea for estimates of L1 and n1 for total floating debris and floating nets. In addition, the data for the 1984 marine mammal observer program were made available to us (L. Jones, National Marine Mammal Laboratory, Seattle, WA, pers. commun.).

RESULTS

Total Floating Debris

From Dahlberg and Day (1985), an estimate of all debris was based on a strip transect with a width of 50 m. They do not state the length of their transects but state that an average of 5.5 h/day were spent watching for debris and that 1,516 nmi were sampled from Alaska to Hawaii (Dahlberg and Day 1985). This gives an average transect length of 47 nmi covered per 5.5 h. So the sampling unit will be defined here as a transect 47 nmi long by 50 m wide. Twelve objects were seen in the Gulf of Alaska (n1) and we estimate 670 nmi (Dahlberg and Day 1985, fig. 3) was surveyed (L1). Dahlberg and Day (1985) gave a density estimate for all floating marine debris as 0.28 pieces/km^2, but they did not publish a variance estimate. Day and Shaw (1987) give density and variance estimates for large floating plastic for the subarctic North Pacific (Gulf of Alaska) and, separately, for the Bering Sea.

Estimates of required sample sizes (number of transects) for estimating total floating debris are presented in Table 1. In general, in order to estimate density to any degree of precision (low cv(D)), 2 months or more of daily transects (5.5 h of observation for a 47-nmi-long by 50-m-wide transect) would be needed. Dahlberg and Day (1985) carried out about 14 transects, which would put their estimate in the 0.50 cv(D) category (not a small coefficient of variation).

Table 1.--Sample size estimation for all floating marine debris using a strip "transect of 47 nmi long by 50 m wide for the Gulf of Alaska and the Bering Sea for different coefficients of variation for the density. (L - total transect length and n - number of transects needed to cover that length.)

CV(D)	L (nmi)	n
0.10	16,750	994
0.25	2,680	57
0.50	670	15
0.80	262	6
1.0	167	4
1.2	117	3

Nets

From Jones and Ferrero (1985), 8,759 nmi (L1) were surveyed in 1984 with 12 pieces of net seen (nI). A density estimate of floating nets would be 0.0074 nets/km^2. A transect for this study was 2 nmi in length and 100 m in width. A total of 1,410 transects were made.

Estimates of total sample size (number of transects) for estimating floating nets are presented in Table 2. In all cases, a large number of transects (2 nmi length by 100 m width) would need to be made to get even an inaccurate estimate of the density of nets. There were 1,410 transects made in 1984, which would put the net density estimate in the 0.80 cv(D) category, a large coefficient of variation.

DISCUSSION

The number of transects needed to produce a reasonable estimate "for floating marine debris and especially for nets is extremely large. This demonstrates that targeting for a specific type of debris that is relatively rare, like floating nets, will take a large commitment of resources. These sample size estimates, however, depend on a large number of factors.

First, the approach we used is a nonparametric approach that is extremely general and requires sighting 25 or more objects to produce estimates of means and variances with any degree of accuracy (Burnham et al. 1980). Sample sizes for estimating rare objects like floating *nets* **will be** extremely large. A parametric approach such as using a binomial distribution may lead to smaller sample sizes but then the underlying model will have *to* be verified (Ribic and Bledsoe 1986).

Second, there was little information on which to base preliminary estimates of density and variation. Some of this had to do with the way

Table 2.--Sample size estimation for floating nets using a strip transect of 2 nmi long by 100 m wide for the Gulf of Alaska and the Bering Sea for different coefficients of variation for the density. (L = total transect length and n - number of transects needed to cover that length.)

cv(D)	L (nmi)	n
0.10	218,975	109,488
0.25	35,036	17,518
0.50	8,760	4,380
0.80	3,422	1,711
1.0	2,190	1,095
1.2	1,521	761

the data were reported. For example, in some cases we could not determine the length of a transect so we could not use the reported data. But more importantly, there is little published information on which to base preliminary estimates. Dahlberg and Day (1985) worked along long. 155°W. Jones and Ferrero (1985) worked in the middle of the gillnet fishery. Whether these studies are representative of the rest of the unsampled area is not known.

Third, transect length and width are not standardized, so sample size estimates in this paper depend on a specifically defined transect. Density estimates depend on the dimensions of the strip transect. Therefore, generalizations are difficult, since most researchers use different transect widths and lengths for their transects (e.g., Mio and Takehama (1988) used a width of 10 m).

Fourth, due to lack of information on variation for the Gulf of Alaska and the Bering Sea, we did not consider stratification (Cochran 1977), which could be potentially very useful in determining sample allocation and the placement of transect lines. Dahlberg and Day (1985) and Ignell and Dahlberg (1986) noted the concentration of debris in downwelling areas and frontal zones. A large-scale survey such as that of Mio and Takehama (1988) for the Gulf of Alaska and the Bering Sea would greatly improve our knowledge of the distribution of marine debris and improve survey design immensely.

Further refinement of the survey objective would be helpful when we consider placement of the transect lines. If a study is a one-time occurrence, the transects can be considered temporary and location will be decided by where the ship goes. However, if the study is to be a long-term study, thought should be given to permanent transects. For example, Day and Shaw (1987) compared the density of debris along long. 155°W previously sampled by Dahlberg and Day (1985). The long. 155°W line would be an example of a permanent transect that could be surveyed over time. Another example is the study of Yagi and Nomura (1988), where the long. 137°E line was surveyed between lat. 0° and 34°N each summer and winter for 9 years; however, they commented that their limited coverage of the area did not allow them to make conclusions about changes in marine debris distribution over time.

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CHARACTERIZATION OF MARINE DEBRIS IN SELECTED HARBORS OF THE UNITED STATES

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ABSTRACT

As part of a program to characterize anthropogenic debris in the marine environment, the U.S. Environmental Protection Agency conducted field surveys in the harbors of nine major metropolitan areas of the United States: New York, Boston, Philadelphia, Baltimore, and Miami on the east coast, and Tacoma, Seattle, Oakland, and San Francisco on the west coast. The surveys were designed to provide information on the types, relative amounts, and distributions of marine debris in several geographic regions of the United States. Neuston net (0.3-mm mesh) tows were conducted during outgoing tides on consecutive days. After each net tow, the debris, which ranged in size from small plastic pellets to large plastic sheeting, was identified, categorized, and counted. Seven of the ten most common debris items collected were plastic or polystyrene materials. The data are being used to qualitatively characterize marine debris in coastal metropolitan areas and to examine potential regional variations and sources.

INTRODUCTION

In response to domestic and international concerns about marine plastic debris, the U.S. Congress passed the Marine Plastic Pollution Research and Control Act of 1987. Title II of this act directs the U.S. Environmental Protection Agency (EPA) to conduct a study and to issue a Report to the Congress on methods for reducing plastic pollution. One section of the comprehensive Report to the Congress discusses the types and sources of marine plastic debris, the transport and fate of this debris, and its effects on the marine environment and on human health and safety.

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

It also lists what EPA believes to be items of concern in, the marine debris. These items are pellets, condoms, tampons, syringes and medical items, nets and traps, line and rope, six-pack yokes (or similar beverage yokes), and plastic bags and sheeting.

Because few data were available prior to the preparation of the Report to the Congress, EPA determined that field studies were necessary to collect data to adequately characterize plastic debris and its sources along the coastal United States. The Harbor Studies Program (Redford 1990), initiated by EPA in 1988, focuses on examining plastic and other floating debris in major harbors along the U.S. Atlantic and Pacific coasts. The objective of this field program was to characterize the types, relative amounts, and distributions of marine debris in representative harbors. This paper presents a summary of the results of the first nine surveys conducted under this program.

METHODS

Sample Collection

Floating debris often is observed concentrated in dense windrows, commonly referred to as debris slicks (EPA 1988), that appear to be influenced by surface currents and winds. Because the location, size, shape, and integrity of slicks were anticipated to be highly variable within each harbor, sampling was not conducted along predetermined transects but, rather, was directed toward the denser areas within the slicks.

Sampling at each harbor was conducted on 2 or 3 consecutive days between November 1988 and February 1989. Sampling dates and the total number of samples collected at each location are presented in Table 1.

The sampling plan for each location designated two or three areas within each harbor, based on criteria such as (1) presence of combined sewer overflows (CSO's) and stormwater outfalls in close proximity, (2) areas of heavy ship traffic or boating activity, (3) highly industrialized locations, and (4) areas that would represent overall debris conditions in the harbor. Because accumulated debris within the harbor is most likely to be transported out of the harbor with an outgoing tide, all sampling activities were initiated 1 to 2 h before ebb tide at each location. Selected areas within a harbor were sampled concurrently by deploying two or more small vessels.

Samples were collected by using a 0.33-mm mesh neuston net with dimensions of either 1 x 2 x 4, or 0.5 x 1 x 4, or 0.5 × 1 × 2 m. To minimize disturbances from the wake of the vessel, the net was towed from a boom positioned abeam of the vessel.

Sampling was conducted in slicks that were observed to be generally dense with floating debris. Each tow made through a slick was considered a single sample, regardless of the tow length. Generally, tows were conducted at a speed of 2 kn for approximately 20 rein, or until a sample volume of approximately 80 L was collected. If more than one tow was made

Table 1. --Summary of harbor studies sampling activities, November 1988 through February 1989.

Location	Dates sampled	No. of samples
New York[a,b]	11, 12, 13 November 1988	43
Boston	2, 3, 4 December 1988	49
Philadelphia[a,c]	26, 27 January 1989	29
Baltimore[a]	29, 30 January 1989	29
Miami	3, 4, 5 February 1989	31
Tacoma[b]	15, 16, 17 February 1989	11
Seattle[a]	15, 16, 17 February 1989	6
Oakland	21, 22, 23 February 1989	12
San Francisco	21, 22, 23 February 1989	14
Total		224

[a]CSO's observed discharging.
[b]Rainfall $\geq$1 in.
[c]Spring high tide during sampling period.

within a slick, each tow sample was considered to be a replicate. Following each tow, the captured debris was collected and placed into labeled containers.

Meteorological conditions and the dimensions and location of each sampled slick were recorded on a sample-tracking form. Visual fixes of landmarks were used to plot tow locations on navigational charts.

Sample Processing and Analysis

All samples were processed and analyzed immediately after returning from the field. Prior to processing, all items in a sample were rinsed with tap water. Processing entailed separating all anthropogenic material from natural materials, and sorting and identifying the debris items by specific, descriptive categories (Fig. 1). Many of these categories were adapted from the national beach survey data card developed by the Center for Marine Conservation. All debris items within a category were counted and the totals were recorded on these or similar inventory or data sheets.

The data for each harbor sampling site were entered into a data base and the percent composition was calculated for each item or combination of items. Samples were photodocumented immediately upon return to the laboratory, All percentages discussed herein are calculated based on numbers of items found, not on weight or volume of the items.

RESULTS AND DISCUSSION

During this study, items were enumerated but they were not weighed or measured in any other manner. All cited percentages are based on the numbers of items found.

Attach Sample Label Here

FLOATABLES SURVEY DATA INVENTORY SHEET

PLASTICS
Absorbant Material
Bags and Ties
Bags ≤ 1-gal capacity
Condiment bag
Garbage bag tie
Bags > 1-gal capacity
Misc. bags
Misc. pieces
Vegetable sack
Banding Material
Electrical wire tie
Strapping band
Bottles
Bottles ≤ 1-gal capacity
Bottles > 1-gal capacity
Beverage bottles
Misc. bottles
Misc. pieces
Caps and lids
Caps/lids
Cap/lid liners
Cap/lid pieces
Pull tab from plastic lid
Cigarette/Cigar Items
Wrappers and packs
Cigar tips
Cigarette butts & filters
Disposable lighters
Containers
Lemon juice dispensers
Misc. containers
Dishware
Cups, spoons, forks, straws
Dishes/plates
Misc. pieces
Drug Paraphernalia
Crack vial caps
Crack vials w/caps
Crack vials w/o caps
Fishing/Boating Items
Floats & lures
Fishing line-monofilament
Netting
Food Wrappers--Misc.
Hair Care & Cosmetic Items--Misc.
Housewares & Tools--Misc.
Labels--Misc.
Line/Rope
Filament
Rope length ≤ 2 ft
Rope length > 2 ft
Medical
Band-aids
Band-aid wrappers
Cough syrup bottles
Cylindrical tubes
Cylindrical tube pieces
Lip balm & containers

Misc.
Needle covers
Pill vials & caps
Syringes (whole)
Syringes (pieces)
Syringes with blood
Tube ends only
Vials
Vial caps
aneous
Foil wrappers (plastic-coated)
Hardhat band
Wrappers
Polyvinylchloride (PVC)
Toys
Tubing
Vials
Pellets & Spherules
Pellets
rsona
Condoms (whole)
Condoms (pieces)
Diapers
Panty liners
Q-Tips (whole)
Q-Tips (tubes only)
Sanitary items
Sanitary napkins
Tampon applicators
Tampon wrappers
Photographic Items
Film containers
Photos
Sheeting
≤ 2 ft
> 2 ft
Six-Pack Holders
Whole
Pieces
Writing Utensils--Misc.

GLASS
Bottles
Alcohol bottles
Food bottles
Light bulbs
Misc. Pieces

PAPER
Bags
Whole
Pieces

(Continued on Reverse Side)

Cartons/Cardboard Boxes
Whole
Food Items & Wrappers
Beverage cartons
wrappe
wrappe
Gum wrappers
Housewares Items
tches
paper
aneous
tems
eces
wrappers
tems
paper

TEXTILES
Cotton
Rope

STYROFOAM
Band--Pieces
Buoys
Conta
Beverage labels
Cups & bowls (pieces)
Cups & bowls (whole)
Egg cartons
Fast food containers (whole)
Fast food containers (pieces)
Plates & trays (pieces)
Plates & trays (whole)
Miscellaneous
Pieces smaller than a baseball
Pieces larger than a baseball
Polyurethane foam
Spheres
Stripping (possibly rubber)
Wrappers
Peanuts

RUBBER
Balloons
Whole
aneous
rubbe
Foam rubber stripping
Pieces
Tires & wheels
Tubing
Rubberbands
Pieces

METAL
Cans
Aerosol cans
Beverage cans
Candy Wrappe
Foil
rappe
Lids (Beverage)
st Ties
Wheel
Wire

WOOD
Burned Wood
Cut Lumber (2 x 4)
Ice Cream & Popsicle Sticks
Matches
Medical--Tongue depressors
Penc
Toothp

MISCELLANEOUS
Charcoal
Fibrous Material
Soap
Sponge

Supplemental Sheet Yes ___ No ___ (Check One)

Figure 1.--Data inventory sheet showing descriptive categories. Form adapted from Center for Marine Conservation National Beach Survey Data Card.

All Cities

For all cities combined, 81% of all the debris collected was plastic or polystyrene (Fig. 2). Polystyrene, a plastic material, is treated separately based on its physical properties and uses. Miscellaneous debris, composed primarily of grease balls, tar, and slag, represented 12% of all debris. The remaining major debris categories (wood, paper, metal, rubber, glass, and textile) comprised approximately 7% of all debris. A summary of debris in each major category for each city and in all cities combined is presented in Table 2 and Figure 3.

The most abundant category of debris was plastic. Of the cities sampled, Tacoma had the greatest percentage of plastic (84%), due primarily to an unusually large number of plastic pellets/spherules collected in a single sample. Baltimore ranked second highest with 70%. Debris from Seattle contained the lowest percentage of plastic (41%).

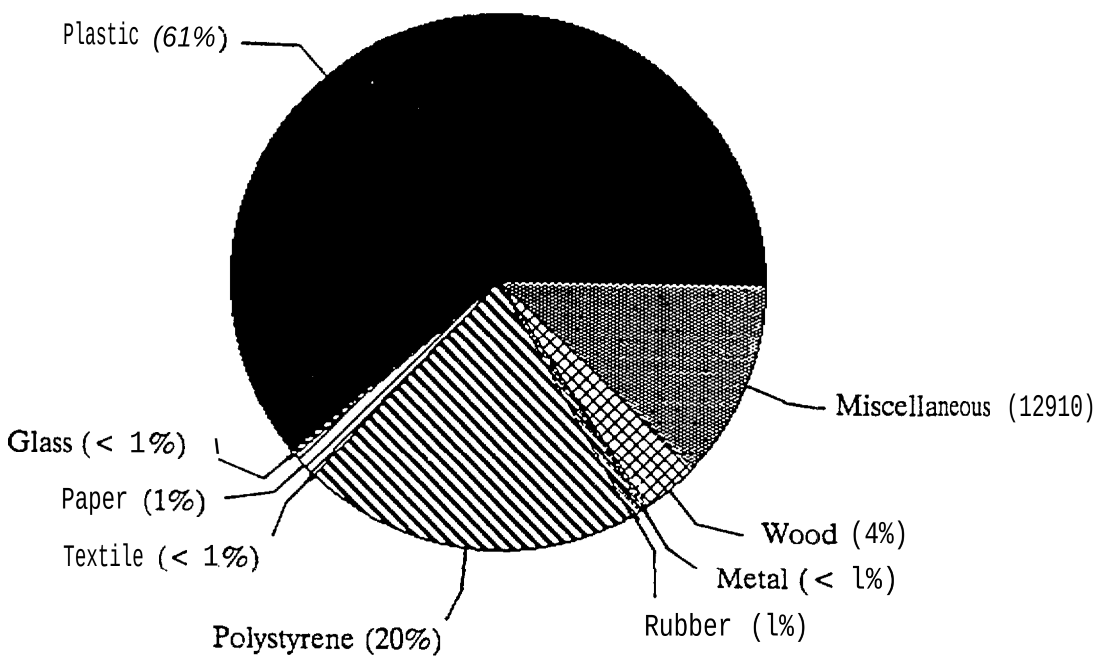


Figure 2. --Percent composition of all debris categories in all cities, November 1988 through February 1989. Percentages are based on the total number of items.

Table 2.--Summary of percent composition[a] of items of Environmental Protection Agency concern and all debris categories found in marine debris samples collected in U.S. harbors, November 1988 through February 1989. All percentages are rounded to the nearest tenth.

Composition	New York	Boston	Phila- delphia	Balti- more	Miami	Tacoma	Seattle	San Francisco	Oakland	All cities
Items of concern										
Pellets	19.5	29.7	34.0	19.5	24.0	85.5	16.4	16.8	29.7	30.4
Condoms	0.2	0.2	0.9	0.4	0.1	0.0	0.0	0.1	0.1	0.2
Tampons	0.2	0.1	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.1
Syringes or medical	0.1	0.1	0.1	0.6	0.1	0.0	0.0	0.1	0.0	0.1
Nets or traps	0.0	0.0	0.0	0.0	0.1	0.0	0,4	0.0	0.0	0.0
Line or rope	3.8	0.3	0.6	0.5	1.1	0.2	3.4	0.7	0.3	1.6
Six-pack yokes	0.1	0.1	0.3	0.3	0,7	0.0	0.1	0.1	0.1	0.1
Plastic bags or sheeting	4.8	1.9	9.1	16.0	17.3	1.6	8.0	5.3	9.2	6.3
Total	28.7	32.3	45.5	37.3	43.2	87.4	28.4	23,0	39.4	38.9
All categories										
Plastic	59.1	61.1	64.2	69.9	47.0	84.0	41.3	43.5	56.9	61.3
Glass	0.0	0.1	0.2	0.9	0.6	0.1	0,4	0.5	0,7	0.2
Paper	1.6	0.7	2.1	0.9	3.5	0.3	4.8	2.1	2.2	1.5
Textile	0.1	0.0	0,1	0.1	0.0	0,1	0.0	0.4	0",1	0.1
Polystyrene	9.9	18.2	24.0	24.5	37.0	12.6	43.6	46.9	34.6	20.3
Rubber	1.2	0.8	0.9	0.5	0.4	0.0	1.1	1.1	0.6	0.8
Metal	0.2	0.3	0.3	0.7	0.9	0.1	1.1	0.5	0,9	0.4
Wood	6.8	0.9	1.1	1.1	6,3	1.3	5.5	3.3	2.9	3.6
Miscellaneous	21.1	18.0	7.2	1.5	4.4	1.5	2.1	1.8	1.2	11.8

[a]Based on the total number of items found in each city.

ALL CATEGORIES

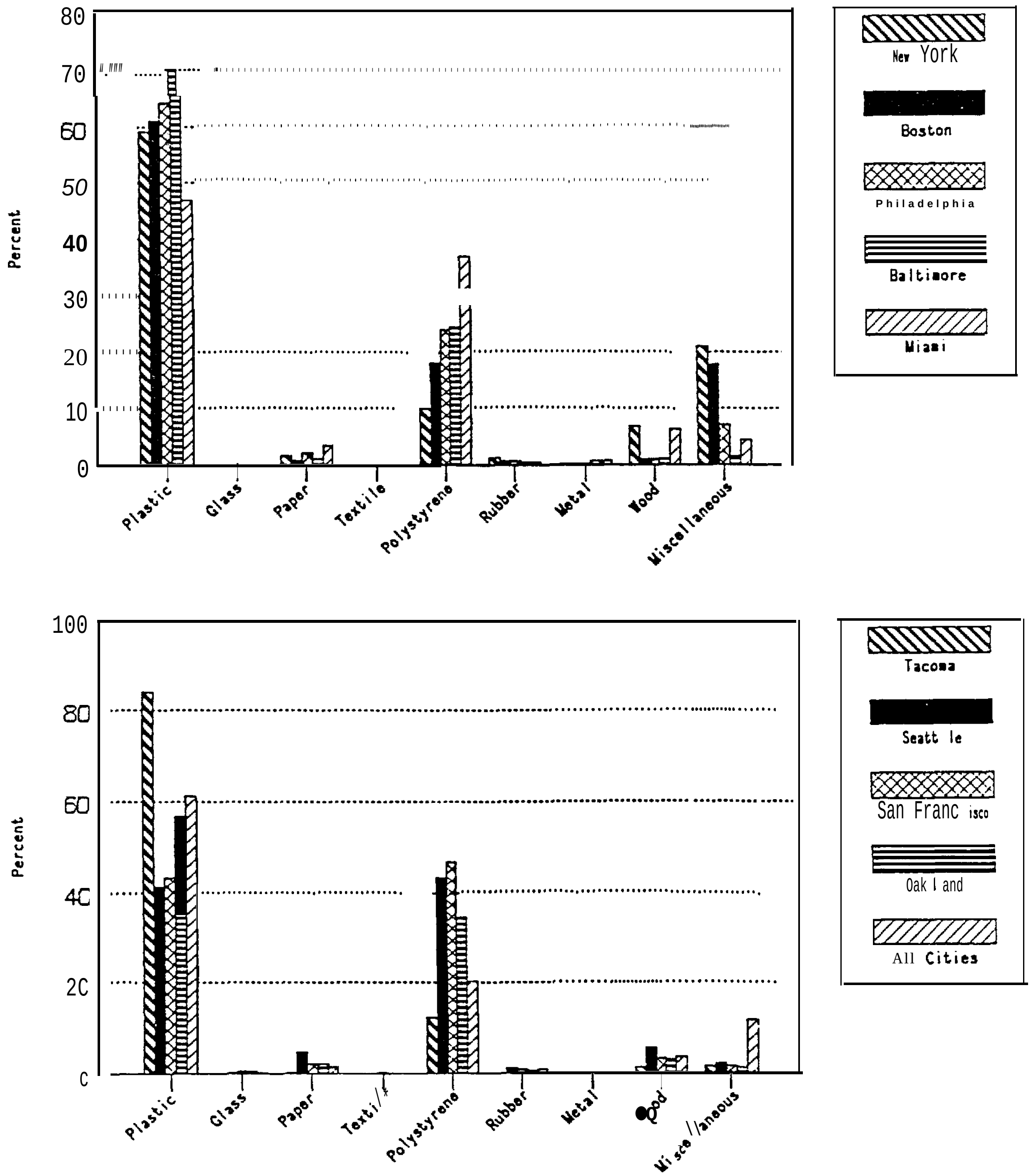


Figure 3. --Percent composition of all debris categories in each city. Percentages are based on the total number of items.

The second most abundant category of debris was polystyrene. Of the cities sampled, San Francisco had the greatest percentage of polystyrene (47%). Debris from New York contained the lowest (10%). The combined percentages of plastic and polystyrene debris found in each city are given in Figure 4.

The 10 most common items found in the study (Table 3) accounted for 75% of all debris. Four of these, plastic pellets/spherules, miscellaneous plastic pieces, polystyrene pieces smaller than a baseball, and cigarette butts were among the most abundant items found in all nine cities. Plastic pellets/spherules, the raw material, or resin, used in the manufacture of plastic products, constituted the most common item overall; it was also the most common item found in five cities (Boston, Philadelphia, Baltimore, Tacoma, and Oakland) and among the five most common items *in* two additional cities (New York and San Francisco).

In all, seven of the most abundant items were composed of plastic (five items) or polystyrene (two items). The two remaining categories include miscellaneous (two items) and wood (one item). The three most common types of plastic item included plastic pellets/spherules, miscellaneous plastic pieces, and plastic sheeting shorter than 0.6 m (2 ft). Plastic pellets/spherules comprised 26% of all debris collected. Miscellaneous plastic pieces (13%), and plastic sheeting shorter than 0.6 m (2 ft) (5%)-ranked second and fifth overall. Polystyrene spheres (4%) and polystyrene pieces smaller than a baseball (10%) were also common.

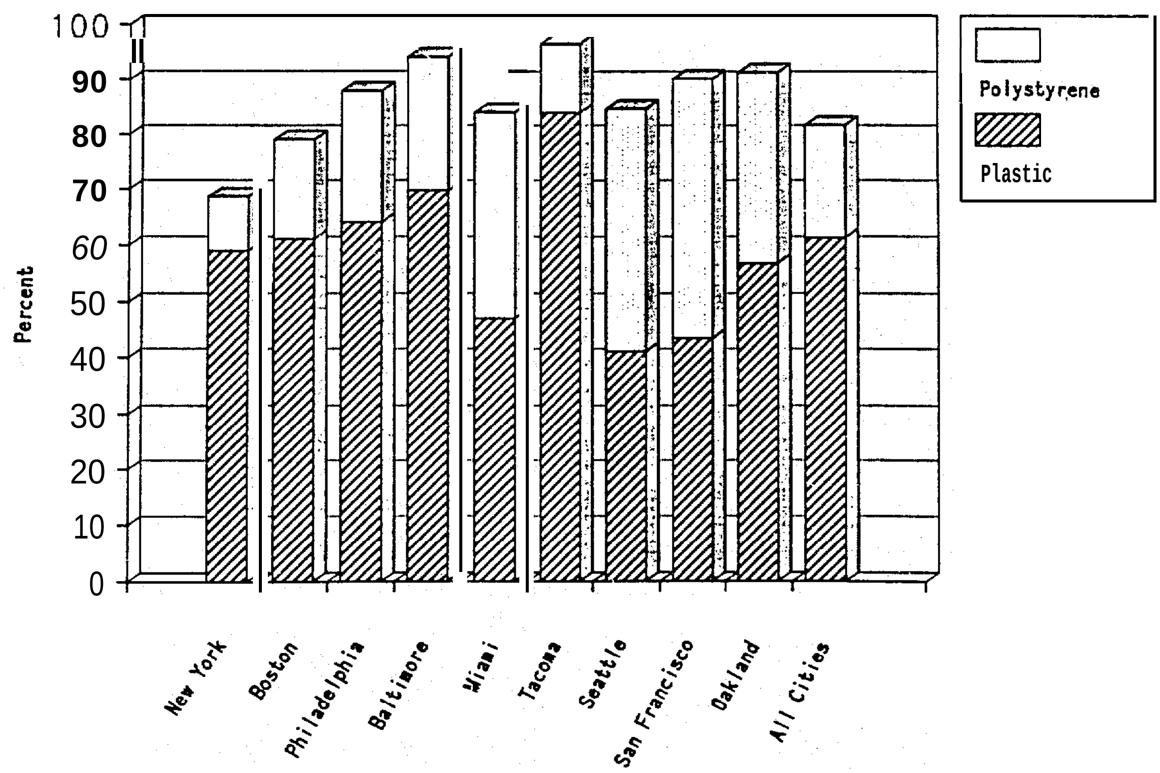


Figure 4. --Percent composition of plastic and polystyrene debris in each city. Percentages are based on the total number of items.

Table 3.--Summary of the most common items found in marine debris samples collected from all cities sampled, November 1988 through February 1989.

Category	Debris item	Quantity	Percent[a]
Plastic	Pellets/spherules[b]	11,406	25.90
Plastic	Miscellaneous pieces	5,785	13.14
Polystyrene	Pieces smaller than a baseball	4,350	9.88
Miscellaneous	Grease balls	2,696	6.12
Plastic	Sheeting <0.6 m (2 ft)[b]	2,100	4.77
Polystyrene	Spheres[b]	1,938	4.40
Plastic	Cigarette butts and filters	1,550	3.52
Miscellaneous	Slag	1,503	3.41
Plastic	Food wrappers	959	2.18
Wood	Miscellaneous pieces	923	2.10
Total of most common items		33,210	75.41
Total of all items in all cities		44,037	100.00

[a]Based on the total number of items found in each city.
[b]Item of Environmental Protection Agency concern.

The EPA-designated items of concern made up 39% of all debris (Fig. 5). They included the following items enumerated in this study:

- Pellets--Plastic pellets/spherules; polystyrene spheres.
- Condoms--Condoms (whole, pieces).
- Tampons--Tampons; tampon applicators; tampon wrappers.
- Syringes or medical--Syringes (whole, pieces, with blood); needle covers; vials and vial caps; insulin bottles.
- Nets or traps--Netting; floats and lures.
- Line or rope--Plastic rope (<0.6 m (2 ft) and >0.6 m (2 ft)); filaments; strapping bands; fishing line (monofilament); textile rope.
- Six-pack yokes (or similar)--Six-pack yokes (or similar) (whole and pieces).
- Plastic bags or sheeting--Plastic bags (<3.8 L (1 gal) and >3.8 L (1 gal)); condiment bags; miscellaneous plastic bags (whole and pieces); plastic sheeting (<0.6 m (2 ft) and >0.6 m (2 ft)).

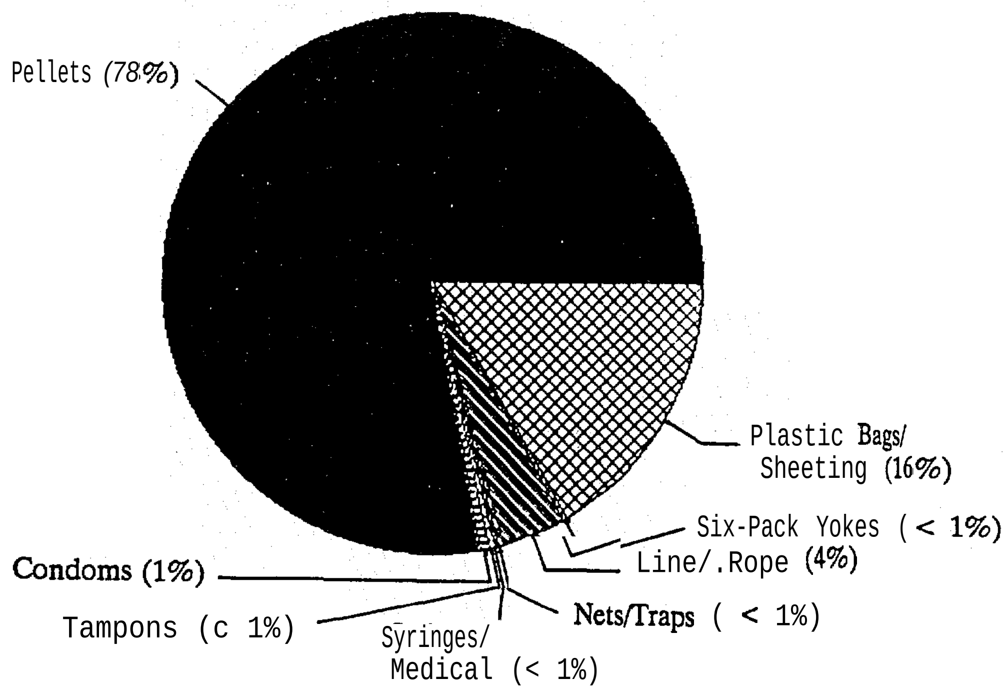


Figure 5.--Percent composition of items of Environmental Protection Agency concern in all cities. Percentages are based on the total number of items.

Items of concern constituted 87 and 46% of the total debris in Tacoma and Philadelphia, respectively. The lowest percentage of items of concern (23%) was found in San Francisco. Pellets were the most common item of concern found in all cities combined (30% of all debris and 78% of all items of concern), and ranged from 16% of all debris in Seattle to 86% of all debris in Tacoma. In all cities combined, plastic bags/sheeting was the second most common item of concern (6% of all debris; 16% of all items of concern).

Several debris items found during this study are typically associated with human sewage, medical waste, or illegal drug usage, as follows:

Sewage-related debris

Condorns (whole and pieces)	Tampons
Diapers	Tampon applicators
Panty liners	Tampon wrappers
Sanitary items	Fecal matter
Sanitary napkins	

Medical-related items

Syringes (whole and pieces)	Pill vials and caps
Syringes with blood	Cylindrical tubes (whole and pieces)
Needle covers	Tongue depressors
Vials and vial caps	Miscellaneous pills
Miscellaneous medical items	

Drug-related items

- Crack vials with caps
- Crack vials without caps
- Crack vial caps
- Illegal substances

Sewage-, medical- , and drug-related debris each comprised <1% of all items in each city (Table 4) except Philadelphia, where approximately 2% of the debris was sewage-related. Philadelphia, Baltimore, and New York had the highest percentages of all three types combined. The combination of these three types made up over 2% of the debris in Philadelphia, and more than 1% of the debris in Baltimore and New York. Exactly 1% of all debris found in all cities combined was sewage-, medical-, or drug-related.

Out of approximately 200 items identified, 26 items were common to all cities. These items were

Plastic

- Bags <3.8 L (1 gal) and >3.8 L (1 gal)
- Bottles <3.8 L (1 gal)
- Caps/lids (whole and pieces)
- Cigar/cigarette wrappers and packs
- Cigar tips
- Cigarette butts and filters
- Cups, spoons, forks, straws
- Food wrappers
- Filaments
- Rope shorter than 0.6 m (2 ft)
- Miscellaneous piece
- Pellets/spherules
- Sheeting <0.6 m (2 ft)
- Coffee stirrers

Paper

- Food wrappers
- Miscellaneous pieces

Polystyrene

- Cups and bowls (pieces)
- Pieces smaller than a baseball
- Peanuts
- Miscellaneous packing material
- Spheres

Wood

- Miscellaneous pieces

Miscellaneous

- Food items
- Grease balls

Of these items, seven items (plastic pellets/spherules, plastic bags >3.8 L (1 gal) and <3.8 L (1 gal), plastic filaments, rope shorter than ().6 m (2 ft), and two types of polystyrene spheres) were items of EPA concern. None of these items was directly attributable to sewage-, medical-, or drug-related activities.

Table 4.--Number and percent composition[a] of sewage-, medical-, and drug-related debris.[b]

City	Sewage-related Number	%	Medical-related Number	%	Drug-related Number	%	Total[c] Number	%
New York	63	0.45	32	0.23	119	0.85	214	1.54
Boston	29	0.31	10	0.11	27	0.28	66	0.70
Philadelphia	45	1.59	2	0.07	21	0.74	68	2.40
Baltimore	40	0.92	27	0.62	6	0.14	73	1.68
Miami	4	0.14	3	0.10	1	0.03	8	0.27
Seattle	0	0.00	2	0.28	0	0.00	2	0.28
Tacoma	0	0.00	1	0.02	0	0.00	1	0.02
San Francisco	3	0.09	2	0.06	0	0.00	5	0.15
Oakland	1	0.07	1	0.07	0	0.00	2	0.02
Total	185	0.42	80	0.18	1 74	0.40	439	1.00

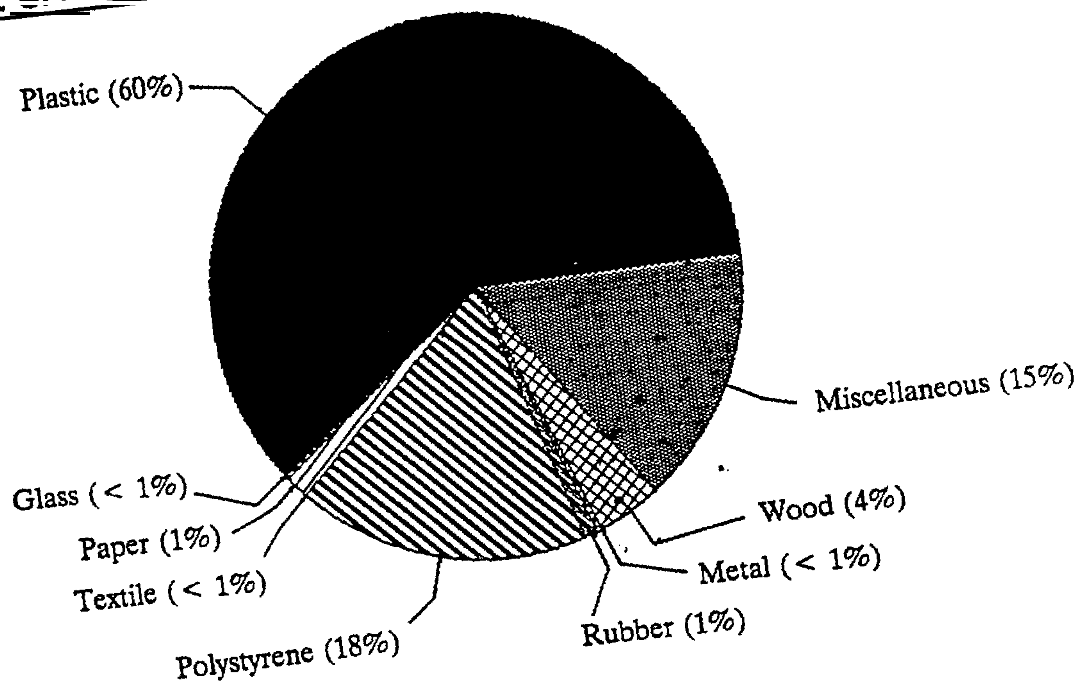
[a]Based on the total number of items found in each city.
[b]Defined in text.
[c]Sum of sewage-, medical-, and drug-related debris.

It is interesting to note that, of the 26 items listed above, 7 were related to food packaging or consumption and 3 were related to tobacco use. Food and tobacco generally are packaged in a wrapper or container when purchased; increasingly these containers or wrappers are being made of plastic. Disposal of these wrappers or containers is often careless, especially if the item is consumed during travel. In addition, the plastic wrappers are very lightweight and are easily transported by the wind. Either careless disposal by consumers or wind action over approved disposal sites such as dumpsters and trash receptacles could account for the presence of many plastic food and tobacco containers and wrappers.

East Coast Versus West Coast

Comparison of the results from east coast cities (New York, Boston, Philadelphia, Baltimore, and Miami) and west coast cities (Seattle, Tacoma, San Francisco, and Oakland), showed certain similarities and differences in debris composition (Figs. 6 and 7). Cities on both coasts had nearly the same percentages of plastic debris. Glass, paper, textile, rubber, and metal debris were found in low levels (<1%) on both coasts; these items were less common than wood debris, which was found in very similar proportions on both coasts. In contrast, east coast cities had a higher percentage of miscellaneous debris, which was primarily in the form of grease balls, tar, and slag. The contribution of polystyrene to the total debris was one to two times greater in the west coast cities than in the east coast cities.

ALL CATEGORIES



ALL CATEGORIES

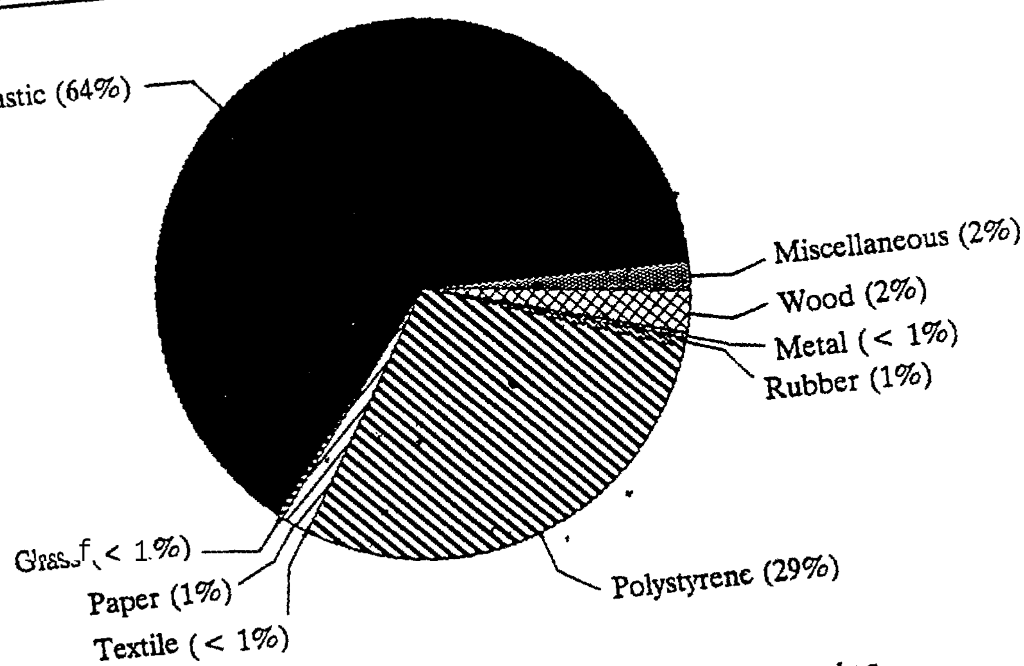
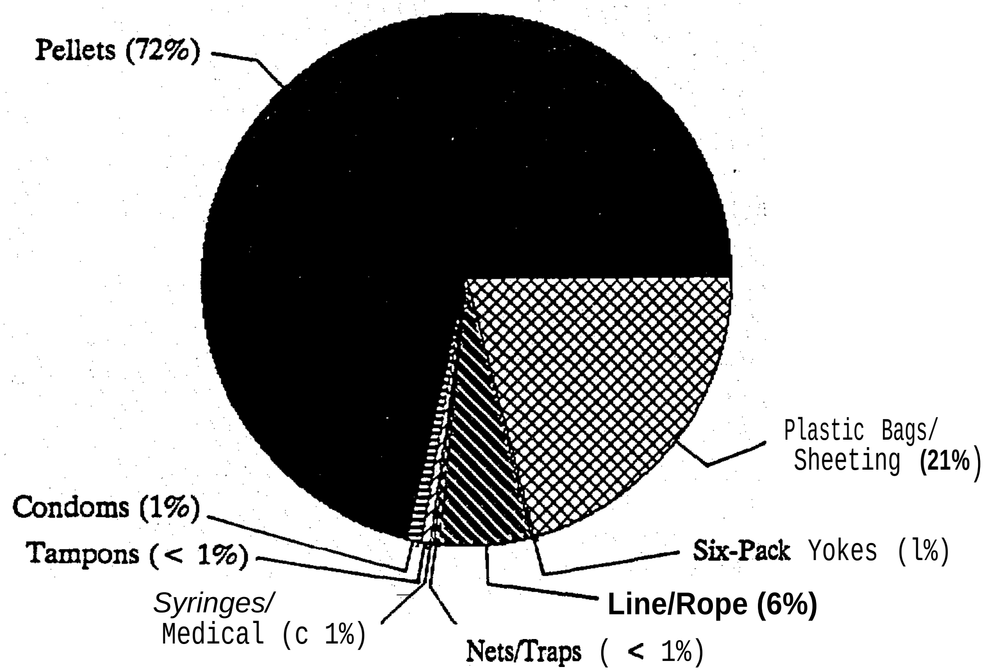


Figure 6. · percent composition of all debris categories. (A) East coast cities. (B) West coast cities. percentages are based on the total number of items.

ITEMS OF CONCERN (34 % OF DEBRIS)



ITEMS OF CONCERN (56 % OF DEBRIS)

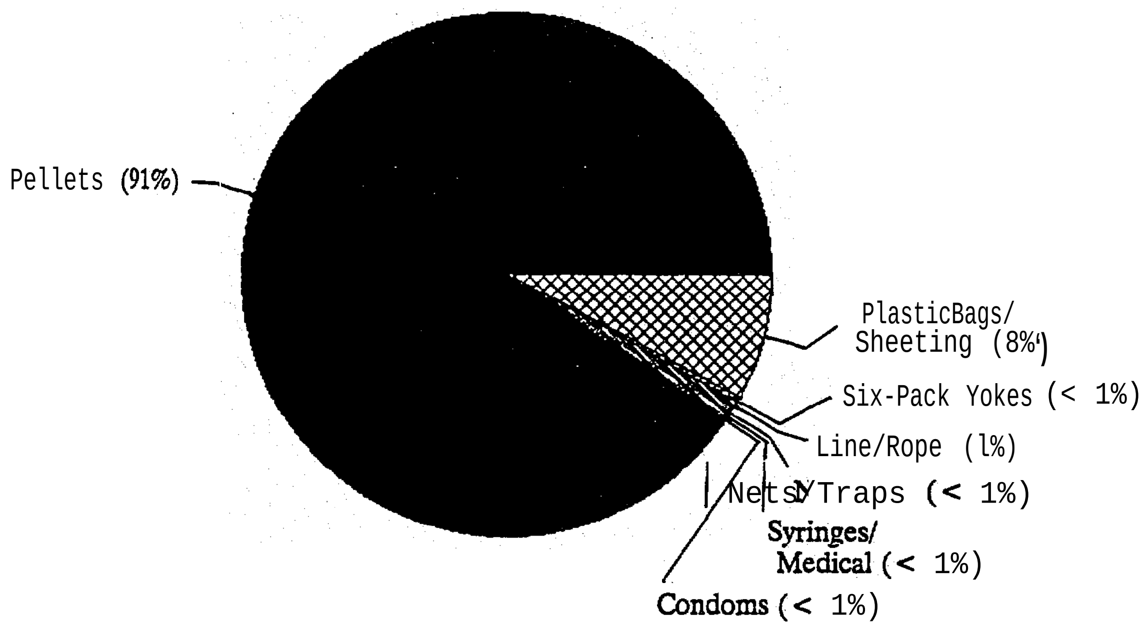


Figure 7.--Percent composition of items of Environmental **Protection** Agency concern. (A) East coast cities. (B) West coast cities. Percentages are based on the total number of items.

Over one-half of all debris items found in west coast cities were items of EPA concern, the majority of which were represented by pellets in Commencement Bay near Tacoma. Nearly one-third of the debris in eastern cities consisted of items of EPA concern, and approximately three-fourths of the items were pellets. Another item of EPA concern, plastic bags/sheeting, was common on both coasts, although proportionally greater on the east coast. Line/rope was more common on the east coast than on the west coast.

Sewage-, medical-, and drug-related debris were uncommon on both coasts (Table 4), and combined they totaled 1% of all debris found. Most of these three debris types were found in east coast cities. The larger presence of these on the east coast is likely to be due to the greater frequency of CSO and storm sewer discharges in eastern cities. No drug-related debris was found in the west coast cities.

Medical Debris

The greatest numbers of medical-related debris items were found in three east coast cities (Table 4): New York (32 items, or 0.23% of all New York debris), Baltimore (27 items, or 0.62% of all Baltimore debris), and Boston (10 items, or 0.11% of all Boston debris). A total of 7 syringes and syringe pieces, including 1 syringe containing blood, were found in New York; 7 syringes and pieces were found in Boston, and 13 syringes and pieces were found in Baltimore. Very little medical debris, only two items of which were syringes, was found in the remaining cities.

All of the syringes found during this study were the l-cc insulin-dispensing type. In Baltimore, the needles typically were capped at one or both ends, probably indicating that they were used and disposed of by someone who had been instructed as to safe and proper syringe disposal. However, in New York and Boston the syringes usually were in pieces and not capped at either end.

SUMMARY

Plastic debris (including polystyrene) was numerically the largest component of marine debris in surface slicks from every city sampled. Plastic pellets were a significant portion of the plastic debris and were collected in every harbor. Several sewage-, drug-, and medical-related items were found during the study, but these items were not major components of the debris.

These surveys were the first in a continuing series of surveys sponsored under EPA's Harbor Studies Program. The program is providing the first semiquantitative evaluation of marine debris in U.S. harbors. Future surveys are being planned to study additional cities along the east and Gulf coasts, and many of the cities discussed in this study will be resampled.

ACKNOWLEDGMENTS

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The authors wish to thank all EPA and Battelle employees who assisted in sample collection and processing, tasks which were typically tedious and, at times, unpleasant. We also wish to thank Margarete Steinhauer for presenting this study at the Second International Conference on Marine Debris.

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PRELIMINARY REPORT ON THE DISTRIBUTION OF SMALL-SIZED MARINE DEBRIS IN SURUGA BAY

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ABSTRACT

From 17 to 29 March 1988, a survey to collect small marine debris was conducted in Suruga Bay. Tows (10-min) were made at 24 stations using a circular tow net with a diameter of 1.4 m and mesh size of 1.7 mm at the mouth and 0.5 mm at the cod end.

A total of 665 pieces of debris were collected during the survey. Of these, terrestrial debris and plants such as wood made up 50.1% of the total, followed in decreasing order by seaweed (19.5%), Styrofoam (13.8%), plastic sheets (13.2%), and other plastic pieces (3.3%).

Plastic sheet debris was found at most stations, whereas Styrofoam showed a tendency to accumulate in specific areas.

The distribution of each type of small debris corresponded well to the distribution of large debris observed by sightings conducted during the same cruise.

INTRODUCTION

Petrochemical products flowing and thrown into the sea are causing a number of problems. It has been pointed out that marine organisms swallow debris fragments together with their food. These fragments are generated when drifting petrochemical products in the sea are, in the process of their deterioration, broken up by physical factors such as waves. It is necessary to examine these small floating objects in order to understand the changes in size as well as the distribution and movement of drifting petrochemical products over the course of time.

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

METHODS

This research was carried out at 24 stations in Suruga Bay from 17 to 29 March 1988 (Fig. 1). The nets used for collecting debris were 1.4 m in diameter. The first two-thirds of the net had a mesh size of 1.7 mm; the remaining third a mesh size of 0.5 mm. The net was towed for 10 min at a speed of 3 kn with the mouth of the net half submerged. Collected objects were immediately preserved in formalin and brought back to the laboratory, where they were counted and weighed and the information recorded. Those with maximal dimensions of 5 cm were excluded.

RESULTS

Major petrochemical products collected in this survey were fragments of plastic, plastic sheeting, and Styrofoam. Among the natural debris was terrestrial debris such as wood fragments and straw as well as drifting seaweed (Table 1). A total of 665 pieces of debris were collected. Debris deriving from petrochemical products accounted for 30.4% of the total (Styrofoam fragments 13.8%, fragments of plastic sheeting 13.3%, and plastic fragments 3.3%). Debris of terrestrial origin accounted for 50% of the total (the largest percentage), and seaweed for 19.5%. Plastic sheet fragments were extensively distributed, being collected at 66.7% of the 24 research stations (Fig. 1). The distribution of other plastic and Styrofoam was limited, occurring at only 29.2 and 20.8% of the stations, respectively. Natural debris of terrestrial origin was collected at 66.7% of the stations and seaweed at 62.5% of the stations.

Plankton, mainly Copepoda, sardine fry, and fish eggs were collected at all the research stations. These types of plankton numbered more than 1,000 at each station.

The highest densities of marine debris were found all across the middle of Suruga Bay. Research stations with high densities of plastic sheet fragments were continuous, as seen in the case of stations 12, 13, 22, and 17. A similar distribution pattern was observed for all drifting objects. The distribution of Styrofoam fragments was limited, but high densities were found in geographical positions similar to stations 7, 6, and 1.

Currents and winds were considered to be major factors in moving this debris. It has been reported that the surface current in Suruga Bay can be affected by the Kuroshio, which flows eastward off the bay. As shown in Figure 2, Inaba (1988) pointed out two such instances. The course of the Kuroshio during the survey period was more offshore, corresponding to Case 2 in Figure 2 (Meteorological Agency of Japan 1988). It is assumed that' the flow of outer oceanic water is from west of the mouth of the bay and divides into two currents near the center of the bay, with one current moving around the mouth of the bay clockwise and the other moving counterclockwise toward the inner side of the bay. The area of the highest densities of marine debris is on the boundary between these currents, which would represent a front. Strong northeast winds were blowing for several days during the survey period, but the distribution of marine debris was considered to be affected more by surface currents than by the winds.

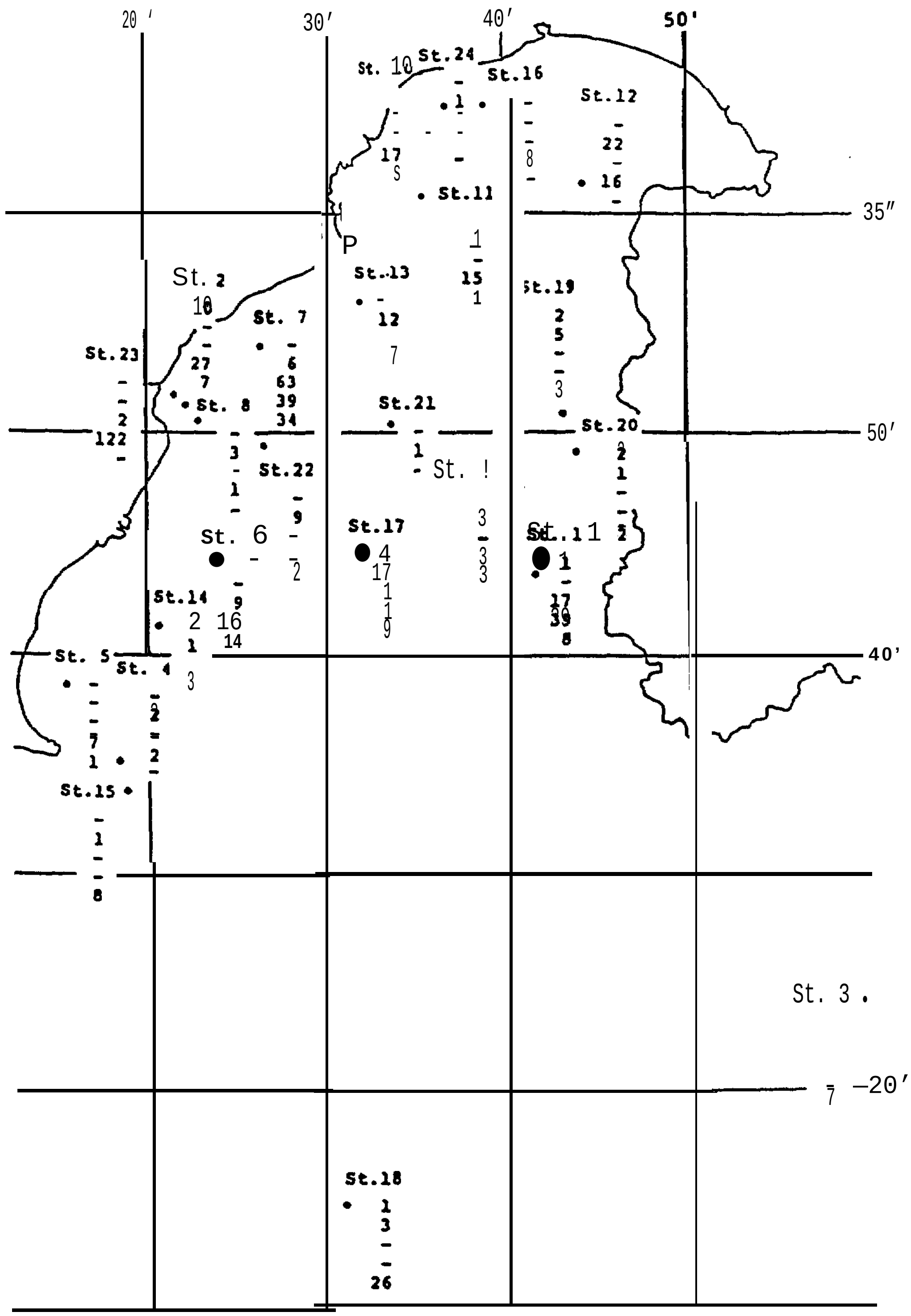

Figure 1. --Stations (St.) and data collected in minute marine debris survey. At each station, numbers from the top down indicate plastic pieces, plastic sheets, Styrofoam, land plants, and seaweed, in that order.

Table 1---Sampling location and composition of minute marine debris in Suruga Bay.

Station	Time	Latitude N	Longitude E	Plastic pieces	plastic sheets	Styrofoam	Land plants	Seaweed	Copepoda	Eggs	Larvae
1	12,50	34°43.72′	138°41.68′	1	. .	17	39	8	42	10	--
2	7.17	34°51.19′	138"22.56′	10	--	--	27	7	--	--	--
3	11.56	34"24,30′	138°59.13′	--	. .	--	. .	7	. .	3,230	--
4	16.42	34°36.32′	138°18.60′	. .	2	--	2	---	58	--	7
5	7.10	34"37.30′	138°16.22′	--	. .	--	7	1	1,120	84	--
6	11.04	34''43.58′	138°22.92′	--	--	9	16	14	15	--	--
7	16.40	34"54.90′	138"28.68′	--	6	63	39	34	--	--	--
8	7.17	34"50.75′	138°22.01′	--	3	. .	1	.-	37	--	--
9	11.35	34°47.72′	138°40,85′	--	3	--	3	3	25	154	--
10	14.42	35°04.05′	138°34.32′	--	--	.-	17	5	--	. .	--
11	9.11	35"02.33′	138"32.60′	--	1	--	15	1	26	15	--
12	10.31	35°02.70′	138"44.63′	--	22	. .	16	. .	15	46	--
13	12.45	34"57.33′	13$''32,44′	--	12	. .	7	--	25	12	--
14	17,05	34°41.56′	138"20.30′	2	1	.-	3	--	43	82	--
15	7.44	34°34.05′	138°19.06′	--	1	. .	--	8	. .	--	--
16	11.54	35"05.48′	138"37.65′	--	--	--	18	.-	22	57	--
17	17.03	34°45.49′	138°32.08′	4	17	1	1	9	121	15	--
18	12.02	34°14.81′	138°30,55′	1	3	--	--	26	--	19	34
19	16.32	34''51.26′	138"43.14′	2	5	--	--	3	12	38	--
20	7.11	34"48.68′	138"44.37′	2	1	--	--	2	--	--	1,540
21	7.25	34°50.28′	138"37.42′	. .	1	--	. .	--	--	3	. .
22	12.08	34°49.17′	138°26.96′	--	9	--	--	2	--	--	6
23	7.14	34"51.66′	138"22.70′	--	--	2	122	--	--	--	6
24	13.03	34"05.22′	138°36.72′	--	1	--	--	. .	--	.-	5

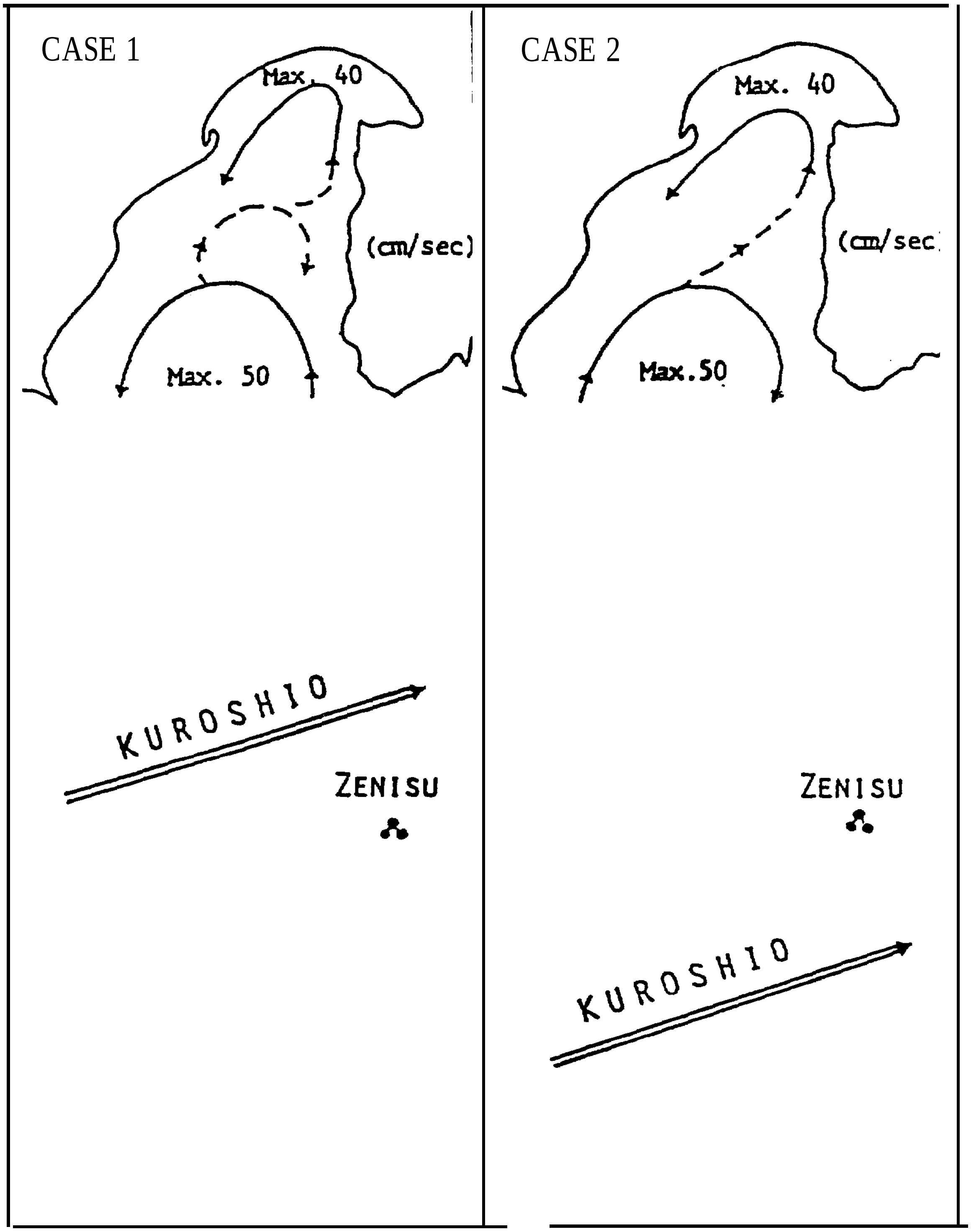

Figure 2. --Diagram showing the relationship of the Kuroshio to the surface current of Suruga Bay (Inaba 1988).

Plankton and marine debris showed an inverse correlation. Areas where plankton were found in large quantities were influenced a great deal by the open ocean. It is reasonable to assume that plankton and marine debris showed different distributions because the plankton, being totally submerged are not influenced at all by the wind.

Small floating objects were found most frequently in areas influenced heavily by coastal currents. The distribution of drifting petrochemical product fragments corresponded well to that of the larger floating objects. It is therefore conjectured that petrochemical products drifting in the sea gradually deteriorate and are broken into small fragments.

More detailed studies will be needed to find out the distribution and abundance of Styrofoam fragments.

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

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ABSTRACT

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

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

INTRODUCTION

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

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

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

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

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

METHODS

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

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

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

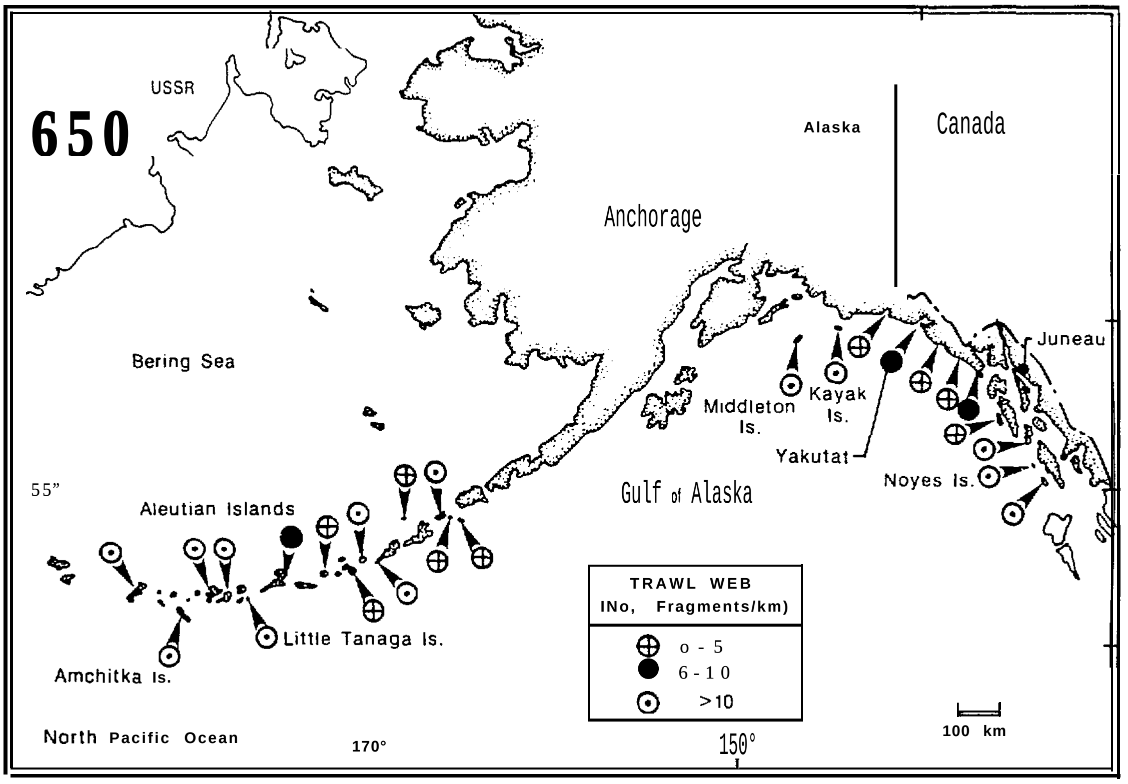

Figure 1. --Locations of beaches surveyed for plastic debris and quantity of trawl web fragments (number per kilometer) found in Alaska, 1982-88.

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

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

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

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

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

RESULTS

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

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

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

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

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

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

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

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

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

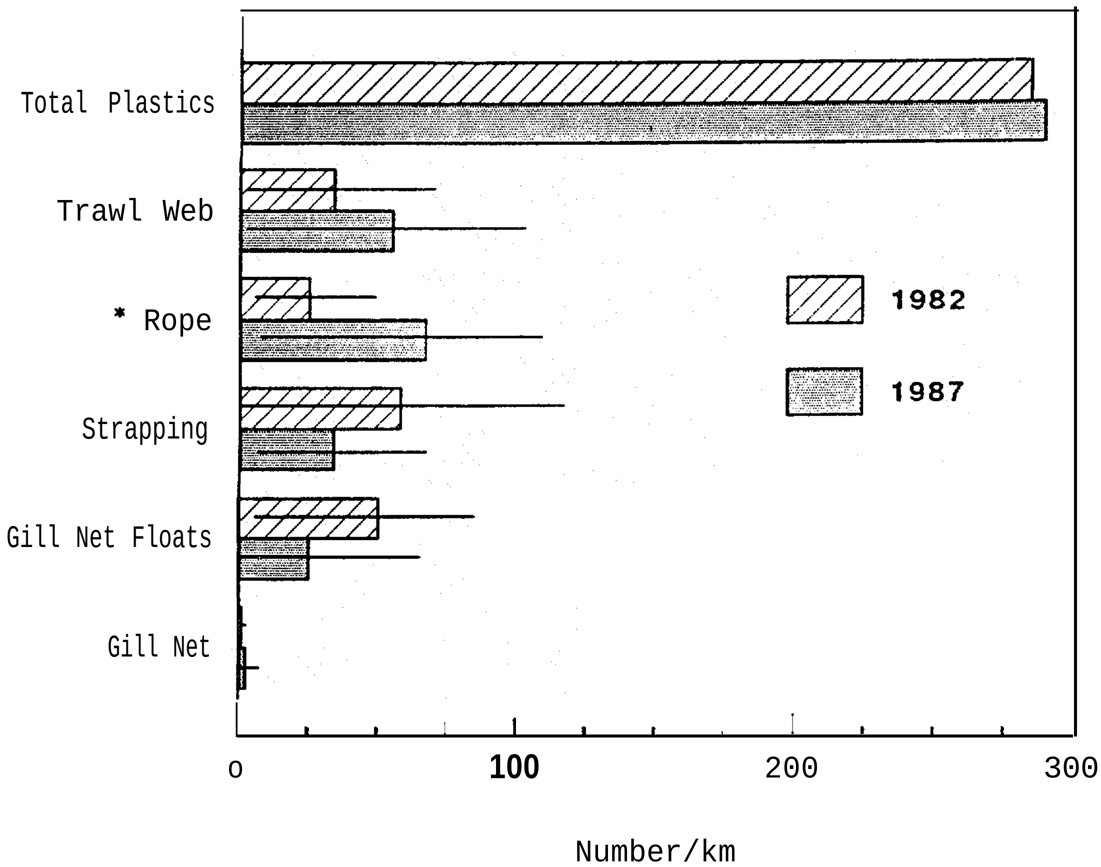

Figure 2. --Quantities (mean ±SD) of entanglement debris and total plastics found on Amchitka Island, Alaska, in 1982 and 1987. Data based on ten l-km beaches. Asterisk denotes significant difference between years $P < 0.05$.

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

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

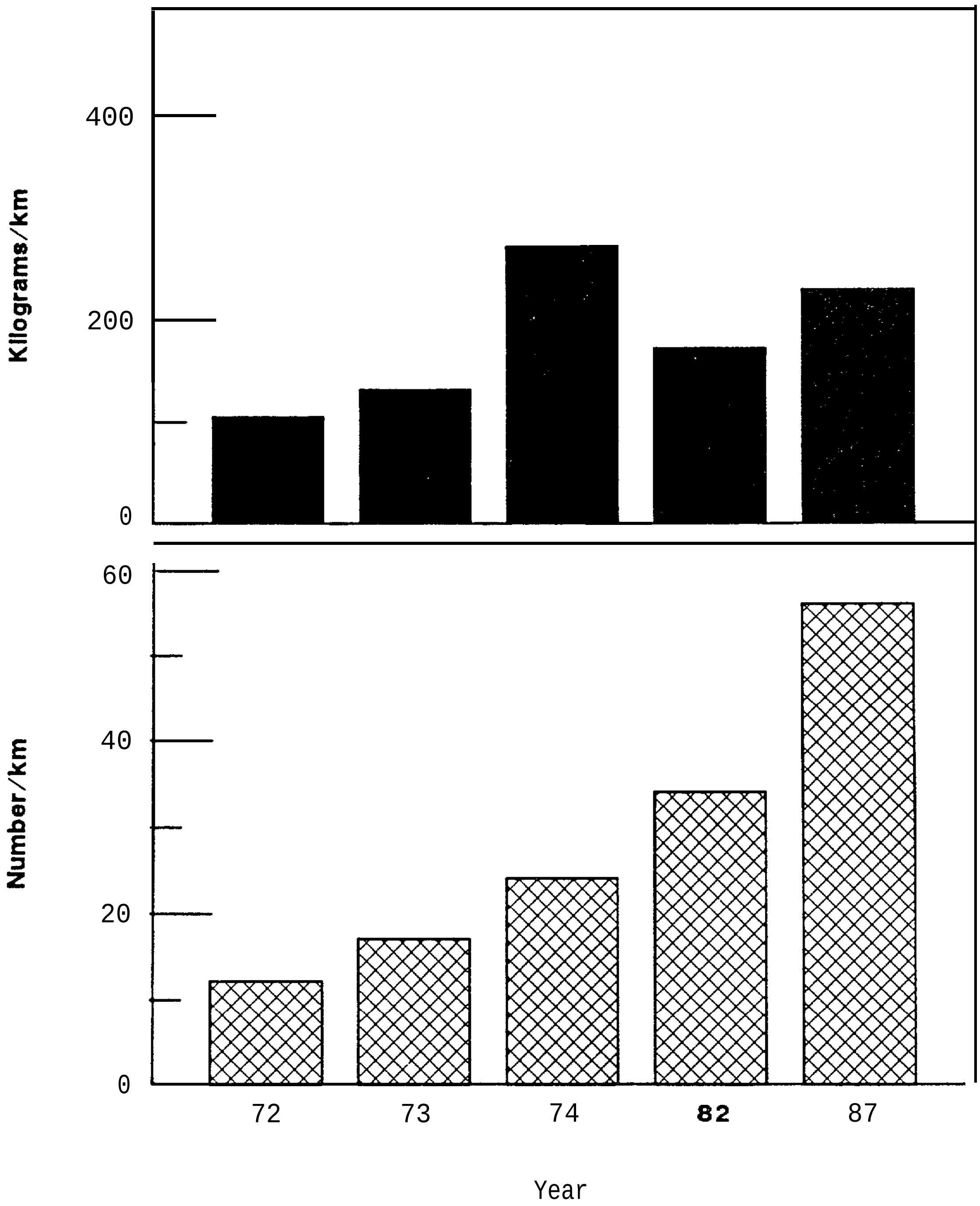

Figure 3. --Number and weight of trawl web fragments found on Amchitka Island, Alaska, from 1972 to 1987. Ten l-km beaches surveyed in each year. Data for 1972-74 from Merrell (1985).

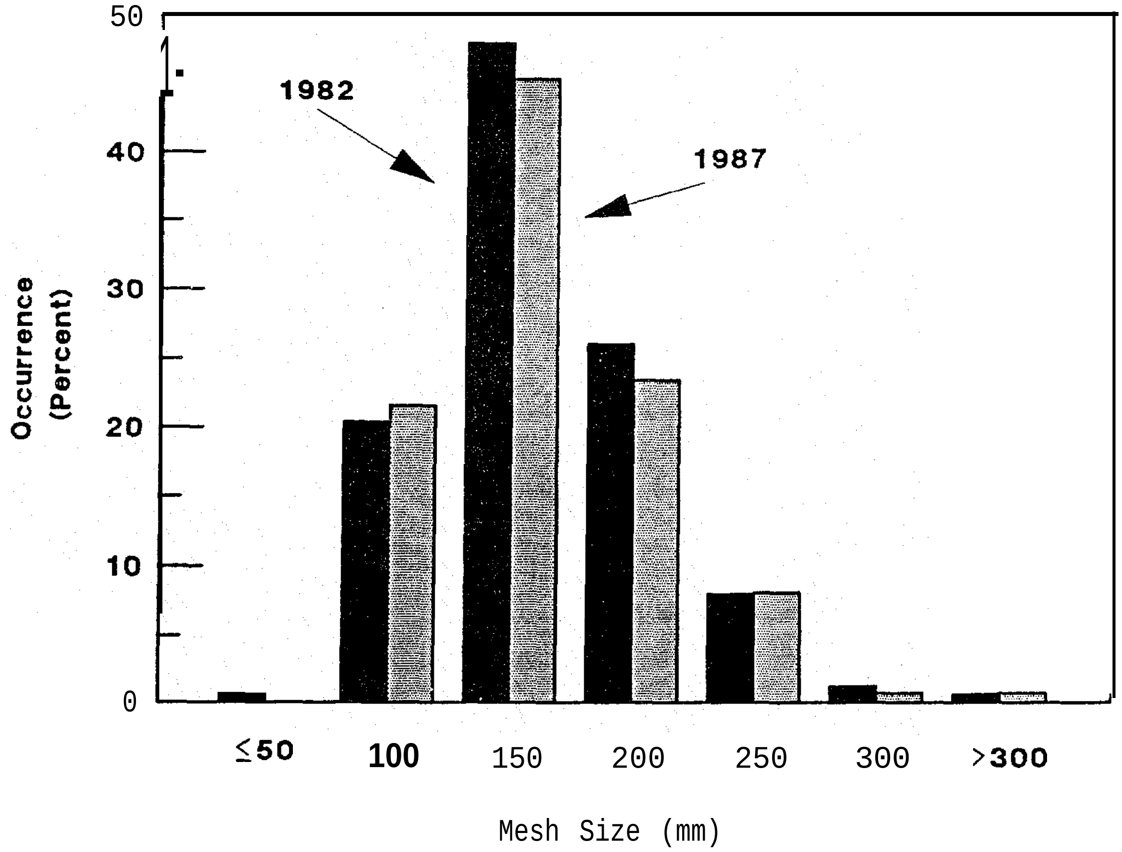

Figure 4.--Percent occurrence of different mesh sizes of trawl web fragments found on Amchitka Island, Alaska, in 1982 (n = 333) and 1987 (n = 282). The X-axis label is upper limit of interval.

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

DISCUSSION

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

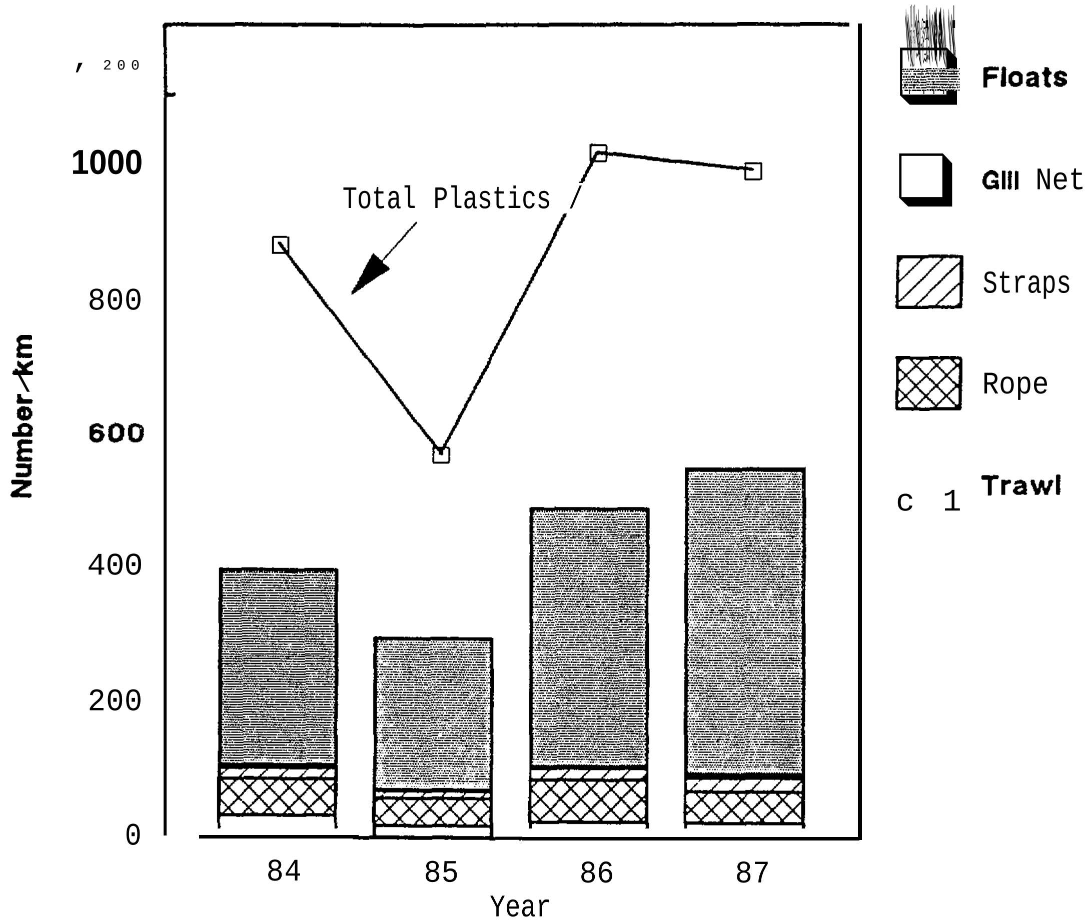

Figure 5. --Quantities of entanglement debris and total plastics found on Middleton Island, Alaska, from 1984 to 1987. Data based on two l-km beaches.

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

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

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

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

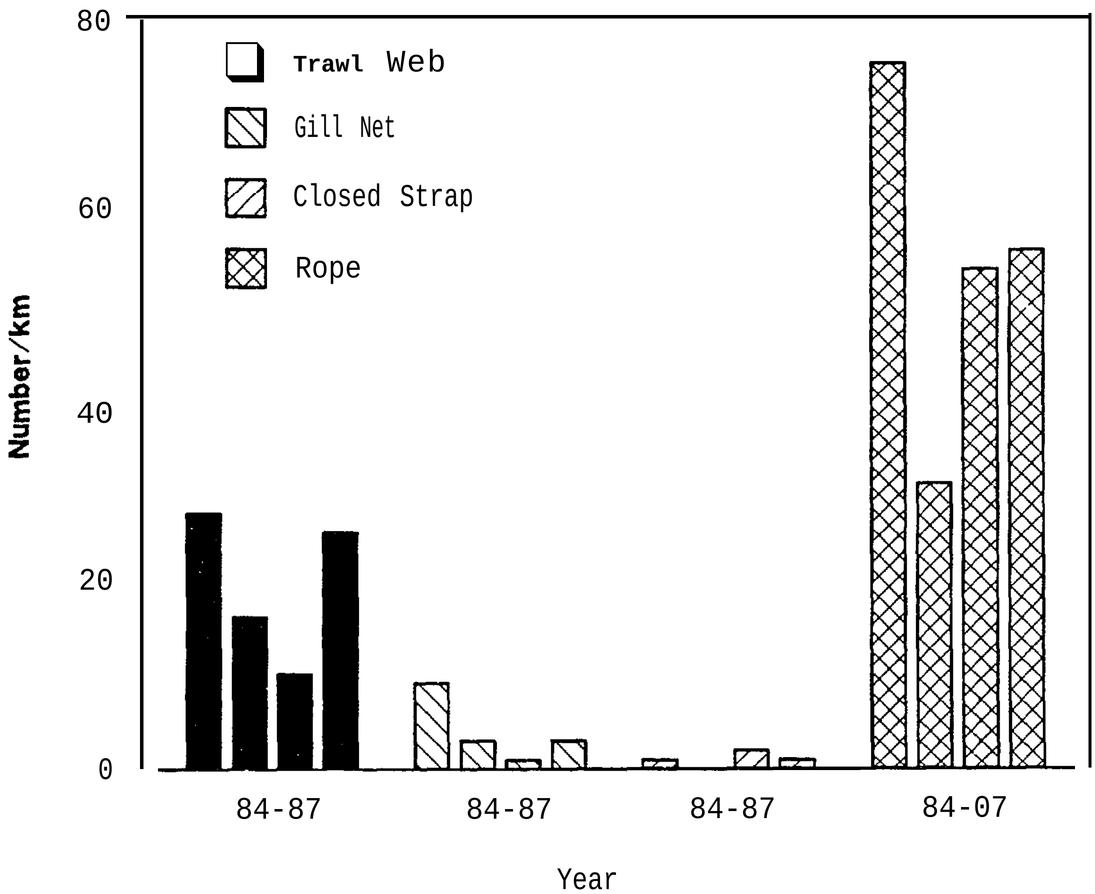

Figure 6.--Accumulation of entanglement debris on a l-km beach on Middleton Island, Alaska, that was cleared of all debris annually from 1984 to 1987.

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

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

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

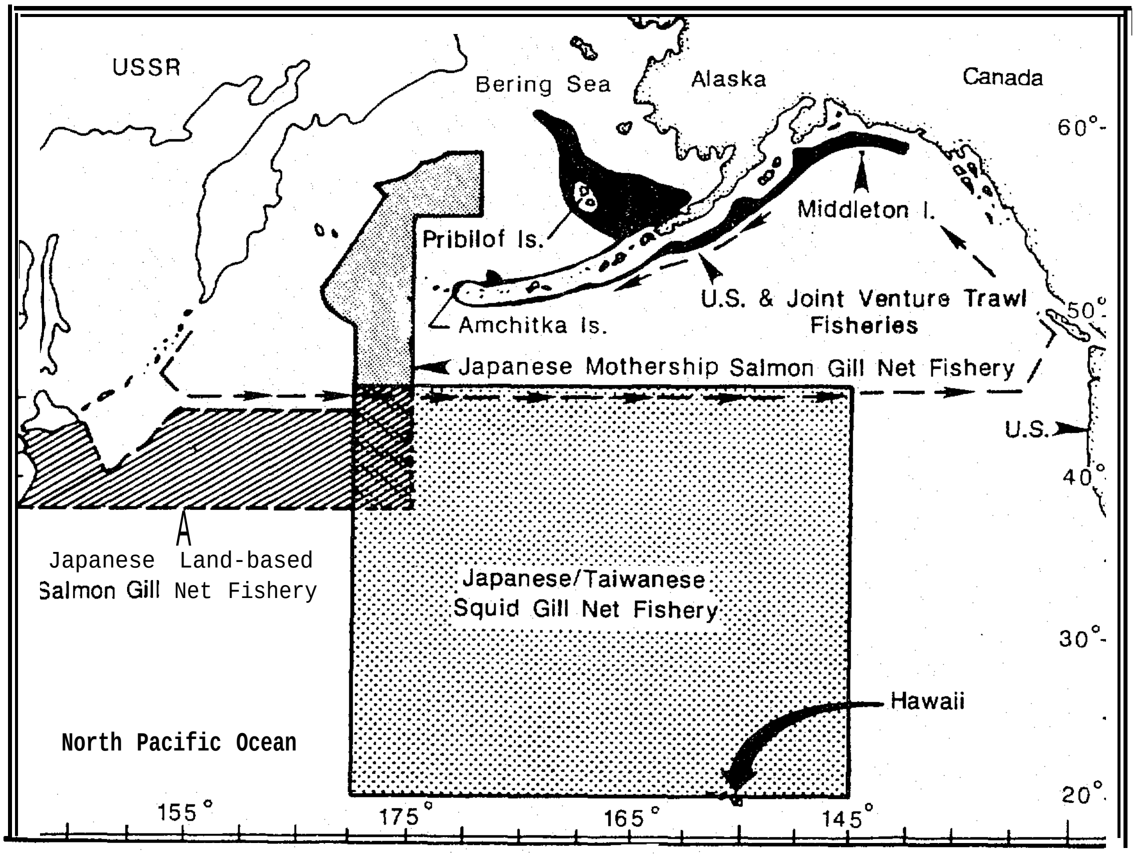

Figure 7. --Major trawl and gillnet fisheries in the North Pacific Ocean and Bering Sea. Adapted from Low et al. (1985) and Merrell (1985). Broken arrows indicate major ocean currents (Reed and Schumacher 1985).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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A SURVEY OF PLASTICS ON WESTERN ALEUTIAN ISLAND BEACHES AND RELATED WILDLIFE ENTANGLEMENT

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ABSTRACT

A 10-day survey of 25 beaches (mean length of beach surveys - 149 m (162 yd)) on seven different islands (Attu, Agattu, Shemya, Buldir, Kiska, Little Kiska, and Adak) in the outer Aleutian Islands was conducted 12-20 July 1988, using the U.S. Fish and Wildlife Service's research vessel MV *Tiglax* as a base. Sites were randomly selected, and beaches were surveyed for all plastic from sea level to high storm tide level. Representative plastic samples were collected and all beaches photographed. Of the total 3.7 km (2.3 mi) of beach observed, 3,153 plastic objects were counted, representing 67 different finished plastic products. Debris was identified from Japan, the U.S.S.R. , South Korea, People's Republic of China, Taiwan, Norway, and the United States. Most prevalent were items from Japan; of those that were identifiable, most were fishing related.

A precipitous decline in the Steller's sea lion, *Eumetopias jubatus*, was noted on Attu Island (77% decrease since 1979), where pinniped surveys were conducted. The results coincide with a reported 65% overall reduction in the western Aleutian Islands population of Steller's sea lions over the past 10 years. Plastics are suspected of contributing to their decline. An adult bull sea lion on Buldir Island was photographed with a strapping band and massive entanglement scar around its neck, with reports of two other entangled, scarred, but live sea lions on Kiska Island, and one on Agattu Island. Some two dozen dead seabirds were discovered during the beach surveys wrapped in plastic although exact cause of death could be ascertained for only one. The *Tiglax* was temporarily entangled in rope from an apparently active brown king crab, *Paralithodes camtschaticus*, pot.

There was a statistically significant difference in the amount of plastic found on beaches in protected coves versus that discovered on open, unprotected beaches. There was also a statistically significant difference in fishing-related versus

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non-fishing-related plastics spotted on the beaches surveyed. If the amount of plastic located on these beaches is at all indicative of that found elsewhere on Alaska's 57,924 km (36,000 mi) of shoreline, plastic debris poses a serious potential problem for fish-and wildlife.

INTRODUCTION

Worldwide, plastics in the marine environment alone have been suggested to be as great a cause of mortality to marine mammals, seabirds, and sea turtles as are oil spills, pesticide poisoning, or contaminated run-off (Schneidman 1987). It is postulated that if all dumping and discarding of plastics were to stop immediately, plastics would continue to wash ashore for at least another 100 years (R. J. Wilber, Sea Education Association, Woods Hole, Mass., pers. commun.).

Reports of the presence and impacts of plastic debris in the North Pacific Ocean are fairly common in the recent scientific, popular, and governmental literature (Manville 1988). From the standpoint of origin, plastic debris can be classified as either land-based or ocean-going. Although attempts have been made to quantify at-sea plastic debris in the North Pacific and elsewhere, these attempts are difficult and yield only rough estimates. Dahlberg and Day (1985), for example, found more than 80% of the debris sighted at sea in the North Pacific to be plastic, with over 33% of this consisting of pieces of expanded polystyrene (e.g., cups, floats, boxes). Their observations were limited to floating debris, however, which does not include plastic materials denser than seawater.

Ignell and Dahlberg (1986) surveyed 7,337 km (3,960 mi) of the central and western North Pacific Ocean, and located 1,802 man-made objects adrift on the sea surface, 61 and 26% of these plastic and Styrofoam, respectively. The proportion of plastic materials they found was consistent with that found by Venrick et al. (1973), Shaw and Mapes (1979), and Dahlberg and Day (1985).

Because of the growing concerns about the aesthetic deterioration of our nation's coastline- -including beaches in the North Pacific Ocean--a number of recent beach cleanup surveys have been conducted (e.g. , Centaur Associates and the Center for Environmental Education (CEE) 1986), but their findings tend to emphasize floatable plastics while often excluding those plastics denser than seawater.

Ghost nets--lost or discarded nets or net fragments, especially drift gillnets--which can continue to fish for years, were reported by Manville (1988) as among the most damaging forms of plastic debris that entangle fish and wildlife in the North Pacific Ocean and elsewhere. The nets sometimes sink from the weight of dead animals, seaweed, or barnacles, and continue to catch fish on the oceans' bottoms. They also may ball up and continue to float, or wash ashore. Also reported were packing bands, six-pack yokes, nets, net fragments, and other plastics which bind and/or strangle virtually every species of marine mammal, sea turtle, seabird, many varieties of fish, and numerous invertebrates (such as lobsters and crabs) .

Fowler (1982, 1987) and Fowler and Merrell (1986) reported that perhaps the best documentation of the results of entanglement in the North Pacific involves northern fur seal, *Callorhinus ursinus*. Extensive data, including the incidence of entanglement scars, were collected from 1967 through 1984 from young male seals killed in the annual commercial seal harvest on the Pribilof Islands, Alaska. These and other data indicated an alarming trend. The population is declining annually at 4-8%; its numbers are now less than half those of 30 years ago. Entanglement, particularly in trawl net fragments, plastic packing bands, and other plastic trash, is believed to be a contributing and perhaps even significant factor in the species' decline. Northern fur seals are presently listed as "depleted" under the Marine Mammal Protection Act, and were recently petitioned for listing as "threatened" under the Endangered Species Act.

While the studies by Fowler (1982, 1987) and others provide the best evidence of wildlife entanglement in plastic debris--especially northern fur seals--and while there is clear evidence that marine debris affects individuals of many species (Manville 1988), Heneman and GEE (1988) felt that evidence of serious population effects on marine wildlife is inconclusive. They cited the fact that few studies had been done on derelict nets or traps, and that while there was clear evidence that entanglement in marine debris kills or injures seabirds, there is no evidence that this is a significant problem for any seabird population. Heneman and CEE's research, however, was not conducted in the North Pacific Ocean.

The Japanese claim that the problem of lost driftnets in the North Pacific is negligible, estimating that only 0.05% of their net sets are lost per operation (the National Marine Fisheries Service estimate is 0.06% (Hinck 1986)). When applied to the setting of more than 32,985 km (20,500 mi) of net per night, plus an additional 16,090-32,180 km (10,000-20,000 mi) of driftnet from Taiwan, South Korea, and others (S. LaBudde, Earthtrust, Honolulu, Hawaii, pers. commun.), a 0.06% loss of net means at least 29-39 km (18-24 mi) of net are lost each night and some 1,542-2,058 km (959-1,279 mi) of *net* each season. These figures do not account for discarded nets or net fragments.

The northern (Steller's) sea lion, *Eumetopias jubatus*, was reported to have declined by about 50% in the eastern Aleutian Islands between 1957 and 1977 (Braham et al. 1980; King 1983), while western Aleutian populations were reported fairly stable or experiencing only moderate declines during that period (Early et al. 1980; Loughlin et al. 1984) . Since 1977, declines continued in the eastern Aleutian Islands (Merrick et al. 1986), but no surveys had been conducted in the western Aleutians from 1979 until 1988. Results from five sites surveyed there in the mid-1970's compared with the 1988 study indicated a 65% reduction in sea lions in the western Aleutians (Byrd and Nysewander 1988). Entanglement was suggested as a possible contributing factor to declines in the eastern Aleutians (Loughlin et al. 1986), but few incidence were reported in the western islands.

Less well known is the status of seabird populations in the Aleutian Islands, and the role plastics may play in affecting these species. Commercial fishing continues to be the largest human activity in the Bering Sea. Factory ships with their fleets of catcher boats stay on location for months processing million of tons of seafood and dumping their wastes in the process (S. LaBudde, Earthtrust, Honolulu, Hawaii, pers. commun.). In Kotzebue Sound north of the Aleutians, data collected in 1977, 1981, and 1987 indicate that the horned puffin, *Fratercula corniculata*, may be experiencing a dramatic 75% decline on Chamisso Island (A. Sowls, Alaska Maritime National Wildlife Refuge, Homer, Alaska, pers. commun.). The cause of the decline is as yet unknown.

While plastic debris has been reported on the beaches of southern Alaska (Nottingham 1988), on the Pribilof and eastern Aleutian chain (Byrd 1984), and as far out in the Aleutians as Amchitka Island (Merrell 1980, 1984), no plastics beach surveys were reported in the literature from the far western Aleutian Islands prior to July 1988.

METHODS

Twenty-five beach surveys were conducted on seven outer Aleutian Islands from 12 to 20 July 1988 using the U.S. Fish and Wildlife Service's (FWS) research vessel MV *Tiglax* as a base. Surveys were undertaken on beaches in the westernmost U.S. islands located in the Near Islands group (Attu, Agattu, and Shemya Islands), Buldir Island, the Rat Islands (Kiska and Little Kiska Island), and the Andreanof Islands (Adak Island, Fig. 1) . Surveys were conducted on an opportunistic basis when the *Tiglax* was either at anchor or was able to stop long enough to deploy us, and when weather and seas were sufficiently favorable to allow beach landings in a motorized, Zodiac inflatable. Beach sites to be surveyed were then randomly selected, and beaches were walked and scanned for all plastic from existing sea level to the storm high tide level/upper wrack line (Wilber 1987) . Representative plastic samples were collected and all beaches were photographed. No attempt was made to assess the amounts by weight or volume of plastics present on the beaches, although the numbers of complete trawl nets and relative amounts of driftnets were noted.

Attempts were made to identify the source of plastic items by linking origin of the product, item, or piece by identifiers which were often embossed, stamped, or molded into the plastic.

Five open-water plastic surveys were conducted while the *Tiglax* was steaming between islands (Fig. 1). Surveys were conducted from either the bridge of the vessel or the flying bridge, looking for floating or drifting plastic visible from the bow of the ship while it cruised at speeds of 8-10 kn. Surveys were conducted for approximately 30-min intervals.

Particular attention was paid to wildlife entangled in plastic. Where such animals were spotted, they were photographed. Carcasses were carefully examined for external evidence of plastic or for plastic entanglement scars. Rough necropsies were conducted on dead seabirds whose crops were intact to determine if plastics had been ingested.

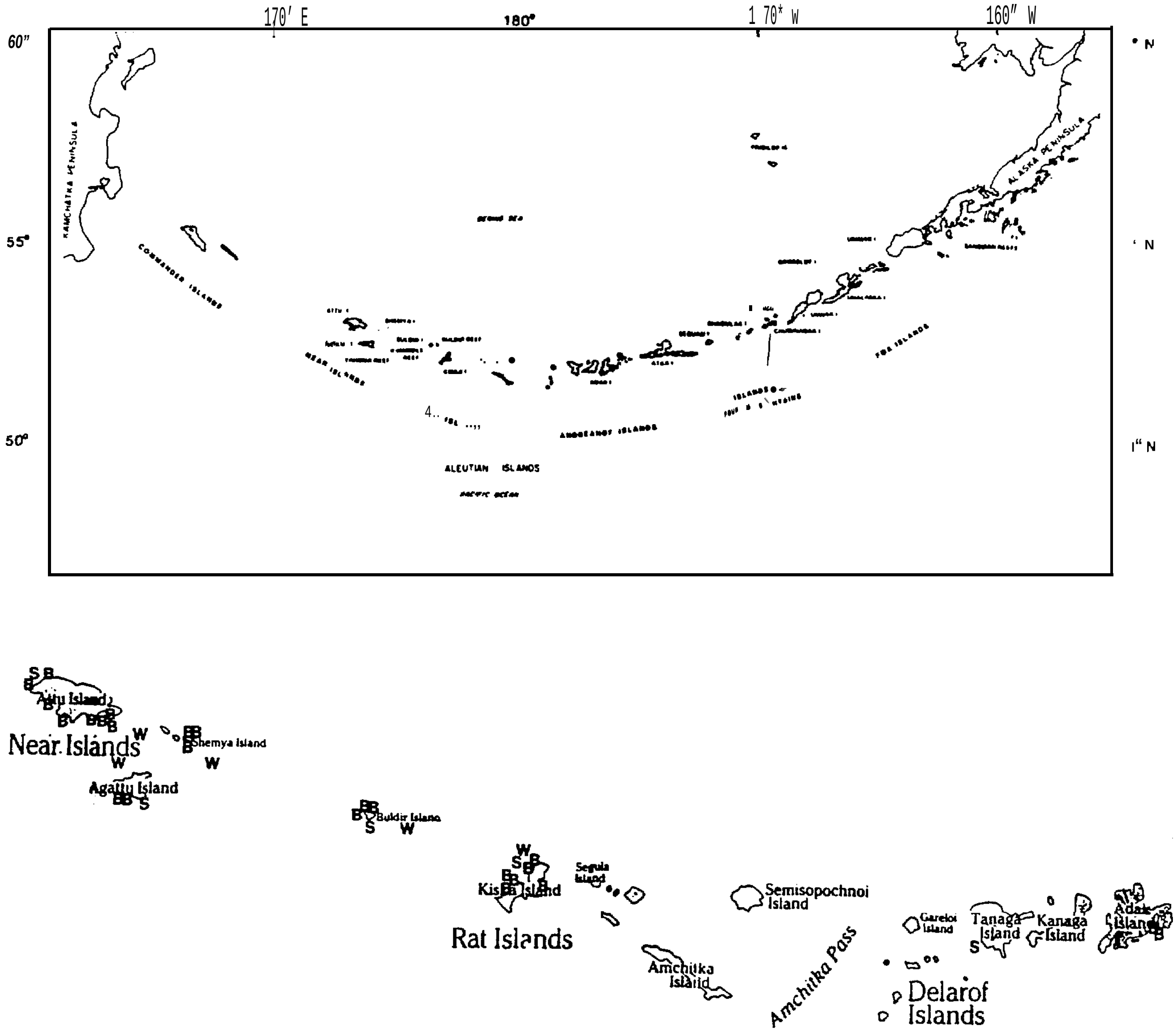

Figure 1. --Locations of 25 beach surveys conducted on 7 outer Aleutian Islands from 12 to 20 July 1988 (B), 5 Steller's sea lion surveys conducted from late June to mid-July 1988 (S), and 5 open-water plastics surveys conducted from 12 to 20 July 1988 (W). Map after Byrd and Day (1986).

Beaches were classified as protected, located in coves, bays, or harbors; or as unprotected, located on promontories, points, or similar areas facing the open ocean. In addition to the presence or absence of protective physical barriers, beach classification also was based on the likelihood of prevailing storm tracks, waves, and weather conditions which could augment accumulation of debris.

The randomization test for two independent samples (for large samples) was used to test the statistical difference in the amount of plastic found on protected beaches versus that discovered on open, unprotected beaches (Siegel 1956). This test was also used to examine the difference between fishing-related and nonfishing-related plastics located on the beaches. Fishing-related debris consisted of material specifically used for fishing, material used in the packaging of fish and fish products, or material used by fishermen during the capture and processing of fish.

Northern sea lion counts were conducted either from land or at sea between approximately 1000 and 1800 on five islands during late June and early July (Fig. 1). This enabled peak bull, cow, and pup counts (Loughlin et al. 1986; Byrd and Nysewander 1988). Uhen counts were made on land within the rookeries, numbers of sea lions were assessed "using spook counts" where one or two researchers drove bulls and cows into the water to facilitate counting the pups still on land. All animals were carefully assessed for signs of entanglement using binoculars and a telephoto-equipped 35-mm camera. Where haul sites and rookeries could be seen from headlands above, such as on Kiska Island, counts were made from land by one researcher using binoculars. Where counts were made from the water, three or four observers stationed 30-75 m (33-82 yd) offshore in a Zodiac inflatable counted all pinnipeds. Where counts were made by more than one observer, replicated tallies were averaged to provide the most representative value for each site. Counts were conducted on Attu, Agattu, Buldir, Kiska, and Gramp Rocks. Counts made in 1988 were compared with those made in 1977 (Day et al. 1978) and 1979 (Early et al. 1980).

RESULTS AND DISCUSSION

Beach Surveys

Twenty-five beach surveys were conducted on seven outer Aleutian Islands from 12 to 20 July 1988. Beach surveys averaged 148 m (162 yd) in length. On the 3.7 km (2.3 mi) of beach observed, 3,153 plastic objects were discovered, representing 67 different finished plastic items. No raw polyethylene pellets (nibs), or spheres or spherules of polystyrene were discovered, although due to time limitations attempts were not made to look carefully for them in the high wrack lines. On the average, 126 different plastic items were found per survey. All beaches examined, including the most protected, contained plastic; at least 15 items were deposited on the cleanest (a protected cove on the south side of Shemya Island).

Most prevalent of the plastic items found on the beaches were rope, Styrofoam driftnet buoys, fishing net (mostly trawl nets, but some driftnet segments) , and bottles (Table 1). Like the beaches of Bermuda and the

Table 1.--Types and incidence of plastics found on 25 beaches of 7 islands in the outer Aleutian Islands, Alaska, July 1988.

No.	Plastic item	Count	No. of beaches with item	Type[a]
1	Rope (piece, complete coil)	706	24	F
2	Styrofoam buoy	535	15	F
3	Fishing net (mostly trawl)	360	24	F
4	Bottle (other plastic)	331	21	N
5	Hard plastic buoy	215	17	F
6	Plastic piece	157	15	N
7	Piece of Styrofoam	148	23	F/N
8	Cap and lid	111	17	N
9	Strapping band	102	21	F/N
10	Fish-sorting basket	61	12	F
11	Bottle (green plastic)	55	15	N
12	Japanese beer crate	49	8	N
13	Bag	35	15	N
14	Shoe	27	10	N
15	Cup, spoon, fork, plate	23	12	N
16	Sheeting (large plastic)	19	11	F/N
17	Sheeting (small plastic)	18	9	F/N
18	Tub	16	2	N
19	Milk jug	15	9	N
20	Jug	14	5	N
21	Glove	12	8	F/N
22	Bucket	11	9	F/N
23	Polyvinyl chloride pipe	11	7	N
24	Soda bottle	9	8	N
25	Monofilament fishing line	9	4	F
26	Hard hat	7	4	F/N
27	Packaging	7	1	N
28	Styrofoam fast food container	6	4	N
29	Insulation for cable	6	3	N
30	Disposable lighter	5	2	N
31	Styrofoam egg carton	4	3	N
32	Styrofoam cup	4	2	N
33	Cable liner	4	2	N
34	Reflector	4	2	N
35	Boot (with plastic parts)	4	1	F/N
36	Brush	3	3	N
37	Six-pack holder	3	3	N
38	Styrofoam cooler	3	2	F/N
39	Insulation	3	2	N
40	Slipper	3	2	N
41	Toy	3	2	N
42	Drift card[b]	3	1	N
43	Container top	3	1	N
44	Gas can	2	2	F/N
45	Styrofoam life ring	2	2	F/N

Table 1.--Continued.

No.	Plastic item	Count	No. of beaches with item	Type[a]
46	Electrical tape	2	2	N
47	Pen	2	1	N
48	Tooth brush	2	1	N
49	Bowl	1	1	N
50	Indoor-outdoor carpet	1	1	N
51	Caulking tube	1	1	N
52	Counter top	1	1	N
53	Dishwasher sprayer	1	1	N
54	Electrical fixture	1	1	N
55	Filter	1	1	N
56	Garbage can lid	1	1	F/N
57	Ice tray	1	1	N
58	Mylar food pouch	1	1	N
59	U.S. Navy sonabuoy container	1	1	N
60	Plug	1	1	N
61	Pump	1	1	N
62	Ring	1	1	N
63	Shower curtain	1	1	N
64	Soap dish	1	1	N
65	Thermos top	1	1	N
66	Trash can	1	1	F/N
67	Watering jug for plants	1	1	N
	Subtotal	3,153		
1	Crab buoy attached to rope[c]	2	--	F
2	Piece of floating Styrofoam[c]	4	--	F/N
	Subtotal[c]	6		
	Grand total	3,159		F - 7 N - 48 F/N - 13

[a]F indicates item is fishing-related; N indicates that it is non-fishing-related; F/N indicates that it is both.

[b]National Marine Fisheries Service drift card.

[c]Items discovered during open-ocean survey while departing north end of Kiska Island, 19 July 1988.

Bahamas, which are heavily littered with plastic delivered from a large Atlantic Ocean circulation pattern known as the central gyre (Wilber 1987), the Aleutian Islands act as "sieves" for plastics circulated by waters from the Japanese and Bering Sea currents. Nevertheless, if the amount of plastic located on these Aleutian Island beaches is indicative of that found elsewhere on Alaska's 57,924 km (36,000 ❑i) of shoreline, there is tremendous opportunity for entanglement or ingestion by wildlife.

Litter was identified from Japan, the U.S.S.R. , South Korea, the People's Republic of China, Taiwan, Norway, and the United States, although most of the plastic could not be specifically related to country of origin. Most prevalent were items from Japan; those identifiable were mostly fishing related.

There was a statistically significant difference in the amount of plastic found on protected beaches versus that discovered on unprotected beaches ($P < 0.001$, df - 23, 22,502; Table 2). There also was a statistically significant difference in the amount of fishing-related versus non-fishing-related plastics located on beaches examined ($P < 0.001$, df - 24, 14,083; Table 1).

Although beaches varied considerably in composition, ranging from sandy to pebbly to rocky to boulder-covered, accumulations of plastic litter were not consistently different among the beaches (Table 2). These findings were consistent with those reported by Merrell (1980, 1984).

When comparing the total amount of plastic (N - 2,457 items) versus Styrofoam (N - 696 items) found on the 25 beaches, non-Styrofoam plastic made up 78% of the waste stream while Styrofoam consisted of about 22%.

Of particular interest was the discovery of a six-pack beverage yoke on each of three remote beaches (Table 2), since I had been asked to look for and testify about them before a joint congressional hearing held after my return to Washington, D.C. , on 26 July (U.S. Government Printing Office (GPO) 1988). One of these yokes was a Hi Cone Eco photodegradable beverage ring (manufactured by Illinois Tool Works), which had not then begun to show any signs of embrittlement.

Open Water Surveys

Five open-water plastic surveys were conducted while the *Tiglax* was underway between islands. One open-water survey on 19 July off the north end of Kiska Island produced two buoys from a brown king crab, *Paralithodes camtschaticus*, pot, one rope from the pot, and four pieces of floating Styrofoam over an 8 km (5 mi) course (Table 1). Even the *Tiglax* was not immune to entanglement plastics. Her hull became ensnared in the rope from an apparently active brown king crab fishing set.

Dead Seabirds

During the 25 beach surveys, some two dozen dead seabirds were located wrapped in, lying next to, or partially entangled in plastic debris,

Table 2.--Amounts of plastic found on 9 protected and 16 unprotected beaches of 7 islands in the outer Aleutian Islands, Alaska, July 1988.

No.	Beach location[a]	No. of plastic items discovered
	Protected	
1	South Side Beach, Shemya Island	15 (s)
2	Scotts Cove, southwest side, Shemya Island	34 (s)
3	Casco Bay, Inlet Beach, southwest side, Attu Island	19 (r)
4	Casco Bay, small subbay, southeast side, Attu Island	18 (S)
5	Casco Bay, small subbay, southeast side, Attu Island	22 (p/r)
6	Casco Bay, another subbay, Attu Island	19 (s/r)
7	Alcan Harbor, northwest boat dock, Shemya Island	37 (r)
8	Sweeper Cove, Adak Harbor, Adak Island	22 (b)
9	Sweeper Cove, Adak Harbor, Adak Island	21 (b)
	Unprotected	
1	Temnac Beach, south side inlet, Attu Island	37 (s/p)
2	Etienne Cove, southwest side, Attu Island	184 (s)
3	Wrangell Beach, Wrangell Point, Attu Island	511 (p/r)
4	Earle Cove, north side, Attu Island	45 (s/p)
5	Karab Cove, south central, Agattu Island	286 (P)
6	Karab Cove, south central, Agattu Island	48 (s/p)
7	North Bight Beach, near base camp, Buldir Island	329 (r)
8	North Bight Beach, sea lion rookery, Buldir Island	63 (r)
9	North Bight Beach, near base camp, Buldir Island	235 (r)
10	Dark Cove, Kiska Island	284 (s/r)
11	Dark Cove, Kiska Island	379 (s/r)
12	Rock beach, north side, Little Kiska Island	64 (r/b)
13	Three-Mile Beach, Kiska Island	31 (b)
14	Three-Mile Beach, Kiska Island	113 (b/s)
15	Three-Mile Beach, Kiska Island	174 (b/s)
16	North Three-Mile Beach, Kiska Island	170 (b)

“Beaches designated as protected were located in coves, harbors, or bays, while those designated as unprotected were located on points, promontories , or areas subject to direct wave action from the open ocean, prevailing storm tracks, and weather conditions which likely augmented the accumulation of debris.

[b]b = boulder beach, p = pebble beach, r = rock beach, s = sand beach.

CA six-pack beverage yoke was discovered on each of these three beaches, but at Karab Cove, Agattu Island, the yoke was a Hi Cone Eco photodegradable carrier.

including trawl nets, a piece of driftnet, and plastic rope. With the exception of one dead sooty shearwater, *Puffinus griseus*, wrapped in a piece of trawl net that appeared to strangle it, it usually was impossible to determine the cause of death, given the decomposition of the majority of the carcasses. A Leach's storm petrel, *Oceanodroma leucorhoa*, however, was discovered in August 1988 on Buldir Island entangled in monofilament fishing line which apparently killed the bird (G. V. Byrd, Alaska Maritime National Wildlife Refuge, U.S. Fish and Wildlife Service, Nome, pers. commun.) .

Field necropsies revealed no ingested plastics in the few birds (a tufted puffin, *Lunda cirrhata*, two glaucous-winged gulls, *Larus glaucescens* , a sooty shearwater, two crested auklets, *Aethia cristatella*, a least auklet, A. *pusilla*, and a common murre, *Uris aalge*, whose crops were intact. More research on seabird mortality needs to be conducted in the outer Aleutian Islands. Plastics are of special concern since seabirds tend to concentrate in areas where current upwellings reach the surface or where tidal rips occur (J. F. Piatt, Alaska Fish and Wildlife Research Center, FWS, Anchorage, Alaska, pers. commun.)--the same areas where ghost nets, drifting plastic debris, and other flotsam may also occur. Although the impacts of lost or discarded fishing gear and other plastic debris have been difficult to quantify, the few data available suggest that lost gear may be as efficient at killing birds and mammals as is active gear (DeGange and Newby 1980; Jones and Ferrero 1985; Piatt and Nettleship 1987).

Northern Sea Lion Counts

Attu Island

Although counts were made for northern (Steller's) sea lions on 8 and 14 July, the second count was made at a more appropriate hour and therefore was considered more representative. A comparison of this 1988 count with the one made in 1979 (Early et al. 1980), shows a precipitous 77% decline from about 5,700 animals *to* approximately 1,300 (Byrd and Nysewander 1988). Cause of the decline is unknown.

Agattu Island

Counts were made in mid-June when harem bulls were at their peak and on 9-11 July after most pups were born. The estimated 1988 count of 3,000 sea lions was less than half the number counted in 1979 (Byrd and Nysewander 1988). One bull was seen with a piece of trawl net fragment wrapped around its neck.

Buldir Island

Twenty-two areas were identified for sea lion surveys at Buldir Island, and June and July counts were made for most of these sites. Less than 1,900 sea lions were counted in 1988, 70% fewer than the 1979 survey (Byrd and Nysewander 1988). I photographed a harem bull with a massive entanglement scar around its neck and the strapping band apparently still present. The animal appeared robust and generally healthy, and maintained a territory with one cow (but no pups) several hundred meters west of the Bull Point Beach sea lion rookery.

Kiska Island

Earlier single counts on Kiska and Tanadak Islands were followed by a mid-July count from land. The overall total for Kiska and Tanadak Islands in 1988 was 2,414 sea lions, a 64% decline from the total seen in 1979 (Byrd and Nysewander 1988). A bull and a cow were seen with deep scars around their necks from previous apparent plastic entanglement.

Gramp Rocks

In 1977, Day et al. (1978) reported sighting over 2,200 sea lions on Gramp Rocks. In late June 1988, over 900 pinnipeds were observed from land, representing a 59% decrease in the population.

Although it was certainly possible that some entangled sea lions were overlooked, those observed represented only a tiny fraction of total population examined. Sea lion populations have declined, probably drastically, in the western Aleutian Islands in the past decade--an overall 65% reduction for the five sites examined--but the reasons for this decline remain unclear. Entanglement has been suggested as a possible contributing factor, especially in the eastern Aleutian Islands (Loughlin et al. 1986; Byrd and Nysewander 1988), but it needs much closer examination in the western Aleutians.

Since pups and juvenile sea lions, like their northern fur seal counterparts, are curious, inquisitive, and playful (King 1983), they may suffer much higher mortality due to entanglement in plastic fishing debris than observed. Since so little research has been done on the sea lions in the western Aleutians, mortality due to plastic entanglement--although suspected by this author to be a contributing factor to their decline--needs more detailed study and analysis.

Presentation of Survey Data at Congressional Hearing

Using data from this study, information was presented at a joint congressional hearing on six-pack yoke legislation on 26 July 1988 (U.S. GPO 1988). Those bills, H.R. 5117 and S. 1986, requiring that six-pack beverage yokes be made degradable within 24 months, were passed by Congress and signed into law late in 1988 by President Reagan.

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ENTRAPMENT OF SEA-DEPOSITED PLASTIC ON THE SHORE OF A GULFOF MAINE ISLAND

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ABSTRACT

During 1987, 300 kg of sea-deposited plastic debris were collected and removed from the 14.45-km shoreline along a wilderness island in eastern Maine. Exactly 1 year later, 124 kg of plastic were collected along the same shoreline. The plastic debris was not uniformly distributed among shoreline habitats. Beach, boulder, marsh, and meadow shorelines were found to catch plastic debris, and ledge shores were found to repel plastic. The western half of the island, facing the prevailing wind, had twice the plastic accumulation of the eastern half.

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

WASHUPS OF FLOATABLE WASTE MATERIALS AND THEIR IMPACT ON NEW YORK BIGHT BEACHES

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ABSTRACT*

During the summers of 1987 and 1988, the New York Bight once again experienced a series of incidents in which waterborne, floatable, waste materials and debris were stranded on area beaches. Medically-related wastes were of particular concern. The sources of floatable wastes are identified and local climatological data are used to explain the process by which floatable material was transported.

The climatology of the summers of 1987 and 1988 are compared with that of 1976, when similar strandings of floatable wastes occurred on the south shore of Long Island. The summer wind records of these years are also compared with the historical wind record, 1959-1988. The basis of these comparisons are measures of wind persistence and relative energy. These analyses indicate the unusual nature of the conditions that prevailed in 1976, 1987 and 1988 and how they differed from each other. During unusually persistent winds, floatable debris in near surface waters can be transported in excess of 100 km in a direction opposed to the general flow over the continental shelf. While major washups of floatable wastes are unusual, we now know under what conditions they are likely to occur. Emphasis must be placed on alleviating the problem at the sources.

*Abstract from "Meteorological conditions leading to the 1987 and 1988 washups of floatable wastes on New York and New Jersey beaches and comparison of these conditions with the historical record." *Estuarine*, Coastal and *Shelf* Science (1990) 30:59-78. Academic Press Limited. London. By permission.

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PLASTIC DEBRIS AND DERELICT FISHING GEAR ON SHACKLEFORD BANKS, NORTH CAROLINA

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ABSTRACT

Surveys of the quantity, type, and source of plastic debris on beaches on Shackleford Banks, Cape Lookout National Seashore, North Carolina, were conducted in December 1986 and September 1987 by the National Marine Fisheries Service Beaufort Laboratory and the National Park Service. Eight l-km beaches established as benchmarks were surveyed and measured using standard beach survey methods developed in Alaska. In 1986 an average 863 items/km of beach were found. Packaging industry items comprised 51%; fishing gear (commercial and sport), 15%; fragments, 14%; maritime industry, 8%; miscellaneous, 7%; and personal effects, 5% of the total debris. Fourteen percent of the debris items were categorized as entanglement dangers, and 55% were categorized as ingestible dangers to marine animals such as the endangered marine turtles: Fishing gear contributed significantly to the entanglement items and packaging contributed significantly to the ingestible items.

In 1987, an average of 1,073 items/km of beach were found, an increase of 25% from 1986. Four transects of beach cleared of all debris in 1986 and resurveyed in 1987 increased 117% from 526 items/km to 1,141 items/km. Composition was similar to that found in 1986. Shackleford Banks ranks high in the amount of plastic debris on its beaches when compared to beaches in Texas, Oregon, and Alaska. Because several species of endangered marine turtles utilize the barrier islands of the southeast United States for nesting, plastic debris may pose a serious threat to their well-being.

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ANTHROPOGENIC AND NATURAL DEBRIS ON A SOUTH TEXAS BARRIER ISLAND BEACH

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ABSTRACT

The results of a long-term study to estimate the quantity of both natural and man-made debris that washed up on the gulf beach of Mustang Island, Texas, are presented. The study beach is 12 km long and has been monitored since 1978 with over 1,800 observations and 4,000 man-hours of observational effort. Four types of debris measurements are made: (1) estimates of 40 different categories of debris and litter using a ranking system (done hi-daily since 1983); (2) counts of some 70 categories of debris items (done weekly since early 1987); (3) quantity (weight) and quality of all debris at three 10-m-wide beach transects (done weekly for 1 year in 1987); (4) counts of four key anthropogenic litter items thought to be typical of four separate sources (done hi-daily for the past year). Method 1 shows seasonal tendencies but is not precise enough to indicate longer term trends. Method 2 gives much more accurate quantitative data but still reveals no trends over the 2-year period. Method 3 reveals associations of anthropogenic and natural material, quantifies "uncountable" items like tar balls, and allows examination of the world of "microtrash." Method 4 shows the short- and long-term variability of litter associated with commercial fishing and offshore oil activities, and material from south of the United States-Mexico border.

Some results of the study to date:

- There is a seasonal variation in quantity of most beach debris--highs in spring and autumn, lows in summer and especially winter.

- Most anthropogenic litter comes from offshore and is identifiable with commercial fishing, recreational boating, offshore drilling and production, and the international merchant marine (items from 60 countries have been found here).

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- Short-term variability is large and is attributable to winds, storms, tides, currents, beachgoing, and beach cleaning activities.

- Despite this variability, anthropogenic debris is a permanent feature of this beach's flotsam and jetsam. Some high counts: Styrofoam 1,100/km, plastic bags 1,000/km, plastics of all kinds 1,600/km, l-gal (3.785 L) milk jugs 50/km, laughing gull 500/km and sanderling 150/km (the two dominant bird species), Portuguese man-of-war 1,200/km, people 25/km. Some high numbers by weight: Sargassum 2,600, tar balls 2,100, driftwood 1,000, plastic debris 140 kg/km.

SOLID WASTE ON THE ISRAELI COAST--COMPOSITION, SOURCES, AND MANAGEMENT

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ABSTRACT

Counts of litter pieces of six Mediterranean Sea beaches in Israel *were* conducted at monthly intervals between May 1988 and January 1989. Litter consisted of 71.6% plastic items, 7.9% wood, 5,7% metal pieces, 3.1% glass, and 11.7% other. Most of the litter, such as beverage bottles, food containers, cosmetics remnants, plastic bags, pieces of garments, and foam rubber mattresses, is related to recreation activity and is therefore land-based garbage. The absence of fishing gear remnants and large food packaging material indicative of ships' garbage, and the sparseness of litter with inscriptions and imprints showing foreign origin, further support the conclusion that most of this garbage is land-based.

This finding contrasts those of similar studies which were carried out on other coasts around the world such as Amchitka Island, Alaska; Helgoland Island, Germany; and the west European shores. There, most rubbish consisted of fishing gear, lavatory cleansers, household cleaners, and containers bearing inscriptions indicative of foreign origin, and is marine-based. The difference in the litter reflects the differences between Israel and the mentioned locations in coastal *use,* ship traffic, and winds, waves, currents, and tide conditions.

The significance of identifying the litter source is that mitigation of this problem in Israel is rather simple because it is easier to control land-based litter than sea-based. There are indications that proper publicity, education, and control will reduce the problem.

INTRODUCTION

During the last two or three decades, there has been growing concern about marine pollution by persistent litter. Most of the reports on this subject deal with litter in the oceans and only a few with coastal litter. Some reports, such as those of Carpenter et al. (1972), Gregory (1977,

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1983), and Shiber (1979, 1987), provided qualitative and quantitative information on coastal garbage; others showed the deleterious effect of the coastal rubbish on seals (Merrell 1980) and seabirds (Schrey and Vauk (1987); and others investigated the sources and fate of the coastal litter (Dixon and Cooke 1977; Merrell 1980; Dixon and Dixon 1981; Vauk and Schrey 1987).

Due to the temperate climate of the Mediterranean Sea and the large number of sunshine hours, its surrounding countries are presently undergoing an intensive development of coastal-oriented tourism. Although coastal pollution is one of the deterrents to tourism, tourism may be important as a contributor of waste to the beaches. Very little information is available on litter pollution of the Mediterranean Sea and its coasts. Shiber (1979, 1982, 1987) reported on the occurrence of plastic beads on the beaches of Lebanon and Spain, Saydam et al. (1985) on floating garbage off Turkey, and Morris (1980) and McCoy (1988) on litter floating in the east Mediterranean.

The gravity of solid waste as a marine and coastal pollutant was recognized by the Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention) which, in one of its protocols, prohibits the dumping into the Mediterranean Sea Area of (among others) ". . persistent plastic and other persistent materials. . . ." In order to evaluate the magnitude of this pollutant in the Mediterranean Sea, the United Nations Environmental Programme has set up a program to monitor solid and persistent litter in the Mediterranean Sea and on some of its coasts. This report is a partial result of that effort.

THE ISRAELI COASTLINE

The Mediterranean coastline of Israel extends for 200 km from the Egyptian border in the south to Akhziv on the Lebanese border in the north (Fig. 1). It is a smooth, slightly curving coastline, with Haifa Bay being the only large indentation in it, and may be divided into two sections. The southern section, from the Egyptian border to Akko, consists of long beaches, 30-50 m wide, covered by fine to medium quartz sand. The northern part, from Akko to the Lebanese border, is mostly a rocky coastline with pocket beaches which are covered by coarse, biogenic sand.

During the winter, alternating high and low barometric pressures cross the east Mediterranean Sea from west to east, subjecting the Israeli shoreline to storms at about a 10-day frequency. During the storms, winds blow from the west and southwest. Before and after the storms, wind direction is generally from the east. During spring and autumn, winds are commonly from the east (land), and during summer, the sea breeze changes from a maximum of 18-20 km/h shoreward at noon to no wind at night and about 6 km/h seaward early in the morning. The mean significant wave height during the winter is 1.1 m, during spring and autumn 0.5 m, and in the summer 0.7 m. The alongshore current during the winter storms is from south to north; whereas during the summer it is mostly from north to south in the study area. Tidal range is approximately 30 cm, and tidal currents are insignificant.

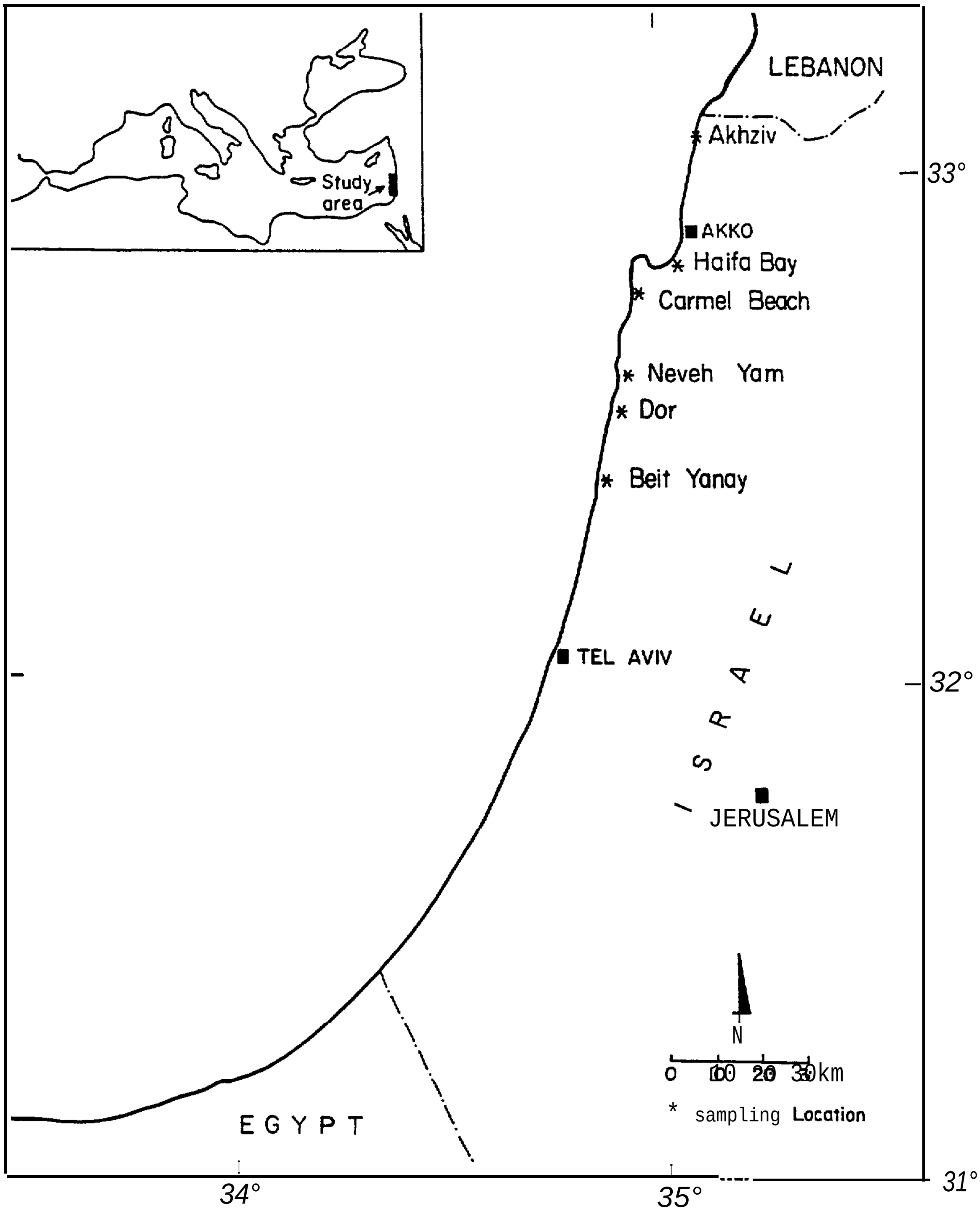

Figure 1. --Station location map.

Some 70 beaches, declared as public swimming beaches, are present on the Israeli coastline. "Declared" beaches are operated by the various municipalities, which are responsible, among other things, for keeping these beaches clean during the swimming season. Though most of the bathers go to declared beaches, undeclared beaches are popular too and are visited by many during the summer. Once or twice a year, the Office of Environmental Quality, together with local councils, conducts a cleanup of almost the entire shoreline of Israel.

The purposes of this study *were* to evaluate the quantity of the coastal litter on the Israeli coastline, to find out if there is any relationship between beach morphology or beach use and litter, to determine whether the rubbish is land-based or sea-based, and to recommend means and ways to treat this problem.

METHODS

Six beaches were selected for this study. They differ in their morphology, sedimentology, and type of use; their locations are given in Figure 1.

On each beach five to eight transects were established. The locations of transects were randomly determined at each sampling date. The transect was 5 m wide, oriented normal to the beach, from the water line to the back of the beach. The back of the beach was determined as the foot of the coastal cliff, the dunes, or the vegetated area. All litter pieces larger than 2 cm found on a transect constituted a sample. Sampling started in May 1988 and continued until January 1989 at roughly monthly intervals, yielding 330 samples.

RESULTS

Because the sampling program still continues as these lines are written, the distribution of litter in space and time will be discussed in the future. Only litter composition is treated here.

The relative abundance of the various litter constituents and the types of materials identified are summarized in Figure 2 and Table 1. The most abundant components are plastic fragments. Most of these are hard plastic ranging in size from 2 cm (the smallest size counted) to 30 cm, and in most cases they could be identified as fragments of plastic containers or bottles. There were also a few straps from large packing crates. Although no special count was made, most of the plastic containers and bottles originally contained beverages, food, and cosmetics (mostly suntan lotion). Only a small fraction of the plastic containers were cleansers or various types of oil related to household or industrial activities. Plastic and metal caps were counted separately, but they came from the plastic containers and bottles and were included under the plastic category. Most of the metal components were tins used for beverages; the rest were either food cans or aerosols. In a similar way the glass fraction was dominated by soft drink bottles, with low numbers of other items such as light bulbs. The wood category included driftwood as well as crate fragments.

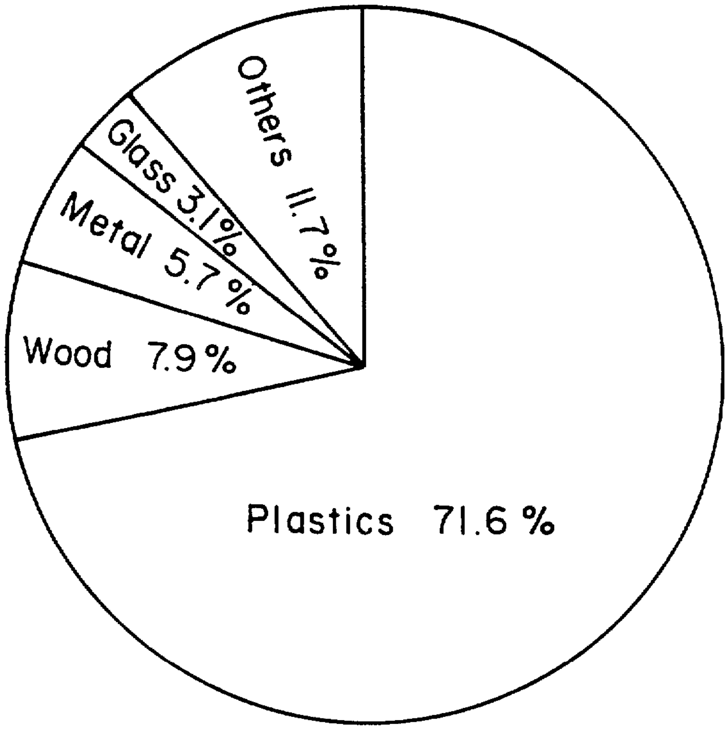

Figure 2. --Relative abundance of litter components.

Items of foreign origin (as indicated by inscription or imprinting) were found in low numbers. Most of these were from Lebanon but a few items with Turkish, Greek, and Spanish inscriptions were found as well. Although items were found at most of our sampling stations, the one in Akhziv, close to the border of Lebanon, contained the most.

DISCUSSION

Rubbish Composition and Sources

Examination of the litter components shows that most of the garbage on the Israeli coastline results from beach recreation activity. This is indicated by the original contents of most of the containers, bottles, and cans (beverages, food, and cosmetics), by the plastic bags used by beachgoers to carry their food and other belongings, by fragments of Styrofoam floats for children who go into the water, by remnants of rubber foam mattresses for lying on the beach, and by the various garment pieces, such as rubber sandals, which are good indicators of beachgoers. Mixed with this, and represented in smaller quantities, is garbage that originated from other sources. This fraction is represented by wood, rope, miscellaneous bottles and containers, and plastic and metal straps.

The absence of fishing gear remnants and packaging material of food in bulk, characteristic of ship litter, is considered to be evidence that most of the coastal litter is land-based. The paucity of foreign garbage pieces

Table 1. --Total litter in sampling stations during study period.

Material	Number of items		Percentage	
Plastic				
Fragments	3,634		31.9	
Bags	2,322		20.4	
Containers and bottles	1,076		9.5	
Caps and covers	1,069		9.4	
Other	40		0.4	
Subtotal		8,141		71.6
Wood		904		7.9
Metal				
Cans	498		4.4	
Containers	90		0.8	
Aerosols	66		0.6	
Subtotal		654		5.8
Glass				
Bottles	308		2.7	
Other	51		0.4	
Subtotal		359		3.1
Other				
Cartons	358		3.1	
Ropes	319		2.8	
Styrofoam	292		2.6	
Garments	234		2.0	
Foam rubber	105		0.9	
Subtotal		1,311		11.4
Total		11,366		99.8

is further evidence of this. Foreign litter on Akhziv beach is a result of the alongshore current which flows during summer mostly from the north and carries the garbage from Lebanon to Israel, thus impacting the northern beaches of Israel. Had it been ships' litter, the whole coastline would have been affected.

Comparison With Litter From Other Coastlines

Merrell (1980, 1984, 1985), who studied the coastal litter in Amchitka Island, Alaska, between 1972 and 1982, found that out of the 24 most common litter items, 12 were used in commercial fishing. In 1974, these constituted 65% by counts, and in 1982, 34%. Merrell attributes the rest of the litter to garbage which was discarded from the fishing fleets in the Pacific Ocean. Vauk and Schrey (1987), who investigated litter on the beach of Helgoland Island in the German Bight, reported that 99.2% of the 8,539 waste items found on the beach were identifiable as ships' waste.

Dixon and Dixon (1981, 1983) report on a series of coastal litter surveys which were conducted in the United Kingdom; the Western Isles of Scotland; Cherbourg Peninsula, France; West Jutland, Denmark; and Portugal. In all instances they noted that the most abundant plastic containers found were for lavatory and household cleaners. Plastic and carton containers for milk were also abundant, but their relative abundance was not the same on all of these coasts. Bottles of mineral water, wine, and soft drinks were found in small percentages. The geographical origins of the containers indicated that many were from countries foreign to the beach on which they were found. In short, most of the litter stranded on the beaches of western Europe is seaborne and has not been brought by people coming for recreational purposes.

The difference between the coastal litter found on the Israeli shore and litter items described above is clear--most of the waste in Israel is of local origin and is related to beach recreation activity, whereas a major proportion of the discussed examples is foreign and related to commercial fisheries and ship traffic. The reasons for this difference are clear. For the islands of Amchitka and Helgoland, the litter production by local inhabitants is negligible in comparison to that which lands from the sea. On western European shores, intensive ship traffic and commercial fisheries produce much marine-based litter which is spread widely by the strong winds, currents, and tide. The input of land-based litter by beachgoers, on the other hand, is rather limited due to the short summer recreation period in these countries. The situation in Israel is the opposite. The summer beach recreation period is long (April-November), ship traffic in the east Mediterranean is much lighter than in the North Sea, the English Channel, and the eastern Atlantic, and winds and currents which may bring garbage from the sea are ❑oderate (see above).

Mitigation of Coastal Litter in Israel

The significance of the findings of this study is that the control of solid waste on the Israeli shore is less of a problem than it is on many other coastlines. Most students of coastal and marine litter problems admit that there is little hope of controlling disposal of garbage from ships in the near future (Dixon and Dixon 1981; Bean 1987). As this source of garbage is limited in the case of the Israeli coastline, the attention there should be focused on those who pollute the beach, namely the beachgoers. This is a matter of culture, and has to be treated with the classical tools of education, legislation, and law enforcement. Indeed various programs to educate bathers to keep the beach clean are under way. Plastic refuse bags are distributed to beachgoers by youngsters, and classes of young students are called for voluntary beach cleaning operations. The idea is that these activities will not only help *to* clean beaches but will also educate children to keep them so in the future. There are signs that this approach will be successful. Figure 3 shows a plastic bag which was filled with garbage by beachgoers who were conscientious not to leave their refuse spread on the beach. However, due

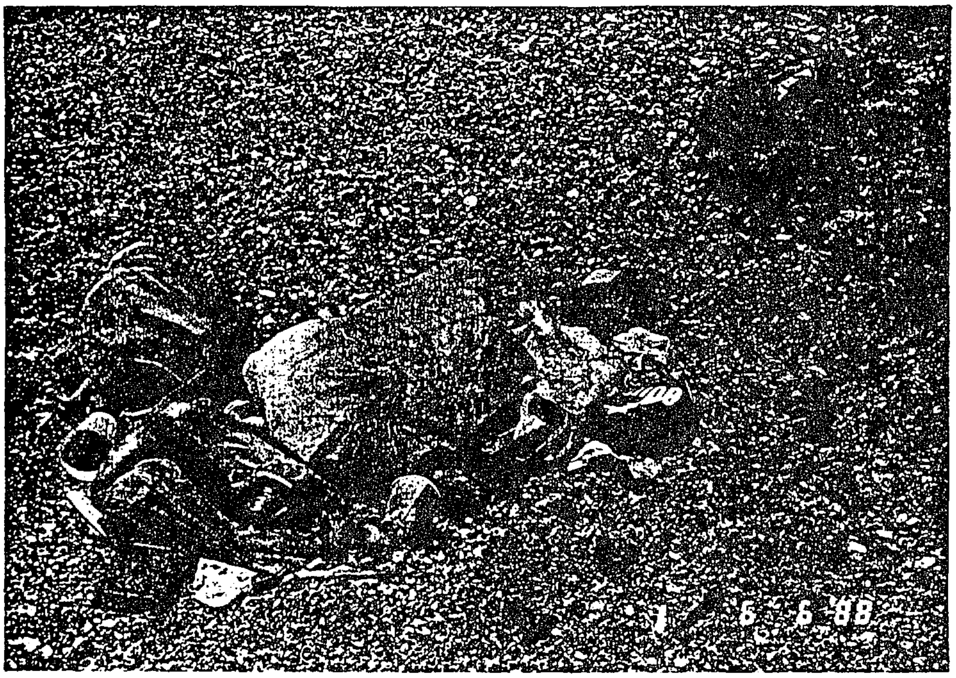

Figure 3.--Plastic bag filled by beachgoers with their garbage to prevent it from spreading on the beach.

to the lack of a nearby trash bin, the bag was left on the beach. A program of placing trash bins on some nondeclared beaches is now under way in Israel.

ACKNOWLEDGMENTS

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NATIONAL MARINE DEBRIS DATA BASE: FINDINGS ON BEACH DEBRIS REPORTED BY CITIZENS

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ABSTRACT

The Center for Marine Conservation (CMC) has established a National Marine Debris Data Base to involve citizens in the collection of standardized information on marine debris. This information collected over time will serve as a means to monitor legislative and other efforts to reduce marine debris.

During the first year of this program, more than 47,500 volunteers in 25 U.S. states and territories recorded detailed information on types and quantities of debris collected during one 3-h period in the fall of 1988. All completed data cards were returned to CMC for analysis.

The data showed that approximately 62% of the 1,973,995 debris items reported were plastic. The most common debris items were fragmented pieces of plastic and foamed plastic (Styrofoam-like). More than 56% of all debris was packaging and disposable plastic products that can be generated by a diversity of ocean- and land-based sources. Using indicator items it was found that approximately 8% of all debris reported was indicative of dumping of galley wastes by vessels, 2% was operational wastes generated during activities conducted by cargo vessels and offshore petroleum operations, 6% was fishing and boating gear, and 0.4% was sewage-associated wastes indicative of inadequate sewage treatment practices. The presence of these indicator items suggests that some of the untraceable debris items may also be generated by these sources. Only 0.09% of the debris was categorized as medical wastes suspected to be from illegal dumping, storm water runoff, or inadequate sewer systems. More than 1,000 debris items from 45 countries were reported, in addition to items traceable to 10 cruise line companies. Volunteers also reported finding more than 45 cases of wildlife entanglement or ingestion of debris, most of which were birds entangled in plastic fishing line.

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INTRODUCTION

More than 47,500 U.S. citizens participated in the first national volunteer effort to categorize the types and quantities of marine debris found in U.S. coastal areas. Information from this citizen monitoring effort was compiled by the Center for Marine Conservation (CMC)--formerly the Center for Environmental Education--in the National Marine Debris Data Base. The data base was established to gather and analyze information collected by citizens at beach cleanups conducted as part of the annual Coastweeks celebration each fall. Sponsored by the U.S. Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration, and the U.S. Coast Guard, the data base was established to utilize the efforts of citizen volunteers to identify specific debris problems in different parts of the country and to monitor the effectiveness of Annex V and other measures implemented to reduce debris. This paper presents information on how the data base was organized and national findings on the types of debris reported the first year. Detailed information on the types of debris reported and analyzed on the national, state, and local level is available from the CMC in a report entitled "Cleaning America's Beaches: 1988 National Beach Cleanup Results."

METHODS

Since 1986, the CMC has compiled extensive information on the types and quantities of marine debris found on the Texas coastline using data collected by citizens during volunteer beach cleanups. Based on these data findings, the CMC has published two reports on the debris problem in Texas which include documentation on the sources of debris and recommendations for Federal, state, and local governments, industry, and other groups to reduce the marine debris problem (Center for Environmental Education 1987, 1988).

In 1988, using the Texas data collection system as a model, the CMC initiated the first national data collection effort. After contacting all coordinators that planned to conduct beach cleanups during Coastweeks '88 (17 September-10 October), 25 states agreed to participate in a national data collection effort. For many of these states, 1988 would be their first cleanup effort and coordinators were eager to obtain information on the types and quantities of debris found on their coastlines. The timing of this national event was also important since the data collected would establish a baseline of information on beach debris prior to the enactment of MARPOL Annex V on 31 December 1988.

In order to produce a data card that would be representative of the types of beach debris found nationwide, the CMC requested comments from beach cleanup organizers as to what types of debris were prevalent on their coastline and what information was needed to evaluate the debris problem on the state and local levels. The CMC had previously developed a data card for use in Texas that reflected the great diversity of debris known to occur on the Texas coastline. (Due to circulation patterns in the Gulf of Mexico, Texas beaches receive the brunt of debris dumped into the Gulf.) Because of this diversity of debris, the Texas data card served as

BEACH CLEANUP DATA CARD

Thank you for completing this data card. Answer the questions and return to your area coordinator or to the address at the bottom of this card This information Will be used in the Center for Environmental Education's National Marine Debris Dara Base and Report to help develop solutions to stopping marine debris

Name ______ Affiliation ______

Address ______ Occupation ______ Phone (___) ______

City ______ State _ Zip ______ M _ F _ Age. ______

Today's Date Month ______ Day — Year ______ Name of Coordinator ______

Location of beach cleaned ______ Nearest city ______

How did you hear about the cleanup? ______

SAFETY TIPS

1. Do not go near any large drums.
2. Be careful with sharp objects.
3. Wear gloves.
4. Stay out of the dune areas.
S. Watch out for snakes.
6. Don't lift anything too heavy.

WE WANT YOU TO BE SAFE

Number of people working together on this data card _ Estimated distance of beach cleaned _ Number of bags filled —

SOURCES OF FOREIGN DEBRIS Please list all items that have foreign labels

Country	Item Found
Example: Mexico	plastic bottle - "Clarisol"

STRANDED AND/OR ENTANGLED ANIMALS (Please describe type of animal and type of entangling debris Be as specific as you can)

______

______

______

What was the most peculiar item you collected? ______

Comments ______

______

Thank you!

PLEASE RETURN THIS CARD TO
YOUR AREA COORDINATOR
OR MAIL IT TO:

Center for Environmental Education
1725 DeSales Street. NW
Washington. DC 20036

A **Membership Organization**

Center for Environmental Education

EPA

NOAA

Figure 1. - -Beach cleanup data card, sides 1 and 2.

ITEMS COLLECTED

You may find it helpful to work with a buddy as you clean the beach, one of you picking up trash and the other taking notes. An easy way to keep track of the items you find is by making tick marks. The box is for total items; see sample below.

egg cartons ~~||||~~ ~~||||~~ ~~||||~~ | Total 16 cups ~~||||~~ ~~||||~~ ~~||||~~ ~~||||~~ || Total 22

PLASTIC

Total number of items

bags:
- trash
- other

bottles:
- beverage, soda
- bleach, cleaner
- oil, lube
- other

buckets

caps, lids

cups, spoons, forks, straws

diapers

disposable lighters

fishing line

fishing net:
- longer than 2 feet
- 2 feet or shorter

floats & lures

hardhats

light sticks

milk, water gallon jugs

pieces

pipe thread protector

rope:
- longer than 2 feet
- 2 feet or shorter

sheeting:
- longer than 2 feet
- 2 feet or shorter

6-pack holders

strapping bands

syringes

tampon applicators

toys

vegetable sacks

"write protection" rings

other (specify)

GLASS

bottles:
- beverage
- food
- other (specify)

fluorescent light tubes

light bulbs

pieces

other (specify)

STYROFOAM® (or other plastic foam)

Total number of items

buoys

cups

egg cartons

fast-food containers

meat trays

pieces:
- larger than a baseball
- smaller than a baseball

other (specify)

RUBBER

balloons

gloves

tires

other (specify)

METAL

bottle caps

cans:
- aerosol
- beverage
- food
- other

crab/fish traps

55 gallon drums
- rusty
- new

pieces

pull tabs

wire

other (specify)

PAPER

bags

cardboard

cartons

cups

newspaper

pieces

other (specify)

WOOD (leave driftwood on the beach)

crab/lobster traps

crates

pallets

pieces

other (specify)

CLOTH

clothing/pieces

(OVER)

Figure 1. -- Continued.

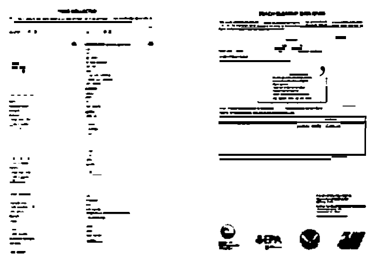
A GUIDE TO GOOD DATA COLLECTION

When you help at a beach cleanup. you'll be asked not only to remove marine debris. but to record on Data Cards the kinds and amounts of trash you find

The Information you record on these cards will be used by The Center for Environmental Education (CEE) in a national marine debris study to help policy makers on the state, federal and international levels develop solutions to ending the serious marine debris problems facing all coastal states

Data collected since 1986 and analyzed by CEE has been used m reports. m testimony on Capitol Hill and at the International Maritime Organization meetings m London to determine how plastic trash will be handled by ships at sea and at ports all around the world

DAIA COUNTS! . . . YOUR HELP WILL MAKE A DIFFERENCE I



HELPFUL TIPS FOR DATA COLLECTORS:

1. Count items m groups of five like this , and record the total m the box.
2. Do not write the words "Lots"' or "'Many" Only numbers of items can be put into the computer.
3. Stranded Animals: In this section, please hst animals you find stranded or dead on the beach and, if possible. any entangling debris Kerns
4. Sources' In this section, please list foreign Items found and country if Identifiable
5. Please leave natural items on the beach like driftwood, sea whip and seaweed. Awid stepping on dune grass and plants. These things hold the sand and prevent erosion.
6. Work with a few people. have one person record the numbers while others collect and bag the trash.
7. Please return your data card to your area coordinator so that all your data will be added to state and national totals.

National Marine Debris Data Base Sponsored By:

Center for Environmental Education

EPA United States Environmental Protection Agency

NOAA

Return this card for future use

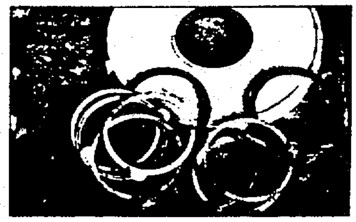
Figure 2.- -Guide used by volunteers for data collection, sides 1 and 2.

GUIDE TO MARINE DEBRIS

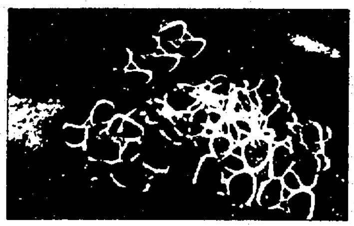
The best data recording can be done if you know what the items listed on your cards look like.

Here are some examples of unusual items you may find.

Light Sticks. Listed under plastic, these clear plastic tubes about 6 inches long are roomy used by fishermen. When new, the liquid Will glow in the dark and attract fish to baited hooks.



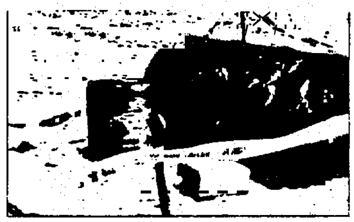
Write Protection Rings. Lined under plastic, these are used on computer tapes on ships doing seismic testing.



6-Pack Rings. Listed under plastic, these items are used to hold cans.

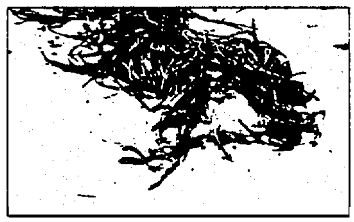
Wooden Pallets. Listed underwood. these Items are used to help stack and transport cargo.

Strapping Bands. Listed under plastic, these strong, —, light-weight plastic bands are used m bind materials and boxes.



55 Gallon Drums. Listed under metal, these drums could contain dangerous chemicals. **Do not** go **near a drum** because the vapor or liquid Could hurt you.

Vegetable Sacks. Listed under plastic, these large mesh bags are used to hold bulk quantities of onions, potatoes, or fruit.



Sea Whip. This yellow, orange or purple colony of animals is long, thin and has a dark string-like core. This may look like wire or rope, but it is a natural item found from North Carolina to the Gulf of Mexico. Please leave this on the beach.

FOR YOUR SAFETY

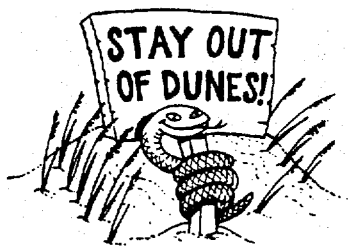
Do not approach any 55 gallon drums. They may contain dangerous liquids. Even me vapor could harm you, Leave the drum, but record it on your card,

Do not go into the dunes: snakes maybe mere.

Be very careful of broken glass and other sharp objects.

Wear gloves

Don't lift anything heavy



THANK YOU for your help and interest In keeping the coast and ocean safe for all of us and for marine wildlife!

Figure 2. - -Continued.

an important model for the subsequent development of a system for categorizing and classifying beach debris on a national level.

The resulting data card was divided into eight major category types--plastic, glass, Styrofoam, metal, rubber, paper, wood, and cloth (Fig. 1). ("Styrofoam" was used instead of the more technical term "foamed plastic" because it was felt that volunteers would more readily recognize this term.) In total, the data card listed 64 types of debris items. In addition, for each major category there was a listing for "other" to ensure that items not listed on the data card were recorded. Data cards also requested specific information on the sources of foreign debris items as indicated by product labels or other markings, observations of entangled or stranded marine wildlife, observations of peculiar debris items, and comments from volunteers.

With funding from the EPA, the CMC distributed 43,000 data cards to cleanup organizers in the 25 participating states and territories. One thousand additional data cards in the Spanish language were sent to Puerto Rico.

The CMC also developed and distributed 43,000 copies of a l-page guide for data collection (Fig. 2). The guide gave information on how to use the data card, identified certain debris items that might not be familiar to volunteers, and explained how this information would be used to compile a national assessment of beach debris. Volunteers were encouraged to work in pairs during the cleanup--one person to pick up trash while the other recorded debris.

Each state beach cleanup coordinator was responsible for distributing the data cards and guides to their volunteers and for returning all completed data cards to the CMC for data entry and analysis. All data were then entered into the CMC's National Marine Debris Data Base and analyzed on the basis of national, state, and local findings.

FINDINGS

More than 47,500 volunteers participated in beach cleanups in 1988 in 25 U.S. states and territories (Table 1). One 3-h cleanup was conducted in every coastal state. While the data collected from these cleanups provided a means to assess the debris problem in marine areas, it also provided interesting insights into the extent of the debris problem in inland waters of the United States.

Beach cleanup volunteers covered more than 5,600 km (3,500 mi) of U.S. shorelines and collected nearly 1,000 tons of debris. The methods used to weigh debris varied from state to state, and therefore the weight of debris collected is not exact. However, it is of interest to note that the greatest amount of trash per mile of beach was reported in the states bordering the Gulf of Mexico, particularly Louisiana, Mississippi, and Texas.

On analyzing the data cards, it became obvious that the number of debris items recorded was only an estimate of the true amounts. Some

Table 1. --Number of volunteers, distance cleaned, and amount of debris collected during 1988 beach cleanups (asterisk indicates information not available).

State	Number of volunteers	Distance cleaned (miles}	Distance cleaned (kilometers)	Debris collected (pounds)	Debris collected (kilograms)	Debris per mile (pounds)	Debris per mile (kilograms)
Alabama	630	40	64	8,340	3,786	208.50	94.66
Alaska	238	10+	16+	10, 300+	4,676+	*	*
California	5,700	1,100	1,770	200,000	90,800	181.82	82.55
Connecticut	14	2	3	190	86	95.00	43.13
Delaware	650	54	87	6,054	2,749	112.11	50.90
Florida	10,676	914.6	1,471.6	388,000	176,152	424.23	192.60
Georgia	268	50	80	200,000	90,800	4,000.00	1,816.00
Hawaii	3,037	102.8	165.4	100,000	45,400	972.76	441.63
Louisiana	2,700	77	124	180,000	81,720	2,337.66	1,016.30
Maine	1,410	114	183	15,200	6,901	133.33	60.53
Maryland	171	18	29	3,750	1,702	208.33	94.58
Massachusetts	2,200	150	241	50,000	22,700	333.33	151.33
Mississippi	1,200	30	48	90,000	40,860	3,000.00	1,362.00
New Jersey	250	15.4	24.8	10,021	4,550	652.41	296.19
New York	150	4.2	6.7	4,560	2,070	1,085.71	492.91
North Carolina	3,500	150	241	94,000	42,676	626.67	284.51
Oregon	2,200	120	193	28,400	12,894	236.67	107.51
Pennsylvania	174	7	11	2,445	1,110	349.28	158.57
Puerto Rico	407	17.3	27.8	12,640	5,739	730.64	331.71
Rhode Island	500	100	161	15,000	6,810	150.00	68.10
South Carolina	3,000	198	319	30,000	13,620	151.52	68.79
Texas	5,987	120.6	194.0	428,000	194,312	3,548.92	1,611.21
Virginia	130	19.8	31.9	12,900	5,857	651.51	295.79
Virgin Islands	435	3.2	5.1	*	*	*	*
Washington	1,904	100+	161	64,000	29,056	540. 00+	245. 16+
Total	47,531	3,517.84	5,660.2	1,953,800	887,025		

volunteers did not count debris items but only commented on the tremendous amounts of debris found. In cases where actual counts were not made, the cards were not added to the data base. But for the most part, volunteers made deliberate and careful efforts to record information. Some who could not identify certain debris items actually sent this trash to the CMC for identification.

Understandably, data collected during volunteer beach cleanups are highly variable and therefore cannot be interpreted exactly, but beach cleanup data can reveal important trends in the relative types, quantities, and distribution of debris. For instance, the data showed that most of the debris found on our nation's coastline is plastic (including Styrofoam). The amount of plastic debris reported surpassed all other categories, accounting for 1,222,708 of the 1,973,995 debris items reported, or approximately 62% (Fig. 3). The remaining debris items consisted of approximately 11.8% paper, 11.4% metal, 9.5% glass, 2.3% wood, 1.8% rubber, and 1.3% cloth. This abundance of plastic debris is also apparent on the state level (Table 2).

The most common debris items reported nationwide were fragmented pieces of plastic and foamed plastic (Styrofoam-like). The data indicate that these plastic pieces accounted for more than 13% of all debris reported. The 12 most common debris items recorded were plastic eating utensils, metal beverage cans, foamed plastic cups, glass beverage bottles, plastic caps and lids, paper pieces (or fragments), plastic trash bags, miscellaneous types of plastic bags (other than trash or salt bags), glass pieces (or fragments), and plastic soda bottles. Collectively, these 12 debris items constituted more than 56% of all debris items recorded (Table 3). Other debris items reported in abundance included approximately 42,700 metal bottle caps, 30,800 plastic six-pack connector rings for

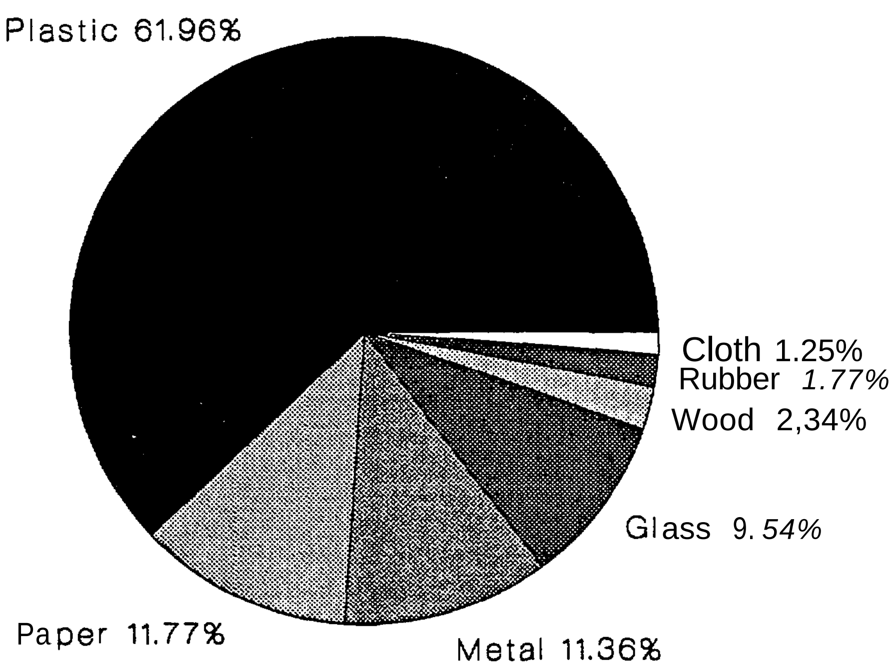


Figure 3. --National composition of debris reported.

Table 2.--Composition of total debris reported during 1988 beach cleanups.

	Percent of total debris collected						
	Plastic	Metal	Paper	Glass	Wood	Rubber	Cloth
National	61.94	11.36	11.77	9.54	2.34	1.80	1.25
			By state				
Alabama	63.48	10.81	10.58	10.21	1.87	1.90	1.15
Alaska	56.45	17.83	6.04	15.79	1.21	1.77	0.91
California	47.97	12.11	19.43	15.86	1.42	2.04	1.19
Connecticut	65.99	7.85	7.70	10.54	3.51	2.69	1.72
Delaware	56.82	15.16	14.02	6.78	2.60	2.88	1.76
Florida	59.67	13.31	11.35	10.27	2.72	1.34	1.33
Georgia	57.42	21.13	7.12	9.26	1.99	1.98	1.10
Hawaii	52.14	11.86	16.70	14.54	1.36	2.22	1.19
Louisiana	74.42	7.37	3.58	9.32	1.71	1.87	1.74
Maine	59.69	10.85	12.38	9.74	2.30	3.60	1.45
Maryland	55.79	21.54	7.38	9.10	2.15	2.59	1.46
Massachusetts	61.03	11.40	14.17	7.06	2.49	2.29	1.56
Mississippi	66.29	12.49	7.45	9.63	2.21	1.08	0.85
New Jersey	94.53	1.66	2.47	0.13	0.13	0.85	0.22
New York	77.63	8.99	6.59	4.15	1.02	0.74	0.88
North Carolina	51.81	13.62	20.23	7.22	4.10	1.63	1.39
Oregon	70.16	5.62	14.98	4.85	1.72	1.60	1.10
Pennsylvania	55.85	10.33	22.92	5.19	1.20	2.35	2.17
Puerto Rico	43.36	19.08	11.54	22.09	2.29	0.58	1.05
Rhode Island	60.63	13.20	13.34	6.96	1.26	3.34	1.26
South Carolina	58.86	11.82	16.71	5.81	4.00	1.69	1.11
Texas	76.54	6.73	3.87	8.58	1.63	1.60	1.05
Virginia	61.42	10.65	8.80	8.87	4.29	4.74	1.22
Virgin Islands	60.36	15.23	6.39	13.12	2.44	1.14	1.33
Washington	57.46	7.12	24.58	8.12	1.24	1.07	0.41

beverage cans, 27,600 small pieces of plastic sheeting, 25,200 paper cups, 22,500 foamed plastic fast-food containers.'

This information indicates that the majority of debris items found on U.S. shorelines are packaging and disposable plastic products that can be generated by a diversity of ocean- and land-based sources. Certain items, however, are traceable to specific debris sources, and can be used as "indicators" of dumping by maritime and other groups. These indicator items were first identified by the CMC in 1986 with the assistance of the Texas Coastal Cleanup Steering Committee, which included representatives of marine industry groups familiar with the types of debris that could be generated by industry members.

Table 3.--Twelve most common debris items reported during 1988 beach cleanups.

Debris item	Total number reported	Percent of total debris collected
Plastic pieces (or fragments)	134,685	6.82
Small foamed plastic (Styrofoam) pieces	125,725	6.37
Plastic cups, spoons, forks, and straws	112,465	5.70
Metal beverage cans	99,847	5.06
Foamed plastic (Styrofoam) cups	95,807	4.85
Glass beverage bottles	95,028	4.81
Plastic caps and lids	90,998	4.61
Paper pieces	85,864	4.35
Plastic trash bags	78,025	3.95
Miscellaneous types of plastic bags	74,672	3.78
Glass pieces	65,819	3.33
Plastic soda bottles	58,116	2.94
Total	1,117,051	56.59

Using this information, 28 indicator items were identified which fall under four categories: 1) galley wastes generated by crew members on vessels, 2) operational wastes generated during activities conducted by cargo vessels and offshore petroleum operations, 3) fishing and boating gear, and 4) sewage-associated wastes indicative of inadequate sewage treatment practices. Table 4 lists the debris items included under each of these categories. A fifth category, medical wastes, was also identified using plastic syringes as the indicator item. Although the source of syringes as beach debris has not been clearly identified, syringes are suspected to be from illegal dumping, storm water runoff, or inadequate sewer systems.

These 28 indicator items accounted for more than 16% of the debris reported nationwide, with approximately 8% galley wastes, 6% attributable to recreational and commercial fishing and boating, and 2% operational-type wastes. Sewage-associated wastes and medical wastes were comparatively less common, accounting for 0.4 and 0.09% respectively. This information should not be interpreted to mean that these are the only wastes generated by specific ocean- and land-based sources. Rather, the presence of indicator items may show that some of the untraceable debris items are also be generated by these same sources.

Furthermore, comparisons of indicator items on the state level showed regional differences in the amount of debris traceable to these sources. For instance, the amounts of galley and operational-type wastes found in states bordering the Gulf of Mexico were much higher than the national figures. On the other hand, while offshore-generated wastes were notably absent on inland beaches on Lake Erie, Pennsylvania, the amount of sewage-associated wastes reported from the Pennsylvania cleanup was six times

Table 4.--Categories and quantities of indicator items used for national assessment of debris reported during 1988 beach cleanups.

Category	Indicator items	Total number reported
Galley wastes	Plastic trash bags	78,025
	Plastic milk and water gallon jug	26,148
	Plastic bleach, cleaner bottles	19,300
	Foamed plastic meat trays	14,721
	Foamed plastic egg cartons	9,526
	Plastic vegetable sacks	6,770
Subtotal		154,490' (7.83%)
Fishing or boating gear	Plastic rope	47,786
	Plastic fishing line	16,563
	Plastic oil and lubricant bottles	12,002
	Plastic light sticks	9,307
	Plastic fishing nets	8,136
	Foamed plastic buoys	7,876
	Plastic floats and lures	5,980
	Rubber gloves	5,748
	Plastic salt bags	3,797
	Wooden fish and crab traps	1,309
	Metal fish and crab traps	1,281
Subtotal		119,785 (6.07%)
Operational wastes	Plastic strapping bands	11,665
	Plastic sheeting-longer than 60 cm (2 ft)	7,383
	Glass light bulbs	6,905
	Plastic pipe thread protectors	5,084
	Write-enable protection rings	3,054
	Fluorescent light tubes	2,209
	Wooden pallets	1,737
	Wooden crates	1,075
	Plastic hardhats	857
Subtotal		39,969 (2.03%)
Sewage-associated was tes	Plastic tampon applicators	7,584 (0.38%)
Medical wastes	Plastic syringes	1,718 (0.09%)
Total number of indicator items		343,546 (16.39%)

greater than the national figure, indicating that inadequate sewer systems were a problem in this area.

By noting product labels and other markings, volunteers also reported more than 1,000 foreign label items from 45 countries. In addition, debris from 10 cruise line companies was reported.

Finally, during the 3-h beach cleanup, volunteers reported finding more than 45 cases of wildlife entanglement or ingestion of debris. Of these, more than 40 were birds, most of which were entangled in plastic fishing line.

DISCUSSION

Due to the diversity of debris items and their multiple uses, data collected during beach cleanups cannot realistically be used *to* estimate total amounts of debris found in marine areas or the exact sources of debris items. However, comparison of relative amounts of debris can reveal important national, state, and local trends in the types and distributions of beach debris. In particular, the first year of the National Marine Debris Data Base demonstrated that plastics account for the majority of waste on our nation's shorelines. Having established a baseline of information on the types and quantities of plastic waste, future beach cleanups can help *to* monitor legislative and other efforts to control the discharge of plastic trash into marine areas.

By monitoring the presence of indicator items, citizen beach cleanups can also serve to identify what groups are not complying with offshore dumping regulations. This type of information is especially important for developing solutions to the debris problem on the state and local levels.

The great majority of items reported during beach cleanups, however, are virtually untraceable to their specific sources. Yet this information contributes greatly to the underlying theme of a beach cleanup--increased awareness. Since much of this debris consists of items that are used by the general public, those who participate in beach cleanups learn that marine industries are not the only sources of marine debris and that the solution lies with us all. Others who do not participate in beach cleanups hear about data results in the press and media and may consider proper disposal of their trash. Finally, it is hoped that those who manufacture *or* distribute products that are reported as debris will realize the need to initiate and support efforts that encourage proper disposal and prevent these items from becoming debris.

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GUIDELINES FOR THE DESIGN OF BEACH DEBRIS SURVEYS

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ABSTRACT

Beach surveys give valuable information as to the types, quantities, and sources of marine debris floating at sea. With the passage of Annex V of MARPOL, however, a decrease in marine debris needs to be detected to demonstrate the effectiveness of mitigating legislation. In order to detect a decrease in marine debris washed ashore, beach survey methodology will need to be standardized. Standardization of survey methods based upon the authors' experience in Alaska is discussed, as is the design of beach surveys to detect between 30 and 50% decreases in the amount of marine debris washed ashore after 5 years, with 95% confidence and power of 80%. Preliminary findings suggest that the number of surveys of a given beach needed to detect a 50% change will be large (bimonthly surveys for 5 years). Annual surveys have low power for detecting a 50% decrease after 5 years, although this result depends on estimates of within-beach variability. Hopefully, this proposal will lead to a discussion of standardized methodology for marine debris beach surveys and the detection of change.

INTRODUCTION

Plastics and other synthetic materials discarded at sea constitute "marine debris" and are now recognized internationally as a form of marine pollution. There is no consensus, however, on how to monitor marine debris after it has washed ashore. Standardized protocols for monitoring other

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

pollutants have been established; examples are tar ball pollution (IOCARIBE 1980) and chemical pollution (Kullenberg 1986). Developing standardized methods will make planning easier and comparison between areas more meaningful.

One of the easiest and most cost-effective methods for arriving at an index of marine debris pollution is the beach survey (Dixon and Dixon 1981; Merrell 1985), The use of beach surveys as indices of floating marine debris, however, requires planned surveys with a clear statement of objectives and assumptions.

This paper has two objectives: (1) to outline the steps involved in planning a beach survey, and (2) to consider two different sampling designs for detecting a decrease in marine debris following the implementation of MARPOL Annex V.

METHODS

A literature review was conducted to identify all published papers on the subject of beach surveys of marine debris excluding tar. Tar pollution was excluded because of the widespread use of standardized techniques to census tar balls on beaches (IOCARIBE 1980). Studies were divided into two groups. The first group focused on describing marine debris on the study area. The second focused on using the beach survey as an indicator of floating marine debris. Next, for all studies, we checked whether the entire beach was surveyed or only portions (transects) of it. Studies were then put into a conceptual framework proposed for planning beach surveys.

The design of surveys to investigate the effect of mitigating legislation (MARPOL Annex V) to reduce the input of debris into the ocean was based on intervention analysis of time series (Hipel et al. 1978; Lettenmaier et al. 1978; Barnard et al. 1985). We also considered a repeated measures l-factor experimental design (Myers 1972) as a second design.

First, we were interested in determining the sample size (number of surveys) needed over 5 years *to* detect a 30 to 50% change in the amount of marine debris with power (probability of detecting the change) of 0.80 and an alpha of 0.05. An estimate of the variance between years was based on data in Merrell (1985) for Amchitka Island 1972-74. This estimate was used to translate the percentage change into trend or standard deviation ratios needed to use the graphs in Lettenmaier et al. (1978). We also considered the effect on power of changing sample sizes in detecting a standardized difference of 1 standard deviation (45% change) over 5 years for alpha - 0.05 and alpha = 0.20. In all cases, gamma, the ratio of number of samples before mitigation to total number of samples, was 0.15 or 0.20. Lettenmaier et al. (1978) showed that gamma should be small for the linear intervention model we used.

Secondly, we were interested in the power associated with doing annual surveys for 5 years and detecting a change between 20 and 50% and an alpha of 0.10. Power was taken from Cohen (1977). For Amchitka Island, an estimate of within-beach variability was calculated from Merrell (1980) for 1972-74 and a mean of 361 pieces of debris per kilometer (Merrell 1984) was used to translate percent change into pieces of debris per kilometer. For the Yakutat area, an estimate of within-beach variability was calculated from data collected 1984-87, and a mean of 205.95 pieces of debris per kilometer was used to translate percent change into pieces of debris per kilometer.

RESULTS

General Beach Survey Design Considerations

The process of beach survey design is summarized in Figure 1. From the published literature, most beach surveys have been short term (one-time surveys) and focused on a single study area (individual beaches) (Cundell 1973; Gregory 1977, 1978, 1983; Bigg 1982; Gregory et al. 1984; Neilson 1985; Willoughby 1986; Henderson et al. 1987; Center for Environmental Education 1988; Marine Plastic Debris Task Force 1988). This focus on the shoreline or beach has led to massive volunteer efforts to clean beaches with little or no reporting of data. These types of studies are valuable for cleaning beaches and gathering information on the types and composition of debris on various coastlines. But quantitative analysis of such data is restricted due to small sample sizes (an annual cleanup means that the sample size is 1) and missing data (especially where data are voluntarily reported) .

Few studies stated that their objective was to use the beach debris surveys as an index of floating marine debris, Most studies using beach surveys as an index of oceanic debris were European (Dixon and Cooke 1977; Dixon and Dixon 1981; Shell UK 1985; Federal Republic of Germany 1986; Vauk and Schrey 1987). In the United States, the only published program using beach debris surveys as an index of marine debris is that of Merrell and Johnson in Alaska (Merrell 1980, 1984, 1985; Merrell and Johnson 1987; Johnson 1988; Johnson and Merrell 1988).

In all cases, a precise definition of the sampling unit is needed (Fig. 1). The natural unit is the entire beach from the water's edge to the seaward limit of terrestrial vegetation. In Alaska, most beaches surveyed are 1 km long (Merrell 1985). In England, Dixon and Dixon (1981) used transects, noting that there was too much debris to be totally counted. Where possible, we propose that the entire beach be the survey unit, with results standardized to length (e.g. , debris per kilometer). In all cases, the same sampling units should be surveyed over time to minimize variability between surveys.

Before the actual sampling units are chosen, it is best to survey the area of interest to determine beach characteristics and debris distribution (Fig. 1). This is where massive volunteer cleanup efforts can be utilized to help plan the study. It is important to know substrate type, beach slope, prevailing winds, ease of access, and recreational use of the area (Dixon and Dixon 1981; Merrell 1985). Depending upon one's objective, all these factors can influence the choice of beach. Preferred beaches are

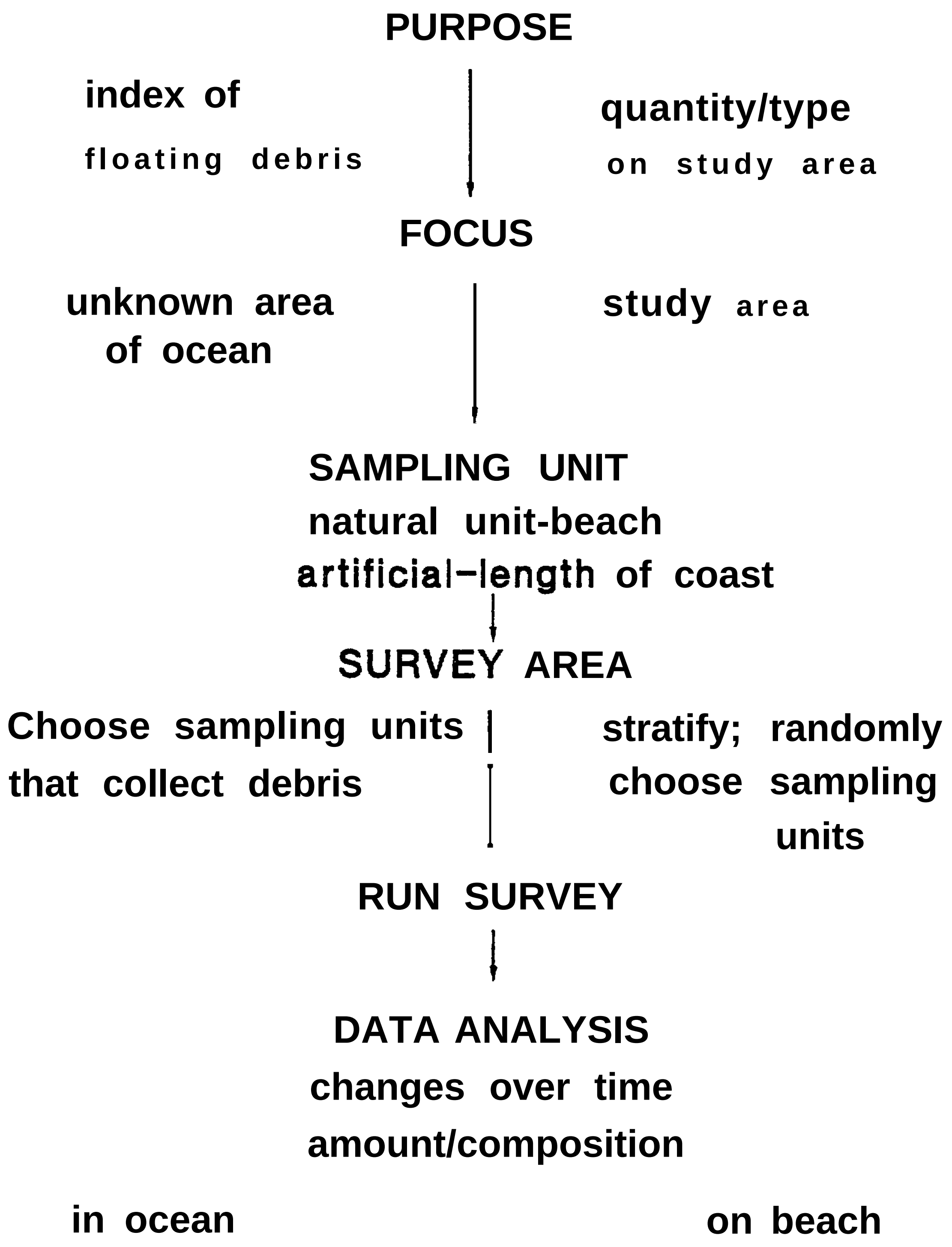

Figure 1. - -Steps in the design of beach surveys.

moderate-to-steep sand or gravel beaches that are exposed to open ocean. Beaches should have 1 km of similar substrate and scope and be as far as possible from urban areas to minimize bias from local refuse.

Analysis of beach survey data depends on the purpose of the study as well as on the method of data collection. For example, Henderson et al. (1987) examined the distribution of net fragments on the beaches of the Northwestern Hawaiian Islands because they were interested in the location of the debris within the beach. Comparisons between years for beaches is possible with the following caveat. The common statistical tests such as t-tests and analysis of variance (Zar 1986) are not appropriate here because the same beaches are censused over time. The more appropriate techniques are paired-t tests, repeated measures analyses of variance, and their nonparametric equivalents (Conover 1980; Zar 1986). The use of time-series analysis is not appropriate because of the extremely low sample sizes usually found in these studies.

If the focus of the study is an index of floating marine debris, changes over time are of interest but the change is for an unknown area of ocean (Fig. 1). It is not appropriate to extrapolate to other beaches. Merrell (1980) stated that he had problems in extrapolating debris abundance to other beaches.

Beach Surveys as Indicators of Oceanic Debris

There are at least two important assumptions made when using beach surveys as indicators of floating marine debris (Ribic and Bledsoe 1986). The first assumption is that the debris at time t (the first sampling period) is not the same debris as that at time t+1 (the second sampling period). In other words, the same debris is not counted twice. The easiest way to fulfill this assumption is by clearing the beach of all surface debris after each survey (e.g. , Cundell 1973; Shell UK 1985; Federal Republic of Germany 1986; Henderson et al. 1987). Sometimes this is not practical, especially when debris (e.g., trawl web) is partially buried or snarled on drift logs. In this case, debris can be tagged (Johnson 1988) for identification on later surveys. Tagging studies can provide information on minimum time between surveys as well as information on the loss and deposition rates of beach debris.

The second assumption is that the amount of debris on a beach is related to the amount of debris floating in an unknown area of ocean, and that this area is the same between surveys. In other words, the oceanic area swept onto the beach, when integrated over time, is the same between surveys. This is an important assumption if we want to conclude that a decrease in beach debris over time is due to mitigation measures and not due to a change between years in the area swept onto a beach. We would encourage a study of this assumption if beach surveys are to be useful as indicators of marine debris.

Detecting Change Due to Implementation of Legislation

We will model the potential impact of mitigating legislation (MARPOL Annex V) on the quantity of marine debris washed ashore with the simplest model: A gradual linear decrease in marine debris over time after the enactment of the law.

An extremely high survey effort over years will be needed to detect any decrease between 30 and 50% (Table 1). For a 45% decrease, a sample size of 180 translates into a beach survey 3 out of 4 weeks per month per year for 5 years. Detecting a 50% change would call for almost biweekly surveys every month for 5 years. However, the probability of detecting a 45% change is nil using annual surveys and is low using quarterly surveys (Table 2), i.e., the change would have to be so drastic that no statistics would be needed to notice it.

Using a different approach, we looked at treating annual debris counts as a repeated measure on beaches. An estimate of within-beach variability for Amchitka Island was 203 pieces of debris per kilometer. For the Yakutat area, an estimate of within-beach variability was 57 pieces of debris per kilometer. We then calculated minimum and maximum power for changes between 20 and 50% (Table 3) at alpha - 0.10. For Amchitka Island, the probability of detecting any change was low due to the high variability within beaches. Detecting a change of 50% with annual surveys has a power as low as 0.43-0.76 (Table 3). For the Yakutat area, however, the probability of detecting a change of 40% or more using annual surveys was between 0.50 and 0.95 (Table 3). This is due to the low within-beach variability.

DISCUSSION

We are just beginning to realize the magnitude of the marine debris problem. In order to quantitatively assess the problem, standardized beach surveys can be used. Standardization of methodology will make comparisons between areas easier and will ensure the validity of estimates.

It is important for researchers to state explicitly the objectives of their beach debris surveys. Whether or not a survey will be used as an index of floating marine debris affects the survey design from the choice of a particular sampling unit to the data collection and analysis.

A key assumption in using beach surveys to detect a difference due to mitigation is that the area of ocean swept onto the beach is constant between years. Firm conclusions about the effect of mitigating measures in decreasing floating marine debris based on beach debris surveys depend on this assumption. An attempt, therefore, should be made to evaluate its reasonablenesss.

Beach debris surveys are useful for determining the types and quantities of debris as well as entanglement potential. But the use of beach surveys to detect change with any degree of confidence and power will be more difficult. Preliminary sample size estimates are large for detecting a 50% decrease (power of 0.80; alpha - 0.05). Whether or not annual surveys will be adequate for detecting a 50% change (alpha - 0.10) depends on the estimate of within-beach variability. On Amchitka Island, variability on the same beach is large, and annual surveys will not be adequate for detecting a 50% decrease. In the Yakutat area, however,

Table 1. --Required sample sizes for detecting changes between 30 and 50% of beach debris for alpha - 0.05, power - 0.80, gamma - 0.20, and an estimate of variability - 103.429 pieces of debris per kilometer for a linear intervention model. n - total surveys spread over 5 years.

Percent change	Standardized difference	n
30	0.71	1,000
40	0.95	200
45	1.1	180
50	1.2	100

Table 2.--Probability of detecting a 45% change over 5 years (power) with a gamma - 0.15.

	Power	
	alpha	
n	0.05	0.20
5 (annual)	<0.10	<0.10
20 (quarterly)	0.20	0.45

Table 3. --Minimum and maximum power for a one-factor repeated measures design with alpha = 0.10 and k - 5 for detecting changes in beach debris between 20 and 50% for Amchitka Island and Yakutat beaches.

Percent change	Amchitka Island		Yakutat	
	Minimum	Maximum	Minimum	Maximum
20	0.14	0.22	0.20	0.34
30	0.22	0.38	0.33	0.63
40	0.30	0.58	0.52	0.87
45	0.46	0.67	0.61	0.94
50	0.43	0.76	0.71	>0.94

within-beach variability is lower, and annual surveys have a chance of detecting a 50% decrease over 5 years.

Designing a study to measure the impact of legislation to decrease the amount of marine debris will take more planning and a greater commitment of resources. As can be seen from our preliminary findings, sample sizes to detect a given change with stated precision will be large. An improved design could be constructed if we had better variance estimates of debris between beaches as well as within beaches, as well as consensus about the magnitude of the change we would like to detect. In addition, identifying and understanding factors that affect the deposition of debris will be critical in evaluating the success of mitigating legislation.

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THE COMPOSITION AND ORIGIN OF MARINE DEBRIS STRANDED ON THE SHORES OF SUBANTARCTIC MACQUARIE ISLAND

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ABSTRACT

The coastline of subantarctic Macquarie Island (lat. 54"35'S, long. 158°55'E) was surveyed over an 8-week period in 1988 to determine types, quantities, and possible sources of marine debris. Lost fishing gear consisted of buoys, ropes, and net fragments. Gear from both trawling and longline fishing operations were represented, with debris identified from Russian, Polish, Japanese, Taiwanese, and South American sources. Three types of litter which potentially entangle marine mammals were found: plastic packing straps, ropes, and net fragments. Plastic bottles, small plastic fragments from broken plastic bottles, and small pieces of expanded polystyrene were common. Litter accumulated in highest densities on open beaches of the west coast of the island. Overall density of marine debris was less than densities reported for islands in the South Atlantic Ocean and the Indian Ocean, or from the coast of Alaska.

INTRODUCTION

Plastic litter and other man-made debris have been recognized as major pollutants of open ocean and coastal surface waters (Shomura and Yoshida 1985; Day and Shaw 1987; Pruter 1987). The distribution of this debris is widespread. Debris has been reported from coastlines near populated, industrial regions of the world (Shiber 1979, 1982), and from open water such as the Mediterranean Sea and the North Sea, which are traversed by busy shipping lanes (Morris 1980; Dixon and Dixon 1983; McCoy 1988), as well as from remote areas such as Alaska (Merrell 1984; Merrell and Johnson 1987) and islands in the Southern Ocean (Gregory 1987; Ryan 1987b; Ryan and Watkins 1988). The slow breakdown of many artifacts allows them to disperse over long distances, often distant from their source (Carpenter and Smith 1972; Ryan 1987b).

Little is known of the impact and fate of much of this debris, although adverse effects through entanglement and ingestion have been documented in seabirds (Azzarello and van Vleet 1987) and marine mammals (Bonner and McCann 1982; Fowler 1985; Laist 1987). The long lifespan and

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

widespread dispersal of such litter make it important to monitor strandings of artifacts in remote sectors of the Southern Ocean in order to identify the major sources of debris and to determine a baseline index of distribution and relative abundance. Parties to the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) have agreed to monitor and report the occurrence of artifacts in the Southern Ocean (Morris 1985). Difficulties in monitoring floating debris, particularly small plastic artifacts , highlight the importance of beach surveys in determining densities, abundance, and sources of such debris.

The present study identifies the types and origins of marine litter stranded at Macquarie Island.

STUDY AREA AND METHODS

Macquarie Island (lat. 54035'S, long. 158°55'E) is situated in the Southern Ocean. It lies on the Macquarie Ridge approximately 1,500 km south-southeast of Tasmania and 640 km southwest of the Auckland Islands. The island is approximately 34 km long and varies in width from 250 m at the northern isthmus to a maximum of 5 km midway along the island. Commercial sealing took place on the island from 1810 until 1919 (Cumpston 1968) . Since 1948, the Australian National Antarctic Research Expeditions (ANARE) have maintained a permanent station on the island. Most of the present day land-based activity on the island is centered around the isthmus and at the six field huts on the island. The nearest ship-based fishing activities occur over the Campbell Plateau, about 700 km to the northeast, and around the Kerguelen group, 5,000 km to the west.

The entire coastline of Macquarie Island (ea. 94 km) was surveyed for stranded artifacts over a 6-week period from June to August 1988. All sizable artifacts (excluding wooden objects) were identified (where possible) from manufacturers' marks in order to determine their origins. All objects were collected and removed from the beaches. Larger objects, such as fishing buoys and floats, were recorded, marked, and stockpiled above high water level at various locations around the island. The rocky nature of much of the coastline precluded sampling of items smaller than 10 mm. Artifacts were categorized according to type of material: plastic, metal, glass, and other. Objects collected from the beach below the ANARE station refuse dump were not included in the survey. Similarly, wooden objects were not included, to avoid confounding the results with wooden remains from sealing activities and old shipwrecks.

The coastline was surveyed in seven convenient arbitrary sectors (Fig. 1), which varied in size and topography. Some sectors were dominated by rock shelf coastline with large boulders, while others had more open beach (Table 1). This is the first survey of marine debris undertaken at Macquarie Island.

RESULTS

A total of 1,034 man-made artifacts was recorded from 94 km of shoreline at Macquarie Island. This represents a density of 11

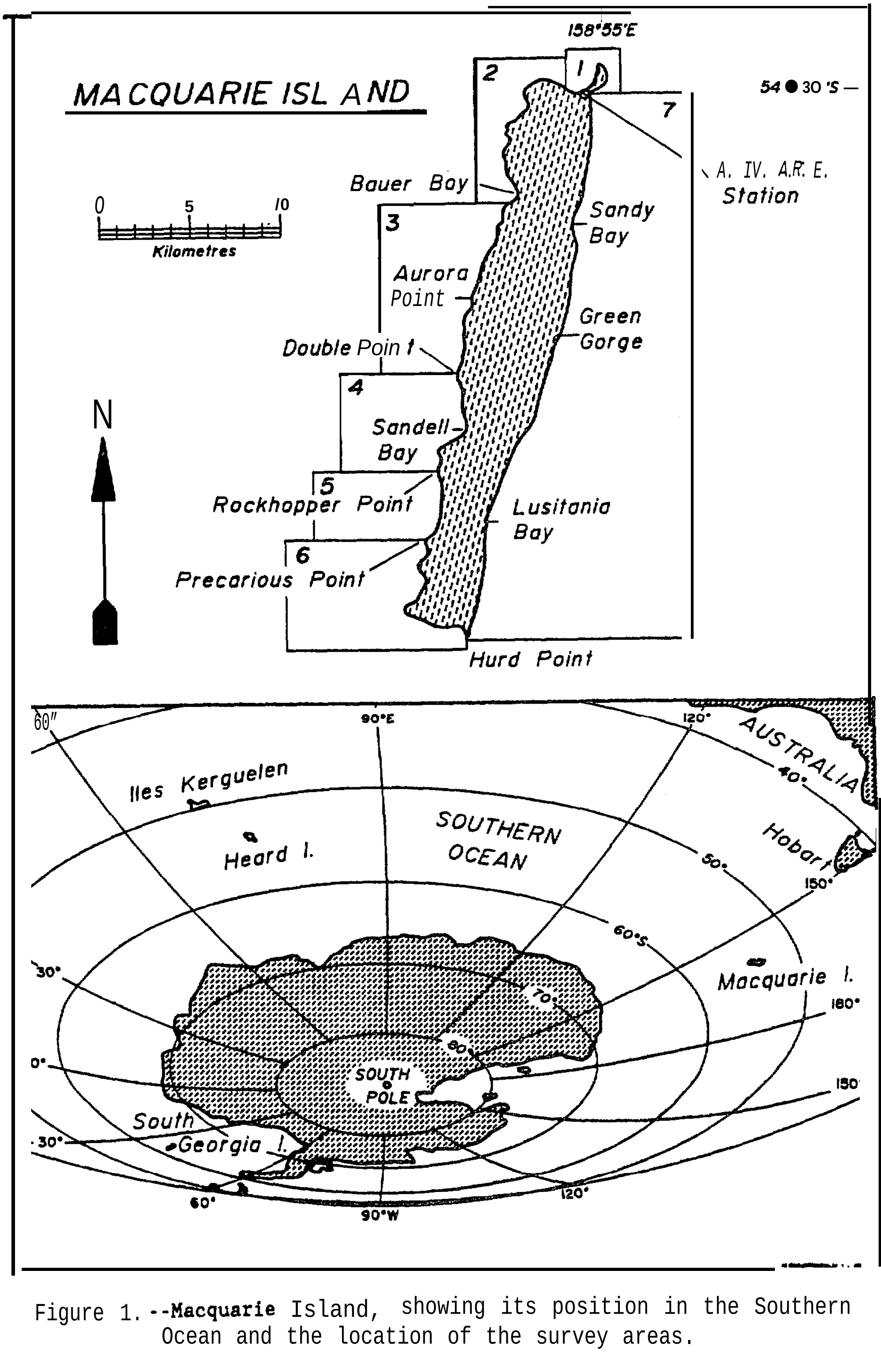

Figure 1. --Macquarie Island, showing its position in the Southern Ocean and the location of the survey areas.

Table 1. --Relative topography and density of artifacts on sectors of coastline at Macquarie Island.

Sector	Length of coastline (km)	Open beach (%)	Density of artifacts (items/km)	(items/km open beach)
1	4	25	2.5	10
2	16	38	12.2	32.5
3	16	16	19.4	124
4	8	44	39.0	89.1
5	5	20	13.8	69
6	8.5	24	11.6	45.5
7	36	67	0.6	0.9

artifacts/km coastline. Densities of artifacts varied over the island, with the greatest found in sector 4 (39 items/km) and the least (0.6 item/km) on the east coast (Table 1). Plastic items were most abundant, accounting for 60% of all objects. A wide variety of plastic items was recorded. Containers and bottles of various shapes, sizes, and uses were common, while fragments from degrading bottles and polystyrene pieces of various sizes were ubiquitous. Plastic bottles and containers made up 28% of plastic artifacts, while expanded polystyrene and other foamed products contributed 13% of plastic items. Miscellaneous small plastic pieces, including fragments of a size easily ingested by birds, made up 26% of plastic objects. Metal objects contributed 34%, while glass and miscellaneous items such as cork, hemp, cloth, and wax contributed 6% (Table 2). Objects of fisheries origin (buoys, ropes, and netting) accounted for 47% of all stranded artifacts, 29% of all plastic objects, and 89% of all metal objects.

Fishery Debris

A variety of objects originating from fisheries was recorded, including artifacts from both trawl fisheries (eastern European), and longline fisheries (predominantly Japanese). Common items included plastic and metal head line floats from trawl nets, and longline tellings (marker buoys) or surface floats (Table 3). Head line floats were often found attached to fragments of trawl net, and were occasionally found strung together with polypropylene rope in groups of up to six. Three varieties of metal head line floats were recorded: an aluminium alloy float with two separate attachment lugs bearing a Polish manufacturer's mark (55% of all metal buoys), an aluminium alloy float with a single attachment lug containing two holes (26%), and a steel float (17%). Longline tellings were usually covered in rope mesh, often with fragments of rope or mesh trailing from the floats. Ten inflatable plastic floats possibly used as longline pickup buoys or fenders were recovered. Two Japanese glass longline fishery floats, both covered in mesh, were found. Eleven

Table 2. --Numbers of artifacts found on beaches along different sectors of coastline at Macquarie Island.

Artifacts	Sector 1	2	3	4	5	6	7	Total
Plastic objects (total)	6	141	198	175	34	52	15	621
Fisheries floats	3	33	53	46	18	18	6	162
Polypropylene ropes	--	2	3	2	--	1	--	8
Netting	--	4	--	--	--	1	--	5
Expanded polystyrene	--	20	26	7	4	11	5	73
Other foamed plastics	--	--	2	1	--	1	--	4
Bags	--	3	--	--	--	--	--	3
Packing straps	--	5	4	1	--	1	--	11
Bottles and containers	--	39	54	61	6	5	3	168
Drift cards	3	3	1	6	2	--	--	15
Miscellaneous	--	32	55	51	4	14	1	157
Metal objects (total)	6	48	79	131	30	43	5	342
Fishery floats	5	40	72	117	28	39	4	305
Containers	--	4	2	6	2	1	--	15
Aerosol cans	--	3	3	8	--	1	--	15
Satellite buoys	--	--	1	--	--	2	1	4
Miscellaneous	1	1	1	--	--	--	--	3
Other objects (total)	1	9	34	12	8	5	2	71
Glass floats	--	--	--	--	1	1	--	2
Bottles and globes	1	7	25	6	3	2	1	45
Cork objects	--	--	1	--	--	2	--	3
Hemp rope	--	--	--	4	2	--	--	6
Bamboo	--	1	1	--	--	--	--	2
Miscellaneous	--	1	7	2	2	--	1	13
Grand total	13	198	311	318	72	100	22	1,034

fragments of rope were recorded. These were of varied length up to about 30 m. Two fragments of teased nylon antichafing blankets were collected, as well as a 2-m fragment of 120-mm stretched mesh codend.

Origin of Artifacts

The country of origin of some of the artifacts could be identified. Most objects were of South American, eastern European (mainly Polish or Russian), or oriental origin (Table 4). The items of fishing debris were identified from writing on floats. Country of origin of fishing floats does not necessarily imply use by that country's fishing fleet, as several nationalities are known to use Japanese floats, although Japanese floats produced for the export market are imprinted in English (R. Burbury pers. commun.). The metal head line floats (Table 3) were of the variety used by

Table 3.--Artifacts which originated from fishing activity washed ashore at Macquarie Island,

Fishing activity debris	Number
Longline fishery debris	
Longline tellings (plastic)	72
Dahn-pole floats	1
Polystyrene surface floats	4
Inflatable pickup floats	10
Trawl fishery debris	
Plastic head line floats	79
Metal head line floats	297
Steel bobbins	8
Trawl-web netting fragments	4
Ropes	11
Antichafing blanket	2
Codend net fragment	1
Miscellaneous fishery debris	
Fender or marker buoy	5
Plastic top buoys (use unknown)	6

the Russian and Polish trawl fisheries, although 55% of these bore a Polish manufacturer's mark. Plastic head line floats included 52 of Russian origin and 2 varieties of Argentinean float (brand names Moscuzza and Arex, Table 4). Plastic containers and other litter were identified to country of origin where brand names or manufacturers' names could be read. Most of these artifacts were discarded containers of household consumables such as detergents, shampoos, drinks, aerosol cans, and general food items.

Fifteen plastic drift cards were collected from the coast of Macquarie Island. Of these 13 were of South African origin (Shannon et al. 1973; Lutjeharms et al. 1988), and 2 were Australian.

State of Decay

Plastic objects were found in various stages of decay, ranging from almost pristine with easily discernible printing and little or no sign of ultraviolet degradation to brittle' and disintegrating. Most plastic fishing floats had broken lugs, and 32% were in fragments. Generally, fishing floats made of aluminium alloy showed little sign of degradation, although some had broken lugs while others showed signs of pitting. All steel objects *were* corroded. Many plastic bottles were disintegrating into small fragments, and this type of fragment contributed 46% of miscellaneous plastic objects (Table 2). Most glass bottles were whole.

Table 4.--Countries or regions of origin of artifacts found on Macquarie Island. Where regions only are used, sources of the objects could not be identified more specifically.

Country or region	Fisheries gear	Plastics	Other litter
South America	1	3	4
Argentina	17	4	1
Orient	23	--	--
Japan	37	10	4
China	3	1	--
Scandinavia	1	4	1
Germany	--	1	4
Switzerland	--	--	1
Britain	--	2	2
France	2	--	3
Eastern European	168	--	--
U.S.S.R.	51	3	12
United States	--	2	--
Australasia	--	2	9
South Africa	--	--	13

DISCUSSION

The artifacts stranded at Macquarie Island can have either local or oceanic sources. Some objects may have resulted from the activities of the ANARE station, as rubbish has been dumped in the isthmus area in the past. However, in recent years all plastic, metal, and glass refuse generated by the station has been removed from the island. Thus, in the essential absence of a local source, the stranded artifacts were all derived from oceanic sources, that is, they drifted to the island from distant source-regions.

Macquarie Island lies just to the north of the Antarctic Polar Front (Tchernia 1980). The main oceanic drift pattern which influences Macquarie Island is the West Wind Drift, which has a slight northerly component (Shannon et al. 1973; Lutjeharms et al. 1988). Within that westerly drift, mean surface drift speeds in the Southern Ocean at the latitude of Macquarie Island have been determined at between 14.6 and 19.0 cm/sec (Shannon et al. 1973; Bye 1988; Lutjeharms et al. 1988). Drifting buoys show a tendency to accumulate in areas corresponding to the historic locations of the various frontal systems of the Southern Ocean (Lutjeharms et al. 1988), and the pattern of drift towards these fronts is also demonstrated by the amount of plastic litter which tends to accumulate there (Gregory et al. 1984; Gait 1985; Day and Shaw 1987), Most litter stranded on Macquarie Island would have come from the west (e.g. , South American debris), and the influence of the West Wind Drift together with the prevailing westerly winds would explain the high incidence of strandings on the west coast of the island and the low incidence on the east coast. The northerly component of the West Wind Drift, the tendency of floating material to accumulate at oceanic fronts, and the movement of Antarctic Water toward Macquarie Island in winter, suggest debris stranding at Macquarie Island may originate with ships operating both to the north and to the south of the Antarctic Polar Front.

The debris stranded at Macquarie Island originated in several countries. However, the country of origin of artifacts does not necessarily represent the drift tracks, as much of this debris is probably derived from the fishing fleets and other vessels operating in the Southern Ocean. It is possible that some articles with Spanish writing originated on the coast of South America or from vessels operating in that region. Driftwood originating in South America (predominantly *Nothofagus* spp.) has been reported from South Georgia (Lewis Smith 1985), and from Macquarie Island (Barber et al. 1959).

The significant contribution of fisheries-related objects to the debris on Macquarie Island is similar to that found on other islands in the Southern Ocean (Burton and Williams 1985; Ryan 1987b; Ryan and Watkins 1988), and to the situation on remote beaches in the Northern Hemisphere (Merrell 1984). Fishing gear can become a marine pollutant as a result of accidental loss or deliberate dumping. Fragments of net, line, and associated gear can be lost through snagging, but fishing gear which is worn or damaged beyond further use is often discarded at sea (Pruter 1987). Although vessels have little control over damage to fishing gear, it is possible to control the amount of gear which is actively discarded.

There are two major types of fisheries which operate in the Southern Ocean: bottom and midwater trawling and ocean longlining. The fisheries-related debris which washed ashore on Macquarie Island originated in both these fisheries. Trawl fishing operations for fish and krill in the Southern Ocean are dominated by the U.S.S.R. and Japan, with lesser amounts taken by Poland and the German Democratic Republic. For fish and krill, significant fisheries occur in the Atlantic Ocean sector around South Georgia and the Scotia Arc, and for fish only, around Iles Kerguelen in the Indian Ocean sector (Northridge 1984; Williams 1988). The high number of metal head line floats, Russian plastic head line floats, and other trawl gear (Table 3) were probably lost from the eastern European trawlers operating in these areas, with the majority of fishing gear coming from Iles Kerguelen as they are not only closer to Macquarie Island than is South Georgia, but also closer to the Antarctic Polar Front. Some of the plastic head line floats were of Argentinean origin, and probably came from offshore trawling near the coast of South America. These, along with other South American artifacts, were probably carried to Macquarie Island by the West Wind Drift. Fishing gear from longline fisheries was probably lost from Japanese, Taiwanese, or Korean vessels operating to the north of the Antarctic Polar Front, and possibly quite close to Macquarie Island at times (Robins 1985).

The density of stranded artifacts along a shoreline is determined by a number of geographical factors including beach orientation relative to prevailing currents and winds, offshore reef structure, beach gradient and texture, and local tide and storm effects (Ryan 1987b). The overall density of artifacts on Macquarie Island (n/km) was less than the densities reported for Prince Edward Island off Africa (32/km), Gough Island (14/km), Tristan da Cunha and Inaccessible Island (from 292 to 807/km; all Ryan 1987b), or Amchitka Island in Alaska (193 to 499/km; Merrell 1980). These differences may be due, in part, to sampling methods, as the surveys above concentrated on particular beaches whereas this survey took into account the entire coastline of Macquarie Island. Surveys of stranded artifacts are often concentrated in areas of noticeably high density with the aim of determining (through repeated surveys) the accumulation rate of debris at one site over time. This may result in inflated estimates of density and make intersite comparisons of density difficult or even invalid. The almost north-south orientation of Macquarie Island results in one coast being exposed to prevailing westerly winds and currents, while the other coast is relatively sheltered. Thus, densities of artifacts in different parts of the island vary widely (Table 1). The low density of artifacts on the east coast (0.6/km) is probably due to the prevailing westerly winds, and surveys from other subantarctic islands have shown that quantities of stranded litter are greatest on the windward (westward) shores (e.g., Gregory 1987; Ryan 1987b). Despite the difficulties of interisland comparisons, the density of stranded litter on Macquarie Island appears to be less than on islands in the Atlantic and Indian sectors of the Southern Ocean (Ryan 1987b), and much less than for remote areas of Alaska (Merrell 1980). This is probably related to the proximity of fishery operations, with most fishing occurring far to the west of Macquarie Island.

The high proportion of plastics among stranded artifacts at Macquarie Island is similar to that reported on other islands of the Southern Ocean (Ryan 1987b) and elsewhere (e.g., Merrell 1980, 1984; Pruter 1987; Shiber 1987). The high incidence of plastics in stranded litter is probably due to the increased use of plastics over the last few decades, particularly for packaging, and the slow rate at which plastics degrade. Surveys in the North Sea and off the coasts of northwest Europe have shown that most marine litter is primary or secondary packaging, particularly plastic bottles, the majority of which originate with the disposal of garbage by ships at sea (Dixon and Dixon 1981, 1983). Plastics decay slowly, with little ultraviolet degradation occurring at sea (Shannon et al. 1973).

The impact of stranded artifacts on local fauna and flora is difficult to assess. Plastic particles are commonly ingested by seabirds but most ingestion probably occurs at sea (Ryan 1987a). Some seabirds at Macquarie Island ingest small fragments of plastic, some of which may have been ingested on shore (Slip pers. observ.).

The density of entanglement-type litter stranded at Macquarie Island is less than densities reported for the Northern Hemisphere (Merrell 1980, 1984). Although the southern elephant seal, *Mirounga leonina,* and fur seal, *Arctocephalus* spp., populations have been closely monitored over the last 5 years, to our knowledge there have been no recent reports of entanglements in these species at Macquarie Island, although one fur seal was sighted with a plastic packing strap collar in 1975 (G. Copson pers. commun.). Greater concentrations of trawl debris occur in areas of concentrated fishing effort (e.g., Fouler 1987), and as the major fishing effort in the Southern Ocean is far to the west of Macquarie Island, the densities of entanglement debris may be low enough to cause little impact on the marine mammals. However, these species are wide ranging, and fatal entanglements of marine mammals at sea are believed to far outnumber those where the animal reaches shore (Fouler 1987). Thus, once debris is stranded it apparently has little impact on the marine mammals, and ingestion of small plastic fragments by some bird species is likely to be the major impact on local wildlife. The impact of these artifacts is therefore likely to be much greater prior to their stranding.

The amount and variety of stranded artifacts at Macquarie Island demonstrate the preponderance and ubiquity of plastics. The hazards posed to wildlife and shipping by marine litter demonstrate the need for active programs to prevent littering at sea and on land.

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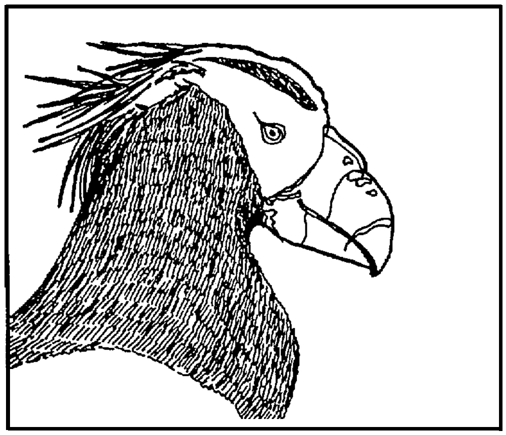
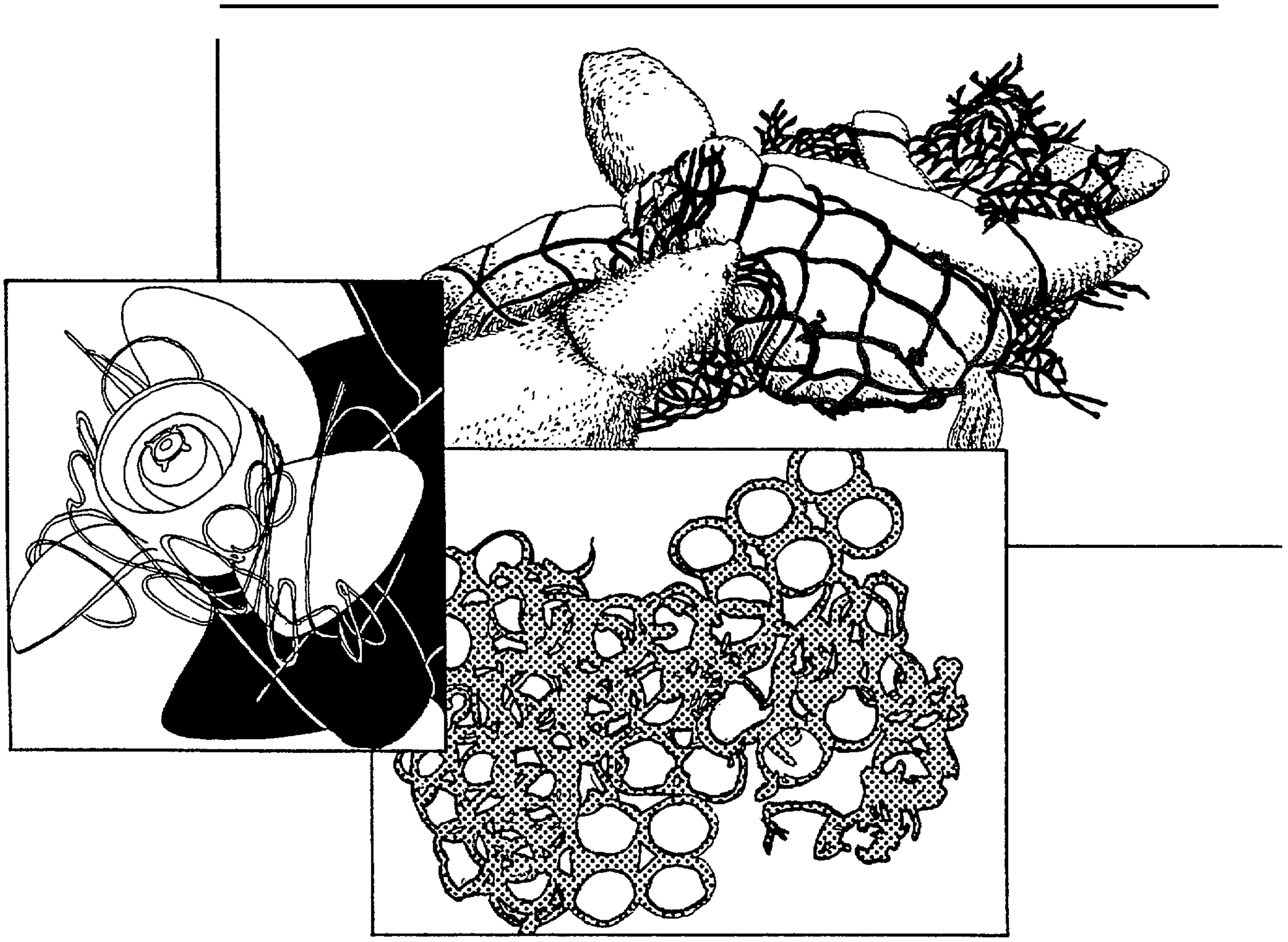
SESSION II



ENTANGLEMENT OF MARINE LIFE AND GHOST FISHING



DISTRIBUTION OF MARINE DEBRIS AND NORTHERN FUR SEALS IN THE EASTERN BERING SEA

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ABSTRACT

To obtain basic information about entanglement rate and mortality of the northern fur seal, *Callorhinus ursinus*, at sea, we conducted sighting surveys of fur seals and marine debris along eight transect lines in 1984 and four in 1985 and 1988 in summer near the Pribilof Islands in the eastern Bering Sea. These southeast to northwest transects were approximately 300-500 km long. We observed 710 fur seals and 7 debris items of fisheries origin in 1984, 345 seals and 17 debris items in 1985, and 343 seals and 18 debris items in 1988. In 1985, one dead male fur seal was observed entangled in a trawl net fragment weighing 40 kg. Distributions of both marine debris and fur seals were concentrated in the area along the continental slope west of the Pribilof Islands. It is considered that this co-occurrence is a result of the mutual relationship between fish resources, seals' feeding, fishing grounds of trawlers in the area, and northward-flowing current.

INTRODUCTION

Japanese trawlers began operating in the eastern Bering Sea in 1933 and other nations have begun fishing there later the U.S.S.R. in 1959, South Korea in 1968, Taiwan in 1974, Poland in 1979, and West Germany in 1980. The estimated total number of trawl-fishing vessels off Alaska increased from 5 in 1933 to 432 in 1963, and dropped to 317 in 1983 (Low et al. 1985).

At the 10th meeting of the North Pacific Fur Seal Commission (NPFSC), the survival rate of fur seals that were entangled in fishing net fragments was reported (NPFSC 1967). Since then, the United States has been actively collecting data on entanglement of fur seals (Scordino 1985). Japan-United States joint research started in 1983 (Bengtson et al. 1988; Scordino et al. 1988). The fur seal population on the Pribilof Islands has steadily declined since the 1960's, and entanglement of seals has been suggested as a partial cause (Fowler 1982).

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

Merrell (1980) estimated that about 1,645 metric tons of plastic material were dumped into the Bering Sea and Aleutian Islands area each year in the 1970's. Dahlberg and Day (1985) encountered 0.356 trawl debris items per 1,000 km in the central North Pacific between Kodiak Island and Hawaii, whereas Jones and Ferrero (1985) found 1.349 pieces of trawl net debris per 1,000 km off the Aleutian Islands in the North Pacific. The common pelagic distribution of fur seals and marine debris has not, however, been studied at all. If the drifting routes and local accumulations of marine debris coincide with migration routes and feeding grounds of fur seals, the probability that seals will become entangled in marine debris will increase. The greater the density of marine debris, the greater will be the number of entangled seals. To properly assess the impact of entanglement on the fur seal population, the common distribution and density of fur seals and marine debris at sea must be known.

In this study, we conducted a sighting survey for fur seals and marine debris in the eastern Bering Sea in 1984, 1985, and 1988, and obtained basic information on the pelagic distribution of fur seals and marine debris.

MATERIALS AND METHODS

We conducted sighting surveys of northern fur seals and marine debris along eight transect-line; from 13 July to 8 August 1984, four from 12 to 21 July 1985, and four from 10 to 23 July 1988 in the eastern Bering Sea using RV *Shunyo Maru* (Table 1). These southeast to northwest transects were approximately 300 to 500 km long. The survey areas made up of blocks measuring 30 min of latitude by 1 degree of longitude, were 248,845 km² in 1984, 152,937 km² in 1985, and 184,066 km² in 1988. In 1984, both western and eastern areas of the Pribilof Islands were surveyed, and in 1985 and 1988 only the western area was surveyed (Fig. 1).

Sightings were conducted by one or two people from the pilothouse and four or five people from the flying deck (8 m above sea level) on top of the pilothouse each day from sunrise to sunset. Observers were placed on both sides of the ship and surveyed the area on only one side. Each observer engaged in sightings for 4 h and rested for 1 h. Binoculars (7 x 50) were used only to confirm the kind and number of objects observed. We recorded the number, the time, and the location of fur seals and marine debris encountered. The speed of the ship during sightings was about 8 kn in 1984 and 1985 and about 10 kn in 1988. The ship's course was not changed except to collect debris of fishing origin such as fishing net fragments, plastic packing bands, floats, and ropes. When visibility dropped to less than about 200 m, the survey was interrupted.

In 1984 and 1985 we concentrated on sighting of fisheries-related debris; however, in 1988 we recorded all floating debris including Styrofoam, nylon bags, wood, and debris of fisheries origin. Because the debris surveys differed among years, we compared only the distributions and densities of fisheries-related debris.

Table 1.--Research period, area east or west of the Pribilof Islands, distance traveled, and number of fur seals and pieces of debris of fisheries origin observed.

Period	Days	Area	Distance traveled (km)	Number of fur seals observed	Number of pieces of debris of fisheries origin observed
13-19 July 1984	7	East	1,133	71	1
25 July-8 Aug. 1984	9	West	1,855	639	6
12-21 July 1985	9	West	1,892	345	17
10-23 July 1988	9	West	2,184	343	18

RESULTS

Distribution and Kinds of Debris of Fisheries Origin

In 1984, seven pieces of debris of fisheries origin were found: two on the continental shelf northwest of the Pribilof Islands, four near the continental slope southeast of the islands, and one to the south of *St.* George Island (Fig. 2A). In 1985, 17 pieces of debris of fisheries origin were found 2 on the continental shelf, 12 along the continental slope, and 3 northwest of Umnak Island (Fig. 2B). In 1988, 18 pieces of debris of fisheries origin were collected 2 on the continental shelf, 9 along the continental slope, and 7 southwest of the Pribilof Islands (Fig. 2C). Generally, debris items were found along the continental slope during the 3 years.

Debris of fisheries origin collected in 1984, 1985, and 1988 included trawl nets, gillnets, string, rope, floats, and plastic packing bands. Fifteen trawl net pieces collected ranged in weight and mesh size from 15 g, 7 cm to 40 kg, 20.5 cm; two gillnet pieces were similar at 1.75 kg, 11.7 cm and 1.8 kg, 11.5 cm. Three of four packing band pieces collected weighed 6.4 kg or more (Table 2). Trawl net accounted for 71.4% (five pieces) of all debris in 1984, 41.2% (seven pieces) in 1985 and 16.7% (three pieces) in 1988 (Table 3). Trawl net constituted the major part of the collection in 1984, floats in 1988.

Entanglement of Fur Seal

We found a dead male fur seal (110 cm long and weighing 20 kg), which we estimated to be 2 years old, entangled in a net fragment about 30 nmi southwest of St. Paul Island on 19 July 1985. The net fragment was gray trawl net weighing 40 km (mesh size 20.5 cm; twine size 7.6 mm).

Distribution of Fur Seals

The sighting frequency of fur seals (number of fur seals sighted per 1 km) was calculated for each block measuring 30 min of latitude by 1 degree of longitude.

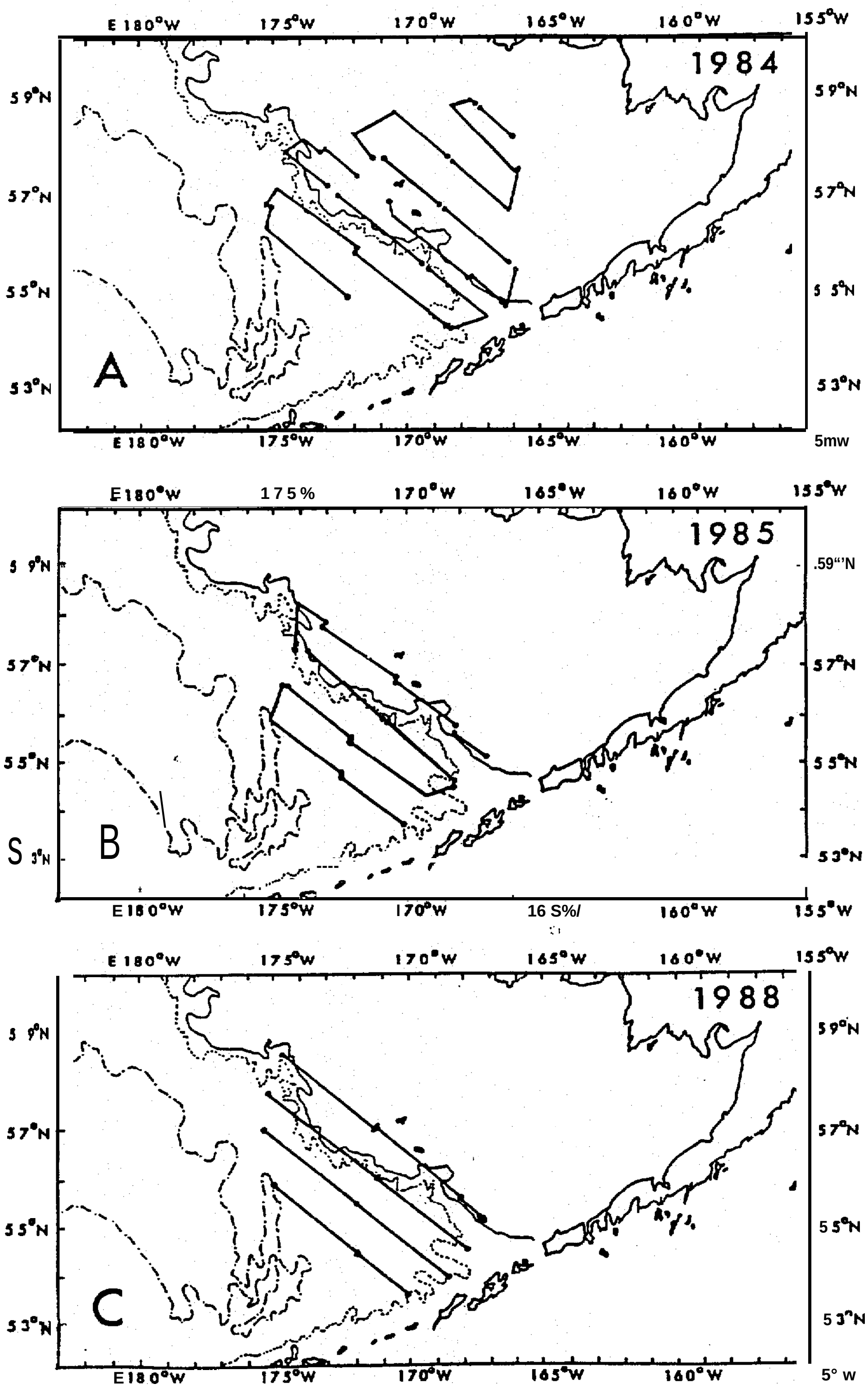

Figure 1. --Transect line surveyed in 1984 (A), 1985 (B), and 1988 (C) (— · 100 fathoms, --- = 1,000 fathoms, — ·— 2,000 fathoms)"

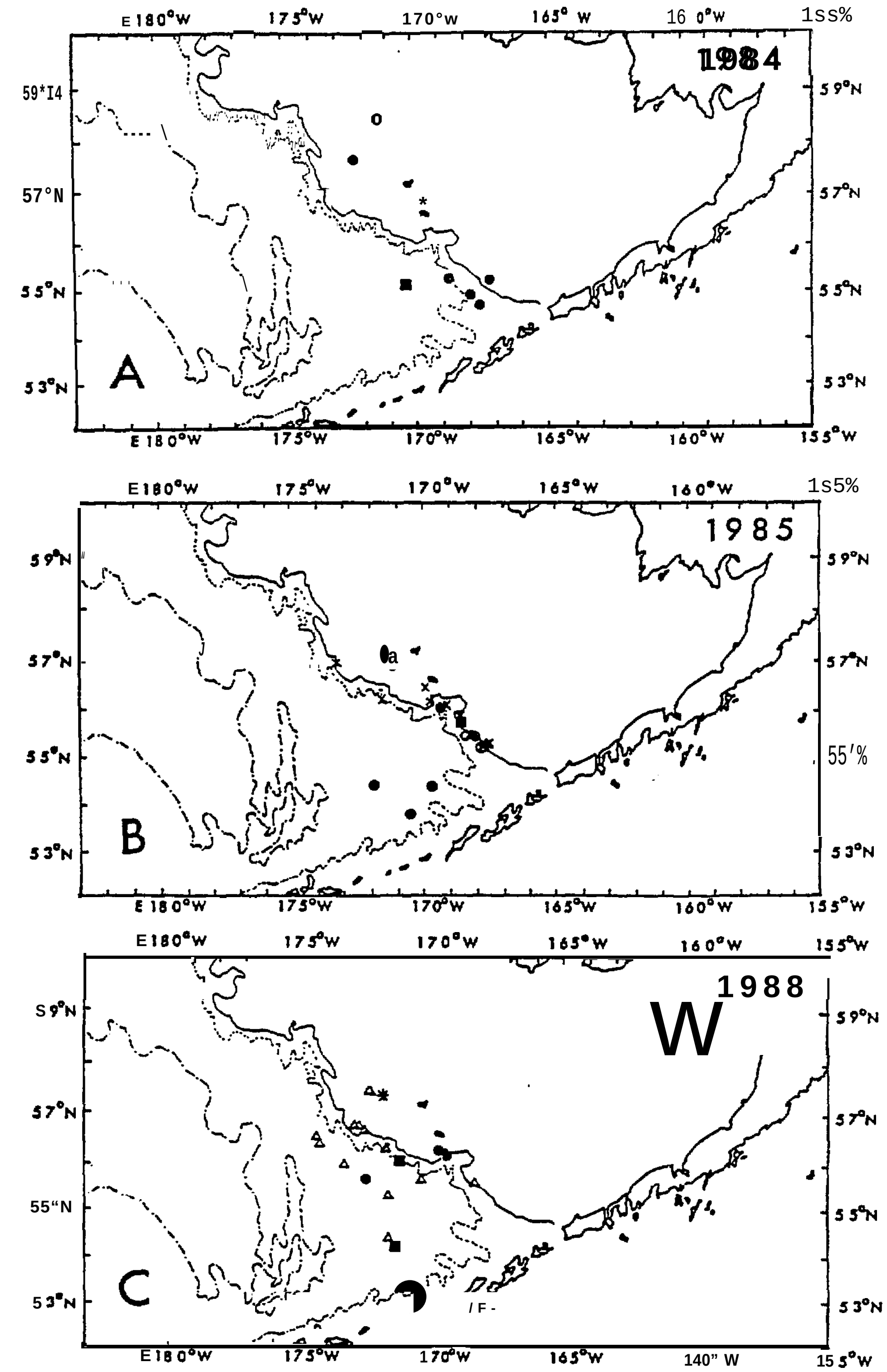

Figure 2. --Location of debris of fisheries origin.
•= trawl net, o = gillnet, ✱ = unidentified net,
⊗ - string, x = rope, A - float, ▪- plastic packing band.

Table 2. --Kinds (PP - plastic packing band), date, location, and characteristics of fisheries-related debris observed on the line transect surveys, 1984, 1985, and 1988, in the eastern Bering Sea.

No.	Kinds	Date	Latitude N	Longitude W	Color	Weight (kg)	Mesh (mm)	Twine (mm)	Length (m)
1	Gillnet	14 July 1984	58°20′	171″26′	Green	1.8	115	0.5	--
2	Trawl net	25 July 1984	55°13′	167°18′	Blue	17.6	140	4.0	--
3	Trawl net	29 July 1984	57°34′	172°20′	Blue	3.0	130	5.0	--
4	Trawl net	5 Aug. 1984	54°40′	167°37′	Green	0.015	70	3.0	--
5	Trawl net	5 Aug. 1984	54″48′	167°55′	Orange	0.35	200	3.5	--
6	Trawl net	5 Aug. 1984	55°10′	168°43′	Green	1.15	135	4.0	--
7	PP band	6 Aug. 1984	55°04′	170°22′	Yellow	9.4.	--	--	--
8	Trawl net	12 July 1985	53°43′	170″21′	[a]Green	--	--	--	--
9	Trawl net	12 July 1985	54°20′	171°45′	Green	6.4	155	3.0	--
10	Trawl net	15 July 1985	54°16′	169°31′	Gray	0.52	170	3.0	--
11	Trawl net	19 July 1985	57″02′	171°20′	Orange	2.9	125	6.0x4.5	--
12	Trawl net	19 July 1985	56″57′	171°07′	Gray	40.0	205	7.6	--
							114	3.4	--
13	Trawl net	20 July 1985	56″05′	169°12′	Green	0.07	--	4.2	--
14	Trawl net	21 July 1985	55°25′	168°01′	Orange	0.03	195	2.2x4.6	--
					Black		--	3.4	--
					Green	--	--	2.0x4.4	--
15	Gillnet	21 July 1985	55°25′	168°06′	Green	1.75	117	0.5	--
16	Rope	17 July 1985	56°09′	171°33′	White	0.71	--	18.5	2
17	Rope	17 July 1985	56°59′	173°18′	Yellow	0.2	--	25.0	1.3
18	Rope	20 July 1985	56°18′	169°49′	Yellow	4.8	--	18.0	20
19	Rope	20 July 1985	56′′12′	169°31′	White	1.8	--	19.8	6
20	Rope	20 July 1985	56°03′	169°06′	Yellow	8.6	--	18.0	50
21	Rope	20 July 1985	55°50′	168°32′	Yellow	2.0	--	17.4	13
22	Rope	21 July 1985	55″13′	167°27′	Yellow	0.1	--	12.4	1
23	String	21 July 1985	55°16′	167°34′	Orange	0.02	--	3.0x5.0	2
24	PP band	20 July 1985	55°50′	168°32′	White	0.01	--	--	2
25	Net	17 July 1988	57°17′	171°58′	(a)	--	--	--	--
26	Trawl net	12 July 1988	55°32′	172°25′	Gray	--	--	--	--
27	Trawl net	23 July 1988	56°06′	169°19′	Orange	0.82	129	5X3	--
28	Trawl net	23 July 1988	56°13′	169°32′	Orange	0.75	195	5X3	--
29	Float	10 July 1988	54°17′	171°41′	--	--	--	--	--
30	Float	12 July 1988	56°28′	174°18′	--	--	--	--	--
31	Float	12 July 1988	56°29′	174°18′	--	--	--	--	--
32	Float	12 July 1988	55°59′	173°13′	--	--	--	--	--
33	Float	13 July 1988	55°16′	171°40′	--	--	--	--	--
34	Float	15 July 1988	55°39′	170°21′	--	--	--	--	--
35	Float	16 July 1988	56°14′	171°42′	--	--	--	--	--
36	Float	16 July 1988	56°34′	172°28′	--	--	--	--	--
37	Float	16 July 1988	56°44′	172°47′	--	--	--	--	--
38	Float	16 July 1988	56°44′	172°48′	--	--	--	--	--
39	Float	17 July 1988	57°28′	172°21′	--	--	--	--	--
40	Float	23 July 1988	55°37′	168°18′	--	--	--	--	--
41	PP band	10 July 1988	54°09′	171°24′	Yellow	6.4	--	--	[b]Roll
42	PP band	15 July 1988	56°01′	171°11′	Yellow	6.4	--	--	[b]Ro 11

[a]Not collected.
[b]The roll of plastic packing band was estimated to be >100 m.

Table 3.--Kinds, number, and percent of fisheries-related debris pieces collected during line transect surveys in 1984, 1985, and 1988 in the area west of the Pribilof Islands.

Kind		1984	1985	1988	Total
Trawl net	No.	5	7	3	15
	%	(71.4)	(41.2)	(16.7)	(35.7)
Gillnet	No.	1	1	0	2
	%	(14.3)	(5.9)	(0.0)	(4.8)
Unidentified net	No.	0	0	1	1
	%	(0.0)	(0.0)	(5.6)	(2.4)
Float	No.	0	0	12	12
	%	(0.0)	(0.0)	(66.7)	(28.6)
Rope	No.	0	7	0	7
	%	(0.0)	(41.2)	(0.0)	(16.7)
String	No.	0	1	0	1
	%	(0.0)	(5.9)	(0.0)	(2.4)
Plastic packing band	No.	1	1	2	4
	%	(14.3)	(5.9)	(11.1)	(9.5)
Total	No.	7	17	18	42

In July 1984, we surveyed the area east of a line extending through St. George and St. Paul Islands. Most blocks showed fewer than 0.3 seal/km or showed no seals in this area.

In August 1984 and in July 1985 and 1988, we surveyed the area west of same line. In August 1984, more than 0.3 seal/km were seen in many blocks along the continental slope, and southwest of the islands over 0.9 seal/km were seen. No seals were found to the southeast or over the continental slope (Fig. 3A). Mean frequency of seals in all blocks west of the islands was greater than to the east, differing significantly ($t = 4.7528$, $P < 0.0001$).

In July 1985, we found fur seals mainly on the continental shelf and along the continental slope. Frequencies of over 0.6 seal/km occurred in two blocks to the northwest and southwest of St. Paul Island (Fig. 3B). Mean frequency of seals of this year was less than in August 1984, differing significantly ($t - 2.449$, $P < 0.005$).

In July 1988, we found frequencies greater than 0.3 seal/km only on the continental shelf and along the continental slope within about 200 km of the Pribilof Islands. Frequencies were greater than 0.9 seal/km in two

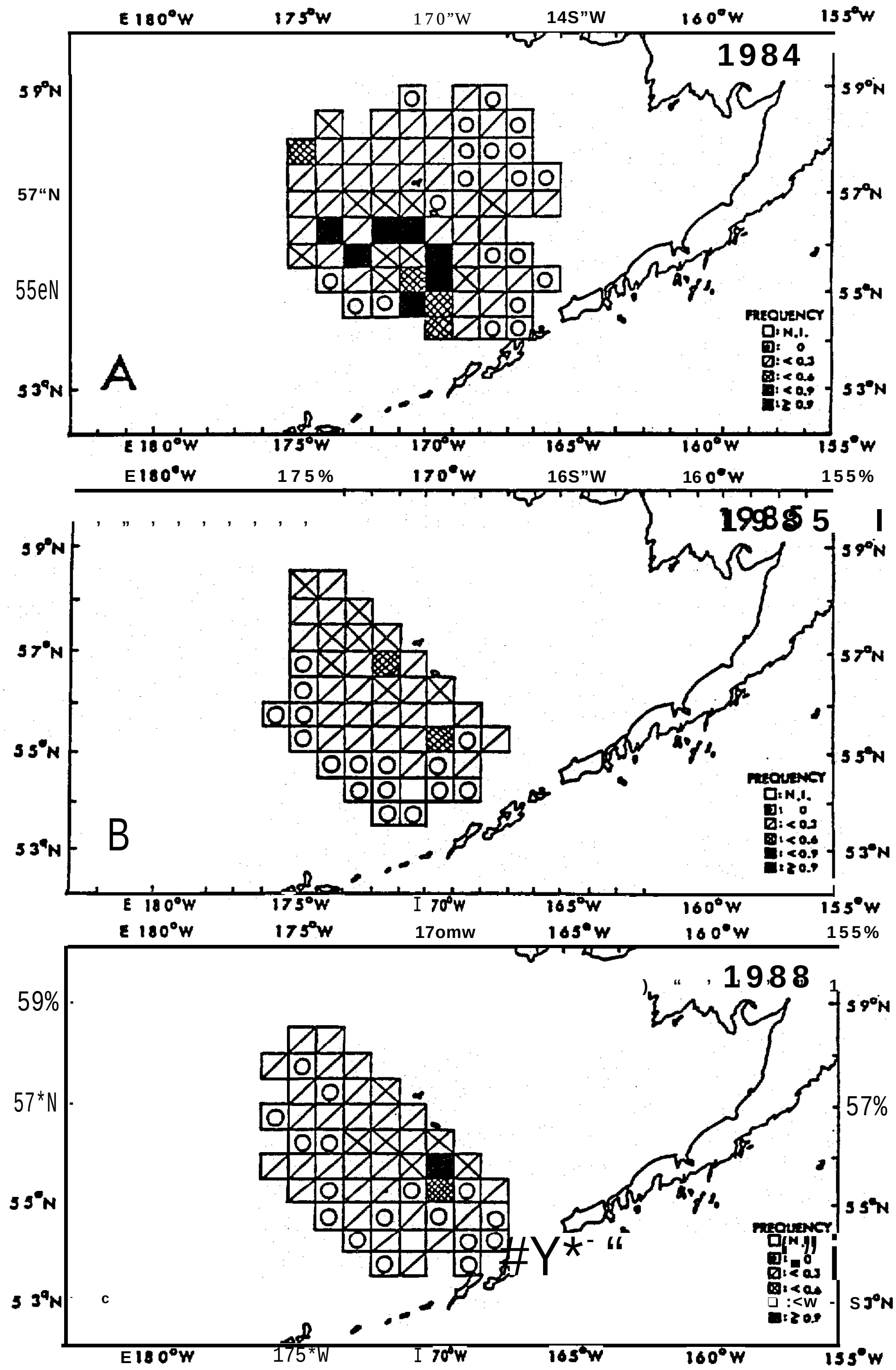

Figure 3. --Sighting frequency of fur seals per block measuring 30 min of latitude by 1 degree of longitude including transect line. Frequency equals the number of fur seals sighted per 1 km of research distance. (NI - not investigated.)

blocks along the continental slope south of St. George Island. Generally we saw no seals near the northwestern and southeastern ends of the continental slope or along the southwestern edges (Fig. 3C). Mean frequency of seals this year was almost the same as in July 1985, not significantly different ($t = 0.6499$, $P > 0.006$).

Coincident Sightings of Fur Seals and Fisheries-Related Debris

The sighting frequencies of fur seals in coincidental areas surveyed in 1984, 1985, and 1988 were 360.4/1,000 km in 1984, 211.0/1,000 km in 1985, and 197.8/1,000 km in 1988, whereas the densities of debris (of fisheries origin only) were 2.561/1,000 km in 1984, 7.975/1,000 km in 1985, and 9.798/1,000 km in 1988 (Table 4).

DISCUSSION

Most female fur seals at St. Paul Island deliver pups in July. After a perinatal fast of 8-10 days, they go to sea to feed for 4- to 10-day periods punctuated by 1-2 days of nursing their pups. Feeding trips lengthen as pups age until they are weaned at about 120 days postpartum (Peterson 1968). York and Kozloff (1987) reported that the number of newborn pups on St. Paul Island did not change greatly between 1981 and 1986. Therefore, we believe that the greater number of fur seals sighted in 1984 was due to the later survey period (late July-early August) and consequent greater proportion of lactating females at sea then, compared with 1985 and 1988 when surveys were in early to mid-July.

In all years, we found most seals near the continental slope in the eastern Bering Sea. Echo soundings of fish biomass, which we conducted simultaneously with transect surveys, indicated that the walleye pollock, *Theragra chalcogramma*, biomass was greatest in that area (Harada et al. 1985). Kajimura (1984) reported that fur seals in the Bering Sea ate mostly capelin, *Mallotus villosus*, and walleye pollock in July and August.

Table 4.--Sighting frequency of fur seals and fisheries-related debris (fishing nets, rope, string, plastic bands, floats) observed on the line transect surveys in 1984, 1985, and 1988 west of the Pribilof Islands.

Period	Research distance (km)	Seals No.	Debris No.	Frequency per 1,000 km Seals[a]	Frequency per 1,000 km Debris[b]
25 July-8 Aug. 1984	1,562	563	4	360.4	2.561
12-21 July 1985	1,630	344	13	211.0	7.975
10-23 July 1988	1,633	323	18	197.8	9.798

[a]Number of seals divided by research distance.
[b]Number of debris items divided by research distance.

Trawl-net fisheries for those species also operate primarily along the continental shelf and the continental slope in the eastern Bering Sea (Mito 1986), also suggesting that the greatest fish biomass is concentrated there. We believe that our observations showing most marine debris and most fur seals concentrated in the area from the continental shelf to the continental slope west of the Pribilof Islands are related to the concentration of prey resources and marine debris (e.g. , fishing net, plastic packing bands) in that area and to the northward currents along the continental slope (Favorite et al. 1976) which act to concentrate debris there.

As fur seals migrate in winter from the Pribilof Islands to as far south as Mexico in the eastern Pacific (lat. 32°N) (Kajimura and Loughlin 1988), we feel that it is important to conduct surveys in waters off British Columbia, Washington, Oregon, and California in the future to ascertain the distribution and abundance of marine debris and fur seals there.

ACKNOWLEDGMENT

We greatly appreciate the crew of RV *Shunyo Maru* for their cooperation in the survey and the officials of the Fishing Ground Preservation Division, Fisheries Agency, Government of Japan, for their assistance and advice in planning the survey. We especially thank the National Marine Mammal Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, who provided us the opportunity to conduct these surveys.

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POTENTIAL IMPACT OF ENTANGLEMENT IN MARINE DEBRIS ON THE POPULATION DYNAMICS OF THE NORTHERN FUR SEAL, *CALLORHINUS URSINUS*

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ABSTRACT

A model of the population dynamics of the Pribilof Island population of the northern fur seal, *Callorhinus ursinus*, was developed using field estimates of age- and sex-specific mortality and reproductive rates. In the model, mortality rates of pups and juveniles are density dependent, while rates for older seals are constants for each age and by sex. Model-predicted pup production is compared to pup counts made in the field.

If initialized at 1912 numbers, the model population increases at the rate observed between 1912 and 1940, then oscillates around the population level of the 1940's and 1950's, thought to be the carrying capacity of the Pribilof Islands. When the female harvest (including pelagic collections) of 1956-74 is added to the simulation at the annually specified rates, the predicted pup production decreases until 1965, but recovers to preharvest levels by 1975.

Entanglement rate and resulting mortality are assumed to be proportional to the rate of entanglement of subadult males in the harvest, specified by year. When both female harvest and mortality resulting from entanglement in plastic debris are added to the simulation, the model population declines at observed rates, suggesting that entanglement mortality can account for the recent decline in the fur seal population. The model indicates that the population will continue to decline at 1% per year if mortality remains at current levels. This rate of decline is slower than the 4-8% decrease per year of the 1970's because of higher pup and juvenile survival rates at lower population density. The model indicates that a reduction in entanglement mortality rates by 20% would be enough to stop the current population decline and maintain the population at current levels.

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INTRODUCTION

In the early 1900's, the population of the northern fur seal, *Callorhinus ursinus*, breeding on the Pribilof Islands in the Bering Sea had been reduced by harvesting to about 300,000 total individuals and fewer than 100,000 pups born per year. A ban on harvesting in 1911 by international agreement allowed the population to recover, such that a population level estimated at about 2 million total individuals was reached by the 1940's and continued through the 1950's. (See reviews by York and Hartley 1981; Lander and Kajimura 1982; Scheffer et al. 1984; Fowler 1985a.) In 1956, harvest of females was begun in an effort to reduce the population size to a level at which the then-predicted maximum sustainable yield in pup production could be obtained. The harvest of females was continued until 1968, and pelagic collections of females for research purposes were made between 1958 and 1974 (York and Hartley 1981). When the female harvest was ended, it was expected that the population would increase and return to the 1950's population level. However, the population has continued to decline at 4-8% per year since the late 1970's (Briggs and Fowler 1984). Evidence indicates that this decline may be the result of lethal entanglement in fishing debris and plastic packing bands (Fowler 1985a, 1985b).

In order to evaluate quantitatively the effect of the female harvest and entanglement on the Pribilof Island fur seals, we have developed a population dynamics model and have compared resulting predicted pup production against estimates made in the field. The population model consists of annual age classes of males and females with mortality and reproductive rates which are dependent on age and sex. Mortality of pups on land and of juveniles during their first 20 months at sea is density dependent, while mortality rates of older seals and pregnancy rates of females are density-independent, age-specific constants using best available estimates. Harvest mortality is considered separate from natural mortality and, when applicable, occurs only during the summer harvest season. Entanglement mortality rates are added to natural mortality when simulating the population dynamics of the last two decades.

MODEL ASSUMPTIONS

The age-specific pregnancy rates calculated by York (1979), using data from the pelagic collections conducted by the United States and Canadian Governments between 1958 and 1974, are assumed as birth rates (Table 1 and Fig. 1). Therefore, reproductive rates in the model are dependent solely on the number of adult females, assuming that enough adult males are present to impregnate those females at all population densities. The sex ratio at birth is assumed 1:1.

Natural mortality of seals age 2 or more years is assumed to be constant by age class and sex. In the model, natural mortality does not include mortality due to commercial harvest (or pelagic collection for research purposes) or recent mortality believed to be due to entanglement in fishing gear. Natural mortality rate estimates by age and sex are available from several sources (Chapman 1964; Lander 1979, 1980a, 1981; Eberhardt 1981; Smith and Polacheck 1984). Those of Lander (1980a, 1981;

Table 1. --Pregnancy rates (York 1979), age-specific natural mortality rates (Lander 1980a, 1981), and harvest rates on immature males (Lander 1980a) used in the population dynamics model. (Asterisks indicate rates which are density dependent and therefore not constants.)

Age	Percent of females pregnant	Natural survival rate (per year) Female	Male	Male harvest rate (per year)
1	0	*	*	0
2	0	0.840	0.78	0.028
3	0	0.920	0.77	0.403
4	4	0.940	0.76	0.573
5	37	0.940	0.74	0.147
6	70	0.945	0.72	0
7	80	0.950	0.72	0
8	85	0.950	0.72	0
9	87	0.938	0.70	0
10	88	0.924	0.65	0
11	88	0.906	0.63	0
12	88	0.884	0,60	0
13	87	0.858	0.55	0
14	84	0.876	0.50	0
15	81	0.789	0.43	0
16	77	0.743	0.30	0
17	71	0.692	0.20	0
18	63	0.630	0.10	0
19	56	0.564	0	0
20	47	0.490		
21	37	0.411		
22	26	0.330		
23	11	0.300		
24	0	0.250		
25	0	0.200		
26	0	0.150		
27	0	0.100		
28	0	0.050		
29	0	0		

Table 1 and Fig. 2) are assumed in the present model, after correction for subadult male harvest rate was made.

The use of constant mortality rates assumes that mortality is independent of population density. While there is no evidence to date that mortality of older fur seals is density dependent, there is evidence of density dependence for the mortality of pups on land and for juveniles <2 years old (Fowler 1984, 1985a; Smith and Polacheck 1984). Thus, density-dependent relationships for these age groups are included in the model.

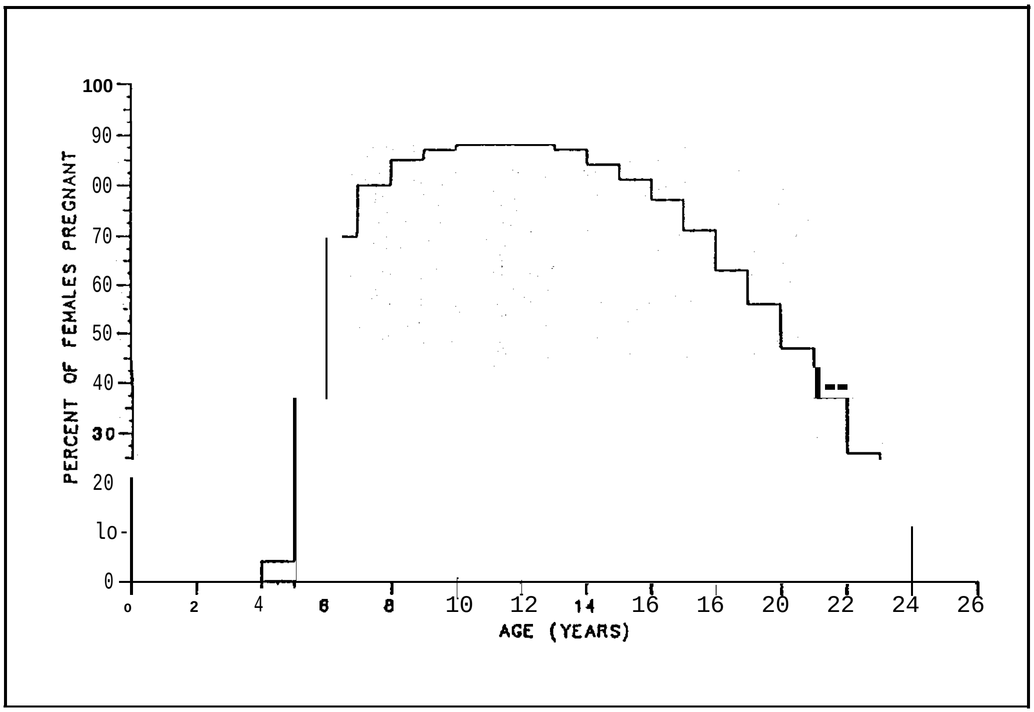

Figure 1. --Pregnancy rate as a function of age.

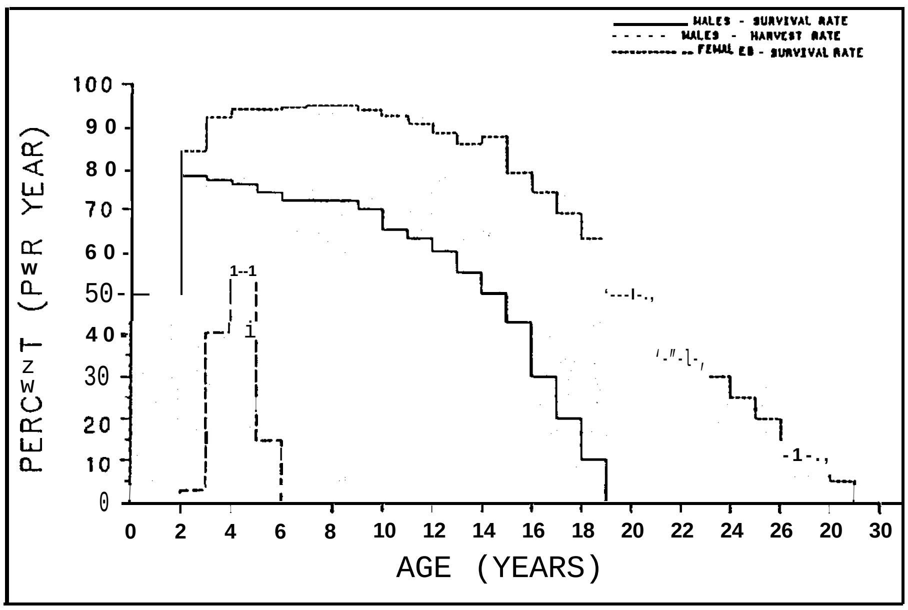

Figure 2. --Natural survival and harvest rates as functions of age and sex (after Lander 1980a, 1981).

The mortality of pups on land appears to increase with increasing number of pups counted on the rookeries (Lander 1979; Swartzman 1984). the model, natural mortality rate of pups on land is a function of the In number of pups born, assuming the functional relationship drawn by Swartzman (1984) between pups born on St. Paul Island and their estimated mortality (line SL in Fig. 3). Pups born on St. Paul are assumed to represent 80% of the total for the two islands, St. Paul and St. George (Briggs and Fowler 1984; Smith and Polacheck 1984). Pups are assumed to remain on land for 128 days (based on data of Gentry and Holt 1986) and on-land mortality is applied over that time period. Male and female pups suffer the same rate of mortality while on land.

Survival during the first 20 months at sea also appears to be related to the number of pups born (Chapman 1961; Lander 1979; Eberhardt 1981; Fowler 1985a, 1985b). Using data for the 1950 to 1970 year classes (Fig. 4, line PA), Lander (1979) found that survival of males during their first 20 months at sea is linearly related to pup survival on land. As pointed out by Fowler (1985b), when data for the years after 1970 are included, the relationship no longer holds. Fowler presented evidence that this difference in juvenile mortality is related to the increase of entanglement in fishing debris and other plastic materials, which he believed to become significant after 1965. Therefore, a linear regression for the data of 1950-65, excluding 1956, is used in the present model, as suggested by Fowler (1985b, line PB in Fig. 4).

Survival rates of female juveniles appear to be higher than those of males of the same age (Chapman 1961, 1964; York 1987). However, the magnitude and density dependence of female juvenile survival is unknown. Using a variety of techniques, Chapman (1961, 1964) estimated the ratio of female to male survival to age 3. From a simple population model using weighted-average pregnancy rates and mortality rates of females older than 3 years, Chapman (1961) calculated that this ratio should be about 2.0. In a similar analysis, Chapman (1964) calculated a ratio of 1.72 using 1920's population estimates and 1.27 using 1950's data. Based on tagging returns, Chapman (1964) estimated the ratio of female to male survival to age 3 for 10 year classes (1951-60), finding an average value of 1.64. However, he pointed out that these estimates are probably biased such that the ratio should be higher. Two of the ten tagging estimates were about 1.27, and the other eight (later) estimates averaged 1.74. Thus, two values for the ratio of female to male survival to age 3 *were* tried in the present model, 1.27 and 1.74. Since mortality of pups on land is assumed the same for both sexes and mortality from age 2 to 3 is 1.077 times as high for females as males (Table 1), the ratio of female to male survival during the first 20 months at sea is assumed 1.18 or 1.62.

Because the number of males over the age of 2 years has no influence on female survival rate, reproductive-rate, or future population size in the model, the mortality rate of males older than 2 influences only the number of males in the population. Thus, harvest rate of subadult males is assumed to be *zero* in all simulations reported here, except as indicated where the 1970's harvest rates in Table 1 and Figure 3 are used.

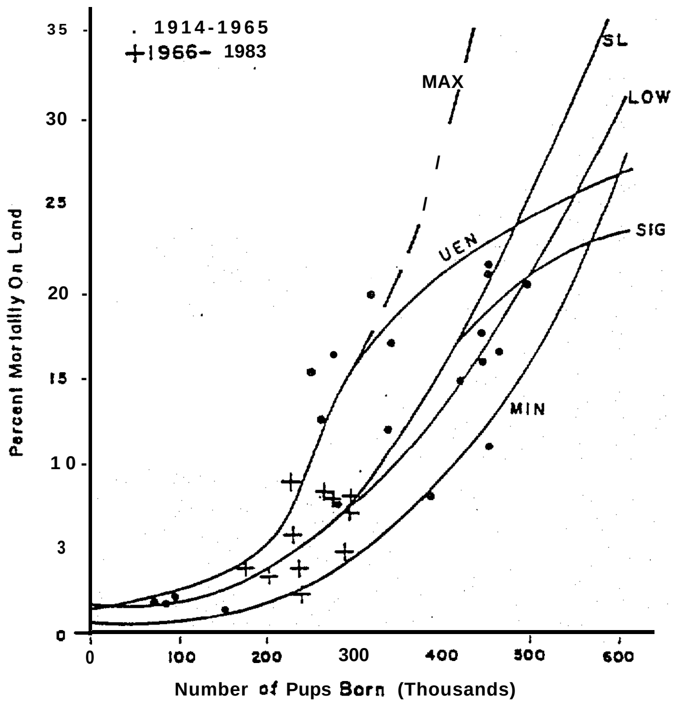

Figure 3. --Alternate density-dependent pup mortality curves. Data are from Lander (1980b); SL is the curve drawn by Swartzman (1984) through the data; MAX and MIN are the maximum and minimum curves tested here; UEN is a sigmoid alternative to MAX; SIG is a sigmoid alternative to SL; and LOW is a lower version of SL.

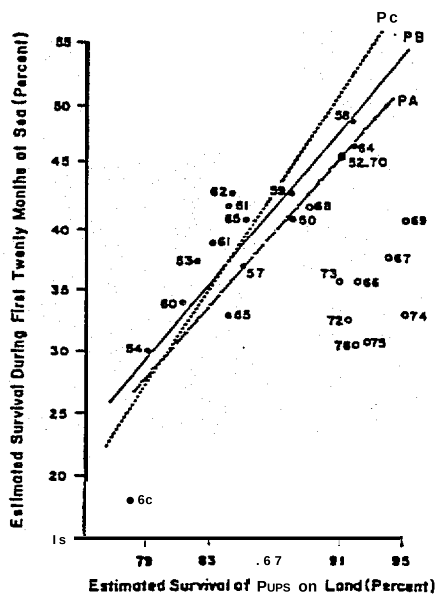

Figure 4. --Alternate linear regressions of juvenile mortality rate as a function of pup survival. PA is from Lander (1979), regressed on the data for 1950-70; PC is the same, but for 1950-65 (before significant entanglement is thought to have occurred); and PB is for 1950-65, excluding 1956.

Harvest rate of females is assumed to be zero, except when specifically simulating the years 1956 to 1974. For those years, the numbers of females by age harvested or collected pelagically (as reported in York and Hartley 1981) are subtracted from the model population at the time of harvest during the specific year. As assumed by York and Hartley, the age distribution of females in the harvest where age was not determined is assumed to be the same as that for harvested females of known age. The age distribution of females grouped as older than a specified age (e.g., 10 years) is assumed to be equivalent to the age distribution in the model population for that year.

Entanglement mortality rates are the least known of the model parameters which must be estimated. Fowler (1985a, 1985b) has shown that, while there is a linear relationship between male juvenile survival the first 20 months at sea and pup survival on land using data up to 1965, following 1965 the model no longer fits the observations. The discrepancy between the model and observed juvenile mortality for the years after 1965 is linearly correlated with the rate of entanglement observed in the subadult male harvest. This suggests the discrepancy is due to entanglement mortality. The discrepancy (as percent mortality) is added to natural mortality of juveniles up to 2 years of age in the model when entanglement is added to the simulation. Because the average percent entanglement in the harvest has stabilized at 0.4% since the late 1970's, the corresponding discrepancy of 15% mortality is assumed for both male and female juveniles as a starting point in model simulations. The discrepancy has ranged from 7 to 25% since 1966 as rates of entanglement have varied (Fowler 1985b).

Mortality rate for entangled males between 2 and 3 years of age was estimated by Fowler (1985b) from the relative frequency of entangled males in the 2- and 3-year-old age classes in the harvest. His estimate is that 5.5% of 2- to 3-year-old males become entangled each year and that 90.3% of entangled males die. Thus, 5% mortality due to entanglement is used in model simulations for male seals between 2 and 3 years of age. Females of this age are assumed to suffer the same or higher rates of entanglement mortality, due to their smaller size (see Discussion).

Entanglement mortality rates of older seals are not available. Fowler (1985b) suggests that entanglement mortality of seals over 3 years of age is assumed to be between O and 5% per year. Different values were tried in various simulations. Both males and females are assumed to suffer the same entanglement mortality once past the age of 3.

For all simulations, the populations were initialized at 1 January sizes and ages. A daily time step was used. Mortalities and births were calculated on appropriate dates in the yearly cycle.

RESULTS

Simulation of the Population at Carrying Capacity

Assuming the above-described pregnancy rates, constant natural mortality rates for seals over age 2, no harvest on either males or females, and no entanglement mortality, the density-dependent pup mortality relationship SL in Figure 3, and the male juvenile survival relationship PB in Figure 4, population equilibria were found for each of the two assumed values of the ratio of female to male survival up to the age of 3, 1.27 and 1.74. Assuming this ratio is 1.27, the population reaches 1.73 million total individuals (censused on 1 January), 1.15 million total females, and 442,000 pups born per year. If the female to male survival ratio is assumed to be 1.74, the total population reaches 1.95 million seals, 1.39 million females, and 540,000 pups born each year.

In the 1940's and 1950's, the fur seal population on the Pribilofs was relatively stable, with 525,000-576,000 pups born each year in the 1950's. This population is thought to have been at carrying capacity for the Pribilof Islands (Fowler 1985a). The model population, assuming a female-to-male survival ratio to age 3 of 1.74, is consistent with observations, while the lower ratio of 1.27 causes the model population to fall short of the observed levels.

If the model is initialized at 15% of the equilibrium population size, a level where pup production matches that of 1912, the model population and number of pups born increase at the same rate as observed pup counts in the 1910's and 1920's, 7.4% per year (Fig. 5). The model population overshoots the equilibrium size in the early 1940's, and afterwards oscillates around the equilibrium of 540,000 pups born per year, with the oscillation damping out over time. The agreement between the model and the observed rate of increase in the 1910's and 1920's suggests that the assumed pregnancy and mortality rates are realistic. Furthermore, a ratio of female to male survival to age 3 on the order of 1.74 is consistent with available data. This ratio was suggested by Chapman's results (1961, 1964), even though he and others have been more comfortable with a much lower ratio. When this same simulation is run with the female-to-male juvenile mortality ratio at 1.27, the projected population increase from the 1912 level is less than the observed rate of increase (Fig. 6).

To determine how sensitive the simulated carrying capacity population is to the various pregnancy and mortality rates assumed, these rates were varied individually within the range of possibilities observed to determine resulting population size. Alternate pregnancy rates by age (up to age 11) were taken from Chapman (1964) and from estimates reported in Smith and Polacheck (1984, table 11), which were based on Japanese collections of females between 1958 and 1960. The Japanese estimates represent the highest reported values for pregnancy rates of younger females. These high rates increase pup production to 583,000 per year (+8%) and decrease the total number of females by 9% (Table 2). Chapman's pregnancy rate estimates increase pup production by only 2% and have almost no effect on the total number of females in the population.

The density-dependent relationship between pups born and pup mortality on land is associated with a large amount of variation, and a number of alternate curves through the observed data were tried (Fig. 3). The resulting carrying capacity population varies from 23% higher to 25% lower than the model result using the standard assumptions (Table 2). Thus, the model is fairly sensitive to this assumed relationship.

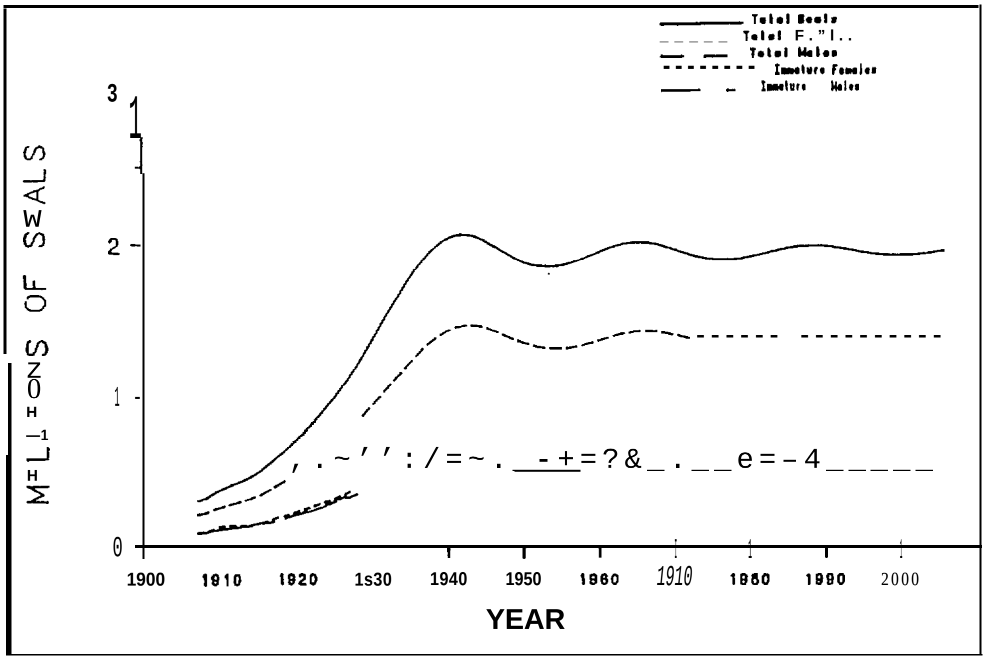

Figure 5a.

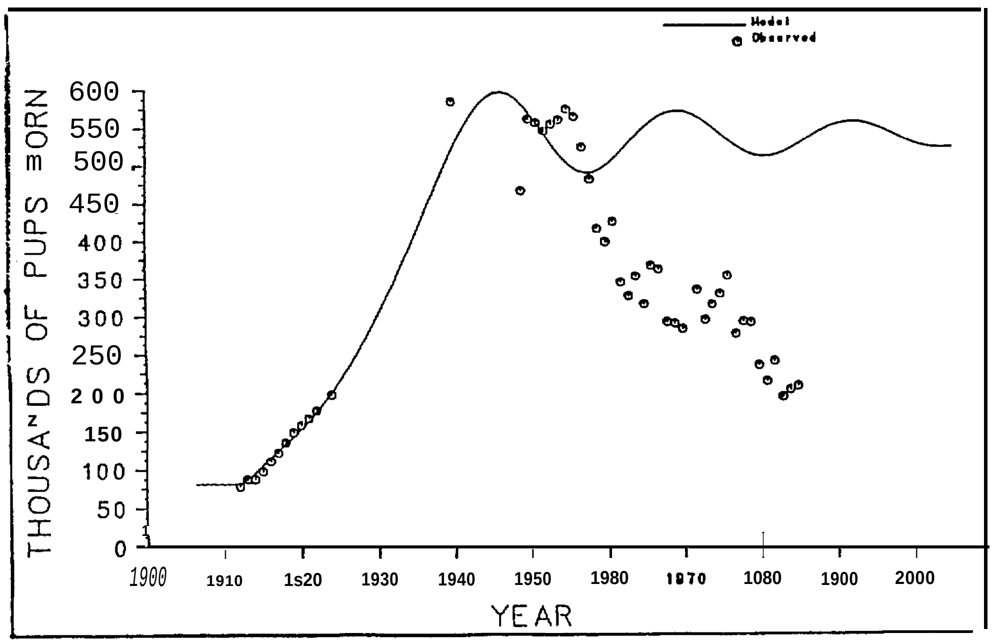

Figure 5b.

Figure 5. --Simulated increase in (a) population level (on 1 January) and (b) number of pups born each year from the depleted population of 1912 to carrying capacity reached by the 1940's. The ratio of female to male survival to age 3 is 1.74. Harvest and entanglement-induced mortality are assumed zero in the simulation.

Table 2. --Resulting equilibrium population levels (on 1 January) and number of pups born each year (in millions of seals) when reproductive rates or mortality rates of certain age groups are varied (see text for specific rate variations) from the standard run producing the best fit to the 1950's carrying capacity population (pregnancy as in Table 1; pup mortality as curve SL in Figure 3; male juvenile survival as line PB in Figure 4; ratio of female to male survival to age 3 - 1,74; no harvest; and mortality over age 2 as in Table 1).

Reproductive or mortality rate(s) varied	Total seals	Total females	Pups born
Standard run (equilibrium of Fig. 5)	1.95	1.39	0.540
Pregnancy rates:			
As in Chapman (1964)	1.93	1.38	0.553
As in Japanese collections, 1958-60	1.79	1.27	0.583
Pup mortality curve (from Fig. 3):			
MIN	2.37	1.71	0.647
LOW	2.23	1.59	0.622
SIG	2.20	1.57	0.611
UEN	1.62	1.16	0.450
MAX	1.46	1.04	0.407
Male juvenile survival line (from Fig. 4):			
PA	1.92	1.37	0.533
PC	1.91	1.36	0.527
Ratio of female to male survival to age 3:			
2.0	2.00	1.46	0.570
1.64	1.92	1.36	0.529
1.37	1.81	1.23	0.473
1.27	1.73	1.15	0.442
1.08	1.54	0.99	0.376
Subadult male harvest rates:			
As in Table 1	1.92	1.39	0.540
Adult female mortality rates:			
As in Chapman (1964)	1.96	1.39	0.509
As in Smith and Polacheck (1984)	1.90	1.31	0.454

Male juvenile survival as a function of pup survival on land was varied to be as line PA in Figure 4, i.e. , the relationship in Lander (1979), and as line PC in Figure 4, i.e., including all data from 1950 to 1965 in the regression. The resulting population size differed from the standard run using line PB (Fig. 4) by at most 2%. Thus, the results are insensitive to this amount of variation of the relationship.

The ratio of female to male survival to age 3 has been estimated by Chapman (1961, 1964) as between 1.25 and 2.0. The resulting model population sizes range from 18% less than to 5% greater than the standard population model run where the ratio is 1.74 (Table 2). Thus, the model is fairly sensitive to the assumed ratio within the range of estimates which have been made. If the ratio is assumed to be 1.0, the population reaches an equilibrium 30% lower than the standard model equilibrium (Table 2), a level well below the 1950's population size.

As mortality of males over the age of 2 has no influence on female or pup population size in the model, the model population is insensitive to variation in subadult male harvest rates or variation in natural mortality of males over the age of 2. A subadult male harvest rate equivalent to that in the 1970's (Lander 1980a) reduces the total male population by 5% (Table 2).

Mortality rates of females over the age of 3 as given by Chapman (1964) result in the same number of total females in the population as the standard model assumptions (Lander 1981), but the age distribution is such that only 509,000 pups are born per year (-6%, Table 2). The lower estimated survival rates of Smith and Polacheck (1984) reduce the female population by 6% and pup production at equilibrium by 16%. However, the estimates of Lander (1981) are based on considerably more data than the other two sets of estimates, and the error of the standard model run associated with error in adult female mortality rates is probably somewhat less than these results.

Simulation of the Pribilof Population Decline Since 1958

When the female harvest and pelagic collection of 1956-74 is removed from the simulated carrying capacity population during those years, the predicted number of pups born decreases until 1965 and subsequently recovers to the preharvest level by 1975 (Fig. 7). While the female harvest may account for some of the decline after 1958, it is clearly a minor perturbation from which the population should have rapidly recovered, assuming the carrying capacity remained unchanged from the 1950's level.

The population decline after the female harvest ceased has been a subject of much discussion in recent years, with the prevailing opinion being that lethal entanglement is the most likely causative factor (Fowler 1985a, 1985b). Assuming that entanglement became significant in 1966 (as suggested by Fowler), that an additional 15% of males and females die from entanglement by age 2, and that 5% mortality of all seals age 2 and older is due to entanglement, the resulting pup production is as in Figure 8. Under these assumptions, the model population does not decline as fast as the observed pup production indicates it should. This suggests that entanglement mortality may have been significant before 1966, or that there is some other cause of the additional mortality after 1958. If the same assumed mortality rates are initiated in 1960, the model decline fits the observed more closely (Fig, 9).

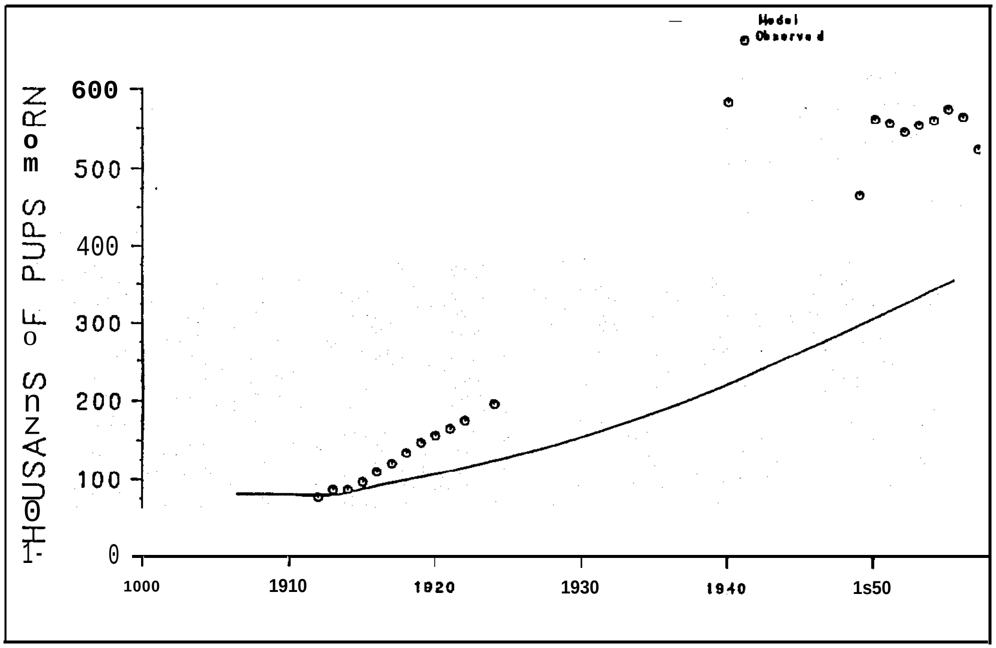

Figure 6. --Number of pups born in model population assuming the same rates as in Figure 5, except the ratio of female to male survival to age 3 is assumed to be 1.27.

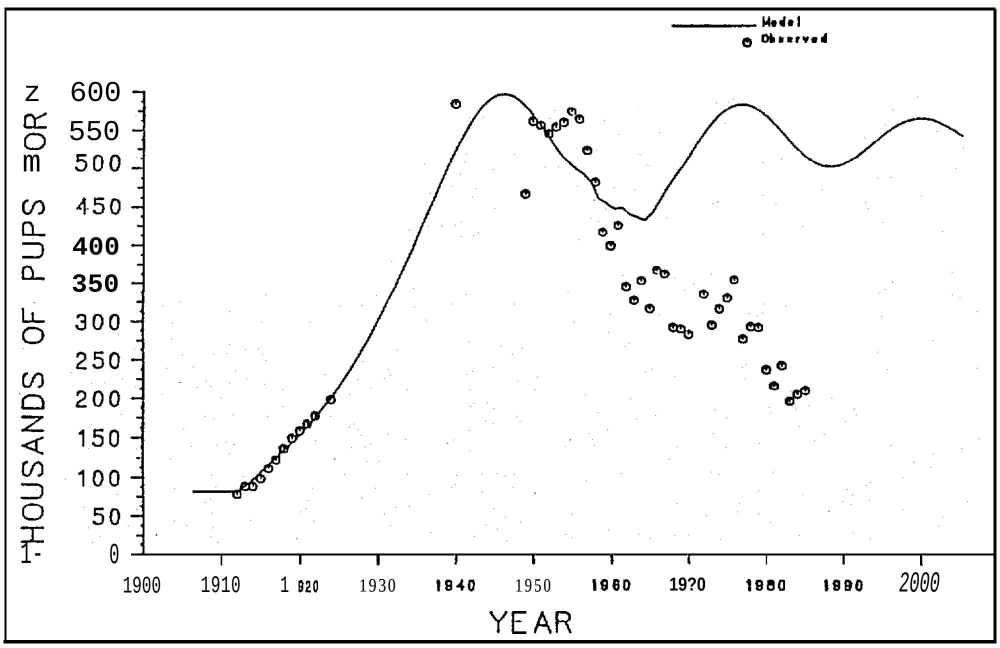

Figure 7. --Number of pups born to modeled and observed populations over time, including simulation of female harvest between 1958 and 1974 but assuming no mortality due to entanglement.

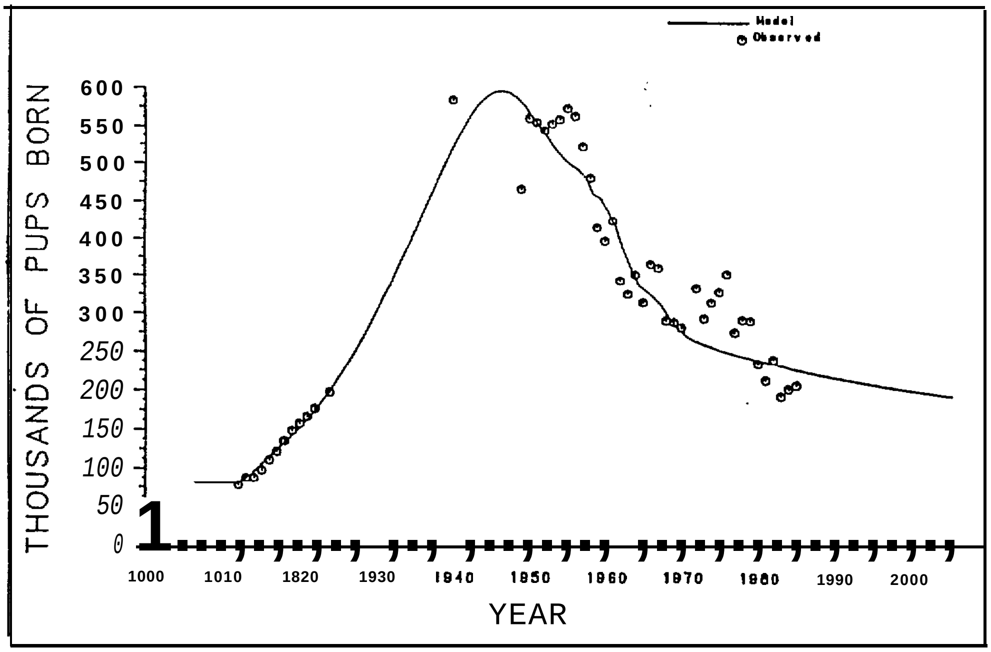

Figure 8. --Number of pups born to modeled and observed populations over time, including simulation of female harvest (1958-79) and constant entanglement mortality of 15% before and 5% after 2 years of age beginning in 1966.

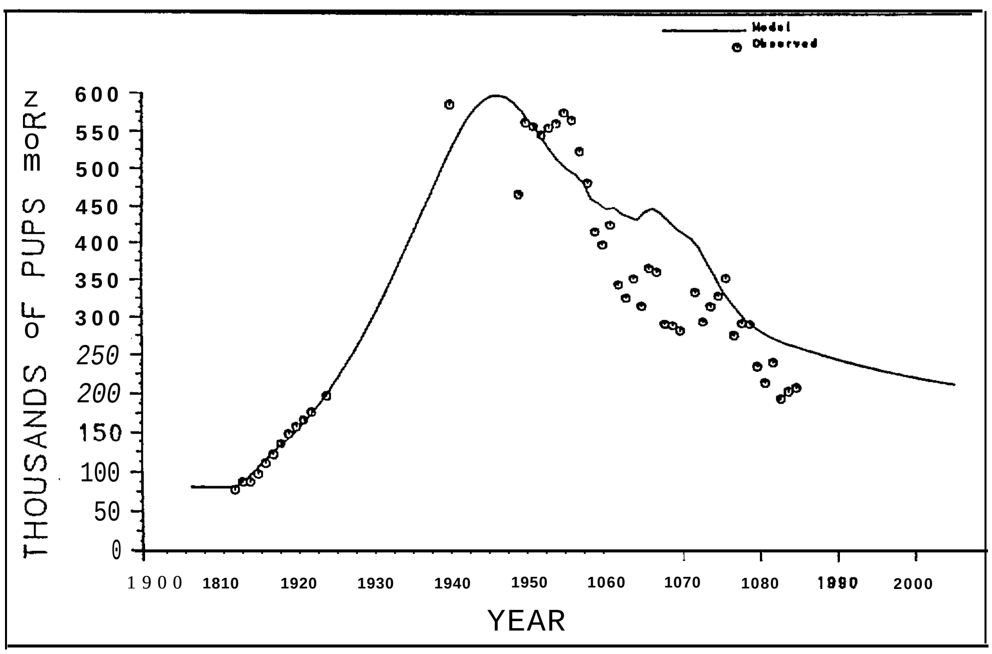

Figure 9. --Number of pups born to modeled and observed populations over time, including simulation of female harvest (1958-79) and constant entanglement mortality of 15% before and 5% after 2 years of age beginning in 1960.

In the model runs shown in Figures 8 and 9, all seals over age 2 are assumed to suffer 5% mortality per year due to entanglement. If seals over age 3 are assumed to suffer insignificant (zero) mortality due to entanglement, as suggested by Fowler (1985b), the model population declines to only 1.06 million total females with 401,000 pups born per year, a level much higher than observations for the last two decades (Fig. 10). Thus, adult females must be suffering mortality over and above Lander's (1981) estimated rates, whether due to entanglement or some other cause.

The rate of entanglement in the subadult male harvest was not constant between 1967 (the first year of observation) and the present. Before 1970, entanglement rate was below 0.4%. From 1973 to 1975 it increased to about 0.7% and subsequently stabilized at about 0.4% (Fowler 1985b). Before 1970, male juvenile survival was closer to 10%, rather than 15%, below the expected rate from line PB in Figure 4. Between 1973 and 1975 the discrepancy between observed and expected (line PB) was about 20%.

Assuming that entanglement varied proportionately for all age classes of seals, all entanglement mortality rates in the model were reduced by one-third over 20 months (one-fifth per year) before 1970 and increased by the same amount for 1973 to 1975. Thus, an additional 10 to 20% of juveniles are assumed to die from entanglement by age 2. Entanglement mortality of all seals over 2 years is assumed to vary between 4 and 6% per year. The resulting pup production is compared to the observed in Figure 11. The fit to the observed is improved by this inclusion of variable entanglement rate in the model (compare Figs. 9 and 11).

If the same assumptions used for the simulation of Figure 11 are made, only with 2- to 3-year-olds suffering 8 to 12% mortality per year (an annual rate equivalent to the additional 15% lost over 20 months as juveniles ±20% of that value) while rates for seals over 3 remain at 4 to 6% per year, the resulting decline is as in Figure 12. This latter simulation brings the model population level down to the same level as the current pup counts on St. Paul Island indicate. Figure 13 shows associated total population numbers.

Model Predictions of Future Population Numbers

The model simulation of Figure 13 (and Figs. 8, 9, 11, and 12 as well) indicates that, while the current rate of decline is much slower than the 4 to 8% decline of the 1970's, the Pribilof fur seal population would continue to decline at about 1% per year for the next 50 years or more if mortality rates remain at current levels. If entanglement mortality were eliminated (and assuming pre-1960 survival rates still hold), the population could recover to the 1950's carrying capacity level after about 15 years, as evidenced by the increase from the late 1920's to the 1940's (Fig. 5). If current entanglement mortality rates (as assumed in Figs. 8 and 9) were halved for all age groups, the population could recover in about 50 years to a total of 1.61 million seals, 1.13 million total females, and 400,000 pups born, where the model population stabilizes (Fig. 14). This is a size equivalent to the observed population in 1960. If entanglement mortality rates were held at the levels assumed for the 1960's

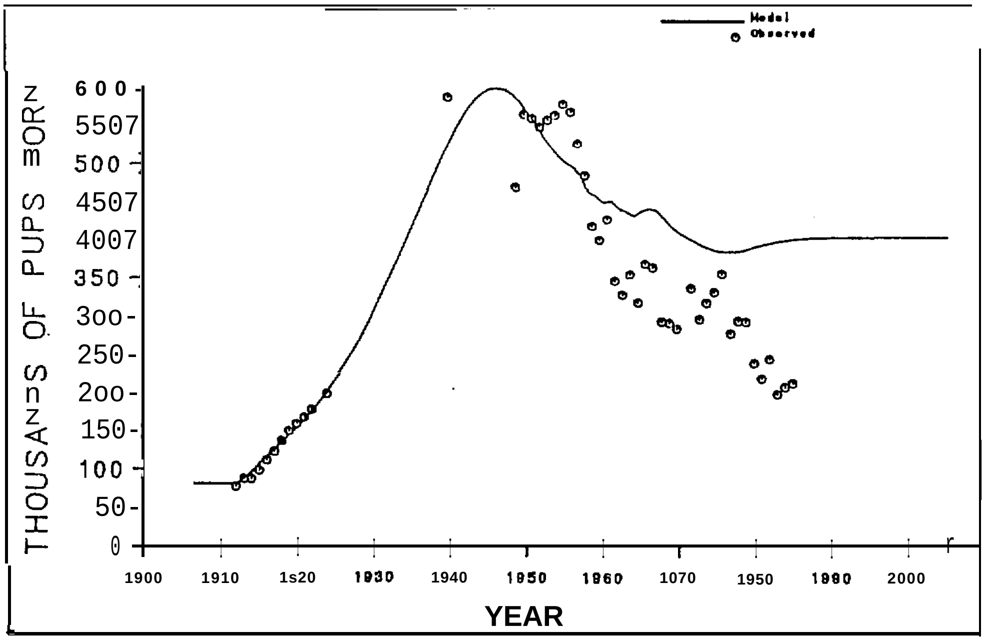

Figure 10. --Number of pups born to modeled and observed populations over time, including simulation of female harvest (1958-74) and, beginning in 1966, constant entanglement mortality of 15% before age 2, 5% from age 2 to 3, and no entanglement mortality over the age of 3 years.

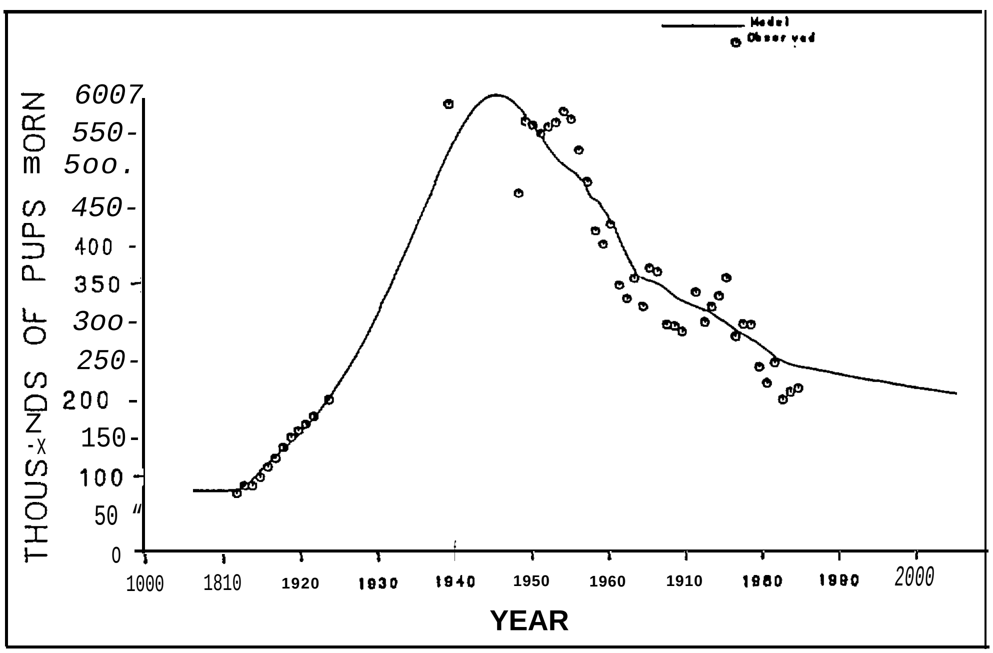

Figure 11. --Number of pups born to modeled and observed populations over time, including simulation of female harvest (1958-74) and variable entanglement mortality rates (10-20% before and 4-6% after age 2 years) beginning in 1960.

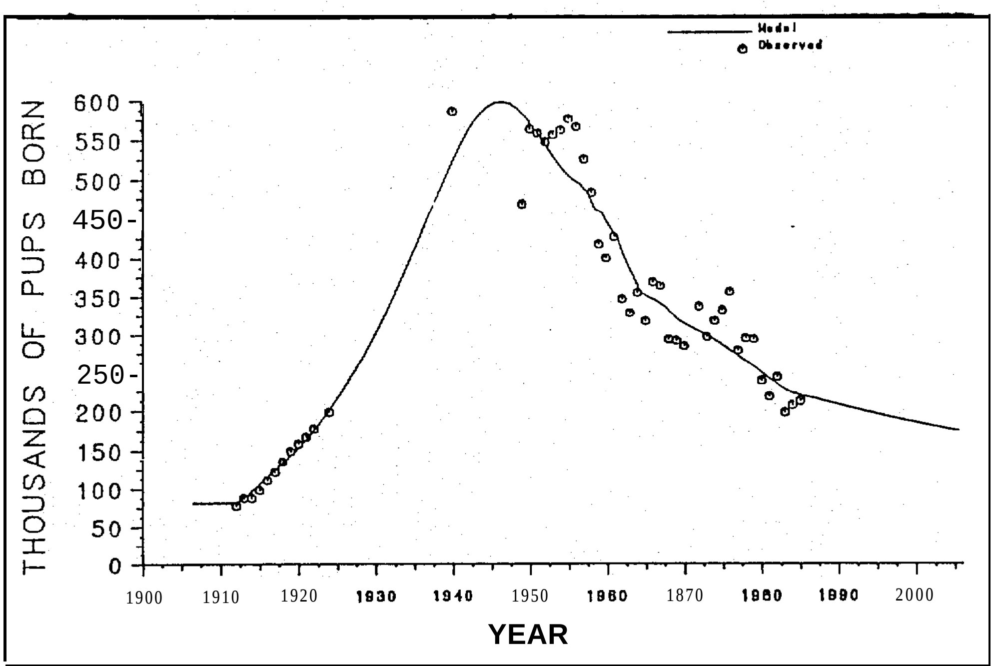

Figure 12. --Number of pups born to modeled and observed populations over time, including simulation of female harvest (1958-74) and variable entanglement mortality rates (10-20% before age 2, 8-12% between 2 and 3 years, and 4-6% after age 3 years) beginning in 1960.

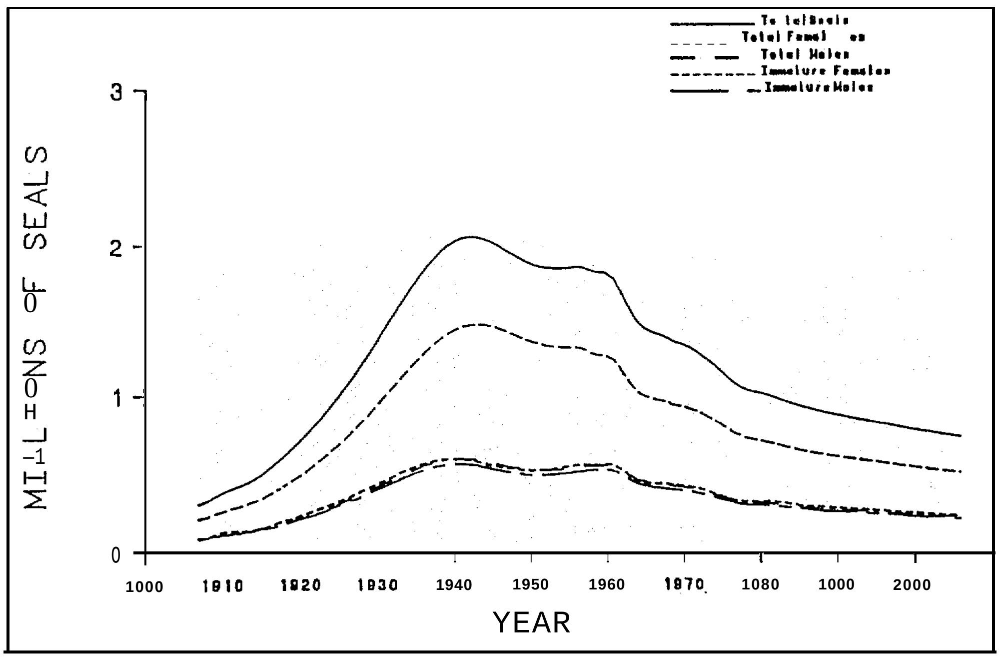

Figure 13. --Simulated population numbers (on 1 January) for the simulation of Figure 12.

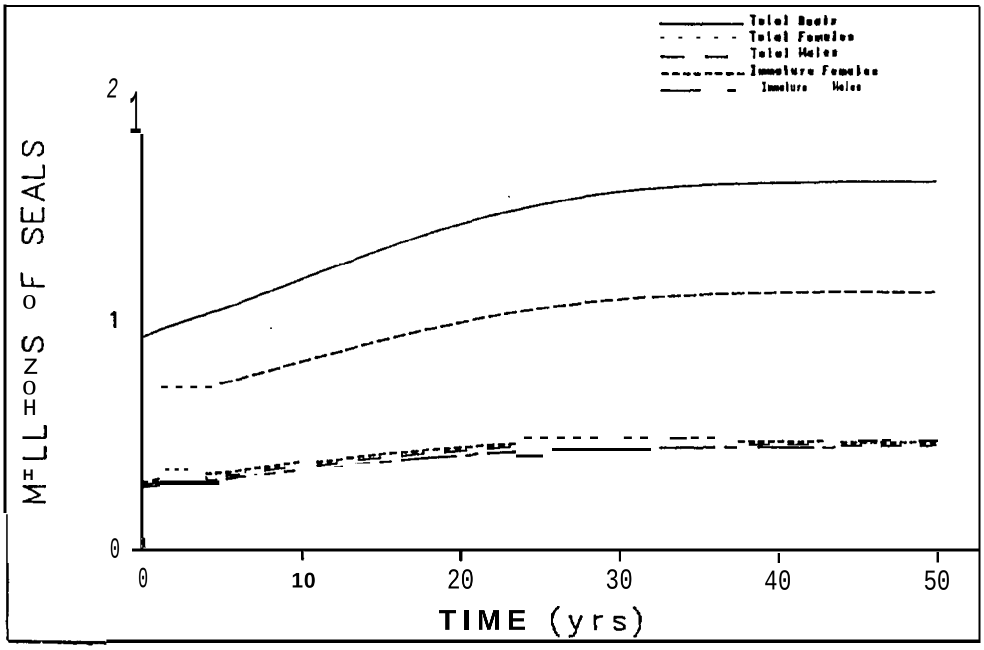

Figure 14. --Simulated population numbers (on 1 January) assuming that current entanglement rates are halved and after initializing with the estimated population size in 1987.

in the model run of Figure 12 (an additional 10% of juveniles die before age 2, 8% per year from age 2 to 3, and 4% per year over age 3), the population would increase slowly from present levels (917,000 total seals, 637,000 females, and 214,000 pups born in the 1987 simulated population) to 1.29 million seals, 896,000 females, and 301,000 pups born per year after 50 years and would stabilize at 1.34 million seals, 932,000 females, and 315,000 pups after 90 years.

DISCUSSION

The model results show that current estimates of pregnancy and natural mortality rates as outlined above are consistent with observational data from 1912 to 1958 if the ratio of female to male survival to age 3 is assumed to be 1.74. The model simulates the population increase from 1912 to the 1940's and predicts the appropriate carrying capacity level thought to have prevailed in the 1940's and 1950's. Lower estimates of the female-to-male juvenile survival ratio yield much *lower* equilibria and rates of population increase than have been observed on the **Pribilofs**. Clearly, the model is sensitive to female juvenile survival rate. However, this vital statistic is the least well known and least studied of all the vital rates involved. Tagging or other studies on female juveniles would greatly facilitate the estimation of their current survival rates.

Model sensitivity analysis shows that model results are also highly dependent upon the choice of the density-dependent relationship between pup mortality and number of pups born. The considerable variability associated with this functional relationship (Fig. 3) is undoubtedly due to the dependence of pup mortality on other factors besides total number of pups born. Actual pup density on the rookeries, climatic conditions, and competition with other species for food are other possible factors (which are not necessarily independent) which could be considered in developing more predictive functional relationships.

The model is relatively insensitive to changes in pregnancy rates and adult female natural mortality rates within the range of estimates available in the literature. Therefore, these vital statistics appear to be well enough known for modeling purposes.

The carrying capacity of the Pribilof Islands population appears to be regulated by the density of pups born on the rookeries. Subsequent survival as juveniles appears to be causally related to survival rate on land (Lander 1979, Fig. 4). This suggests that lower survival rate at higher population density is primarily due to reduced fitness of pups, whether by increased spread of disease, slower weight gain due to competition for food or space among lactating females, or other effects of crowding. The model is consistent with the view that there is no significant density-dependent control of mortality over the age of 2 years.

Owing to the weak density-dependent control of the fur seal population, the maximum pup production is at carrying capacity, not at a lower population size. This is in agreement with observations in the field during and after the period of female harvest in the late 1950's and 1960's.

The population decline after 1958 has been a subject of intense interest in recent years (e.g., Eberhardt 1981; Fowler 1984, 1985a, 1985b; Smith and Polacheck 1984; Trites 1984). The initial decline may be partially accounted for by the female harvest of 1956 to 1968 (York and Hartley 1981 and present model), but after 1960 it is evident that other factors are involved (Fig. 7). The model results suggest that entanglement mortality can account for the decline after 1960 if the following assumptions are made regarding female mortality (male mortality has no influence on pup production): An additional 15% of juveniles (less than age 3), on average, died from entanglement; an average of 5% of seals over age 3 suffered lethal entanglement; and significant entanglement mortality (at these rates) began in 1960.

The fit of the model to the observed pup counts is improved considerably if entanglement mortality rate is varied as a function of the entanglement rate observed in the subadult male harvest. A variation of ±50% of entanglement rate, i.e. , 0.2 to 0.6%, appears to result in ±33% variation in the mean discrepancy between observed male juvenile survival rate and that predicted from line PB in Figure 4 (Fowler 1985a), or ±20% variation in entanglement mortality rate per year. If entanglement mortality rates of all age groups vary to this degree in proportion to variation in observed entanglement rates, the appropriate curvature in the model pup curve after 1965 is produced.

The best fit is obtained if 2- to 3-year-old females are assumed to have suffered twice the entanglement mortality rates of males of the same age. If females over 3 years of age are assumed to not die at significant rates from entanglement, the decline in pups born since 1960 cannot be accounted for, and the model predicts that a stable population size of 1.49 million seals, 1.06 million females, and 401,000 pups born per year should have been reached by about 1985 (Fig. 10). Higher entanglement mortality of females as opposed to males of the same age could be accounted for if entanglement rate is a function of body size, rather than age as assumed by Fowler (1985a, 1985b). Even at 1 year of age, male fur seals are almost twice the size of females; a 3-year-old male is the same size as a 6-year-old adult female, and the largest females (up to 20 years old) are not as large as a 5-year-old male (Lander 1980a). This suggests that if entanglement is primarily a function of size, adult females could be expected to suffer the same entanglement rates as subadult males, perhaps 5% per year as estimated by Fowler (1985b), and immature females even higher rates. The assumption of 10% entanglement mortality rate for 2- to 3-year-old females is consistent with this hypothesis. Clearly, more information is needed on female entanglement rate and mortality as a function of age. The assumption that males and females of the same age suffer the same mortality rates is unlikely, especially given the disparity in size.

In the above analysis it is assumed that pups on land do not suffer entanglement mortality. In the model, pups of mothers dying from entanglement are assumed to die. Recent evidence reported by DeLong et al. (1988) suggests that mortality rates of pups may be increased by nonlethal entanglement of their mothers, since the females are less efficient at foraging and providing milk for the pup. However, as evident in Figure 3, pup mortality rates on land at a given density do not appear to have changed from 1914-65 to 1966-83, before and after the hypothesized onset of entanglement. Therefore, there is no evidence to support the hypothesis that nonlethal entanglement of lactating females has significantly affected pup mortality on land or the pup population as a whole.

As shown by the model results in Figure 14, a reduction of the current extrinsic mortality rate (due to entanglement or some other cause) by 50% would allow the fur seal population to recover at least partially. If this mortality is in fact due to entanglement, halving the current entanglement rate (to 0.2% from 0.4% of subadult males), which would reduce the annual entanglement mortality rate by 20%, would stop the current decline in pup production, according to model predictions. This suggests that it would be necessary to halve the density of plastic debris in the North Pacific and Bering Sea region to stop the decline and maintain the population at current levels.

The model results reported here suggest that the fur seal population can recover from single-event perturbations such as substantial harvest of the breeding population (females in the case of fur seals) or some other cause of mortality of finite duration. After the fur seal population was reduced by 1912 to 15% of its carrying capacity level, the population was able to recover fully in 30 years. Recovery would be faster after smaller perturbations . However, long-term, continuous additional sources of mortality, such as lethal entanglement, form a much more serious threat to the population. While single-event perturbations are significant in the short term, chronic sources of additional mortality are much more important when considering the long-term stability of the population.

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STUDIES OF THE POPULATION LEVEL EFFECTS OF ENTANGLEMENT ON NORTHERN FUR SEALS

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ABSTRACT

Recent studies have focused on entanglement among the juvenile male northern fur seal, *Callorhinus ursinus*, as a means of evaluating the effects of entanglement at the population level. Most entanglement-related field studies were conducted on St. Paul Island, Alaska, in the 1980's but the analyses include relevant data from the late 1970's. Reported here are the results of recent studies on monitoring of entanglement, estimates of entanglement-caused mortality, and the effects entanglement may have on the chances an animal is observed on the breeding islands.

The observed proportions of seals entangled in 1985 and 1986 were consistent with those observed during the last few years of the commercial harvest (about 0.4%). The proportion observed in 1988 was 0.29%, the lowest observed since 1970. The change reflects a drop in the numbers of animals entangled in fragments of trawl webbing. The frequency of occurrence of trawl webbing among the entangling debris was about half the former levels whereas the proportion of seals entangled in other types of debris did not change.

These studies confirm earlier estimates indicating that, after 1 year, the survival of seals entangled in debris light enough to permit the animals to return once to land is about half of the survival of nonentangled seals. Data indicate that the main factor contributing to the success of entangled animals that do survive is escapement from the debris.

Rates at which entangled animals are resighted indicate that the proportion of animals resighted drops with an increase in the size (weight) of debris.

Data from radio-tagged seals confirm that entangled seals go to sea for longer periods of time than do controls.

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

INTRODUCTION

Entanglement in marine debris, specifically in plastics associated with the commercial fishing industry, has been documented for a number of species of seals and sea lions (Fowler 1988). The effects of entanglement in such debris have been the subject of a number of studies, especially as related to the impact on the northern fur seal, *Callorhinus ursinus*. Many of these studies have examined effects at the population level (Fowler 1982, 1985, 1987; Swartzman 1984; French and Reed 1990; Swartzman et al. 1990). Others have studied the effects at the level of the individual (Fowler 1988).

Entanglement of northern fur seals in marine debris has been a concern for several decades. The first sightings of entangled seals occurred just after World War II. Records of entanglement among young males taken in the commercial harvest or seen in juvenile male roundups have been maintained since 1967. Concern about the potential role of entanglement-caused mortality has given rise to research focused on determining as clearly as possible the extent to which entanglement contributes to a reduction in survival and to declining trends in the population (Swartzman 1984; Fowler 1985, 1987; French and Reed 1990; Swartzman et al. 1990).

This paper reports on recent field work to assess the effects of entanglement on the population of northern fur seals breeding on St. Paul Island, Alaska. The objectives of this work are: (1) continued monitoring of the proportion of seals entangled, (2) determination of the nature of entangling debris, (3) determination of the mortality caused by trawl webbing, especially as related to effects at the population level, and (4) assessment of the relative rates at which entangled and control animals are resighted. Part of the study of relative rates of refighting addresses the question of whether or not an animal's chances of being seen again are altered by being, or having been, entangled.

METHODS

Most of the data treated in this study deal with young male fur seals of the size (roughly 105 to 125 cm in total length) formerly taken in the commercial harvest on St. Paul Island. The commercial take of fur seals,. which ended in 1984, was the earliest source of data on entanglement. Other data, as the main focus of this paper, were collected during 1985, 1986, and 1988 from animals of the same size (and same approximate age) to ensure comparability with historical data. Males of this size are usually between the ages of 2 and 5 years, mostly 3-year-olds.

The studies reported here involved roundups, a procedure conducted during the breeding season. A total of 63 roundups were conducted in July and early August 1985. Sixty-one were conducted in July and early August 1986; 66 were completed during July 1988.

During roundups, young males are herded together to be examined for debris or tags and for applying tags. To conduct a roundup, field biologists approach an area (called a hauling ground) near a breeding rookery where young males come ashore in large numbers. Avoiding disturbance to the rookeries, the members of the research team position themselves between the hauling ground and the water. The males on the hauling ground are then surrounded and herded away from the rookery but close to the water's edge. Care is taken to minimize the movement required of the animals and to allow them sufficient space to prevent crowding and overheating.

Once the seals are in a controlled group, field workers then allow small numbers of animals to leave the group and file toward the water. Once one or more seals begin moving toward the water, other seals follow. This movement is controlled (to ensure that tagged flippers will be seen) by the field crew. While moving toward the water, seals pass between observers , some of whom are engaged in counting seals while others watch for tags and entangling debris. Others of the field crew remain prepared to capture seals, while the remainder work to assure that the main group of seals remains in place.

When an entangled or tagged seal is seen among those leaving, the movement of seals from the main group is stopped. If tag numbers cannot be read, if tags are to be applied, or if a detailed examination of the debris is required, the seal is captured with a wooden pole fitted with a rope noose (<2% of these seals escape to the water without being captured). If tags are to be applied, or the debris examined in detail, the seal is placed on a restraint board (Gentry and Holt 1982) for a few minutes. Tags are applied on the trailing edge of each foreflipper, about 2-3 cm distal from the hairline.

If the captured animal is entangled, the nature of the entanglement is recorded (and tags applied if not previously tagged). Data recorded at the time of tagging include the tag number; the color, size, and type of debris; mesh size (if it is a net fragment); and the extent of the wound the debris has caused. A sample of the debris is removed (if there is enough) to be used later for measuring twine size and for any analysis necessary for identification of the plastics involved.

Two control seals about the same size as the entangled animal are also tagged to compare rates of return in succeeding years. The choice of tagging two control seals is arbitrary. Tagging more controls than entangled seals ensures a larger sample of returns to be used in comparing the relative rates of return of the two groups. It also aids in the study of the frequency of refighting rates and the locations (for study of intermixture) of resighted seals.

In ❑ost cases, seals that are *not* handled and seals released after being tagged or examined return directly to the water. By the end of the roundup, all seals have returned to the water.

Some of the animals seen in the first roundup are seen again in later roundups, The resulting sampling scheme is one of sampling with replacement, and the data for both the control animals and the entangled animals are treated accordingly.

Other sets of the data reported in this paper are from similar studies prior to 1985 in which animals were sighted in the commercial harvest prior to 1985. During the harvests, animals were herded together and moved to special areas where they were killed. These data from harvests, therefore, are treated as samples without replacement.

In previous studies of fur seal entanglement, two approaches have been used to categorize debris on seals according to its size (weight). For continuity and comparison, both are used in this study with distinction depending on the terms used. The first approach divides the debris into "light" or "heavy" categories depending on whether it is light enough for the entangled seals to return (at least once) to the breeding islands or so heavy that they cannot return. This definition suffers from lack of precision because the two categories are not discrete; their overlap is dependent on factors such as how far the seal has to swim to haul out on land. The upper limit of the light category is about 400 g, since over 90% of the entangled seals observed on land are in debris that weighs <400 g (Fowler 1987),.

The second approach uses three distinct weight categories. The debris seen on animals is either weighed (after being removed) or subjectively evaluated (when entangled animals are released with debris intact). The weight of debris is classified as small (<150 g), medium (between 1.50 and 500 g), and large (>500 g).

To study the behavior of entangled animals, and the influence of entanglement on the chances of being resighted, radio transmitters (weighing about 40 g) were attached to 16 control and 16 entangled animals to monitor their presence and absence in the vicinity of the hauling grounds or rookeries. A radio transmitter was attached with epoxy glue to the back of the animal's head while the animal was restrained following procedures described in Loughlin et al. (1987). Each radio-tagged seal was also marked with bright paint applied to the radio and glue. Each radio was a 3.5-V transmitter, manufactured by Advanced Telemetry Systems, Inc. All radios transmitted within the frequency range of 164 to 166 MHz.

Data on the behavioral effects of entanglement were all collected in 1988. After attaching radios early (17 to 26 July), observers, using hand-held receivers, listened for radio-tagged seals during a daily visit to each haulout site until 29 August. A computer attached to a receiver was set up at the southern end of St. Paul Island (Reef Point) to scan for and record radio signals from each of the radio-tagged animals within receiving distance (approximately 5 km).

The amount of time the seals spent on shore was estimated in two ways. Detailed data for seven animals (three control and four entangled) were available from the computer at Reef Point. The computer scanned for the presence of these animals for 10 sec every 15 rein, 24 h/day. We estimated the duration of intervals spent on land or at sea *to* the nearest quarter hour, Because the signals occasionally were blocked by the animals lying on the transmitters, and because the animals frequently entered the near-shore water without going to sea, we considered an animal to be at sea only when its transmitter had not been heard for at least an hour. Hence, by this definition, trips to sea could never be shorter than 1 h.

The second method for estimating the time ashore involved the use of data obtained from observers with hand-held receivers. If the radio on a given animal was heard during a survey, the seal was considered to have been on land all day. If the signal from that radio was not heard, the seal was considered to have been at sea all day. When the signal from a given animal was heard one day but not on the next day, we assumed that the animal had departed halfway between the two observations. This gave us an onshore estimate to the nearest half day for all 32 animals.

Standard methods were employed in conducting the usual statistical tests (e.g., chi-square tests) where noted. The level of significance chosen for statistical tests was P = 0.05, unless otherwise noted. The analysis of data resulting from the refighting of tagged animals involved both standard approaches (e.g., the Seber-Jolly method; Seber 1973) and a regression analysis specifically designed for this study. The latter was developed to make *use* of all the existing data to address questions unique to this study. The specifics of the procedure used in this analysis, with the assumptions involved in estimating survival from entanglement-caused mortality, are presented in the Appendix.

RESULTS

During 1985, 1986, and 1988, 22,211, 22,572, and 24,519 (respectively) male seals of the size conventionally taken in the harvest were sampled. As will be presented in more detail below, about 25% of these totals were repeated sightings. Table 1 shows the numbers of seals that were tagged each year and percentage resighted in subsequent years.

Of the 49 tagged animals released in 1985 and resighted in 1986, 12 (24%) were originally tagged as entangled animals. The change from a ratio of 85:172 (85/172 - 0.494, entangled to controls) tagged in 1985 to 12:37 (12/37 - 0.324) resighted in 1986 is not statistically significant (chi-square test). There was no field effort in 1987, so no samples were collected in that year. Of the 14 seals tagged in 1985 and resighted in 1988, 1 (7.7%) had been tagged as entangled. The change in ratio from 85:172 (85/172 = 0.494) *to* 1:13 (1/13 - 0.077) between 1985 and 1988, and from 12:37 to 1:13 (12/37 - 0.324 to 1/13 - 0.077) between 1986 and 1988 are statistically significant (binomial probability tests).

Of the 407 animals tagged in 1986, 128 (31.4%) were entangled. Of 46 seals tagged in 1986 and resighted in 1988, 6 (13%) were tagged as entangled seals in 1986. The change from a ratio of 128:279 (128/279 - 0.459) to 6:40 (6/'40 - 0.150) between 1986 and 1988 is also statistically significant (chi-square test).

Of the eight seals resighted in 1988 after having been tagged as entangled in earlier years (including one tagged prior to 1985), six had lost their entangling debris. No seals have been resighted as entangled after originally having been tagged as controls.

Table 1.--Comparison of numbers of tags applied (in parentheses) and resighted (percent resighted shown in brackets below the numbers resighted) by year for entangled and nonentangled seals, each row corresponding to the tags released in the first year for that row (from Fowler et al. 1989).

	Year			
Controls	1985	1986	1987	1988
Nonentangled	(172)	37	--	13
		[21.5]	--	[7.6]
		(279)	--	40
			--	[14.3]
			--	--
			--	--
				(104)
Entangled	(85)	12	--	1
		[14.1]	--	[1.2]
		(128)	--	6
			--	[4.7]
			--	--
			--	--
				(52)

Table 2 presents the percentage of juvenile male seals found entangled, by year, for 1981 to 1988 in terms of the kinds of debris in which they were entangled. More detailed presentations of the data for 1988 are available in Fowler et al. (1989). Figure 1 illustrates the percentage of entangled seals observed in the harvests since 1967 and in the roundups since 1985. Table 2 also shows the composition of the debris found on animals in terms of proportions entangled. The proportion entangled in 1988 was the lowest observed since 1970 and was about half of the mean proportion observed from 1981 to 1986.

The frequency distribution of the size of debris seen on the animals per year is shown in Table 3. The numbers and percentages of those animals resighted in subsequent years, in relation to the size of debris, are presented in Table 4. None of the seals entangled in large pieces of trawl webbing were resighted more than 1 year subsequent to their being tagged,

Table 2.--Debris found on juvenile male fur seals in 1988 compared to 6 earlier years, expressed as the observed percent of juvenile male seals entangled by debris category.

Type of debris	Entanglement (%)						
	1981	1982	1983	1984	1985	1986	1988
Trawl net fragments	0.29	0.24	0.30	0.22	0.36	0.27	0.15
Monofilament net fragments	0.00	0.01	0.01	0.02	0.01	0.01	0.00
Plastic packing bands	0.08	0.10	0.07	0.09	0.05	0.06	0.07
Cord, rope, string	0.04	0.04	0.02	0.05	0.08	0.07	0.05
Miscellaneous items	0.03	0.01	0.03	0.01	0.01	0.01	0.01
Total	0.43	0.41	0.43	0.39	0.51	0.42	0.28
Sample size	102	102	112	87	76	70	53

Table 3.--Annual percentage frequency distribution of the size of debris on entangled seals that were tagged and released.

Year	n	<150 g(%)	150-500 g(%)	>500 g(%)
1983	84	63	23	14
1984	57	81	12	7
1985	78	72	20	8
1986	128	72	21	7
1988	53	72	15	13
Total	400	71	19	10

whereas seals in small debris were resighted up to 5 years later. The refighting rate of animals in medium-size debris was intermediate to those for large and small debris.

A summary of the results of the radio tagging study using hand-held radio receivers is presented in Table 5. The table contains data from both full and partial records because the study was of insufficient length to encompass an entire long feeding trip for all of the tagged seals. Furthermore, almost no seal completed a full cycle, from departure on a trip to sea followed by a return and an on-land interval until departure for the next feeding trip. For that reason, the estimated percentages of time spent on land during the course of this study may be different from those over an entire season spanning several full cycles. However, the entangled seals spent more time at sea than did controls. Twelve of sixteen entangled

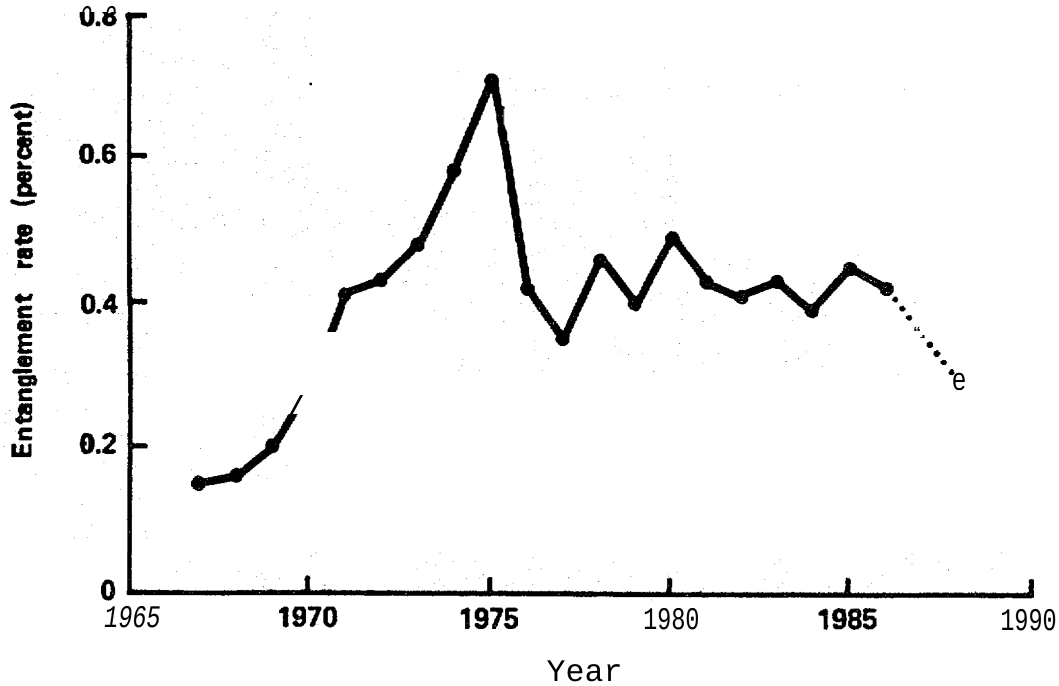

Figure 1. --The percentage of juvenile male seals found entangled in the commercial harvest from 1967 to 1984 and in research roundups from 1985 to 1988, on St. Paul Island, Alaska.

Table 4.- -The numbers and percentages of tagged animals listed in Table 3 that were resighted by year in relation to size of entangling debris and year.

Year tagged	Year resighted	Size of debris		
		<150 g(%)	150-500 g(%)	>500 g(%)
1983	1984	18(34)	3(16)	2(17)
1983	1985	4(8)	1(5)	o(o)
1983	1986	3(6)	o(o)	o(o)
1983	1988	l(o)	o(o)	o(o)
1984	1985	14(30)	2(29)	o(o)
1984	1986	9(16)	o(o)	o(o)
1984	1988	o(o)	o(o)	o(o)
1985	1986	9(16)	3(19)	o(o)
1985	1988	1(2)	o(o)	0(0)
1986	1988	6(7)	o(o)	o(o)
Combined years		65(23)	9(12)	2(5)

Table 5. --Comparison of the percent of time spent on land (present) and at sea (absent) for entangled and control seals fitted with radio tags. Data are from daily surveys with hand-held receivers on all hauling areas on St. Paul Island.

Seals[a]		Percent of time	
		Present	Absent
Entangled-fr	(N - 4)	35	65
Controls-fr	(N = 13)	28	72
Entangled-pr	(N - 12)	13	87
Control-pr	(N- 3)	10	90
Entangled-t	(N- 16)	19	81
Control-t	(N- 16)	25	75

"fr - males with full records, pr = males with partial records, and t - all males combined.

seals had not returned to land by the end of the study, whereas only 3 of 16 control seals had not returned (chi-square test, P < 0.005, or 0.001 with continuity correction). Typically, both entangled and control seals made several short trips while in the vicinity of St. Paul, and then departed on one long feeding trip. Selecting this longest trip to sea for each seal, we found that the entangled seals had significantly longer trips (30.9 days) than did controls (24.3 days). For seals that did not return from their long trips, the time from departure until the end of the study was used. Therefore, these were actually minimum estimates of their trip lengths.

The hand-held receivers could not detect the short trips taken between daily scans. Thus , the proportion of time on land (Table 5) actually estimates the time when the seals were in the vicinity of St. Paul, but not necessarily ashore. However, the data collection computer, which was able to detect short trips for seven seals, provided estimates of the time actually spent ashore at Reef Rookery. These data indicated that the four entangled animals spent a smaller proportion (44.8%) of their visit to St. Paul on land than did the controls (55.3%), but the difference is not statistically significant. The mean time between the application of tags and the departure to sea for a long feeding trip for entangled animals was 7.59 days; that for the controls was 6.17 days (no significant difference).

In 1988, 7 of 16 entangled seals fitted with transmitters were resighted in subsequent roundups. Four of sixteen controls with transmitters were resighted. There is no significant difference between these rates of resighting (chi-square test).

Analyses of the data in Table 1 are possible through the application of two very similar methods described in Brownie et al. (1978) and the Seber-Jolly method (Seber 1973). These methods result in estimates of survival of both categories of seals (entangled and controls) . The annual survival of entangled seals estimated by these two methods (the same for each) is 0.22 (0.95 confidence limits of ±1.00, assuming a Poisson distribution for the resightings), and 0.51 (0.95 confidence limits of ±0.446) for controls. Although not statistically significant, the estimated survival for the entangled animals given by these results is 42% that of the controls. The estimated survival for the controls (0.51) is lower than the estimates of survival produced by Lander (1981) for juvenile males (about 0.8, including the effects of unobserved entanglement), but the difference is within the confidence limits shown above.

We also used the data in Table 1 in a regression analysis to estimate the ratio of the probabilities of being resighted for entangled and control animals and the survival factor associated with entanglement in light debris. The basis of the regression analysis is demonstrated in Figure 2, which shows the declining rate at which entangled animals were resighted relative to the controls. Each data point is corrected for the ratio of entangled to nonentangled animals, as shown in Table 6.

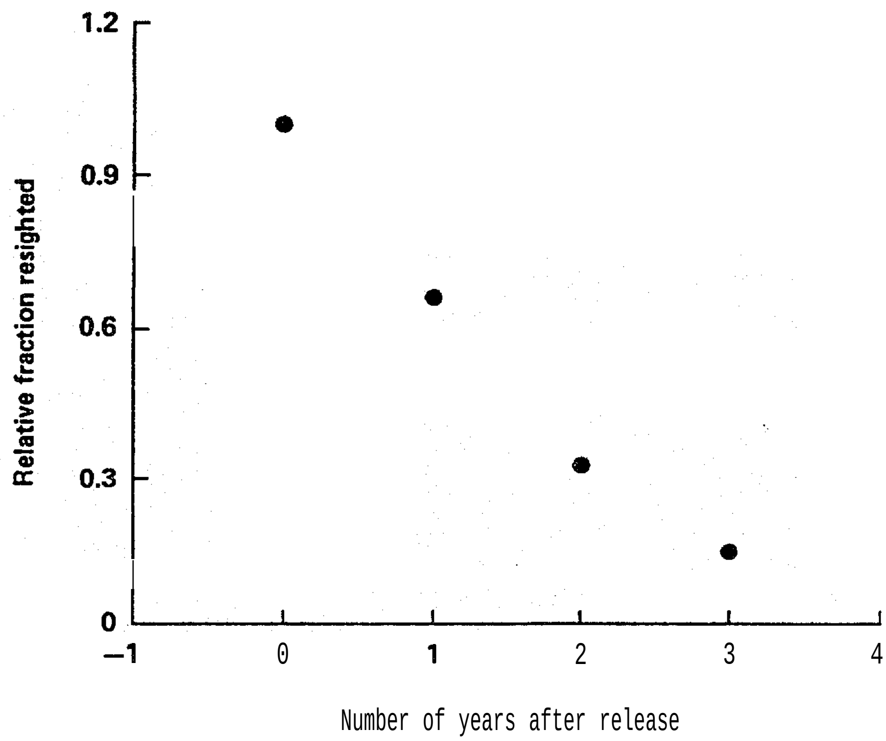

Figure 2. --Relative rates of return for entangled juvenile male fur seals compared to controls (nonentangled tagged seals) for varying time intervals. The relative rate of return is F*(C/D) $= p_{i,k}(N_{[illegible]}/N_{[illegible]})$ and the time interval is $x = (k-i)$, from Table 6 and Appendix. The point at time zero, with an adjusted ratio of entangled to control animals of one, was not used in the regression analysis.

Table 6.--List of data as extracted from Table 1 for regression analysis to estimate entanglement related survival; for a linear model of y - a + bx. See Appendix for details.

A Year i	B Year k	C $N_{c,i}$	D $N_{e,i}$	E $\ln(N_{c,i}/N_{e,i})$	F $p_{i,k}$	G $\ln(p_{i,k})$	Y E+G	X B-A
1985	1986	172	85	0.7048	0.3243	-1.1260	-0.42	1
1986	1988	279	128	0.7792	0.1500	-1.8971	-1.12	2
1985	1988	172	85	0.7048	0.0769	-2.5649	-1.86	3

The results of the regression analysis, with the assumptions involved in estimating survival from entanglement-caused mortality, are presented in the Appendix. The estimated annual survival of seals entangled in light debris is about half (0.49) that of nonentangled seals. The probability of refighting an entangled seal was estimated to be about 1.35 times as great as the probability of refighting a control (given that they are both alive) . However, this estimate is not significantly different from 1.0 (the case where the probabilities of seeing a seal from either group are the same).

It should be made clear that the total annual survival among entangled animals (including the effects of other sources of mortality along with those due to entanglement) is the product of natural survival and survival from entanglement. If we use the survival for juvenile males from Lander (1981)--about 0.8--the overall survival for seals entangled in light debris would be about 0.4 (i.e., about 0.8 x 0.5 - 0.4 for 3-year-old males). This is a higher survival rate than that from the Seber-Jolly analyses presented above (0.22).

Table 7 contains data on the frequency of refighting tagged seals during the season when tags were applied. These data show that the fraction of resighted control animals is nearly the same as the fraction of resighted entangled animals (both being about 25%). No statistically significant differences were found between the rates of refighting for entangled and control animals for any year or for the total (chi-square tests) .

DISCUSSION

Although there is insufficient information to draw conclusions, the data collected in 1988 on St. Paul Island suggest a decline in the proportion of juvenile male northern fur seals that are entangled. Most of the change seems to be associated with a reduction in entanglement in trawl webbing, possibly a reflection of reduced occurrence of trawl webbing among pelagic debris as reported in 1988 by Japanese scientists (Fowler et al. 1989) . The proportion of seals entangled in other forms of debris seems to be about equal to the proportion observed in the past 7 years. The differences between 1988 and previous years may be a result of changes in the

Table 7. --Comparison of numbers of tags applied to entangled and control juvenile male fur seals in 1985, 1986, and 1988 with the numbers in each category resighted the same season. The numbers in parentheses are the percent of the tags applied that were resighted.

	Number of tags			
	Controls		Entangled	
Year	Applied	Resighted	Applied	Resighted
1985	170	35(20.6)	76	21(27.6)
1986	165	54(32.7)	70	19(27.1)
1988	104	21(20.2)	52	15(28.8)
Total	439	110(25.1)	198	55(27.8)

rate of loss and discard of net fragments. Various education programs at national and international levels have been in place for several years, and international regulations prohibit the discard of such debris.

Severe wounds caused by prolonged entanglement in light debris contribute to death. Bengtson et al. (1988), demonstrated that pups become entangled in net fragments with mesh sizes much smaller than those seen on the subadult males in the roundups. The subsequent growth of those seals caught in debris light enough for them to survive the effects of drag in the water then results in wounds and death. Seals remaining entangled in debris often suffer from wounds that increase in size as a result of the seals' growth (DeLong et al. 1990). The degree to which wounds and resulting infections contribute to mortality in comparison to other sources of mortality caused or accentuated by entanglement (such as starvation, strangulation, and predisposition to predation) cannot be determined from existing data.

Some seals survive because they escape from the debris. Escape has been reported for animals resighted in other studies (Scordino 1985; Fowler 1987), some within the season during which animals were tagged. Of the total of eight seals resighted in 1988 after having been tagged as entangled in earlier years, six had lost their entangling debris. How this affects estimates of survival of seals in light debris has not been determined; conceivably, individuals that have lost their debris would be resighted with the same probability as control animals.

All debris on entangled animals that was later lost had been judged to weigh <150 g at its first sighting; otherwise it was similar to commonly observed debris. One possible explanation for this pattern is that the animals in small debris are the most likely of the entangled animals to return to the breeding islands. There they can come into contact with substrates (such as rocks) where the debris can abrade or otherwise wear to the point of breaking and falling off. Such wear is noted on the debris on many of the seals seen in the roundups, and on a few occasions debris has broken and fallen off during the handling of entangled animals. In view of the small numbers of animals resighted as entangled and the low survival of entangled animals, it would appear that most animals that remain entangled eventually die as a result of the debris.

The relative rate of refighting of animals originally tagged as entangled varies with the size of debris. A statistically significant (chi-square) decline in the rate at which seals are resighted with increasing size of debris is seen in Table 4. Corresponding information reported by DeLong et al. (1990) shows that of 17 females experimentally entangled in 200-g fragments of trawl net, 2 (12%) returned to the same rookery to give birth 1 year later. This is equal to the 12% resight rate of the seals entangled in medium-sized debris (Table 4). Thus, factors such as exhaustion, starvation, and drowning (likely acute factors at sea) appear to be increasingly important in the causes of death due to entanglement as debris size increases. If the survival of seals in large debris is proportional to the rate at which they are resighted, the survival of those in debris weighing just over 500 g would be about one-fourth (5/22) the survival of those in small debris. Therefore, survival resulting from the effects of entanglement alone would be about 0.11 ((5/22) × 0.49 - 0.11; using the 0.49 from the Appendix). Assuming survival from natural causes is 0.8 (Lander (1981), whose results may include some mortality due to entanglement), the total survival for this large-debris group is calculated as 0.09 (0.8 × 0.11 = 0.088). This implies a turnover in the population of about 2.4 times per year (turnover meaning the number of entangled seals that die for every entangled seal occurring in the population, and being equivalent to the instantaneous mortality rate, or the negative natural log of survival ; -ln 0.09 - 2.42). Presumably, following the trend in Table 4 to even larger debris, the turnover rate continues to increase with the size of entangling debris. If the estimated survival for controls from the Seber-Jolly analyses presented above were used (0.51 in place of 0.8), this estimated turnover would be even more rapid.

Seals that are entangled in large debris may find it impossible to return to land. Seals are seen entangled at sea in debris that is clearly large enough to prevent their returning to land (Fowler 1987). This is important in interpreting the information in Table 4. The number of seals entangled in large debris resighted on land may be small not because the seals thus entangled have died soon after entanglement, but because the debris prevents them from returning to the islands to haul out. This effect would be greater with increasing size of entangling debris. Such a trend would affect estimates of entanglement-related mortality. However, failure to return has the same effect on the population as mortality; an animal that does not return to its breeding colony is removed from the reproductive population.

Whether or not a seal is entangled may affect its chances of being seen in roundups. This is important in estimating the proportion of seals entangled and their survival rates. Factors that may affect estimates include: 1) time spent *on* land and at sea, 2) entangling debris or scars attracting the attention of observers, 3) relative proportions of the *two* groups which remain at sea for the entire season, a factor about which nothing is known, and 4) probability of seeing seals that have lost entangling debris compared with the probability of seeing entangled seals.

Entanglement results in prolonged at-sea portions of the feeding cycles for northern fur seals. Previous work on radio-tagged entangled male seals showed that the pelagic phase of feeding cycles was about twice as long for entangled seals as for controls (Bengtson et al. 1989). The results of this study are consistent with this effect of entanglement. Similar results have been noted for females (DeLong et al. 1990). It has *not* been possible *to* produce accurate estimates of the effects of entanglement on the portion of time spent on land. As a consequence, the relative time spent on land (as a fraction of the complete feeding cycle) remains undetermined. Thus, it is not possible, with the data from radio tagging, to quantify the effect of altered feeding cycles on the chances of a seal being seen.

Other data concerning the probability of refighting a seal are inconclusive. Based on data in Table 7, it would appear that once seals return to the islands, entanglement does not significantly affect their chances of being seen at least twice. Such a comparison can also be made with the smaller sample of radio-tagged animals (these seals being more visible with the bright paint). In 1988, no significant difference was found in the rates of resighting entangled and control seals fitted with transmitters in subsequent roundups.

Based on conventional mark-recapture analyses and results presented in the Appendix, seals entangled in light debris experience an annual survival that is about half (0.41 co 0.49) that for control seals. Previous estimates are very similar (0.42, Fowler 1987; 0.46, Fowler 1985.)

Regardless of a seal's probability of being resighted, it is obvious that entangled seals suffer higher mortality than do controls (Fig. 2). We have considered whether the reduced relative rates of refighting between initial release and the first resighting (e.g., the change between the first two points *in* Fig. *2)* could have been due only to differences between the probabilities of seeing entangled or control seals. Both groups would have experienced similar survival, and the change would have been entirely due *to* a higher probability of seeing control animals. If this were the case there would be no further changes in the ratios over time. A level relationship would emerge between the points for years 1-3, all of which would be lower than the ratio at year O, the time of release. The continued decline is indicative of the predominate effect of lowered survival among entangled seals.

Combined with other factors, the mortality caused by entanglement in light debris lowers the total survival for juvenile males entangled in light debris to about 0.39, assuming independence of the causes of mortality and a natural survival of 0.8. Each year, then, the number of seals in light debris that die would be about the same as the number of seals in light debris that are estimated to be alive in the population at the time of sampling (94% as many, based on a turnover of 0.94 from -ln(0.39) = 0.94, as the instantaneous rate of mortality).

A great deal of progress has been made in understanding the extent and effects of entanglement in marine debris on northern fur seals. However, precise estimates of the contribution of entanglement to the survival and trends at the population level have yet to be produced. Several studies indicate that young fur seals are more likely to become entangled than larger seals. Pups can become entangled even before leaving land (DeLong et al. 1988). Pups have been observed entangled or becoming entangled in large fragments of debris. Groups of pups often become entangled together or in succession (Fowler 1987; DeLong et al. 1988). Experiments show that pups are susceptible *to* entanglement in about four times as much debris as older animals because they can pass their heads through net fragments of smaller mesh size (Fowler 1987; Bengtson et al. 1988). A greater proportion of entangled animals among the young (also less experienced) seals is also consistent with the view that immature seals are more curious than older seals and are, therefore, more likely to be attracted to debris in which they may become entangled.

Research continues to show that mortality rates are quite high for seals that become entangled in larger debris. The results of the studies reported here indicate an annual survival (from the effects of entanglement) of about 0.09 for seals in debris weighing just over 500 g. Combined with the potential that larger net fragments have a higher probability of attracting seals and the fact that seals have been observed entangled in groups in large debris (Fowler 1985; DeLong et al. 1988), entanglement *in* large debris obviously deserves attention. However, logistic and financial constraints have made such studies impossible.

The need for studies *to* examine this problem is emphasized by the implications of previous attempts to account for the effects of large debris. Trawl webbing accounts for about two-thirds of the light debris (Table 2), so the portion of the juvenile male population entangled in light pieces of trawl webbing has been (before 1988) about 0.003 (0.66 x 0.004 - 0.00264; 0.004 being the proportion entangled in light debris of all kinds). On beaches, at sea, and on entangled animals seen away from the breeding colonies, the frequency of occurrence of pieces of heavy trawl webbing is about five times that of light (Fowler 1987). Assuming, that for every piece of light debris on an entangled seal there are five pieces of heavy debris also entangling seals, then entanglement in heavy debris involves about 1.5% of the juvenile male population (0.003 x 5 - 0.015).

As mentioned above, pups during their first few months at sea may be four times more susceptible to entanglement than juvenile males. If so, 6% of their numbers become entangled each year (4 x 0.015 - 0.06). Accounting for the turnover from mortality of seals in large debris (estimated earlier as 2,4 times per year for debris just over 500 g) produces the implication of an entanglement-caused ❑ortality of over 14% (2.4 x *0.06 = 0.14).* This does not account for the mortality in light debris. Entanglement in heavier debris has been observed to involve more than one animal per piece (Fowler 1985, 1988; "DeLong et al. 1988). This, combined with the greater attraction large debris must have for seals (the larger pieces presumably being more easily seen because of their size), could result in higher rates of entanglement and mortality.

If, as indicated by field observations (Fowler 1988; DeLong et al. 1990), entanglement involves both sexes (especially among the younger age classes), entanglement and resultant mortality may have contributed significantly to the declining trends among fur seal populations (Fowler 1985, 1988). Such implications are consistent with recently observed population trends, and models consistent with such trends have been constructed (Swartzman 1984; French and Reed 1990; Swartzman et al. 1990). These observations emphasize the need for better studies to clarify our estimates of the degree to which entanglement has caused these trends. Feasible field studies to verify the role of entanglement in large debris have yet to be designed and conducted.

CONCLUSIONS

The 1988 results of field research on entanglement of northern fur seals through roundups of juvenile males on St. Paul Island, Alaska, showed:

1. A reduction of the proportions observed entangled on land from about 0.4 to 0,29%.

2. Entanglement in fragments of trawl webbing in 1988 was about half of entanglement levels observed for this kind of debris in previous years.

3. The rate of refighting for animals tagged in 1985 and 1986 and resighted in 1988 showed that entangled animals tagged in those years were seen at rates that were significantly less than the rate at which controls were resighted.

4. The pelagic portion of the feeding cycle of entangled seals is greater (and a larger portion of their time may be spent at sea) than that of control seals, but the extent of the difference is unknown.

Analysis of these data in combination with data from previous studies (data on resighted animals collected in 1986, also on St. Paul Island, and data on debris collected from 1967 through 1988) showed that:

5. The estimated survival due to being entangled in light debris ranged from 0.41 to 0.49, close to estimates of about 0.5 or less from previous work.

6. Combined with natural survival, the total survival Of entangled seals is probably <0.39, with the equivalent of nearly a complete turnover in the population of juvenile males entangled in light debris each year.

7. Mortality increases with the size of entangling debris based on the observation that survival for seals entangled in large debris is less than for those in small debris.

8. The probability of refighting entangled seals (or seals that once were entangled), compared to that of nonentangled seals, has yet to be clearly evaluated.

9. A great deal has been learned about the specifics of mortality caused by entanglement in debris weighing <500 g. Implications for effects at the general population level are serious. However, the main result of this progress is a continuing emphasis on the need to refine estimated mortality rates caused by large debris, especially pieces much larger than 500 g.

10. More studies will be required to better understand the interacting factors associated with the probability of entangled seals being resighted in the roundups.

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APPENDIX

ESTIMATION OF ENTANGLEMENT-RELATED SURVIVAL AND THE RELATIVE PROBABILITIES OF ENTANGLED AND CONTROL FUR SEALS BEING RESIGHTED

To make use of the data on the returns of male fur seals (i.e., those resighted) as shown in Table 1, we make a set of assumptions and define the following terms. Let

$N_{c,ik}$ = the number of control seals tagged in year i and resighted in year k, where k > i (i - 1985,1986, k - 1986,1988).

$N_{e,ik}$ - the number of seals tagged in year i as entangled animals and resighted in year k (regardless of whether or not they were entangled when relighted), where k > i (i - 1985,1986, k - 1986,1988).

$p_{i,k}$ - $N_{e,ik}/N_{c,ik}$, or the ratio of numbers of seals resighted in year k that were entangled when first tagged in year i to the numbers of nonentangled (control) seals tagged in year i and resighted in year k.

$s_{c,j}$ - the annual survival of control animals, or the animals tagged without debris in year j, for j from i to k (i.e., $s_{c,j}$ = survival from j to j+1). This is the probability of surviving from natural causes of mortality.

se - the annual survival of animals entangled in light debris (debris light enough to return to the breeding islands), and is assumed not to vary from year to year. This is the probability of surviving entanglement given that an animal has survived natural causes of mortality and is assumed *to* be independent of SC $_j$ (so their total annual survival is $S_{c,j}s_e$).

$N_{e,i}$ - the number of seals tagged as entangled animals in year i (i = 1985, 1986), and

$N_{c,i}$ - the number of seals tagged as controls in year i (i - 1985, 1986).

Different proportions of entangled seals may return to the islands to be seen when compared to controls. Once in the vicinity of the islands, entangled seals may be seen at different rates than the controls for various reasons. These include the possibility of different fractions of time spent on land and entangled seals being seen more readily than controls because of their entanglement, or the effects of having been entangled. Thus we define

f_{ek} - the probability of refighting a seal in year k given that it was entangled when tagged and that it is alive. This probability is expressed on the basis of a unit of searching effort that is the same as applied in looking for control animals. It is assumed to vary from year to year but not in relation to f_{ck} (below), and

f_{ck} - the probability of refighting a control animal in year k given that it is alive in the population, again as based on the unit of effort spent in searching for both control and entangled seals. This is also assumed to vary from year to year but not in relation to f_{ek} (f_{ek}/f_{ck} is assumed constant).

With these terms, the expected number of seals that were entangled when tagged and sighted in year k after being tagged in year i, for one unit of effort is

$$E(N_{e,ik}|N_{e,i}) - f_{ek}ß_k s_e^{(k-i)}N_{e,i}$$

(i = 1985,1986, k = 1986,1988, and $ß_k$ is the product of $s_{c,j}$ for j from i to k), and the expected number of controls for the same circumstances is

$$E(N_{c,ik}|N_{c,i}) - f_{ck}ß_k N_{c,i}$$

($ß_k$ is the product of $s_{c,j}$ for j from i to k).

Substituting the observed for the expected values we have the following moment estimators:

$$N_{e,ik} = f_{ek}ß_k s_e^{(k-i)}N_{e,i} \quad \text{and} \quad N_{c,ik} = f_{ck}ß_k N_{c,i}.$$

The ratio of these two equations, then, is

$$N_{e,ik}/N_{c,ik} = p_{i,k} - (f_{ek}/f_{ck})(N_{e,i}/N_{c,i})s_e^{(k-i)}$$

which can be used to estimate f_{ek}/f_{ck} and s_e.

We note that variability in natural survival (i.e., the survival of the controls and that part of the survival of entangled animals from natural effects) can occur over time and not affect the calculation since these terms cancel in the formulation of the equation above. We also *note* that the probability of refighting animals from each of the two groups can vary from year to year as long as their ratio remains the same, as assumed above. Effort spent in refighting entangled and control seals is the same (the same roundups) but the number of roundups can vary from year. This is because effort for each of the two groups influences the above relationships only as a ratio in f_{ek}/f_{ck} (i.e., it cancels and need not be defined).

By rearranging terms we have

$$p_{i,k}(N_{c,i}/N_{e,i}) - (f_{ek}/f_{ck})s_e^{(k-i)},$$

and taking the natural log of this equation results in the following linear equation which can be used for regression analysis and the estimation of relevant parameters as defined above:

$$\ln[p_{i,k}(N_{c,i}/N_{e,i})] \quad - \ln(f_{ek}/f_{ck}) \quad + \ln(s_e)(k-i).$$

Using this equation and the data from Table 6, the estimated parameters determined from regression analysis for the above equation are

$$\ln(f_{ek}/f_{ck}) = 0.307 \text{ and } \ln(s_e) - -0.720 \; (R^2 - 1.00,\ p - 0.011).$$

These results imply that the ratio of the probabilities of being resighted is about 1.35 (calculated as $e^{0.307}$, with 95% confidence limits of 0.95 to 1.95). Thus , the chances of being resighted after being tagged as an entangled animal, given that the animal has survived, are estimated to be about 1.35 times that of being resighted as a control, but this does *not* differ significantly from 1 or an equal probability. The estimated survival of entangled animals from the effects of entanglement is 0.49 (calculated as $e^{-0.720}$ with 95% confidence limits of 0.41 to 0.57).

In addition to the small sample size, other factors prevalent in this analysis need noting. The data points for the 1- and 3-year time intervals are not independent. A random difference between the mean (here assumed constant) survival from entanglement in the first year will be seen as a bias in the same direction in the third. With this set of data, this does not affect the estimate of entanglement-related survival as much as it does the estimated ratio of probabilities of being resighted. This is because the slope of the line as seen in Figure 2 (the estimate of survival) depends more on a rotation about the point for the 2-year time interval than the distance the line is above or below the second point. The height of the line will be affected by the interdependence of the two end points.

The effect of assuming that the survival from risks caused by entanglement is independent from surviving the risks of other, natural, causes has not been explored. The same holds for the assumption that the ratio of the probabilities of being resighted for the two categories remains the same over time. However the various steps in the derivation of the linear equation used in this analysis might contain hidden assumptions, or sources of statistical error, have yet to be examined.

A STUDY OF THE EFFECTS OF COMMERCIAL FISHING DEBRIS ON *CALLORHINUS URSINUS* FROM BREEDING ISLANDS IN THE WESTERN PACIFIC

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ABSTRACT

In this paper, data and analyses are presented concerning the incidence of entanglement among the northern fur seal, *Callorhinus ursinus,* from the breeding islands of the western Pacific. This work was undertaken to further explore the degree to which waste disposed from fishing vessels is a source of mortality for this species. Based on the available data, estimates of the minimum proportion of various age and sex groups entangled within the population are produced. Historical data show that injuries caused by fishing nets shreds (66%), ropes (20%), fishing line (8%), and packing bands and collars made of other materials (6%) are contributing to the mortality of northern fur seals. The incidence of entanglement, and therefore the resulting mortality among the Tyuleniy (Robben) Island population, is higher than for the population on the Komandorskie (Commander) Islands. The higher incidence of entanglement on Robben Island may be related to declines in the population on that island in comparison to the relative stability on the Commander Islands, where the incidence of entanglement is less.

BACKGROUND

The intensity of exploitation of living marine resources increases annually (Moiseev 1979). The number of fishing fleets increases correspondingly (Yerukhimovich and Yefremenko 1985). Increasing intensity in fishing brings with it various negative effects on the environment. One of the aspects of this influence is the pollution of the ocean with scraps of fishing gear, packing materials, and other waste from the commercial fisheries, directly threatening many marine organisms. Fish, seabirds, reptiles, and marine mammals get entangled in such materials and die (DeGange and Newby 1980; Fowler 1982, 1985, 1987; Kuzin 1985; Shomura and Yoshida 1985).

A determination of the extent of the negative influence of commercial fishing waste and pollution in the ocean is not possible for the majority of marine organisms. But the continuous and systematic observation of

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northern fur seals, returning each year to their hauling grounds (near the breeding colonies) after wintering in the ocean, provides the opportunity to determine the number of individuals entangled in marine debris. The resulting data allow for the calculation of estimates of the extent of damage caused by marine debris resulting from loss and discard by commercial fisheries as well as other human activities.

From the historical data, the kinds of debris found on entangled seals is known. Of the total number of entangled seals on Robben Island, 66% are entangled in fragments of fishing nets. Another 20% are found entangled in ropes, 8% in fishing line, and 6% in packing bands and collars made of other materials of commercial fishing waste (Kuzin 1985). Fowler's data (1982) showed that in the Pribilof Island population as many as 50,000 seals may die annually as a result of injuries caused by foreign objects. Over a life time, entanglement may cause the death of 15% of a cohort (Fowler et al. 1990). Similar estimates for other populations of fur seals, however, are unavailable.

In order to obtain estimates of entanglement-related mortality for populations of fur seals on both Robben and the Commander Islands, the statistical data presented annually to the Northern Pacific Fur Seal Commission regarding the incidence of entanglement among northern fur seals on hauling grounds are used.

METHODS

For estimating the effects of commercial fishing debris on fur seal populations, we have used the data from the commercial harvest of bachelor seals (2- to 5-year-old males, also referred *to* here as juvenile males). These data were collected by counting the total and the number of entangled male seals in the commercial harvest for each year from 1975 to 1986 on both Robben Island and the Commander Islands (Table 1). All entangled seals were of the same size category as the remaining seals taken in the harvest. These harvests were conducted during the months of June and July of each year, and all entangled seals were killed along with the other seals taken. Seals with scars only were not counted as entangled such that the counts included only male seals observed with entangling debris. Entangling debris found on the seals was then identified and frequencies were tabulated for each category of debris. Pieces of monofilament gillnet were included in the category of net shreds along with pieces of trawl net debris.

With the data on total numbers taken in the harvest and the counts of entangled seals among them, collected as described above, the incidence of entangled animals among the juvenile males (2 to 5 years old) was determined by dividing the number of entangled seals taken by the total in the harvest for each year and location.

For other age groups and sex groups of seals, data are not available from their primary concentrations on the breeding rookeries. However, data have been recorded for entangled individuals from these categories, as noted for seals found on hauling grounds. Thus, the percent of all entangled animals found on hauling grounds that fall into each category

Table 1.--Number of juvenile male fur seals taken and the incidence of seals entangled in debris in the commercial harvest by year and location (breeding islands in the western Pacific).

Year	Number harvested		Number entangled		Percent entangled	
	Robben	Commander	Robben	Commander	Robben	Commander
1975	2,500	1,730	27	30	1.08	1.73
1976	2,569	2,768	69	68	2.68	2.46
1977	4,069	2,766	69	66	1.69	2.39
1978	3,188	3,032	81	32	2.54	1.06
1979	2,933	2,524	33	13	1.13	0.52
1980	3,107	2,544	26	44	0.83	1.73
1981	3,613	5,117	113	35	3.12	0.76
1982	2,924	5,075	124	75	4.20	1.48
1983	2,582	5,717	24	34	0.92	0.59
1984	2,322	5,294	35	37	1.50	0.70
1985	459	5,097	4	47	0.87	0.92
1986	2,034	--	34	--	1.67	--
Total	32,300	41,664	639	481	1.97	1.15

can be determined. The categories used in this study are: mature males (older than 6 years), half-mature males (or "half bulls," 6 years of age), bachelors (younger than 6 years), females, and pups. Since exact ages are not known, the numbers in each age category are determined on the basis of experienced judgment.

To analyze the data resulting from the field work described above, a method for estimating lower bounds of the proportion of each age-sex class was developed. The following is an explanation of the procedure used.

As mentioned above, the empirical data are for a population consisting of several categories or age-sex groups. One category is represented by data for which the incidence of entanglement can be clearly determined (i.e., the bachelor males, which will be represented by subscript j). The other groups (e.g., pups, females) are those for which we wish to have estimates of the incidence of entanglement. These groups will be represented by subscript i.

To develop a procedure for estimating the proportion of seals entangled in each group, their total numbers in the population as a whole are defined as P_i. The total for the bachelor males is defined as P_j. The proportion entangled (or incidence of entanglement) is defined as c_i and c_j, respectively, for each of the two categories, so that the numbers entangled are c_iP_i and c_jP_j. Of these, a proportion of each category is seen, a proportion defined as a (α_i and α_j, respectively) so that the actual numbers of entangled animals seen on land are $\alpha_i c_i P_i$ and $\alpha_j c_j P_j$ for the two cases. It is assumed that the probability of seeing an entangled animal of any category is the same as the probability of seeing a nonentangled animal of the same category or that entanglement does not influence the probability of being seen. This may be summarized as follows:

Category	Total population	Fraction entangled	Numbers entangled	Proportion seen	Entangled animals seen
i	P_i	C_i	C_iP_i	a_i	$\alpha_iC_iP_i$
j	P_j	C_j	C_jP_j	α_j	$a_jC_jP_j$

The desired estimate is of C_i, knowing C_j. This can be accomplished by dividing the number of entangled animals seen from category i ($\alpha_iC_iP_i$, for which there are data) by the number of animals seen in category j ($\alpha_jC_jP_j$, also for which there are data) and multiplying this ratio by $C_j(\alpha_jP_j \ / \ \alpha_iP_i)$:

$$(\alpha_iC_iP_i \ / \ \alpha_jC_jP_j) \ \ C_j \ \ (\alpha_jP_j \ / \ \alpha_iP_i) \ = \ C_i$$

For this equation to produce the correct estimate (disregarding the statistical aspects of the problem), then, it is seen that either values for α_iP_i and α_jP_j must be known (which they are not) or their ratio must be known. If this ratio were 1.0, the number of the two segments seen would be equal.

Based on observations on hauling grounds, the total number of seals in the bachelor category is always larger than the total for each of the other categories listed in Tables 2 and 3. (Here we refer to the total present, not the number of entangled seals seen.) Because of this, the equation above can be used by assuming $(\alpha_jP_j \ / \ \alpha_iP_i) > 1.0$ to determine lower bounds to the entanglement rates for the categories other than for bachelors. The value of the expression $(\alpha_jP_j \ / \ \alpha_iP_i)$ will always be greater than 1.0 since α_jP_j (the number of bachelor males seen on hauling grounds) is always greater than the number seen for other groups. Thus, the expression used to produce estimated lower bounds for the proportion entangled for groups other than bachelor males is:

$$C_i > N_iC_j \ / \ N_j$$

where:

C_i is the proportion of animals of the age-sex group in question that are entangled;

$N_i = \alpha_iC_iP_i$ is the number of entangled animals of the age-sex group in question as observed at the hauling grounds;

C_j is the proportion of bachelors that are entangled; and

$N_j = \alpha_jC_jP_j$ is the number of entangled bachelors observed at the hauling grounds.

Table 2.--Number and percent of entangled fur seals falling in various age and sex categories as observed at hauling grounds on Robben Island.

Year	Bulls		Half bulls		Bachelors		Females		Pups		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1974	4	1.5	10	3.8	115	43.4	136	51.3	--	--	265	100
1975	--	--	---	-	27	77.1	8	22.9	--	--	35	100
1976	2	2.2	1	1.1	69	71.2	21	22.6	--	--	93	100
1977	2	2.8	---	-	69	97.2	--	--	--	--	71	100
1978	53	18.0	47	15.9	58	19.7	135	49.9	1	0.3	294	100
1979	16	19.2	9	10.8	16	19.3	42	50.6	--	--	83	100
1980	1	0.8	4	3.5	102	88.7	8	6.9	--	--	115	100
1981	11	15.7	5	7.1	19	21.1	32	45.7	3	4.3	70	100
1982	4	3.2	5	4.3	65	52.4	50	40.3	--	--	124	100
1983	12	12.4	---	-	13	13.4	72	74.2	--	--	97	100
1984	16	18.4	5	5.7	18	20.7	47	54.0	1	1.1	87	100
1985	10	10.8	---	-	31	30.0	61	59.8	--	--	102	100
1986	5	6.8	2	2.4	19	22.9	53	63.9	4	4,8	83	100
1987	10	13.5	8	10.8	13	17.5	43	58.1	--	--	74	100
Total	146	9.2	96	6.0	634	39.8	708	44.4	9	0.6	1,593	100
Calculated minimum percent of entangled individuals:												
		0.45		0.30		[a]1.97		2.19		0.03		

[a]From Table 1.

RESULTS

The numbers of seals taken in the commercial harvests on Robben Island and the Commander Islands, and the numbers of entangled seals among them are shown in Table 1 for 1975 through 1986. Also shown is the resulting incidence of entanglement expressed as a percent of the harvest. The number of entangled seals from the other categories, as observed on the hauling grounds, are shown in Table 2 for Robben Island, and Table 3 for the Commander Islands. Tables 2 and 3 also show the fraction of the total number of entangled animals observed as accounted for by seals in each category. Thus, the totals of the categories are each 100% for all observed entanglement, by year and island.

The results of calculations to determine the lower bounds to estimates of the percent entangled among each age-sex group of northern fur seals are presented in the last lines of Tables 2 and 3. The proportion of the total population which is entangled depends on the fraction of the population comprised by each of the age-sex categories. However, it can be seen that the lower bound for the overall entanglement rate must be between 0.03 and

Table 3. --Number and percent of entangled fur seals falling in various age and sex categories as observed at hauling grounds on the Commander Island.

Year	Bulls No.	Bulls %	Half bulls No.	Half bulls %	Bachelors No.	Bachelors %	Females No.	Females %	Pups No.	Pups %	Total No.	Total %
1974	--	--	--	--	--	--	--	--	--	--	--	--
1975	1	2.9	2	5.7	13	34.1	19	54.3	--	--	35	100
1976	--	--	--	--	--	--	--	--	--	--	--	--
1977	8	9.4	11	12.9	25	29.4	30	35.3	11	12.9	85	100
1978	--	--	--	--	--	--	--	--	--	--	--	--
1979	63	26.8	2	2.0	126	53.6	41	17.4	5	2.1	237	100
1980	26	24.1	--	--	40	37.0	39	36.1	3	2.8	108	100
1981	21	15.9	7	5.3	85	64.4	19	14.4	--	--	132	100
1982	17	12.2	16	11.5	81	58.3	25	17.9	--	--	139	100
1983	36	39.1	5	5.4	20	21.7	31	33.7	--	--	92	100
1984	--	--	--	--	--	--	--	--	--	--	--	--
1985	--	--	--	--	--	--	--	--	--	--	--	--
1986	13	27.7	3	6.4	21	44.6	10	21.3	--	--	47	100
1987	--	--	--	--	--	--	--	--	--	--	--	--
Total	185	21.1	46	5.3	411	46.9	214	24.5	19	2.21	875	100
Calculated minimum percent of entangled individuals:												
		0.52		0.13		al. 15		0.59		0.05		

[a]From Table 1.

2.19% for Robben Island and between 0.05 and 1.15% for the Commander Islands. These estimated lower bounds cover the period from June through August (3 months), the time during which seals are seen on the hauling grounds.

DISCUSSION

It is natural that some seals that are entangled in commercial fishing waste die at sea without being seen on land, especially in the areas where seals from the western Pacific overwinter (Pacific Ocean and Sea of Japan in the Japanese, Korean, and American exclusive economic zones). However, data concerning entanglement rates and mortality for these areas are not available. In Fowler's (1985, 1987) work and Fowler et al. (1990), information is presented as a basis for accounting for unseen mortality at sea. After accounting for debris that is too large for seals to return to land, mesh sizes that pups become entangled in, and the mortality rates observed in large debris, as many as 30 to 35 seals per year may die for each one that is observed alive. The effects of the size composition of debris at sea has not been considered in its effects on seal populations of the western Pacific. Neither have the effects of mesh size. However, in view of the levels of entanglement presented in Tables 2 and 3, it is clear that an even lower ratio of unseen mortalities to observed entanglement would be necessary to achieve similar levels of mortality thought possible for the Pribilof population. Further data on the size composition (by weight and mesh) of debris from beaches and pelagic habitat in the western Pacific will be necessary to extend this evaluation of the potential effects of marine debris on the mortality of fur seals.

There is a very important observation to be noted in the data in Tables 2 and 3, an observation that deserves to be emphasized. At the Commander Islands, the incidence of entanglement among seals is lower than at Robben Island. Among bachelors, the incidence of entanglement is 1.7 times as high on Robben Island as on the Commander Islands. The minimum level of entanglement for females is almost four times as high. The importance of this observation comes from the fact that this may be one of the reasons why the Commander Island seal population did not decrease in recent years, while other populations declined. This emphasizes the need for further information on the composition of debris (by weight and mesh size) to determine if there are differences between the western and eastern Pacific. Such differences might explain the divergence in dynamics between the population of fur seals on the Commander Islands (no recent declines) and the Pribilof Islands (a decline in the late 1970's).

If mortality due to entanglement is as high in the western Pacific as is thought possible for the Pribilof population, as many as 3.7 to 6.7 thousand seals die from entanglement annually. In the North Pacific as a whole, then, as many as 60,000-65,000 northern fur seals may die due to the discard and loss of gear and debris from commercial fisheries. Those figures are 1.7-2 times higher than the figures of the potential annual harvest of juvenile male northern fur seals in the U.S.S.R. and the United States.

It is known that 60% of the Robben Island seals, 5-6% of the Pribilof seals, and 28-30% of the Commander Island seals winter in Japanese waters (Ashchepkov and Kuzin 1986). Cooperative efforts involving all interested countries seem necessary for studying the problem of the pollution of the ocean by commercial fishing waste. The existing fisheries-oriented scientific associations among the Pacific countries provide the opportunity for their leadership to inform fisheries organizations about the sources of debris and the volume of the damage caused by commercial fishing to marine resources. The solving of this problem depends on how soon and how completely sailors and fishermen realize the seriousness of marine pollution and that the discard of debris is contrary to international regulations.

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AN INDEX OF FUR SEAL ENTANGLEMENT IN FLOATING NET FRAGMENTS

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ABSTRACT

While information has been published on transect surveys based on visual sighting of floating marine debris, few attempts have been made to link the estimates of floating marine debris density to the entanglement rate observed in subadult male fur seals. Both published and unpublished survey data were used to develop a data base consisting of the location and season during which floating marine debris *were* observed and the estimated density of the debris. In conjunction with this data base, similar information was used for at-sea sightings of fur seals to calculate an index of potential entanglement by season (winter and breeding season, spring and fall migration). Our main conclusion is that much more information is needed to cover the known range of migrating northern fur seals. However, with these limited data, it appears that seals are most at risk during the breeding season and during the fall migration. Our conclusions are tentative due to assumptions used in calculating the index and the lack of geographical overlap between oceanic debris surveys and fur seal surveys.

INTRODUCTION

The fact of entanglement and the problems it may cause animals is not an area of debate (Center for Environmental Education 1986). But the role of entanglement in contributing to the recent decline of the northern fur seal, *Callorhinus ursinus*, on the Pribilof Islands remains to be clearly

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defined (Fowler 1985, 1987; Scordino 1985). We (Swartzman et al. 1990) have taken a modeling approach to this problem, but the model is only as good as the estimates of the parameters and their inherent variability. In this paper, we calculate an index of potential entanglement by using information on floating marine debris and at-sea locations of fur seals. Problems with this approach are discussed.

METHODS

A review of all papers dealing with floating marine debris was used to gather information on the density of marine debris by area. All estimates from the papers were translated into number of net fragments per square nautical mile for comparison and mapped by area (using blocks of latitude and longitude as defined in the papers). We could not separate the nets into different types (trawl web or gillnet) because the data as presented in the papers were not separated by type. Unpublished data of Yoshida and Baba (Far Seas Fisheries Research Laboratory, pers. commun.) and the 1984 marine mammal observer program data (L. Jones, National Marine Mammal Laboratory, Seattle, WA, pers. commun.) were used to calculate additional density estimates by area. A strip transect density estimate (number of net fragments per square nautical mile) was calculated using a half width of 50 m (Dahlberg and Day 1985) and mapped.

For fur seal occurrence, the data in Kajimura (1980) were used. Those data are presented in summary form in terms of number of degree blocks where 0, 1-4, 5-8, or 9+ seals were seen per hour of observation for all surveys in 1958-74 by month. We calculated an index of high density of seals by 5 degree blocks from these data by month. The index of high density was chosen as the number of degree blocks with five or more seals sighted per hour of observation divided by the total number of degree blocks sampled. We calculated this index for four time periods: January-March, April-June, July-October, and November-December. These periods correspond to winter, spring migration, breeding season, and fall migration (Kajimura 1980), respectively. For each time period, the index of high density was the average of the indices for the months making up the particular period. The indices were mapped for each time period.

The two maps (debris density and fur seal occurrence) were put onto the same scale and superimposed, and areas of overlap identified by time period. Areas of no effort (indicated as blank spots on the maps) for either base set (debris or seals) automatically meant a blank spot for the combined set. For the areas of overlap, an index of potential entanglement was defined as the product of the estimated density of marine debris and the index of high fur seal density. Assumptions made because of the available data include:

- There are no age and sex differences for probability of fur seal occurrence. (Data were not divided into age and/or sex categories.)

- There have been no major changes in the pelagic distribution of fur seals. (Data were collected between 1958 and 1974.)

- Net density is constant over the seasons. (Data were not available on a seasonal basis.)

- The density and location of small and large net fragments are the same. (Data were not presented on a size basis, therefore, differences in probability of entanglement due to differences in size of net fragment cannot be factored into the index.)

- There are no seasonal changes in fragment-specific probability of entanglement. (No information was available on this point.)

The magnitude of the numbers was used to compare the relative probability of potential entanglement between areas within a time period and between time periods.

RESULTS

The papers with the most information on the density of floating nets were those by Jones and Ferrero (1985), Yoshida and Baba (1985), Baba et al. (1988), andMio and Takehama (1988). Most of the information on floating marine debris has been collected in the North Pacific Ocean in the middle of the fishing fleets (Fig. 1). Most of the information on the presence of fur seals has been collected along the coast and in the Gulf of Alaska (Fig. 2). Fur seals have been seen offshore in the North Pacific Ocean (Kajimura 1980). However, since sighting effort is not recorded, these data cannot be used in a direct evaluation of the probability of entanglement. There are two areas where the maps overlap: around the Pribilof Islands and off the coasts of Washington and Oregon (Fig. 3).

Although there is little overlap between the two maps, for those areas where we could calculate an index of potential entanglement, the highest indices occurred during the breeding season (July-October) around the Pribilof Islands and in the fall migration (November and December) off the coasts of Washington and Oregon (Fig. 3). The index was also relatively high for some blocks off the coasts of Washington and Oregon for the winter season (January-March) and the spring migration (April-June) (Fig. 3).

DISCUSSION

The major problem in estimating the level of entanglement at sea is the lack of systematic observations of both fur seals and marine debris in the same area. The lack of data is so extreme as to present major problems in calculating indices of entanglement while seals are in their pelagic environment. As can be seen from this analysis, there was little overlap between the sets of data for the areas that were surveyed. In addition, for the existing data sets, the units for marine debris density and the probability of fur seal occurrence are not the same. There were no data for the effort behind the fur seal sightings. These circumstances lead to obvious problems in trying to use the existing empirical data to calculate

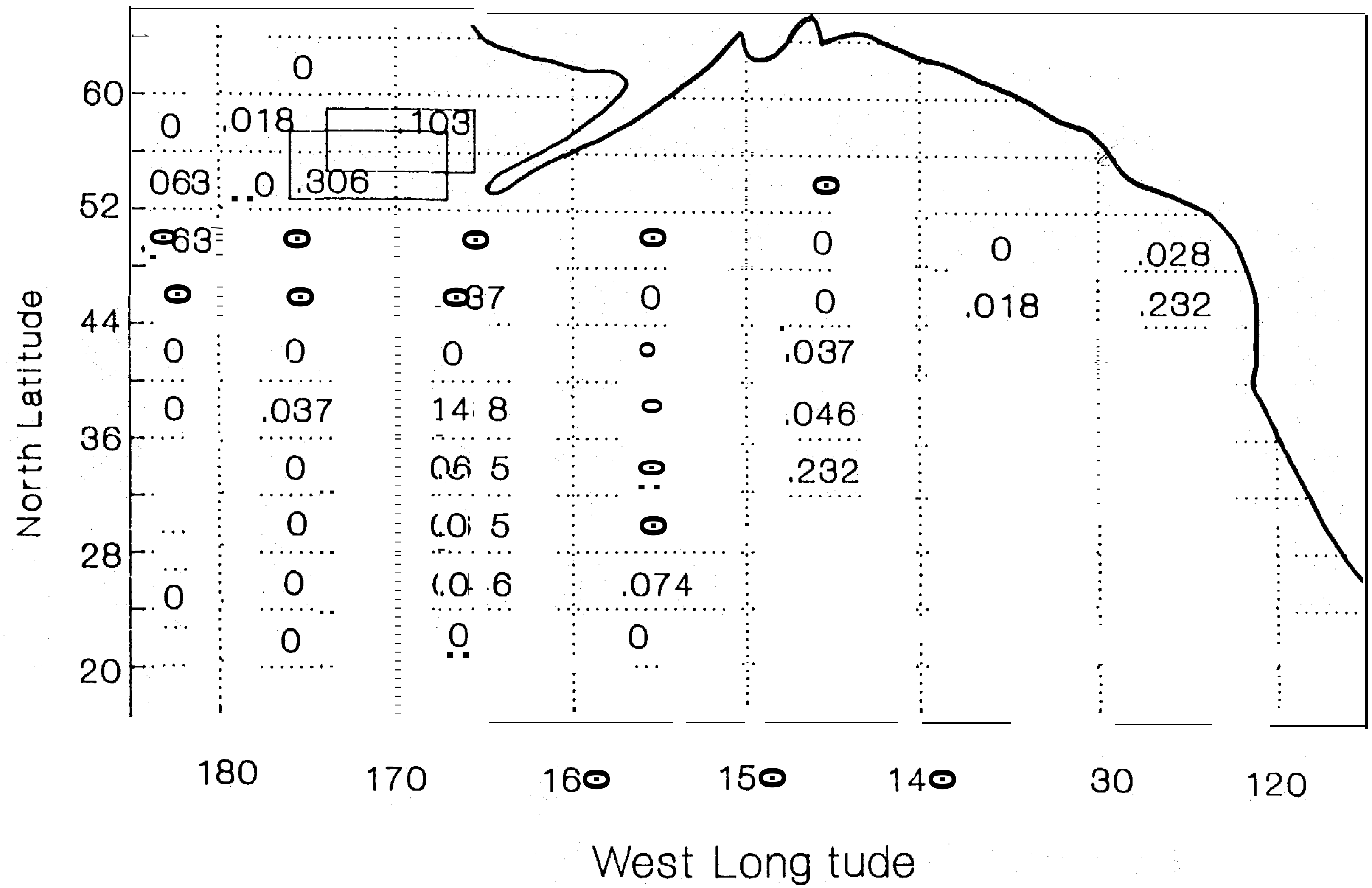

Figure 1.--Density of floating nets by blocks of 4° latitude and 10° longitude calculated from published and unpublished data. The two solid line rectangles indicate areas around the Pribilof Islands where densities were calculated for 2 separate years. The coastline is outlined in black.

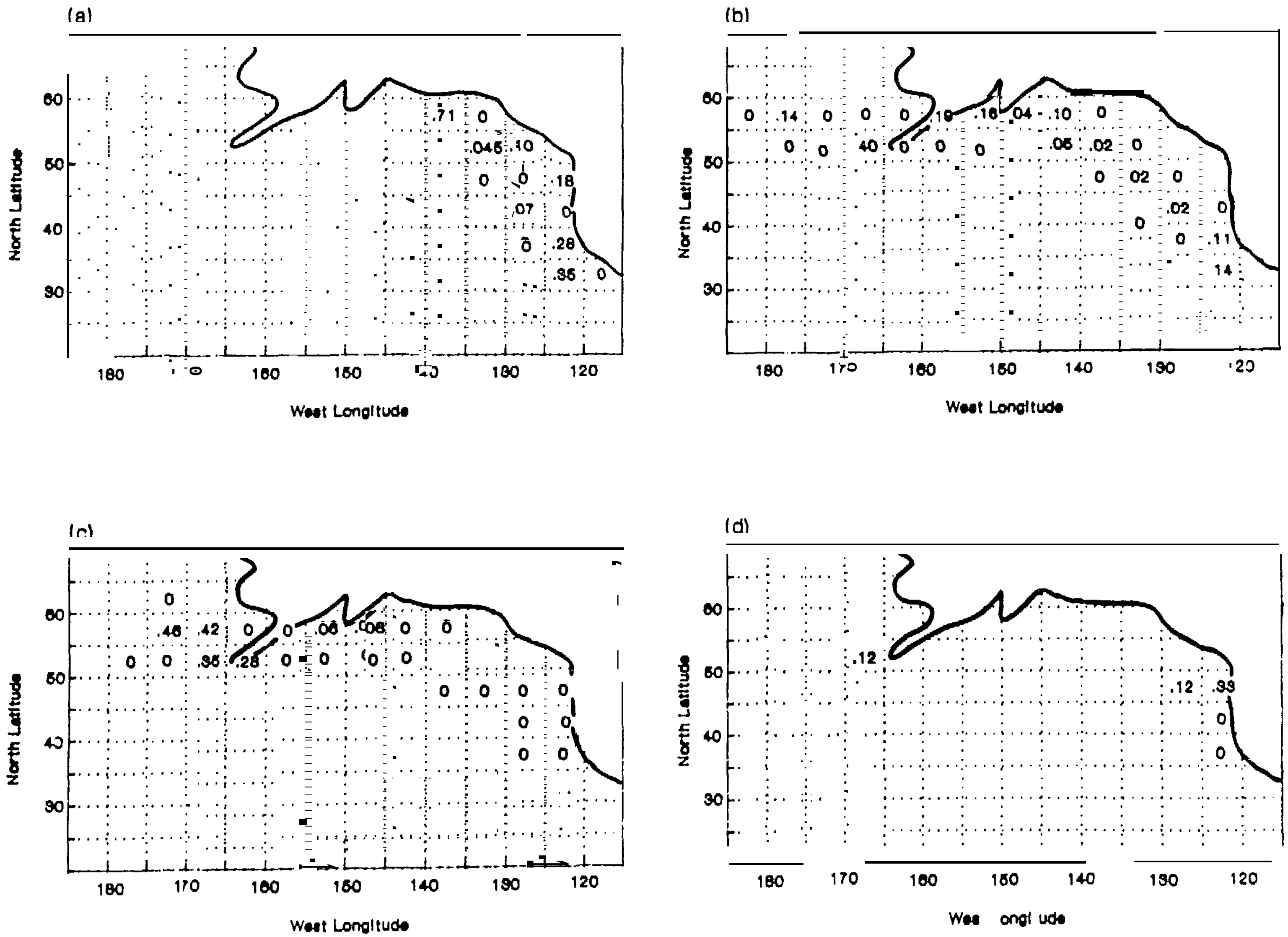

Figure 2.--Index of high fur seal density calculated from data in Kajimura (1980) for four time periods: (a) January-March, (b) April-June, (c) July-October, and (d) November-December. The coastline is outlined in black.

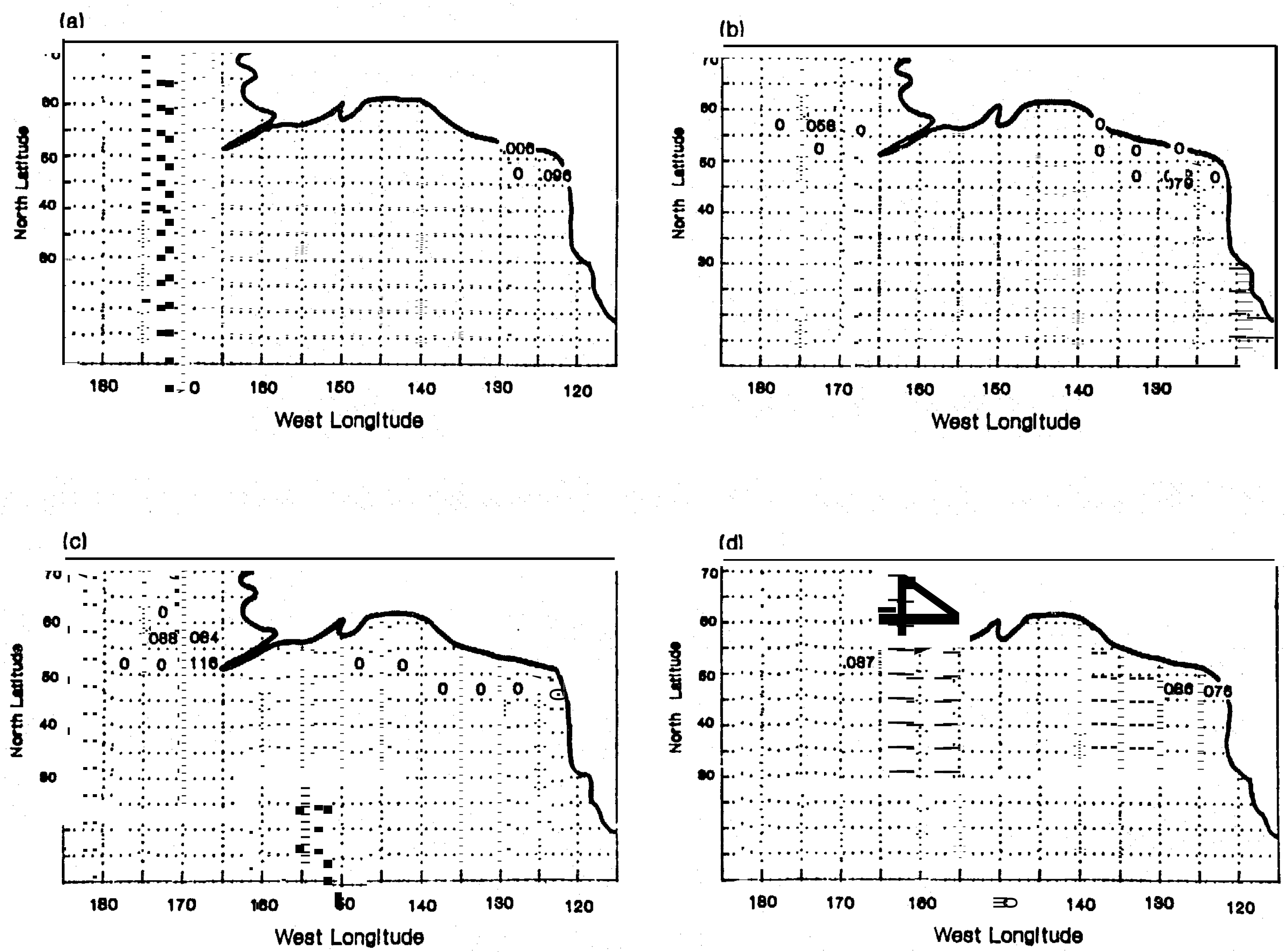

Figure 3.--Index of potential entanglement for common areas between Figures 1 and 2 for four time periods: (a) January-March, (b) April June, (c) July-October, and (d) November-December. The coastline is outlined in black.

an index. What is needed is a study specifically designed and coordinated for three purposes. The first purpose would be to estimate the density and location of floating net fragments; the second would be to record the numbers and location of fur seals; and the third would be to collect information on the number of fur seals entangled in debris. All three parts of the study should consider the seasonal aspects of the distribution and abundance of both seals and debris. The data from such a study would have the debris and fur seal variables on the same scale (e.g. , number per unit area) as well as contain information on the location and date of observed at-sea fur seal entanglement. Until such a study is done, combining results of other studies for such purposes will be highly speculative and will depend on a large number of assumptions, as evidenced by this study.

The assumptions used in this study were made to compensate for the lack of data on variables such as differences in location by age and sex for seals and differences in large and small net fragment densities and location. Changing an assumption will affect the value of the index, but whether the comparisons are changed will depend on how the assumption is changed. For example, if the probability of entanglement upon encounter changes with season, then the comparisons between seasons would be affected.

Given all the assumptions, the index calculated here indicates that the probability of potential entanglement may change depending on the season of year and, in a related fashion, on location. If the relatively high potential entanglement. index around the Pribilof Islands found here is valid, then it may indicate that the entanglement problem begins as soon as the young of the year go to sea and continues as the animals migrate south for the winter. Since the first year after weaning is a stressful time for young animals, the actual impact of entanglement may be severe for fur seals going to sea for the first time.

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STUDIES OF THE EFFECTS OF ENTANGLEMENT ON INDIVIDUAL NORTHERN FUR SEALS

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ABSTRACT

During the field seasons of 1985 and 1986, studies were conducted to determine the effects of entanglement on the northern fur seal, *Callorhinus ursinus*. These included surveys of entanglement rates among pups and adult females, an experiment on the effects of entanglement on adult females, and a study of the selectivity of mesh size in the entanglement of pups. Complementing these studies are data on the history of the development of wounds for entangled juvenile males that have been seen more than one time.

In 1985, 40 parturient females and their pups were captured at Zapadni Reef rookery on St. Paul Island. Half of the females were treated as controls and tagged with both flipper tags and radio tags and released. Pieces of trawl net weighing 200 g were placed on the other 20, simulating entanglement common to fur seals. The attendance cycles and rates of return of these animals were then compared for the two groups for several feeding cycles, and the rates of return were compared the following season. Three of the entangled females freed themselves of the debris. Of the remaining 17, 3 failed to return after their first trip to sea, 4 failed to return after their second trip, and 2 did not return after their third trip. One control did not return after her second trip to sea. The time spent at sea by the entangled animals was twice as long as for the control animals. In 1986, 2 of the 17 entangled animals were observed, whereas 12 of the 20 controls were observed.

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Ground surveys for females were conducted on rookeries chosen for ease of access to observe animals. Entangled females were counted during these surveys, and the counts were converted to entanglement rates by using the numbers of pups estimated for each of the rookeries as an indication of the number of females present. Rates calculated on this basis ranged from 0.06 to 0.23% for the sample rookeries with a mean of 0.15%. This is to be compared to the 0.4% seen for the juvenile males.

Between 11 September and 16 October 1986, 39 entangled pups were observed. Of these, five were in a single piece of trawl webbing that had become wrapped around a channel marker, and another five were in a piece of blue trawl webbing that washed ashore. As with other components of the population, trawl webbing comprised the highest portion of the entangling debris (19 out of the 39 observed). Entanglement rates for these animals are not known because we have no information on the portion of the pup population that had already departed for sea. The live entangled pups were tagged and released.

During 1985, experimental studies of pup entanglement showed that pups of the size of those found on the islands in October can become entangled in trawl debris with mesh sizes as small or smaller than 16 cm (stretched). All experimental pups placed in a tank with pieces of net with mesh sizes between 18 and 22 cm became entangled within 5 h or less. Some became entangled about their face in pieces with mesh sizes as small as 14 cm.

Data on the interannual history of a small number of entangled subadult males indicate that growth in body size and abrasion brought about by movement cause wounds to increase in size.

STUDIES OF THE EFFECTS OF NET FRAGMENT ENTANGLEMENT ON NORTHERN FUR SEALS PART 1: DAILY ACTIVITY PATTERNS OF ENTANGLED AND NONENTANGLED FUR SEALS

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ABSTRACT

Effects of net fragment entanglement on the behavior of fur seals were examined using radio telemetry. Radio transmitters were attached to three fur seals 5-8 years old kept in an aquarium . Two of the seals were entangled with 1- and 2-kg fishing net fragments, respectively, around their necks. Using radio telemetry, their activity patterns were recorded for 36 days, from 28 January to 4 March 1985. The seal entangled with the 2-kg net showed the shortest active time per day and the nonentangled seal showed the longest. Active time of the entangled individuals increased after removal of the nets. It becamed clear that the active time of fur seals was diminished by entanglement in net fragments.

INTRODUCTION

It has been reported that some northern fur seal, *Callorhinus ursinus*, returning to breeding islands were entangled in marine debris such as fishing net fragments and packing bands (Scordino 1985). The fur seal population of the Pribilof Islands declined to less than half of its" 1940's peak, and mortality due to entanglement is suspected as a major cause of the population decline (Fowler 1982). In what period and at what rate do entangled fur seals die? This issue was examined through tag and refighting surveys of entangled fur seals on St. Paul Island (Bengtson et al. 1988; Scordino et al. 1988). The survival period of entangled animals is considered to vary according to the damage caused by entanglement. There have been only a few reports about the effects of net fragments on fur seals (Feldkamp et al. 1987) . This study was intended to examine the effects of entanglement on activity patterns of fur seals using radio telemetry.

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MATERIALS AND METHODS

Experimental Fur Seals and Radio Equipment

The three female fur seals used in the experiment were captured off Joban coast, north Japan, between 4 and 9 March 1982, and had been kept in captivity for 3 years. The estimated ages of the animals were 5-8 years and body weights were 29.5-36.0 kg at the beginning of the experiment (Table 1). The experiment was conducted in an aquarium, Izu-Mito Sea Paradise, Numazu, central Japan, where the animals were kept.

A radio transmitter and trawl net fragments were attached to the seals on 28 January 1985. Of the three, one (referred to hereafter as NO) was loaded only with a transmitter. A transmitter and a 1-kg net fragment were attached to one of the remaining two (N1), and a transmitter and 2-kg net fragments to the other (N2). Trawl nets used in the experiments were those commonly used in commercial fishing; they were made of polyethylene with a twine size of 3.4 mm and a mesh size of 24 cm. The transmitter was cylindrical in shape, 35 mm in diameter, 155 mm long, and 200 g in atmospheric weight. It had a life of about 6 months (Fig. 1). Receivers and recorders were installed in an observation room near the experimental area (Fig. 2).

The transmitter was attached with a harness made of nylon webbing belts sewn together with colored tapes for individual recognition. Immediately after attachment of the transmitter and net fragments, the animals were released into the experimental area (Fig. 2). The experimental area, made by partitioning an inlet with nets, was about 1,400 m^2 and had a natural beach. The deepest part at high tide was about 7 m; there was a tidal range of about 1.5 m. The sea was calm throughout the year. In addition to the three experimental seals, 33 other fur seals were kept in captivity in this area. Activities of NO were recorded continuously from 4 February to 4 March. Activities of N1 and N2, entangled in net fragments, were recorded from 28 January to 26 February. The nets were intentionally removed on 27 February and their activities without nets were recorded from 28 February to 4 March.

During the entire period, behavior and health of the experimental individuals were checked carefully at a regular time each day. Moreover, in order to compare actual movements with radio records, behavior of the three animals was observed visually several times a day for 4-5 h each time.

During the experiment, fur seals were fed with defrosted mackerel in the amount of 1-4 kg (an average of 2.44 kg) per day at 1000 and 1630 on the beach. At each feeding, food was provided first to each experimental individual, and later to the herd in general.

Weather observations were made around 1400 each day. The average air temperature during the experiment period was 10.2″C (ranging from 6.0° to 18.0°C), with average water temperature at 13.3°C (between 11.1° and 15.8°C) and average humidity at 63.1% (from 38 to 88%).

Table 1.--Information on the three fur seals used in the experiment.

Seal		Capture			Age and size at start of experiment		
			Location				
ID	Sex	Date 1982	Latitude	Longitude	Estimated age (year)	Body length (cm)	Body weight (kg)
NO	F	9 March	36°30′N	141°16′E	6	123	29.5
N1	F	4 March	36°42′N	141°15′E	8	123	36.0
N2	F	8 March	36″26′N	141°06′E	5	120	33.0

Analysis of Activity Records

Figure 3 shows an example of the activity records of a fur seal wearing a telemetry device. Records representing the activity of the animals are called "actograms." Waves in the figure indicate changes in intensity of electric signals due to movement of the animals. When an animal with a transmitter was on land, a continuous wave form was observed (Fig. 3A); movements of the animal on land could be recognized as fluctuations of wave form on the recording paper. The period in which the wave form was fluctuating was defined as active time on land. When the transmitter-loaded animal was in the water and dived, no signal could be received because electric waves are greatly attenuated in seawater. The recording pen then moved straight along the baseline. When the animal emerged, a sharply pointed line was recorded on the paper, corresponding to the abrupt rise of electric wave intensity. Thus, actograms for the animal moving at the sea surface showed a pectinate wave form (Fig. 3B). When the seal was resting at sea, either a flat line or a baseline could be recorded. The former means that the animal was resting with her back upward, and the latter, resting with her back under water. Therefore, the fluctuating wave form indicates activity ashore, and the pectinate wave form indicates activity at sea. We measured the length of such "active" periods in each actogram and calculated the active time and resting time in a day.

RESULTS

General Behavior

During the experiment period, other fur seals did not exhibit special behavior such as avoiding or threatening the transmitter-loaded animals or approaching them with curiosity. The fur seals with transmitters were always within the herd.

Differences in the general behavior of the three fur seals were recognized by visual observation. For several days after the experiment began, N1 and N2 tried to get rid of the attached net fragments by shaking their necks. Seal N2 moved slowly and chiefly engaged in slow swimming or

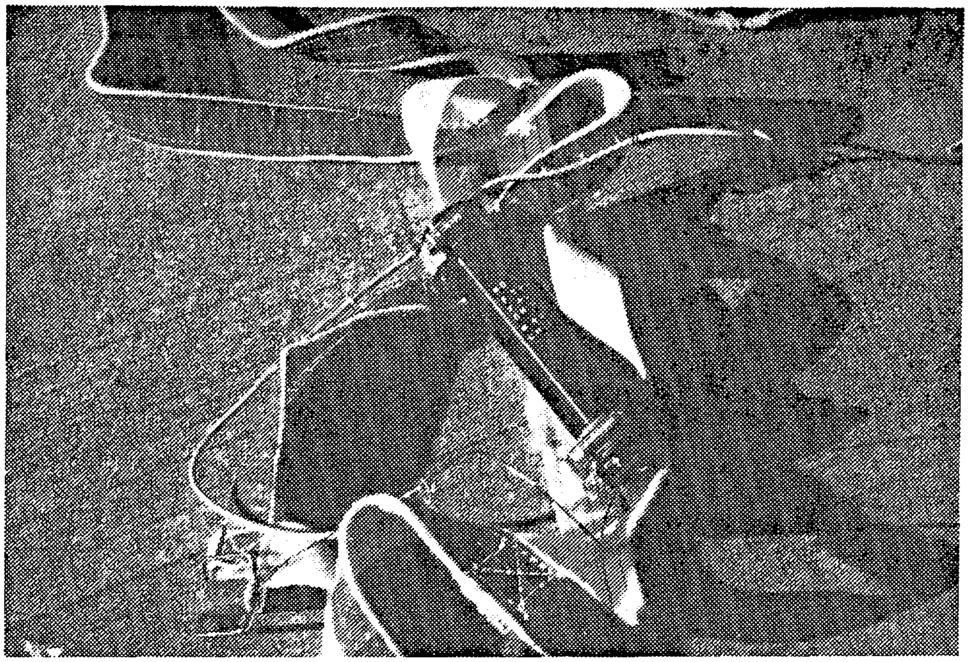

Figure 1. --A transmitter and harness.

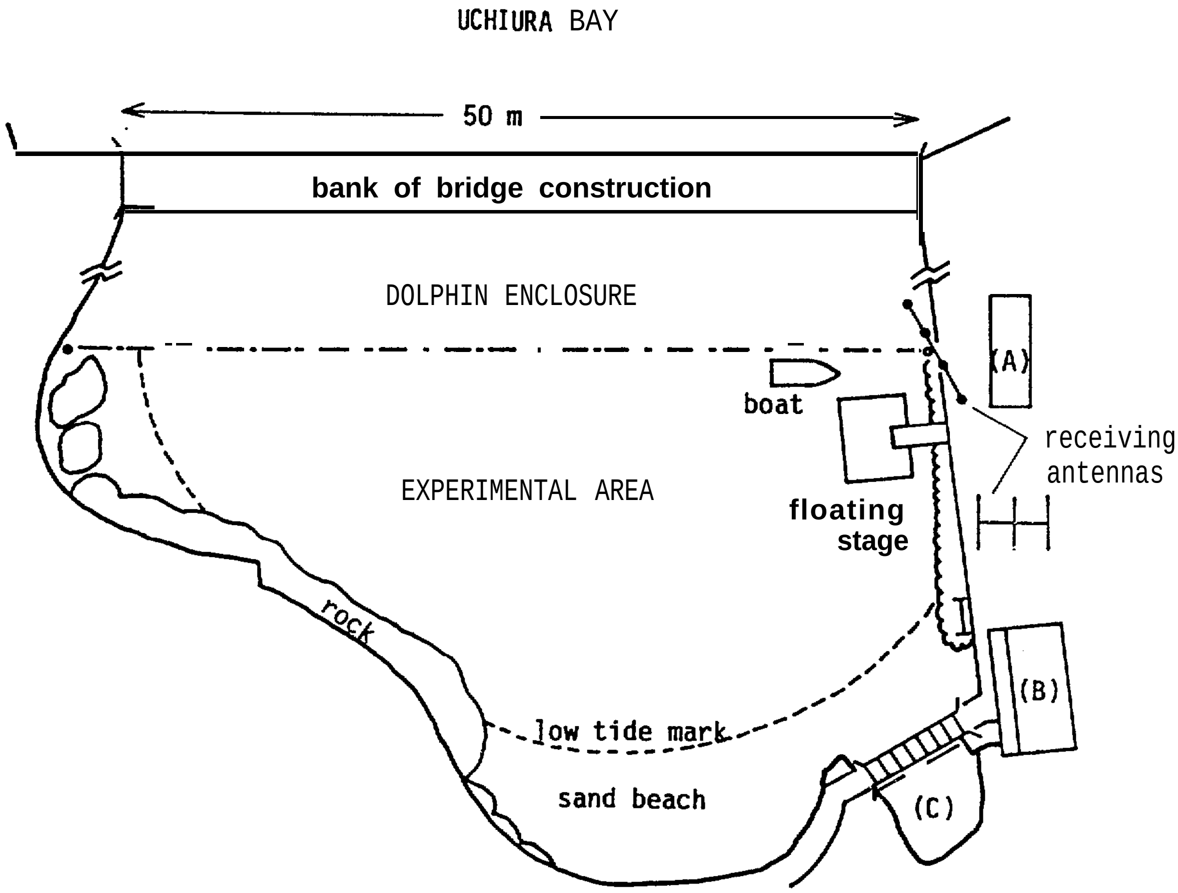

Figure 2. --Map showing the experimental area. A. Observatory where receiving instruments were settled. B. Indoor breeding facility. C. Partitioned section where transmitters were attached.

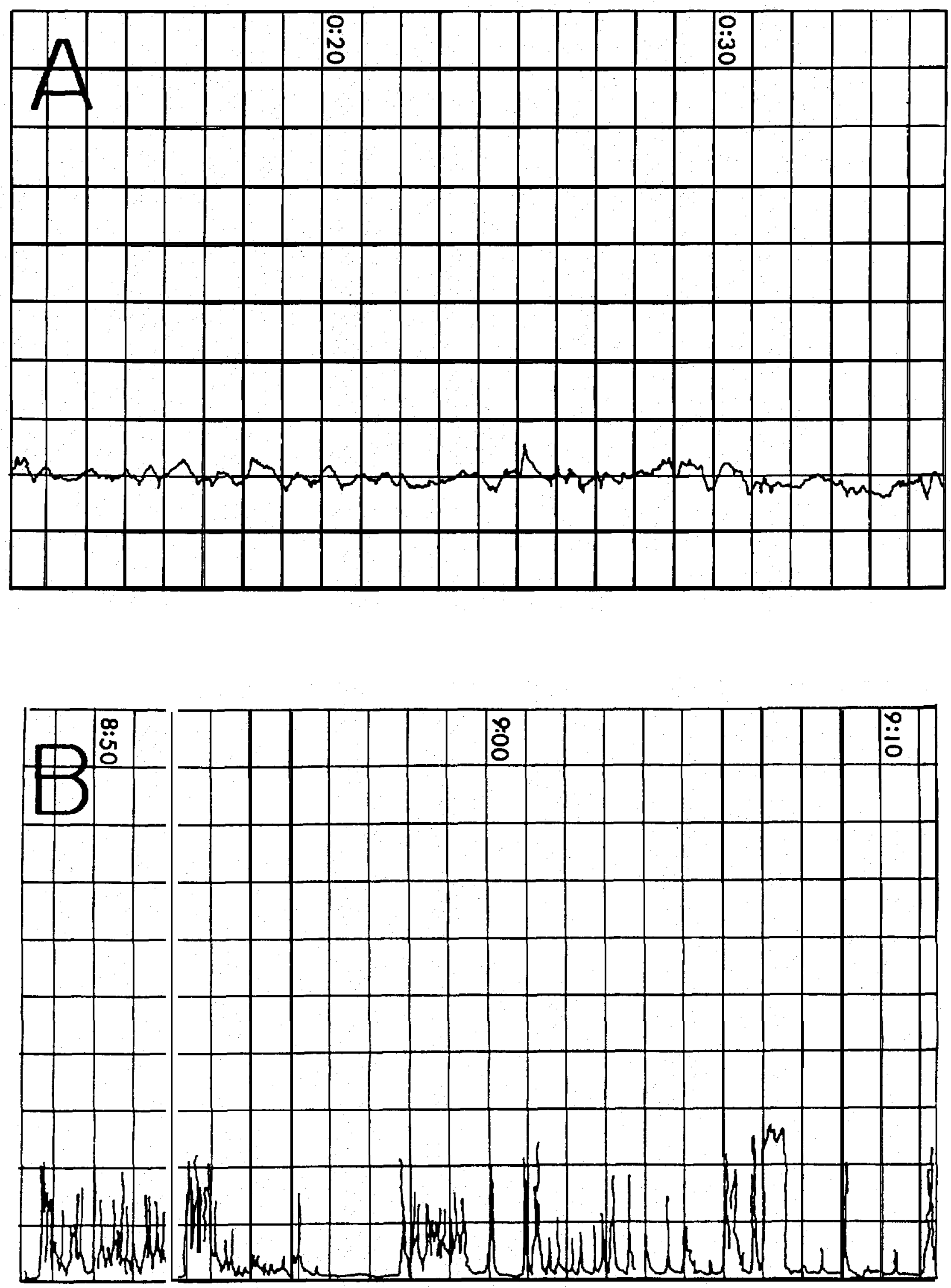

Figure 3. --Actograms, received electronic waves representing the activity of animals. A. Resting on land. B. Swimming at sea.

grooming. Dives and headstands in water, often seen in free-swimming seals, were not observed for N2. Seal N1 moved more smoothly than N2. Sometimes N2 made shallow dives or underwater headstands, but she made no extended deep dives. Seal NO's movements were very smooth and did not differ from those of individuals without transmitters.

For several days after the start of the experiment, N1 and N2 did not draw near to men even at feeding time. Later they approached the feeder as did the other seals. When food was thrown, the nonentangled individuals often caught it before the entangled ones. Seal NO's feeding activity was no different from that of nonloaded fur seals.

Activity Pattern

Active Time

Figure 4 shows variations in active time per day from 4 to 26 February. During this period, the amount of NO's active time fluctuated greatly, while fluctuations were small for N1 and N2. The average daily active time was longest for NO (9.6 h/day), followed by N1 (4.1 h/day) and N2 (1.4 h/day), and any pair of them differed significantly (t-test, $P < 0.01$).

Table 2 shows the daily active times of N1 and N2 before and after the removal of net fragments. The average active time of N2 after net removal was 5.4 h/day, about four times longer than before net removal. The difference was statistically significant (t-test, $P < 0.01$). The average active time of N1 after net removal was 6.7 h/day, about double that of the period of net attachment, which also differed significantly (t-test, $P < 0.01$). The active time of NO did not show a significant change between the two corresponding periods.

Daily Cycle of Activity

Figure 5 shows the average daily cycle of activity. The ratio of activity was calculated every 3 h (activity ratio) and averaged for the experiment period. For N1 and N2, the periods of entanglement and nonentanglement were treated separately. All three seals were very active in two time periods, 0900-1200 and 1500-1800, which corresponded to feeding times. Activity patterns of N1 and N2 did not change remarkably after removal of entangled nets, though the active time increased as mentioned above.

DISCUSSION

Baba and Yoshida (1988) conducted a field experiment in which they attached transmitters to two mature female fur seals, one of which was entangled in a 120-g net fragment, off St. Paul Island and compared their activities using radio telemetry. They reported that the frequency of dives longer than 1 min was less for the entangled animal. In our study, no extended dives were observed for animals loaded with nets of 1 and 2 kg. Although there were differences in research location and the amount of nets

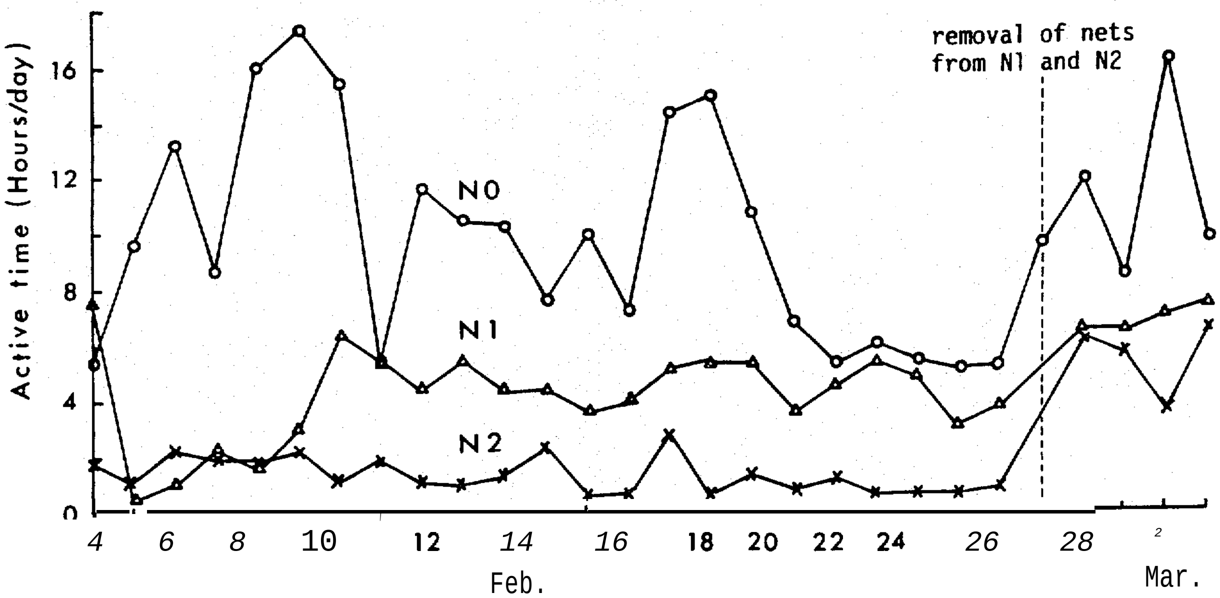

Figure 4. --Variations in daily activity of the three fur seals.

attached, their report is consistent with our study in that net entanglement hindered diving activities.

Daily activity cycles were the same for entangled and nonentangled animals. Baba and Yoshida (1988) also reported that no differences were observed in behavior patterns of entangled and nonentangled fur seals in the open sea. These results indicate that activity patterns of fur seals may not change even if they are entangled in net fragments.

Most of the trawl nets entangling the fur seals on St. Paul Island were <150 g in weight, although the biggest one weighed 6.75 kg (Scordino 1985). Therefore, it is also necessary to examine the effects of smaller net fragments on activity of fur seals.

It is clear that net entanglement suppressed the activity of animals because active time of the animals was short while entangled and increased

Table 2.- -Daily active times of experimental seals with and without attached nets.

	4-26 February 1985			28 February-3 March 1985		
Seal ID	Net weight (kg)	Active time per day mean (min. -max.) (h/day)	S.D.	Net weight (kg)	Active time per day mean (min.-max.) (h/day)	S.D.
NO	O	9.6 (5.0-17.4)	4.0	0	11.4 (8.2-16.1)	3.4
N1	1.0	4.1 (0.4-7.5)	1.7	0	6.7 (6.3-7.3)	0.5
N2	2.0	1.4 (0.6-2.9)	0.7	0	5.4 (3.6-6.4)	1.3

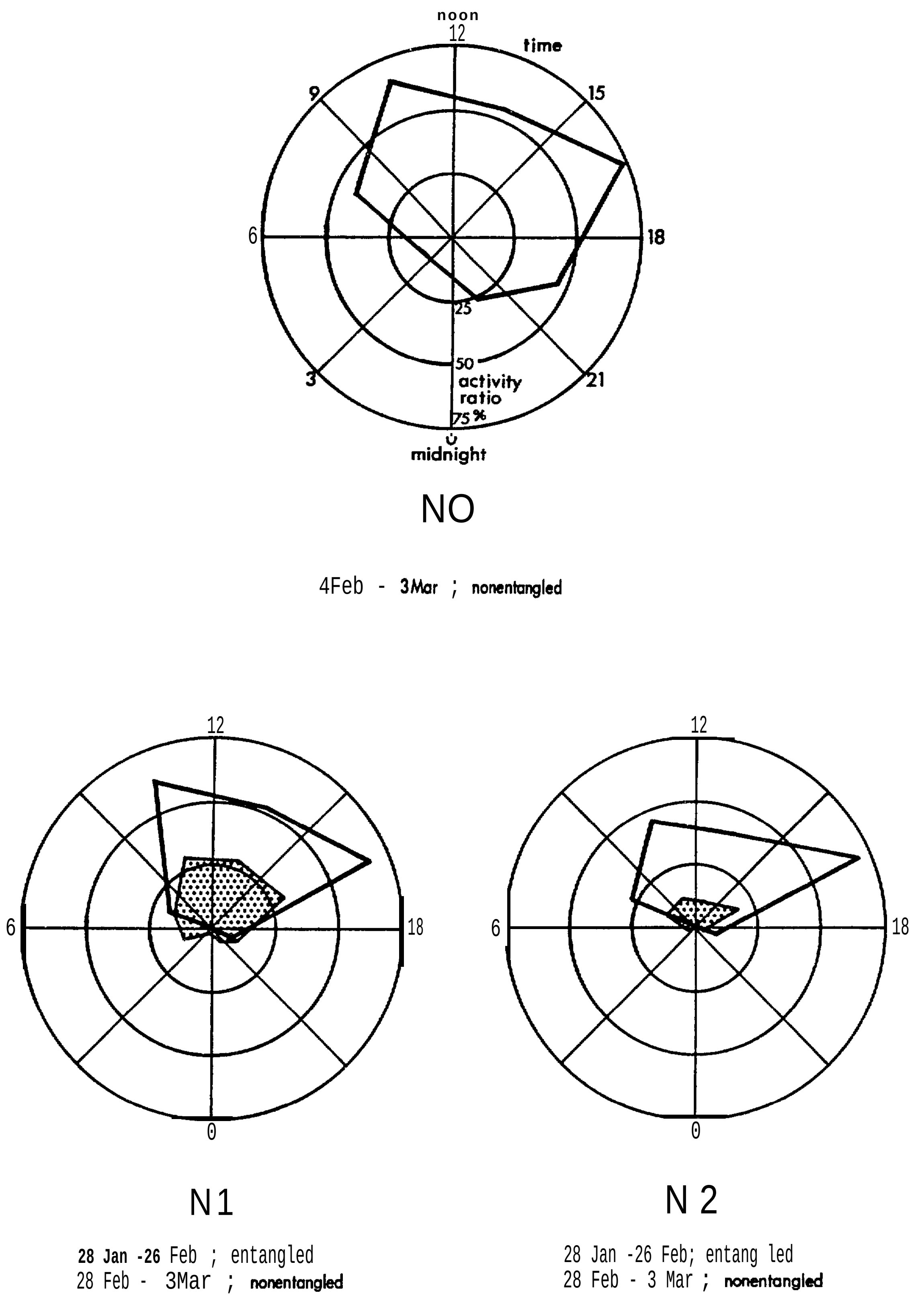

Figure 5. - -Daily activity cycles of three fur seals for entangled (dotted area) and nonentangled (solid line) periods. Activity ratio is defined as the percentage of active time in each 3-h period.

after net removal. The suppression of activity might be due to either the physical burden of nets or an adaptation of animals to conserve energy. A future task should be to study the physiological impact of entanglement and relate it to energy consumption and survival.

ACKNOWLEDGMENTS

We express gratitude to the breeding technicians of Izu-Mito Sea Paradise, who collaborated in the experiment, as well as to the officials of the Fishing Ground Environment Conservation Division of the Fisheries Agency, who provided us with the opportunity to conduct this study.

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STUDIES OF THE EFFECTS OF NET FRAGMENT ENTANGLEMENT ON NORTHERN FUR SEALS PART 2: SWIMMING BEHAVIOR OF ENTANGLED AND NONENTANGLED FUR SEALS

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ABSTRACT

The effects of net fragment entanglement on the swimming behavior of fur seals were observed. Net fragments of six different weights (0.5 to 3 kg) were attached to the necks of eight fur seals, two ❑ales and six females, 4 to 9 years old. They were released in an aquarium pool with fish, and their swimming speed and time required to capture a fish were recorded. Of the eight individuals examined, three showed active feeding behavior. As the amount of attached net was increased, swimming speed decreased and more time was required for an entangled seal to catch a fish. Decrease in swimming speed was proportional to the relative load of net fragments (net weight/body weight).

INTRODUCTION

Marine debris is known to cause problems for various animals such as fish (High 1985), marine mammals (Calkins 1985; Henderson 1985), seabirds (Tull et al. 1972), and turtles (Balazs 1985; Cawthorn 1985). Many fur seals have been found on the breeding islands entangled in fishing net fragments and packing bands (Waldichuk 1978; Scordino 1985). Fowler (1982) noticed that entanglement probably was a cause of recent decline in the Pribilof population of the northern fur seal, *Callorhinus ursinus*. In order to understand the mechanism and impact of net entanglement on northern fur seals, the National Research Institute of Far Seas Fisheries has conducted various experiments at the Izu-Mito Sea Paradise, an aquarium, since 1983. The mechanism of entangling and influence of entanglement on activity patterns of fur seals were surveyed before (Yoshida et al. 1985,

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

1990). In this study, experiments were conducted to understand the effect of net entanglement on swimming behavior of fur seals.

MATERIALS AND METHODS

Swimming speed and feeding behavior of net-entangled fur seals were observed in a pool of the Izu-Mito Sea Paradise in Numazu, Japan, from 27 January to 19 February 1986. The pool was 22 m wide, 10 m long, and 4 m deep (Fig. 1). The front of the pool was made of transparent plexiglass through which underwater movements of fur seals were observed. Trawl net fragments of six different weights were attached to the necks of eight fur seals, two males, and six females, estimated to be from 4 to 9 years old (Table 1). The nets used were gray trawl nets made of polyethylene, with a twine size of 3.4 mm and a mesh size of 24 cm. Specific gravity of the net was 0.77, which meant that a net fragment weighing 1 kg of air had a buoyancy of 340 g in seawater with a specific gravity of 1.03. Weights of the six fragments were 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 kg. As a control, free-swimming animals were also observed.

Experiments were conducted between 1600 and 1730 every day. Fur seals had not been fed since the previous day so that they would respond readily to food. Measurement of swimming speed was conducted in the following marine r. One seal was released into the pool and lured to one corner by a display of food. Then a man showed a fish and threw it 8-10 m from the seal. When the seal started swimming after the fish, one observer recorded the time taken by the seal to swim a distance of 6 m. The distance was measured using the interval of frames supporting the glass wall. Each individual was tested using nets of two different weights per day. For each weight of net, an individual was obliged to swim eight times. One seal could make up to 16 swims in a day. If a seal would not chase a fish, it was removed from the pool and another individual was introduced.

Time to capture a fish was measured for the three seals which readily swam for a fish (Ml, M2, and F1 in Table 1). Basic design of the experiment was the same as that for swimming speed measurement. Live sardine, *Sardinops melanostictus*, 12.5 to 15.0 cm in length and 15-29 g in weight, was used as bait and was thrown 8-10 m ahead of the seal. The time it took the seal to catch the fish was measured. Eight trials were made for each net weight, although the number was reduced when an animal with heavy entanglement looked tired,

To evaluate the effect of net entanglement on the basis of body weight, relative load of attached net was calculated:

$$\text{relative load} = \frac{\text{weight of attached net}}{\text{body weight of fur seal}} \times 100\ (\%)$$

During the experiment period, average air temperature was 7.1°C (1.1°-11.0°C), average water temperature was 12.7°C (12°-13.4°C), and average humidity was 57.4% (36-83%).

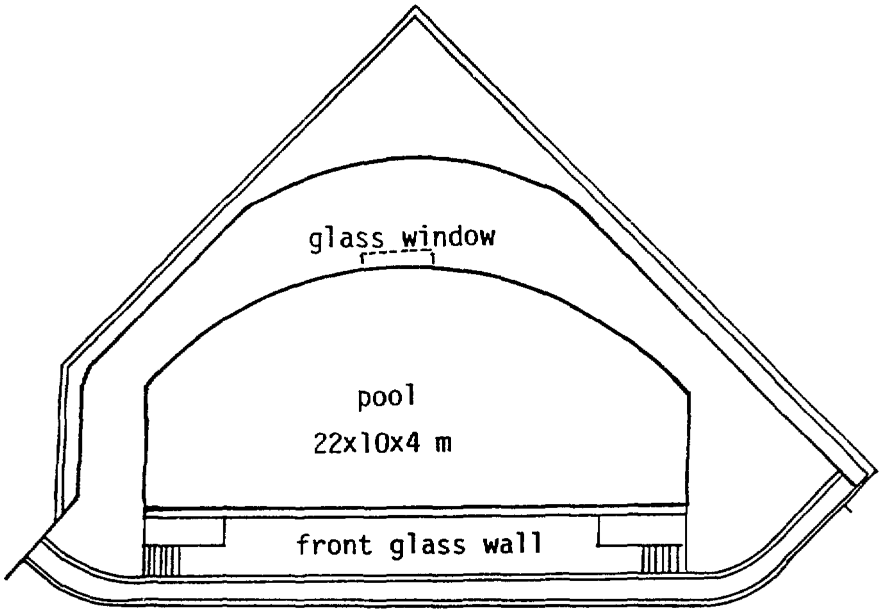


Figure 1.--The pool used in this study. Underwater movements of fur seals were observed through the glass wall.

RESULTS

Individuals Used in the Experiment

Of the six female fur seals used, only one individual (F1) swam actively for fish. She chased fish a total of 32 times for swimming speed measurement, whether she was free-swimming or entangled in 0.5 to 1.5 kg of nets. Two other females (F3 and F5) swam only once or twice, even when they were free from nets. The remaining three made no attempt to swim after a fish. Two males (Ml and M2) tried to catch a fish in every case, whether free-swimming or entangled in up to 3.0-kg nets.

General Behavior

Fur seals often swam on their backs when they were free from entanglement, but entangled seals did not exhibit this type of swimming. All the seals tested were able to swim down to the bottom of the pool (4 m deep) in every degree of entanglement. When they chased a fish, they swam in the upper layer within 1 m of the surface. When entangled seals swam, their bodies twisted up and down. The body undulation was intensified as the amount of attached net was increased.

Swimming Speed

Swimming speed of the three fur seals (Ml, M2, and F1), calculated from the amount of time it took them to pass the 6-m mark, decreased as the weight of attached nets increased (Table 2, Fig. 2). The average swimming speed of Ml without entanglement was 2.98 m/see, but fell to 1.05 m/se

Table 1. --Information on the fur seals used in the experiment.

Seal	Sex	Capture: Date	Capture: Location (Lat.)	Capture: Location (Long.)	Age and size at experiment: Age (year)	Body length (cm)	Body weight (kg)
Ml	M	July 1981	Robben Island		4	137	58.0
M2	M	4 Mar. 1982	36°34'N	141°14'E	4	132	54.0
F1	F	July 1981	Robben Island		4	120	23.0
F2	F	10 May 1980	37°57'N	142°14'E	6[a]	120	35.5
F3	F	8 Mar. 1982	36°26'N	141°06'E	6[a]	121	30.5
F4	F	4 Mar. 1982	36°42'N	141°15'E	9[a]	125	36.0
F5	F	8 Mar. 1982	36"27'N	141°10'E	8[a]	124	38.0
F6	F	9 Mar. 1982	36°30'N	141°16'E	7"	122	32.5

"Estimated age.

when 3-kg nets were attached. That of M2 decreased from 3.04 *to* 0.96 m/see when 3-kg nets were loaded. For both Ml and M2, the speed was about one-third of that in a nonentangled state. The average swimming speed of F1 free from entanglement was 2.51 m/see, but it fell to 0.73 m/sec when 1.5 kg nets were attached.

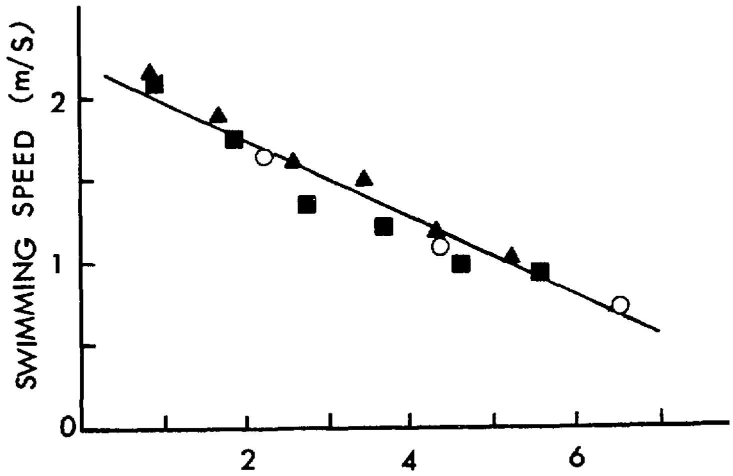
Figure 3 shows the relation between average swimming speed and relative load of net fragments. The relationship was similar for the three individuals. Swimming speed decreased in proportion to the relative load of attached nets. Linear regression of the relationship between relative load and swimming speed was

$$\text{swimming speed (m/see)} = 2.26 - 0.25 \times \text{relative load (\%)} \quad (r = -0.97)$$

Swimming speed of free-swimming animals was excluded from the regression.

Time Required to Capture a Fish

Table 3 shows the time it took for three seals, Ml, M2, and F1, to capture a fish. F1 was not tested with net fragments heavier than 1.5 kg because that much weight seemed too heavy for her. The relationship between weight of nets and time required to capture a fish is shown in Figure 4. Although there was a considerable range, all three seals required more time to catch a fish as the amount of attached net was increased. For the three weights of nets examined, average capture time was the longest for F1. It was observed that when fur seals tried to catch a live fish, they approached the fish and turned their heads quickly to snap at it. Entangled seals had difficulty with the dash and snap.



RELATIVE LOAD OF NET FRAGMENTS(%)

Figure 2. --Changes in swimming speed of three fur seals due to net entanglement. M1: ▲ M2: ■ F1: ○.

Table 2. --Changes in swimming speeds (m/see) of three fur seals due to amount of net entanglement. Speeds were calculated using the time it took the seals to swim a distance of 6 m.

Seal	Weight of net (kg)						
	0.0	0.5	1.0	1.5	2.0	2.5	3.0
	Swimming speed						
Ml							
Mean	2.98	2.16	1.92	1.63	1.50	1.20	1.05
Minimum	2.72	2.06	1.71	1.50	1.39	1.11	0.95
Maximum	3.15	2.40	2.06	1.76	1.66	1.27	1.20
Standard error	0.14	0.11	0.13	0.10	0.08	0.06	0.08
Sample number	8	8	8	8	8	8	8
M2							
Mean	3.04	2.09	1.77	1.37	1.23	1.01	0.96
Minimum	2.60	1.87	1.66	1.25	1.13	0.93	0.82
Maximum	3.33	2.30	1.87	1.57	1.33	1.17	1.09
Standard error	0.29	0.15	0.07	0.10	0.07	0.07	0.11
Sample number	8	8	8	8	8	8	8
F1							
Mean	2.51	1.66	1.09	0.73	--	--	--
Minimum	2.30	1.50	0.90	0.58	--	--	--
Maximum	2.85	1.93	1.25	0.89	--	--	--
Standard error	0.23	0.16	0.15	0.12	--	--	--
Sample number	6	6	6	6	0	0	0

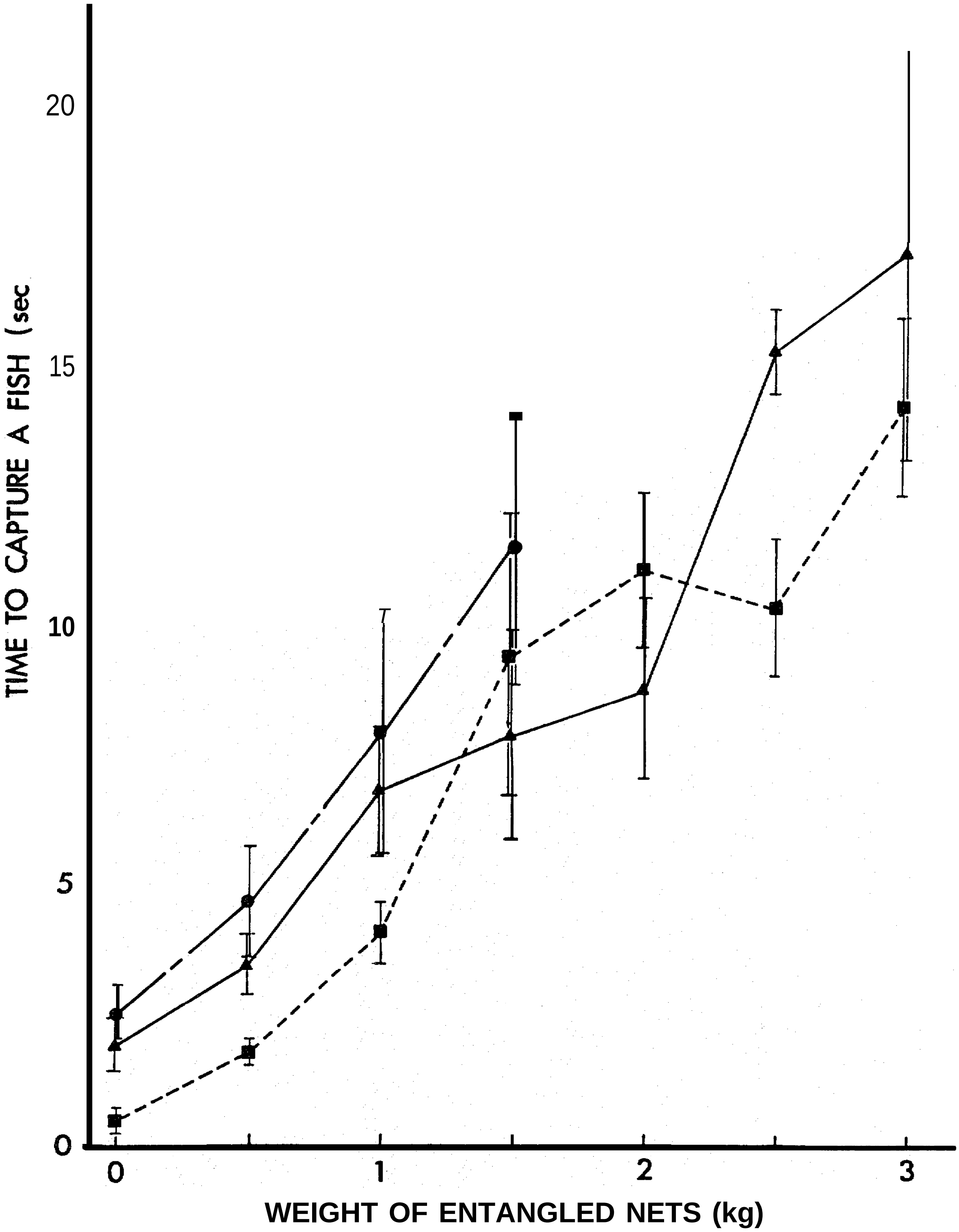


Figure 3. --Relationship between average swimming speed and relative load of attached net. **M1**: ▲—▲ M2 : ■---■ **F1**: ●—●.

Table 3. --Time to capture a live fish, *Sardinops* ***melanostictus***, required by the three seals carrying different weights of nets.

Seal	Weight of net (kg) 0.0	0.5	1.0	1.5	2.0	2.5	3.0
	Capture time (seconds)						
Ml							
Mean	18.1	34.1	68.1	78.8	87.8	152.8	171.6
Range	4-47	11-62	9-115	15-200	30-178	135-191	35-346
Standard error	5.2	5.9	12.1	21.0	17.3	8.0	39.4
Sample number	8	8	8	8	8	8	6
M2							
Mean	4.4	17.6	40.6	94.3	110.9	103.6	142.2
Range	3-5	9-30	15-71	12-247	58-180	67-150	76-210
Standard error	0.3	2.5	5.9	27.4	14.9	13.0	17.0
Sample number	8	8	8	8	8	6	6
F1							
Mean	25.1	46.3	79.0	115.3	--	--	--
Range	14-59	16-97	17-218	30-264	--	--	--
Standard error	5.3	10.7	23.7	27.0	--	--	--
Sample number	8	8	8	8	0	0	0

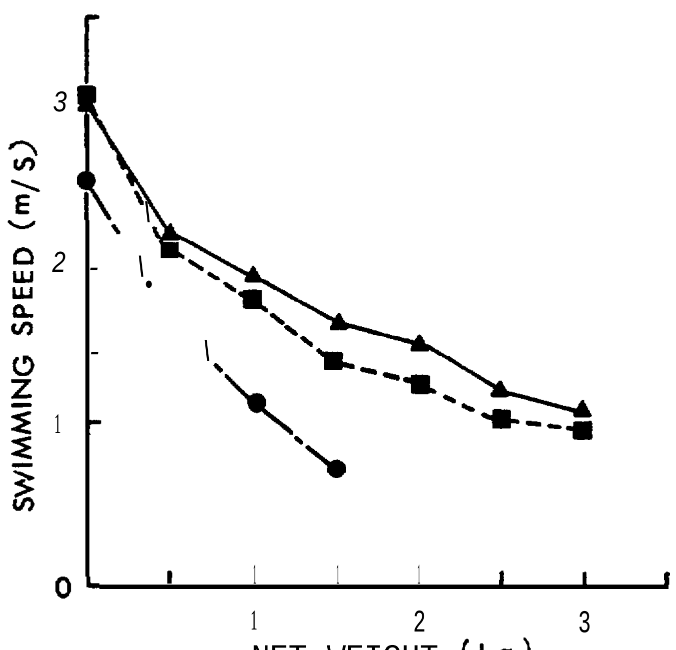


Figure 4. --Relationship between weight of nets and time required to capture a fish. Vertical lines indicate standard error. **M1:**▲——▲ **M2:**■----■ **F1:**●-·-● .

DISCUSSION

Of the eight animals used in these experiments, only three 4-year-olds , one female and two males, tried to capture a thrown fish. Ml and F1 were brought from Robben Island in 1981 as pups and were fed milk by men. All the other seals were caught pelagically. Difference in tractability of the seals might be derived from individual history as well as age, sex, hunger, and disposition.

Swimming speed of the entangled seals decreased as the weight of nets increased. Negative linear relation was observed between swimming speed and relative net load. Decrease in swimming speed might result from two physical forces of net fragments: buoyancy and drag. Buoyancy lifted the body at the neck and shifted the center of gravity. Buoyancy of nets is likely to hinder the dives of entangled seals although all the seals could dive to the bottom of the pool. Body undulation of entangled seals, which was observed when they swan, might be brought about by lifting of the neck caused by buoyancy. At the same time, swimming efficiency was reduced by the drag of the attached nets. These two forces would interfere with diving and swimming and would increase the energy expenditure of entangled seals.

Entangled seals took longer to capture a live fish as the weight of attached nets increased (Fig. 4). The increase in the capture time was derived from a decrease in swimming speed and hindrance of quick body motion. This result indicates that foraging efficiency of entangled seals will be lower than that of free-swimming seals. Heavily entangled seals should suffer from a large expenditure and a small intake of energy. Such an energy problem may be a cause of mortality of entangled seals as well as traumatic damage.

ACKNOWLEDGMENTS

We are grateful to the breeding technicians of the Izu-Mito Sea Paradise, who collaborated in the research, and to officials of the Fishing Ground Environment Conservation Division of the Fisheries Agency, the Government of Japan, who provided us with the opportunity to conduct this study.

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SIMULATING THE ROLE OF ENTANGLEMENT IN NORTHERN FUR SEAL, *CALLORHINUS URSINUS*, POPULATION DYNAMICS

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ABSTRACT

A multiage class model treating populations of both male and female fur seals was developed to examine the plausible long-term effect of their entanglement in discarded net debris. The model is based on the data available on age-specific survival and fecundity including data supporting the assumption of density-dependent survival of pups on land and of juveniles up to age 2 at sea. Also included in the model are age-specific and sex-specific harvests for the subadult male harvest as well as other pelagic and land-based commercial and scientific harvests. Entanglement in the model is linked to the observed incidence of subadult males in the harvest (or roundup). sup- porting work in model development and parameter estimation has involved evaluation of various attempts to estimate both juvenile survival at sea and the mortality rate due to entanglement. This evaluation work has considered the appropriateness of assumptions and statistical tests used. Model results were evaluated by comparison with survey estimates of pup abundance and of harem bulls on the Pribilof Islands for years when these were available (between 1912 and 1960). Post-1960 survey results were used to examine the plausibility of entanglement mortality estimates in predicting the observed fur seal abundance decline. Sensitivity analysis on the model is used to indicate areas where there is a need for either further data collection or further analysis of existing data.

INTRODUCTION

The marked decline in northern fur seal, *Callorhinus ursinus*, populations on the Pribilof Islands since the mid-1970's has been attributed to a variety of causes, one of the most compelling of which is increased mortality due to seals' entanglement in discarded fishing net

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

debris (Fowler 1985, 1987) and other flotsam (e.g., packing bands). Although an earlier decline (1957-64) was probably due to pelagic scientific sampling of females at sea and harvest of females on land, later continued declines have not been explicable as being linked to repercussions of this harvest (York and Hartley 1981).

From observations of numbers of subadult male seals in the harvest entangled (about 0.4%), Fowler (1982), using a simple differential equation model and assumptions about the length of time entangled seals survive and the ratio of seals tangled in large (>0.4 kg) versus small (<0.4 kg) debris pieces (the seals entangled in large debris being assumed to die before reaching land), gave predictions for the possible effects of entanglement on the population. These predictions indicated that the entangled seals observed in the harvest could account for annual seal mortalities as high as 17%. Swartzman (1984) expanded Fowler's model to include age classes and density-dependent pup survival on land, as reflected in data from Lander (1981). Swartzman (1984) showed that the age and duration of susceptibility to entanglement can affect the annual mortality rate due to entanglement. The worst case scenarios (i.e., 2 months or less for half the entangled seals to die with only ages 1-3 susceptible *to* entanglement, or less than 12 months for half the entangled seals to die when all age classes are susceptible to entanglement) result in a long-term elimination of the fur seal population.

We have developed a model to investigate the effect of entanglement on fur seal population dynamics. This model separates male and female populations by age class and separates each age-sex class into entangled and unentangled animals. Sex-specific and age-specific susceptibility to mortality and entanglement mortality rates are also considered. Annual entanglement rate in small (<0.4 kg) debris is grounded in the observed fraction of entangled subadult males in the harvest. In the long-term simulation, harvests of males and scientific samples of females are removed from the population as an amount of seals (rather than as a rate).

The population dynamics of fur seals have been the object of many studies, and several models have been built in this regard. The present model is like many in that it is age-structured. Table 1 gives an overview of these previous models. Current modeling work is motivated by the need *to* synthesize current entanglement information and by the lack of previous treatment of the male population, no inclusion of male harvests and no previous formal sensitivity analysis having been done on previous models. Also, earlier entanglement models are equilibrium models that, while they were based on the best parameter values available at the time they were constructed, were not evaluated by being compared with historical data on pup estimates and bull counts. Finally, our model brings many of the parameter estimates up to date by including the latest available data. The large number of previous models points to the excellent long-term data base on fur seals, although, as will be shown later, assumptions must be made to fill gaps in the data when long-term model projections are made.

Table 1.--Comparison of northern fur seal population dynamics models (F = female, M - male).

Model	Age range/sex	Years	Harvest	Comments
York and Hartley 1981	2-25/F	1956-79	1956-74F	Juvenile survival higher after 1979.
Smith and Polacheck 1981	3-20/F	Not run	--	Challenged differential M/F juvenile survival.
Eberhardt 1981	l-22/F	1952-77	1952-68F	Density-dependent survival to age 3.
Fowler 1982	Pooled	Equilibrium	None	Entanglement effect with several mortalities.
Swartzman 1984	3-20F	Future, equilibrium	None	Density-dependent survival on land.
Trites 1984	1-25/M&F	1950-80	1956-74F constant M	Leslie model sensitivity analysis.
Reed and French 1987	1-29/M&F	1912-2000	1956-76F constant M	Density-dependent pup and juvenile survival.
Swartzman and Huang	2-18M 2-25F	1911-86	1956-76F Subadult male	Entanglement.

MODEL DOCUMENTATION

The model consists of 24 female and 18 male age classes. Populations in each modeled age class are updated by age-specific and sex-specific survival. Sex-specific and year-specific harvests on either (or both) land and sea are also removed from the proper age-sex classes each year. Pup numbers are computed from the adult female population based on age-specific fecundities . Running the model consists of solving a set of differential equations (one for each age-sex class) using the Runge-Kutta method with a time step of 0.25 years. The model is run from 1911 to 1986. The 0.25 time step was chosen to fit with the time period that pups are on land in the Pribilof Islands (3 months), allowing computation of pup survival on land to occur over a single time step. Survival of juveniles from the time they leave land to age 2 is also modeled as a density-dependent factor based on regression analysis of pup counts and male survival estimates (data provided in Lander 1981). Entanglement rate depends on a year-specific susceptibility (based on the observed proportion of entangled subadult males in the harvest each year), an age-specific relative susceptibility factor, and the ratio of seals entangled in large to seals entangled in small debris parameter. Additionally, there are age-specific and sex-specific entanglement mortality and escapement (from entanglement) rates. Animals entangled in large debris (>0.4 kg) are assumed to die rapidly (at the same rate at which they are entangled).

A mnemonic notation is used *to* describe model equations (Swartzman and Kaluzny 1987). The first digit of a variable name denotes the variable type, with x used for state variables, k for parameters, g for intermediate variables, and z for driving variables (unaffected by system behavior and read in from a driver data file). The following letters are descriptive mnemonics such as mrt for mortality or n for numbers. Several parameters are numerically subscripted (e.g., k_1) rather than having a mnemonic name. This was done for parameters that were not easily made mnemonical.

The model is a series of differential equations for the rate of change of female and male seals by age class, with entangled seals (in small net debris) separated from unentangled seals.

$$\frac{dxn_{ij}(t)}{dt} = -(gent_i(t)+kmrt_{ij}+gmrtlg_{ij}(t))xn_{ij}(t)+kesc_{ij}xent_{ij}(t) \qquad (1)$$

where j - 1 for male and 2 for female

i is an age index (l-24 for female; 1-18 for male. These denote ages 2-25 and 2-19 for females and males, respectively)

xn_{ij} = number of unentangled seals in age class i of sex j

$gent_i$ = entanglement rate in small debris for age i seals (yr^{-1})

$kmrt_{ij}$ = natural mortality rate for age i sex j seals (yr^{-1})

$gmrtlg_{ij}$ = entanglement rate in large debris for age i sex j seals (yr^{-1})

$xent_{ij}$ = number of entangled seals in age class i of sex j

$kesc_{ij}$ = rate of escapement from entanglement for age i sex j seals (yr^{-1}).

Population dynamics of entangled seals are:

$$\frac{dxent_{ij}(t)}{dt} \quad -(kmrtent_{ij}+kmrt_{ij}+gmrtlg_{ij}(t)+kesc_{ij})xent_{ij}(t) + gent_i(t)xn_{ij}(t) \qquad (2)$$

where $kmrtent_{ij}$ - entanglement mortality rate for seals entangled in small debris (yr^{-1}).

These equations account for the possibility of entangled seals escaping as reported by Scordino and Fisher (1983), Fowler (1987), and Fowler et al. 1990).

In addition to these continuous time equations there are also discrete time equations that update the population at set times of the year.

- The pupping time (i.e., early July), when pups are produced, ages of the populations are updated, and harvests of subadult males (and pelagic harvests, if any) are taken;

- The time pups leave land, when the density-dependent number of surviving pups is computed.

The number of pups produced in any year are computed from age-specific fecundity

$$xpup(t) = \sum_{i-1}^{24} kfec_i xn_{i2}(t) \qquad (3)$$

where $kfec_i$ - age-specific fecundity including the influence of age-specific maturity.

At the time pupping occurs, the model updates time, ages the seals by 1 year, and removes seals by harvest for that year (harvest includes the subadult male commercial harvest, any harvest of females, and any scientific samples taken that year).

$$xn_{ij}(t+1) - xn_{(i-1)j}(t) \quad - zharv_{ij}(t+1) \qquad (4)$$

where $zharv_{ij}(t)$ = the total harvest and samples of age-sex class ij in year t (data entry).

Harvests are most commonly applied *to* the annual subadult males on the Pribilof Islands, but involved females between 1956 and 1968 and research samples including a variety of age-sex classes in many years. Analogous harvest equations exist for entangled male and female animals (there is a data file for entangled seals as well as for unentangled seals from the harvest statistics).

The survival of l-year-old and 2-year-old seals is treated somewhat differently from the survival of older seals. The natural mortality of seals between age 3 months (the time pups leave land) and age 2 is computed by the density-dependent function

$$gmrt_{mj}(t) = kfmrt_j \frac{-\log_e \left[\frac{ks_1(xpup(t-m+0.25) - ks_2)}{(xpup(t-m+0.25) - ks_3)} \right]}{1.75} \quad (5)$$

Here m denotes age class (1 or 2) and j sex class. The 0.25 year (3 months) adjusts time back to the time pups leave land. The ratio of female to male mortality rates is $kfmrt_2$, and $kfmrt_1$ - 1. The total number of pups leaving land (male + female) in the year for which we are computing mortality rate (m - 1) or in the previous year (m - 2) is $xpup(t-m+0.25)$. Instead of $kmrt_{mj}$, $gmrt_{mj}(t)$ is used in equations (1) and (2) for age classes 1 and 2 to denote that these are intermediate variables rather than parameters. The natural logarithm and 1.75 are used to convert the fraction of seals surviving to age 2 (excluding entanglement) to a rate. A mortality rate must be used instead of a fraction surviving (which is what we estimate from the primary data source) because entanglement mortality may also be incurred by these younger seals. We noted earlier that the model considers age classes beginning with age 2 seals. As such, the above computations for age class 1 seals are not included in the part of the code that deals with the seal age classes, but as a separate calculation. Age class 1 animals are excluded from the model because very little is known about survival rates of pups after they leave land and estimates are based solely on the male juveniles that begin showing up in the Pribilofs at age 2.

At the time pups leave land (at 3 months of age), the model computes the number of pups leaving according to a density-dependent function (Swartzman 1984) and divides them into male and female groups assuming a 1:1 sex ratio.

$$xpup_j(t+0.25) = \tfrac{1}{2}k_1(1.0 - k_2 e^{-k_3 xpup(t)}) \quad (6)$$

Parameters are k_1, k_2, and k_3 in this density-dependent relationship. The seal entanglement rate is assumed to be age, sex, and time specific. A year-specific driving variable, $zprop(t)$, the proportion of entangled subadult males observed in the harvest, is multiplied by an age-specific and sex-specific variable:

$$gent_i(t) - zprop(t)k_4 \cdot e^{-k_5 \cdot i} \quad (7)$$

Here k_4 is the ratio of entanglement rate for pups to the proportion of subadult males in the harvest entangled in small debris, and k_5 is a parameter controlling the age susceptibility of seals to entanglement. Entanglement is represented as an exponential function of age, with youngest seals being most susceptible. The parameter k_5 controls the rate of decline of entanglement susceptibility with age. Setting $k_5 = 0.0$ makes all ages equally susceptible. As a way of simplifying sensitivity analysis, this function was used to represent age changes in susceptibility to entanglement by a single parameter, rather than a vector of parameters. The entanglement rate of age i seals in large debris is equal to $k_6 \cdot gent_i$. The model assumes that seals entangled in large debris die rapidly enough for the mortality rate to be equal to the entanglement rate. Thus, the entanglement rate in large debris is equated to a mortality rate $gmrtlg_{ij}$ (as shown in equations 1 and 2). The parameter k_6 is the ratio of entanglement in large versus small debris.

The mortality rate of seals entangled in small debris $kmrtent_{ij}$ was for convenience also modeled as a function of age and sex. As with entanglement rate, an exponential function was used because it gives flexibility in the change of entanglement mortality with age. The equation is:

$$kmrtent_{ij} - kent1_j e^{-kent2_j \cdot i} \qquad (8)$$

Here $kent2_j$ is a sex-specific parameter for changes in the mortality rate of entangled seals with age. It is analogous to k_5. *The* mortality rate for age 0 seals (i.e., pups) is $kent1_j$.

Model Parameters

Parameter values used in this model are given in Table 2, along with sources of data. A calibration process was used to improve the fit between the model and data. It consisted of changing selected parameters to produce agreement with pup counts on the Pribilof Islands. During calibration, parameters were constrained to be changed only within "reasonable" limits ("reasonable" depending upon the accuracy of the parameter estimate).

The parameters k_1, k_2, and k_3 were estimated using a nonlinear regression based on equation (6) of estimates of pups born against estimates of pups leaving the Pribilof Islands. The regression gave estimates of k_1 = 1.06 x10^6, k_2 - 1.007, and k_3 - 1.04 x 10^{-6}. When the model was run with best estimates for these and other parameters (see Table 2), the fit from 1911 to 1950, the period of population growth, was very poor. We had ascertained earlier (Swartzman 1984) that the population behavior was very sensitive to these parameters (i.e. , k_1, k_2, and k_3). **This** being so, we used bootstrap resampling to obtain estimates of the variance of each parameter (by redoing the regression with different resamples) and then "searched" the parameter space (1,000 Monte Carlo runs) to see which combinations of parameter values provided the best fit to the data during the population growth period. This experiment produced the values for k_1, k_2, and k_3 given in Table 2.

Model-Data Comparison

Our initial desire for this model was to have it replicate the female fur seal population abundance. Any model unable to do that must be judged insufficient for investigating the effect of entanglement on fur seal population dynamics. Figure 1 compares the model to pup numbers and bulls (for the model this includes all bulls 7 years or older), which are the only long-term data available. The vertical dashed lines in Figure 1 show (from left to right) the year pelagic sampling of females began, the year entanglement began, the year commercial pelagic harvest ended, and the year all female sampling ended (both scientific sampling and commercial harvests).

Table 2.--Parameter values and data sources for northern fur seal population dynamics model.

Parameter	Definition	Value	Estimate source
k_1	Maximum land pup survival	728451	Regression; Lander (1981) calibration.
k_2	Density-dependent land pup survival	0.982037	Regression; Lander (1981) calibration.
k_3	Density-dependent land survival exponent	1.609502e-6	Regression; Lander (1981) calibration.
k_4	Ratio of age 0 seal entanglement to fraction of entangled subadult males	5	Fowler (1982) calibration.
k_5	Change of entanglement with age	0.35	Calibration.
k_6	Ratio of large to small net entanglement rates	15	Fowler (1984) calibration.
$kentl_1$	Entanglement mortality rate for younger ❑ales	0.8	Fowler (1982).
$kentl_2$	Entanglement ❑ortality rate for younger females	0.8	Fowler (1982).
$kent2_1$	Entanglement ❑ortality age effect for males	0,35	Calibration.
$kent2_2$	Entanglement mortality age effect for females	0.35	Calibration.
$kfmrt_2$	Ratio of young female to ❑ale ❑ortality rate	0.6	Chapman (1964) calibration.
ks_1	Density-dependent survival to age 2	0.5428	Regression; Lander (1981).
ks_2	Density-dependent sea survival parameter	0.7643	Regression; Lander (1981).
ks_3	Density-dependent sea survival parameter	0.7372	Regression; Lander (1981).
Male seals (age-class-specific)			
$kmrt_{i1}$	Seal mortality rate	--	Lander (1981).
$kesc_{i1}$	Age-specific escapement from entanglement	0.0008	Calibration.
Female seals (age-class-specific)			
$kmrt_{i2}$	Seal mortality rate	--	Lander (1981).
$kesc_{i2}$	Age-specific escapement from entanglement	0.0008	Calibration.
$kfec_i$	Age-specific fecundity	· ·	York and Hartley (1981).

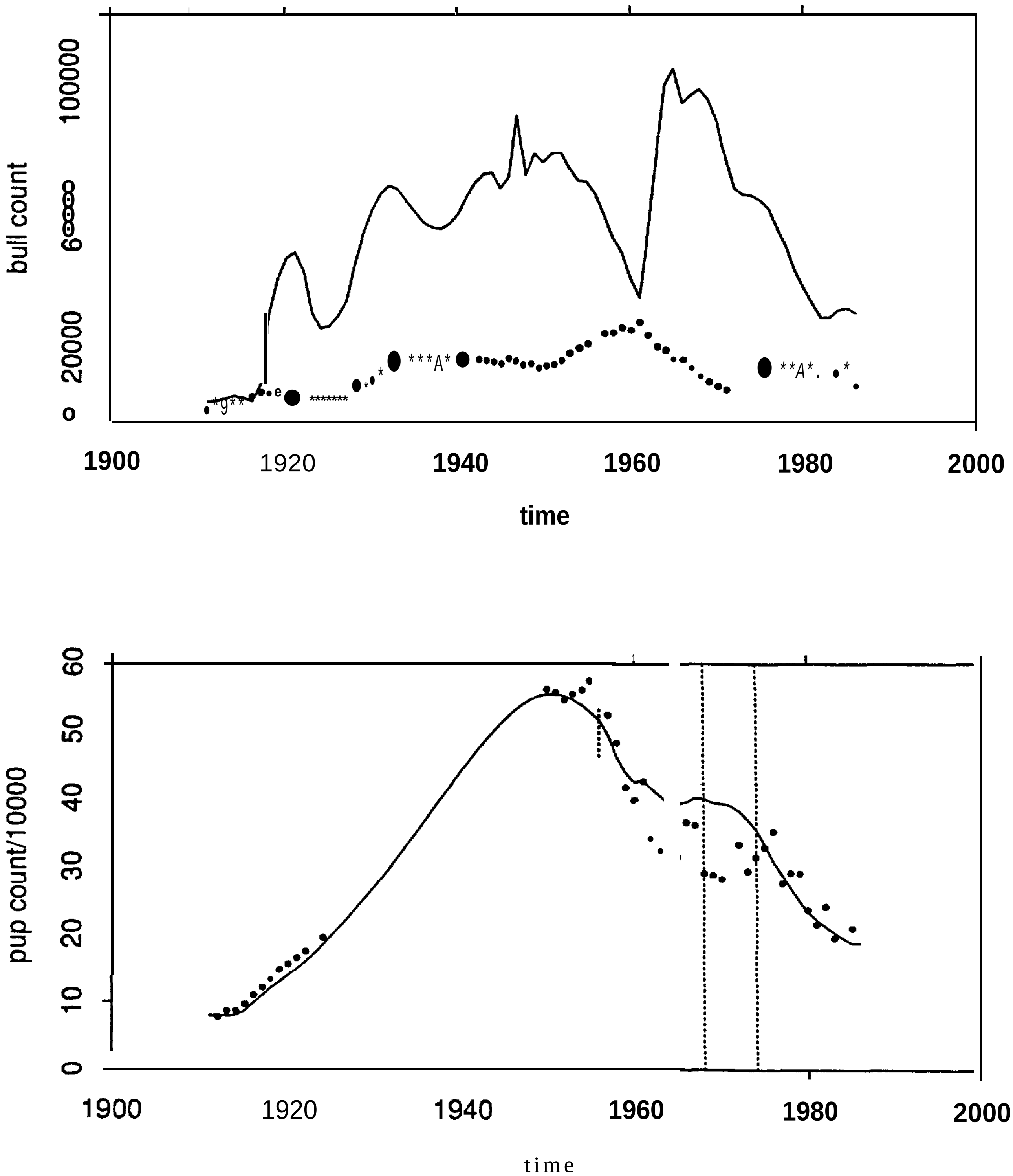

Figure 1. --Model-data comparison between pup and bull counts, 1911-86.

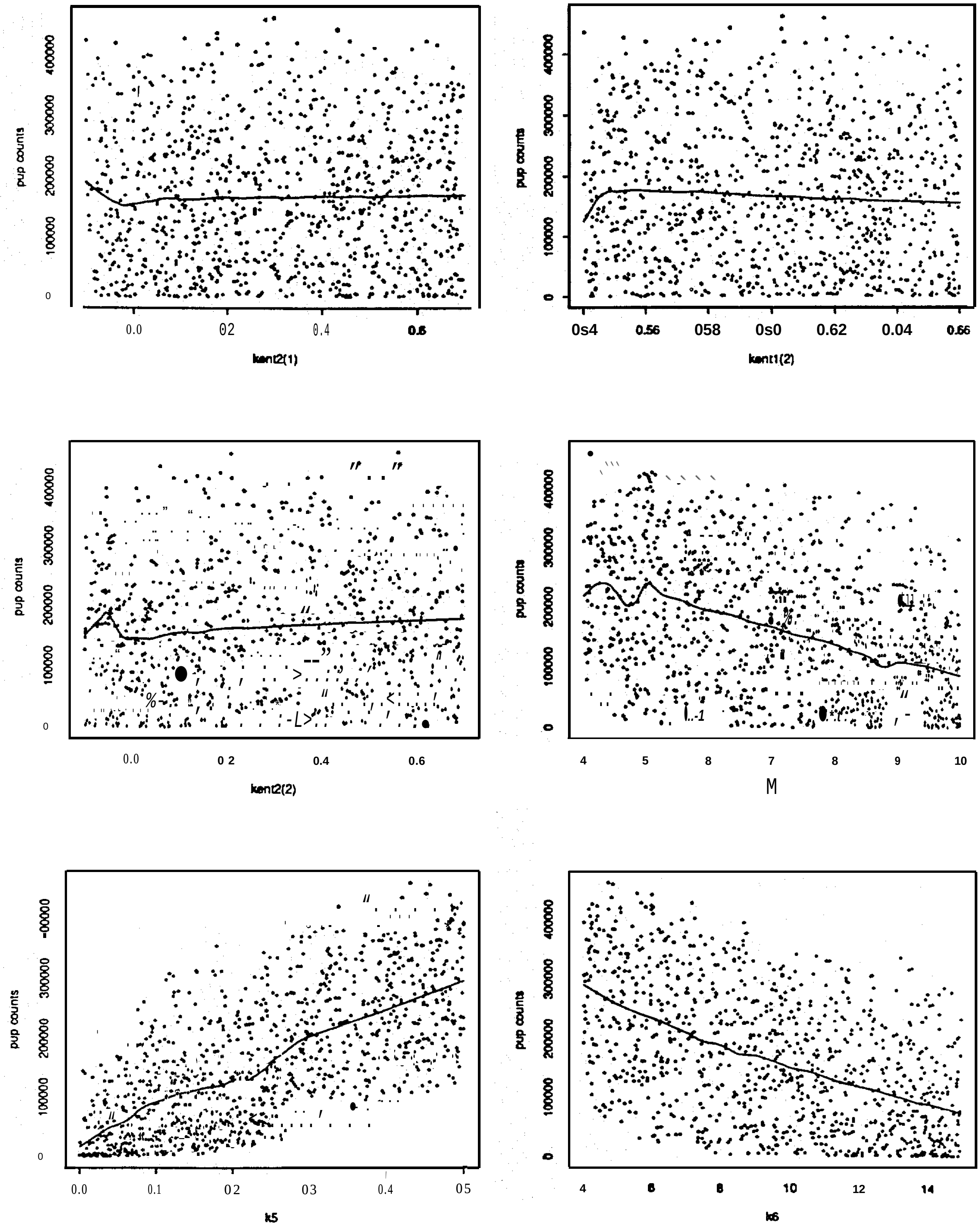

Figure 2. -- Sensitivity of 1986 pup counts to entanglement parameters.

Although the fit to the pups appears credible, the bull counts are overestimated by the model. Through many runs of the model adjusting male parameters (the female population is unaffected by these changes), it became apparent that in order for the model not to seriously underestimate the number of bulls during the late 1950's and early 1960's (a period of large subadult male harvests), bull counts in the model during the earlier period need to be significantly higher than reported counts. The possibility that the model was in error was minimized by our checking the calculations and also observing that the bull counts do not appear to respond to marked annual changes in harvests, especially during the 1940's. Possible explanations for this model-data disparity (remember that during this period the model appears to fit pup counts well) are that (1) the actual number of bulls is much higher than the number of territorial bull counted both with females (harem bulls) and as "idle bulls," (2) the pup estimates during this period are in error and pup numbers were actually significantly higher than those obtained by the tagging estimates made in the 1950's (Chapman 1973), or (3) that estimated survival parameters for males are in error,

If the first alternative is true, then many mature bulls, especially the younger ones (e.g., ages 7 and 8), are at sea much of the time and do not show up in the bull counts. If the model's bull predictions are to be believed, there must have been a very large pool of idle bulls in some years that spent either little or no time on land in the Pribilof Islands. Furthermore, the size of this pool has changed over time, being large in the 1930's and 1940's, small around 1960, large again in late 1960's, and now being drastically reduced.

SIMULATING THE EFFECT OF ENTANGLEMENT ON FUR SEAL POPULATIONS

The fit between model and data in Figure 1 was based on a calibration, where entanglement parameters were selected to best fit the population trajectory for pups after 1960. As recorded in Table 2, several of these entanglement parameters are based on limited data and others are simply based on achieving a fit of the model to the data. This is true of the age specificity of both entanglement rate and mortality rate of entangled seals, which has not been studied in the field. The ratio of the rate of seals entangled in large versus small debris is based only on the relative incidence of these two kinds of debris in land and pelagic surveys (Fowler 1987) . Also, no studies have been devised to estimate susceptibility of seals to entanglement in debris. Therefore, it is to be expected that our uncertainty about the values of these parameters is great.

To investigate the sensitivity of model predictions of pups and adult males in 1986 (chosen as a measure of model performance that directly relates to the effect of entanglement) to changes in entanglement-related parameters, we performed a Monte Carlo sensitivity experiment. Parameter values were sampled from a uniform distribution *over* the range of values judged to be reasonable (within our expectation of what the parameter values may be). Our choice is, of course, somewhat subjective. It is to be expected that our range of acceptable parameter values will narrow considerably as a result of this experiment. This method of using a sensitivity study to narrow the tolerance limits on parameter values by choosing combinations giving realistic model behavior was devised by Hornberger and Spear (1981).

Because we are primarily interested in sensitivity of the seal population to entanglement, we restricted our sensitivity study to parameters directly related to entanglement. These include parameters k_4-k_6, relating to the entanglement rate in both large and small debris and the change over age in susceptibility to entanglement; $kent1_j$ and $kent2_j$, the entanglement mortality rates for males and females and how they change with age; and $kesc_{ij}$, the age-specific and sex-specific rates of escape from entanglement. The pup and bull populations predicted by the model in 1986 were used as an output variable for comparing sensitivity runs. From Figure 1 it is seen that the population consistently declines after 1960, the year entanglement mortality begins to take effect, and therefore the 1986 value is a measure of the degree of decline (all sensitivity runs are at the same population level in 1960 because they differ only in entanglement-related parameters).

Initial results indicated that the escape-from-entanglement parameters $kesc_i$ are significantly less influential than the other parameters. Therefore the Monte Carlo runs were restricted to the other seven parameters. Table 3 gives the values and ranges used for each parameter in the sensitivity study. Due to uncertainty about the parameter values, we chose to sample parameter values from uniform distributions.

Ranges of parameters were set as follows: $kent1_j$, the age O small debris entanglement mortality rate, was set to a range of 10% on either side of the baseline run estimate value of 0.6. Considerable effort has been devoted to estimating the mortality rate of entangled seals, both through observation of marked entangled animals and by looking at the age distribution of entangled versus unentangled seals in the subadult male harvest (Fowler 1987). As such, a modest range of variability was assumed. Three parameters control the age distribution of entanglement effects. Parameter $kent2_j$ is the exponent controlling the age distribution of entanglement mortality for male (j - 1) and female (j - 2) seals, and k_5 is the same for entanglement rate (no sex distinction here). Baseline estimate for each of these parameters was 0.35. Little is known about how susceptibility to entanglement changes with age, except that significantly more young seals are observed entangled in debris on the Pribilof Islands. Having k_5 of 0.35 makes O-age seals 20 times as susceptible to entanglement as 8-year-olds. A range of O (no difference in age susceptibility) to 0.5 (ratio of 55 in age O to age 8 susceptibility) seemed adequate to cover the plausible range of values. For kent2 and kent4 a wider range, from -0.1 (older animals die more rapidly when entangled) to 0.7, was chosen, reflecting our having no data on how long animals at different ages survive when entangled.

The last two sensitivity parameters, k_4 *and* k_6, are not well known. For k_6, the ratio of entanglement rates in large to small debris, Fowler (1984) estimated a value of 5 based on the ratio of large to small debris in beach surveys on Amchitka (Merrell 1980) and the Pribilof Islands.

Table 3.--Parameter values and ranges for sensitivity analysis.

Parameter	Monte Carlo distribution	Best estimate
$kent1_1$	U(0.54, 0.66)	0.6
$kent2_1$	U(-0.1, 0.7)	0.35
$kent1_2$	U(0.54, 0.66)	0.6
$kent2_2$	U(-0.1, 0.7)	0.35
k_4	U(4, 10)	5
k_6	U(4, 15)	15

However, our baseline estimate, which resulted in a reasonable model-data fit, was 15. We therefore chose a range of 4 to 15, putting our estimate at the high end in deference to Fowler's more data-based measure. Parameter k_4 represents the ratio of entanglement rate in small debris for 0-age seals to the fraction of observed subadult male seals entangled on the Pribilof Islands. The latter is the only data-based time series on annual entanglement available. Estimating k_4 is like trying to assess the size of an iceberg from the part above water. There is a lot unknown below the surface. For a range of values, we blanketed our baseline estimate, 5, by 4 and 10, the relatively high lower bound being due to results of preliminary experiments with the model that showed low values of k_4 leading to an overprediction of pup abundance (too weak an effect of entanglement). One caveat of the calibration approach to parameter estimation in this case is that we are assuming entanglement to be the sole cause of the additional mortality since 1960. If, in fact, there are other yet-undiscovered causes, then entanglement parameter values estimated here would be biased. This is to be borne in mind during the discussion of the sensitivity analysis, which examines parameter ranges that lead to realistic behavior, assuming that all sources of mortality are accounted for in the model (either through harvest, sampling, entanglement, or natural mortality, or through density-dependent juvenile survival).

SENSITIVITY ANALYSIS RESULTS

Figure 2 shows results of the sensitivity study for six of the parameters plotted against pup numbers. Results are omitted for $kent1_1$, which is similar to $kent1_2$. A-smooth using supersmoother (Friedman and Stuetzle 1982) was fit to each plot. The three entanglement susceptibility parameters appear to have a stronger effect on 1986 pup numbers than the entanglement mortality parameters. Low values of k_5 (no age-specific or weak age-specific entanglement susceptibility) appear to lead to low 1986 pup predictions.

To get a sense of which parameter combinations led to realistic predictions, we extracted those runs (of the 1,000 runs made) that gave 1986 pup estimates between 170,000 and 200,000 (the baseline run gave 189,000 pups in 1986, close to the pup count estimate for that year).

Figure 3 illustrates which combinations of parameters give realistic model behavior. The first three plots show the entanglement rate parameters against each other for pup numbers within this range, including a super-smooth fit of the resulting scatterplots. The next three plots show each of these parameters' values against pup numbers (for the latter restricted between 170,000 and 200,000 pups). These indicate that over the range of "realistic" pup numbers, none of these parameters has a significant effect on pup numbers (there is no significant slope to the smooths). From the first three plots we deduce that k_4 and k_5 are inversely related to each other, and k_5 and k_6 are inversely related to each other. This can be interpreted to mean that there cannot be a low value of k_5 and a high value of k_4 (and contrariwise a high value of k_5 precludes a low value of k_4). This information is useful because it sets limits of parameter combinations leading to realistic behavior. Furthermore, if more information becomes available concerning any one of these parameters it further delimits the possible values of the other parameters. For example, if observation of entangled animals at sea would indicate that seals are more susceptible to entanglement in large debris than the ratio of large to small debris in beach surveys would indicate (implying a value of k_6 near the upper end of' the 4 to 15 range used here), then the entanglement rate needs to be age-specific, with older animals significantly less susceptible to entanglement than younger animals. Significant benefit for research direction can be derived from these results, because they suggest that improved estimates of entanglement rates in small debris can be obtained by seemingly unrelated (and potentially less expensive) then the studies such as finding out about age-related susceptibility to entanglement.

Another interesting result of this sensitivity study is that entanglement rates are much more important for population survival than is entanglement mortality. Another way of saying this is that the rate at which seals enter the entangled animal pool is more important to long-term population trends than the rate at which they die once they are in it. Assuming mortality rate much larger than the rate of escape from entanglement assures that most animals entering the entangled pool will die before they can leave their mark on future generations through reproduction.

ENTANGLEMENT QUESTIONS AND RESEARCH

The model can be used to explore recovery scenarios such as how the population would respond to removing entanglement or reducing it. However, such an exercise is unnecessary. Except for short-term effects, the response to removing entanglement can be observed in Figure 1 in the model's pup counts during the upward cycle starting around 1923. Intermediate entanglement rates would result in less rapid recovery rates. The actual rate of recovery depends on the specific entanglement rates and combinations of parameters. These include the entanglement parameters (k_4-k_6) as well as the non-entanglement-related parameters that were calibrated to fit time traces from 1915 to 1960 pup counts.

More important than recovery scenarios are dominant questions suggested by the model concerning entanglement. These are:

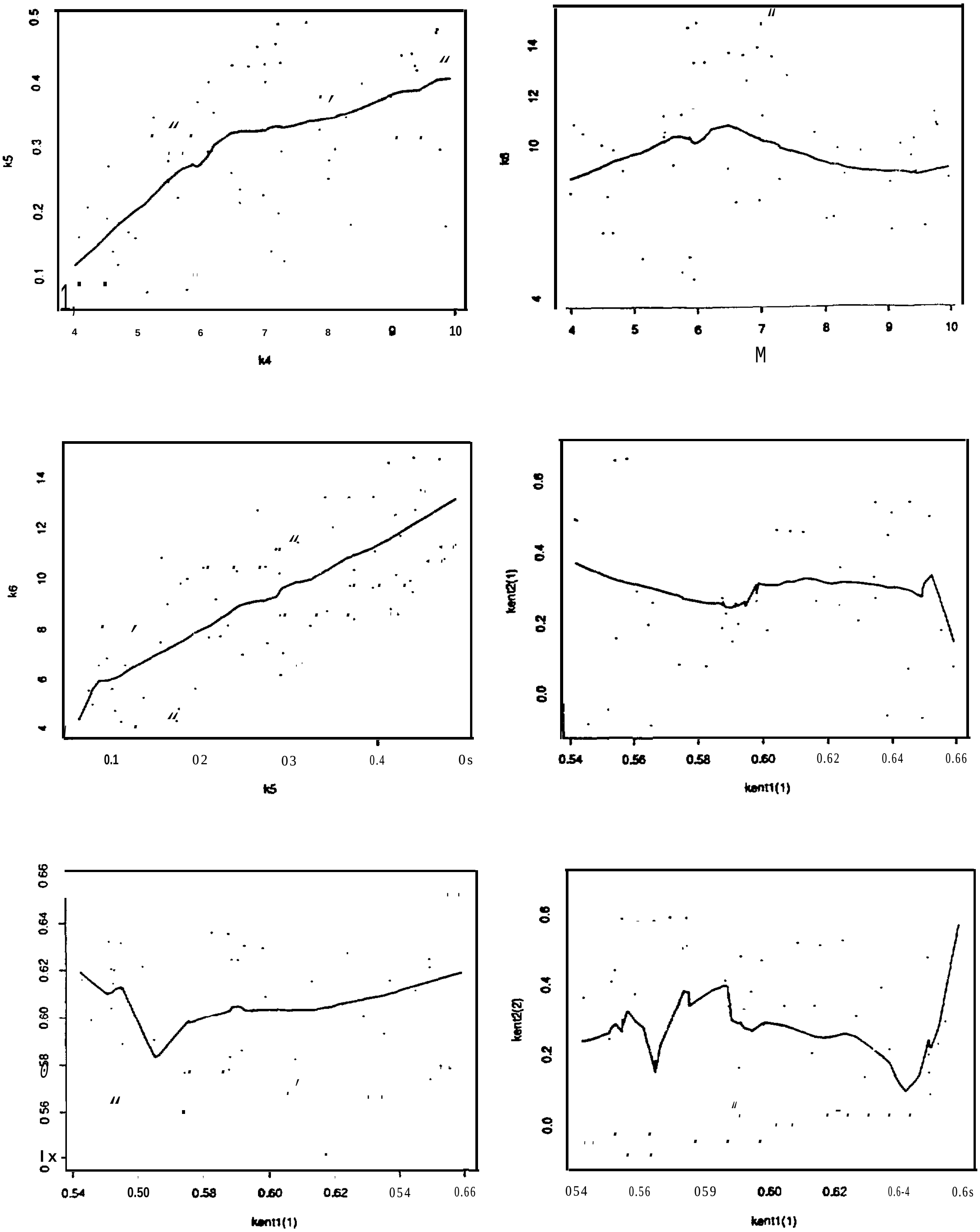

Figure 3. --parameter interaction for 1986 pups and bulls close *to* nominal run levels.

1. What is the rate of entanglement in small debris and how is this influenced by debris abundance and distribution?

2. Are there age differences in susceptibility to entanglement and if so how can we measure them?

3. How relatively susceptible are seals *to* entanglement in large versus small debris?

This modeling exercise has demonstrated that, within the degree of uncertainty that we can answer the above three questions, entanglement is a plausible explanation for the decline in Pribilof Island fur seal populations since the late 1960's. The model's representation of male abundance has raised some questions about using the idle and harem bull counts as an index of total adult male abundance. At the very least, large fluctuations in male harvest are not reflected by subsequent appropriately large changes in bull counts. At the most, a variable, potentially large fraction of the mature males either may not be resident on the Pribilof Islands during the summer or may be resident for only part of the summer. Finally, the modeling has defined the research questions that can help reduce uncertainty about the possible past and future effects of entanglement on seal populations. The first question, about entanglement susceptibility, requires increased (and preferably simultaneous) observation of entangled seals and debris at sea and the development of a debris encounter probability estimate and an estimate of the probability of a seal's being entangled given that it has encountered debris (Ribic and Swartzman 1990). The second question requires taking a closer look at the age-sex distribution of entangled seals on land and perhaps conducting tank experiments on a larger scale than previously done. The third question requires observation of entangled animals at sea and development of statistical methods for estimation based on very infrequent encounters. Research around both the first and third questions may benefit from additional models designed to test various assumptions made in doing the estimates. For example, a Monte Carlo seal-debris encounter model, coupled with further transect observations might help clarify what the probability of entanglement is, given an encounter at sea.

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HISTOLOGICAL OBSERVATION OF DAMAGE TO DERMAL TISSUE OF FUR SEAL CAUSED BY NET ENTANGLEMENT

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ABSTRACT

In 1984 and 1985, experimental studies on the damage to northern fur seals by net entanglement were carried out in Izu-Mito Sea Paradise, an aquarium where fur seals are kept for the National Research Institute of Far Seas Fisheries, Fisheries Agency, the Government of Japan (formerly the Far Seas Fisheries Research Laboratory, Fisheries Agency of Japan).

Two adult female fur seals, captured off Sanriku, northern Japan, in March 1980, were experimentally entangled in fishing net fragments in late January 1984. One seal, No. 1-7, 123 cm in body length and 39.5 kg in body weight, and an estimated 10 years of age, was entangled around the neck with a net fragment weighing 200 g. The second seal, No. 1-8, 113 cm in body length and 36.0 kg in body weight, with an estimated age of 10 years, was entangled with net fragments 300 g in weight. Both seals were kept in the same environment.

Seal No. 1-8 died in September 1984 after 226 days of entanglement, having suffered traumatic damage to pelage and skin. Net fragments were removed from No. 1-7 in March 1985. Damage to skin and pelage was not observed even after 14 months on entanglement, although the state of entanglement was similar to No. 1-8. She died in February 1986. Abnormality was not observed in the skin at the time of death. Cause of death was acute pneumonia in both cases. When they were alive, No. 1-7 was in good health and No. 1-8 was slightly unwell.

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

INTRODUCTION

Fur seal are known to have died from entanglement in fishing net fragments and packing bands (Scordino 1985). It was pointed out that net entanglement may constitute one of the major factors for the decrease in the Pribilof Islands populations of the northern fur seal, *Callorhinus ursinus*. In order to understand the actual state and effects of entanglement, the National Research Institute of Far Seas Fisheries, Fisheries Agency, the Government of Japan (formerly the Far Seas Fisheries Research Laboratory, Fisheries Agency of Japan) conducted field surveys of fur seals and marine debris on breeding islands and at sea. Also, experimental studies were carried out concerning the process of entangling and the effects of entanglement on the behavior of fur seals, both of which were difficult to observe in a natural environment. Little has yet been reported about traumatic wounds to the skin of fur seals caused by net entanglement. In this study, macroscopic observation was conducted on damage inflicted by net entanglement to the pelage and skin of fur seals kept in captivity. Post-mortem histological examination was also made of the lesions of the dermal tissues.

MATERIALS AND METHODS

The experiment was conducted for about 14 months from 10 January 1984 to 31 March 1985 in a breeding facility of the Izu-Mito Sea Paradise, an aquarium in Numazu, central Japan. Two female northern fur seals, with identification numbers 1-7 and 1-8 and an estimated age of 10 years, were used. These individuals were entangled with net fragments during an experiment on the mechanism of entanglement. Seal No. 1-7 was entangled in trawl net fragments of 200 g on 20 January 1984, and No. 1-8 was entangled in a trawl net fragment weighing 100 g on 28 January 1984 and in another fragment of 200 g on 29 January 1984. Nets were removed from No. 1-7 at the end of the experiment on 31 March 1985. Behavior of the two seals and damage to pelage were observed every day in the morning and evening. The net fragments used in the experiment were commercial trawl nets made of polyethylene, with a twine size of 3.4 mm and a mesh size of 24 cm. The nets were cut into 100- and 200-g pieces.

The two individuals were kept in an open breeding facility (Fig. 1) from 10 January to 10 March 1984; afterward they were brought to an indoor breeding pool 1.6 m wide, 2.4 m long, and 1.0 m deep. No landing place was provided in the pool, in order to prevent resting on land except for the breeding season, in imitation of pelagic life. The experimental animals were fed with defrosted mackerel each day at 1000 and 1630. Average daily food consumption of No. 1-7 was 3.8 kg/day (O-5.5 kg/day) and that of No. 1-8 was 2.8 kg\day (0.4-4.0 kg/day). Body weight of No. 1-7 remained almost constant during the entire experiment period, while that of No. 1-8 declined near the time of death.

Necropsy was conducted immediately after the death of the entangled animals for macroscopic and histological inspection of the skin lesions. Histological samples of dermal tissue were fixed with 20% formaldehyde, embedded in paraffin, and cut into sections 4 microns thick with a sliding

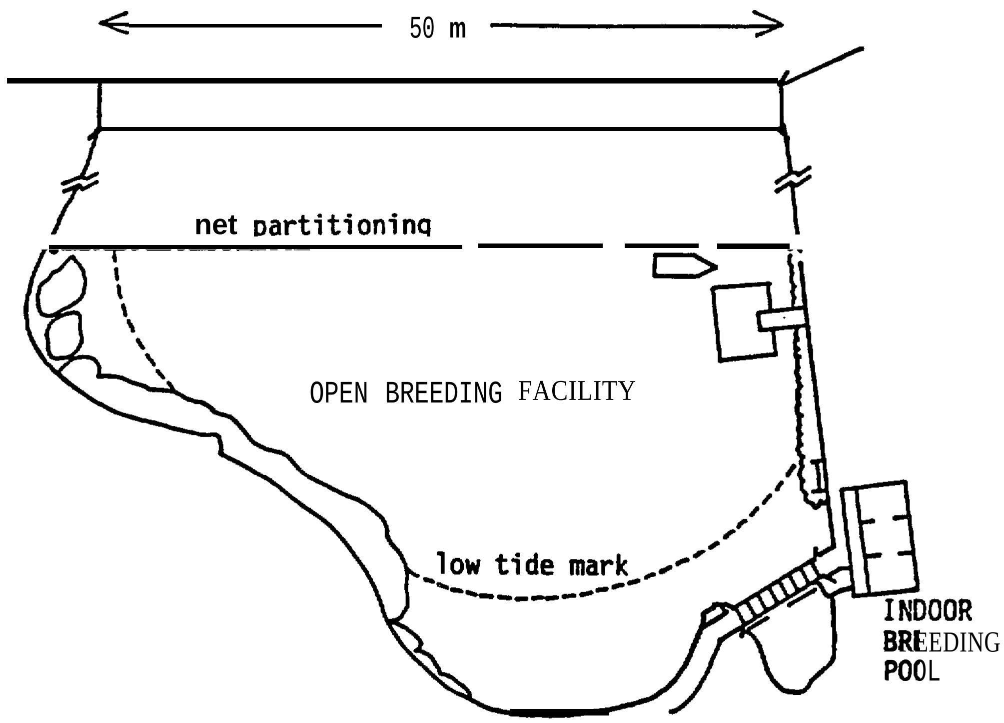

Figure 1. --The breeding facilities at Izu-Mito Sea Paradise.

microtome. The sections were dyed using hematoxylin eosin staining or Masson's method.

Atmospheric temperature during the period ranged from -5° to 30.1°C, water temperature ranged from 12.0° to 28.3°C, and relative humidity ranged from 33 to 92%. Details of the fur seals used in the experiment are given in Table 1.

RESULTS

Behavior of No. 1-7 and Description of Net Entanglement

This individual was in quite good health. On 20 January 1984, she was entangled around the neck by-a bundle of net made into a collar. There was a space between the net collar and the neck into which one finger could be inserted. No damage to the entangled part was observed even after 14 months. Net fragments were removed at the end of the experiment on 31 March 1984. The individual remained in good health with a good appetite, finally dying on 25 February 1986, 11 months after the removal of the nets. Port-mortem examination revealed small whitish nodules about 5 mm in size scattered throughout the lungs. No pus was found in the nodules. The cause of death was diagnosed as acute pneumonia. The cervical region where the net had been entangled was also inspected, but no anomaly was recognized.

Table 1.--Details of the two female northern fur seals used in this study.

Chronology of the experiment	Seal No. 1-7	Seal No. 1-8
Capture		
Date	4 March 1980	7 March 1980
Location	Lat. 36°40'N long. 141°27'E	Lat. 36°30'N long. 141°15'E
Transport to aquarium		
Date	8 March 1980	8 March 1980
Body weight (kg)	29.0	30.5
Beginning of experiment		
Date	10 January 1984	10 January 1984
Estimated age	10	10
Body length (cm)	123	113
Body weight (kg)	39.5	36.0
Net entanglement		
Starting date	20 January 1984	28 January 1984
Weight of nets (g)	200	100
		29 January 1984
		200
Date of removal	31 March 1985*	10 September 1984[b]
Death		
Date	25 February 1986	10 September 1984
Body length (cm)	120.5	114.5
Body weight (kg)	34.5	30.5
Cause of death	Acute pneumonia	Acute pneumonia

[a]Experiment ended.
[b]Seal died.

Behavior of No. 1-8 and Description of Net Entanglement

Judging from daily behavior and feeding activities, this individual was considered in somewhat poor health even before it was entangled in nets. Two net fragments were placed around its neck on 28 and 29 January 1984.

The entangled nets made up a collar consisting of 17 meshes in a bundle (Figs. 2 and 3). The collar was 14 cm in inner diameters, 44 cm in inner circumference, 100 cm in outer circumference, and 7 to 9 cm thick. No remarkable change in behavior was observed after net entanglement. On the morning of 6 June 1984, she delivered a female pup, 65 cm long and 4.2 kg in weight, but the pup was dead when it was discovered. Anatomical inspection revealed the cause of the pup's death to be drowning. Seal No.

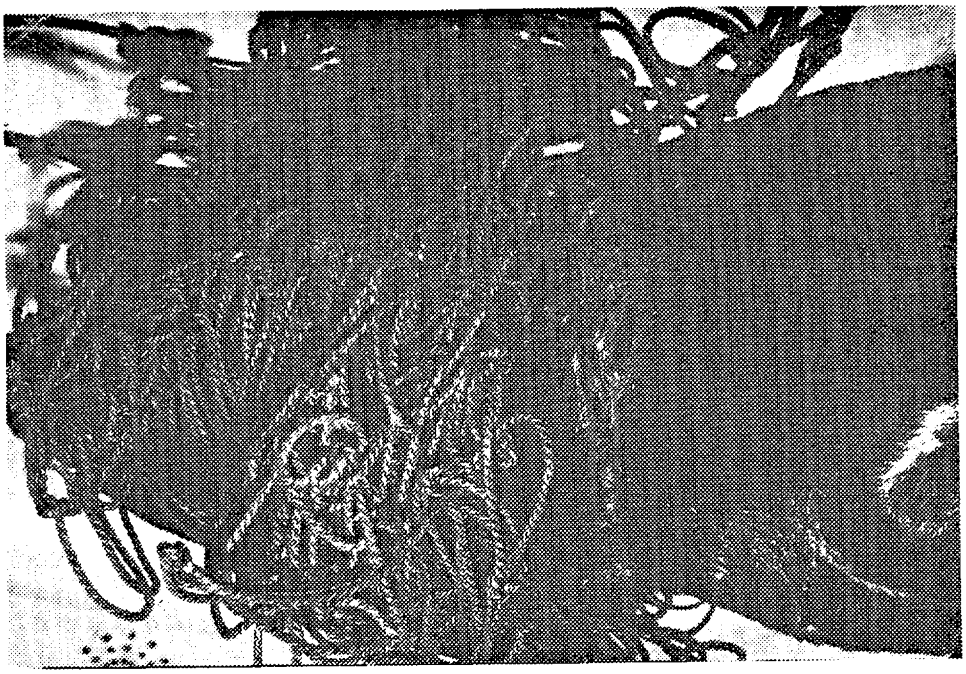

Figure 2. --State of entanglement of fur seal No. 1-8.

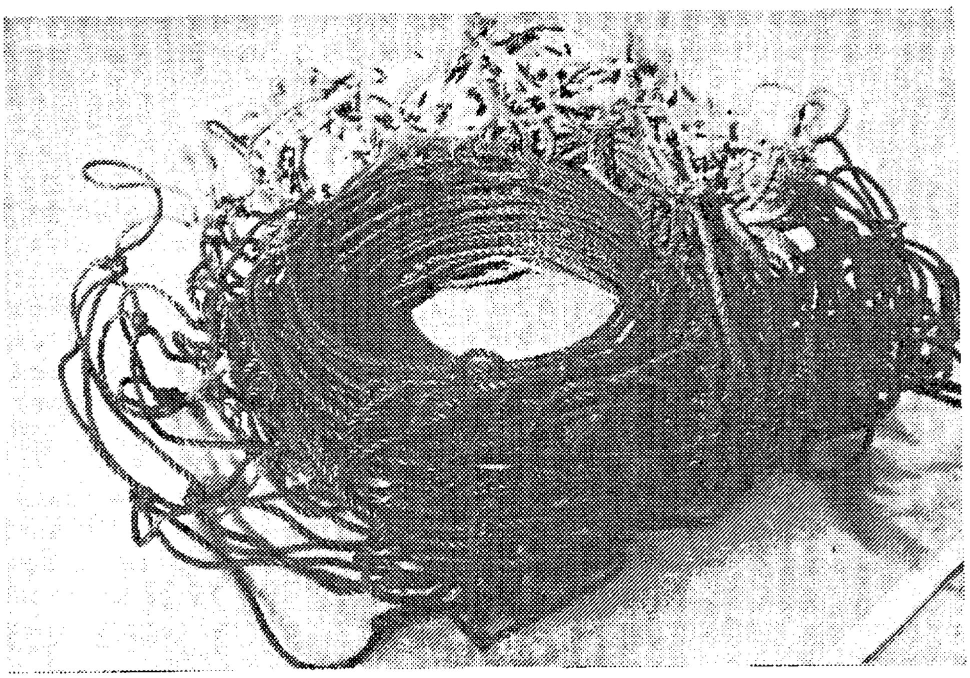

Figure 3. --Collar of entangled net on fur seal No. 1-8.

1-8 ate poorly from 4 September 1984 and died on 10 September, 226 days (7.5 months) after the initiation of net entanglement. Macroscopic and histological observations of the entangled part are described below.

Diagnosis of the Lesions on No. 1-8

The nutritive condition of the body as a whole was moderate. No external scars were observed except around the neck. In macroscopic observation, hair was worn or lost all around the neck, and the epidermis was exposed in some parts. Several wounds due to abrasion by the attached nets were conspicuous: one large scar 1-3 cm wide and 5 cm long on the right side of the neck and two other wounds of 1-2 cm at the scruff. Cross sections of the lesions revealed hardened hyperdermis and a thin muscle layer. The thick adipose tissue consisted of yellow and white parts (Figs. 4 and 5).

In the histological examination, sections of the injured dermal tissue showed degeneration and loss of hair follicles and hair matrices, and degeneration of the hair itself. Connective tissues were partially worn out and necrotized. Proliferation of collagen fiber was observed in the peripheral connective tissues. In these parts, degenerated inner membranes, supposedly derived from venous sinus, were also observed. Rupture and degeneration of muscle layers were distinctive and a part of the connective tissues had been replaced. Congestion and edema of venous ducts were conspicuous and their inner membrane revealed degeneration. However, cell infiltration and inflammatory reactions were undistinctive (Figs. 6 and 7).

As for visceral organs, hyperemia was observed in the lungs and accumulation of blood was conspicuous in the heart. Other visceral organs showed no remarkable change. The cause of death was presumed to be acute pneumonia.

DISCUSSION

No injury occurred around the neck of No. 1-7, entangled in 200 g of fishing nets for 14 months. Seal No. 1-8, entangled at the neck in 300 g of nets for 7.5 months, suffered abrasion of hair and skin. These differences seemed to have been caused by such factors as physical condition, and the amount and tightness of the entangled nets. After anatomical inspection, the cause of death for both individuals was diagnosed as acute pneumonia. As a future task, it will be necessary to examine bacterial infections from the wounds caused by entanglement.

As fur seals used in this experiment were adult, no increase in body weight was observed during the experiment period of 7.5 to 14 months. But it can be assumed that when a young, growing animal becomes entangled in fishing nets, even if the net fragment is small and loose at first, it will gradually become tighter as the animal grows, causing serious damage and possibly death.

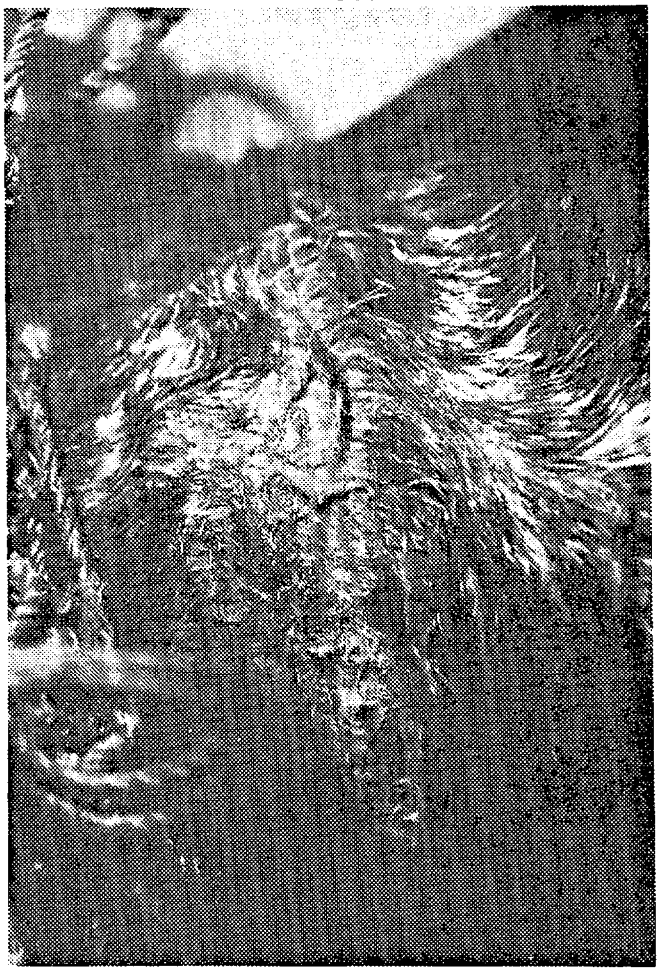

Figure 4. --Abraded wound in the pelage and skin of No. 1-8.

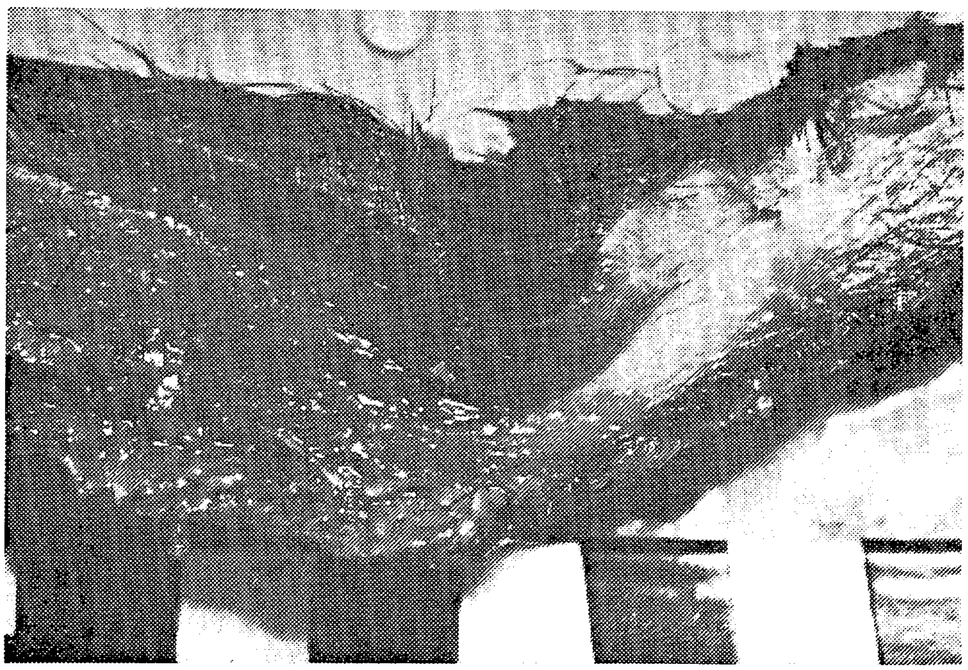

Figure 5. --Cross section of dermal tissues through the lesion on the neck of No. 1-8.

Figure 6.--Section through a lesion in the cervical region of No. 1-8 (hematoxylin eosin staining x 40).

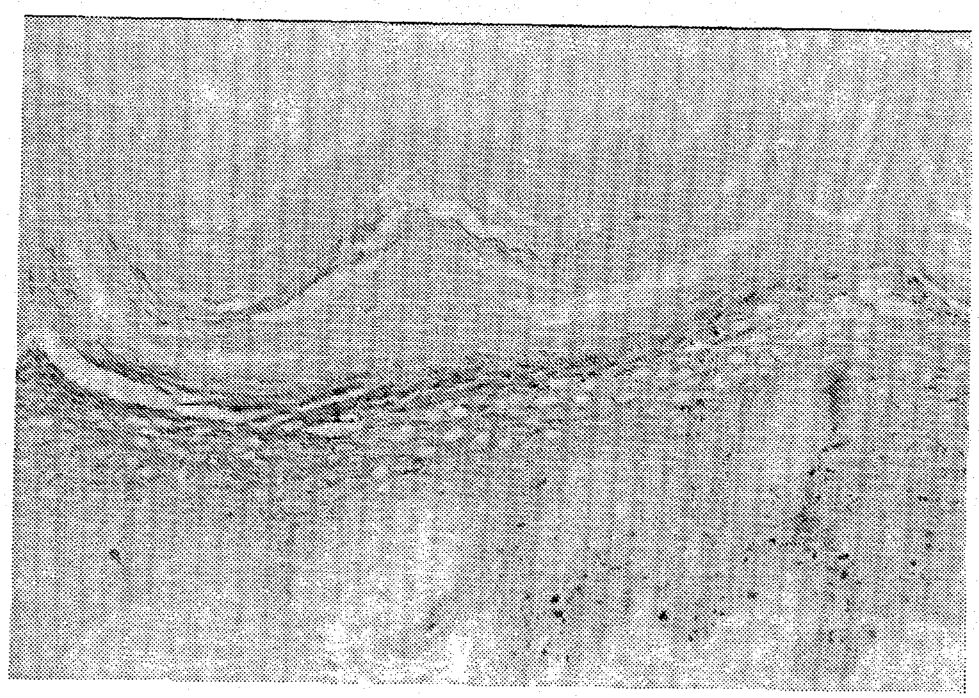

Figure 7.--Section through a lesion in the cervical region of No. 1-8 (Masson's staining x 100).

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RECENT ENTANGLEMENTS OF HAWAIIAN MONK SEALS IN MARINE DEBRIS

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ABSTRACT

During field studies on the Hawaiian monk seal, *Monachus schauinslandi*, in 1985-88, 34 incidents of entanglement in marine debris were observed, including 4 known deaths, injuries to 4 seals, and recent neck scars on 2 seals. The overall entanglement rate increased eightfold, from 0.06 incidents per 100 camp days per 100 seals in 1985 to 0.48 incidents per 100 camp days per 100 seals in 1988. This increase was probably caused by increased amounts of marine debris on and around the islands where seals haul out. Weaned pups were entangled at a higher rate than their proportion in the population, while adults were entangled at a lower rate. Entanglement rates since 1981, when corrected for each island's population size, were highest at Lisianski Island: 4.44 incidents per 100 camp days per 100 seals. Lowest rates were at French Frigate Shoals: 0.37 incidents per 100 camp days per 100 seals.

INTRODUCTION

In the past 25 years, durable and resilient plastic materials have replaced natural fibers in the maritime industry. Polypropylene and nylon nets have replaced antiquated and once prevalent tarred cotton webbing, and various plastic lines are now used in place of manila or other natural hemp fiber (Pruter 1987). This use of persistent plastics has been accompanied by an increase in the impact of lost or discarded materials on wildlife in the marine environment.

Pinnipeds in particular are susceptible to entanglement in marine debris . Entanglements of the northern fur seal, *Callorhinus ursinus*, are well documented (Fowler 1982; Scordino and Fisher 1983; Scordino 1985) and appear to have contributed to a population decline in this species during 1976-81 (Fowler 1985, 1987). Although other pinnipeds may be entangled less often, the list of species known to have become entangled is large: Fowler (1988) recently stated that 16 of the 34 extant pinniped species (47%) are known to have become entangled in marine debris.

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

Entanglements of the Hawaiian monk seal, *Monachus schauinslandi*, in marine debris have been observed since 1974 (Balazs 1979; Andre and Ittner 1980; Alcorn 1984; Henderson 1984, 1985). Pups are particularly susceptible (Henderson 1985). Henderson (1985) documented 35 incidents of Hawaiian monk seals entangled in debris through 1984, noting that the number of observed incidents declined following the inception of a program to periodically remove hazardous debris from haul-out beaches at all Northwestern Hawaiian Islands (NWHI). Entanglements have nonetheless continued since 1984 (Alcorn et al. 1988; Johanos and Austin 1988; Johanos and Withrow 1988; Reddy and Griffith 1988; Westlake and Siepmann 1988; Henderson and Finnegan 1990). This report summarizes all of the published and unpublished reports of Hawaiian monk seal entanglements in 1985-88, thereby updating Henderson (1985). This report also examines all entanglements since 1982 for trends in number and location of occurrences, and sizes of affected animals.

METHODS

Staff biologists of the Marine Mammals and Endangered Species Program (MMESP) of the Southwest Fisheries Science Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, conducted field operations from 1982 to 1988 in the NWHI to monitor the Hawaiian monk seal population. Since 1982, most Hawaiian Islands west of Necker Island (i.e., French Frigate Shoals, Laysan Island, Lisianski Island, Pearl and Hermes Reef, Midway, and Kure Atoll) have been visited and included as study sites. The number of field camp days has varied among the six locations, as has the annual total.

During these studies, all occurrences of entangled or entanglement-scarred seals were recorded. A seal was considered entangled if any part of its body was encircled by debris. Seals resting or asleep on netting or lines were not considered entangled unless their head or body was inside a loop and field personnel thought the animal would not be able to free itself. Seals with entanglement scars, which are distinguishable from scars resulting from other injuries (Henderson 1985) , were documented on scar cards and tallied only in the year in which they were first documented to have acquired the scar. Seals with scars were assumed to have become entangled at the island where first observed.

Data on the number of entangled seals per year and per location were converted to number of occurrences per 100 camp days to account for any variation in the length of the field seasons, and incidents recorded while MMESP personnel were absent from an island have been excluded from most analyses. Two such incidents [documented by the U.S. Fish and Wildlife Service (FWS) and the U.S. Coast Guard] occurred in 1985-88 and have been included only in the overall listing and in data on the size of seals that become entangled.

Data prior to 1985 are from Henderson (1985) except for two entanglements in 1984 at Pearl and Hermes Reef. These were inadvertently omitted by Henderson (1985), and are included here:

Seal	Body part	Type of material	Fate of seal	Comments
Juvenile male	Neck	Plastic ring	Unknown	North Is.
Weaned female	Neck, foreflipper	Net	Unknown	North Is.

The relative number of incidents may be affected by the population size of seals, with more entanglements likely among larger populations. Each island's population is relatively discrete and may differ in size from another island's (Johnson et al. 1982). Furthermore, the total population, as indexed by beach counts of nonpups, increased by approximately 24% in 1983-87 (Gilmartin 1988). In the analysis among islands, the number of incidents at any one location was therefore divided by that island's mean 1983-88 beach count of pups and nonpups. To obtain annual entanglement rates, the entanglement total for each year was divided by the summed mean annual beach counts of pups and nonpups at all islands. Data on mean beach counts are incomplete for 1982; therefore, incidents occurring in 1982 were divided by data from 1983. No total beach counts were collected at Lisianski Island in 1988; hence, the 1988 total beach count includes the 1987 total for Lisianski Island.

Because pups have historically been more susceptible to entanglement (Henderson 1985), a separate analysis divided total incidents per year for 1982-88 by the number of pups known to have been born.

RESULTS

Number of Entanglements, 1985-88

Thirty-four entanglements of Hawaiian monk seals occurred from 1985 to 1988 (Table 1). The total included four known deaths, injuries to four animals, and recent neck scars on two seals. The remaining 24 animals were uninjured and were either released from the debris (20) or escaped unassisted (4). Many of the released seals were loosely entangled; it is unknown whether they might have escaped unassisted. Totals by size classes of the affected seals were 12 pups (nursing or weaned), 7 juveniles, 9 subadults , and 6 adults. When data prior to 1985 were included, the number of documented entanglements of Hawaiian monk seals totaled 71.

Entanglements per 100 camp days per 100 seals decreased to a low of 0.06 in 1985 and rose thereafter to a high of 0.48 in 1988, an eightfold increase (Fig. 1). This trend was also evident if incidents were adjusted by the number of pups born annually, with incidents per 100 camp days per 100 pups being 0.23 in 1985 and 1.34 in 1988 (Fig. 2).

Entanglements by Location, 1982-88

The seal population at Lisianski Island experienced the highest rate of entanglement, at 4.44 incidents per 100 camp days per 100 seals since 1982 (Fig. 3). Kure Atoll was next highest (2.23), followed by Pearl and

Table l. --Summary of entangled and entanglement-scarred Hawaiian monk seals observed in 1985-88.

Year	Location	Size/sex[a]	Incident[b]	Type of material	Fate of seal	Reference[c]	Comments
1985	Kure Atoll	W/M	E, body	Monofilament line	Rescued	Reddy and Griffith 1988	--
		W/F	E, mouth, body	Fish hook and monofilament line	Rescued	Reddy and Griffith 1988	Slight injury from hook.
	French Frigate Shoals (FFS)	J/M	E, neck	Net	Rescued	L. Martin, FWS, pers. commun.	Would have escaped; mesh broke when pulled, Tern Island.
1986	Lisianski Island (LI)	W/F	E, neck	Net and line	Rescued	Westlake and Siepmann 1988	Slight injury.
		S/M	E, muzzle	Line	Rescued	Westlake and Siepmann 1988	Could have escaped.
	Laysan Island	S/M	E, neck,	Line	Rescued	NMFS unpubl. data	--
	FFS	W/M	E, abdomen	Wire	Found dead	Henderson, observation	Wire probably relic of USCG occupation, East Island.
1987	LI	P or W	E, neck	Net	Found dead	Johanos and Withrow 1988	Uncertain if nursing or weaned pup.
		A/F	S, neck	N/A	Alive in 1988	Johanos and Withrow 1988	Seen without scar in 1986.
		W/F	S, neck	N/A	Alive in 1988	Johanos and Withrow 1988	Acquired scar early in 1987.

Table I.--Continued.

Year	Location	Size/sex[a]	Incident[b]	Type of material	Fate of seal	Reference[c]	Comments
1987	Laysan Island	J/?	E, body	Net	Rescued	NMFS unpubl. data	Net loose.
		S/F	E, neck	Line	Escaped	NMFS unpubl. data	Molting seal, line not tight.
		A/F	E, neck	Line and floats	Escaped	NMFS unpubl. data	--
		J/M	E, neck, shoulders	Line	Rescued	NMFS unpubl. data	Line loose.
		A/F	E, neck	Line	Escaped	NMFS unpubl. data	--
	FFS	J/F	E, neck, abdomen	Net and line	Found dead	Henderson, observation	Shark Island.
		S/M	E, abdomen	Line	Rescued	M. Craig, S1, pers. commun.	Line loose, East Island.
		S/F	E, shoulders	Line	Rescued	M. Craig, S1, pers. commun.	East Island.
		S/?	E, neck	Plastic band	No rescue	NMFS unpubl. data	Band cutting into flesh, Whale-Skate Island.
1988	Kure Atoll	A/F	E, neck	Line	Rescued	Henderson and Finegan 1990	Line not tight.
		P/F	E, neck, shoulders	Net and line	Rescued	Henderson and Finegan 1990	On offshore reef, nursing pup, probably would have died.

Table I.--Continued.

Year	Location	Size/sex[a]	Incident[b]	Type of material	Fate of seal	Reference[c]	Comments
1988	Kure Atoll	W/F	E, neck	Net	Rescued	Henderson and Finnegan 1990	--
		W/F	E, neck	Net	Rescued	Henderson and Finnegan 1990	--
		W/F	E, neck	Net	Rescued	Henderson and Finnegan 1990	On offshore reef, probably would have died, rescued by USCG.
	LI	W/F	E, muzzle	Plastic cup	Rescued	NMFS unpubl. data	--
		w/?	E, body	Net	Found dead	NMFS unpubl. data	Entire body wrapped in large net, decomposed.
	Laysan Island	J\M	E, neck	Plastic ring	Rescued	NMFS unpubl. data	Tight but no injury, probably would have been choked.
		S/F	E, neck	Net	Rescued	NMFS unpubl. data	Cutting deeply into flesh.
		S/M	E, body	Net	Rescued	NMFS unpubl. data	Net loose, seal probably would have escaped.
		s/?	E, abdomen	Line	Rescued	NMFS unpubl. data	--
		A/F	E, muzzle	Net	Rescued	NMFS unpubl. data	Net loose.

Table 1.--Continued.

Year	Location	Size/sex[a]	Incident[b]	Type of material	Fate of seal	Reference[c]	Comments
1983	Laysan Island	A/F	E, abdomen	Net	Rescued	NMFS unpubl. data	Same net as previous incident.
		J/F	E, neck	Net	Rescued	L. Hiruki, UA, pers. commun.	-
	FFS	J/F	E, neck	Plastic screen	Rescued	R. Withrow, WA, pers. commun.	Shark Island.

[a]P = nursing pup, W = weaned pup, J = juvenile, S = subadult, A = adult, M = male, F = female, and ? = sex unknown.

[b]E = entangled; S = scarred.

[c]SI = Smithsonian Institution, FWS = U.S Fish and Wildlife Service, USCG = U.S Coast Guard, UA = University of Alberta, and WA = Waikiki Aquarium.

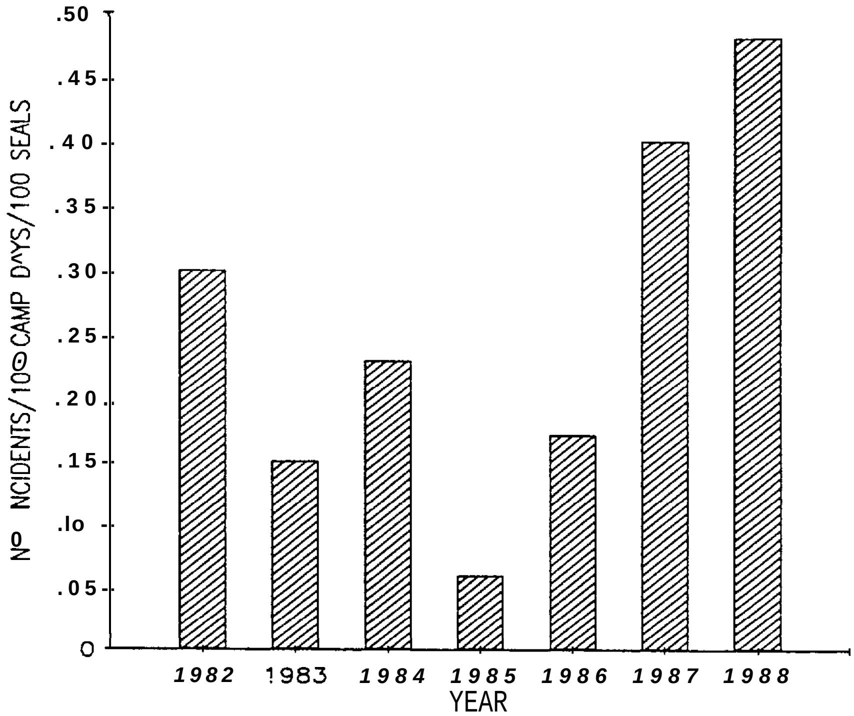

Figure 1. --Annual rates (1982-88) of Hawaiian monk seal entanglement, adjusted for camp days and average beach count (pups and nonpups).

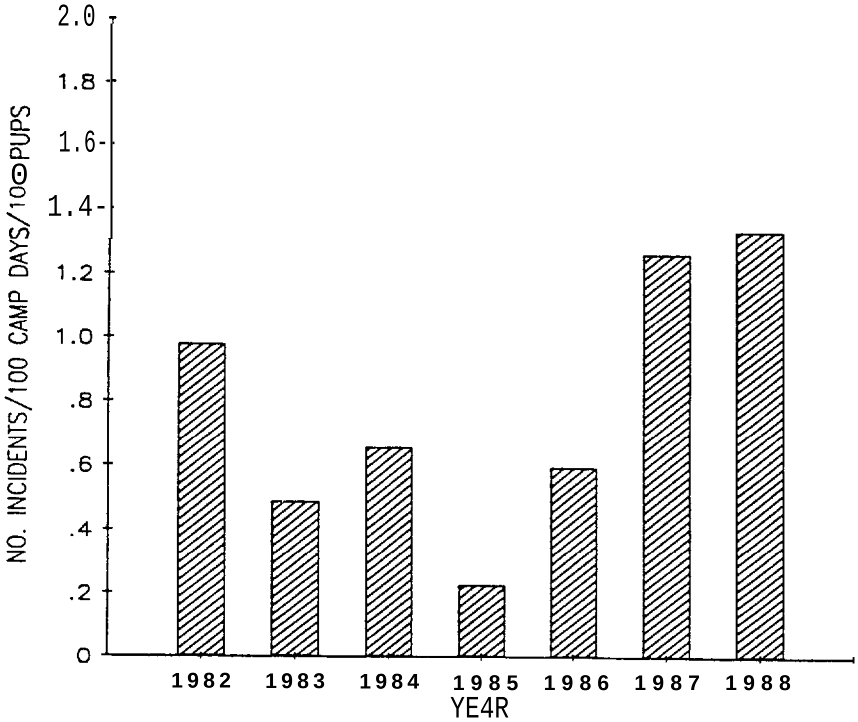

Figure 2. --Annual rates (1982-88) of Hawaiian monk seal entanglement, adjusted for camp days and total pup production.

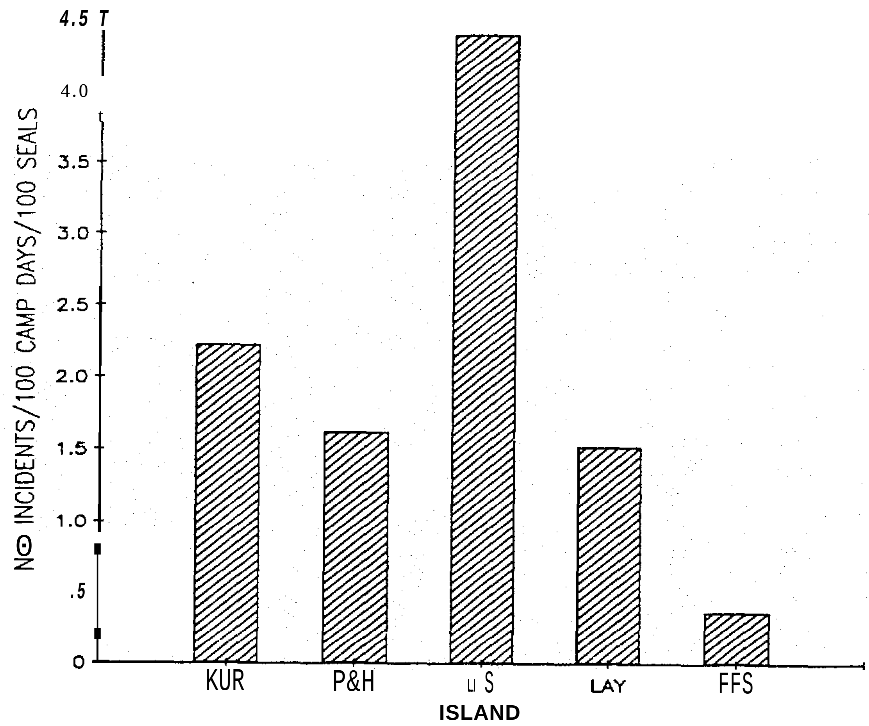

Figure 3.--Location of Hawaiian monk seal entanglement, 1982-88 (Kur = Kure Atoll; P&H = Pearl and Hermes Reef; Lis = Lisianski Island; Lay - Laysan Island; FFS = French Frigate Shoals).

Hermes Reef (1.62), Laysan Island (1.52), and French Frigate Shoals (0.37). One scarred seal has been observed at Midway (Henderson 1985), but MMESP presence there is minimal, beach counts are few, and the seal population is very small (probably 10-20 animals).

Size of Entangled Seals, 1982-88

Pups are most susceptible to entanglement and adults are least susceptible when percent of entanglements is considered in relation to percent of population (Fig. 4). Pups (weaned and nursing) comprise 11.0% of the population (Gerrodette 1985) and yet account for 42.1% of all entanglements from 1982 to 1988. Adults comprise 48.9% of the population and 15.8% of all entanglements. Entanglement rates for juveniles (17.5%) and subadults (24.6%) approximate their population percentages (17.7 and 22.4%, respectively).

Although pups are more susceptible to entanglement, those locations with the most births did not have the most entanglements. Nearly one-third (32.1%) of 1982-88 entanglements occurred at Lisianski Island, whereas only 10.8% of all pups were born there. Conversely, over half (58.8%) of all pups were born at French Frigate Shoals, where 25.0% of the entanglements were documented.

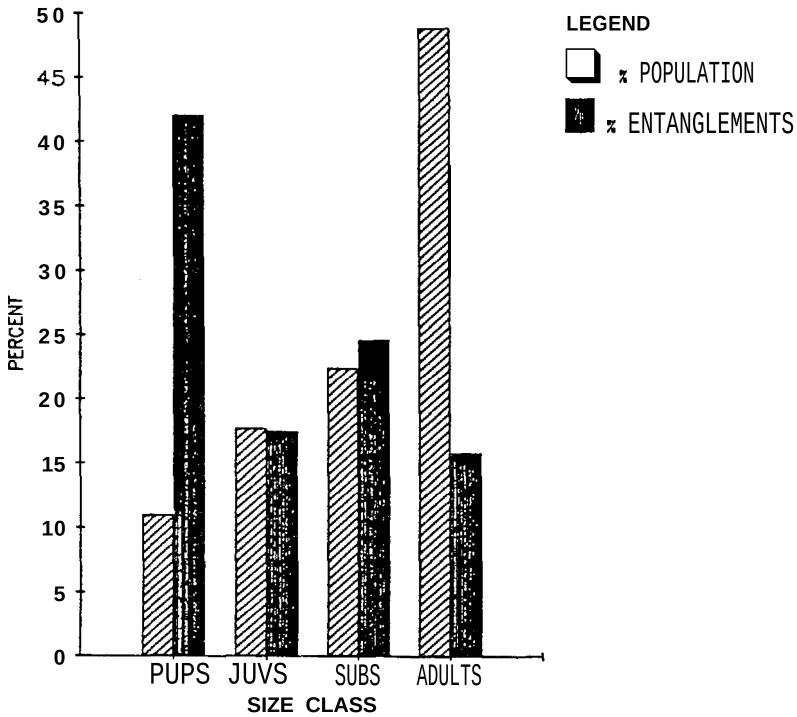

Figure 4.--Size classes of Hawaiian monk seals as percentage of population and percentage of entanglements, 1982-88.

DISCUSSION

The increased incidence of entanglement may result from an increased encounter rate between seals and debris. Such a higher rate could be due to a number of causes: (1) an increase in the seal population, (2) an increase in the relative number of seals in the size class or classes most likely to become entangled, (3) an increased propensity for seals to investigate debris, and (4) an increase in the amount of debris on the islands. Entanglements in 1985-88 have increased more rapidly than any increase in seal population, including the number of pups. In 1985-87, mean beach counts of seals rose approximately 9%, and the number of births also increased by 22% (Gilmartin 1988). However, these increases do not account for the sharp rise in entanglements, which is evident even when adjusted for these factors. No data exist to evaluate whether any recent behavioral changes have occurred among the population to account for increased entanglement.

The amount of debris on beaches in the NWHI has increased in recent years. The number of nets in 1987 alone increased nearly 200% over the 1985-86 average (Henderson unpubl. data). This increase probably has contributed significantly to the rise in seal entanglements. Field biologists routinely remove hazardous debris from the NWHI, an effort credited with reducing seal entanglements (Henderson 1985), yet despite this effort, entanglements have increased. With larger amounts of debris present, more entanglements may occur (1) during the long periods when personnel are absent from these remote islands, (2) while biologists are present but before the beaches have been cleared, or (3) while seals are at sea.

The higher incidence of entanglement at Lisianski Island may be attributable to spatial coincidence of favorable pupping habitat with areas receiving most of the debris. Pups are born predominately on the island's east side (Johanos and Henderson 1986; Johanos and Kam 1986), which also receives more debris because debris is moved toward the island by trade winds from the northeast (Henderson et al. 1987) .

Pups continue to become entangled at a proportionally higher rate than other size classes, a phenomenon that may have several contributing causes (Henderson 1985): (1) entangled pups are most easily observed because they remain near shore for 1-2 months after weaning; (2) pups, unlike older seals, spend proportionally more time in the vicinity of nearshore reefs, which catch and "concentrate" floating debris; (3) weaned pups are not as strong as older seals and are therefore least able to escape from debris; and (4) recently weaned pups are learning to feed and are more likely than nonpups to explore all objects in their novel environment. Bengston et al. (1988) demonstrated experimentally that recently weaned northern fur seal pups readily explore and become entangled in net fragments, and suggested that this behavior could lead to high mortality among fur seals just after weaning.

The periodic presence of biologists in the remote habitat of the Hawaiian monk seal can reduce deaths of seals from entanglement. Of the four mortalities documented here, two could likely have been prevented had personnel been present on the island. Both of these mortalities were at Lisianski Island, a location with sparse coverage by biologists in recent years .

ACKNOWLEDGMENTS

Data were collected under authority of several special use permits and Marine Mammal and Endangered Species permits issued by the FWS and the Protected Resources Division of the National Marine Fisheries Service. I am grateful to FWS staff at the Tern Island station of the Hawaiian Islands National Wildlife Refuge for their logistical support and to the officers and crew of the NOAA ship Townsend *Cromwell* for transporting field personnel. Special thanks are extended to my colleagues in the field--D. Alcorn, S. Austin, B. Becker, M. Brown, B. Choy, M. Craig, R. Forsyth, L. Hiruki, T. Johanos, and R. Morrow- -who observed many of the incidents reported here.

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PINNIPED ENTANGLEMENT IN SYNTHETIC MATERIALS IN THE SOUTHERN CALIFORNIA BIGHT

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ABSTRACT

The California sea lion, *Zalophus californianus*, the northern fur seal, *Callorhinus ursinus*, the harbor seal, *Phoca vitulina richardsi,* and the northern elephant seal, *Mirounga angustiros tris,* that haul out or breed on the southern California Channel Islands, become entangled in synthetic debris at various rates. The percentages of California sea lions entangled, primarily in monofilament gillnet fragments, varied from about 0.08% in 1983 to about 0.16% from 1985 through 1988, while those of northern elephant seals, primarily in packing straps, declined from about 0.15% in 1983 to about 0.10% in 1989. The entanglement rate of harbor seals has varied from 0.0% in 1983-84 to 0.06% in 1986. Entangled northern fur seals have rarely been observed.

Inter- and intraspecific differences in entanglement rates are likely the result of age, sex, and species differences in animal size, diving behavior, and foraging areas. Although entanglement in synthetic materials contributes to mortality of some animals, our studies suggest prevailing entanglement rates have not significantly influenced pinniped demography and population trends in the Southern California Bight.

INTRODUCTION AND METHODS

Pollution of marine environments with nonbiodegradable plastic debris has become an issue of increasing concern during the past several years, especially with regard to entanglement of marine mammals and seabirds in synthetic debris (e.g., see Shomura and Yoshida 1985; Wolfe 1987).

Since 1978 we have studied the incidence of entanglement of pinnipeds in synthetic materials at San Nicolas and San Miguel Islands. We have attempted to distinguish between entanglement in floating marine debris and that resulting from direct interactions of seals and sea lions with commercial fishing and sportfishing operations (Stewart and Yochem 1985, 1987).

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

Below we summarize the results of our surveys made between October 1986 and March 1989, and incorporate our previous surveys to assess trends in pinniped entanglement in the Southern California Bight since 1983.

We quantified rates of entanglement of the California sea lion, *Zalophus californianus*, the harbor seal, *Phoca vitulina richardsi*, the northern elephant seal, *Mirounga angustirostris*, and the northern fur seal, *Callorhinus ursinus*, using methods described earlier (Stewart and Yochem 1985, 1987). Briefly, we surveyed pinniped populations at San Nicolas Island once each month and those at San Miguel Island periodically whenever we visited there to conduct other research. Using binoculars or a spotting telescope, we systematically examined small groups of pinnipeds on rookeries and hauling grounds and recorded the number examined (by sex and relative age whenever possible), the number entangled (and the type of entangling material) , and the number scarred (presumably from prior entanglement); only those animals whose bodies could be seen clearly were sampled during those entanglement surveys.

RESULTS AND DISCUSSION

From March 1988 through February 1989, 30 (0.12%) of 24,731 California sea lions surveyed at San Nicolas and San Miguel Islands were entangled and another 25 (0.10%) were scarred from previous entanglement, slightly fewer than from October 1986 through February 1988 (Tables 1, 2). Slightly more northern elephant seals were entangled but slightly fewer scarred in 1988-89 than in 1986-88 (Tables 1, 3). Relatively few (0.03%) harbor seals were entangled in 1988-89 and none was scarred (Tables 1, 4), and we observed no scarred or entangled northern fur seals (Tables 1, 5). Neither of two Guadalupe fur seal bulls that we observed at San Nicolas Island in summer 1988 was entangled or scarred.

The percentage of California sea lions observed entangled increased from 1983 through 1987 but declined in 1988, while the percentages of entangled northern elephant seals and harbor seals have declined since 1984 (Table 1). The percentages of scarred sea lions and elephant seals observed have remained relatively constant since 1983 and 1984, respectively (Table 2). We have not observed a scarred harbor seal since 1984 nor a scarred northern fur seal since July 1987.

As in previous years (Stewart and Yochem 1985, 1987), the primary material entangling California sea lions in 1988-89 was monofilament gill-net (Table 6); no floats were attached to the entangling monofilament. Since monofilament is negatively buoyant and sinks without the support of flotation devices, we believe that sea lions that were entangled in monofilament became entangled in operational gillnets and were cut out of the nets, leaving some net remaining around the animals' necks. If sea lions (especially young animals) are capable of breaking out of gillnet panels by snapping mesh lines, then some animals may have been entangled in derelict nets (i.e., debris) which were still attached to floats as well as operational, nonderelict nets. Clearly, larger animals, particularly adult males, are capable of breaking free of gillnets once they become entangled (R. DeLong pers. commun.).

Table 1.--Entanglement and scarring rates of pinnipeds in southern California waters by synthetic materials.

Years surveyed	California sea lions	Northern elephant seals	Harbor seals	Northern fur seals
1983-84				
Surveyed	13,174	6,815	1,809	--
% entangled	0.08	0.15	0.00	--
% scarred	0.10	0.09	0.06	--
1985-86				
Surveyed	35,824	17,338	3,342	826
% entangled	0.16	0.16	0.06	0.00
% scarred	0.11	0.20	0.03	0.24
1986-88				
Surveyed	27,733	12,846	3,324	353
% entangled	0.16	0.09	0.03	0.00
% scarred	0.11	0.19	0.00	0.28
1988-89				
Surveyed	24,731	9,775	2,816	422
% entangled	0.12	0.10	0.03	0.00
% scarred	0.10	0.18	0.00	0.00

The observations that we present here, as well as our earlier ones (Stewart and Yochem 1985, 1987), indicate that sea lions become entangled primarily during the first 2 or 3 years of life. Our observations of scarred juveniles and adults indicate that some animals are freed from the entangling material, presumably monofilament, and survive. Others probably die as a result of entanglement either directly through blood loss or indirectly from infection and secondary complications. The magnitude of that mortality is difficult to assess, as many may die at sea, and an insignificant number of tagged sea lions are entangled, preventing an assessment of survival.

For the following discussions we limit the use of the term synthetic marine debris to material other than monofilament. Whether entangling monofilament is obtained during interactions with active fishing gear or from floating derelict nets or net fragments remains difficult to assess. Observations during commercial fishing operations or studies of captive sea lions might clarify whether or not these cases of entanglement are actually related to floating marine debris.

Nevertheless, the increase in numbers of sea lions observed entangled in monofilament in recent years is interesting, considering the restrictions placed in 1983 on the shark and swordfish drift gillnet fishery around the southern California Channel Islands, a fishery that accounted

Table 2.--Entanglement and scarring rates of California sea lions at San Nicolas and San Miguel Islands.

Years surveyed	Adult males	Subadult males	Females/ juveniles	Yearlings	Pups
1983-84					
Surveyed	345	803	7,206	771	4,049
% entangled	0.00	0.12	0.03	0.91	0.02
% scarred	0.58	0.75	0.07	0.00	0.00
1985-86					
Surveyed	1,577	2,272	30,548	1,427	--
% entangled	0.00	0.18	0.15	0.42	--
% scarred	0.44	0.48	0.07	0.00	--
1986-88					
Surveyed	1,384	987	17,619	2,872	4,871
% entangled	0.00	0.00	0.20	0.24	0.02
% scarred	0.14	0.40	0.14	0.00	0.00
1988-89					
Surveyed	710	833	18,670	1,347	3,171
% entangled	0.00	0.12	0.12	0.30	0.13
% scarred	0.70	0.84	0.07	0.00	0.00

for most of the sea lion entanglement and mortality in recent years. Perhaps sea lions became entangled in gillnets north of Point Conception, where the fishery has recently expanded.

In 1988 and early 1989, we were able to confirm that only about 7% of the entangled sea lions observed were entangled in synthetic debris (rubber bands, Table 6). We have no information yet about the survival of sea lions entangled in such debris, and we have not observed any dead sea lions entangled in anything except monofilament gillnet fragments.

All but one entangled northern elephant seal were entangled in synthetic debris (packing bands, Table 6). Elephant seals appear to become entangled during the first 1 or 2 years of life, probably because the circumferences of most packing band debris are too small for the bands to go over the heads of older seals. Scars around the necks of older seals indicate that some seals survive entanglement, although the type of material that entangled those seals is not known. None of the seals that we have observed entangled were tagged, preventing assessment of the influences of various kinds of debris on seals' survival. Five of the adult females that we observed with severely constricting packing bands around their necks gave birth and successfully weaned their pups in 1988.

Since 1983 we have observed only four entangled harbor seals (all juveniles, each with a packing band around its neck), suggesting that they

Table 3.--Entanglement and scarring rates of northern elephant seals at San Nicolas and San Miguel Islands.

Years surveyed	Adult males	Subadult males	Females/ juveniles	Yearlings
1983-84				
Surveyed	1,019	875	4,410	511
% entangled	0.00	0.34	0.07	0.19
% scarred	0.00	0.11	0.07	0.00
1985-86				
Surveyed	1,776	1,485	13,686	391
% entangled	0.00	0.34	0.18	1.02
% scarred	0.28	0.81	0.06	0.51
1986-88				
Surveyed	1,239	1,045	9,802	760
% entangled	0.00	0.00	0.12	0.00
% scarred	0.32	0.77	0.13	0.00
1988-89				
Surveyed	989	658	7,726	402
% entangled	0.00	0.45	0.08	0.25
% scarred	0.81	1.06	0.04	0.00

rarely encounter potentially entangling debris in southern California waters. As it has been speculated that large numbers of harbor seals are incidentally killed each year in gillnet fisheries in southern California, it is surprising that we have seen no harbor seals entangled in gillnets, especially in comparison to the number of California sea lions that are. If young California sea lions that become caught in gillnets are, in fact, capable of breaking out of gillnets, the lack of observations of harbor seals entangled in gillnet fragments may suggest that they are incapable of breaking free. We speculate that such differences may be due to the different modes of propulsion of these two species and consequent differences in potential force generated to permit them to break mesh strands. Harbor seals may then simply die in active or derelict gillnets rather than break free. Clearly, additional observations are needed to sort among these speculations.

Of all cases of pinniped entanglement observed, we can only confirm that 27% were due to marine debris in 1986-88 and 22% in 1988-89, with much of the remainder (perhaps as much as 73%) evidently related to interactions of pinnipeds (especially juvenile sea lions) with commercial gillnet fisheries (see Stewart and Yochem 1987 for additional discussion).

Because relatively few pinnipeds are observed entangled in synthetic material, analysis of trends in entanglement rates (especially debris-related) is difficult. It is clear, however, that relatively large samples

Table 4.--Entanglement and scarring rates of harbor seals at San Nicolas, San Miguel, and Santa Rosa Islands.

Years survyed	Adults	Immatures
1983-84		
Surveyed	1,445	364
% entangled	0.00	0.00
% scarred	0.07	0.00
1985-86		
Surveyed	2,757	585
% entangled	0.00	0.34
% scarred	0.00	0.17
1986-88		
Surveyed	2,021	1,303
% entangled	0.00	0.08
% scarred	0.00	0.00
1988-89		
Surveyed	1,900	916
% entangled	0.00	0.11
% scarred	0.00	0.00

Table 5.--Entanglement and scarring rates of northern fur seals at San Miguel Island.

Years surveyed	Adult males	Subadult males	Females/ juveniles
1985-86			
Surveyed	58	108	660
% entangled	0.00	0.00	0.00
% scarred	0.00	0.92	0.15
1986-88			
Surveyed	15	63	275
% entangled	0.00	0.00	0.00
% scarred	0.00	1.59	0.00
1988-89			
Surveyed	35	59	328
% entangled	0.00	0.00	0.00
% scarred	0.00	0.00	0.00

Table 6.--Types of synthetic material observed entangling pinnipeds at San Nicolas and San Miguel Islands, 1988-89.

Pinnipeds entangled	Monofilament gillnet	Packing bands	Other debris[a]	Total
California sea lions				
Adult females/juveniles	20	--	2	22
Yearlings	15	--	--	15
Pups	3	--	1	4
Total	38	--	3	41
Northern elephant seals				
Subadult males	--	2	1	3
Adult females	--	6	--	6
Juveniles	--	1	--	1
Yearlings	1	--	1	2
Total	1	9	2	12
Harbor seals				
Adults	--	1	--	1
Total	--	1	--	1

[a]Includes rubber bands, polyfilament rope and line, and items other than trawl or gillnet fragments or nylon monofilament line.

(i.e., systematic observations of large numbers of pinnipeds ashore) are necessary to evaluate properly the true rates of entanglement.

Populations of all pinnipeds have been increasing rapidly in the Southern California Bight during the past two decades (e.g., Stewart 1989; Stewart et al. 1990), indicating that entanglement of pinnipeds in marine debris has had only minor influence on population trends.

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MARINE MAMMAL AND SEA TURTLE ENCOUNTERS WITH MARINE DEBRIS IN THE NEW YORK BIGHT AND THE NORTHEAST ATLANTIC

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ABSTRACT

The incidence of ingestion of synthetics by, and entanglement of, marine mammals and sea turtles in the New York Bight (1979-88) and in Iceland (1985) was documented and related to the ecology of these animals. Post mortems of 88 cetaceans, 37 pinnipeds, and 116 sea turtles in the New York Bight revealed ingestion of synthetics in 24 animals. Differences were observed among the groups of animals. Synthetics were found in 3 mysticete whales, in 7 odontocete whales (3 delphinids, 3 physterids, and 1 phocoenid), and in 14 sea turtles (10 leatherbacks, *Dermochelys coriacea*, 3 loggerheads, *Caretta caretta*, and 1 green, *Chelonia mydas*). No synthetics were found in the gut of any pinnipeds or in Kemp's ridley turtles, *Lepidochelys kempi*. Seventy-five individuals were entangled, including 4 mysticetes, 13 odontocetes, and 58 sea turtles. In Iceland, 6 of 82 examined fin whales, *Balaenoptera physalus*, contained ingested synthetics, and 5 of 95 showed signs of previous entanglement. The types of synthetics ingested and the rate of occurrence of both ingestion and entanglement were related to the feeding behavior, timing, and distribution of the species. The results indicate that certain species of marine mammals and sea turtles are more likely to interact with debris than others. In these animals ingestion of synthetics and entanglement appear to be frequent and widespread.

INTRODUCTION

Increased human use of the oceans and inshore waters has resulted in large amounts of man-made materials with which marine organisms come into contact. Organisms interact not only with waste products and floating debris but also with actively used fishing gear. Numerous efforts have been conducted worldwide to assess the amounts (Wehle and Coleman 1983; Bean 1987), types (Carpenter et al. 1972; Dixon and Dixon 1981; Dahlberg and Day 1985; Center for Environmental Education 1987a, 1987b; Henderson et al. 1987), and sources of these materials (Horsman 1982) and their impacts on marine organisms (Shomura and Yoshida 1985; Coe and Bunn 1987; O'Hara 1989). The interactions of marine organisms with these materials, and the

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resulting impacts, are better understood when the ecology of the individual species is considered.

Many marine species have global distributions and occur in both populous and remote areas. An abundance and diversity of marine mammals and sea turtles are found in the New York Bight. This is one of the most heavily stressed coastal regions in the world. With New York City at its apex, the bight is a major port for shipping and fishing. This region's coastal population of over 25 million places heavy demands upon the marine environment through activities such as recreational boating, fishing, and dumping of wastes. In contrast, the Arctic region, which supports large populations of marine mammals (Remmert 1980), is one of the few remaining areas in the world where man's influence is still limited. Despite its remoteness, it has been shown that sperm whales in this region were also impacted by marine debris (Martin and Clarke 1986).

The objective of this research was to examine the incidence of ingestion of synthetics by, and entanglement of, different types of marine mammals and sea turtles in the New York Bight and to provide comparisons with whales in Iceland waters.

METHODS

The study was conducted during the period of 1979 through 1988 in the New York Bight and in Iceland during the summer of 1985. Data on ingested materials in the New York area were collected during post mortems of digestive tracts in stranded animals. Only those stranded animals for which reliable necropsies could be performed were included in this study. Animals examined included 37 pinnipeds, 88 cetaceans (19 mysticetes and 69 odontocetes), and 116 sea turtles (Table 1). Data from Iceland were collected by examining the gut contents of 82 fin whales, *Balaenoptera physalus*, at a whaling station in Hvalfjordur during the 1985 season.

Data on entanglement were also collected during the post mortems of both the New York and Iceland specimens (Fig. 1). In New York, a large number of stranded live animals were also examined for evidence of entanglement, e.g., visible scars as reported by Hare and Mead (1987) or actual attached debris, and in Iceland, 13 additional fin whales were examined for entanglement only.

RESULTS

Ingestion of Synthetics

Evidence of ingestion of synthetic materials was found in 24 animals in the New York Bight during this study (Table 2). The frequency of occurrence varied among groups. Synthetics were present in the gut of three individual mysticetes and in seven odontocetes. Among the odontocetes, 3 out of 8 physterids, 3 of 50 delphinids, and 1 of the 9 phocoenids examined contained synthetic materials. There was no evidence of ingestion of synthetics in any of the pinnipeds.

Table 1.--Stranded marine mammals and sea turtles in the New York Bight from 1979 through 1988. A total of 461 live and dead animals were found along the shores or entangled in nets in the water.

Species	Number of individuals
Cetaceans	
Balaenoptera acutorostrata	5
Balaenoptera physalus	9
Deliphinapterus leucas	1
Delphinus delphis	15
Eubalaena glacialis	1
Globicephala melaena	14
Grampus griseus	1
Kogia breviceps	5
Lagenorhynchus acutus	4
Megaptera novaeangliae	4
Mesoplodon densirostris	1
Phocoena phocoena	9
Physeter catodon	3
Stenella coeruleoalba	7
Stenella plagiodon	3
Tursiops truncatus	10
Ziphius cavirostris	1
Unidentified	6
Pinnipeds	
Halichoerus grypus	2
Phoca groenlandica	1
Phoca vitulina	34
Sea turtles	
Caretta caretta	103
Chelonia mydas	15
Dermochelys coriacea	85
Lepidochelys kempi	122
Total	461

Among the sea turtles, varying amounts of synthetics were found in 10 of the 33 leatherbacks, *Dermochelys coriacea,* in 3 of 35 loggerheads, *Caretta caretta*, and in 1 of 4 green turtles, *Chelonia mydas*. Although there were 44 Kemp's ridleys, *Lepidochelys kempi*, examined in this study, none of these turtles contained synthetics in its gut.

In the Iceland survey during the summer of 1985, plastic material was found in 6 of the 82 fin whales examined.

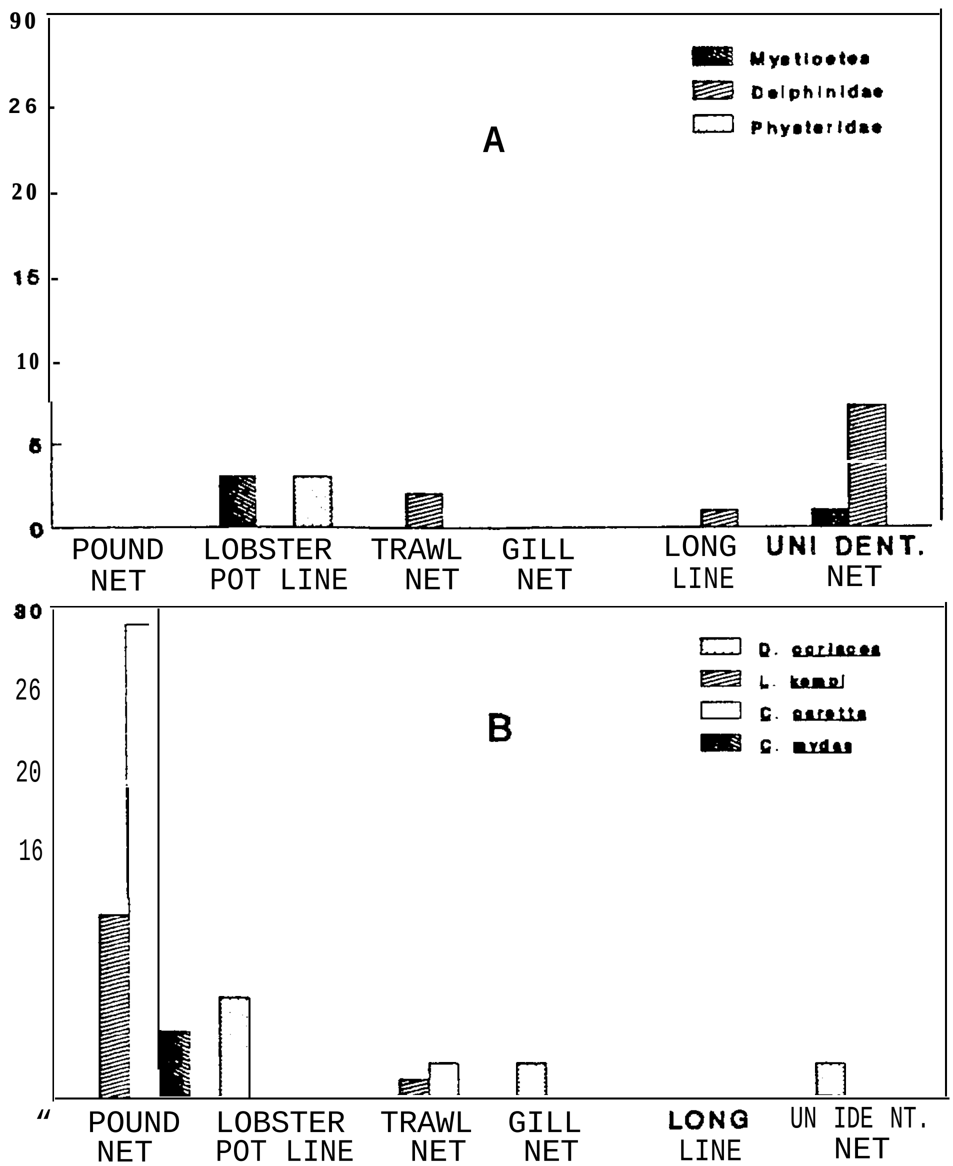

Figure 1. --The incidence of entanglement in different types of gear for marine mammals (A) and sea turtles (B) in the New York Bight from 1979 through 1988.

A wide variety of debris was observed in the stomachs of the animals examined in this study. The various types of debris found in the guts of cetaceans in the New York Bight included plastic toys, cups, polypropylene line, plastic bags, plastic sheets, and some unidentifiable synthetics. Similar materials were found in the Icelandic whales as well. One of these fin whales contained plastic that unfolded to a 1 x 2 m sheet. The most prevalent types of ingested debris observed in cetaceans from both study areas were plastic bags and small pieces of plastic sheeting.

Table 2.--Gut content analysis of marine mammals and sea turtles in the New York Bight from 1979 through 1988 and of fin whales, *Balaenoptera physalus*, from Iceland during the summer of 1985.

Location	Number examined	Number with synthetics
New York Bight		
Cetaceans		
Mysticetes	19	3
Odontocetes		
Delphinidae	50	3
Phocoenidae	9	1
Physteridae	8	3
Ziphiidae	2	0
Pinnipeds		
Phocidae	37	0
Sea turtles		
Dermochelyidae	33	10
Cheloniidae		
Caretta caretta	35	3
Chelonia mydas	4	1
Lepidochelys kempi	44	0
Total		24
Iceland		
Cetaceans		
Mysticetes		
Balaenoptera physalus	82	6

Various lengths of monofilament line, small pieces of different colored plastic, and numerous small polystyrene balls had been ingested by sea turtles. Most of the synthetic material in sea turtles, however, was clear, thin plastic. In some instances entire plastic bags were present, and these were the predominant synthetic material found in leatherback turtles.

For several stranded animals there was strong evidence that ingestion of synthetics was contributory or causative of death. In one pygmy sperm whale, *Kogia breviceps*, a hard, black plastic ball had completely blocked the pyloric valve. The surrounding tissue was hemorrhagic and there was extensive necrosis. This animal was also severely emaciated upon death. Another whale, a pregnant sperm whale, *Physeter catadon*, was found with approximately 300 m of polypropylene line wrapped around its jaw and extending into the stomach. The esophagus and stomach were hemorrhagic and the lower jaw was gangrenous at the time of death. Five leatherback turtles had a large bolus of plastic occluding their digestive tracts. One such bolus was made up of 15 quart-size plastic bags and was blocking the pyloric opening.

Entanglements

From 1979 to 1988 there were a total of 75 individuals in the New York Bight that exhibited signs of entanglement with either debris or inactive or active fishing gear (Fig. 1). These individuals included 4 mysticetes, 13 odontocetes, and 58 sea turtles. No pinnipeds in this study were entangled in gear or debris. In Iceland, 5 of the 95 fin whales examined showed signs of previous entanglement.

Types of entanglement varied among groups of animals (Fig. 1). Three of the four mysticetes were entangled in lines from lobster pot floats, as were three sperm whales. Of the remaining odontocetes, seven exhibited evidence of the animal's having been entrapped in unidentified nets, two in trawl nets, and one in a longline. In the Icelandic fin whales, it was not possible to identify the form of entanglement gear which had made the scars.

The majority of the entanglements occurred in sea turtles, and there were clear differences among the species. The chelonid turtles (loggerheads, greens, and Kemp's ridleys) were primarily caught in pound nets (44 out of 48 turtles), while leatherbacks were entangled in other types of nets (4 of 10) and in lobster pot lines (6 of 10).

The incidence of death among entangled animals was related to the type of entrapping gear. Those types of gear which can hold an animal underwater were more frequently associated with the animal's death. The odontocetes which showed evidence of net entanglement had all died of drowning. These animals appeared healthy prior to death, exhibiting full stomachs, normal blubber thickness, and no specific disease etiology. One leatherback turtle became entangled in a lobster pot line and could not be freed. This animal also drowned. There was no mortality among the 44 turtles entrapped by pound nets, which only encircle an animal and do not confine it under water.

DISCUSSION

Between the years of 1979 and 1988, 461 stranded and entangled animals were found in the New York Bight. These strandings included 17 species of marine mammals and 4 species of sea turtles, and many of the data were collected from carcasses that had washed up along the shores of Long Island, New York. The prevailing wind and current patterns are such that most carcasses in the Long Island Sound or in the eastern bays are transported to shore, but many of those in the ocean float farther out to sea. Thus, while some areas provide an accurate account, strandings along the entire ocean shore probably grossly under-represent the number of pelagic animals that are impacted.

The incidence of ingested synthetics varied among species. The observed patterns could be attributed to several, ecological characteristics of the animals: feeding behavior, seasonal occurrence, and habitat. The type of synthetic found in 19 of 24 animals was floating or neutrally buoyant plastic. Much of this type of refuse originates on land or comes from recreational boating near shore and concentrates inshore during the summer when human activity is highest. Many of the cetaceans are deep water animals, but during the summer they often move inshore, where they have been observed to be feeding heavily. It is likely that ingestion of synthetic materials increases at this time. Animals that stranded during the winter months, such as seals and most Kemp's ridley turtles, contained no synthetic materials.

The ingestion of synthetics also corresponded to the feeding behavior of animals. The mysticetes and a few odontocetes feed throughout the water column by capturing large quantities of food at a time. Plastics and other floating materials are probably ingested along with prey species. Leatherback turtles feed almost exclusively on jellyfish (Mortimer 1981) and probably actively feed on plastic that resembles their prey. Conversely, the Kemp's ridley feeds very selectively on crabs off the bottom and seals in the New York Bight feed primarily on crabs and benthic fish and neither was found to contain debris. In many cases where synthetics were evident, it was difficult to ascertain the direct cause of death due to the decomposed state of the carcass. However, in some animals, the ingestion of synthetic debris caused serious damage and probably resulted in the death of the animal.

The entanglement data were valuable in determining the effects of different types of debris and fishing gear on the species studied. All of these animals must come to the surface to breathe. Debris in the water column or at the surface, such as floating line, can entangle these animals during their normal activities. Lobster pot float lines proved to be a major source of entanglement for pelagic animals such as fin whales, sperm whales , and leatherback turtles. These lines can be more than 100 m long and virtually undetectable below the surface. Types of active or inactive fishing gear that hold animals below the surface, such as longlines, trawlers, and gillnets, can drown marine mammals and sea turtles. Other types of gear that merely confine animals are not a problem. Most of the Kemp's ridley, loggerhead, and green turtles were caught in pound nets with no observed mortalities.

This study examined the impact of two forms of ocean debris. However, there are many other human activities that can affect marine mammals and sea turtles. Recreational boating contributes heavily to fouling the inland waters, and a large proportion of the animals in this study had been struck by boats. Other problems such as heavy metals, pesticides, and sewage runoff are epidemic in many coastal waters. While their effects on marine life may not be immediate, pollutants may result in health problems and have detrimental effects on the long-term survival of populations.

Martineau et al. (1985) showed that ingestion of toxicants drastically reduced the reproductive rate of beluga whales. It is possible that ingestion of debris and entanglement of animals have similar long-term effects, and the numbers of impacted animals are probably much higher than shown in this study (Kraus 1990)

Although the magnitude of the problems of ocean debris is not yet fully realized, this study indicates that the impact of human activity is not restricted to highly populated areas such as the New York Bight. It occurs globally and is found even in such remote areas as Iceland.

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A REVIEW OF GHOST FISHING BY TRAPS AND GILLNETS

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ABSTRACT

Ghost fishing occurs when lost fishing gear continues to catch and kill animals. This paper reviews what is known about ghost fishing in trap and gillnet fisheries, how the information was obtained and how it has been used, how ghost fishing can be prevented, and what regulatory approaches have been taken to address the problem. Some standard terms are proposed to prevent confusion.

Ghost fishing by traps can occur through several mechanisms. The problem is serious in several fisheries, minor in at least one, and remains unexamined for the majority of trap fisheries. Timed-release devices are simple, inexpensive, and effective at preventing ghost fishing by opening the trap some time after loss. In all Dungeness crab fisheries, such devices are required in crab traps, and other regulations attempt to minimize trap loss. In the American lobster fishery, only Connecticut and Maine address ghost fishing, which is known to be a problem. Ghost fishing by traps is poorly recognized as a problem outside North America.

Ghost fishing by coastal gillnets has been documented in several locations and may persist for several years. For large pelagic gillnets the limited evidence suggests that lost nets form tangled nonfishing masses. More work, both descriptive and experimental, is required to document the nature, extent, and persistence of ghost fishing by gillnets, especially by pelagic gillnets if their use continues.

It is not clear how to prevent ghost fishing by gillnets. Preventive measures suggested to date must be examined for possible side effects.

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INTRODUCTION

Ghost fishing can be defined as "the ability of fishing gear to continue fishing after all control of that gear is lost by the fisherman" (Smolowitz 1978a), i.e., when gear is lost, a common occurrence in many fishing operations. The subject was previously reviewed for trap fisheries by Smolowitz (1978a, 1978b, 1978c) and for several gear *types* by High (1985).

Fishing gear that requires active control, for example trawls, troll gear, and purse seines, may become virtually inert and probably catches insignificant numbers of animals after loss. By contrast, gear which normally fishes passively, such as traps, tangle nets, and gillnets, may continue to fish at significant rates after loss.

This paper looks at what is known about ghost fishing by traps and gillnets, how this knowledge was obtained and used, and what measures can be taken to reduce ghost fishing by traps and gillnets. Other fishing gear may well ghost fish--High (1980, 1987) reports Pacific halibut, *Hippoglossus stenolepis*, striking and being caught by bare longline hooks--but the literature at this stage adds little to High's (1985) review for other gear types.

Why Ghost Fishing May Be a Problem

An increasing proportion of fishing gear is now constructed from nondegradable materials such as stainless steel, other metals, fiberglass, injection-molded plastics, vinyl-coated wire, monofilament netting, and polypropylene twine. Whereas fishing gear made from natural materials deteriorated quickly in the sea--Pacific salmon, *Oncorhynchus* spp., fishing ports all featured tanks of copper sulfate for dipping nets to preserve them--gear made from modern materials lasts much longer in the sea.

The very large volumes of fishing gear now deployed translate to a large volume of lost gear even if the loss rate is small. Some crustacean trap fisheries are so overcapitalized that jurisdictions try to limit the large number of traps used. Hundreds of thousands of kilometers of pelagic gillnets are in use. If this gear ghost fishes when lost, then there is a serious biological and economic problem.

Terminology

Some standard definitions are proposed. First, I use "lost" to describe lost or discarded fishing gear. Previous authors have used "ghost" or "derelict" to describe such gear. However, using "ghost" to mean "lost" creates confusion--the lost gear may or may not actually be ghost fishing. Sutherland et al. (1983) propose a distinction between intact lost gear, still theoretically capable of fishing, and damaged or "derelict" gear that can no longer fish. "Derelict" should be limited to this sense. Where gear loss is simulated experimentally, I use the term "simulated lost" gear.

Second, two types of special openings in traps need careful differentiation. Traps can be modified by openings designed to allow animals to escape (Wilder 1945). These openings have been termed "savings gear" (Jew 1961), "escape vents" (Pecci et al. 1978; Anthony and Caddy 1980), and "escape gaps" (Brown and Caputi 1986). Traps can also be modified by openings or mechanisms designed to release animals from a lost trap. These have been termed "biodegradable sections" (Anthony and Caddy 1980), "timed-release mechanisms" (Blott 1978), "ghost panels" (Krouse pers. commun.), "escape panels" (draft Maine legislation), and "destruct panels" (Hipkins and Beardsley 1970). I suggest that the first type of special opening be called "sublegal escape gaps" and that the second type be called a "timed-release" opening.

GHOST FISHING BY TRAPS

Mechanisms

There is no single mechanism of ghost fishing by traps because traps vary widely in their design, intended mode of capture, target species, and conditions of deployment. To understand ghost fishing it is first necessary to look briefly at trap operation.

Some traps simply attract fish or crustaceans with bait. Although the animals can apparently escape at will, a number are found inside the traps: there is a temporary balance between catch and escape rates. Examples are reef fish traps (Munro et al. 1971; Munro 1974), Australian snapper traps (Dews et al. 1988), and British Columbia prawn traps (Boutillier pers. commun.). Difficult exits in fish traps reduce escapement rates to increase the number of fish in the trap (see Munro 1983).

Escape can be made more difficult by fitting "nonreturn valves" to traps (e.g., Munro 1974). Dungeness crab, *Cancer magister*, traps are fitted with hinged metal gates called "triggers" (High 1976) that permit entry but effectively block exit. Sablefish, *Anoplopoma fimbria*, traps may have similar devices (Hipkins and Beardsley 1970). Homarid lobster, *Homarus americanus* and *H. gammarus*, traps commonly have inner chambers or "parlors" to hinder escape (Pecci et al. 1978; Lovewell et al. 1988).

In the simplest form of ghost fishing, trapped animals die in lost traps and their bodies act as bait (von Brandt 1984). Hipkins and Beardsley (1970, p. 29) state: "It appears then that blackcod (sablefish) pots. . will continue to fish with dead fish serving as bait to attract new fish which eventually die to attract more fish and so on ad infinitum until the pot deteriorates. . . ." They present indirect evidence for this mechanism. Pecci et al. (1978) suggest this mechanism may operate in lost American lobster traps. For no species has this "autorebaiting" mechanism been conclusively demonstrated.

Traps may be rebaited by species other than the target species. Alaska king crab *Paralithodes camtschatica* traps are rebaited when Pacific halibut or Pacific cod, *Gadus macrocephalus*, enter and die (High and Worlund 1979). Pecci et al. (1978) report a variety of fishes caught and perhaps acting as bait in simulated lost American lobster traps.

Some species of fish are attracted to live conspecifics in an unbaited trap (Munro 1974); for these, ghost fishing might occur without the autorebaiting mechanism.

In the simplest model of ghost fishing, trapped animals starve in the traps. Other forms of mortality might be important, causing death sooner. In crustaceans, cannibalism of newly molted individuals may occur. Pecci et al. (1978) observed this in simulated lost American lobster traps; Demory (1971) and Barry (pers. commun.) observed this for Dungeness crabs. Scarratt (1965) reported predation of captured American lobsters by amphipods. Ritchie (1972) and Gabites (pers. commun.) report predation on trapped New Zealand spiny lobsters, *Jasus edwardsii,* by octopus, *Octopus maorum*; Morgan (1974) describes predation by *Octopus* sp. on the Western Australian spiny lobster *Panulirus cygnus*; High (1985) describes attempts by O. *dofleini dofleini* to capture trapped Dungeness crabs. Pecci *et* al. (1978) reported mortality of American lobsters in simulated lost traps caused by black sea bass, *Centropristis striata*. Trapped crabs may be smothered when the trap is buried by silt (High 1985).

Even when animals manage to escape from ghost fishing traps, they may die as a result of their confinement--High and Worlund (1979) demonstrated this important effect experimentally for Alaska king crabs.

Fishes and crustaceans may enter unbaited traps. This is reported for Hawaiian spiny lobsters, *P. marginatus*, (Paul 1984) in the laboratory; New Zealand spiny lobsters in the field (Gabites pers. commun.); and American lobsters in the field (Pecci et al. 1978; Smolowitz 1978b; but cf. Karnofsky and Price 1989). Dungeness crabs (Breen 1987) and Alaska king crabs (Meyer unpubl. manuscr.) entered empty traps months after simulated trap loss. Munro (1983) describes fish traps that catch fish unbaited. Juvenile reef fishes in Florida use traps as shelter (Sutherland et al. 1983) . High and Ellis (1973) found that unbaited traps caught as many reef fish as baited traps. For such traps an autorebaiting mechanism is not necessary for ghost fishing to take place.

In some cases dead crustaceans repel conspecifics. Hancock (1974) demonstrated this effect experimentally for the spiny lobster *P. cygnus*, and also presented evidence that the crabs, Cancer *pagurus,* are not attracted to traps baited with the crab *Carcinus maeanas.* Miller (1977) demonstrated in experimental trapping that the Newfoundland snow crab, *Chionoecetes opilio*, are repelled by dead conspecifics, and High (pers. commun.) also reports this for the Alaska king crab. However, Pecci et al. (1978) found that *H. americanus* are not repelled by dead conspecifics. For species repelled by dead conspecifics, the autorebaiting mechanism will not cause ghost fishing.

Thus ghost fishing can occur through a variety of mechanisms: autorebaiting, rebaiting by other species, attraction by living conspecifics, or attraction by the trap alone. The trap may kill through starvation or by facilitating cannibalism and predation. For some species, nonspecific repellency may prevent or reduce ghost fishing. Ghost fishing may be significant on species other than the target species.

Demonstrations That Traps Ghost Fish

Recovered Lost Gear

Recovery, especially after long periods, of lost gear that contains live and dead animals is good evidence that ghost fishing occurs. Hipkins and Beardsley (1970) recovered nine sablefish traps lost for approximately 6 weeks. These contained dead fish and up to 24 live fish per trap, suggesting that the autorebaiting mechanism was operative.

In Oregon, Demory (1971) retrieved 117 Dungeness crab traps which had been abandoned for at least 6 weeks. They contained 3,629 crabs, 91% of which were legal-sized males. Dahlstrom (unpubl. manuscr.) recovered an Oregon Dungeness crab trap, lost for 10 months, containing 20 crabs and 2 empty carapaces. The trap was still in excellent condition. Meyer (unpubl. manuscr.) reports that recovered lost Alaska king crab traps "often contain as many as 100 marketable king crab."

Smolowitz (1978a) recovered 18 intact offshore American lobster traps lost for approximately 9 weeks. They contained 24 lobsters weighing a total of 70.8 kg (156 lb). High and Worlund (1979) recovered a snow crab, *Chionoecetes* spp., trap containing 12 king and 14 snow crabs 3 months after loss. Sutherland et al. (1983), using a submersible, found five undamaged fish traps in Florida, lost for an estimated 4-6 months. These held 14 fish, 14 Caribbean spiny lobsters, *Panulirus argus*, and a fish skull.

When lost traps are empty on recovery, it is often inferred that ghost fishing does not occur. For instance, Boutillier (pers. commun.) observed lost prawn, *Pandalus platyceros*, traps from a submersible in British Columbia; none contained prawns and he concluded that ghost fishing did not occur. However, simulated lost Dungeness crab traps that were empty for considerable parts of the year caught and killed crabs (Breen 1987). If traps ghost fish through other than the autorebaiting mechanism, then an empty trap may subsequently kill. Inferences made from empty traps are suspect unless made over large numbers of traps and over several seasons.

Another inference is often made from the way catch rates fall as soak time increases. Traps left to soak for too long give poor catches; the inference is that most of the catch escapes after the bait ceases to attract. Then by extension ghost fishing is inferred not to be a problem. Examples include the Tasmanian spiny lobster, *J. novaehollandiae* (Kennedy pers. commun.), British crabs and lobsters (Bannister pers. commun.), and Dungeness crabs. However, in Dungeness crab traps the catch rate declines with increased soak time, yet lost traps continue to catch and kill at a slow rate (Breen 1987). So ghost fishing may occur in the long term despite apparent short-term escapement.

Trap Loading Experiments

Ideally, all ideas about ghost fishing should be tested experimentally. Three approaches have been used: experiments in which traps are loaded and escape rates or mortality rates measured, laboratory observations that simulate fishing, and field experiments with simulated lost traps.

Munro (1974) found that 50% of reef fishes escaped from Antillean fish traps after 14 days; this implies a 5% escapement per day and 23% retention after a month. These rates suggest that ghost fishing is likely to occur in such traps. However, Munro (1983) estimated an escapement rate of 12% per day from "Z" fish traps, a rate implying only a 2% retention after 30 days.

Sheldon and Dow (1975) loaded 98 tagged American lobsters into 35 unbaited simulated lost traps and checked the traps by diving and hauling for nearly 2 years. The traps continued to catch lobsters, of which 12-18% died in the traps, demonstrating for the first time ghost fishing for American lobsters.

Newfoundland snow crab traps were loaded and examined at intervals by diving (Miller 1977). After 3 weeks no crabs had escaped. Miller then tested the mechanism of ghost fishing in this species by fishing with four treatments. Unbaited traps and traps baited with dead crabs caught nothing; on average squid-baited traps caught 31 crabs per trap; traps baited with a mixture of dead crabs and squid caught 7 crabs per trap. Miller concluded that dead snow crabs repel conspecifics and that the only loss from ghost fishing would involve those crabs originally attracted by the bait.

High and Worlund (1979) observed a 20% retention rate for legal size Alaska king crabs and 8% for sublegal crabs in experimental traps after 18 days. Mortality in standard traps was 2-7% over this period.

Muir et al. (1984) baited Dungeness crab traps daily and observed that 35% of the captured crabs died in the traps. High (1985) placed Dungeness crabs in traps with and without triggers and sublegal escape gaps. The mortality in traps with functional triggers and sublegal escape gaps was 17% after 12 days, confirming ghost fishing as a problem with these traps.

Laboratory Observations

Paul (1984) observed that Hawaiian spiny lobsters in a large tank normally did not escape from traps. The trap lids "had to be removed to prevent them from becoming permanently trapped inside."

Behavior of reef fishes around traps was observed in a large tank by Harper and McClelland (1983, cited by Heneman and Center for Environmental Education (CEE) 1988). Most species appeared to learn to escape, leading to "an equilibrium state. . with frequent movements in and out of the trap."

Booth (pers. commun.) used a time-lapse camera in a large tank to record the behavior of *J. edwardsii* around simple cane traps, as used in the New Zealand fishery, and parlor-type traps not used in the fishery. There was a rapid turnover of lobsters in the simple trap, but greatly reduced escapement in the parlor traps. Booth concluded that ghost fishing is probably not a problem for the cane traps, but could be a problem if more complex traps were introduced. Plastic truncated-cone entrances on the top of the trap appear to limit escape in this species in large laboratory tanks (Breen unpubl. data; Gabites pers. commun.).

Field Experiments

Information from trap loading and laboratory studies must be treated with caution: problems with extrapolation from the laboratory to the field and from short to long term must be carefully considered. Possibly the best information comes from underwater observations of simulated lost traps. Tagging of trapped individuals by divers can be used to follow turnover.

Pecci et al. *(1978)* reported only 30% escapement in American lobsters entering simulated lost traps observed by divers. Mortality rate was 25%. The authors estimated that a ghost fishing trap caught at a rate near 10% that of a surface-hauled trap, confirming ghost fishing as a problem in this fishery.

Breen (1987) simulated 10 lost Dungeness crab traps in a sheltered bay for 1 year, during which approximately 100 crabs died in the traps. At the end of the study, traps were still killing crabs at a steady rate. The results cannot be generalized directly to other Dungeness crab fisheries. For instance, many traps lost off high-energy beaches are destroyed or put ashore by wave action.

Western Australian snapper, *Chrysophrys auratus*, traps were observed in the field with underwater video (Anonymous 1984; Dews *et* al. 1988; Moran and Jenke 1989) partly to examine possible ghost fishing (Bowen 1961). Fish seemed capable of leaving traps easily and some even swam out "in reverse." Moran and Jenke (1989) simulated lost traps for various periods from 1 to 21 days. Catches were similar to commercial catches after 15 min, indicating that cumulative catching did not occur. These workers concluded that ghost fishing is not a problem with snapper traps. However, three fish were dead in the 21-day trap, suggesting that some ghost fishing may take place.

Hawaiian spiny lobsters appear to move out of simulated lost traps once the bait has deteriorated (Okamoto pers. commun. ; Parrish pers. commun.) .

Rates of Trap Loss

Traps are lost for many reasons. Simple vessel traffic and towboating may sever buoy lines or drag traps into water deeper than the buoy line. Weak or chafed buoy lines may break. Buoys may become detached from the buoy line, or may be attacked by marine birds (Smolowitz 1978b) or mammals (High 1985). Storms or strong currents may 'drown" traps either directly or by rolling them over the bottom, wrapping the buoy line around the trap

(Smolowitz 1978b; Sutherland et al. 1983; von Brandt 1984). Traps set on rocky ground may snag and be unrecoverable (Bowen 1961).

Traps may be carried into deep water, or buoy lines cut, by other fishing activities such as trolling, trawling and gillnetting. When traps are set on ground lines, ground lines may be intentionally cut when lines become fouled. Internecine buoy line cutting or ground line cutting may result from unresolved fishing disputes (Smolowitz 1978b; Breen 1987). In some areas vandals cut buoy lines (Sutherland et al. 1983).

Estimates of trap loss rate must be obtained through surveys or industry interviews. These give the total loss of traps, which might include stolen traps.

American Lobster Traps

For the U.S. American lobster fishery, Smolowitz (1978a) cites anecdotal estimates of the annual loss of traps as 20-30% along the Atlantic seaboard. In the offshore lobster fishery he suggests that 40,000 all-metal traps may have been lost during the period 1971-78. In the inshore fishery Krouse (pers. commun.) suggests an annual loss rate of 5-10% . Based on a 1987 estimate of 1.87 million traps fished, this leads to an annual loss estimate of 93,500-187,000 traps lost annually. An unpublished study (CEE 1987) cited by Heneman and CEE (1988) estimated an annual loss of 500,000 traps annually. In Rhode Island a logbook study led to an estimate of 10-15% annual loss (Fogarty pers. commun.).

In Newfoundland, no estimates have been made of lobster trap loss rate, but divers observe few lost traps on the fishing grounds, Many lost traps are washed ashore (Ennis pers. commun.). Losses have not been estimated in the rest of the Canadian lobster fishery.

Dungeness Crab Traps

In California, 100,000 Dungeness crab traps are estimated lost each year (Kennedy 1986). Some silt into the bottom, but others could fish for an estimated 2 years. In Washington State, Northup (1978, cited in Muir et al. 1984), estimated that 17.6% of the coastal Washington State crab traps were lost in 1975-76, considered a typical year. Barry (pers. commun.) estimated mean annual loss in the same fishery as 11.9%. He considers that ghost fishing traps are <50% of the total loss and may be as low as 10%. In the Puget Sound portion of the fishery, gear loss was estimated from a questionnaire survey to be 15% (Bumgarner pers. commun.). Breen (1987) estimated Fraser River Dungeness crab trap loss as 11%, based on a questionnaire survey. About half those surveyed thought that half the lost traps were ghost fishing.

Thus in several coastal trap fisheries, annual trap loss rates are on the order of 10-20%. American lobster and Dungeness crab fisheries are both cases where more traps than optimum are fished (and thus lost) (Bell and Fullenbaum 1986; Methot 1986). Cumulative trap losses are a cause for concern in fisheries where ghost fishing is known to occur.

The Fate of Lost Traps

Not all lost traps become ghost fishing traps even where ghost fishing is a problem. Smolowitz (1978b) reviews sources of trap destruction. Storms destroy or strand many inshore American lobster and Dungeness crab traps in exposed locales. Burial by storm action or alluvia occurs quickly in some Dungeness crab fishing areas (Hipkins 1972, cited in Smolowitz 1978b; Breen 1987),

Untreated wooden traps are destroyed by borers in a relatively short time, but treated wooden traps may last up to 2 years (Smolowitz 1978b; Fogarty pers. commun.). Twelve percent of the wooden traps used by Sheldon and Dow (1975) were so damaged by lobster chelipeds that escape became possible. Increasingly, however, traps are made from metal (Acheson 1982) or synthetic materials. Averill (pers. commun.) believes that "wooden" American lobster traps last as long as wire traps when lost. Long-term experiments are required to determine the fishing lifespan of various trap types.

High and Worlund (1979) estimate that metal-framed, synthetic mesh-covered Alaska king crab traps could have an effective longevity of 15 years after loss. Breen (1987) found that metal-framed, stainless steel-covered Dungeness crab traps were in excellent condition after a year's submersion. Electrolytic corrosion probably destroys most metal traps eventually. New designs include plastic traps (e.g., Piatt 1988) and vinyl-coated mesh (e.g. , Maynard and Branch 1988), which might last for decades. The present Maine trap inventory is 50-60% vinyl-coated wire (Averill pers. commun.).

Note that much of the information just presented is based on short-term studies. The real fate of lost fishing gear has not been well studied.

Impact of Trap Ghost Fishing

How much fishing takes place by ghost-fishing traps? To answer this for a specific fishery requires 1) estimates of the number of traps fished and the loss rate, 2) an assumption about the percentage of lost traps that ghost fish, 3) an estimate of the rate of mortality in ghost-fishing traps, and 4) an estimate of the effective ghost fishing lifespan of a trap. Ideally, for requirement 3 one should also know the natural mortality rate, because some individuals killed by ghost fishing would have died before commercial capture. Many individuals would also have grown before commercial capture. However, the unavoidable imprecision of the other estimates implies that only a crude answer can be obtained in any case.

For the Newfoundland snow crab fishery, Miller (1977) used spot interviews to estimate trap loss at 8%, and combined this with commercial catch rates and experimental observations to obtain an estimate of ghost-fished catch of 10 metric tons (MT) annually. Smolowitz (1978b) estimated the impact of ghost fishing in the U.S. portion of the American lobster fishery. The estimated annual ghost fishing catch was 670 MT, worth an estimated 1978 US$2.5 million. From a 1976 study using different assumptions (CEE 1987, cited by Heneman and CEE 1988), the economic loss of just those lobsters within traps at the time of loss was estimated at 19"76 US$2.5 million. Krouse (pers. commun.) assumed a loss rate of 5% in the U.S. American lobster fishery and that traps last for 2 years and take two lobsters per year. This leads to an estimate of 204 MT lost to ghost fishing annually, worth 1989 US$1.2 million. This is a conservative estimate, because it is based on the low end of the range of trap loss estimates.

Breen (1987) estimated the impact of ghost fishing in one part of the British Columbia Dungeness crab fishery, using loss rates and lifespan estimates from an industry survey and experimental ghost fishing data. He estimated the ghost-fished catch to be 7% of reported landings, worth about 1985 Can$80,000.

For the sablefish fishery of British Columbia, Scarsbrooke et al. (1988) used trap loss rate from an industry survey, the commercial catch rate, and simple assumptions about turnover rate, trap lifespan, and timed-release device effectiveness. For traps lost from 1977 to 1983, before timed-release devices were fully employed, the estimate of ghost fishing catch was approximately 300 MT annually, compared with landings of 1,000-4,000 MT,

These case's illustrate that ghost fishing can be substantial. I can find no fishery for which the impact of ghost fishing on stocks has been determined, or where ghost fishing is addressed by stock assessments or management plans. In Oregon, where traps are required to incorporate timed-release mechanisms, biologists consider that ghost fishing, although subtracting from the potential catch, would have no stock-recruitment effect. The size limit is set so that all legal-sized males could theoretically be taken without affecting reproduction (Demory pers. commun.) .

Prevention of Trap Ghost Fishing

Remedial measures may either reduce trap loss or prevent lost traps from killing. A simple way to reduce trap loss is to reduce the number of traps fished (Smolowitz 1978b). Effort is excessive in many fisheries, so this approach is often desirable for that reason alone. The extreme solution, vessel trap limits or transferable trap entitlements, is extremely expensive to enforce and therefore was rejected as a management option in the New Zealand *J. edwardsii* fishery (Anonymous 1987).

Trap designs can be improved to reduce storm and current losses caused by traps rolling on the bottom (see Smolowitz 1978b). Losses caused by vessels can be reduced by prohibiting buoyed traps in areas of heavy traffic. In Washington State, trap-free lanes for towboats have been established to minimize trap loss from that source (Bumgarner pers. commun.). The Washington Department of Fisheries also facilitates coordination between trap and net vessels to avoid gear collisions. In the Canadian sablefish fishery, ground lines must be buoyed at each end. In practice, the marking employed far exceeds the minimum standard required (McFarlane pers. commun.). In the Puget Sound recreational trap fisheries of Washington State, regulations require solid buoys (to prevent losses from puncture) and nonfloating buoy lines (to prevent loss from vessel traffic) (Bumgarner pers. commun.).

The large literature on sublegal escape gaps shows that they greatly reduce catches of sublegal crustaceans, presumably through escapement (e.g., Cleaver 1949; Fogarty and Borden 1980; Brown and Caputi 1986; see review in Smolowitz 1978c). Because escape gaps reduce trap saturation effects (Miller 1979), they may lead to increased catches of legal animals.

Ghost fishing mortality was reduced for sublegal American lobsters by sublegal escape gaps in simulated lost traps (Pecci et al. 1978; Smolowitz 1978a). High (1985) found greatly increased sublegal escapement in simulated lost Dungeness crab traps fitted with sublegal escape gaps. Breen (1987) found that as many sublegal as legal Dungeness crabs died in simulated lost traps fitted with appropriate sublegal escape gaps, but the absolute catch rates of legal and sublegal crabs were unknown. Sublegal crabs may have had a high turnover rate in the traps.

Measures to prevent lost traps from ghost fishing usually involve some deliberate failure (timed-release) in a trap component to open the trap or create a new opening for escapement.

Natural fiber twine can be used either to make a timed-release panel or to sew a timed-release panel shut. Panels can also be made from untreated softwood. Blott (1978) tested a variety of materials with potential for use as timed-release elements in traps. Jute and manila twine and steel wire appeared to be realistic, while wool and leather were not.

In Maine, various materials have been tested for use in closing timed-release openings (Averill pers. commun.). industry was given traps with many openings secured with test materials and asked to fish them during their regular season. Mild steel hog rings appear to last the desired time (ea. 200 days), and are consistent in their total degradation time. Cotton twine and sisal twine are also good candidates for this purpose.

Scarsbrooke et al. (1988) tested failure rates of several binding materials for timed-release openings in sablefish traps. They also fished traps with three types of opening in alternation with control traps to measure the effectiveness of timed-release openings. Triangular or square openings were more than 90% effective in allowing trapped fish to escape; simple “slashes” were less effective. They concluded that appropriately shaped timed-release openings eliminated the problem of ghost fishing in these traps.

Plastic crab and lobster traps in Florida (Piatt 1988) have a rectangular opening which the user fills with a timed-release device such as a plywood panel.

Blott (1978) describes a solid timed-release panel made from galvanized steel and held shut with natural twine or a degradable metal ring. The panel can also incorporate the sublegal escape gap, leading to the *name* "catch escape panel." Blott tested various materials for suitability as catch escape panels; galvanized sheet steel seemed most appropriate. Pecci et al. (1978) tested such panels in simulated lost American lobster traps and concluded that such panels "are an effective means of releasing entrapped lobsters." Traps with this type of panel are now commercially available from a Maine manufacturer (Lazarus 1988). However, Averill (pers. commun.) considers that the combination of sublegal escape gaps and a timed-release opening leads to confusion of two separate management issues.

In California, magnesium pins are used to hold together the two halves of plastic or fiberglass traps or to attach the lids of plastic and fiberglass traps (Estrella pers. commun.).

Dungeness crab traps are serviced through the "lid," a hinged section of the top secured by a hook attached by a rubber strap from the side of the trap (High 1976). A timed-release hook, or hook attachment, would allow the trap to open. Breen (1987) unhooked 10 simulated lost traps that had ghost fished for a year. Over a week, 22 of 29 trapped crabs escaped and no new captures were observed. Thus a timed-release device that unhooked the lid would probably be effective in this type of trap.

It is possible to make plastics that are degraded by organisms, light, oxidation, other chemical reaction, and dissolution (see review by Andrady 1988). Various degradable plastic compounds designed specifically for the fishing industry are now being tested (Gonsalves et al. 1989, Gonsalves 1990). Japanese chemists are designing "bacterial co-polymers" which degrade slowly into natural chemicals in water (Doi et al. 1988).

Premature failure of timed-release elements reduces industry acceptance of the concept (Smolowitz 1978b). The early failure of a batch of hog rings used to close timed-failure panels in lobster traps resulted in industry resistance to the devices in Maine (Anonymous 1988; Averill pers. commun.). A similar experience in California led to delayed legislation (Estrella pers. commun.). Material failure rates vary widely with local conditions and probably cannot be predicted accurately. Agencies proposing timed-release regulations must conduct widespread materials testing *to* find a mechanism that will both fail reliably after the desired time and not fail prematurely. Studies conducted by the industry under actual fishing conditions are more likely to be accepted by the industry.

The dollar and time costs of timed-release modifications are important to acceptance by industry (High and Worlund 1979). Breen (1987) calculated the annual economic cost of Dungeness crab trap ghost fishing done in 1985 as Can$1.46 per trap in use, and suggested that annual modifications must therefore cost less than this. This simple study appears to be the only published cost-benefit analysis of the problem. Other managers consider that "off-the-cuff cost-benefit analysis would indicate that [ghost fishing] should be addressed" (Averill pers. commun.).

Finally, Smolowitz (1978b) suggests development of "habipots" that catch animals seeking them as shelter. Such traps would not entrap animals and thus would have only biologically positive effects when lost. Some Octopus traps operate on this principle (Mottet 1975).

Regulations to Prevent Trap Ghost Fishing

The American lobster and Dungeness crab fisheries are interesting to examine for regulations designed to minimize ghost fishing. In both fisheries ghost fishing is known to occur, trap losses are high, and the fisheries take place over several jurisdictions in two countries with differing management approaches.

Dungeness Crabs

California requires all traps to incorporate timed-release devices or openings. These may be trap lid hooks made of soft steel <6 mm diameter, lid hooks attached to the strap with single loops of natural fiber twine, any modification of the upper mesh secured with natural fiber to create a 125-mm diameter hole, or magnesium pins as discussed above. Testing of these materials has been carried out, and cotton twine is the preferred option (Estrella pers. commun.). All traps or ground lines of traps must be buoyed and the buoys marked with identification markings.

Oregon requires Dungeness crab traps to contain a timed-release device as in California (Demory pers. commun.). Individual traps must be buoyed and marked.

Since October 1988, Washington also requires timed-release devices as above but not including the mild steel hook; openings must be unimpeded, at least 76 x 127 mm and closed with natural fiber. Washington also has buoy and buoy line standards described earlier.

In British Columbia, Fisheries and Oceans Canada introduced a regulation in 1990 requiring a single loop of specified cotton twine in the lid strap and nonfloating buoy lines. Traps or ground lines must be buoyed with marked floats, but this regulation is often ignored (Breen 1987).

In Alaska, Dungeness crab traps are required to have timed-release devices (Koeneman pers. commun.). At least as early as 1974, Alaska sablefish traps were required to incorporate timed-release panels (Hipkins 1974, cited in High and Worlund 1979).

Alaska also requires that "traps left unattended for over 2 weeks must have bait removed and doors secured open as protection against ghost fishing." This is the only regulation dealing with ghost fishing listed by Miller's (1976) review of crab management regulations in North America, demonstrating the relatively recent recognition of the problem.

Most other major trap fisheries on the Pacific coast have similar regulations. Scarsbrooke et al. (1988) describe the requirement for a timed-release panel in the sablefish fishery. In this case the fishing industry actually included such devices before being regulated. Regulations governing a new trap fishery for hagfish, *Eptatretus* spp., require timed-failure openings in British Columbia and Oregon (Harbo pers. commun.).

American Lobsters

In the United States, Connecticut has been the only jurisdiction to require incorporation of a timed-release panel into the trap. Maine drafted legislation in 1982, which will take effect in 1990 (Krouse 1989), requiring a timed-release panel at least 95 mm square, made of untreated natural material: twine <5 mm diameter, ferrous metal less than about 2.5 mm diameter, or softwood. In the federally controlled part of the fishery, degradable fasteners closing a timed-release opening will be required in 1992 (Fogarty pers. commun.).

In the federally regulated portion of the fishery, lobster traps must be marked with the owner's identification number, and traps set on ground lines must be marked with a buoy or flagpoles and radar reflectors, depending on how many traps are set.

In the Canadian fishery, no regulations are directed at ghost fishing. Anthony and Caddy (1980) recognized-the problem and recommended that timed-release panels or "links" be included in all traps and especially deepwater traps.

GHOST FISHING BY GILLNETS

Mechanisms

Gillnets work by trapping animals in the mesh of the net; ghost fishing is a simple continuation of the gillnetting process after the net is lost.

A wide variety of species are targeted with many types of gillnet worldwide (see Uchida 1.985 for a comprehensive review) . In comparison with the trap fisheries reviewed above, there has been little work on ghost fishing by gillnets. This may reflect failure to recognize a problem: Herrick and Hanan (1988) review problems caused, inter alia, by California gillnets without considering ghost fishing.

Pelagic or drift gillnets are used by Japan and Taiwan in the North Pacific to catch salmon and squid (Uchida 1985), and in the South Pacific by Japan, Korea, and Taiwan to catch albacore and skipjack tuna (Hinds 1984; Murray 1988). Ghost fishing in pelagic gillnets may be overshadowed by their incidental catch performance. They catch a long list of other nontarget species including fishes, birds, turtles, and marine mammals. Even reindeer have been reported caught by gillnets (Beach et al. 1976). Sloan (1984) and McKinnell et al. (1989) give extensive species lists in the incidental catch in Japanese squid gillnetting off British Columbia. In the same fishery Jamieson and Heritage (1987) estimate the catch of birds at one per 18 km of net set, the catch of mammals at one per 140 km. Harwood and Hembree (1987) estimate the incidental catch of cetaceans in pelagic gillnetting off northern Australia, 1981-85, to have been on the order of 14,000 individuals. Incidental catches of cetaceans are also a serious problem in coastal gillnet fisheries. Read and Gaskin (1988) estimated the catch of harbor porpoises, *Phocoena phocoena*, by groundfish gillnets in the Bay of Fundy, concluding that the incidental catches threaten the population. Recreational gillnetting is a major threat to the endangered Hector's dolphin, *Cephalorhynchus hectori*, in New Zealand (Dawson 1990).

Demonstrations of Gillnet Ghost Fishing

Recovered Lost Gear

In Iceland, synthetic cod gillnets were found a "fairly long time" after loss (von Brandt 1984); they appeared to be fishing actively based on the number and appearance of fish.

Way (1977) described catches of live fishes and crabs in lost demersal Newfoundland cod gillnets retrieved with purpose-designed dragging gear. He concluded that lost gillnets continued to fish "at a declining rate."

DeGange and Newby (1980) described finding a drifting 3.5-km pelagic gillnet lost for at least a month. The net contained 99 birds and 78 fishes. Live birds appeared to be attracted to the net, perhaps by the material already caught, and many of the fish were fresh. These authors confirm the fears of Bourne (1977) that lost gillnet fragments continue to catch and kill birds.

High (pers. commun.) found a lost salmon gillnet with fish skeletons, diving ducks, and seals, *Phoca vitulina*, in varying states of decay, indicating the net continued to kill these animals.

Underwater Observations

After discovering lost salmon gillnets in Washington, High (1985) used scuba to observe them for 6 years. The nets continued to catch crabs, fishes, and birds for 3 years. One net 180 m long contained an estimated 1,000 female crabs (High pers. commun.).

In New England, Carr et al. (1985) made observations from a submersible. They describe fishes entangled in nets estimated to have been lost for at least 2 years. Observations were continued for 3 years from a submersible and remotely operated vehicle (Carr and Cooper 1987; Carr 1988). Nets lost for 3-7 years continued to catch a variety of species, including spiny dogfish, *Squalus acanthius*; American lobsters; and bluefish, *Pomatomus saltatrix*. Later observations on one net indicated that gadoid fish successfully avoided the net, but crabs, Cancer *irroratus* and C. *borealis*, continued to be killed. Carr and Cooper (1987) estimated that lost nets were fishing at approximately 15% of the rate of commercial nets.

Dennis Chalmers (pers. commun.) reported finding a British Columbia herring (*Clupea harengus pallasi*) gillnet lost for at least 4 years: "This net was all bunched and tangled up against a rock ledge in 15 ft [4.6 m] of water and, at the time, there were a few rockfish [*Sebastes* spp.] trapped inside it." Another net found in 11-12 m depth had been lost for at least

7 years. It had no cork line, but the net had enough buoyancy to sit in fishing position and contained several fresh herring.

As in crustaceans, decaying fishes of soroe species may repel conspecifics. It is believed in New Zealand, for instance, that dead rig, *Mustelus lenticulatus*, and rig offal near a net reduce net catches (Bradstock pers. commun.) . This effect might reduce ghost fishing for some species, but no formal research appears to have been conducted.

Schrey and Vauk (1987) reported that more than 2.6% of gannets, *Sula bassana*, visiting Helgoland become entangled in lost gillnets, which caused 30% of the total gannet mortality observed.

Field Experiments

Two simulated lost demersal gillnets were observed by divers in New England (Carr et al. 1985). The nets continued to catch fishes and crabs over 2 1/2 months of observation.

Kim Walshe (pers. commun.) observed simulated lost inshore gillnets by diving for a year in New Zealand. The nets were partly disabled by algal growth and wrapping up, but continued to catch and kill some fish at intervals through the year. Rock lobsters, *J. edwardsii*, are attracted to the fish and are themselves caught by lost inshore gillnets (Anonymous 1978).

Rate of Gillnet Loss

Storms can break gillnets or break off the end markers. Vessels and trawls may run over or cut gillnets. Marine mammals and large fishes may break and carry away nets. In northern waters ice causes gillnet loss (Way 1977). Way also suspected that some nets were simply abandoned at the end of the season. Net fragments may simply be discarded (Gerrodette et al. 1987) . In inshore gillnet fisheries, nets snag on obstructions and are lost.

In the New England groundfish gillnet fishery, loss of nets was investigated by CEE (1987, cited by Heneman and CEE 1988). The study examined claims for lost gear made under a U.S. Federal act providing for compensation for gear loss caused by foreign fishing activities. For 1985 and 1986, claims were made for 48 and 29 km of net, respectively. It is unknown what proportion of the total net loss this represented.

Fosnaes (1975) estimated that 5,000 Newfoundland cod, *Gadus morhua*, gillnets were lost annually. Way (1977) conducted a program of lost net retrieval on commercial grounds, finding 148 nets in 48.3 h in 1975 and 167 nets in 53.5 h in 1976.

The density of lost demersal gillnets on a commercial ground in New England was estimated from a submersible by Carr et al. (1985). They found 10 lost nets over 40.5 ha of bottom in 37.5 h search time.

For large pelagic gillnets, a major concern is the tremendous quantity of net in the water. Eisenbud (unpubl. manuscr.) estimated that 5,000 km of net were used in the Japanese North Pacific salmon net fishery alone. Uchida (1985) estimated that 170,000 km of pelagic net were used in 1984 in the North Pacific. Coe (1986) estimated that more than 1.6 million km of squid net were used by Japan, Republic of Korea, and Taiwan in 1985. Even a very small loss rate results in a very large estimate of lost net.

Pelagic gillnets are lost from most of the same causes as coastal gillnets. Because of their great length (12-15 km), these nets are vulnerable to vessel traffic. In the Japanese fishery, intact nets are easier to recover than fragments because radio buoys and lights are installed at each end; most nets recovered by Japanese observers were fragments (Morimoto pers. commun.). Additional causes of loss suggested by Eisenbud (unpubl. manuscr.) are desertion of nets in prohibited areas after removal of end markers, and simple discard of old netting. A fisheries observer, Goldblatt (1989), describes a pelagic gillnet vessel entangling her own net in the propeller, then cutting away and discarding a large fragment.

Eisenbud (unpubl. manuscr.) reported an estimate that 0.06% of Japanese salmon pelagic gillnet is lost at each set. Gerrodette et al. (1987) report an estimate of 0.05%. They consider this estimate to be low, but Morimoto (pers. commun.) considers that the loss rate would be lower in the squid gillnet fishery because of calmer sea conditions. Tsunoda (1989) observed a Japanese pelagic squid gillnet vessel for 4 weeks and observed no gear loss. When nets were severed by vessels, Tsunoda reports that the crew quickly recovered the subsections. Eisenbud (unpubl. manuscr.) estimated annual loss from the Japanese North Pacific squid and salmon gillnet fisheries to be approximately 2,500 km of net.

The density of lost gillnet material can be estimated at sea from transect surveys (Baba et al. 1990; Day et al. 1990). However, the absolute density of lost nets is very low, net fragments cannot be seen from a significant distance, and the tendency is for drifting debris to become nonrandomly distributed by winds and currents. Assessing the impact of lost gillnets through direct surveys is therefore difficult.

Fate of Lost Gillnets

Gillnets are usually made from synthetic materials which can last for long periods of time. High (1985) observed that lost salmon gillnets continue to kill birds and fish for 3 years, and estimated that crabs may be killed for at least 6 years. The direct observations of Chalmers (pers. commun., described above) on herring gillnets tend to support these estimates.

In inshore waters, algal growth on sunken nets may stop fishing by making the nets highly visible to fishes and birds (High 1985; Dennis Chalmers pers. commun.), but Kim Walshe (pers. commun.) reports that fish are caught even in overgrown nets. Strong currents cause the net to tangle lead line over cork line (Way 1977) *or* end over end (High 1985). High suggests that rolled netting stops catching birds and fishes but may continue to catch crabs. Drift macrophytes and the catch of fish and crabs may cause the net to sink and stop fishing efficiently (Way 1977; Carr et al. 1985; Millner 1985, cited in Heneman and CEE 1988). Dogfish caused twisting of the demersal gillnets observed by Carr et al. (1985). These authors found three main types of lost net configuration, and speculated that these related to how the nets were lost.

Gerrodette et al. (1987) attached radio transmitters to four sections of gillnet 50-1,000 m long, then monitored the simulated lost nets, The shortest net "collapsed" very quickly, but the largest net remained in fishing condition for at least 10 days, The authors estimated that a l-km net would remain in a fishing configuration for several weeks.

In a similar study, Mio et al. (1990) examined five simulated lost pelagic gillnets, each 1,200 km long, for nearly 4 months. At the end of this time all nets had twisted themselves together end for end to form a large mass. One net completed this process in 20 days; the others took longer.

The wrapping up of nets may be accelerated by storms. Sloan (1984) observed that squid gillnets off British Columbia became tangled at wind speeds >65 km/h.

Merrell (1984) estimated that netting at sea survives for <10 years. This estimate is based on "aging" nets found stranded.

Prevention of Gillnet Ghost Fishing

As with traps, the most effective way to prevent ghost fishing is to prevent gear loss. In the Japanese pelagic gillnet fishery, vessels are required to mark nets with a radio buoy at one end and radar reflectors at both ends. Radio communication is used to deflect vessel traffic around the nets. Discarding of netting is prohibited, and old netting is disposed of on land (Morishita pers. commun.) .

Gillnets could be hung from the cork line with natural fiber twine (Way 1977; von Brandt 1984). In theory when the net is lost the twine would rot, and the lead line would pull the net into deep water. This idea is being examined experimentally for coastal gillnets in New England (McKenzie pers. commun.). The tendency of nets to become tangled (lead line over cork line) might prevent sinking, but would also reduce ghost fishing potential. There is also a danger that sinking the net simply transfers a surface ghost fishing problem to the bottom, as suggested by the salmon gillnet observations.

In British Columbia, a proposal to require herring gillnets to be hung with cotton twine has been drafted, but is still under discussion with industry (Dennis Chalmers pers. commun.).

I am aware of no research into degradable materials for use in the web itself. The use of natural fiber for gillnets would be a backward step because of the massive effort required to maintain and preserve nets during fishing, Gillnets are commonly made from monofilament nylon (Uchida 1985), whereas the major effort in degradable plastics has been aimed at polyethylene or polyolephanes (Scott 1990) or composites of polyethylene or polypropylene and natural material (Blott pers. commun.). A potential problem is that degradable nets would form many smaller net fragments instead of one large one.

CONCLUSIONS

Ghost fishing has not been well studied. Significant information exists for only two gear types: traps and gillnets. The importance of ghost fishing as a potential problem is underscored by very large volumes of fishing gear in use, high gear loss rates in many fisheries, and the widespread use of nondegradable materials such as plastics and stainless steel for fishing gear construction.

The fishing behavior of lost traps has been examined for only a handful of fisheries, mostly in North America. For most of the world's many trap fisheries, the impact of lost gear has simply not been addressed.

Ghost fishing by traps can operate through several mechanisms depending on trap type and the target species. Where impact has been estimated, ghost fishing sometimes emerges as only a small problem (e.g., Newfoundland snow crab and Western Australian snapper); in other cases (American lobsters, Dungeness crabs), ghost fishing is clearly an important biological and economic waste.

Modifications to stop traps from ghost fishing are simple and effective, and can be inexpensive. Such modifications are quick and easy to service once installed. Management agencies should determine whether ghost fishing is a problem in specific trap fisheries. If it is, they should conduct research into material failure rates and require timed-release devices or panels in all traps. Appropriate and properly designed research is required both to convince the industry of the problem and to develop effective timed-failure devices for specific situations.

For Dungeness crab fisheries, all jurisdictions now recognize the ghost fishing problem and attempt to control it. In the American lobster fishery, where ghost fishing was well documented much earlier, most jurisdictions have still not addressed the problem.

In the American lobster and British Columbia Dungeness crab fisheries, the amount of waste caused by ghost fishing would not have been recognized without appropriate experimentation. In no fishery should ghost fishing be rejected as a serious potential problem until proper research has been conducted.

Ghost fishing has been documented in a variety of coastal gillnet fisheries. Lost nets may kill fishes, crabs, birds, and seals for several years . Loss rates of coastal gillnets have not been estimated, but at least two studies indicate a substantial density of lost demersal gillnets on commercial fishing grounds.

The situation in pelagic gillnets is less clear. Loss rates are poorly estimated, At least one study indicates that ghost fishing and continuing entanglement of birds occurs; other studies suggest that pelagic nets form tangled nonfishing masses in a short time. Further information is needed in two areas: documentation of lost gear encountered at sea, and direct study of the fishing behavior of lost pelagic gillnets.

Short of preventing net loss or prohibiting gillnetting, it is not clear how to prevent ghost fishing in gillnets. Studies of preventive measures such as using degradable hangings are embryonic. Preventive measures may simply change the form of the problem. Side effects of intended preventive measures must therefore be examined carefully.

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AN EXPERIMENTAL STUDY OF DERELICT GILLNET FRAGMENTS IN THE CENTRAL PACIFIC OCEAN

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ABSTRACT

An experiment designed to investigate the behavior and fate of derelict gillnet fragments was initiated in August 1986 in the central Pacific Ocean. Four fragments of high-seas squid gillnet, varying in length from 50 to 1,000 m, were observed closely for 3 days and subsequently tracked for up to 10 months by satellite. The net fragments changed length, shape, heading, and location under the influence of wind and current. The time a net remained open in a fishing configuration varied from hours to weeks, depending 'on its initial length. The nets drifted at an average speed of 15 km/day, but with frequent changes in direction, they remained in the general vicinity of the Hawaiian Archipelago. The complex movement of the net fragments means that predicting the drift of marine debris is an oceanographic problem that requires detailed knowledge of surface currents and wind.

1INTRODUCTION

The amount of debris in the world ocean is a matter of increasing concern, both to the scientific community and the public at large. The Workshop on the Fate and Impact of Marine Debris (Shomura and Yoshida 1985) focused attention on the problem, and the National Marine Fisheries Service (NMFS) shortly afterwards established a program (Coe and Bunn 1987) to coordinate research, public awareness, and mitigation efforts.

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

One source of marine debris is fishing operations. The amount of fishing gear in use is staggering. For example, considering only gillnets in the North Pacific, at least 180,000 km of net is available to the various gillnet fisheries (Chen 1985; Gong 1985; Shims 1985; Uchida 1985), an amount that would stretch 4.5 times around the Earth. (This figure is conservative ; it does not include gillnet in the coastal fisheries of Korea and Taiwan.) Even if only a small percentage, for example, 0.05% (Komatsu 1986), is lost in the course of these fishing operations, 90 km of gillnet would enter the North Pacific Ocean every time these nets are used. Gillnets may be lost as a result of storms, cut adrift by a ship crossing the float line, or discarded overboard after being damaged. Such derelict gillnets are a cause for concern because they may 1) continue to catch fish, leading to waste of marine resources and inaccurate estimates of fishing mortality; 2) present a hazard to navigation by fouling ships' propellers; and 3) ensnare and kill such nontarget species as seals, dolphins, whales, turtles, and seabirds.

The impact a piece of derelict gillnet will have depends on its size, shape, location, and length of time in the ocean. This paper reports the results of experiments designed to investigate some of these questions. Specifically, the objectives of the study were to measure the change in shape of derelict gillnet fragments of various sizes over time, to determine the fishing ability of derelict gillnets of known age, and to track the movement of drifting net fragments for periods up to 1 year.

METHODS

Thirty sections ("tans") of used, 113-mm monofilament gillnet of the type used in the Japanese high-seas squid fishery were purchased from Kyoei Unyu Company, Ltd., Hakodate, Japan. Each section measured 50 m long and 9 m deep, with floats at 1-m intervals. Sections were joined together to make four nets, 50, 100, 350, and 1,000 m long.

Attached to each of the four nets was a small, dual-frequency, radio-satellite transmitter buoy (Fig. 1), designed by Telonics of Mesa, Arizona. The buoy, 90 cm in length and 9 cm in diameter, allowed tracking and potential recovery of each net. The UHF satellite transmitter portion of each buoy used the Argos system (Argos 1984) to give a location on the Earth's surface accurate to within several hundred meters. The satellite transmitter broadcast on a schedule of 24 h on, 72 h off; a series of locations was , therefore, available once every 4 days. The VHF radio transmitter portion of each buoy allowed close-range directional tracking and recovery within a radius of approximately 10 km. The radio transmitter broadcast once a second without interruption. The combination of long- and short-range location systems was designed to allow physical recovery of the buoy and net after drifting freely in the ocean for up to 18 months.

To reduce windage and to avoid accidental discovery by fishermen or others, the buoy also was designed to be as inconspicuous, both visually and electronically, as possible. The buoy projected only 25 cm above the ocean's surface. Further, the megahertz frequencies transmitted by the buoy's location systems were beyond the kilohertz frequencies commonly used in ships' radio direction finders (RDF's) for locating buoys.

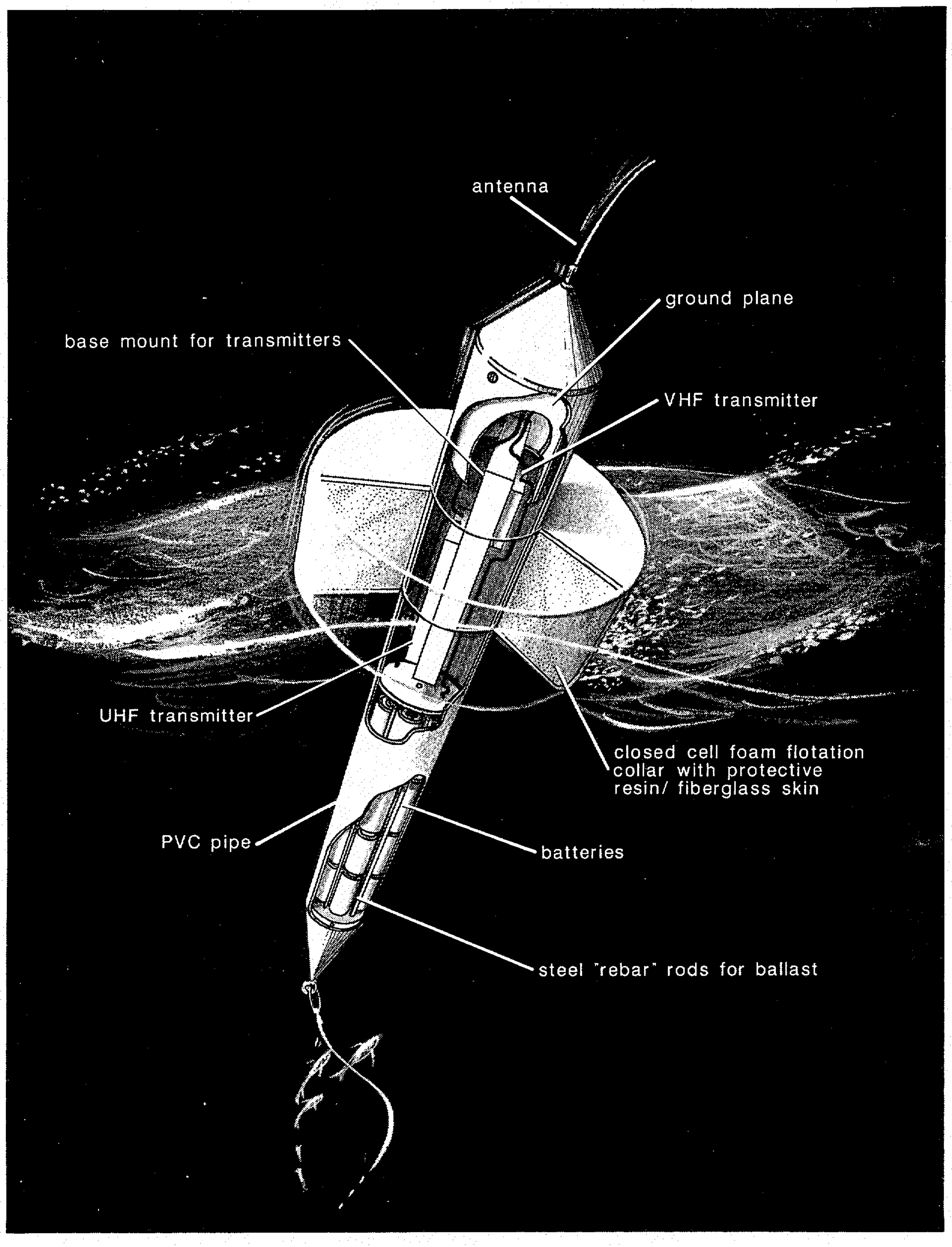

Figure 1. --Dual-frequency transmitter buoy used to track and recover experimental gillnets.

The nets and their associated buoys were deployed on 12 August 1986 from the NOAA ship Townsend *Cromwell* about 10 km east of Southeast Hancock Seamount, northwest of the Hawaiian Archipelago (Table 1). The nets were deployed by letting the ship drift downwind; hence, all nets were initially set parallel to the wind with the transmitter buoy at the downwind end. Measurements of *net* heading, length, and catch were made three times a day for 3 days from an inflatable boat. A temporary buoy was attached to one end of the net to serve *as* a visual target; from the other end, heading was then measured with a hand-held bearing compass, and length with an optical range finder. The configuration of each net was sketched. The longest (1,000-m) net was surveyed in a similar way, except that several visual targets were placed along its length, and measurements ❑ade in sections. Catch and fish aggregation around the nets were monitored by snorkel or scuba diving and documented photographically with video and 35-mm cameras.

Observations and measurements of the nets were confined to daylight hours. To track the nets during the night, larger buoy systems were attached to some nets each night and removed the next morning. Such a system consisted of a large RDF transmitter buoy; a long bamboo pole buoy with strobe light on top and large inflatable float; and a small, round, plastic buoy at the end of a tag line. The whole system had considerable windage. Because such a system probably affected a net's dynamics, the periods during which a large transmitter buoy system was attached to a net were considered in the interpretation of the results. The small radio-satellite transmitter buoys (Fig. 1), which were attached to the nets at all times, were considered *to* have negligible effects.

On the 10th day after deployment, the *Townsend Cromwell* returned and relocated all four nets. Rough seas, however, prevented launching a small boat, and the nets had to be observed from the deck of the *Townsend Cromwell*. After the cruise, the buoys were tracked by satellite until each buoy was either recovered or the signal from the satellite transmitter was lost. Positions were determined from monthly reports of Service Argos, Toulouse, France.

Table 1. --Experimental gillnet deployment on 12 August 1986 and tracking in the central Pacific Ocean. Dates and times are Midway standard time.

Buoy No.	Net length (m)	Deployment Time (h)	Deployment Latitude N	Deployment Longitude E	Recovery Date	Recovery Latitude N	Recovery Longitude	Days tracked (No.)
10013	50	0841	29°46.7′	179°10.3′	11/3/86	28°48.9′	176°57.6′W	83
10010″	100	0945	29°46.8′	179°09.8′	1/7/87	28°14.2′	178°13.2′W	148
10011″	350	1226	29°47.0′	179°08.6′	10/8/86	29°35.2′	176°18.9′W	57
10012	1,000	1330	29″47.6′	179°08.0′	6/17/87	23°00.1′	178°00.0′E	309

"Buoy was not recovered; recovery data reflect time and location at which the signal was lost.

RESULTS

Shape and Heading

During the first. 3 days, fair weather and calm seas greatly aided tracking and observation of the nets. Wind was east-southeast during this initial period but shifted to east-northeast on the second and third days and rose slightly in strength (Table 2). The nets first drifted north-northwest, then north-northeast, traveling about 9 km/day.

The 50- and 100-m nets shortened soon after deployment (Fig. 2). The 50-m net, in fact, had already collapsed by the time of the first observation, 30 min after deployment. "Collapsed" means that the net was folded like an accordion and all floats were close together. The net, however, was still hanging freely in the water; it was not tangled with itself.

The 350-m net contracted to about 40% of its original length during the first few hours, but then contracted more slowly (Fig. 2). By the 10th day, it had collapsed completely. The rate of collapse of this net may have been affected by the large transmitter buoy attached to the downwind end during the first night. The net was slightly longer the next morning (observation at 21 h). After removal of the large buoy system, the net further contracted (25 h) but was longer in the evening (29 h). The next day, the net followed a similar pattern, contracting between morning and afternoon and lengthening by evening. Greater detail of the changes in configuration of this net is shown in Figure 3A. Interestingly, the net rotated so that its heading 50 h after deployment was approximately 140° from its original heading.

Table 2. --Summary of wind and swell observations on 12-14 August 1986, the first 3 days of the gillnet experiment. Data are means calculated from the ship's hourly weather log.

Date	Time (h)	Wind		Swell	
		Speed (kn)	Heading	Height (ft)	Heading
12 August	0100-1200	9	116"	3	121°
	1300-2400	11	115"	3	116°
13 August	0100-1200	10	100°	3	118°
	1300-2400	14	70°	4	98°
14 August	0100-1200	13	74°	3	88°
	1300-2400	13	68°	4	83°

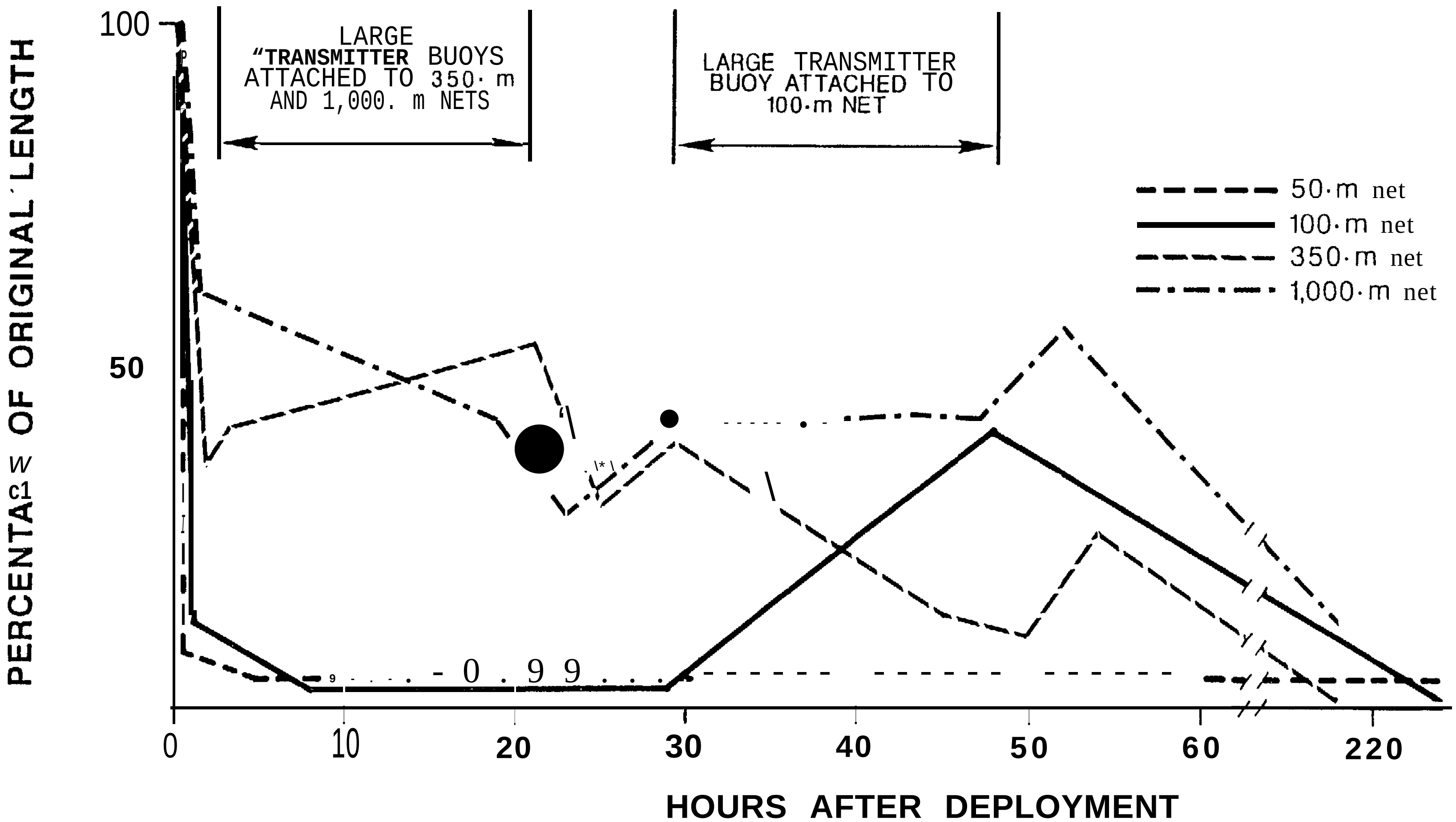

Figure 2. --Percentage of original lengths of four experimental derelict gillnets over time. During the first and second nights of observation, large transmitter buoys attached to certain nets may have affected net lengths.

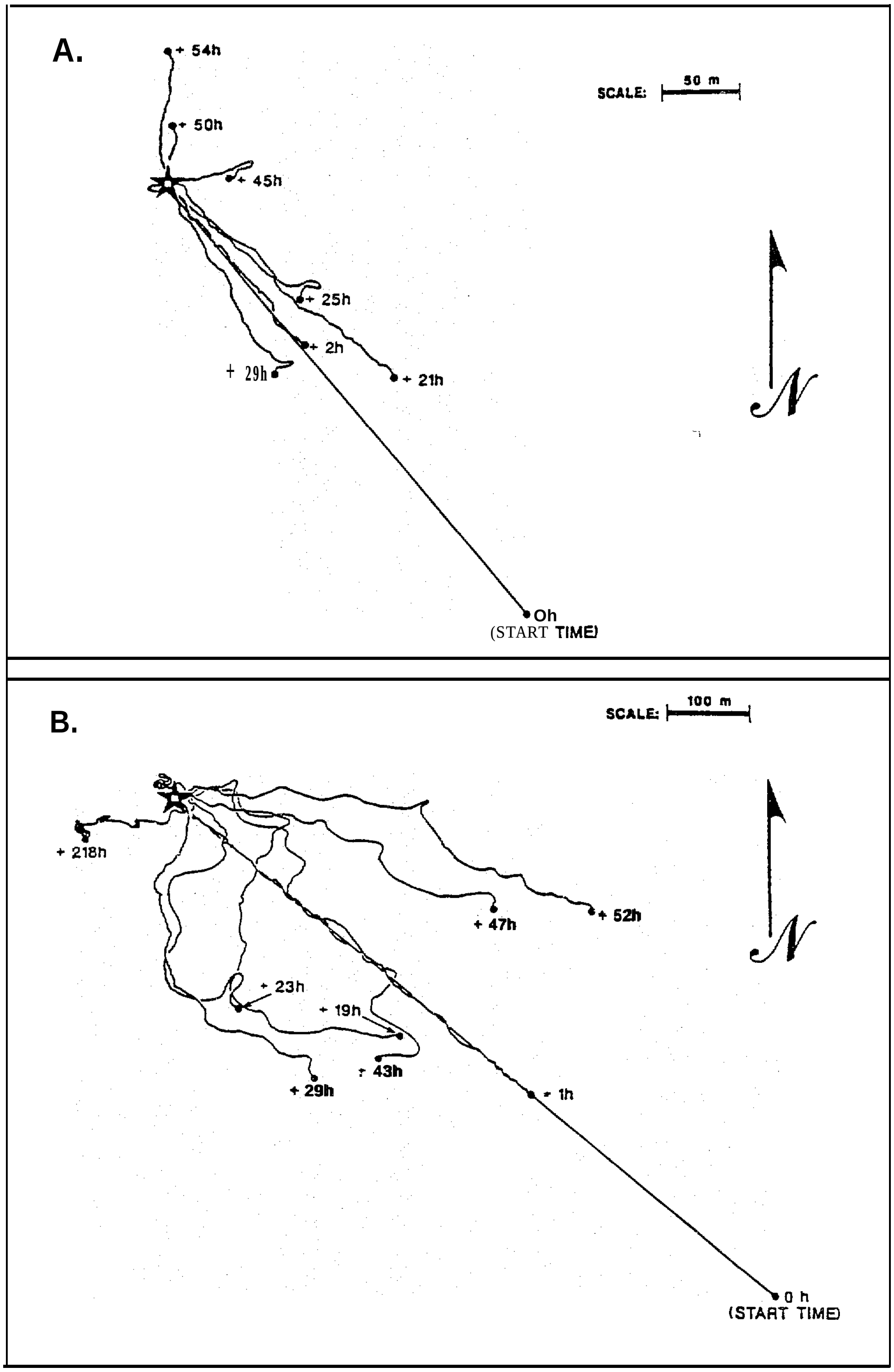

Figure 3. --Shape and heading of two experimental derelict gillnets at various points in time after deployment. The original windward end of the net (without the transmitter buoy) was placed at the origin (★) of each sketch. A) 350-111 net. B) 1,000-m net.

The 1,000-m net followed a pattern of contraction and expansion similar to the 350-m net, except that its relative size 52 h after deployment was only about 50% of original length instead of 25% (Fig. 2). The 1,000-m net also rotated in the same direction as the 350-m net, but only by about 30″ during the same period. By the 10th day (218 h), its heading had changed completely (Fig. 3B).

The time required for a gillnet to collapse was related to its original length. Figure 4 shows the time required for the various fragments of net to collapse to 10% of their original length as a function of their original length.

Catch

Very little was caught in any of the gillnets during the initial 3 days of observation. On the morning of the second day, a small marlin (*Makaira* sp.), about 1 m total length, was entangled in the 1,000-m net at the surface. On the third day, a large flyingfish (Exocetidae) was similarly caught in the same net. None of the other nets had any animals entangled in them by the end of the third day. Three small kahala (*Seriola* sp.) were observed swimming around the 350-m net on the second day. One opelu (*Decapterus* sp.) and three small kahala were seen around the 1,000-m net on the third day. Soon after the nets were deployed, several albatross (*Diomedea* sp.) landed on the water near the float line, but each left after a short investigation.

After 10 days, nothing was visible in the 50-, 100-, or 1,000-m nets, although one mahimahi, *Coryphaena hippurus*, was swimming near the latter. The floats of the 350-m net were in a tight group with numerous small kahala swimming nearby. A rotting, 2-m shark of undetermined species was entangled in the net, together with several bony fish too rotten to identify.

Movement

The location of each net during the entire course of the study, plotted once every 4 days, is shown in Figure 5. The number of days the buoys were tracked ranged from 57 to 309 (Table 1). The buoys and nets stayed in the general vicinity of the northwestern end of the Hawaiian Archipelago. For several months they remained north of Midway, then moved south . After 83 days at sea, the 50-m net and buoy 10013 were recovered by the *Townsend Cromwell*. Several species of fish were swimming near the net, and two pilotfish, *Naucrates ductor*, were caught in it (Table 3). No large animals were entangled in the net,

Buoy 10012, which was tracked the longest, traveled as far south as lat. 17°37.8′N, then returned north and west (Fig. 5). It was recovered after 309 days at sea by the chartered fishing vessel *Feresa*. The 1,000-m net was no longer attached to the buoy at that time. It is not known when the net became separated from the buoy, but the absence of barnacles, together with damage to the buoy, suggested that separation may have occurred only a short time before recovery. The buoy failed to transmit a

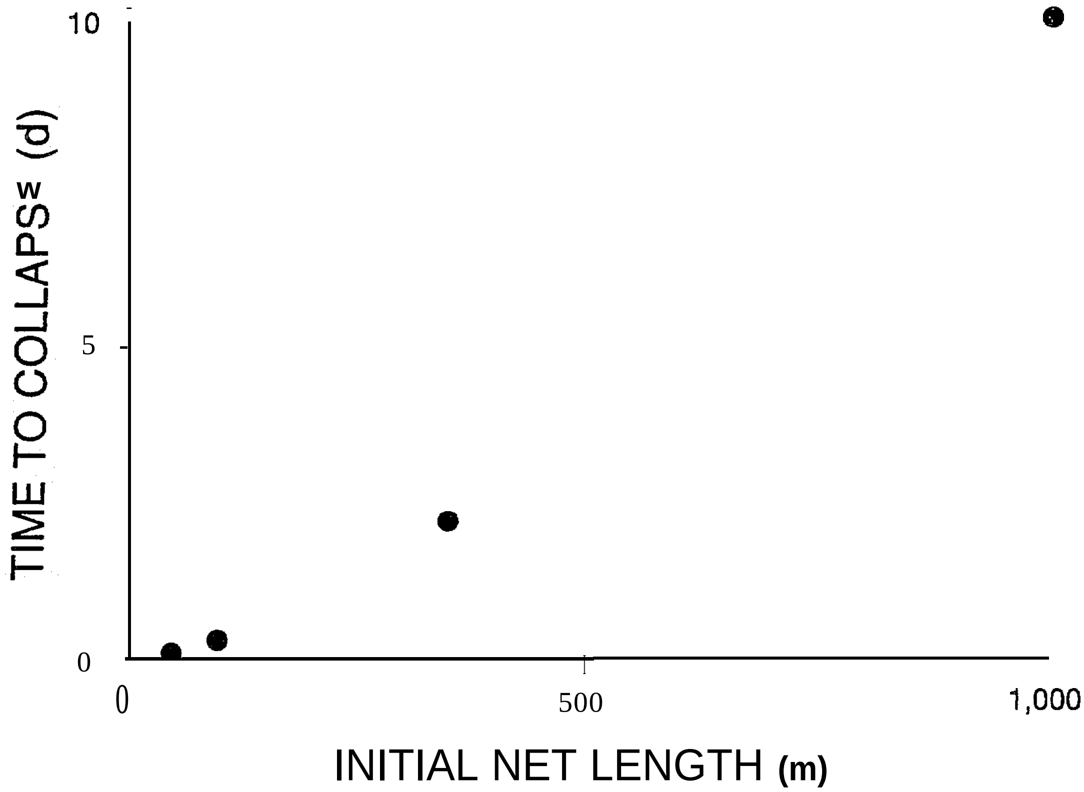

Figure 4.--Time required for a fragment of gillnet to collapse to 10% of original length as a function of its original length.

position on 8 June 1987, 9 days before recovery (Fig. 5), and was possibly entangled in the net at that time.

The two remaining nets and buoys were not recovered because their signals were lost. Signals stopped after 57 days for the 350-m net and 148 days for the 100-m net (Table 1). The reason for signal loss is not known, but the most likely explanation is that the buoys became entangled in the nets and submerged. Buoy 10010 on the 100-m net stopped transmitting about 15 km southeast of Kure Atoll (Fig. 5). Possibly the net became caught on the reef, but searches by plane and boat in August 1987 failed to find it.

For each 4-day interval, the mean speed of each buoy was computed. Mean speed per 4-day interval varied widely, from less than 1 km/day to nearly 50 km/day (Fig. 6). The 4-day mean speeds reflect several types of water movement: advection, inertial movement, and other eddies of various scales. Overall mean speed was 14.8 km/day or about 0.3 kn. The frequent and abrupt changes in speed and direction, however, meant that the distance

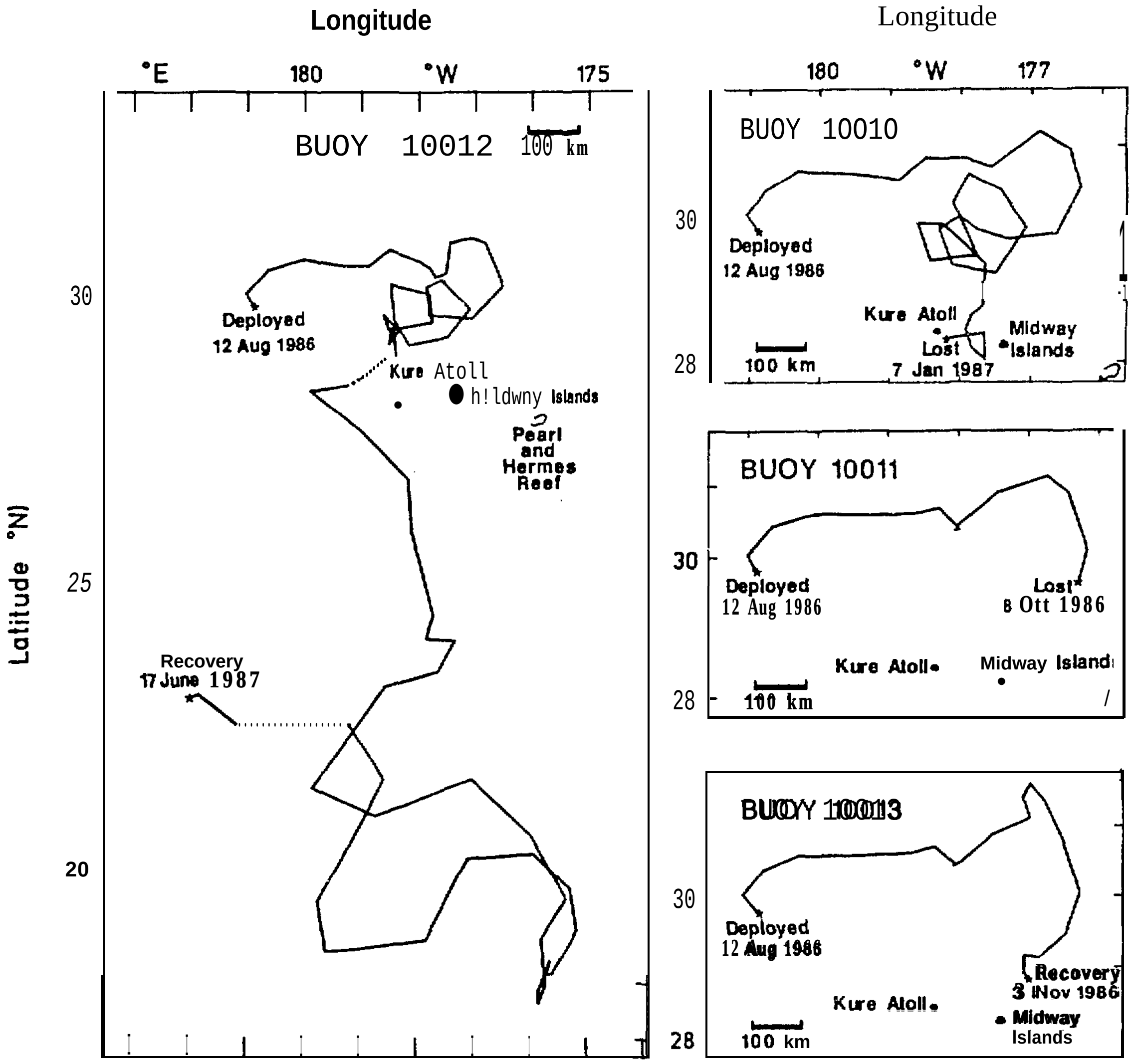

Figure 5. --Positions of four experimental derelict gillnets in the central Pacific Ocean, plotted at 4-day intervals. Dotted lines connect positions more than 4 days apart.

from the point of release did not bear any simple relation to time (Fig. 7). The four buoys traveled more or less together as long as they were tracked; the buoy tracked the longest (buoy 10012) drifted nearly 1,500 km from the point of deployment, then returned (Figs. 5, 7).

DISCUSSION

The amount of gillnet that becomes lost, detached, or discarded in the course of gillnet fishing operations is not known with any precision. Based on fishing activity, however, the total amount is undoubtedly large. The loss rate of 0.05%, mentioned earlier, is an unsubstantiated estimate given by a Japanese Government official (Komatsu 1986) during public hearings on the incidental catch of marine mammals during high-seas driftnet salmon fishing. Eisenbud (1985), citing a 1982 letter from Richard B. Roe,

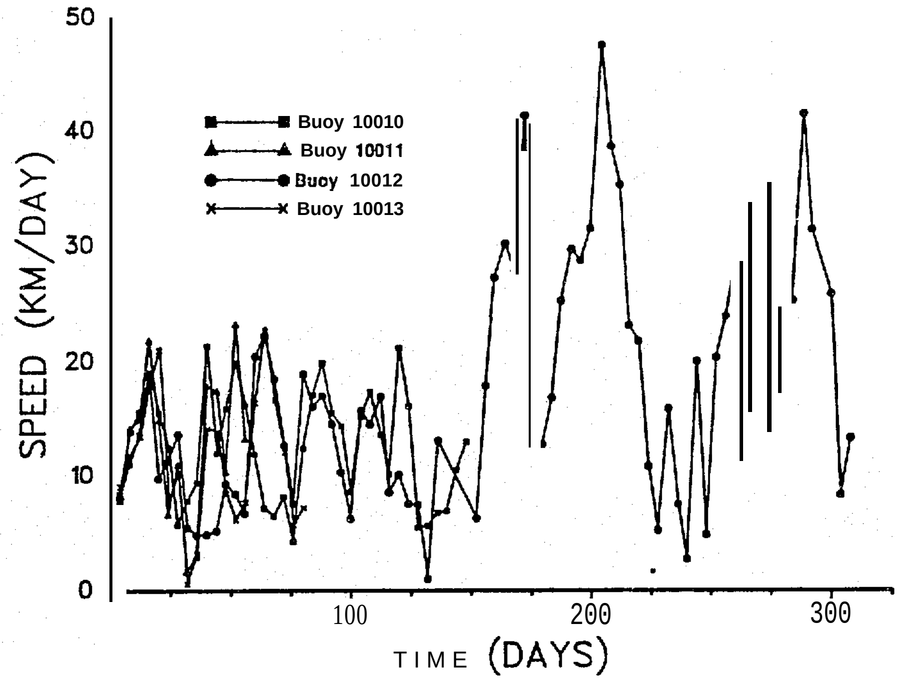

Figure 6. --Mean speed in each 4-day interval for the four gillnets, plotted as a function of time from deployment.

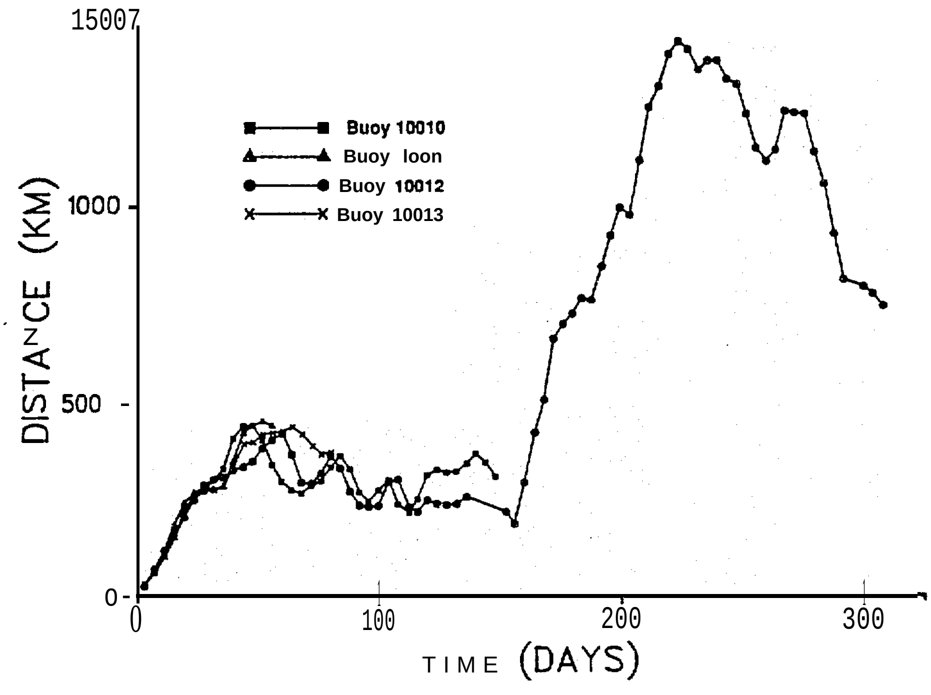

Figure 7. --Distance of each fragment of gillnet from the point of deployment, plotted as a function of time from deployment.

Table 3. --Biological observations near the 50-m gillnet recovered on 3 November 1986 north of Midway. The net had been drifting for 83 days. N = number of individuals sighted.

Species sighted	N	Sighting location
Pilotfish, *Naucrates ductor*	2	Caught in net.
Barracuda, *Sphyraena helleri*	20	Swimming near net.
Mahimahi, *Coryphaena hippurus*	2	Swimming near net.
Alutera scripts	11	Swimming near net.
Naucrates ductor juveniles	14	Swimming near net.
Unidentified fish, possibly *Kyphosus* sp.	7-12	Swimming near net.
Black-footed albatross, *Diomedea nigripes*	7	On surface near net.

NMFS, mentions an estimated 0.06% loss rate for the same fishery. Such a low loss rate, even if accurate for this fishery, is unlikely to apply to other types of gillnet fishing. For example, coastal gillnetting operations are likely to have a higher rate of net loss because of more boat traffic and a greater chance of nets becoming hung up on the bottom. Even so, applying this minimum loss rate to the total amount of available gillnet means that thousands of kilometers of derelict gillnet enter the North Pacific every year.

The fishing ability of a net depends on its size and configuration in the water (see also Mio et al. 1990). Left alone, a drifting gillnet will eventually collapse and become entangled with itself. The rate at which this happens depends, among other things, on the original length of the net. Rapid collapse of short sections of net is expected because of the weight of the lead line and local turbulence; longer nets have greater resistance to these small-scale effects. Over the range of sizes of gillnet fragments used in this study, it appeared that the rate of collapse was approximately 100 m/day (Fig. 4). Thus, net fragments less than 100 m long collapsed in less than a day, those several hundred meters long in several days, and those 1 km or longer in several weeks. These rates give a first approximation of the length of time a derelict gillnet would remain in an active fishing configuration. Note that these estimates apply to *intact* fragments of gillnet--that is, with both float and lead lines attached. The absence of a lead line, in particular, might affect the rate at which a net fragment collapses.

The rate of collapse may also depend on other factors. High wind and swell may make the net collapse faster. If a large animal, such as a shark or seal, is caught in a net, its struggling may also hasten the collapse of the net. If a buoy is attached to one end of the net, the force of wind on the buoy may keep the net open much longer, as demonstrated by the effect of the large transmitter buoy system on the 100-m net in this study. After 1 day, the net was completely collapsed, but after the large buoy system was attached to it overnight, the net lengthened (Fig. 2). The nearby 50-m net, which did not have a large buoy system attached to it, did not lengthen during the same period. The force of the wind on the large buoy, which was at the downwind end of the net, caused a constant pull on one end of the net and was the likely cause of its lengthening.

Once collapsed, a gillnet is still capable of catching fish, though much less effectively. The rapid collapse of the nets in this study suggests that the catch rate of a lost or discarded gillnet will, for the target species, decline rapidly. Whether the hazard of a derelict gillnet also declines rapidly for nontarget species, however, is not resolved by this study. A floating mass of *net* will attract fish that may, in turn, attract predators like birds, sharks, seals, and dolphins.

The movement of debris on the ocean's surface is controlled by a combination of wind and surface currents. The gillnets used in this study have a large surface area in the water and little above it. Hence, their movement over a period of months (Fig. 5) reflects mainly the movement of the upper 10 m of water rather than wind drift. Currents in the Hawaiian Archipelago are complex and irregular (Wyrtki et al. 1969). Eddies of various sizes are common in Hawaiian waters (Seckel 1955; Patzert 1969), and the loops executed by buoys 10010 and 10012 may indicate such eddies. Movements on smaller space and time scales, such as inertial motion, are not resolved by the 4-day interval between buoy positions in this study. Inertial circling was observed in the finer scale measurements of Matsumura et al. (1990).

The abrupt changes in speed and direction of the nets in this study illustrate that predicting the movement of marine debris is a difficult problem (Gait 1985; Seckel 1985). The movement of marine debris can be approached both experimentally and through simulation modeling (Matsumura et al. 1990). At least around the Hawaiian Archipelago, simple models of linear motion (distance proportional to time) or diffusion (distance proportional to the square root of time) will not predict the movement of derelict gill nets (Fig. 7). The general problem of predicting the movement and fate of debris in the ocean requires greater knowledge of factors affecting the "birth" and "death" rates of the various "species" of marine debris (Gerrodette 1985).

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PRELIMINARY STUDY ON CHANGE IN SHAPE OF DRIFTING NETS EXPERIMENTALLY PLACED IN THE SEA

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ABSTRACT

Research activities to understand the impact of lost drifting nets on marine organisms were initiated in 1988, and an experiment to clarify how the lost nets change their shape at sea was conducted as the first stage of the activities.

Five driftnet sets (40 tans each) were placed in the water in the area around lat. 38°N, long. 158°E, and their shapes were observed from 5 to 25 May. After this, the net sets were allowed to drift, and about 3 months later (in early September) were again observed and subsequently retrieved.

The observations were visual, and recordings were made using a camera-equipped balloon and a video camera from a research vessel.

Three days after setting, one of the nets began twisting into a mass near each end of the net. As time passed, the mass grew larger: the ends of the net approached each other and the net folded in half. Each mass continued to grow, and several small masses also were formed in portions of the long, overlapped net. Twenty days after setting, the net had become one large mass.

All nets observed became masses in the same way, although the speed of formation varied. In September, when the research vessel visited these nets again, each was found floating in a mass,

INTRODUCTION

It has been noted that fishing nets, especially gillnet fragments (hereafter referred to as drifting nets), drift in the sea out of man's control and continue catching marine organisms such as fish while drifting. However, there has been only fragmentary information concerning movements of drifting nets and the actual damage done to marine organisms. Therefore,

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since 1988 we have been conducting research on the movement and changes in shape of drifting nets as well as their impact on marine organisms. This paper examines the changes in the shape of drifting nets in the course of time. Gillnets are thought to be the most effective means of catching fish, as they are set in the sea in a straight line. Once freed from man's control, gillnets are believed to change shape as time passes, with their fishing efficiency gradually declining. We conducted a survey on changes in the shape of drifting nets over time in order to establish a basis *for* research on related changes in fishing efficiency.

METHODS OF SURVEY

The research was conducted in the North Pacific Ocean on the salmon driftnet fishing ground at lat. 35°-45°N, long. 150°E-180°. The first survey was conducted from 1 to 30 May 1988, and the second from 17 August to 30 September. Five nets were used for the experiments, and each consisted of 40 tans of nylon monofilament gillnet with a mesh size of 115 mm.

An Argos buoy and a "self-call" buoy were attached to the net, one at each end. The location of each net was recorded an average of six times a day using information from the Argos buoy.

On the first cruise, experimental drifting nets were observed by sighting from on board the vessel and photographing from above with a remote control camera attached *to* a balloon. On the second cruise, experimental drifting nets were located using information from the buoy. They were retrieved after visual confirmation as well as confirmation through a remote control television attached to a balloon.

RESULTS

The six experimental nets, stretched tight, were set in the area lat. 39°20'-38"43'N, long. 154°33'-155°44'E from 1406 on 6 May to 1710 on 7 May. The experimental nets were observed a total of only 16 times, since they moved in two different directions after setting, with two drifting northeast and the other three southeast. Three nets were observed four times and two were observed twice before being retrieved (Table 1).

Except for net No. 1, each experimental net showed generally the same pattern of changing although they differed in pace. First, each end of the net twisted and formed a small mass (Fig. 1A). Second, each net folded in half and its two ends approached each other. The two ends formed a mass, twisting with each other, and the rest of the net stretched long, overlapping more and more (Fig. 1B and C). Third, as time passed, the stretched part wound around the mass. After reaching the third stage, the stretched part of the net formed a mass slowly, becoming entangled and disentangled. Observed 15 and 18 days after release, it was 50 to 60 m long compared with its original length of 2 km, indicating that it did not need many days to become a complete mass. When the five experimental nets were all collected after drifting for a long time, each net had formed a complete mass (Fig. 1D).

Table 1. --Trajectory and width (← →) change of six floating nets in 1988.

Net No.	Date	Width (m)	Latitude N	Longitude E
1	25 May	2,000	40″04′	153°06′
	15 Sept.	5	40°20′	161″08′
2	7 May	2,000	39″19′	154°50′
	10 May	1,250	39°10′	155″12′
	12 May	120	39°19′	155″25′
	18 May	250	38°12′	159°04′
	23 May	60	38″31′	158°15′
	3 Sept.	5	33°56′	169°15′
3	7 May	2,000	39°05′	155°28′
	11 May	160	38°14′	156″52′
	19 May	130	37″18′	160°14′
	28 Aug.	5	40°51′	171°28′
4	7 May	2,000	38°42′	155°19′
	12 May	310	38°14′	154°55′
	18 May	120	37°29′	158″49′
	31 Aug.	5	35°34′	179°46′
5	7 May	2,000	38°48′	154″04′
	13 May	800	39°25′	153°58′
	16 May	500	39°23′	153″56′
	21 May	250	40°06′	153°45′
	25 May	50	40°12′	153°05′
	11 Sept.	5	39°57′	158°10′
	6 May	2,000	39°06′	154″33′
	8 May	1,150	39°20′	154°28 ′
	10 May	1,080	39°34′	153°23′
	16 May	600	39°19′	158°07′
	22 May	180	39°32′	153″19′

Note: Measurement of width (← →) refers to Figure 1.

As for the time required to reach each stage, the five nets (excluding net No. 1) remaining in this experiment can be divided into two groups (Fig. 2): One group needed 4 to 5 days after release to reach the third stage; the other needed 14 to 16 days to reach the third stage.

The approach of both ends of a drifting net is the basic process of changing the shape. The structure and arrangement of nets and accompanying buoys also seem to affect the changes. In this experiment, buoys were

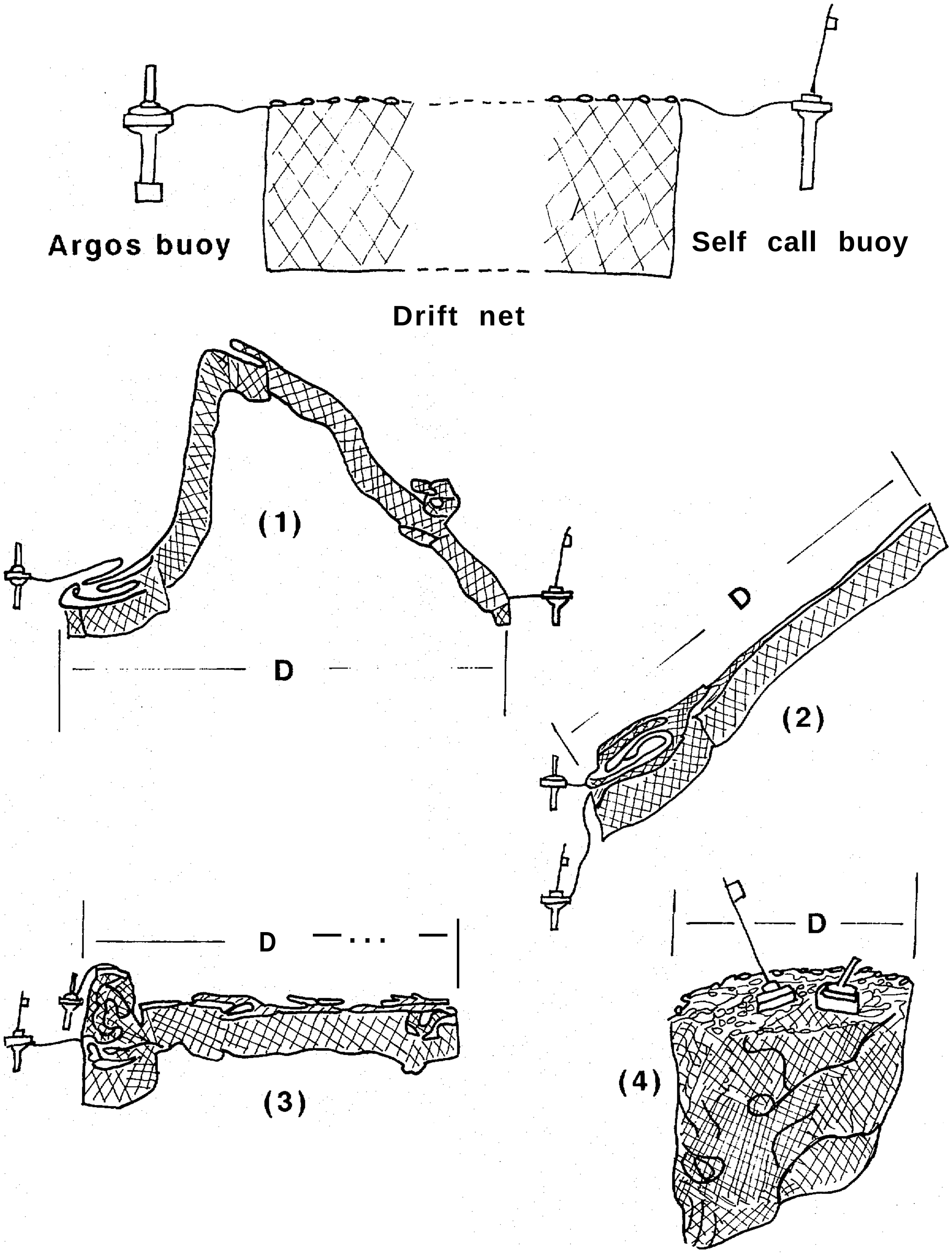


Figure 1. --Schematic diagram showing formation of a mass of floating net after setting ((← →) denotes width of floating net).

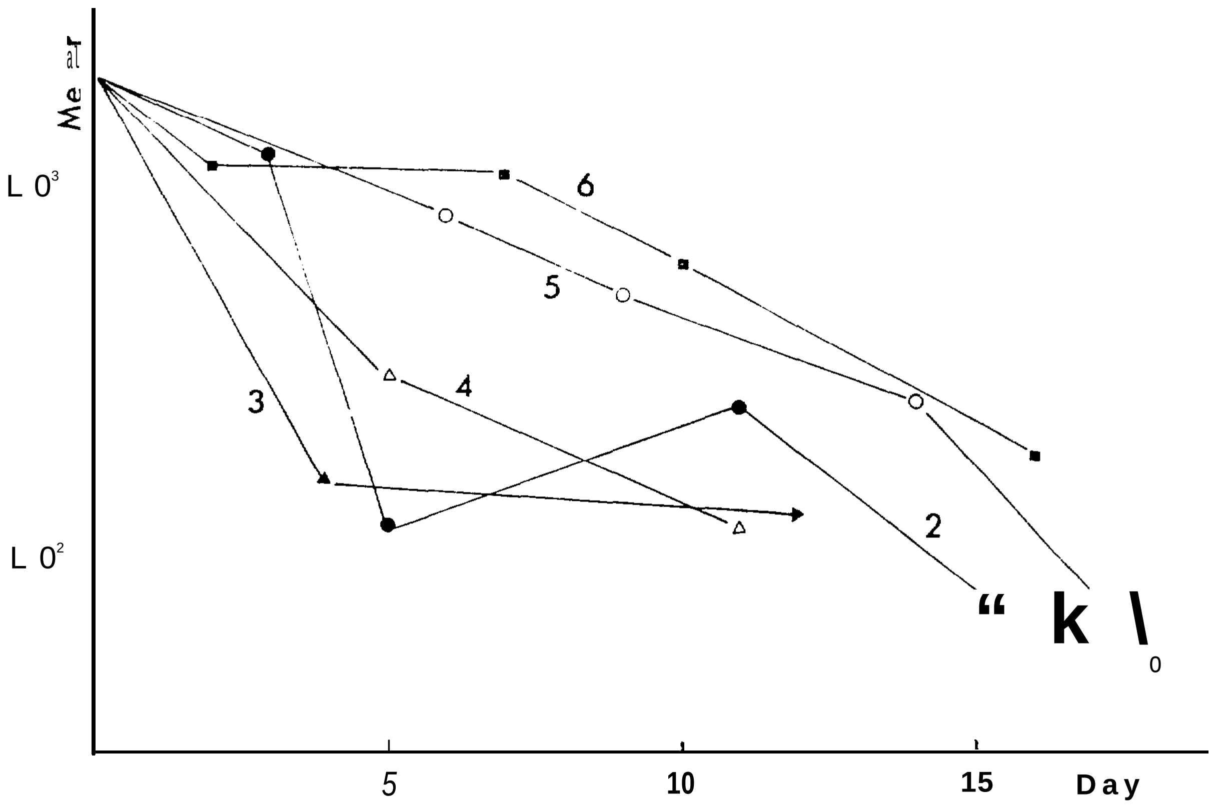
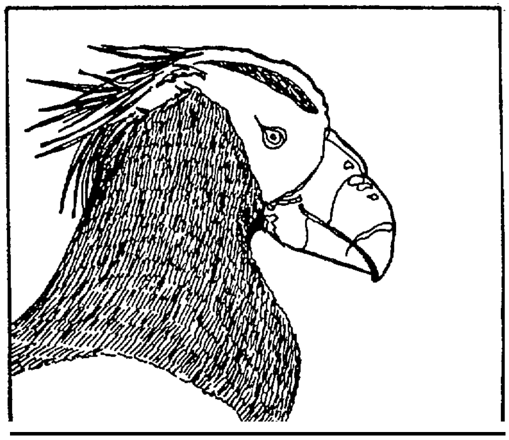


Figure 2. --Relationship between floating period and longest width of net.

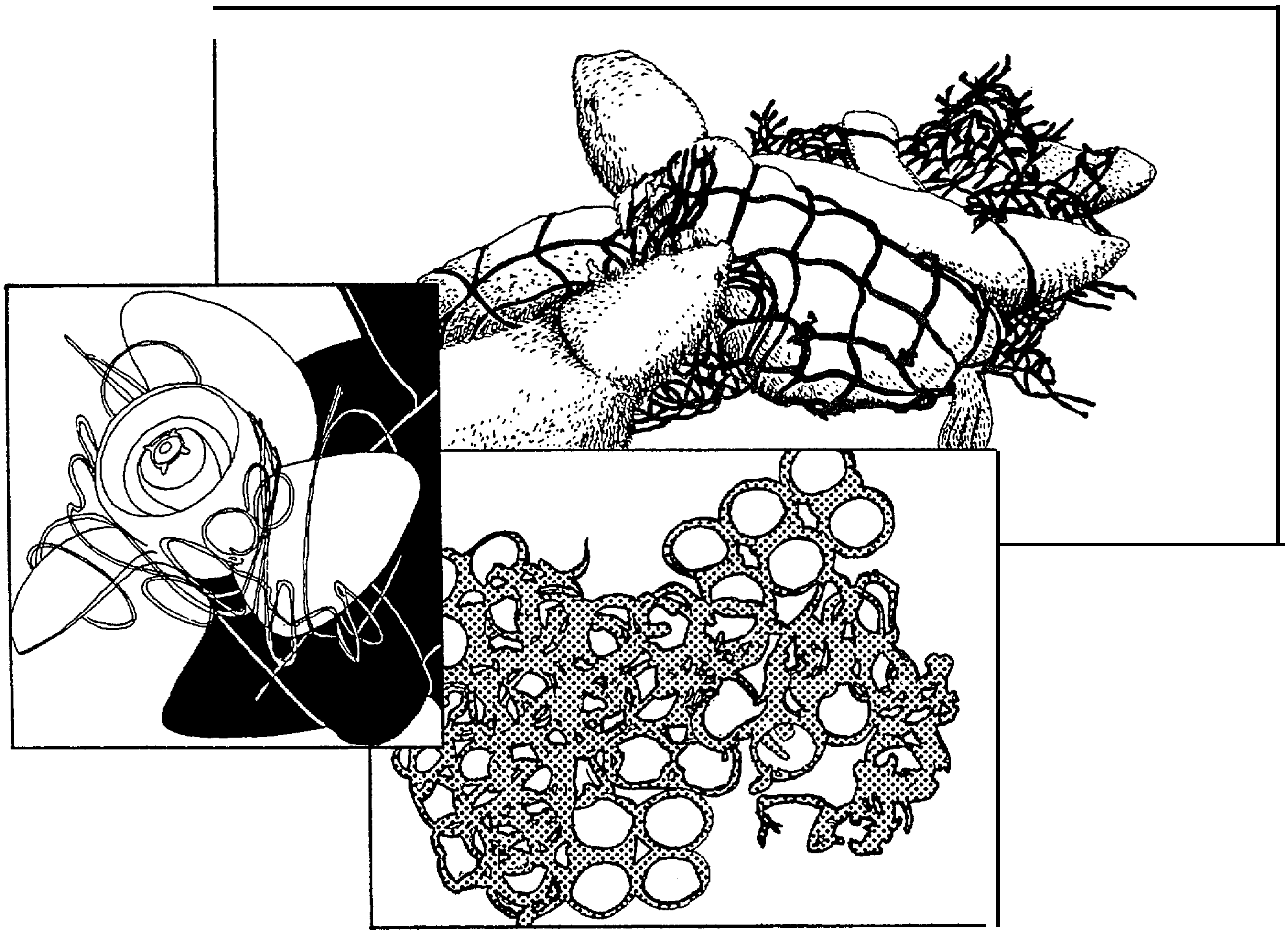
attached at both ends of a net. It may be assumed that the difference in resistance between the buoys and the net helped the two ends approach each other. The Argos buoy is a cylinder 160 mm in diameter and 790 mm in height, with a float 440 mm in diameter and 200 mm in height. It is quite small compared to the size of the net. Eight days into the experiment, the Argos buoy temporarily attached to No. 4 net dropped off, and one end of the net was subject to the same resistance as the net alone. However, both ends of the No, 4 net approached each other in the same way as the other nets.

As both ends behaved in a manner similar to other nets with buoys attached on both ends, it is suggested that there would be no changes in the basic configuration even though the presence of buoys may affect the speed of shape change. We plan to conduct further experiments to study effects of different conditions on net shape changes.

SESSION III



INGESTION BY MARINE LIFE



THE EFFECTS OF INGESTED PLASTIC AND OTHER MARINE DEBRIS ON SEABIRDS

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ABSTRACT

Seabirds ingest plastic particles and other marine debris more frequently than do any other taxon. Despite considerable speculation as to the adverse effects ingested debris has on seabirds, there have been few experiments designed to test these hypotheses. Initial attempts to demonstrate adverse effects were based on correlations between plastic load and bird condition. However, unless the influence of season and breeding status are removed, negative correlations cannot be used to infer an adverse effect from ingesting plastic. Few statistically significant negative correlations have been found among adequately controlled samples, suggesting that the effects of ingestion are either relatively minor or that they frequently are masked by other variables. To avoid ambiguous results, carefully designed experiments are required to assess the severity of the specific adverse effects that have been hypothesized to result from debris ingestion.

Ingested debris may have three specific effects on seabirds: physical damage and blocking of the digestive tract, impairment of foraging efficiency, and the release of toxic chemicals. The severity of these effects depends upon the types of debris ingested and their retention time within seabirds.

At present, severe physical damage and obstruction of the digestive tract is infrequent in seabirds, and probably affects only a small proportion of populations. Virgin (raw) plastic particles were not found to affect the assimilation efficiency of the white-chinned petrel, ***Procellaria aequinoctialis***, but seabird feeding may be affected by large plastic loads that reduce the food storage volume of the stomach, causing reduced meal size and, consequently, the ability to accumulate energy reserves. Experiments on free-ranging seabirds are required to confirm this, potentially the most serious consequence of plastic ingestion by seabirds. An estimate of the critical load size is required to determine the proportion of populations likely to be affected by reduced food intake.

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Little is known about the transfer of toxic compounds from ingested plastic to seabirds, but a significant positive correlation between polychlorinated biphenyls and plastic loads in the great shearwater, *Puffinus gravis*, independent of other organochlorines , suggests that the pathway exists. This warrants confirming experimentally, and the toxicity of various additives such as plasticizers and colorants needs to be determined. Other types of debris such as tar balls and paint also are sources of toxic chemicals to seabirds; the incidence of their ingestion needs to be investigated.

Not all birds are equally vulnerable to the effects of ingested debris. Species that seldom regurgitate indigestible stomach contents, and thus accumulate large debris loads, are most prone to adverse effects. Immature petrels apparently are particularly vulnerable because they cannot unload their accumulated debris by feeding chicks.

INTRODUCTION

On a global scale, seabirds ingest plastic particles and other marine debris more frequently than do any other taxon. At least 82 seabird species out of 140 examined have been found to contain ingested plastic and other debris, and the incidence of ingestion exceeds 80% of individuals in several species (e.g., Day et al. 1985; Fry et al. 1987; Ryan 1987b; Sileo, Sievert, Samuel, and Fefer 1990). Most work to date on plastic and other debris ingestion by seabirds has focused on recording the incidence of ingestion in various taxa (e.g. , Day et al. 1985; Furness 1985a, 1985b; van Franeker 1985; Ryan 1987b; van Franeker and Bell 1988; Sileo, Sievert, Samuel and Fefer 1990). This has proved valuable in several ways; in addition to providing baseline data on the temporal and spatial increase in debris at sea (e.g., Rothstein 1973; Baltz and Morejohn 1976; Harper and Fowler 1987), it has helped raise public awareness of the marine debris problem, and has provided an insight into the dynamics of ingested plastic in seabird populations (e.g. , Day et al. 1985; Ryan 1988b). However, despite being the most important question arising from plastic ingestion, there have been few studies on the severity of adverse effects resulting from plastic ingestion by seabirds (Day et al. 1985; Azzarello and van Vleet 1987; Ryan 1987a). This paper reviews what is known of the impacts of ingested plastic and other debris in seabirds, and identifies key areas for future research.

GENERAL INDICATORS OF ADVERSE EFFECTS

Most attempts to demonstrate adverse effects resulting from plastic and other debris ingestion by seabirds have been based on correlations between debris load and indicators of bird condition (Day et al. 1985; Ryan 1987a) . Weak negative correlations between plastic loads and either body mass or the mass of fat deposits have been detected (Day 1980; Conners and Smith 1982; Furness 1985a, 1985b; Ryan 1987a), but in most cases the lack of adequately controlled sampling (for factors such as age, reproductive status, and time of year) seriously hampers the interpretation of results (Ryan 1987a). The poor relationship between indicators of bird condition and plastic load suggest that the effects of ingestion are either relatively minor or that they frequently are masked by other variables.

The main drawback to using correlations *to* demonstrate adverse effects from plastic ingestion is the inability to separate cause from effect. Ingested plastic may cause poor bird condition, or a bird in poor condition may be more prone to ingest plastic (Conners and Smith 1982), assuming at least some plastic is ingested as a result of "misdirected foraging" (i.e., plastic eaten directly, not incidentally with prey; Ryan 1987b). Similarly, stranded birds may have higher-than-average plastic loads because the ingested plastic has affected the birds' ability to survive adverse weather conditions, or because starving birds are less discriminating and eat more plastic immediately prior to stranding (Bourne and Imber 1982; Ryan 1987b). Day (1980) recorded larger plastic loads in nonbreeding than in the breeding parakeet auklet, *Cyclorrhynchus psittacula*, but this could also be due to age-related foraging differences (Day et al. 1985). The only way to avoid these ambiguous results is to perform experiments designed to test the specific adverse effects postulated to result from debris ingestion.

SPECIFIC EFFECTS OF PLASTIC AND OTHER DEBRIS INGESTION

The specific effects of ingested debris on seabirds can be divided into three categories; physical damage and blocking of the digestive tract, impairment of foraging efficiency, and the release of toxic chemicals (Day et al, 1985; Ryan 1987a). The severity of these different categories of effects varies according to the types of debris ingested and their retention time within seabirds.

Physical Damage and Obstruction of the Digestive Tract

Physical damage and blocking of the digestive tract is the most obvious effect of ingested debris on seabirds, resulting in starvation in extreme cases of gastrointestinal obstruction (e.g. , Parslow and Jefferies 1972; Dickerman and Goelet 1987; Fry et al. 1987). However, obstruction of the digestive tract currently is infrequent in seabirds, and probably affects only a small proportion of populations (Ryan and Jackson 1987). Gastrointestinal obstruction by plastic has been suggested to be an important cause of chick mortality among albatross chicks in the North Pacific (Pettit et al. 1981; Fry et al. 1987), but this is not supported by recent observations (Sileo, Sievert, and Samuel 1990) which found only occasional instances of obstruction.

Threads and fibers may result in obstruction more frequently than other debris types because they form dense, intertwined balls in seabird gizzards, blocking the entrance to the intestine (Parslow and Jefferies 1972; Day et al. 1985). However, intestinal obstruction was not found in any of the more than 200 white-chinned petrels, *Procellaria aequinoctialis*, sampled off southern Africa, despite fibers comprising almost half the mass of ingested plastics (Ryan 1987b; Ryan and Jackson 1987).

To test whether ingested debris interferes with digestion, the assimilation efficiency (digestive efficiency) of white-chinned petrels fed large loads (1.4 g, more than twice the maximum load recorded for the species; Ryan 1987b) of virgin polyethylene pellets was compared with that of control birds (Ryan and Jackson 1987). No significant difference was detected, suggesting that at least virgin pellets have little effect on seabird digestive efficiency. However, similar experiments with other types of plastics are warranted.

Cuts and ulcerations of the stomach lining caused by ingesting sharp objects are more frequent than is intestinal obstruction (e.g. , Day et al. 1985; Zonfrillo 1985; Fry et al. 1987; Ryan and Jackson 1987). These lesions are seldom likely to be lethal, because seabirds tolerate similar injuries from sharp prey items (Baltz and Morejohn 1976; Bourne and Imber 1982; Fry and Lowenstein 1982). However, lesions may have sublethal effects, reducing disease resistance and thus influencing survival (Fry et. al. 1987).

Impaired Foraging Efficiency

Debris accumulated in the stomachs of seabirds has been postulated to impair foraging efficiency as a result of mechanical distension of the stomach. This has two effects: it induces a false feeling of satiation and reduces the food-storage volume of the stomach (Day et al. 1985; Ryan 1988a) . Both these mechanisms would tend to reduce foraging efficiency and consequently the ability to accumulate energy reserves essential for reproduction, molting and the survival of adverse weather conditions (Ryan 1988a) . However, there have been no direct tests of this effect of ingested debris on seabirds.

Ryan (1988a) showed that chickens fed 10 virgin plastic pellets ate smaller meals and grew more slowly than did control birds, although production (growth per unit food eaten) was not affected by plastic loads (which is to be expected if plastic pellets have little or no influence on digestive efficiency, see above). This provides empirical evidence that plastic loads comparable to those found in similarly-sized seabirds affect foraging efficiency in birds. However, experiments on free-ranging seabirds are required to assess the severity of this problem. One possible test would be to monitor the breeding success of birds whose chicks are fed additional plastic loads.

Given the very large frequency of occurrence of ingested plastic and other debris in some seabird populations, it is essential to estimate the critical load size (relative to bird size) beyond which stomach distension caused by accumulated debris has a deleterious effect. A few small particles are unlikely to have an adverse effect, because many seabirds store quantities of squid beaks and naturally occurring indigestible debris such as pumice in their ventriculi (e.g., Furness 1985a; Ryan 1988b). Fortunately, the distributions of total plastic loads in individual birds are strongly skewed, with most birds having very small plastic loads (Fig. 1), and this probably results in a fairly small proportion of seabird populations being adversely affected by stomach distension caused by ingested debris. Even the species with the greatest occurrence of ingested plastic off southern Africa, the blue petrel, *Halobaena caerulea* (92% of birds containing plastic; Ryan 1987b), has 85% of birds containing plastic loads <25% of the maximum load recorded (Fig. 1).

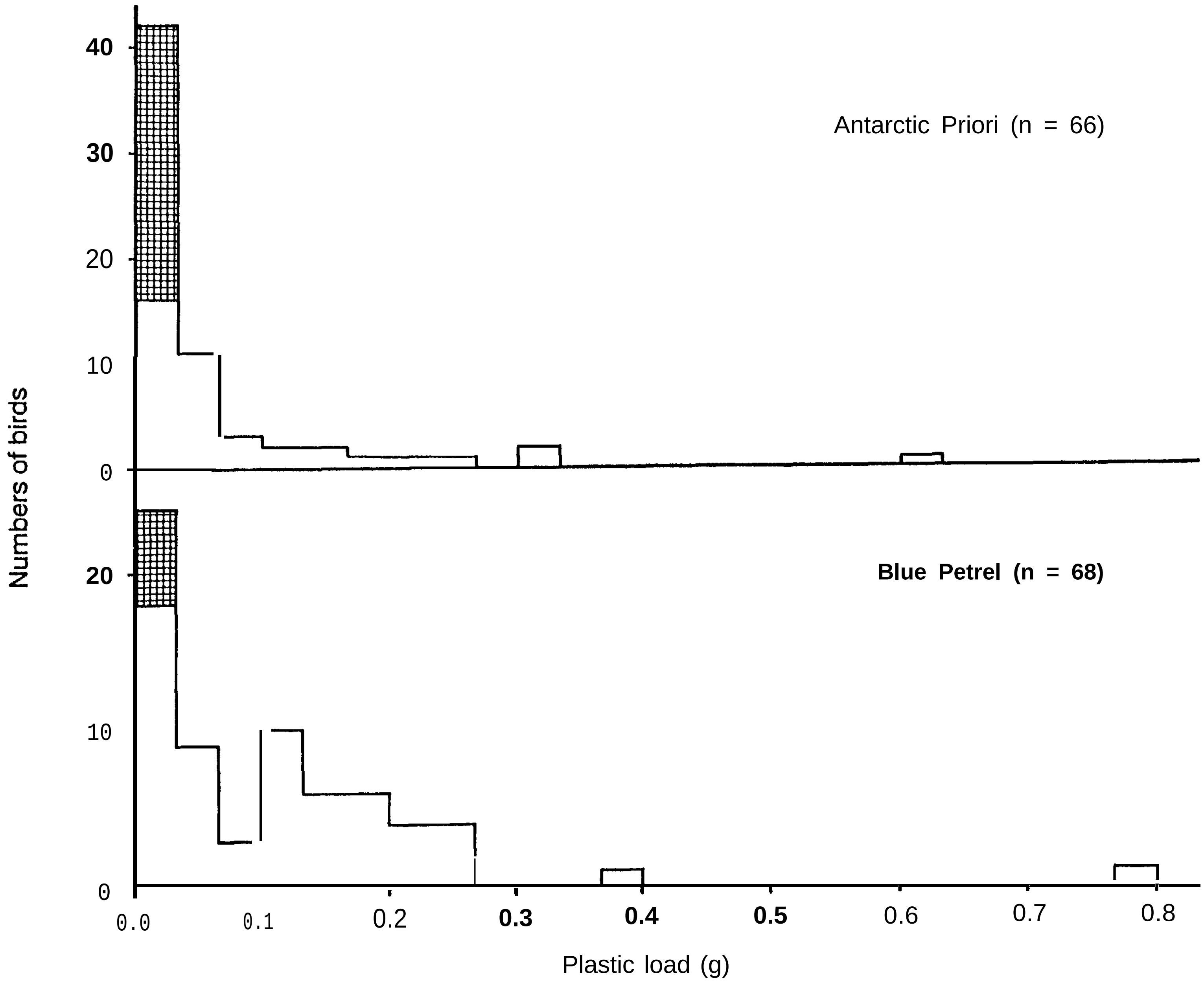

Figure 1. --The total plastic loads (by mass) of individual Antarctic prions, *Pachyptila desolata*, and blue petrels, ***Halobaena caerulea***. *See* Ryan (1987b) for sampling procedures, Hatching depicts birds containing no plastic particles. Note the highly skewed distributions, with relatively few birds having large plastic loads.

Ingested Debris as a Source of Toxic Chemicals

It has been suggested that plastics and other debris ingested by seabirds are a source of toxic chemicals (e.g., Pettit et al. 1981; Bourne and Imber 1982; Day et al. 1985; van Franeker 1985). Plastics contain a variety of toxic additives including colorants, plasticizers, and heat and ultraviolet stabilizers (Gregory 1978; van Franeker 1985; Wirka 1988), and at sea the surface of plastic particles adsorb certain organochlorine compounds, notably polychlorinated biphenyls (PCB's) (Carpenter et al. 1972). The only direct evidence to indicate that seabirds receive toxic chemicals from ingested plastic is the positive correlation found between plastic and PCB loads in female great shearwaters, *Puffinus gravis*, immediately after egg-laying, independent of other organochlorine loads (Ryan et al. 1988). More circumstantial evidence is that both interspecific and intraspecific (geographical) variations in PCB concentrations in eggs of Hawaiian seabirds (Ohlendorf and Harrison 1986) correlate with the prevalence of ingested plastic (Sileo, Sievert, Samuel, and Fefer 1990), although this pattern may result from foraging differences (Ryan et al. 1988). The uptake of toxic compounds from ingested plastics needs to be confirmed by examining seabird tissues for traces of plastic-specific additives (Ryan 1988b). Although the toxicity of plastic additives to seabirds (both singly and synergistically) needs to be determined, it is likely that plastics contribute only a small proportion of the total toxic chemical load borne by seabirds (Bourne 1976; Ohlendorf et al. 1978; Fry et al. 1987; Ryan 1988b).

Other types of debris ingested by seabirds are potentially more serious sources of toxic chemicals. Although not ingested at sea, Laysan albatross, *Diomedea immutabilis*, chicks are killed by lead and perhaps mercury poisoning from ingestion of paint peeling off buildings on Midway (Fry et al. 1987; Sileo, Sievert, and Samuel 1990). This presumably is a localized problem, and can be readily alleviated. However, paint flakes have also been found in the stomach of a pintado petrel, *Daption capense*, collected at sea off southern Africa (Ryan 1990). Birds that frequently scavenge from vessels are likely to ingest some paint, particularly when ship scraping and repainting occurs at sea. Seabirds also ingest tar balls (Brown et al. 1981; van Franeker 1985; Ryan 1986), and petroleum products are known to have adverse toxicological effects on seabirds (e.g., Fry et al. 1986; Koth and Vauk-Hentzelt 1988). More information is required on the incidence of paint and tar ball ingestion by seabirds before an estimate of impacts on seabird populations can be made. Particular attention should be paid to the lifespan of paint and tar balls after ingestion; if they are rapidly broken down in seabirds' stomachs, the incidence of ingestion may be greater than these scattered records indicate.

VULNERABILITY TO THE EFFECTS OF INGESTED DEBRIS

The vulnerability of a given species or age-class of seabirds to the effects of debris ingestion is determined by the type of debris ingested: the sizes and shapes of pieces of debris presumably are important in determining the degree of physical damage to the digestive tract, and different compounds vary as regards toxicity. However, probably the major factor affecting vulnerability is the dynamics of debris ingestion and loss. The magnitude of debris loads in birds are a function of the balance between the rate of ingestion and the rate of loss of ingested debris.

Virtually all debris ingested by seabirds floats in seawater, and is eaten when mistaken for food items, or in association with prey (Day et al. 1985; Ryan 1987b; but see Fry et al. 1987). Inter- and intraspecific comparisons of plastic loads illustrate that the rate of ingestion is related to foraging technique (greatest incidence in surface feeders), foraging niche width (greatest in generalists), and the local density of debris at sea (Ryan 1987b). The rate of loss is related to the maximum size of particles passed through the digestive tract, the rate of erosion within the stomach, and the frequency of regurgitation of indigestible objects. Of these factors, the frequency of regurgitation appears to be the primary determinant of whether or not seabirds accumulate plastic particles and other debris in their stomachs (Ryan 1987b, 1988b).

There are three patterns of regurgitation among seabirds (Fig. 2). Some birds, including giant-petrels, cormorants, skuas, gulls, terns, and albatrosses , frequently regurgitate indigestible stomach contents, preventing any accumulation of ingested plastic or other debris (Ryan 1988b) . These birds are unlikely to suffer many serious effects from the ingestion of persistent debris. The main problems are likely to be ulcerations and lesions caused by sharp objects (e.g. , glass in gulls feeding at refuse dumps) or the release of toxic chemicals (either those rapidly absorbed from the surface of particles, or those associated with debris that is not easily regurgitated, such as tar balls that adhere to the stomach lining).

Other seabird taxa apparently seldom regurgitate indigestible stomach contents (Furness 1985a, 1985b; Ryan 1987b), and it is these accumulators of ingested debris that are likely to show adverse effects resulting from debris causing stomach distension and from obstruction of the digestive tract. For the majority of procellariiform seabirds (petrels, shearwaters, storm-petrels and diving-petrels), the main avenue for removing ingested debris occurs during the chick-feeding period, when plastic particles accumulated throughout the nonbreeding season are fed to the single chick along with the chick's meals that are stored in the parents' stomachs (Fry et al. 1987; Ryan 1988b). This pattern of annual regurgitation results in an annual cycle in the amount of plastic and other debris in breeding adult petrels (Ryan 1988b, fig. 2). Other taxa that seldom regurgitate indigestible stomach contents, such as auks and phalaropes, but do not feed their chicks food stored in the stomach (e.g., Bedard 1969), apparently lack this avenue for plastic loss. These taxa accumulate ingested plastic and other debris (Conners and Smith 1982; Day et al. 1985; Ryan 1988b), but the dynamics of debris loads are poorly understood, and particle loss may depend almost entirely on erosion and subsequent excretion.

Not all seabirds that accumulate ingested plastic and other debris in their stomachs are equally vulnerable to the effects of ingested debris. A consequence of the intergeneration transfer of ingested debris is that chicks fledge with a debris load approximately equal to *2* years' accumulation by adult birds. This initial loading is exacerbated subsequently by the greater ingestion rate of young, naive birds (Day et al. 1985; Ryan 1988b) and the lack of an effective loss mechanism during the protracted immature period (up to 10 years; Croxall 1984). This suggests that immature petrels have the largest debris loads stored in their stomachs, and are most likely to show adverse effects from debris ingestion.

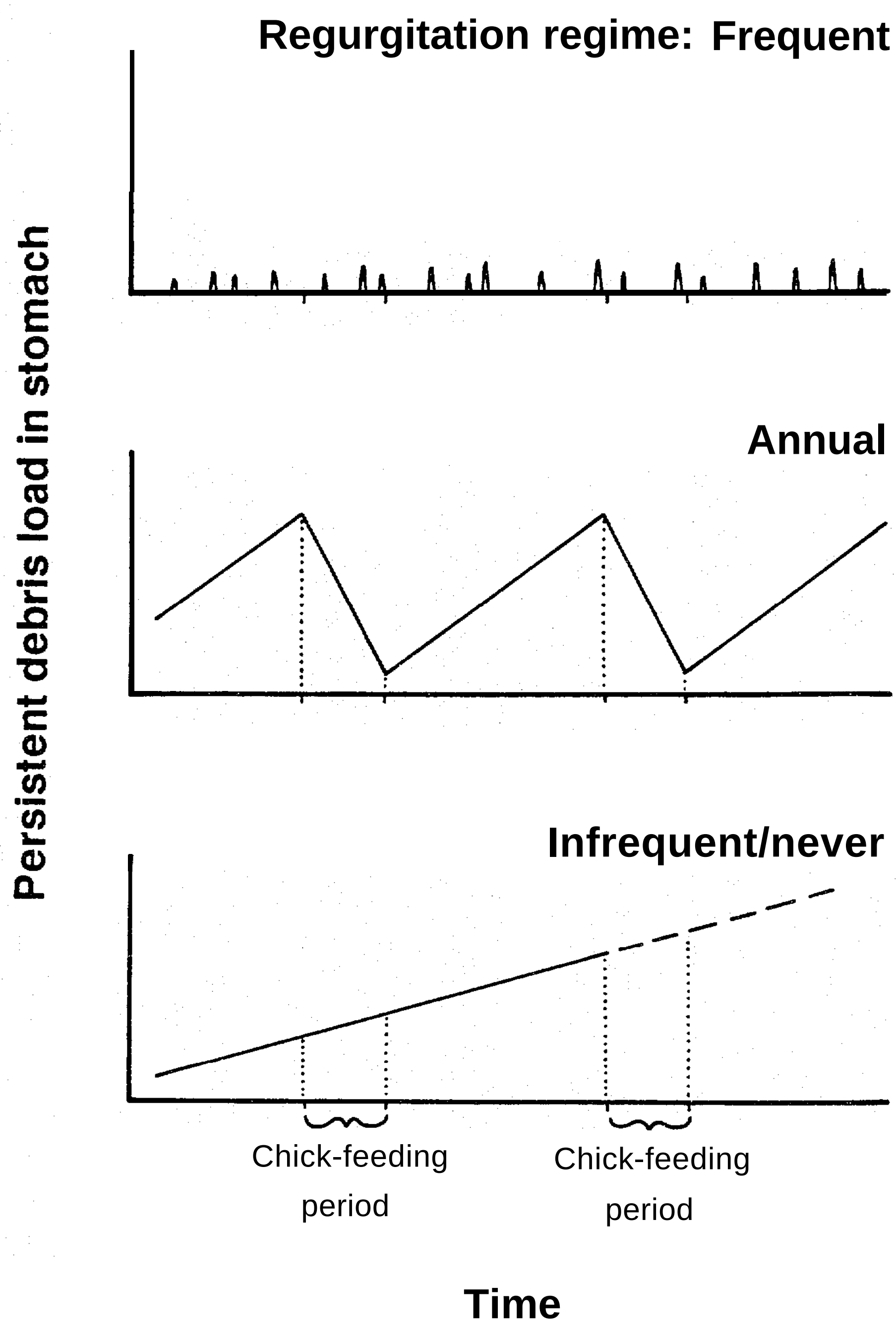

Figure 2. --Diagrammatic representation of the effect of different regurgitation frequencies on the pattern of persistent debris accumulation in seabird stomachs.

FUTURE RESEARCH DIRECTIONS

The preceding review has indicated several areas where both the effects and the dynamics of debris ingestion are poorly understood. The following points summarize key problems that warrant special attention.

1. Verification that stomach distension resulting from accumulated debris causes reduced meal size and thus reduces the foraging efficiency of seabirds.

2. Assuming that 1) holds, an estimate is needed of the critical load size beyond which stomach distension has serious effects.

3. Examination of seabird tissues for plastic-specific additives is required to test whether toxic compounds are assimilated from ingested plastic particles.

4. Assuming that 3) holds, tests of the toxicity of plastics additives to seabirds (both singly and synergistically) are needed.

5. Experimental assessment of the lifespans of different types of debris in seabird stomachs is essential to interpret correctly the dynamics of ingestion.

6. Continued monitoring of debris loads in seabirds is warranted to detect major changes in ingestion patterns or effects, such as an increase in the incidence of obstruction of the digestive tract.

Ingestion by seabirds is a function of the density of debris at sea, and it is only by reducing this density that the incidence of ingestion can be reduced. However, a thorough understanding of both the dynamics and effects of plastic ingestion may enable implementation of measures specifically targeted to lessen the effects on seabird populations.

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INGESTION OF PLASTIC PARTICLES BY SOOTY AND SHORT-TAILED SHEARWATERS IN THE NORTH PACIFIC

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ABSTRACT

Differences in rates of ingestion and types of plastic particles ingested by 218 sooty shearwaters, *Puffinus griseus*, and 324 short-tailed shearwaters, *P. tenuirostris*, obtained between 1970 and 1987 were examined. Of these seabirds, 193 sooty shearwaters (88.5%) and 265 short-tailed shearwaters (81.8%) were found to have ingested plastic particles. Significant differences in ingestion rates by year and area of collection were observed for short-tailed shearwaters. However, only one case of significant difference was observed for sooty shearwaters in the northern North Pacific.

After analyzing plastic particles ingested by these two species of seabirds on the basis of shape and color, plastic molding materials ingested by short-tailed shearwaters were found to account for 67.2% of all particles. On the other hand, sooty shearwaters mainly ingested particles of plastic products, with plastic molding materials accounting for only 38.4%. These differences were believed to reflect the differences in food habits of the two species.

INTRODUCTION

The behavior of actively ingesting objects with no nutritional value, called Pica Phenomenon, is commonly observed among birds, including seabirds (Day 1980). Since the second half of the 1960's, plastic production has increased sharply, and plastic has become a major pollutant of the marine environment. However, the impact of plastic ingestion by seabirds has not been made sufficiently clear.

This study analyzes characteristics of plastic particle ingestion by sooty, *Puffinus griseus,* and short-tailed shearwaters, *P. tenuirostris*, based on records of the number, shape, and color of plastic particles found in gastric contents of the two species of shearwaters prevalent in the subarctic North Pacific Ocean at the same time in summer.

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MATERIALS AND METHODS

All of the shearwaters from whose stomachs plastic particles were extracted were individuals killed incidentally in the course of driftnet fishing. Dates and sites of collection and the number of specimens are shown in Figures 1 and 2 and Tables 1 and 2.

A total of 218 sooty shearwaters were examined. They were obtained at 62 driftnet fishing sites between April and October for 7 years during the period between 1975 and 1987 (Fig. 1, Table 1). A total of 324 short-tailed shearwaters were collected at 62 driftnet fishing sites between April and August for 8 years between 1975 and 1987.

Geographically, collection sites of sooty shearwaters were distributed in the North Pacific in an area bounded by lat. 31°-51°N and long. 143°E-143°W (Fig. 1). Those of short-tailed shearwaters were limited to the northwestern part of the Pacific, two sites in Bristol Bay in the Bering Sea, and all of the Aleutian Basin except for five sites around Cape Navarin (Fig. 2).

Shape and color of plastic particles taken from the stomachs of the two species of shearwaters were examined on an individual basis. Colors were classified into 11 types: white, yellow, brown, yellow-brown, blue, green, red, dark blue, dark green, dark red, and black/gray. Shapes and forms were classified into 13 types: cylinder, pill, dome, sphere, box, asymmetrical molding materials, string, cone, fragments of asymmetrical plastic products, vinyl, rubber, unidentifiable particles, and other. Of these, vinyl and rubber, whose shapes and forms are difficult of determine, are dealt with as independent categories because of their high ingestion *rates* by seabirds. On the basis of these data, frequencies of appearance of plastics were compared and examined by year, month, latitude, and longitude. The cases in which the number of bird individuals were 10 or fewer per item were excluded from statistical testing.

Classification and recognition of plastic particles in this study followed the method of Day (1980).

RESULTS

Interspecies Differences in Plastic Ingestion Rates

Tables 1 and 2 show the location and number of sooty and short-tailed shearwaters with and without plastic particles. The numbers of individuals ingesting plastic particles were 193 (88.5%) for sooty shearwaters (Table 1) and 265 (81.8%) for short-tailed shearwaters (Table 2). The difference in plastic particles ingestion rates between the two species was $\chi^2 = 4.023$ (df = 1, $0.025 < P < 0.05$), indicating slight interspecies differences, although they were not so obvious.

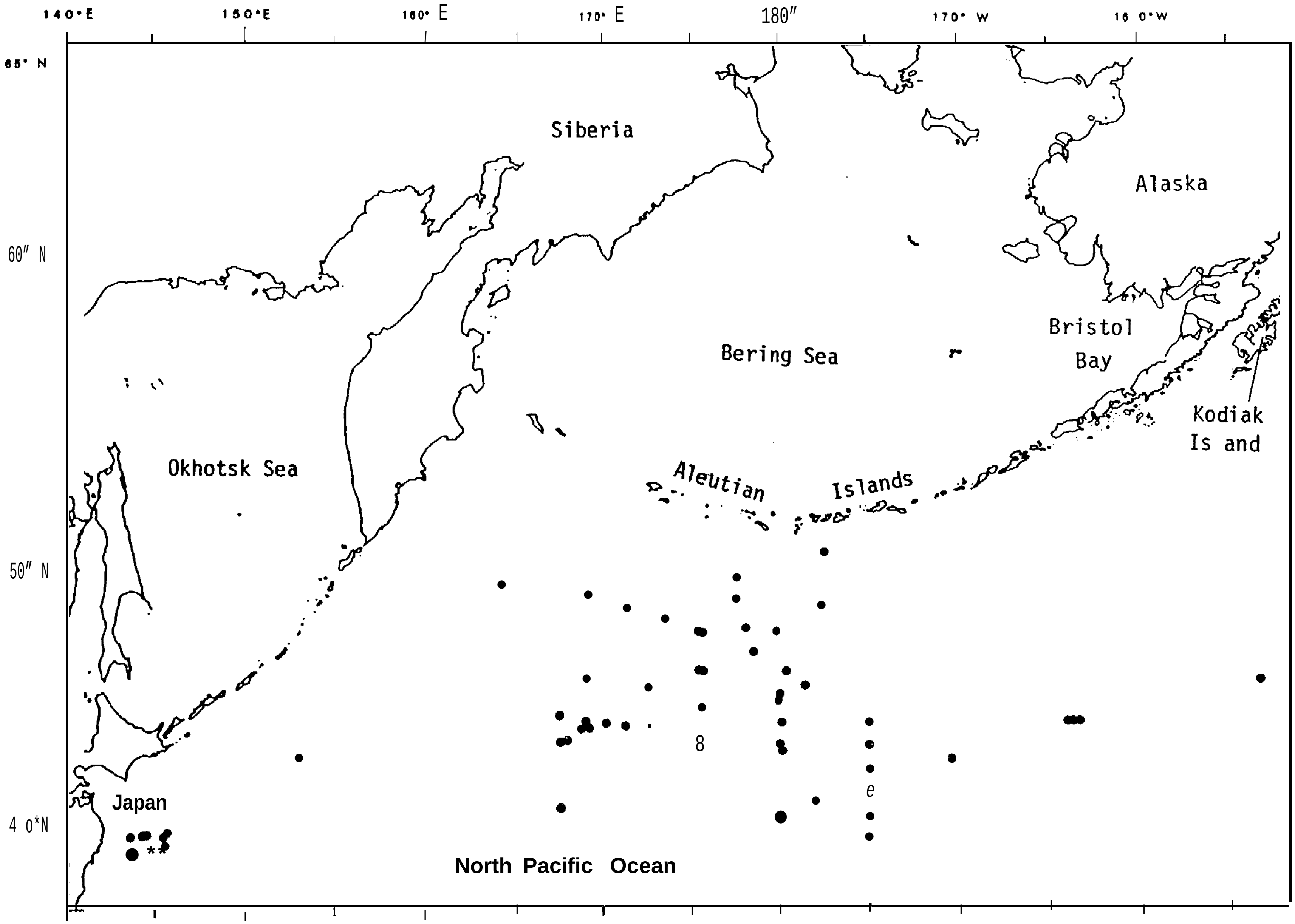

Figure 1. --stations where sooty shearwaters were sampled.

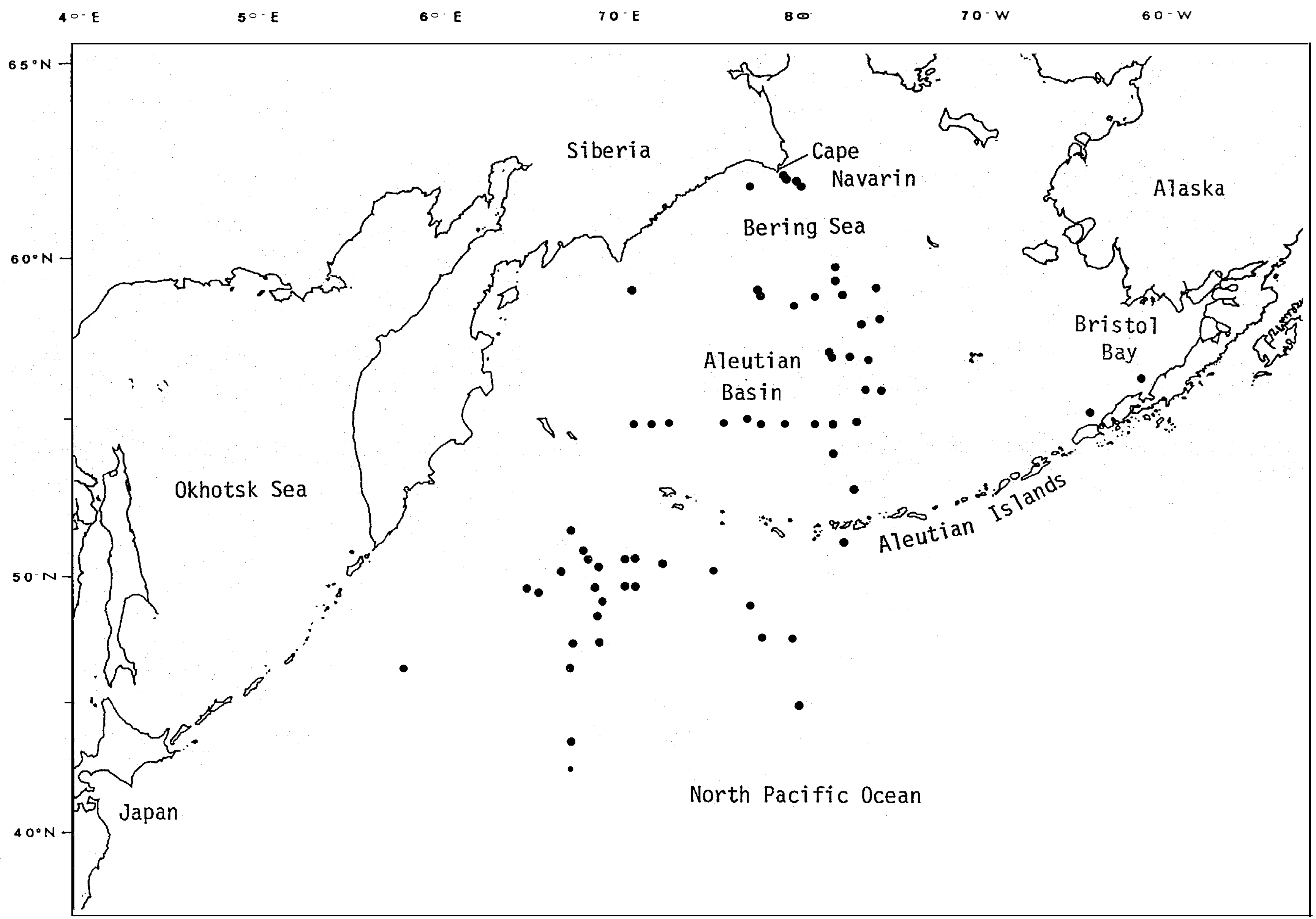

Figure 2 --Stations where short-tailed shearwaters were sampled

Table 1.--Frequency of occurrence of plastics in sooty shearwaters.

Date		Location		With plastic		Without plastic		Total number
		Latitude	Longitude	No.	Frequency (%)	No.	Frequency (%)	
19 Apr.	1975	40°35'N	167°31'E	1	100	0	0	1
13 June	1977	47"38'N	178°01'E	1	50.0	1	50.0	2
14 June	1977	47°37'N	179°44'E	0	0	2	100	2
14 July	1978	44°28'N	167°25'E	8	100	0	0	8
17 July	1978	45°30'N	172°25'E	3	75.0	1	25.0	4
26 July	1978	48°47 'N	177°28'E	2	66.7	1	33.3	3
28 July	1978	44°58'N	179°58'E	1	100	0	0	1
2 Aug.	1978	48°31'N	177°34'W	3	75.0	1	25.0	4
2 Aug.	1978	46°00'N	175°33'E	1	100	0	0	1
3 Aug.	1978	47°30'N	175°30'E	2	100	0	0	2
5 Aug.	1978	50°25'N	177°32'W	1	100	0	0	1
8 Aug.	1978	49°29'N	164°12'E	1	100	0	0	1
14 June	1979	45°00'N	180°00'	1	100	0	0	1
19 June	1979	40°06'N	179°59'W	5	100	0	0	5
22 June	1979	39°00'N	175°00'W	1	100	0	0	1
23 June	1979	40°00'N	175°00'W	1	100	0	0	1
24 June	1979	41°00'N	174°59'W	9	100	0	0	9
25 June	1979	42°00'N	175°00'W	6	100	0	0	6
26 June	1979	43°00'N	175°00'W	7	100	0	0	7
27 June	1979	43°59'N	174°59'W	4	100	0	0	4
26 July	1979	49°33'N	177°32'E	0	0	1	100	1
29 July	1979	43°15'N	175°24'E	5	100	0	0	5
30 July	1979	44°32'N	175°29'E	14	77.8	4	22.2	18
31 July	1979	43°58'N	179°58'W	4	100	0	0	4
31 July	1979	46°00'N	175°30'E	3	75.0	1	25.0	4
1 Aug.	1979	43°01'N	180°00'	1	100	0	0	1
1 Aug.	1979	47°30'N	175°29'E	2	100	0	0	2
2 Aug.	1979	48°00'N	173°28'E	9	81.8	2	18.2	11
3 Aug.	1979	48°29'N	171°19'E	2	66.7	1	33.3	3
4 Aug.	1979	48°59'N	169°09'E	4	100	0	0	4
7 Aug.	1979	42°48'N	153°02'E	4	100	0	0	4
5 Sept.	1979	43°54'N	172°40'E	1	100	0	0	1
11 Sept.	1979	46°46'N	178°19'E	1	100	0	0	1
16 Sept.	1979	45°35'N	178°24'W	1	100	0	0	1
2 Oct.	1979	40°40'N	178°03'W	1	100	0	0	1
3 Oct.	1979	40°40'N	178°03'W	6	100	0	0	6
9 Oct.	1979	43°56'N	171°41'E	1	100	0	0	1
10 Oct.	1979	44°02'N	170°37'E	10	90.9	1	9.1	11
11 Oct.	1979	43°53'N	169°22'E	0	0	1	100	1
12 Oct.	1979	44°01'N	169°19'E	1	100	0	0	1
13 Oct.	1979	45°56'N	168°58'E	2	100	0	0	2
14 Oct.	1979	43°51'N	169°38'E	1	100	0	0	1
15 Oct.	1979	43"27'N	167°53'E	5	100	0	0	5
16 Oct.	1979	43°22'N	167°35'E	2	100	0	0	2

Table 1.--Continued.

Date	Location		With plastic		Without plastic		Total
	Latitude	Longitude	No.	Frequency (%)	No.	Frequency (%)	number
13 June 1980	40°02'N	179°58'E	2	66.7	1	33.3	3
16 June 1980	42°58'N	179°59'W	0	0	1	100	1
20 June 1980	46°04'N	179°34'W	1	50.0	1	50.0	2
29 July 1980	43°00'N	175°28'E	4	100	0	0	4
21 Apr. 1986	38°35'N	145°30'E	3	100	0	0	3
27 Apr. 1986	39°30'N	144°30'E	1	50.0	1	50.0	2
29 Apr. 1986	39°37'N	145°38'E	10	90.9	1	9.1	11
30 Apr. 1986	38°32'N	144°23'E	1	100	0	0	1
1 May 1986	38°31'N	143°32'E	1	100	0	0	1
2 May 1986	39°00'N	145°30'E	1	50.0	1	50.0	2
18 July 1986	45°00'N	150°02'W	1	100	0	0	1
5 May 1987	39°30'N	143°29'E	1	100	0	0	1
6 May 1987	39°30'N	144°30'E	2	100	0	0	2
7 May 1987	39°29'N	145°30'E	0	0	1	100	1
18 Aug. 1987	42°28'N	170°33'W	7	100	0	0	7
21 Aug. 1987	43°59'N	163°33'W	6	100	0	0	6
23 Aug. 1987	43°59'N	163°57'W	4	80.0	1	20.0	5
24 Aug. 1987	43°58'N	163°40'W	1	100	0	0	1
3 Sept. 1987	45°40'N	153°24'W	9	100	0	0	9
Total			193	88.5	25	11.5	218

Yearly Differences in Plastic Ingestion Rates

Plastic ingestion rates by year and by species are shown in Tables 3 and 4. Based on comparisons of data for the period (excluding 1975, 1977, and 1980), the plastic ingestion rate of sooty shearwaters was $X^2 = 1.034$ (df = 3, $0.5 < P < 0.75$), indicating no significant differences (Table 3). On the other hand, the ingestion rate for short-tailed shearwaters for the entire period excluding 1973 was $X^2 = 74.757$ (df = 6, $P < 0.005$), showing significant differences (Table 4). The plastic particle ingestion rate of short-tailed shearwaters for 1970-73 was conspicuously lower than rates for other years, although the number of specimens was small for all the year. Comparing 1970-72 with 1975-79, an extremely significant difference of $X^2 = 67.822$ (df = 1, $P < 0.005$) was observed. It was suggested that the increase in plastic particle ingestion by short-tailed shearwaters reflected the increased production of synthetic resins.

Monthly Differences in Plastic Ingestion Rates

Plastic ingestion rates of two species of shearwaters by month were shown in Tables 5 and 6. No significant difference was found in plastic

Table 2.--Frequency of occurrence of plastics in short-tailed shearwaters.

Date	Location: Latitude	Location: Longitude	With plastic: No.	With plastic: Frequency (%)	Without plastic: No.	Without plastic: Frequency (%)	Total number
5 July 1970	55°21′N	164°00′W	13	46.4	15	53.6	28
18 July 1972	56°23′N	161°03′W	27	52.9	24	47.1	51
29 Apr. 1973	49°30′N	170°30′E	2	50.0	2	50.0	4
30 Apr. 1973	50°30′N	170°30′E	2	100	0	0	2
21 Apr. 1975	42°30′N	167°30′E	1	100	0	0	1
22 Apr. 1975	43°33′N	167°30′E	4	100	0	0	4
26 Apr. 1975	46°30′N	167°30′E	2	50.0	2	50.0	4
28 Apr. 1975	47°30′N	167°30′E	1	50.0	1	50.0	2
4 May 1975	51°30′N	167°30′E	1	100	0	0	1
9 May 1975	50°30′N	171°00′E	1	100	0	0	1
11 May 1975	49°30′N	171°00′E	2	66.7	1	33.3	3
16 May 1975	47°30′N	169°01′E	4	100	0	0	4
17 May 1975	48°30′N	169°00′E	3	100	0	0	3
27 May 1975	50°25′N	172°30′E	2	100	0	0	2
10 June 1976	55″00′N	171°00′E	11	100	0	0	11
11 June 1976	55°00′N	172°00′E	12	100	0	0	12
13 June 1976	55°00′N	173°00′E	12	92.3	1	7.7	13
15 June 1976	55°00′N	176°00′E	2	100	0	0	2
16 June 1976	55″10′N	177°17′E	2	66.7	1	33.3	3
17 June 1976	55°00′N	178°00′E	1	100	0	0	1
18 June 1976	55°03′N	179°20′E	1	100	0	0	1
19 June 1976	55°00′N	179°00′W	2	100	0	0	2
20 June 1976	55°00′N	178°00′W	1	100	0	0	1
21 June 1976	55°03′N	176°50′W	1	100	0	0	1
24 June 1976	56°55′N	176°00′W	1	100	0	0	1
26 June 1976	57°00′N	177°00′W	5	100	0	0	5
27 June 1976	57°00′N	178°00′W	2	100	0	0	2
29 June 1976	58°56′N	178°08′E	2	100	0	0	2
30 June 1976	59°00′N	178°00′E	1	100	0	0	1
6 July 1976	59°00′N	171°00′E	2	100	0	0	2
9 July 1976	61°44′N	177°40′E	4	100	0	0	4
11 July 1976	61°54′N	179°59′W	2	100	0	0	2
12 July 1976	61°48′N	179°39′W	1	50.0	1	50.0	2
13 July 1976	62°02′N	179°40′E	2	66.7	1	33.3	3
17 July 1976	62°05′N	179°36′E	2	100	0	0	2
2 June 1977	49°30′N	165°01′E	1	100	0	0	1
3 June 1977	49°22′N	165°43′E	4	100	0	0	4
4 June 1977	50°03′N	166°59′E	4	100	0	0	4
5 June 1977	49°26′N	168°48′E	5	100	0	0	5
7 June 1977	50°16′N	169°00′E	4	100	0	0	4
8 June 1977	50°35′N	168°31′E	3	100	0	0	3
9 June 1977	50°54′N	168″10′E	2	100	0	0	2
11 June 1977	50°08′N	175°21′E	16	94.1	1	5.9	17
13 June 1977	47°38′N	178°01′E	2	100	0	0	2

Table 2. --Continued.

Date	Location		With plastic		Without plastic		Total number
	Latitude	Longitude	No.	Frequency (%)	No.	Frequency (%)	
14 June 1977	47°37'N	179°44'E	3	100	0	0	3
23 June 1977	56°04'N	176°14'W	2	100	0	0	2
25 June 1977	56°00'N	175°14'W	5	100	0	0	5
30 June 1977	57°02'N	178°02'W	1	100	0	0	1
2 July 1977	57°58'N	176°18'W	5	100	0	0	5
4 July 1977	58''10'N	175°37'W	4	100	0	0	4
5 July 1977	59°03'N	175°32'W	1	100	0	0	1
8 July 1977	58°45'N	178°54'W	1	100	0	0	1
9 July 1977	58°30'N	179°58'E	1	100	0	0	1
11 July 1977	59°13'N	177°51'W	4	80.0	1	20.0	5
12 July 1977	58"52'N	177°28'W	2	100	0	0	2
14 June 1978	52°55'N	176°59'W	14	93.3	1	6.7	15
19 June 1978	54°00'N	178°02'W	10	83.3	2	16.7	12
26 July 1978	48°47'N	177°28'E	1	50.0	1	50.0	2
28 July 1978	44°58'N	179°58'E	1	100	0	0	1
14 June 1979	51°02'N	177°31'W	33	91.7	3	8.3	36
4 Aug. 1979	46"24'N	158°18'E	1	50.0	1	50.0	2
4 Aug. 1979	48°59'N	169°19'E	1	100	0	0	1
Total			265	81.8	59	18.2	324

particle ingestion rates for either species. The rate for sooty shearwaters was χ^2 = 3.517 (df - 5, 0.5 < P < 0.75), and the rate for short-tailed shearwaters was χ^2 - 4.060 (df = 3, 0.25 < p < 0.5).

More than 85% of the sooty shearwaters were found to have ingested plastic particles in all the months between April and October except May, when there were few specimens collected (Table 5). Slightly lower values were obtained for short-tailed shearwaters in April, although no significant differences were shown in ingestion rates (Table 6). Day (1980) made clear that there are seasonal differences in plastic particle ingestion by short-tailed shearwaters observed near Kodiak Island, and showed that the birds there actively ingest in June and August. In this study, no seasonal trend in plastic particle ingestion was identified, as collection sites of short-tailed shearwaters were scattered in outer waters and collection was not made at regular monthly intervals in areas where this species stays for a long time.

Latitudinal Differences in Plastic Particle Ingestion

Tables 7 and 8 show the plastic particle ingestion rates by 5° latitudinal belts. A significant difference of X^2 - 7.248 (df - 2,

Table 3.--Frequency of occurrence of plastics in sooty shearwaters by year.

	With plastic		Without plastic		
Year	No.	Frequency (%)	No.	Frequency (%)	Total number
1975	1	100	0	0	1
1977	1	25.0	3	75.0	4
1978	22	88.0	3	12.0	25
1979	114	91.2	11	8.8	125
1980	7	70.0	3	30.0	10
1986	18	85.7	3	14.3	21
1987	30	93.8	2	6.3	32
Total	*193*	*88.5*	*25*	*11.5*	*218*

Table 4.--Frequency of occurrence of plastics in short-tailed shearwaters by year.

	With plastic		Without plastic		
Year	No.	Frequency (%)	No.	Frequency (%)	Total number
1970	13	*46.4*	15	53.6	28
1972	27	*52.9*	24	47.1	51
1973	4	*66.7*	2	33.3	6
1975	21	*84.0*	4	16.0	25
1976	69	*94.5*	4	5.5	73
1977	70	*97.2*	2	2.8	72
1978	26	*86.7*	4	13.3	30
1979	35	*89.7*	4	10.3	39
Total	265	*81.8*	*59*	18.2	324

$0.025 < P < 0.05$) was found for *sooty* shearwaters as a result of comparisons of the first three belts in Table 7. Further, examination by belt presented a rate of $X^2 - 5.750$ (df - 1, $0.01 < P < 0.025$) between lat. 40°-45°N and 45°-50°N, indicating a difference. The plastic ingestion rate for the belt of lat. 40°-45°N was higher at 93.1%, while that for lat. 45°-50°N was slightly lower at 80.3%.

Table 5. --Frequency of occurrence of plastics in sooty shearwaters by month.

Month	With plastic No.	With plastic Frequency (%)	Without plastic No.	Without plastic Frequency (%)	Total number
April	16	88.9	2	11.1	18
May	5	71.4	2	28.6	7
June	38	86.4	6	13.6	44
July	45	84.9	8	15.1	53
August	48	90.6	5	9.4	53
September	12	100	0	0	12
October	29	93.5	2	6.5	31
Total	193	88.5	25	11.5	218

Table 6 .--Frequency of occurrence of plastics in short-tailed shearwaters by year.

Month	With plastic No.	With plastic Frequency (%)	Without plastic No.	Without plastic Frequency (%)	Total number
April	12	70.6	5	29.4	17
May	13	92.9	1	7.1	14
June	205	81.0	48	19.0	253
July	33	89.2	4	10.8	37
August	2	66.7	1	33.3	3
Total	265	81.8	59	18.2	324

Table 7. --Frequency of occurrence of plastics in sooty shearwaters by 5° latitudinal belts.

Latitudinal range	With plastic No.	With plastic Frequency (%)	Without plastic No.	Without plastic Frequency (%)	Total number
35°-40°N	21	84.0	4	16.0	25
40°-45°N	122	93.1	9	6.9	131
45°-50°N	49	80.3	12	19.7	61
50°-55°N	1	100	0	0	1
Total	193	88.5	25	11.5	218

Table 8.--Frequency of occurrence of plastics in short-tailed shearwaters by 5° latitudinal belts.

Latitudinal range	With plastic No.	With plastic Frequency (%)	Without plastic No.	Without plastic Frequency (%)	Total number
40°-45°N	6	100	0	0	6
45°-50°N	31	81.6	7	18.4	38
50°-55°N	93	92.1	8	7.9	101
55°-60°N	124	74.7	42	25.3	166
60°-65°N	11	84.6	2	15.4	13
Total	265	81.8	59	18.2	324

As regards short-tailed shearwaters, a significant difference of X^2 = 12.645 (df = 3, 0.005 < P < 0.01) was found after comparing the last four belts in Table 8. Further, in the comparison of all areas, there were significant differences, with the rates standing at X^2 = 0.030 (df - 1, 0.01 < P < 0.05) between lat. 45°-50°N and 60°-65°N and x^2 - 11.347 (df - 1, P < 0.005) between lat. 50°-55°N and 50°-60°N. This suggests the presence of differences in plastic ingestion rates for short-tailed shearwaters between the North Pacific and the north Bering Sea. Comparing lat. 45°-50°N and 55°-60°N, a rate of X^2 = 8.954 (df = 1, P < 0.005) was obtained. Thus visible differences were found in the plastic ingestion rates between north and south.

These were believed to reflect both differences in distribution, migration, and summer residence of both species of shearwaters in the subarctic North Pacific region, and differences in abundance of plastic particles by area.

Longitudinal Differences in Plastic Ingestion Rates

Tables 9 and 10 show the plastic particle ingestion rates for two species of shearwaters by 5° longitudinal strips.

With regard to sooty shearwaters, no significant difference in ingestion rates was found between strips (x^2 - 13.559, df - 7, 0.05 < P< 0.1). On the other hand, a significant difference was observed for short-tailed shearwaters, with X^2 - 69.748 (df = 4, P < 0.005). This significant difference occurred because the plastic ingestion rate for 40 individuals obtained in Bristol Bay in Alaska was only 50.6%, and the collection sites for these seabirds were limited to long. 165°-160°W. It was not evident why the plastic particle ingestion rate for short-tailed shearwaters in this strip was conspicuously low. These 40 short-tailed shearwaters were full of *Thysanoessa raschii*, a species of euphausiids, suggesting that the abundance of plastic particles in the area was low and plastic particles in the stomach and gizzards had moved to the intestine.

Table 9. --Frequency of occurrence of plastics in sooty shearwaters by 5° longitudinal belts.

Longitudinal range	With plastic No.	With plastic Frequency (%)	Without plastic No.	Without plastic Frequency (%)	Total number
140°-145°E	6	85.7	1	14.3	7
145°-150°E	14	82.4	3	17.6	17
150°-155°E	4	100	0	0	4
155°-160°E	--	--	--	--	--
160°-165°E	1	100	0	0	1
165°-170°E	24	96.0	1	4.0	25
170°-175°E	26	83.9	5	16.1	31
175E°-180°	40	78.4	11	21.6	51
180°-175°W	22	88.0	3	12.0	25
175°-170°W	35	100	0	0	35
170°-165°W	--	--	--	--	--
165°-160°W	11	91.7	1	8.3	12
160°-155°W	--	--	--	--	--
155°-150°W	10	100	0	0	10
Total	193	88.5	25	11.5	218

Table 10. --Frequency of occurrence of plastics in short-tailed shearwaters by 5° longitudinal belts.

Longitudinal range	With plastic No.	With plastic Frequency (%)	Without plastic No.	Without plastic Frequency (%)	Total number
155°-160°E	1	50.0	1	50.0	2
165°-170°E	40	93.0	3	7.0	43
170°-175°E	46	92.0	4	8.0	50
175°E-180°	41	91.1	4	8.9	45
180°-175°W	97	92.4	8	7.6	105
175°-170°W	--	--	--	--	--
170°-165°W	--	--	--	--	--
165°-160°W	40	50.6	39	49.4	79
Total	265	81.8	59	18.2	324

Number of Shapes and Colors of Plastic Particles Ingested by Two Species of Shearwaters

Tables 11 and 12 show the number of plastic particles classified by shape and color found in the stomachs of 192 sooty shearwaters and 265 short-tailed shearwaters. For both species, 13 shapes and 11 colors were used.

Such shapes as cylinder, pill, dome, sphere, box, and asymmetrical plastic pellets were apparently molding materials for making plastic products. All the other particles were judged to be fragments of plastic products. Ingestion rates of these molding materials were 38.4% for sooty shearwaters (Table 11) and 67.2% for short-tailed shearwaters (Table 12). A significant difference was found in the interspecies comparison of ingestion rates (χ^2 - 298.7, df = 1, $P < 0.005$), showing that sooty shearwaters have a strong tendency to ingest plastic particles with no preference as to shape. On the other hand, short-tailed shearwaters have a strong tendency to ingest molding material particles having consistent shapes. Molding materials were 39.4% of the total weight for sooty shearwaters , whereas for short-tailed shearwaters they were 74.6%. It is interesting to note that a highly significant difference of $\chi^2 = 624.830$ (df = 12, $P < 0.005$) was found after comparing the rates of total number of particles by shape for the two species. However, in terms of order of ingestion by shape, $r_s = 0.9272$ ($n = 13$, $P < 0.01$), indicating similarity between the two species.

As for the color of plastic particles ingested by the two species of seabirds, a highly significant difference (χ^2 - 515.588, df - 10, $P < 0.005$) was found when comparing the numbers of particles by color, but the order of ingestion was similar for the two species ($r_s = 0.8727$, $n = 11$, $P < 0.01$).

The average number and weight of plastic particles ingested per individual were 8.45 particles weighing 134 mg for sooty shearwaters and 8.79 particles weighing 140 mg for short-tailed shearwaters.

DISCUSSION

Day (1980) examined plastics ingested by seabirds in Alaska and discussed the occurrence and characteristics of plastic pollution in them. Much remains unknown about the impact of plastic particle ingestion on seabirds, but Carpenter et al. (1972) found that polychlorinated biphenyls (PCB's) are concentrated on the surface of spherical polystyrene molding materials. Further, as regards great shearwater, *P. gravis,* Ryan et al. (1988) found that a high-level positive interrelation of r_s - 0.700 existed between the amount of ingested plastic particles and PCB in adult birds. Day (1980) suggested that hydrocarbon pollutants arising from plastic particle ingestion are not only affecting breeding capability but also causing abnormal behavior.

For short-tailed shearwaters, a species subject to global-scale migration, it is believed that the variation in amounts of body fat in

Table 11.--Number of shapes and colors of plastic ingested by sooty shearwaters.

Shape	Color: White	Yellow	Brown	Yellow brown	Blue	Green	Red	Dark blue	Dark green	Dark red	Black/ gray	Total	Percent
Cylinder	41	6	0	70	0	2	1	0	1	0	117	238	14.6
Pill	14	6	29	26	0	0	0	0	1	1	28	105	6.4
Dome	2	0	2	4	0	0	0	0	0	0	1	9	0.6
Sphere	0	0	64	2	0	0	1	0	0	0	8	75	4.6
Box	1	0	2	6	0	0	0	0	0	0	3	12	0.7
Asymmetrical molding material	53	10	21	40	4	40	1	1	3	0	14	187	11,5
String	52	0	5	0	2	4	0	0	1	0	50	114	7.0
Cone	1	0	0	0	0	0	0	0	0	0	1	2	0.1
Asymmetrical plastic products	168	27	28	67	12	42	8	1	6	1	41	401	24.6
Vinyl	90	0	16	0	9	3	0	0	0	0	180	298	18.3
Rubber	0	0	1	0	0	0	0	0	0	0	3	4	0.3
Unidentifiable particles	27	3	3	17	2	10	0	1	2	1	21	87	5.3
Other	17	7	12	36	0	15	1	2	1	0	8	99	6.1
Total	466	59	183	268	29	116	12	5	15	3	475	1,631	
Percent	28.6	3.6	11.2	16.4	1.8	7.1	0.7	0.3	0.9	0.2	29.1		

Table 12.--Number of shapes and colors of plastic ingested by short-tailed shearwaters.

Shape	Color											Total	Percent
	White	Yellow	Brown	Yellow brown	Blue	Green	Red	Dark blue	Dark green	Dark red	Black/ gray		
Cylinder	232	21	225	407	3	7	9	0	0	4	68	976	41.9
Pill	47	1	56	111	0	0	1	0	0	3	14	233	10.0
Dome	3	6	7	18	0	0	0	0	0	0	0	34	1.5
Sphere	4	0	2	11	0	10	0	0	0	0	2	29	1.2
Box	6	0	10	10	0	1	0	0	0	0	1	28	1.2
Asymmetrical molding material	58	13	49	92	12	26	2	0	1	0	12	265	11.4
String	20	0	3	0	6	15	0	0	0	0	4	48	2.1
Cone	1	0	1	1	0	1	0	0	0	0	0	4	0.2
Asymmetrical plastic products	97	16	18	126	10	42	49	3	8	1	10	380	16.3
Vinyl	102	0	5	0	19	5	1	0	0	0	9	141	6.1
Rubber	29	0	1	7	0	0	0	0	0	0	6	43	1.9
Unidentifiable particles	20	0	12	28	4	10	5	2	3	0	12	96	4.1
Other	19	1	4	14	2	9	2	1	0	0	1	53	2.3
Total	638	58	393	825	56	126	69	6	12	8	139	2,330	
Percent	27.4	2.5	16.9	35.4	2.4	5.4	3.0	0.3	0.5	0.3	6.0		

connection with long-distance migration between Northern and Southern Hemispheres causes changes in PCB density in internal organs and tissues (Tanaka et al. 1986). It will be necessary to examine the impact of plastic particle ingestion on seabirds throughout their entire life history.

In this study, it is suggested that differences in plastic particle ingestion by sooty and short-tailed shearwaters are related not only to food habits of the two species but. also to their distribution and migration in the subarctic North Pacific region. Sooty shearwaters arrive in the area just south of the Subarctic Boundary at lat. 38°-40°N in early April. These adult birds have just completed breeding in the Southern Hemisphere. Sooty shearwaters migrate northward, keeping pace with northward migration of Pacific saury, *Cololabis saira*, and the Japanese sardine, *Sardinops melanostictus*. In June and July, subadults and hatching year birds arrive also from the Southern Hemisphere to the area just south of the Subarctic Boundary, and then migrate even farther north in the same manner as adult birds. Therefore, as Day and Shaw (1987) showed, life of the sooty shearwaters in the Northern Hemisphere starts in areas where plastic pollution is intense. Further, they range in summer from lat. 41°-42°N to the Aleutian Islands, extending to around lat. 55°N in the Okhotsk Sea. Sooty shearwaters tend to stay in this area longer than short-tailed shearwaters. Especially *to* be noted is that sooty shearwaters migrate only in a nomadic mode after arriving in the North Pacific Subarctic Zone, and their movement is determined by food distribution. This causes emergence of flocks composed of individuals in different stages of growth. Therefore it may be difficult to determine changes in plastic particle ingestion rates in terms of year, month, latitude, and longitude.

Short-tailed shearwater parent birds, which complete breeding in Tasmania in the Southern Hemisphere, fly toward the Northern Hemisphere in mid- and late March and arrive in the Bering Sea in late April (Shuntov 1961) . These short-tailed shearwaters continue northward migration without resting around the Subarctic Boundary. After staying in the summer resident area, they migrate directly southward to the Southern Hemisphere for breeding. They therefore live in a condition immune from the plastic-polluted areas in the North Pacific. Lower plastic particle ingestion rates for 40 short-tailed shearwater individuals collected at Bristol Bay in the Bering Sea were probably due *to* the fact that they were breeding adult birds. Subadult and hatching year birds arrive in areas around lat. 40°N in mid-April and early June, continuing northward to around lat. 53°N in June-July. The northern limit for adult birds is north of lat. 70°N, while subadult and hatching year birds live in a nomadic mode between lat. 45°-60°N. This means that younger birds are exposed to plastic pollution for a longer period of time, with the likelihood of increased plastic particle ingestion rates over both time and space. The results of this study coincide with this finding.

This study showed that short-tailed shearwaters had a tendency to ingest more plastic molding materials, while sooty shearwaters ingested more plastic product fragments. This reflects the food habits of the two species. Short-tailed shearwaters feed mainly on small, low-class organisms originating from the biological production process in the surface layers of the ocean, these include juvenile fish, euphausiids, copepods, larval and juvenile squid, and amphipods (Ogi et al. 1980). They are particularly fond of euphausiids, which appear in the surface not as single individuals but usually as patches or swarms. The body size of euphausiids is relatively uniform. Short-tailed shearwaters must catch them quickly and continuously. They probably actively ingest plastic molding materials because these resemble organisms forming patches or swarms.

Sooty shearwaters, on the other hand, feed on Japanese sardines (Ogi unpubl. data) and Pacific sauries (Ogi 1984) in large quantities. They are also known to consume large quantities of larval and juvenile squid and euphausiids (Brown et al. 1981), but regardless, it is obvious that the food niche of sooty shearwaters is higher than that of short-tailed shearwaters. It is assumed, therefore, that they select less specifically plastic molding materials resembling small-sized organisms.

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THE INCIDENCE OF PLASTIC IN THE DIETS OF PELAGIC SEABIRDS IN THE EASTERN EQUATORIAL PACIFIC REGION

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ABSTRACT

Between 1984 and 1988, 921 seabirds of 39 species were collected during cruises in the eastern equatorial Pacific. Cruises were centered in the areas of the South Equatorial Current, Equatorial Countercurrent, and the northern Peru Current. The majority of species, mostly gadfly petrels and storm-petrels, had not previously been checked for plastic ingestion. Ingestion was a function of feeding behavior, area of the ocean frequented, and the amount of time passed since birds frequented polluted areas. Species that resided year-round in the equatorial region had eaten little plastic, but those species or populations that had recently come from the area of the southern Peru Current (off Chile), the North Pacific (off Japan or California), or the Tasman Sea/northern New Zealand area, had high plastic loads in their digestive tracts. Results suggest that the residency time of plastic in the digestive tract of petrels is less than 1 year.

INTRODUCTION

On the basis of research and literature reviews by Day (1980; Day et al. 1985), who worked mostly in the northern Pacific, and by Ryan (1987a, 1987b, 1988a, 1988b; Ryan and Jackson 1987) in the southern Atlantic, we now recognize that the ingestion of plastic is a pervasive phenomenon in seabirds. At present, 69 seabird species are known to ingest plastic while feeding at sea, and the incidence of ingestion has risen steadily since the

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1960's. The species most likely to eat plastic are members of the order Procellariiformes. The factors that make these species so susceptible are 1) their feeding behavior (many feed at the surface, are omnivorous, and scavenge frequently); 2) their morphology (petrels have muscular gizzards in which indigestible items become trapped, whereas most other seabirds do not); and 3) their inability (albatrosses are an exception) to eject indigestible matter through the formation of pellets. It is believed that seabirds eat the plastic, usually in the form of industrial pellets and fragments of larger items, either because they mistake it for food or because edible organisms are attached to the plastic.

Geographic variation in the incidence of plastic indicates that seabirds feeding near to industrialized areas are the most likely to eat it. The plastic remains in digestive tracts until it degrades from abrasion and digestive processes or until adult birds feed it to their chicks. Day et al. (1985) estimated that the degradation process for an individual plastic pellet requires on the order of 6 months, but Ryan and Jackson (1987) proposed a time scale of 1 to 2 years. Ryan (1988b) further proposed that it is through feeding plastic to chicks that adults rid themselves of most of the plastic that has accumulated in their gut.

As yet, little work has been done on the incidence of ingestion in seabirds that forage far at sea, i.e. , away from pollution sources. (See Ainley et al. 1990, who looked at plastic in the diets of Antarctic seabirds.) In this paper we present information on the incidence of plastic in the diets of seabirds that frequent Pacific equatorial waters. The sampling efforts closest spatially to ours were those by Harrison et al. (1983) and Sileo et al. (1990), who noted plastic in the diets of several species breeding in the Northwestern Hawaiian Islands, in the North Pacific a few thousand kilometers away from our study area. A number of species pass through our study area from various directions, and the incidence of plastic in them offers some clues as to where they are encountering it, and, on the basis of the time passed since visiting polluted areas, whether or not the degradation process and that of off-loading through chick feeding are important processes by which birds relieve themselves of plastic. In addition, several of the species we sampled had not been inspected before for evidence of plastic ingestion.

METHODS

In conjunction with the Equatorial Pacific Ocean Climate Study (EPOCS) of the National Oceanic and Atmospheric Administration (NOAA), we have been characterizing the community structure of open-ocean seabirds using the eastern equatorial Pacific as our study area. Included in our studies are the analyses of prey items. On six cruises (boreal autumn 1984, spring 1986, spring and autumn 1987, and spring and autumn 1988) we collected 921 seabirds of 39 species using a shotgun (Table 1). During each collection, we attempted to obtain up to five individuals of each species present. We noted which individuals had ingested plastic and, except for autumn 1984, counted the number of plastic pieces. Based on necropsy, we determined whether individuals were adults or subadults. The study area is between lat. 15°N and 15°S and long. 170° and 85°W (Fig. 1). Collections were made

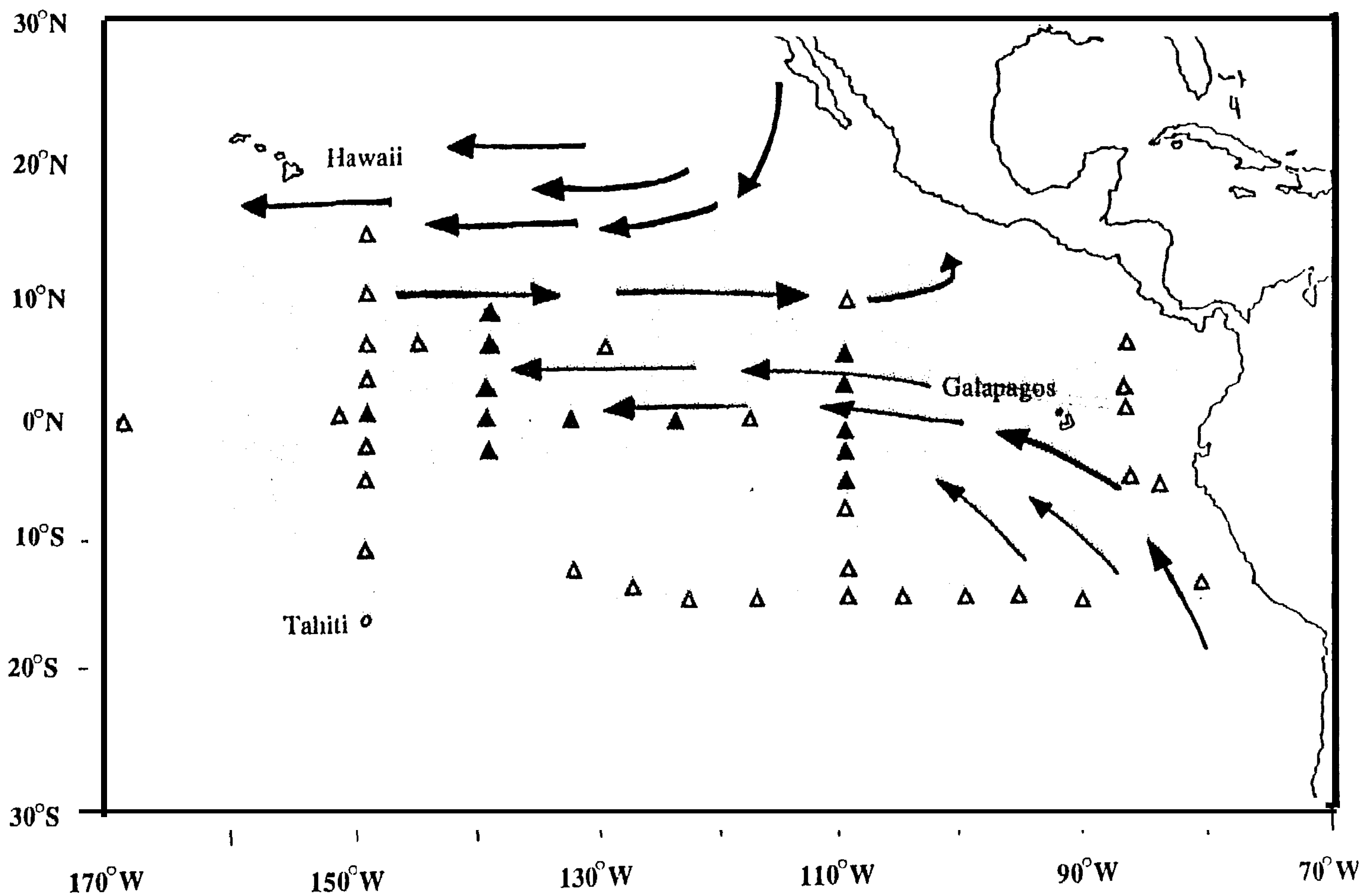

Figure 1.--The study area in the eastern equatorial Pacific (shading), and sites where seabirds were collected (open symbols, on one cruise only; closed symbols, on four or more cruises); arrows indicate ocean currents.

Table 1.--The incidence of plastic in the diets of Pacific equatorial seabirds, and a comparison to other studies.

Species[b]	Cruise[a] A84[c]	S86	S87	A87	S88	A88	Total[a] No.	%	Other studies %	Source[d]
Petrels										
Bulweria bulwerii			0 (7)		0 (10)	0 (2)	19	0	0	3
*Daption capense**			88 (8)				8	88	14-57	1,5
*Pachyptilla belcheri**			83 (6)				6	83	0-57	5
*Procellaria aequinoctialis**			67 (3)				3	67	0-57	1,5
Pterodroma alba			0 (2)			0 (9)	11	0		
Pterodroma arminjoniana			0 (8)			0 (3)	11	0		
*Pterodroma cookii defilippiana**		0 (3)	67 (6)				9	44	10	4
*Pterodroma e. externa**	0 (3)	0 (5)	0 (27)	0 (21)	0 (13)	0 (35)	104	1		
Pterodroma e. cervicalis		100 (1)	0 (2)		0 (7)		10	10		
Pterodroma inexpectata						0 (1)	1	0	0	1
Pterodroma leucoptera	0 (6)	75 (4)	20 (15)	7 (28)	26 (19)	5 (20)	92	15		
*Pterodroma l. longirostris**		100 (1)	50 (6)	33 (6)	50 (10)	100 (2)	25	52		
Pterodroma l. pycrofti					50 (2)		2	50		
Pterodroma neglects				0 (2)	0 (5)	0 (1)	8	0		
Pterodroma nigripennis		0 (1)	0 (4)	0 (3)	0 (14)	7 (15)	37	3		
Pterodroma rostrata	0 (2)		0 (21)	0 (13)	7 (15)	0 (16)	67	2		
Pterodroma ultima			0 (1)			0 (4)	5	0		
Puffinus bulleri					100 (1)		1	100		
Puffinus griseus			50 (2)		0 (6)	100 (17)	25	72	10-67	2,5
Puffinus nativitatus			50 (2)			0 (1)	3	33	0	3
Puffinus pacificus			0 (15)		0 (7)	8 (13)	35	3	0	2
Puffinus tenuirostris						100 (1)	1	100	47-100	2

Table 1. --Continued.

Species[b]	Cruise[e] A84[c]	S86	S87	A87	S88	A88	Total[a] No.	Total[a] %	Other studies %	Other studies Source[d]
			Storm-Petrels							
Fregetta grallaria		0 (2)	0 (3)		0 (1)	0 (2)	8	0		
Nesofregetta fuliginosa	0 (2)	0 (1)	0 (1)	0 (3)	0 (1)		8	0		
Oceanites gracilis			0 (2)				2	0		
*Oceanites oceanicus**			0 (8)				8	0	19-75	1,5
Oceanodroma castro			0 (2)		0 (3)	0 (2)	7	0		
*Oceanodroma hornbyi**		0 (1)					1	0		
Oceanodroma leucorhoa	6 (18)	0 (1)	9 (22)	13 (45)	0 (16)	16 (49)	151	11	25	2
*Oceanodroma markhami**		0 (3)	0 (7)		50 (2)		12	8		
Oceanodroma melania			0 (2)				2	0		
Oceanodroma tethys	7 (29)	0 (12)	0 (32)	0 (45)	0 (29)	0 (29)	176	1		
Pelagodroma marina		0 (1)	88 (8)		50 (4)		13	69	50-88	4,5
			Other							
Fregata minor			0 (3)				3	0		
Gygis alba			0 (2)				2	0	0	3
Phaethon lepturus			0 (1)				1	0		
Phaethon rubricauda			0 (2)				2	0	0	3
Stercorarius parasiticus					50 (2)		2	0	0-50	2,5
Sterna fuscata			0 (19)	0 (2)	0 (5)	0 (9)	35	0	0	3
Sterna lunata			0 (4)		0 (1)		5	0	0	3

[a]In each column is given the number of seabirds with plastic followed by the total number inspected.

[b]Species marked by an asterisk (*) were collected at the outer edge of the Peru Current, or breed in that area; see text.

[c]The cruises are designated as A (autumn) or S (spring) by year (e.g., A84 = autumn 1984).

[d]Source: 1, Ainley et al. 1990; 2, Day et al. 1985; 3, Harrison et al. 1983; 4, Imber *in* Day et al. 1985; 5, Ryan 1987b.

while the ship tended permanently moored oceanographic buoys, and thus were mostly from the same sites on each cruise. During spring 1987, however, the ship worked in the outer reaches of the Peru Current off Peru, and birds were collected there as well.

In our analyses, we statistically compared proportions using t-tests following angular transformations (Sokal and Rohlf 1969). Regressions were by Spearman rank correlation (r_s).

RESULTS

We looked for plastic in the stomachs of 39 species, 21 of which had not been previously inspected for this. Highest rates of plastic ingestion were, evident in species that frequented the periphery of the study area or moved through it. Most obvious were the nine species that came from the edge of the Peru Current (Table 1). Plastic was found in all but one of these, and in seven the incidence equaled or exceeded 45% of the birds inspected. Incidence was very low in the Juan Fernandez petrel, *Pterodroma e. externa*, which nests on islands off Chile, but in the cape petrel, *Daption capense*, and the narrow-billed priori, *Pachyptila belcheri*, both of which only winter in the Peru Current, incidence exceeded 80%.

Various patterns of ingestion were apparent in several longer distance migrants that either pass through or spend the nonbreeding portion of their annual cycle in the study area. Incidence of plastic was very high in the sooty shearwater, *Puffinus griseus,* a species that migrates across the study area between its breeding islands in the southwestern Pacific (New Zealand) and its wintering grounds in the North Pacific. Incidence was 0% in shearwaters collected on their northward postbreeding journey during spring (n - 6) but was 95% among those individuals flying south in the autumn (n = 19). In the Leach's storm-petrel, *Oceanodroma leucorhoa*, which breeds on islands ringing the eastern and central North Pacific but which otherwise resides in the study area, frequency of plastic relative to its annual cycle was the opposite of the shearwater. Plastic occurred in 11% overall. During autumn, just after the breeding season, 13.4% contained plastic (n = 112) compared to 5.1% during spring (n = 39; t = 3.261, P - 002), after breeders had departed. The same relative seasonal pattern was also evident in the white-winged petrel, *Pterodroma leucoptera*, which breeds in the Tasman Sea but otherwise resides in the study area. Plastic occurred in 15% of these birds overall, with a seasonal breakdown of 5.6% (n = 54) during autumn, just before the nesting period, and 28.9% (n = 38) during spring, just after the nesting period '(t = 3.104, P - 0.003). Finally, in the Stejneger's petrel, *Pt. l. longirostris*, which breeds off Chile and then migrates to North Pacific waters off Japan, plastic occurred in the same proportion of birds regardless of season (spring, coming from the nesting grounds off Chile: 52.9%, n = 17; autumn, coming from waters off Japan: 50.0%; n = 8).

Among species that reside in equatorial waters year-round, the incidence of plastic ingestion was very low, and in most it was nil. An instructive comparison is that between the migratory Leach's storm-petrel and the year-round resident wedge-rumped storm-petrel, O. *tethys*, two species that are closely associated in the study area (unpubl. data). In Leach's, ingestion was 11%, but in wedge-rumped storm-petrel, it was only 1% ($t = 4.289$, $P < 0.001$).

Ingestion frequencies for each species were tracked by the number of plastic particles per bird. Individuals of species in which ingestion frequency was high also had large numbers of pieces in their gizzards and vice versa (r_s - 0.7385, df- 14, $P < 0.001$; for species where $n > 4$ individuals; Table 2). On the basis of that relationship, we might project for species in which samples were small, that if the one or two individuals inspected had eaten a large number of pieces, a larger sample should show a high proportion of individuals with plastic. For example, we inspected only one short-tailed shearwater, *Pu. tenuirostris*, but it contained 14 pieces of plastic. This species is known to eat large amounts of plastic (Day et al. 1985). The pattern should hold for the Buller's shearwater, *Pu. bulleri*, for which there are no other published data on plastic ingestion (the one individual in our sample contained seven pieces). One exception would be Juan Fernandez petrel, in which only 1 individual of 104 inspected contained plastic: 4 pieces, a relatively large number of pieces in our data set.

We compared the frequency of plastic as a function of age (subadult versus adult) in species where $n > 10$ birds. Compared *to* adults, a larger proportion of subadults should have ingested plastic (Day et al. 1985; Ryan 1987b). We found, though, that the proportion of breeding adults, nonbreeding adults, subadults, and unknowns that had ingested plastic (5.9, 35.6, 56.4, and 2.0%, respectively) did not differ from the proportion of these age classes in the total samples (7.9, 37.4, 51.8, and 3%, respectively; $\chi^2 = 8.78$, df = 3, $P > 0.05$). Plastic was not more prevalent in subadults.

DISCUSSION

We found little evidence that terns, tropicbirds, or frigatebirds ate plastic, as also noted by Harrison et al. (1983), Day et al. (1985), and Sileo et al. (1990). These species eat active prey, and even if they did ingest plastic, they lack a gizzard where, in Procellariiformes, plastic accumulates.

Among the petrels we sampled, ingestion was mainly a function of feeding behavior, what parts of the Pacific Ocean they frequented, and the amount of time passed since leaving polluted areas. Petrels such as Juan Fernandez petrel or wedge-tailed shearwater, *Pu. pacificus*, which chase airborne flyingfish and squid or prey being driven to the surface by predatory fish (i.e., very active prey), exhibited low rates of plastic ingestion. The majority of other petrel species are less specialized feeders, and they eat prey both live and dead. Some species, such as white-faced storm-petrel, *Pelagodroma marina,* and prions, genus *Pachyptila*, almost always contain very high loads of plastic (Day et al. 1985; Ryan 1987b). It is probable that their prey search-images (including particle size) and their propensity to associate with convergence account for their high susceptibility to plastic as food. On the other hand, some species

Table 2.--The average number of pieces of plastic, and standard error, in the gizzards of seabirds collected in the study area.

Species	Average number of pieces	SE	Number of birds
Daption capense	8.4	2.3	7
Pachyptila belcheri	8.2	3.4	5
Procellaria aequinoctialis	3.5	1.5	2
Pterodroma cooki defillipiana	9.8	4.8	4
Pterodroma e. externa	4		1
Pterodroma e. cervicallis	1		1
Pterodroma leucoptera	2.1	0.8	14
Pterodroma l. longirostris	3.1	0.6	14
Pterodroma l. pycrofti	2		1
Pterodroma nigripennis	1		1
Pterodroma rostrata	1		1
Puffinus bulleri	7		1
Puffinus nativitatus	1		1
Puffinus griseus	10.5	2.7	18
Puffinus tenuirostris	14		1
Puffinus pacificus	1		1
Oceanodroma leucorhoa	3.3	0.4	16
Oceanodroma markhami	2		1
Pelagodroma marina	12.2	3.5	9

that are obligate scavengers, such as Tahiti petrel, *Pt. rostrata*, do not eat much plastic (unpubl. data). They, too, might have a particular search-image.

Temporal and geographic aspects of plastic ingestion were also evident, and these patterns bear on the question of how long plastic is retained in seabird guts. Ryan (1988b) proposed that most of the observed seasonal change in plastic loads is a function of the transfer of plastic from breeding adults to chicks rather than degradation within the digestive tracts of adults. If this is correct, we should have found highest incidence in subadults (who have never bred and thus have never had an opportunity to disgorge plastic), lowest incidence in postbreeding adults, and intermediate values in nonbreeding adults. Our data do not indicate such a pattern. First, in species for which samples were sufficiently large to make comparisons, we found no indication that subadults had more or less plastic than adults. Second, the seasonal patterns we observed suggest that degradation is an important process, and that the time scale is on the order of 6 months or slightly longer. Ryan and Jackson (1987) assumed that degradation rate is constant throughout the time that plastic resides in a seabird digestive tract, and they based their extrapolation on plastic fed to birds and then inspected after retention for only 12 days, However, plastic subjected constantly to digestive acids and abrasion could degrade at a faster rate as time passes, especially if its surface-to-volume ratio increases. Van Franeker and Bell (1988) found that the mass of plastic particles in cape petrels collected in the Antarctic (where there is no plastic to replenish ingested loads) decreased by 50% over a 3-month period. This rate supports a shorter degradation period than that proposed by Ryan and Jackson (1987; see Day et al. 1985).

We interpret our seasonal and geographic data as follows. Those birds that reside year-round in the region of the South Equatorial Current and the Equatorial Countercurrent (Wyrtki 1967), i.e., our study area, exhibited only incidental ingestion of plastic. We observed little floating debris during our censuses, probably because there are few, if any, large industrial source areas in the central Pacific for plastic and there are no large human population centers except for Oahu. Among petrel species of the Northwestern Hawaiian Islands, which lie in the North Equatorial Current, Harrison et al. (1983) also found only low levels of plastic ingestion. We did not collect any samples in the Panamanian Bight, where we observed much floating plastic and other flotsam on our bird censuses.

Compared to year-round equatorial residents, results were much different for petrels that were either passing through the study area or that came a long way from polluted areas to spend their nonbreeding period there. Those species that had just come from areas where industrial plastic pellets are common, for example, off Japan and California (Day et al. 1985; Pruter 1987), had ingested significant amounts of pellets. Several of these species, including adults and subadults, had higher plastic loads after frequenting polluted waters (where adults bred). This suggests that loss of plastic while in plastic-free waters (because erosion outpaces ingestion) is important. Since the migrations are annual, degradation over a 6- to 12-month period would best fit the patterns. As examples, species or populations that had come from the eastern and central North Pacific had high plastic loads (i.e., Buller's, short-tailed, and sooty shearwater and Leach's storm-petrel). The first three were in the prebreeding portion of the annual cycle, and the last was postbreeding. This inconsistency is contrary to the off-loading through chick-feeding hypothesis. When specimens of these speciews have been inspected in California waters they contain much plastic (Balz and Morejohn 1976). The fact that sooty shearwaters migrating north from New Zealand or Leach's storm-petrel not newly arrived from the north have low plastic loads confirms that it is in the eastern North Pacific that these species are ingesting plastic. Sooty shearwaters, probably of the South American breeding population, also frequent the Peru Current, but we did not collect any. A portion of the New Zealand population of this species migrates to polluted waters off Japan, but the eastern Pacific position of our study area and the flight directions observed indicate that the birds we sampled were moving between New Zealand and the eastern North Pacific.

The incidence of plastic ingestion was also high in species collected at the periphery of the Peru Current or that came to the study area from waters off Chile (i.e. , cape petrels, prions, white-chinned petrel, *Procellaria aequinoctialis*, Cook's petrel, *Pt. cooki defilippiana*, and Stejneger's petrel). Cape and white-chinned petrels collected south of South America have much lower plastic loads than those inspected in this study (Ainley et al. 1990). This supports the suggestion that the specimens inspected in this study encountered the plastic in the Peru Current. Stejneger's petrel moves through the study area between Chilean waters and waters off Japan, and thus its plastic could have come from either area. Unlike the other migrants discussed above, these petrels had similar plastic loads regardless of whether they were moving south or north. This supports the suggestion that they were ingesting plastic off Chile and off Japan. Bourne and Clark (1984) noted specific areas of nearshore Chile where significant amounts of plastic had accumulated, but little information is available on a larger geographic scale. One species they observed in association with scum and flotsam lines was *Pa. belcheri*, which in our samples contained much plastic. Species from the northern part of the Peru Current (i.e., several species of the genus *Oceanodroma*) had low plastic loads .

Though not as high as in the birds noted above, the occurrence frequency of plastic was high in white-winged petrel, which as far as we know nests in the subtropical Tasman Sea area. The pattern of low plastic incidence before breeding and after wintering away from polluted areas, but high incidence after breeding, again is contrary to the chick off-loading hypothesis. Along the Equator, one of two individuals of Pycroft's petrel, *Pt. longirostris pycrofti*, which breeds in northern New Zealand, contained plastic, and four of six white-faced storm-petrels, that could also have come from northern New Zealand, contained much plastic. Imber (in Day et al. 1985) reported plastic in 50% of specimens of the latter species from Chatham Island (NZ); Harper and Fouler (1987) found that plastic was prevalent in prions washed ashore in northern New Zealand; van Franeker and Bell (1988) noted significant loads of plastic in Antarctic-breeding species that wintered in the Indian Ocean and Tasman Sea; and Gregory (1978) has noted significant amounts of plastic on most New Zealand beaches, north and south. Thus, it is not surprising that petrels that spend time in New Zealand waters show high plastic ingestion. It is surprising that those sooty shearwaters that were newly arrived to our study area from New Zealand had no plastic, although the large majority of sooty shearwaters nest away from and south of the main islands of New Zealand, and thus away from industrialized areas. This may account for the lower rates of plastic ingestion in these birds.

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PREVALENCE AND CHARACTERISTICS OF PLASTIC INGESTED BY HAWAIIAN SEABIRDS

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ABSTRACT

The prevalence of plastic in 18 species of seabirds at seven study sites in the Hawaiian Islands and Johnston Atoll was studied during 1986 and 1987. Stomach samples were collected by induced emesis from 1,803 live birds of 15 species and during necropsy of 277 dead birds of 5 species. The prevalence of ingested plastic varied greatly among species; age, year of collection, and location of the study site had less pronounced but significant effects. Ingested plastic was absent or uncommon in terns and noddies. Plastic was not found at all in samples from gray-backed terns, *Sterna lunata*, or white terns, *Gygis alba*. The prevalence was low in sooty terns, *Sterna fuscata* (0 to 8%), and brown, *Anous stolidus*, and black noddies, *A. minutus* (0 to 3%). Plastic was much more prevalent (67 to 100%) in chicks of black-footed, *Diomedea nigripes*, and Laysan albatrosses, *D. immutabilis*. In the 11 other species prevalence ranged from 0 to 44% depending on the age, year of collection, and location. The mean volume of plastic in samples collected at necropsy from Laysan albatross chicks was higher in 1986 (46 cc) than in 1987 (5 cc). Prevalence was generally higher in seabirds which fed at the surface. Fragments of manufactured articles were the most common type of plastic found. Other plastics included pellets, Styrofoam, bottle caps, bags, and sponges. The largest individual item (200 cc) and the greatest diversity of plastic items were found in albatross chicks.

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INTRODUCTION

Production of plastic products and dumping of plastic garbage in the ocean have increased dramatically in the past 25 years. From 1960 to 1985 the United States increased plastic production from 2.9 to 20.7 billion kg (6.3 to 47.9 billion lb) per year (Iudicello and O'Hara 1986). The prevalence of plastic ingestion by seabirds also has increased. Plastic was first reported in the stomachs of seabirds in 1960, when it was discovered in broad-billed prions, *Pachyptila vittata*, that were killed during storms on New Zealand (Harper and Fowler 1987). By 1985, at least 70 species of seabirds from all the world's oceans were known to ingest plastic (Day et al. 1985; Ryan 1987a).

Seabirds ingest a wide variety of plastic types, but 2- to 5-mm diameter plastic pellets and fragments of manufactured plastic products are most common (Day et al. 1985; Ryan 1987a). Other types of plastic found in seabird stomachs include Styrofoam, fibers, bags, bottle caps, and toys (Kenyon and Kridler 1969; Harrison et al. 1983; Dickerman and Goelet 1987; Ryan 1987a). Plastic particles may be eaten intentionally, accidentally mistaken for prey, or ingested secondarily when hidden within a food item (Day *et* al. 1985). For example, small plastic particles may be confused with fish eggs or small invertebrates, while larger pieces can be mistaken for squid, jellyfish, fish, or other large prey. Flyingfish often deposit their egg masses on floating debris such as plastic, which may then be ingested by albatrosses (Pettit et al. 1981; Harrison et al. 1983).

Plastic ingestion has not been reported as a significant health problem in seabird populations, but several studies have indicated negative effects on individual birds. Ingested plastic may distend or block the proventriculus or intestine, causing erosions or ulcers (Pettit et al. 1981; Sileo and Fefer 1987) or possibly starvation (Dickerman and Goelet 1987). The presence of ingested plastic was correlated with elevated (but nonthreatening) concentrations of polychlorinated biphenyls in great shearwaters, *Puffinus gravis* (Ryan *et* al. 1988), and with reduced body w-eight in red phalaropes, *Phalaropus fulicarius* (Connors and Smith 1982) and domestic chickens, *Gallus domesticus* (Ryan 1988a). Other studies have shown no correlation between body weight and plastic presence (Day et al. 1985; Ryan 1987b). Ryan and Jackson (1987) found no reduction in assimilation efficiency in white-chinned petrels, *Procellaria aequinoctialis*, artificially fed large quantities of plastic particles.

Studies of the prevalence of plastic ingestion in seabird communities, based on examination of regurgitations or carcasses, have been conducted in the North Pacific (Day et al. 1985) and South Atlantic Oceans (Furness 1985; Ryan 1987a). Reports of plastic in Laysan and black-footed albatrosses have shown that these birds ingest the widest variety of plastic items (Kenyon and Kridler 1969) and ingest the largest volumes of plastic more frequently than other seabirds (Fry et al. 1987; Sileo and Fefer 1987). Harrison et al. (1983) reported cursory data for other Hawaiian seabirds, but systematic study of the prevalence of plastic ingestion in the Hawaiian avifauna has not been done. Our objective was to determine the prevalence of ingested plastic in three orders of Hawaiian seabirds (Procellariiformes, Pelecaniformes, and Charadriiformes) from different islands by examining stomach contents. We evaluated the prevalence of ingested plastic for associations with species, location of study site, year of collection, and ages of birds sampled.

STUDY AREA AND METHODS

Stomach samples were collected from 18 species of seabirds on Kauai, Maui, Nihoa, Tern, and Laysan Islands, Pearl and Hermes Reef, and Midway in the Hawaiian Islands. Approximately 5 million seabirds of 22 species nest on these islands (Harrison et al. 1984). Samples were also collected on Johnston Atoll, 1,400 km southwest of Honolulu. Seabirds from remote, uninhabitated islands were sampled by the authors or other biologists as travel circumstances permitted. One of us (Sievert) spent 4 months in 1986 and 6 months in 1987 on Midway.

To avoid killing large numbers of seabirds, a stomach pumping method was used to recover the proventricular contents (Wilson 1984; Ryan and Jackson 1986). The method reportedly recovers 89 to 100% of the proventricular contents, although Ryan and Jackson (1986) found that the proportion (by mass) of food recovered by a single pumping was negatively correlated with total stomach content in white-chinned petrels. Seawater was pumped through a 10-mm (outside diameter) plastic tube into the proventriculus of larger species with a manual pump (Black and Decker Model No. JSO-1500). Smaller species, such as terns and petrels, were given seawater using a 6-mm (outside diameter) plastic tube attached to a 140-cc syringe. Seawater was pumped into the proventriculus until water became visible in the esophagus. The tube then was quickly removed and the bird inverted over a container. The bill was held open with one hand and large objects were massaged through the esophagus if the bird was having difficulty regurgitating. A l-mm diameter mesh net was used to skim plastic items from the surface of the regurgitant for later characterization.

The samples were collected from April 1986 to November 1987 by induced emesis from live seabirds or during necropsy of carcasses. Necropsy samples were obtained from carcasses found dead of natural causes and from six euthanized Laysan albatross chicks. All necropsies *were* performed by the authors, Dehydration was the most common natural cause of death in 1987 (Sileo et al. 1990). Seabird stomach samples were collected by different biologists in different locations, which resulted in statistical confounding of investigator effect with location. The confounding was unavoidable because the remoteness and inaccessibility of the study sites precluded replicative sampling by different biologists. Investigator effect was minimized by having each biologist complete a training session for the stomach pumping method. For most species, stomach samples were collected from chicks because they *were* more accessible and more easily captured. All live birds were approached *on* foot and captured by hand. Age of the seabirds was determined by plumage characters. When it was not possible to differentiate between free-flying juveniles and adults, all were assigned to an arbitrary “either” category. Birds were sampled once and banded with a U.S. Fish and Wildlife Service leg band to prevent repetitive sampling.

We tested the effectiveness of the sampling technique by pumping the stomachs of six Laysan albatross chicks, then euthanizing and examining them. The volume of proventricular content not removed by the stomach pump was determined. We necropsied birds that were found dead and inspected their digestive tracts for the presence of plastic. This was the only method used for 58 Benin petrels, *Pterodroma hypoleuca*, 3 dark-rumped petrels, *Pterodroma phaeopygia,* and 18 Newell's shearwaters, *Puffinus auricularis* (*newelli*). The proventriculus and ventriculus of all necropsied birds were examined, and the intestines also were examined for a sample of 39 black-footed albatrosses, 57 Laysan albatrosses, and 12 Bonin petrels. Contents of the entire intestine from pyloris to cloaca were stripped. All plastic was separated from the stomach content by fresh water flotation and saved for later characterization.

Plastic was characterized by type, volume, and color. Types were fiber, pellet, Styrofoam, fragment, bottle cap, bag, sponge, and other. Fiber included fishing line, net fragments, and rope. Pellets were 2 to 5 mm diameter spherical polyethylene particles primarily used as the raw material for manufacturing plastic products (Carpenter et al. 1972). Bottle caps included all types of plastic lids, and bags were defined as plastic film less than 1 mm thick in the form of a bag or sheet. Other included children's toys, cigarette lighters, hair combs, balloons, gloves, condoms, tubing, sandals, wrappers, and bandages. The number of plastic items of each type per bird was counted except for fiber, which was recorded as present or absent. Plastic fragments were assigned to one of five color groups: white, which included white, yellow, tan, and brown; black, which included gray and black; blue, which included purple and blue; green, which included all shades of green; and red, which included pink and red. One of us (Sievert) was studying growth rates of a marked population of albatross chicks at a study site on Midway. Albatross carcasses found dead at this study site were dissected and the total volume of recovered plastic was determined by water displacement. The buoyant contents were placed in a wire screen bag (1.5-mm diameter mesh) and immersed in a 2,000-ml beaker filled with tap water. The volume of water displaced was measured. In 1986, all measurements were made in l-cc increments, and in 1987, in 5-cc increments. The volume of the largest plastic fragment from each bird was calculated from the linear dimensions of the fragment.

Statistical analysis of the plastic prevalence data followed the general recommendations of Freeman (1987). Chi-square tests for association were used for 2 x 2 tables of plastic prevalence and other independent variables. Fisher's exact test was used when cell expectations were small (<5). Several 2 x 2 tables were combined using the Cochran-Mantel-Haenszel procedure to test hypotheses of an overall association between plastic prevalence and the independent variables. This procedure provided a means for stratifying the plastic prevalence data from each unique combination of island, age, species, and year so that there was only a single independent variable in each test. Hypothesis tests were considered significant at the 0.05 level, however, P values for each test are also reported. Samples from wedge-tailed shearwaters, *Puffinus pacificus*, and red-tailed tropicbirds, *Phaethon rubricauda*, from different islands permitted assessment of the effect of geographic location on plastic ingestion. The influence of year of collection was determined by comparing prevalence in 1986 and 1987 in 11 combinations of species, location, and age. The prevalence in chicks was compared to adults in nine combinations of year, species, and location. If the prevalence of two or more closely related species were not significantly different, data from the species were combined to make comparisons with broader taxonomic groups.

RESULTS

In 1987 stomach pumping removed at least 50% of the proventricular plastic from five (83%) of six Laysan albatross chicks, each of which contained 5 to 10 cc of plastic (Table 1). Stomach pumping failed to remove any plastic from the remaining chick, which contained 5 cc of plastic as well as 100 cc of rock. The rock was primarily buoyant volcanic pumice. Induced emesis recovered half of the proventricular plastic as long as the pumice content was less than 55% of the total proventricular content. For comparison, the prevalence of proventricular plastic in the carcasses of Laysan albatross chicks examined by dissection at Midway was 94% in 1986 and 98% in 1987 (Table 2).

Stomach-pumped samples from both 1986 and 1987 were collected from 11 unique combinations of species, location, and age (Table 2). Significant differences between years of collection were found for red-tailed tropicbird chicks at Midway and adult wedge-tailed shearwaters at Kauai; however, the overall test for a significant association between year of collection and plastic prevalence was not quite significant (P - 0.053). To remove potential investigator effect, combinations where all the birds were sampled by only one of us (Sievert) were analyzed. These included the five combinations sampled at Midway, and the overall P value (0.029)

Table 1. --Rock, plastic, and other proventricular contents removed by stomach pumping from six Laysan albatross chicks that were then euthanized and necropsied.

	Total content		Rock content		Plastic content	
Bird No.	Volume present[a] (cc)	Percent removed	Volume present[a] (cc)	Percent removed	Volume present[a] (cc)	Percent removed
1	140	3	100	5	5	0
2	100	20	55	18	10	50
3	60	17	20	25	10	50
4	45	44	15	67	5	100
5	20	50	10	50	10	50
6	20	50	5	100	10	50

[a]Volumes were measured in 5 cc increments.

Table 2.--Statistical comparisons of the prevalence of plastic in stomach samples collected from Pacific seabirds.[a]

							P Values				
Method[b]	Year	Species[c]	Site[d]	Age[e]	N	%	1986-87	Age	Islands		Species
N	1986	BFAL	M	C	28	89	--	--	--	--	ab 0.433
N	1986	LAAL	M	A	31	35	--	i 0.000	--	--	--
N	1986	LAAL	M	C	78	94	--	i 0.000	--	--	ab 0.433
N	1986	BOPE	M	B	58	29	--	--	--	--	--
N	1987	BFAL	M	C	18	100	--	--	--	--	ac 1.00
N	1987	LAAL	M	C	43	98	--	--	--	--	ac 1.00
N	1987	NESH	K	I	18	11	--	--	--	--	--
P	1986	BFAL	L	C	56	79	a 0.097	--	--	--	--
P	1986	BFAL	T	C	1	0	--	--	--	--	--
P	1986	LAAL	L	C	24	92	c 0.161	--	--	--	--
P	1986	LAAL	T	C	12	92	d 0.245	--	--	--	--
P	1986	WTSH	K	A	150	18	i 0.024	--	ba 1.00	ca 0,452	--
P	1986	WTSH	M	A	15	13	j 0.304	h 0.620	ba 1.00	da 0.716	dc 1.000
P	1986	WTSH	M	C	11	27	--	h 0.620	--	--	--
P	1986	WTSH	T	A	48	23	k 0.272	--	ca 0.452	da 0,716	--
P	1986	CHSH	M	A	1	0	--	--	--	--	dc 1.000
P	1986	RTTB	M	A	8	0	--	c 0.054	--	--	--
P	1986	RTTB	M	C	16	44	g 0.001	c 0.054	--	--	--
P	1986	RFBO	L	A	34	0	--	--	--	--	--
P	1986	RFBO	L	C	7	0	e 1.00	--	gb 1.00	--	--
P	1986	RFBO	M	A	4	0	--	b 1.00	--	--	--
P	1986	RFBO	M	C	19	11	f 0.119	b 1.00	gb 1.00	--	--
P	1986	SOTE	M	A	26	8	--	f 0.172	--	--	ba 1.00
P	1986	SOTE	M	C	36	0	h 0.493	f 0.172	--	--	bb 1.00
P	1986	GBTE	M	A	7	0	--	--	--	--	ba 1.00
P	1986	GBTE	M	C	29	0	--	--	--	--	bb 1.00
P	1986	BRNO	M	A	17	0	--	a 1.00	--	--	--
P	1986	BRNO	M	C	86	1	b 1.00	a 1.00	--	--	--
P	1986	BLNO	L	A	18	0	--	--	--	--	--

Table 2.--Continued.

Method[b]	Year	Species[c]	Site[d]	Age[e]	N	%	P Values 1986-87	Age	Islands		Species
P	1987	BFAL	L	c	36	92	a 0.097	--	eb 0.710	--	aa 0.239
P	1987	BFAL	N	c	21	86	--	--	fb 1.00	--	--
P	1987	BFAL	P	c	35	97	--	--	--	--	ad 0.614
P	1987	BFAL	T	c	35	89	--	--	eb 0.710	fb 1.00	ae 0.206
P	1987	LAAL	L	c	35	100	C 0.161	--	--	--	aa 0.239
P	1987	L4AL	P	c	35	91	--	--	--	--	ad 0.614
P	1987	LAAL	T	c	6	67	d 0.245	--	--	--	ae 0.206
P	1987	BUPE	N	A	38	5	--	--	--	--	--
P	1987	WTSH	J	A	60	5	--	--	ab 0.004	--	--
P	1987	WTSH	K	A	35	3	i 0.024	g 0.067	bb 0.003	cb 0.064	--
P	1987	WTSH	K	c	7	29	--	g 0.067	--	--	--
P	1987	WTSH	L	A	35	14	--	--	ga 0.145	ea 0.888	da 0.782
P	1987	WTSH	M	A	35	29	j 0.304	--	ab 0.004	dd 0.093	--
							--	--	bb 0.003	ga 0.145	--
P	1987	WTSH	N	A	60	3	--	--	fa 0.033	--	db 0.522
P	1987	WTSH	T	A	85	15	k 0.272	--	cb 0.064	fa 0.033	--
							--	--	db 0.093	ea 0.888	--
P	1987	CHSH	L	A	36	17	--	--	--	--	da 0.782
P	1987	CHSH	N	A	2	50	--	--	--	--	db 0.522
P	1987	SOSP	L	A	18	33	--	e 0.903	--	--	--
P	1987	SOSP	L	c	17	35	--	e 0.903	--	--	--
P	1987	RTTB	J	c	50	4	--	--	aa 1.00	--	--
P	1987	RTTB	M	A	39	5	--	d 1.00	--	--	--
P	1987	RTTB	M	c	48	2	g 0.0001	d 1.00	aa 1.00	--	--
P	1987	RTTB	T	c	50	14	--	--	--	--	--
P	1987	MABO	L	c	20	5	--	--	--	--	--
P	1987	RFBO	L	c	35	3	e 1.00	--	ec 1.00	gc 1.00	--
P	1987	RFBO	M	c	35	0	f 0.119	--	dc 1.00	gc 1.00	--
P	1987	RFBO	T	c	35	0	--	--	dc 1.00	ec 1.00	--
P	1987	GRFR	M	c	45	18	--	--	--	--	--

Table 2.- -Continued.

Method[b]	Year	Species[c]	Site[d]	Age[e]	N	%	P Values 1986-87	Age	Islands		Species
P	1987	SOTE	M	C	35	3	h 0.493	--	--	--	bc 1.00
P	1987	GBTE	M	A	10	0	--	--	--	--	--
P	1987	GBTE	M	C	25	0	--	--	--	--	bc 1.00
P	1987	BRNO	M	C	35	0	b 1.00	--	--	--	--
P	1987	BRNO	T	C	15	0	--	--	--	--	ca 1.00
P	1987	BLNO	T	C	35	3	--	--	--	--	ca 1.00
P	1987	WHTE	M	C	35	0	--	--	--	--	--

[a]Rows having the same letter codes and the same P value were compared by the Cochran-Mantel-Haenszel procedure (Freeman 1987). The first letter of a double letter P value code indicates a species group comparison; the second letter of a double letter code indicates the two members of a paired comparison within the designated group.

[b]N - sample collected at necropsy, P - sample collected by stomach pumping.

[c]BFAL - black-footed albatross, BLNO - black noddy, BRNO - brown noddy, BOPE - Benin's petrel, BUPE - Bulwer's petrel, CHSH - Christmas shearwater, GBTE - gray-backed tern, GRFR - great frigatebird, LAAL = Laysan albatross, NESH - Newell's shearwater, MABO - masked booby, RFBO - red-footed booby, RTTB - red-tailed tropicbird, SOSP - sooty storm petrel, SOTE = sooty tern, WHTE - white tern, WTSH - wedge-tailed shearwater,

[d]J - Johnston Atoll, K - Kauai, L = Laysan Island, M - Midway, N - Nihoa Island, P = Pearl and Hermes Reef, T - Tern Island.

[e]A - adult, C - chick, B - both adults and free-flying immatures, and I - free-flying immatures.

indicated a significantly higher prevalence in 1986. Thus year of collection had a significant effect in species and age combinations from Midway.

To test age, prevalence data based on stomach-pumped samples collected from both adults and chicks of eight combinations of species, location, and year of collection were compared (Table 2). None of the individual results were significantly different; however, in all species except the sooty tern, the trend was for higher prevalence among chicks. This caused a significant overall association between age and prevalence (P - 0.05). A second analysis of age was done which included the 1986 necropsy samples from the Laysan albatrosses at Midway. There was a significant difference between the Laysan albatross chicks and adults (P < 0.00), and the overall association between age and prevalence was again significant (P < 0.00).

In 1987 the adult wedge-tailed shearwaters of Johnston Atoll had significantly lower prevalence (5%) of plastic in pumped stomach samples than at Midway (29%) in individual tests (Table 2), and the overall test of association also showed a significantly (P = 0.01) lower prevalence at Johnston. In 1987, adult wedge-tailed shearwaters had higher prevalence (29%) at Midway than at Kauai (3%), and at Tern Island (15%) than at Nihoa (3%). The individual tests for these particular combinations were significant (Table 2), but the overall tests of association were not (P = 0.064, and P - 0.078, respectively), suggesting the absence of a consistent pattern in differences in prevalence among these island pairs. No other significant differences were detected between locations.

It was possible to compare prevalence between black-footed and Laysan albatrosses using both stomach-pumped and necropsy samples for five combinations of location, age, and year of collection (Table 2). Neither the individual results nor the overall test of association (P - 0.98) were significant. Consequently, data from both species of albatrosses were combined for later comparisons with other taxa. Stomach pumped samples from three combinations of location, age, and year were used to compare gray-backed terns and sooty terns. Again, neither individual nor overall (P = 0.264) tests of association were significant, and both species of terns were combined for comparison with other taxa. Brown noddies and black noddies were also not significantly different (P = 1.00) and were combined. Finally, the combined terns were compared to the combined noddies, and again neither individual (P - 0.542, 1.00, or 1.00) nor the overall (P = 0.519) tests of association were significant, so that all tern and noddy species were combined for comparisons with other taxa. Stomach-pumped samples from Christmas shearwaters, *Puffinus nativitatis*, and wedge-tailed shearwaters were compared for three combinations of location, age, and year (Table 2). There were no significant individual or overall (P - 0.69) association, and data from these two species of shearwaters were combined for comparisons with other taxa. In comparisons between taxonomic groups , the albatrosses had significantly higher prevalence, the terns and noddies the lowest, and the shearwaters, tropicbirds, and boobies were intermediate (Table 3).

Table 3.--Comparisons of the prevalence of ingested plastic in stomach samples of five taxonomic groups of Hawaiian seabirds. A "-" means that the taxa in the row had significantly lower prevalence than the taxa in the column, "ns" means that there was no significant difference between the taxa in the *row* and column, "+" means that the taxa in the row had significantly higher prevalence than the taxa in the column, and "nc" means no comparison was done.

Taxa[a]	LAAL/BFAL	GBTE/SOTE BLNO/BRNO	RFBO	CHSH/WTSH	RTTB
LAAL/BFAL		+	+	nc	+
GBTE/SOTE BLNO/BRNO			ns		
RFBO		ns		ns	[illegible]
CHSH/WTSH	nc	+	ns		+
RTTB		+	+		
Range of prevalence in chicks (%)	67-100	0-36	0-11	27-29	2-44
Range of prevalence in adults (%)	35	0-8	0-34	3-29	0-5

[a]BFAL - black-footed albatross, BLNO - black noddy, BRNO = brown noddy, CHSH - Christmas shearwater, GBTE - gray-backed tern, LAAL = Laysan albatross, RFBO - red-footed booby, RTTB - red-tailed tropicbird, SOTE = sooty tern, WTSH = wedge-tailed shearwater.

Necropsy examinations of carcasses revealed plastic in the intestines of many of the albatrosses (Table 4). While plastic was usually present in both the proventriculi and ventriculi of albatrosses, it was more common in the ventriculi of petrels and shearwaters (Table 4). The mean volume of plastic in the Laysan carcasses was about nine times greater in 1986 than 1987 (Table 5).

Albatrosses held the widest diversity of plastic types and were the only species to ingest bottle caps, bags, sponges, and a variety of other items. Styrofoam, fibers, sponges, bags, and bottle caps were more common in black-footed albatrosses than Laysan albatrosses, whereas plastic pellets were more common in the latter. Fragments were the most common type of plastic ingested by all the species except Benin petrels, which contained fibers most frequently. Albatrosses ate the largest individual plastic items; the volume of the largest single item (plastic sheet) recovered was 200 cc. Albatrosses also ate the largest fragments (up to 25.2 cc); petrels, shearwaters, tropicbirds, boobies, and frigatebirds ingested moderate-sized ones; and storm-petrels and terns consumed the smallest (up to 2.0 cc, Table 6). Most of the fragments recovered were white regardless of the species of bird (Table 7). Samples from sooty storm-petrels, *Oceanodroma tristrami*, contained red fragments more frequently than samples from any of the other species. Great frigatebirds, *Fregata minor*, contained only white or black fragments.

DISCUSSION

Although we never recovered more than 50% of the volumes of plastic greater than 5 cc, or over 50% of the total stomach content of the euthanized albatross chicks, the reliability of stomach pumping seemed acceptable for simply detecting the presence of plastic in Laysan albatross chicks, and thus for prevalence information. Efficacy in the other species was not determined. Ryan and Jackson (1986) got higher (89-100%) yields of the total stomach content of petrels than we did for albatross chicks, although Ryan and Jackson were studying the removal of all dietary items and we were interested only in detecting the presence of plastic. Large volumes of proventricular rock seemed to interfere with removal of small volumes of plastic. Other reports also state that stomach pumping is less effective in birds that have full stomachs with tightly packed contents (Ryan and Jackson 1986). Stomach pumping removes only the proventricular content of petrels, and may or may not remove gizzard content from Pelecaniformes, Charadriiformes, and some Procellariiformes (Diomedeidae) (Ryan and Jackson 1986). Our stomach pumping results possibly underestimated prevalence in our study and this may have been more significant in individuals with small plastic loads. But stomach pumping precluded killing 1,803 seabirds, simply to learn what they were eating.

There are several reports that the prevalence of ingested plastic in seabirds is increasing over the long term. Day et al. (1985) reported increases in short-tailed shearwaters, *Puffinis tenuirostris*, in the 1970's. Van Franeker (1985) noted an increase in the number of plastic particles in fulmars, *Fulmaris glacialis*, in the North Sea through the early 1980's. Harper and Fowler (1987) reported long-term interannual increases in plastic prevalence based on large samples of prions, *Pachyptila* spp., found dead on New Zealand beaches from <5% in 1960 to >20% in 1970. Fry et al. (1987) show that the prevalence (80-90%) in the Laysan albatrosses of the Northwestern Hawaiian Islands in the late 1980's was higher than the 74% reported by Kenyon and Kridler (1969), although the sampling methods were different. Frequency of occurrence increased in Antarctic prions, P. *desolata*, in the Southern Ocean during the early 1980's (Ryan 1988b). It is widely assumed that increasing prevalence in seabirds reflects increasing pollution of the marine environment, and this is probably correct; however, the marked short-term interannual difference we found (44% in red-tailed tropicbird chicks at Midway in 1986 versus 2% in 1987) in the same species at the same nesting colony examined by the same scientist suggests that long-term relationships must be interpreted carefully. Such interannual variation might be caused by changes in the amount of plastic dumped in the ocean, movement of floating plastic by winds and currents, seabird foraging areas, or feeding behavior. The volumes of plastic we recovered from the necropsied albatross chicks are 10 to 100 times greater than the volumes reported for other species (Day et al. 1985; Furness 1985; Ryan 1987a, Bayer and Olson 1988; van Franeker and Bell 1988). The mean 18.3 cc volume (estimated as 0.9053 x weight) recovered from Laysan albatross chicks by Kenyon and Kridler (1969) compares well with our data.

Table 4.--The prevalence of plastic in the gastrointestinal tracts of seabird carcasses examined by necropsy in the Hawaiian Islands in 1986 and 1987 [percent containing plastic (number examined)].

Species	Age[a]	Plastic location		
		Proventriculus	Ventriculus	Intestines
Black-footed albatross	Chick	95 (44)	93 (44)	30 (20)
Laysan albatross	Chick	100 (131)	95 (131)	39 (57)
Benin petrel	Both	27 (99)	82 (99)	0 (12)
Dark-rumped petrel	Both	33 (3)	100 (3)	--
Newell's shearwater	Both	8 (36)	17 (36)	--

[a]Both = Juveniles plus adults.

Table 5.--Volume of plastic removed from the proventriculi of black-footed and Laysan albatross carcasses found dead of natural causes on Midway.

Year	Black-footed albatross			Laysan albatross		
	N	Range	Mean	N	Range	Mean
1986	25	0-198	39	45	1-186	46
1987	18	5-165	33	76	5-20	5

With the inclusion of the results from this study, 80 species, or approximately 25% of the world's seabird species, have been shown to ingest plastic. The pronounced differences in the prevalence of ingested plastic between different taxa of Hawaiian seabirds was expected. Seabird biologists have reported interspecific differences for seabird communities in the North Pacific and Southern Ocean and have attributed them primarily to differences in feeding behavior (Day et al. 1985; Ryan 1987a). Species feeding primarily at the ocean surface ingested more plastic, possibly because of increased exposure to it.

Geographic variations in prevalence in a given species are usually attributed to differences in the environmental availability of plastic, although no study has attempted to test this assumption (Day et al. 1985; Ryan 1988b). The mean density of plastic particles in Alaskan waters was 910 particles/km^2 (calculated from Day and Shaw 1987), in the South Atlantic it was 2,080 particles/km^2 (calculated from Morris 1980), and in the subtropical North Pacific (the Hawaiian Islands region) it was 96,100 particles/km^2 (Day and Shaw 1987). The corresponding percentages of

Table 6. --Mean volume (cc) of the largest plastic fragment[a] removed from the proventriculi and ventriculi of individual Hawaiian seabirds during 1986 and 1987.

Species	Proventriculus		Ventriculus	
	N	Mean volume	N	Mean volume
Black-footed albatross	51	2.056	16	0.089
Laysan albatross	47	0.649	63	0.073
Petrels (Benin, Bulwer's, dark-rumped)	4	0.041	20	0.014
Shearwaters (wedge-tailed, Newell's, Christmas)	54	0.117	6	0.006
Sooty storm-petrel	30	0.017	--	--
Red-tailed tropicbird	14	0.051	--	--
Boobies (masked, red-footed)	2	0.054	--	--
Great frigatebird	5	0.329	--	--
Sooty tern	1	0.002	--	--

'Fragments were flat pieces of manufactured plastic, 1-3 mm thick, typically from broken plastic bottles or other containers.

Table 7. --Prevalence (number of stomach samples containing the color/the total number of samples examined x 100) of different colors of plastic fragments' removed from the proventriculi of Hawaiian seabirds during 1986 and 1987. Stomach samples were obtained by stomach pumping.

Species	N	Plastic color (%)[b]				
		White	Black	Blue	Green	Red
Black-footed albatross	82	93	27	43	41	13
Laysan albatross	78	95	32	49	50	27
Wedge-tailed shearwater	51	84	8	24	29	8
Sooty storm-petrel	30	87	13	10	27	40
Red-tailed tropicbird	14	57	43	21	7	0
Great frigatebird	5	80	40	0	0	0

'Fragments were flat pieces of manufactured plastic, 1-3 mm thick, typically from broken bottles or other containers.

[b]Color groups were : white - white, yellow, tan and brown; black = gray and black; blue - purple and blue; green - green; red = pink and red.

seabird species that ingested plastic in these three regions were 41 (Day et al. 1985), 60 (Ryan 1987a), and 89 (this study), suggesting a positive relationship between plastic availability and the prevalence of ingestion. The same relationship may explain the lower prevalence of plastic in adult wedge-tailed shearwaters at Johnston Atoll compared with the same species at Midway. The beaches of Johnston Atoll have much less plastic refuse than those of the Northwestern Hawaiian Islands (S. I. Fefer, unpubl. observ.), suggesting a lower density of plastic in the surrounding waters used for feeding. Much of the plastic in these waters may be of Japanese origin as indicated by Pettit et al. (1981), who found that 108 of 109 identifiable plastic items in dead albatross carcasses at Midway were manufactured in Japan. Movement of floating plastic by ocean currents provides an explanation for the high prevalence of Japanese plastic in Hawaiian waters and the reduced amount of plastic on Johnston Atoll. The Kuroshio moves surface waters from near Japan southeast to the Hawaiian region, and may carry plastic with it (Fry et al. 1987). Johnston Atoll is affected primarily by the North Equatorial Current, which probably has less intense shipping and fishery activity and hence less plastic.

Day et al. (1985) found that subadult parakeet auklets, *Cyclorrhynchus psittacula*, and tufted puffins, *Lunda cirrhata*, contained more plastic than adults, and Ryan (1988b) found the same association for blue petrel, *Halobaena caerulea*, chicks. The high prevalence in albatross chicks, and probably chicks of other species in the Hawaiian Islands, was likely due to the regurgitational chick-feeding process and the inability of very young chicks to regurgitate indigestible. All Hawaiian seabirds except white terns feed their chicks by regurgitation, and plastic items ingested by the parents are probably passed to the chicks. Ryan (1988b) proposed that this "intergenerational" transfer of plastic reduces occurrence in the adult populations while increasing it in the chick populations. Plastic is usually expelled from the proventriculus of albatross chicks by regurgitation late in the chick-rearing period (Clarke et al. 1981), and the volume of plastic in a given chick, and perhaps the prevalence in the chick population, are reduced at that time. Other seabirds (giant petrels, cormorants, skuas, gulls, and terns) also regurgitate indigestible matter. The presence of plastic in the intestines of some birds indicates that plastic is also removed by defecation. Interspecific differences in physiology, the ratios of proventricular to ventricular volume, or the total volume of plastic ingested may have influenced the interspecific differences in the distribution of plastic through the gastrointestinal tract.

It was not determined if the color composition of fragments from the stomach samples reflected the color distribution of floating fragments at sea or some feeding specificity by the birds. Day et al. (1985) found that some Alaskan seabirds selectively consume plastic particles similar to prey items.

Black-footed albatrosses ingest about 10 times the volume of fish eggs ingested by Laysan albatrosses (Harrison et al. 1983), and might be expected to ingest more plastic pellets if these are mistaken for fish eggs. However, we found pellets more often in Laysan (52%) than black-footed albatrosses (12%, $P < 0.001$). Black-footed albatrosses probably do not ingest single fish eggs, but instead consume large masses of eggs attached to floating objects, which may explain the higher (34%) prevalence of fibers in the proventriculi of black-footed albatrosses than Laysans (11%, $P < 0.001$).

The size of plastic particles relative to common food items may be important in explaining why albatrosses ingest much larger plastic pieces than other Hawaiian seabirds. Black-footed and Laysan albatrosses both ingest larger size classes of squid and other food items than most Hawaiian seabirds (Harrison et al. 1983). It is also possible that black-footed albatrosses have more frequent contact with large plastic items due to their habit of feeding on refuse dumped overboard by ships (Miller 1940).

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THE INCIDENCE OF PLASTIC IN THE DIETS OF ANTARCTIC SEABIRDS

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ABSTRACT

We investigated the diets of seabirds at sea in the Antarctic from 1976 to 1988. During the study period, on eight cruises in the Ross, southern Scotia, and Weddell Seas and Drake Passage, we collected or pumped the stomachs of 1,223 seabirds of 23 species. The stomach contents of species that feed below the sea surface contained little plastic, as expected; these birds live entirely on live prey. Among species that feed at the surface, most of which eat both live and dead organisms, incidence of plastic was highest among the smaller ones and those that are omnivores, or feed on zooplankton and micronekton. This includes the majority of Southern Ocean flighted birds. Incidence of plastic among them was a function of the degree to which their populations frequented waters outside of the Antarctic during the winter. Among those species that live south of the Antarctic Convergence year-round there was little evidence of plastic ingestion. Among those species that are summer visitors to the Antarctic, incidence of plastic in the diet decreased with increased latitude. These results indicate either that the Antarctic Convergence blocks plastic debris, which is commonly found at the sea surface in the north, from entering the Southern Ocean, or that other factors such as the northward movement of pack ice sweeps the sea clear of plastic. Results also suggest that floating plastic debris is not yet the problem in the Antarctic that it is in more northern waters.

INTRODUCTION

Much has been learned recently about the ingestion of plastic by seabirds, mainly through the efforts of Day (1980; Day et al. 1985) in the northern Pacific, and of Ryan (1987a, 1987b, 1988a, 1988b, 1988c; Ryan and Jackson 1987) in the southern Atlantic. At present, 69 seabird species are known to ingest plastic while feeding at sea; 37 of these species frequent oceans of the Southern Hemisphere (see reviews in Day et al. 1985; Ryan 1987b). The incidence of ingested plastic in seabirds has been rising steadily since the 1960's, with the earliest records from procellariiform birds (Harper and Fowler 1987). The large majority of species now known to

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eat and retain plastic in their alimentary tracts are members of the order Procellariiformes.

Geographic variation in the incidence of plastic ingestion among seabirds is a function of proximity to areas of industrialization and human population centers. Among the 100 or so species investigated to date and for which sample sizes are greater than 30, in the following, about 80% of individuals carry plastic loads (see summaries in Day et al. 1985; Ryan 1987b; Sileo et al. 1990): Laysan and black-footed albatross, *Diomedea immutabilis* and *D. nigripes,* short-tailed shearwater, *Puffinus tenuirostris,* and parakeet auklet, *Cychlorrhynchus psittacula*, which frequent polluted waters of the North Pacific Rim; northern fulmar, *Fulmarus glacialis*, in the polluted northeastern Atlantic and the North Sea; greater shearwater, *Puffinus gravis,* which ranges between southern Africa and the polluted northwestern Atlantic; white-faced storm-petrel, *Pelagodroma marina,* and cape petrel, *Daption capense*, *in waters* off southern Africa; and blue petrels, *Halobaena caerulea*, in waters off southern Africa and the southwestern Pacific. High incidence of plastic also have been detected in seabirds of various species sampled off the U.S. west coast (Balz and Morejohn 1976).

In this paper we present information on the incidence of plastic in the diets of Antarctic seabirds, and compare our findings with the background of information just reviewed. The only samples collected previously in the Antarctic were reported by Ryan (1987b) and van Franeker and Bell 1988), and included small samples of five species.

METHODS

Birds were collected at sea off the Antarctic Peninsula and in the Ross Sea (Fig. 1) during investigations of their diets and ❑arine ecology (Ainley et al. 1984, 1988, in press; Fraser and Ainley 1986). One sample of 60 Adélie penguins, *Pygoscelis adeliae*, was obtained by pumping stomachs at Palmer Station, Anvers Island (lat. 64°S, long. 64°W), in the Drake Passage; other penguin samples, except those from the Ross Sea, were obtained at sea also by stomach pumping. A sample of 75 castings was obtained from blue-eyed shags, *Phalacrocorax atriceps*, also at Palmer Station. All other birds were shot and contents of the proventriculus and ventriculus were obtained by dissection, collecting areas in the Ross Sea, December-January 1977-80, are summarized in Ainley et al. (1984); those in the southern Scotia Sea (Weddel Confluence region), November 1983 and August 1988, are summarized in Ainley and Sullivan (1984); those in the Weddell Sea, March 1986, are in Sullivan and Ainley (1988); and those in the Drake Passage and adjacent areas, July-August 1985-87, are in Pietz and Strong (1987).

Unlike Day (1980), Ryan (1987a, 1987b, 1988a, 1988b, 1988c; Ryan and Jackson 1987), and others (e.g., Furness 1985) who actually were attempting to directly characterize plastic ingestion in seabirds, we collected information incidental to other work. Therefore, except for the most recent sampling in August 1988, we did not quantify the number, size, and color of the particles found in digestive tracts.

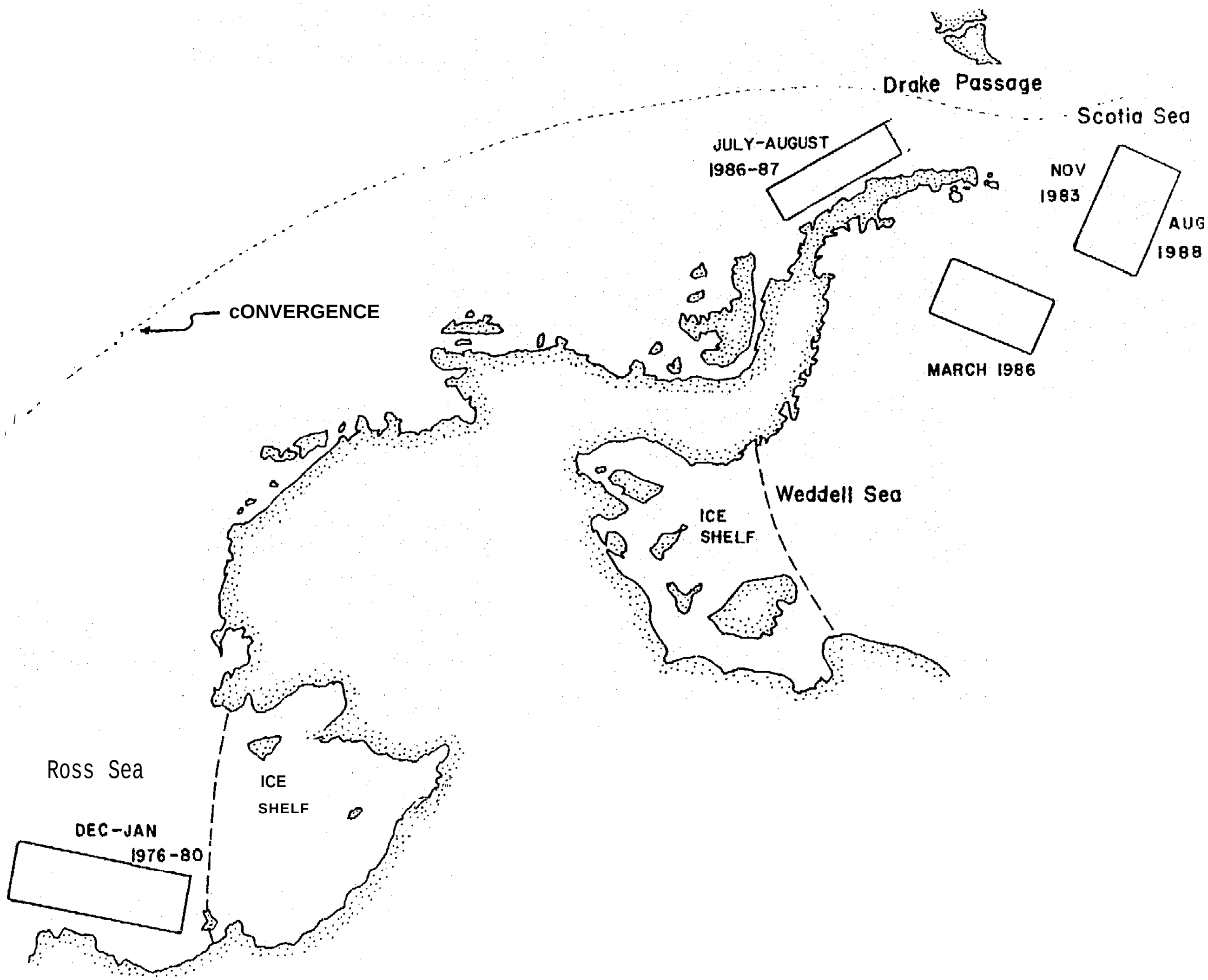

Figure I.--The areas and time periods in which seabird stomach samples were collected.

RESULTS

We observed no large accumulations of plastic in any of the birds inspected. The greatest number of pieces was 22 in a blue petrel, but usually it was much smaller (the next largest quantity was 8, also in a blue petrel). The birds that contained plastic in August 1988 averaged ($\pm$SD) the following numbers per bird; blue petrel, 5.1 + 5.4 (n - 14); cape petrel, 1 (n - 4); and snow petrel, *Pagodroma nivea,* 1 (n = 4). As observed in other studies, most of the plastic consisted of small (3-6 mm diameter) fragments and "pellets." Styrofoam occurred rarely (1 of 74 pieces of plastic in 1988). One Antarctic petrel, *Thalassoica Antarctica,* had eaten a piece of rubber from a (meteorological?) balloon; and a snow petrel had eaten threads of polypropylene rope.

No plastic was observed in any species that feed by diving beneath the sea surface (penguins, *Aptenodytes* and *Pygoscelis* spp. ; the shag; and the diving petrel, *Pelecanoides urinatrix*), all of which feed on live micronekton (Croxall 1987, and papers therein; Table 1). Neither did we find plastic in any species that lack a well-developed gizzard or regularly regurgitate castings of indigestible material (albatrosses, *Diomedea* spp. ; shags; skuas, *Catharacta* spp.; gulls, *Larus* spp.; and terns, *Sterna* spp.). Among those birds whose stomachs or gizzards did contain plastic (petrels, Procellariidae, only), incidence was higher in the smaller species. Such patterns are consistent with previously published information (Day et al. 1985; Ryan 1987b; but see Sileo et al. 1990, for the exception presented by the large albatrosses); these species tend to eat zooplankton or micronekton, and also scavenge dead organisms.

The frequency of occurrence of plastic decreased with increasing latitude in each of the four areas sampled, except to some extent in the Ross Sea (Table 2). The same pattern also emerged for only those species having a relatively high frequency of plastic ingestion. For example, in the Scotia Sea, the frequencies of plastic in blue petrels, cape petrels, Antarctic prions, and Wilson's storm-petrels combined, were 17, 6, 0, and 0% at lat. 56"-58°S (n - 60), 59°S (n - 51), 60°S (n = 50), and 61°-620S (n - 17), respectively.

A pattern seemingly inconsistent with the latter finding is evident in a comparison between frequencies of occurrence of plastic in Scotia Sea and Weddell Sea samples (Table 1). Within a species, the frequency of plastic is much higher in birds from the more southerly Weddell Sea than in birds from the Scotia Sea. The Weddell Sea sample, which was from autumn, however, contained a much higher proportion of subadult nonbreeders, which would be expected to contain larger plastic loads (Ryan 1988c). Indeed the frequency of plastic in blue petrels in this sample was 88%, and in winter samples it was 90%, which were rates similar to those reported for this species off the coast of Africa. In spring, when there were many more adults in the sample, frequency was 21%.

Table 1. --The frequency of occurrence of plastic in the digestive tracts of seabirds collected in various sectors of the Southern Ocean.[a]

Species	Ross Sea	Drake Passage	Scotia Sea	Weddell Sea	Total
Aptenodytes forsteri			0 (8)	0 (17)	0 (25)
Pygoscelis adeliae	0 (5)	0 (60)	0 (29)	0 (lo)	0 (104)
Pygoscelis papua		0 (5)			0 (5)
Phalacrocorax atriceps		0 (1)[b]			0 (1)
Diomedea palpebrata[c]	0 (2)				0 (2)
Macronectes giganteus[c]	0 (2)	0 (5)	0 (4)	0 (2)	0 (13)
Procellaria aequinoctialis[c]			0 (lo)		0 (lo)
Fulmarus glacialoides[c]	0 (13)	0 (4)	2 (49)	6 (18)	2 (84)
Thalassoica antarctica[c]	2 (40)	0 (25)	0 (66)	0 (53)	<1 (184)
Pagodroma nivea[c]	0 (108)	0 (77)	3 (139)	0 (39)	1 (363)
Daption capense[c]	50 (4)	5 (20)	11 (63)	31 (16)	14 (105)
Pterodroma inexpectata[c]	0 (4)				0 (4)
Pterodroma brevirostris[c]			0 (5)	9 (23)	7 (28)
Halobaena caerulea[c]			44 (45)	88 (17)	56 (62)
Pachyptila vittata[c]	67 (3)		4 (51)	20 (15)	10 (69)
Pelecanoides urinatrix[c]			0 (4)		0 (4)
Oceanites oceanicus[c]	37 (27)		4 (49)	33 (15)	19 (91)
Fregetta tropica[c]			0 (6)		0 (6)
Catharacta maccormicki	0 (25)				0 (25)
Larus dominicanus		0 (15)			0 (15)
Sterna paradisaea			0 (lo)	0 (14)	0 (24)
Sterna vittata	0 (12)			0 (5)	0 (17)
Chionis alba	0 (2)				0 (2)

[a]Percentage with sample sizes in parenthesis.
[b]Samples of 30 pellets in 1977 and 45 in 1987 contained no plastic.
[c]Birds of the order Procellariiformes; see Table 2.

DISCUSSION

Plastic was found in 36% of the 23 species examined, a percentage much lower than that of most other regional studies: 100% of 10 species in California (Balz and Morejohn 1976), 76% of 15 at Gough Island (Furness 1985), 71% of 14 in New Zealand (Imber *in* Day et al. 1985), 56% of 95 in a world survey (Day et al. 1985), 60% of 60 from the Southern Hemisphere (Ryan 1987b), and 98% of 22 in Hawaii (Sileo et al. 1990). In another study of seabirds in the equatorial Pacific, Ainley et al. (1990) found plastic in 59% of petrel species. Thus, an unusually low incidence of contamination is evident in the Antarctic as compared to other areas of the world ocean (see also van Franeker and Bell 1988).

Table 2.--Frequency of occurrence of plastic in procellariiform birds, by latitude and sampling sector in the Southern Ocean.[a]

Latitude N	Ross Sea	Drake Passage	Scotia Sea	Weddell Sea
56″-58″			15 (183)	
59°			7 (119)[b]	
60°			1 (93)	
61°-62″		3 (37)	0 (97)	
63°-640		0 (60)[b]		25 (60)
65°-66″		0 (34)		9 (137)
67°-69°	11 (35)			(b)
70°-75″	18 (63)[b]			
76°-78″	0 (46)			

‘Percentages, with sample size in parenthesis, are given; see Table 1 for procellariiform species.
[b]Approximate northern edge of the pack ice.

The greatest frequency of occurrence found by us was in blue petrels, but the 56% rate was much lower than the 90% reported for this species by Ryan 1987b). A relatively high incidence was also evident in our Antarctic samples of the cape petrel (14%), Antarctic priori, *Pachyptila desolata* (10%), Kerguelen petrel, *Pterodroma brevirostris* (7%), and Wilson’s storm-petrel, *Oceanites oceanicus* (19%). For these species, however, rates were much lower than those reported by Ryan (1987b), van Franeker and Bell (1988), Ainley et al. (1990), and Sileo et al. (1990) for other areas. Harper and Fowler (1987) reported a rate equivalent to ours for Antarctic prions found dead on beaches in New Zealand. In the present study, frequencies of plastic occurrence for the Antarctic fulmar, *Fulmarus glacialoides*, white-chinned petrel, *Procellaria aequinoctialis*, and Antarctic petrel were negligible, as also noted by van Franeker and Bell (1988) for the Indian Ocean sector of Antarctia. Ryan (1987b) found a similarly low rate for this sample of Antarctic petrels from the Antarctic, but higher rates of 11% in fulmars found dead on beaches in southern Africa and of 57% in white-chinned petrels from southern African waters. Ainley et al. (1990) found a rate of 67% for the latter species in the Peru Current. Not the present, nor Ryan’s, nor van Franeker and Bell’s studies detected much plastic in snow petrels, which are restricted to the Antarctic. Thus, a low incidence of plastic contamination is again indicated for Antarctic waters .

Our findings also indicate that the greater the distance south from the Antarctic Convergence the less likely birds are to have eaten plastic. More southerly individuals either have weaker ties to waters outside the Antarctic (where densities of plastic are greater, Morris 1980; Pruter 1987), or they have not frequented northern waters recently. If bird residency time in pollution-free waters is a factor, such a pattern might also support the idea that over time there is a gradual attrition of plastic from digestive tracts (Day et al. 1985; Ryan and Jackson 1987; Ryan 1988a; van Franeker and Bell 1988; Ainley et al. 1990). Again, however, the pattern indicates that the density of plastic is very low in Antarctic waters. In other words, once south of the Antarctic Convergence, northern seabirds lose plastic from their digestive tracts faster than they gain it.

Both the patterns described above and other patterns indicate that at present there is little plastic floating on the surface of ocean waters south of the Antarctic Convergence. Antarctic surface waters flow northward away from the continent, and then sink beneath subantarctic waters at the Antarctic Convergence (Deacon 1964) . Where the Antarctic Convergence is particularly well developed, flotsam (e.g., kelp fragments) is much in evidence along its northern edge (D. G. Ainley, pers. observ. ; S. S. Jacobs, Lament Doherty Geological Observatory, pers. commun.). Thus , the convergence may act to some degree as a barrier to flowing debris and pollutants from the north (though not an absolute barrier, because eddies are able to transport some northern waters across the convergence; Jacobs, pers. commun.). Because there is little human activity in the Antarctic, there is at present a relatively low rate of disposal of plastics. This helps to maintain the apparent low densities of floating plastic there, but few efforts to directly sample the abundance of floating plastic in Antarctic waters have been reported (Gregory et al. 1984; Pruter 1987). One additional factor that may help to sweep Antarctic waters clear of plastic is the seasonal, northward advance of the pack ice (Jacobs, pers. commun.) . In that each of our samples was collected with respect to the pack ice edge (because we were comparing the diets of birds in and out of the ice), and the decreasing plastic loads we detected were not a function of absolute latitude south of the convergence (i.e. , position of the pack ice edge differed for each sample), our results indicate t-hat northward movement of ice would indeed help to clear any plastic from the sea surface in the Antarctic. In fact, a great deal of organic detritus (e.g., dead diatoms) is scoured from the water column by the freezing process, transport north, and released by melting at the ice pack edge, where a large amount of detrital material can be found (C. W. Sullivan, Department of Biological Sciences, University of Southern California, pers. commun.).

Assuming that most of the plastic found in the birds inspected in this study was ingested near to or north of the Antarctic Convergence, the frequency of occurrence of plastic in seabirds provides an index of how strongly certain petrel species are tied to Antarctic seas. Considering the dearth of ecological studies in Antarctic waters during the spring and winter, such an index is useful in characterizing the avifauna. Those seabird species with low frequencies of occurrence of plastic should exhibit the weakest tendencies to exit the Antarctic during the winter. These data, therefore, suggest that Antarctic and snow petrels, and a significant proportion of Antarctic fulmars, do not leave the Antarctic during winter, as do so many other "Antarctic" seabirds. In fact, the only plastic found in snow petrels was in individuals that had moved north with the pack ice during winter, and were thus close to the Antarctic Convergence. Along these same lines of reasoning, one might expect a large amount of plastic to accumulate along the Antarctic Convergence, and the higher incidence of plastic in certain species, especially the blue and Kerguelen petrels, may indicate that these species frequent the convergence area more than most other species or that in general they frequent water mass convergence (cf. Bourne and Clark 1984). Census results support these distributional patterns (Ainley and Fraser, unpubl. data) .

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PLASTIC DEBRIS INCORPORATED INTO DOUBLE-CRESTED CORMORANT NESTS IN THE GULF OF MAINE

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ABSTRACT

The incorporation of plastic debris into double-crested cormorant, *Phalacrocorax auritus*, nests is reported on three islands in the Gulf of Maine, Of the 497 nests examined during 1987 and 1988, 188 nets (37%) contained plastic debris. Sections of lobster trap line, plastic bags, and pieces of fishing net dominated this debris. The significance of this is discussed and future monitoring of plastics in seabird nests is recommended.

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

INGESTION OF PLASTICS BY TELEOST FISHES

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ABSTRACT

Ingestion of plastic debris by many types of animals such as turtles and seabirds is well documented and considered to be a serious threat to their survival. Marine fishes also ingest plastic debris but the amount ingested and the effect of the ingested debris are not well documented. If large amounts of inert plastic debris were ingested, it might affect the fishes' well-being by blocking the digestive tract and reducing the feeding drive. Also, certain types of debris could cause injury to the digestive tract and, depending on its chemical composition, might even have a toxic effect.

In this paper we review the literature to determine what is known about ingestion of plastics by marine fishes and report on our studies on ingestion of plastic particles by larvae and juveniles. There is at present no comprehensive list of fishes known to have ingested plastic. However, observations made incidental to other studies indicate that many species do at least occasionally ingest plastic. Plastics have been found in larvae, juveniles, and adults of both pelagic and demersal species. Currently, there is no clear evidence that juvenile and adult fish have been affected by ingesting plastic. Studies in the field on larval fish have suggested that swallowed plastic spheres could cause intestinal blockage and that polychlorinated biphenyls associated with the surface of the spherules could have toxic effects.

Laboratory experiments to determine the effects of plastic ingestion on larval and juvenile fish have been equivocal. In some cases the fish were observed to take particles, but then reject them.

We have found in our laboratory studies on larvae that five of six species tested--Atlantic menhaden, *Brevoortia tyrannus*, pinfish, *Lagodon rhomboids,* spot, *Leiostomus xanthurus*, striped mullet, *Mugil cephalus*, and two species of flounder, *Paralichthys* Spp . --will feed on polystyrene microsphere. However, only spot and mullet were found to have particles in their gut. Particles passed from the gut after a period of time and larvae subsequently fed on brine shrimp larvae.

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INTRODUCTION

Plastic debris is a common contaminant of marine waters and is potentially available for ingestion by marine life. Since the report of Carpenter and Smith (1972) on contamination of the Sargasso Sea surface by plastic particles, numerous surveys have reported on finding various types of plastics in waters from around the world (Carpenter et al. 1972; 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; Shaw 1977; Shaw and Mapes 1979; Shiber 1979, 1987; Morris 1980; Dahlberg and Day 1985; Day et al. 1986; Ignell and Dahlberg 1986). A more extensive discussion of the worldwide distribution of plastics in the sea is given by Pruter (1987).

Ingestion of plastic debris by many types of animals (e.g., marine turtles and birds) is, in fact, well documented and in many cases considered to be a serious hazard (Balazs 1985; Day *et* al. 1985; Azzarello and Van Vleet 1987; Fry et al. 1987; Gramentz 1988). For marine fishes, the ingestion of plastic debris and its subsequent effect is not well documented, but it is assumed that they, like other marine animals, will be unable *to* distinguish between normal prey and small pieces of plastics. Fish may swallow pieces mistaken for prey or ingest pieces incidental to normal feeding. Once ingested, this debris may block the digestive tract, lessen feeding, and cause ulceration or other physical injury to the stomach lining. It has been suggested that ingested plastics may also release toxic chemicals (Day et al. 1985). Animals weakened by the adverse effects of ingestion may then be more susceptible to disease and predators (Laist 1987).

The objectives of this paper are twofold:

1. to review what is known about the ingestion of plastics by marine fishes, and

2. to present recent field and laboratory data on plastic ingestion in larval and juvenile fishes.

REVIEW OF INGESTION

Larvae and Juveniles

The best documentation for ingestion of plastic by marine fishes is, somewhat surprisingly, for larval and juvenile stages. Carpenter et al. (1972) were the first to report larval fishes feeding on plastic. They reported that of 14 species of fishes collected by oblique plankton tows, 8 species contained plastic in their guts (Table 1). These authors found bacteria and polychlorinated biphenyls (PCB's) present on surfaces of the plastic particles. They speculate that a main effect of ingesting the particles may be intestinal blockage in some of the smaller fish.

Kartar et al. (1973), working in the Severn Estuary, United Kingdom, in 1972-73, found as many as 30 polystyrene particles in the stomachs of

Table 1.--Larval and juvenile fishes collected in the field with plastics in their gut.

Species	Mean size (mm)	Source
Clupeidae		
Brevoortia patronus, gulf menhaden	7.6	Govoni (pers. commun.)
Clupea harengus, Atlantic herring	42	Carpenter et al. 1972
Gadidae		
Ciliata mustela, five-beard rockling	--	Kartar et al. 1976
Pollachius virens, pollock	30	Carpenter et al. 1972
Atherinidae		
Menidia menidia, Atlantic silverside	16	Carpenter et al. 1972
Sciaenidae		
Micropogonias undulatus, Atlantic croaker	6.3	Govoni (pers. commun.)
Labridae		
Tautogolabrus adspersus, tautog	91	Carpenter et al. 1972
Gobiidae		
Govius minutus, sand goby	--	Kartar et al. 1976
Cottidae		
Myoxocephalus aenus, grubby	5.8	Carpenter et al. 1972
Cyclopteridae		
Liparis liparis, striped seasnail	--	Kartar et al. 1976
Pleuronectidae		
Platichthys flesus, flounder	20-50	Kartar et al. 1973
Pseudopleuronectes americanus, winter flounder	4.6	Carpenter et al. 1972

O+ and 1+ year class flounder, *Platichthys flesus* (Table 1). In more recent work in the same estuary, Kartar et al. (1976) found onlya few particles in the sediment and none in four common species of fish which previously contained plastics. Flounder contained particles, but the numbers found per fish had declined between 1973 and 1975. They conclude that this type of plastic pollution has almost ceased in this particular estuary.

The gut contents of over 3,000 larval gulf menhaden, *Brevoortia patronus*, spot, *Leiostomus xanthurus*, and Atlantic croaker, *Micropogonias undulatus*, from the northern Gulf of Mexico were examined at the Beaufort

Laboratory, National Marine Fisheries Service (NMFS), between 1979 and 1982. Inert material, some of which was plastic, was found in only 20 of the fish (Govoni pers. commun.). Although this research was not designed to look specifically for plastic, it is certain that particles would have been observed had they been present in the gut in amounts found by Carpenter et al. (1972) and Kartar et al. (1973).

Colton et al. (1974) examined over 500 larvae from 22 species collected in water containing high concentrations of plastic spheres and found no plastic particles in the gut contents. They followed up their field work with laboratory experiments to determine if fish held in tanks would feed on these plastic particles and, if so, to measure any resulting effects of ingestion. Five species were tested over a 2-week period (Table 2). Samples were taken at regular intervals to determine if they had fed on the plastic particles. No particles were found in the guts of juveniles or larvae. Tomcod, *Microgadus tomcod*, and striped killifish, *Fundulus majalis*, juveniles were observed to feed on the particles, but they either rejected the particle or it passed through the gut with no harmful effect. These authors concluded that at present levels of abundance, the ingestion of plastics by larvae and juveniles would be minor compared to other pollution problems,

In the laboratory, Hjelmeland et al. (1988) demonstrated that larval Atlantic herring, *Clupea harengus*, would ingest polystyrene spheres (Table 2). The spheres, which had no nutritional value and were not degradable by digestive enzymes, nevertheless induced digestive secretion. However, the response was significantly lower than that obtained when the larvae were fed living prey.

Adults

To our knowledge, there has been no study specifically directed at ingestion of plastics or the effects of ingestion of plastics on adult fish. Most available information has been collected incidental to other studies. This is in spite of the fact that ingestion of plastics is continually cited as a potential hazard to fish (Laist 1986; U.S. Congress 1986).

There are several feeding studies that report finding plastics in the guts of fish incidental to the main objective of the study. A series of papers by Manooch (1973) and various coauthors (Manooch and Hogarth 1983; Manooch and Mason 1983; Manooch et al. 1984, 1985) are a good example. These authors found plastics of various types in five species of pelagic fishes and one anadromous fish (Table 3).

It is assumed that these plastic items were eaten accidentally or that they were mistaken for natural prey. Tuna, *Thunnus* spp., and dolphin, *Coryphaena hippurus*, seem to have the most diverse collection of plastics in their guts (Fig. 1), and this is probably due to both their feeding habits and their association with drift lines where plastic and other debris are known to collect (Manooch and Mason 1983; Manooch et al. 1984). These authors suggested that gut contents of dolphins could serve as indicators of surface water quality.

Table 2.--Results of laboratory experiment using plastic microsphere.

Species	Life stage	Results
Clupeidae		
Clupea harengus, Atlantic herring	Larval	Ingested pellets.'
Gadidae		
Melangrammus aeglefinus, haddock	Larva l	Ingestion negative no plastic in gut.[b]
Microgadus tomcod, tomcod	Juvenile	Ingested plastic but rejected or passed it.[b]
Cyprinodontidae		
Fundulus majalis, striped killifish	Juvenile	Ingested plastic but rejected or passed it.[b]
Gasterosteidae		
Gasterosteus aculeatus, threespine sticklebacks	Juvenile	Ingestion negative no plastic in gut.[b]
Pleuronectidae		
Pseudopleuronectes americanus, winter flounder	Lanai and juvenile	Ingestion negative no plastic in gut.[b]

[a]Hjelmeland *et* al. 1988.
[b]Colton et al. 1974.

There is some observational evidence (Manooch pers. commun.) that plastics may remain in the guts of fish for long periods of time and be encysted in the stomach or gut lining. The long-term effect of this is not known but could hardly be beneficial to the fish.

Plastic cups were reported from the stomachs of cod, *Gadus morphua*, whiting, *Micromesistius poutassou*, and pollock, *Pollachius virens,* off the coast of the United Kingdom (Anonymous 1975). One pollock was found to contain four cups. Apparently the source of the cups was from the cross-channel ferries. The author concludes that the fish will eventually die since the cups are indigestible, but no evidence is presented for this statement.

CURRENT NATIONAL MARINE FISHERIES SERVICE RESEARCH

Previous studies have shown a high degree of patchiness in plastic distribution in the sea. This patchiness is attributable to currents, winds , and differential inputs (Shaw and Mapes 1979). In recent years scientists have focused increasingly on oceanographic fronts for numerous

Table 3.--Plastic found in adult marine fishes.

Species	Type of plastic	Source
Gadidae		
Gadus morphua, Atlantic cod	Plastic cups	Anonymous 1975.
Micromesistius poutassou, blue (pout) whiting	Plastic cups	Anonymous 1975.
Pollachius virens, pollock	Plastic cups	Anonymous 1975.
Percichthyidae		
Morone americana, white perch	Plastic pellets	Carpenter et al. 1972.
Morone saxatilis, striped bass	Plastic cigar holder	Manooch 1973,
Coryphaenidae		
Coryphaena hippurus, dolphin	Nylon rope, bottle, packaging, colored fragments	Manooch et al. 1984.
Scombridae		
Acanthocybium solanderi, wahoo	Fragment of black plastic sheeting	Manooch and Hogarth 1983.
Euthynnus alletteratus, little tunny	Packaging	Manooch et al. 1985.
Thunnus albacares, blackfin tuna	Plastic bag, colored fragments	Manooch and Mason 1983.
Thunnus atlanticus, yellowfin tuna	Colored fragments	Manooch and Mason 1983.
Triglidae		
Prionotus evolans, striped searobin	Plastic pellets	Carpenter et al. 1972.

reasons; among them are the observations that fishes (as well as sea turtles, marine mammals, and seabirds) are often aggregated about these zones along with the flotsam and other debris.

Both adult and larval fishes, including species of economic importance, have been observed in aggregations along frontal zones, but there has been little work describing the possible effects of associated debris.

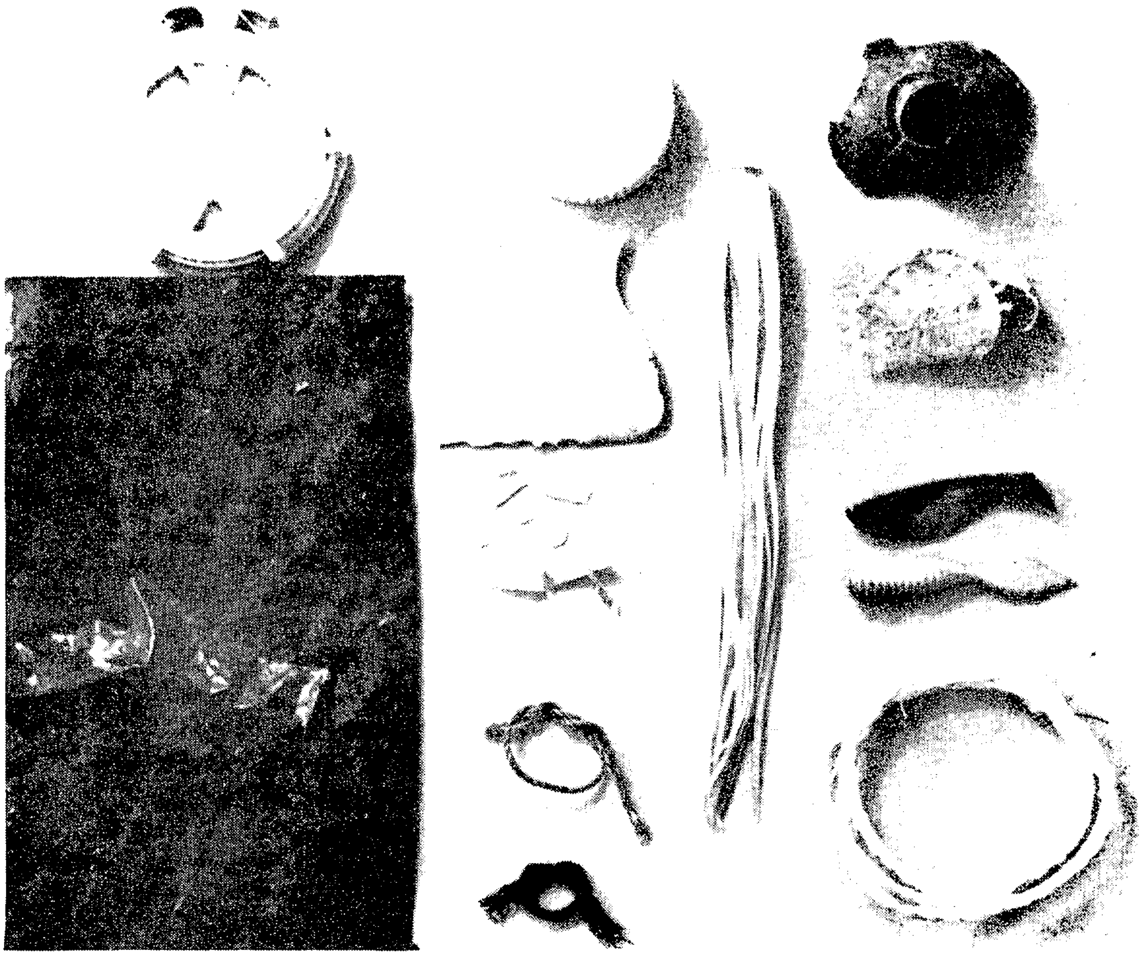

Figure 1.--Material removed from stomachs of adult dolphin and tuna by Manooch (see Table 3).

The objectives of the ongoing studies are to:

- continue co characterize and quantify microdebris particles in coastal waters in and around fronts, and
- determine if larval and early juvenile fish will ingest plastic particles under laboratory conditions, and if so, to assess the effect of the particles on the fish (e.g., prevention of feeding).

Distribution and Characterization

Although plastic pellets have been reported in average densities of 1,000 to 4,000 km^2 on the surfaces of the North Atlantic, South Atlantic, and Pacific Oceans (Carpenter et al. 1972; Carpenter and Smith 1972; Colton et al. 1974; Morris and Hamilton 1974; Wong et al. 1974; Gregory

1977; Shiber 1979; Day 1980), their distribution and abundance in the Gulf of Mexico is not well documented. We examined samples from three sites in the northern Gulf of Mexico (Cape San Bias, Florida, the plume of the Mississippi River, and Galveston, Texas) collected on a cruise in 1981. At each of these sites, sample tows were made with a multiple opening and closing net and environmental sensing system (MOCNESS) (Wiebe et al. 1976) at the surface, mid-depth, and bottom of the water column. Water samples from these stations were examined for the presence of small plastic particles such as those found by Carpenter et al. (1972) and Colton et al. (1974) (Fig. 2).

Of the 51 samples examined from the December collection, 27 were from the surface and the remaining 24 were from the middle of the water column. The greatest number of particles were found in the upper 7 m of the water column in the vicinity of Southwest Pass (Tester et al. 1987) (Table 4). This may be a reflection of both the high utilization of this area by shipping and industry and the outflow of the Mississippi River.

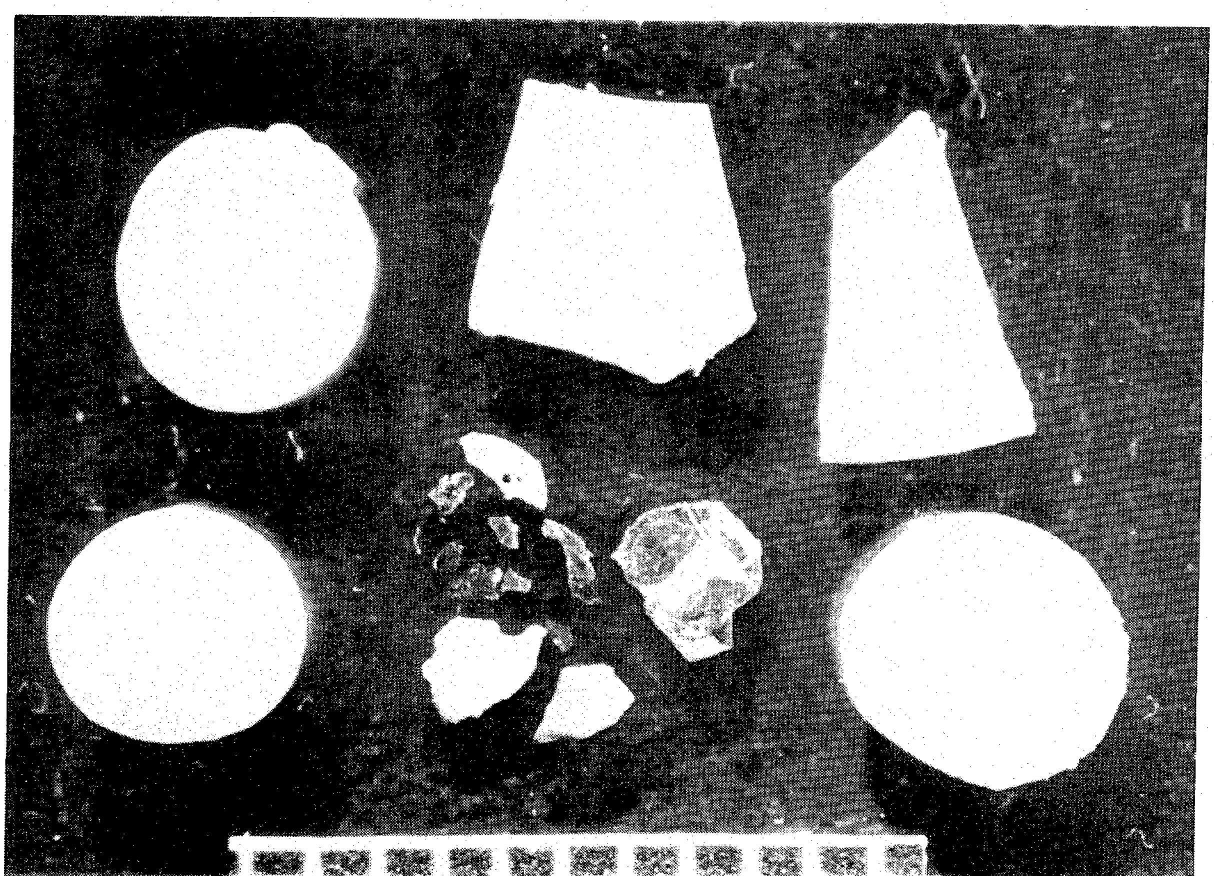

Figure 2. --Plastic material removed from samples collected at three sites in the northern Gulf of Mexico. Scale at bottom in millimeter.

Feeding Experiments

During 1988 and 1989, we conducted a series of feeding experiments (Settle et al. in prep.) to determine 1) if early life stages of marine fishes would ingest plastic particles in the laboratory, and 2) what effects ingestion might have. A similar, but inconclusive, investigation was attempted by Colton et al. (1974). We used polystyrene microsphere sorted to appropriate food particle size (100-500 pm). All plastic particles were "aged" in algae-rich seawater for at least 2 weeks. Six species of fish were used; Atlantic menhaden, *Brevoortiatyrannus*, pinfish, *Lagodon rhomboids,* spot, *Leiostomus xanthurus*, striped mullet, *Mugil cephalus*, southern flounder, *Paralichthys lethostigma*, and flounder, *Paralichthys* spp. Menhaden were laboratory spawned; all others were collected from the Newport River estuary, North Carolina. Fish were maintained in 5-L tanks and starved for 48 h prior to the introduction of plastic particles. Particle concentrations ranged from 200 to 1,000 L^{-1}.

All species except *Paralichthys* spp. were observed ingesting plastics, but rejection was also commonly observed (Table 5). Experiments lasted from 10 min to 19 h. At the end of the experimental period, fish were killed and their guts examined. Four of the six species had plastic particles in their alimentary tract. Thus, even though some plastics were rejected, some were fully ingested as well. Mullet and spot ingested the greatest quantity of particles, with some containing over 30 particles (maximum 45) (Fig. 3).

These results showed conclusively that these species would ingest aged plastic particles when deprived of food for 48 h, and in some cases retain particles in the gut for several hours.

Based on these results, a second series of experiments were conducted on mullet (21-25 mm SL) and spot (16-23 mm) to investigate if plastic ingestion would cause mortality. As in the previous work, the fish were starved for 2 days prior to the start of the experiment. The fish were initially fed plastic spheres (1,000 L^{-1}), with brine shrimp, *Artemia* spp., added after 10 min. These experiments were conducted for 10 days during which brine shrimp were added on a daily basis. Plastic spheres were left in the tank throughout the experiment.

Both spot and mullet were observed *to* ingest plastic particles when they were first added. They also were observed to reject some of the particles. Spot took plastic from the water column and off the bottom while mullet fed only from the water column. When brine shrimp were present, both species appeared to select them over the plastic and usually rejected plastic if ingested. There was no experimental mortality observed during the 10-day period and the fish were observed defecating. Therefore, it does not appear that the plastic blocked the gut.

At the end of the experiment the fish were sacrificed, measured, and examined for plastic in their guts. Six of twenty-four spot contained plastic. It is likely that spot ingested particles throughout the experiment, either those resuspended in the water each day or those on the

Table 4. --Small plastic particles in the Gulf of Mexico. Samples were taken from the surface to near bottom. Stations Al, B1, and D1 were only in 18.3 m (10 fathoms) of water, and A2, B2, and D1 were in 91.4 m (50 fathoms) of water. Plastics were collected only at the depths indicated.

Region	Station	Sample depth (m)	Particles per 100 m^3
Mississippi River	Al	1	26
		2	67
		5	31
		5	19
		6	5
		7	60
	A2	1	2
		2	1
Cape San Bias, Florida	B1	1	5
		3	1
		8	2
	B2	1	1
		30	1
		31	2
Galveston, Texas	D1	1	4
		5	9
	D2	1	1

bottom. Particles were well distributed throughout the alimentary tract, giving the impression that they were being effectively passed (Fig. 4). None of 20 mullet contained pellets at the end of the 10 days although they were observed to feed on them during the course of the experiment.

DISCUSSION AND CONCLUSIONS

There is now ample evidence to state that marine fish of many species will eat plastic debris. Larval and juvenile fishes have been collected in the field with plastic fragments and raw plastic pellets in their guts. Adult fishes have been found with a wide variety of material in their guts ranging from unidentified fragments to whole cups and bottles. There is almost no evidence, however, to determine the magnitude of the problem or to determine if ingestion is an important cause of mortality in fish.

Table 5.--Results of aged polystyrene microsphere feeding experiments (Settle et al. in prep). (+ indicates plastics were ingested, - indicates plastics were not ingested.)

Species	Size range (mm)	Particle size (m)	Ingestion	Percent with plastic in gut
Clupeidae				
Brevoortia tyrannus, Atlantic menhaden	9-29	100-500	+	0
Sparidae				
Lagodon rhomboids, pinfish	11-14	350-500	+	15
Sciaenidae				
Leiostomus xanthurus, spot	19-25	350-500	+	15
Mugilidae				
Mugil cephalus, striped mullet	18-25	210-350	+	75
Bothidae				
Paralichthys lethostigma, southern flounder	13-15	210-250	+	6
Paralichthys spp., flounder	10-15	350-500	-	0

It has been suggested that ingestion of plastic production pellets by larval and juvenile fishes may cause blockage of the digestive tract and prevent normal feeding. There is no experimental evidence that we know of to support this. In those laboratory experiments where larvae have fed on pellets (Colton et al. 1974; Hjelmeland et al. 1988; Settle et al. in prep.), the pellets have either been rejected or passed through the gut. In our experiments the larvae subsequently fed on brine shrimp nauplii and appeared healthy. Had the larvae been fed angular particles or particles containing toxic chemicals, the results may have been different. In the sea, dead larvae would seldom if ever be collected because of rapid decomposition.

Food habit studies confirm that large fish also eat plastic material, but the frequency and quantity of material eaten is not well documented. Ingestion of large pieces of plastic by fish may cause a health problem. Many predatory fish have large mouths and can swallow large pieces of plastic. They cannot digest the plastic, however, and it may prove to be too large to pass from the stomach into the gut and out the anus. If the fish cannot regurgitate the piece, it may block the intestine or cause ulceration.

Figure 3 .-- Spot, *Leiostomus xanthurus* (17 mm standard length), with ingested polystyrene microsphere (350-500 µm) in the gut.

We conclude that the overall ingestion of inert plastic by larval and juvenile fish is probably not a significant mortality factor at this time in the ocean environment. Monitoring of larval fishes from different areas to determine if the frequency of occurrence of plastic in the guts is changing should be continued and incorporated into ongoing ichthyoplankton studies.

We also recommend that studies be conducted to determine if larger predatory fishes can swallow and subsequently pass large, irregular pieces of plastic. Additional mortality caused by plastic ingestion might be detrimental to populations of certain species of sport fish already under intense fishing pressure.

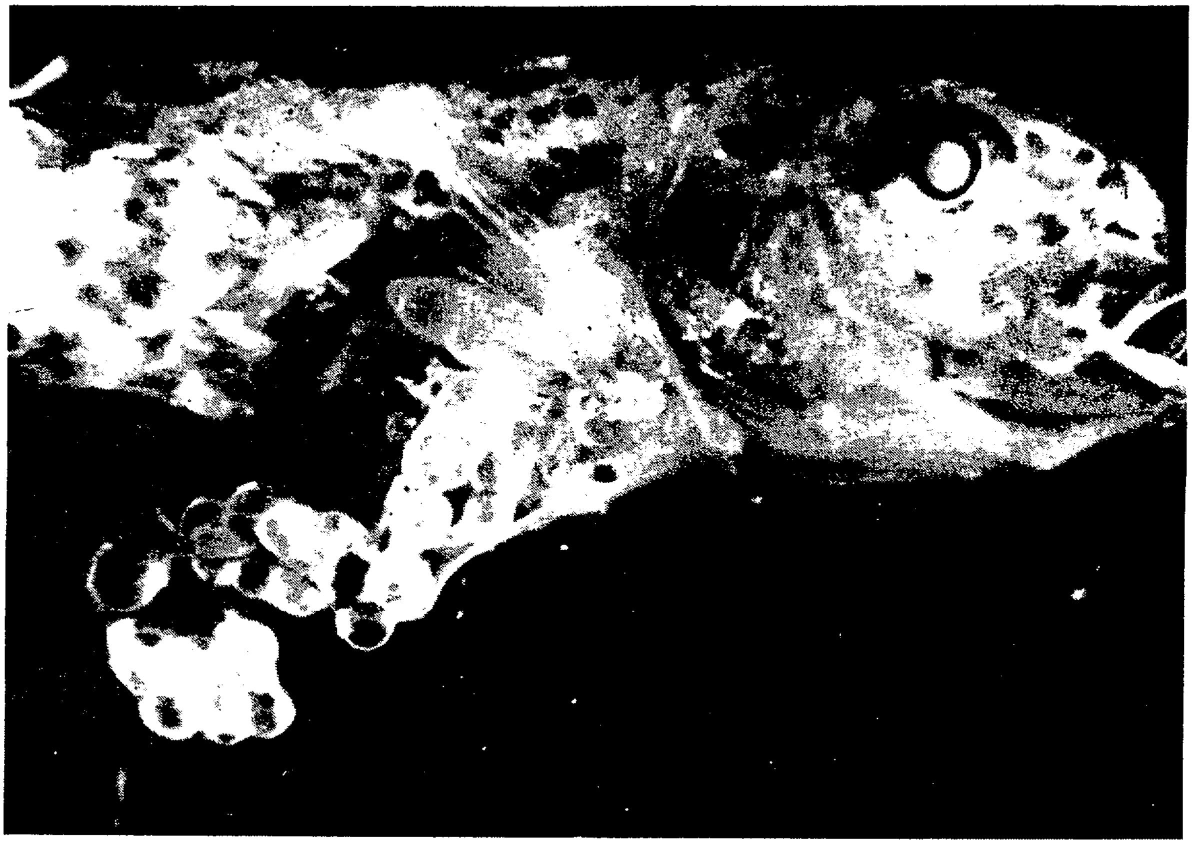

Figure 4. --Spot, *Leiostomus xanthurus* (17 mm standard length), partially dissected to show polystyrene microsphere (350-500 pm) distributed throughout the alimentary tract.

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SYNTHETIC MATERIALS FOUND IN THE STOMACHS OF LONGNOSE LANCETFISH COLLECTED FROM SURUGA BAY, CENTRAL JAPAN

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ABSTRACT

Stomach contents of a total of 372 longnose lancetfish, *Alepisaurus ferox* Lowe, 296 stranded on the beach of Miho Key in Suruga Bay between 1964 and 1983 and 76 fished by gillnets in waters near the key between 1969 and 1975, were examined. In addition to food organisms, many synthetic items such as pieces of polyethylene and vinyl were found in the stomachs. This paper examines the presence of these synthetic materials in the stomachs of longnose lancetfish. Major results of this study were as follows:

- Synthetic materials found in the stomachs were mostly soft polyethylene and vinyl pieces of various sizes and colors. Intact plastic soft drink bottles were also found.

- The feeding ratio of synthetic materials in the stomach of lancetfish was 62.2% for stranded specimens and 63.2% for gillnet specimens.

- Average number of pieces of synthetic materials in the stomach was 3.1 for stranded specimens and 2.2 for gillnet specimens.

- The feeding ratio and number of synthetic pieces in the stomachs of longnose lancetfish have increased sharply during the past several years, suggesting that there have been increases in the amounts of synthetic materials in Suruga Bay and neighboring waters. There are concerns that the neglected synthetic materials may impact large marine organisms adversely.

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INTRODUCTION

Longnose lancetfish, *Alepisaurus ferox* Lowe (Alepisauridae), is widely distributed in the Pacific, Atlantic, and Indian Oceans. It has a large mouth, large eyes, and very sharp bladelike teeth. Its body tissue is soft and watery. It is well known as voracious fish (Fig. 1).

In Suruga Bay and Sagami Bay, located at the center of Honshu in Japan, longnose lancetfish are often stranded alive on the shore by waves. Strandings are especially frequent between December and May on the shores of Kambara, Numazu, Miho, and Ohsesaki, which are located at the inmost part of Suruga Bay (Kubota and Uyeno 1970).

Since 1964, the author has been collecting lancetfish caught with gillnets and boat seines and those stranded on the shore of Miho Key to study their morphology and food habits (Fig. 2; Kubota and Uyeno 1970, 1978; Kubota 1971, 1973, 1977; Kubota and Mori 1975; Okutani and Kubota 1976).

The stomachs of the fish examined contained many pieces of synthetic materials such as polyethylene and vinyl in addition to ordinary food items (e.g., fishes, cephalopods, shrimps, salps, *Pyrosoma*).

It was pointed out that synthetic materials found in the stomachs of lancetfish are from pollution of the ocean and that they served as an index for effects on large nekton such as fish (Kubota 1977). No previous study has examined the effects of synthetic materials on marine nekton.

The objectives of this study were to determine the amounts of synthetic material ingested by longnose lancetfish and to determine how it had changed with the time.

MATERIALS AND METHODS

In this study, 372 fish were examined. Of these, 296 were found stranded on the shore of Miho Key and the remaining 76 were caught in gillnets in the area near Miho Key between December and May. The lengths of the fish range from 50 to 125 cm. Immediately after collection, 'measurements of meristic characters were made in the laboratory. Food items found in stomachs were removed for identification. The amount and size of nonfood items were also recorded. Nonfood items included leaves, pieces of wood, straw, fragments of orange, fragments of vegetable, rubber, vinyl pieces, polyethylene pieces, and intact plastic soft drink bottles.

RESULTS

Synthetic materials eaten by lancetfish were mostly soft polyethylene and vinyl pieces. Both size and color of these items varied (Fig. 3). Besides these materials, intact plastic soft drink bottles (38 mm in diameter and 74 mm in height) were found in the stomachs of 11 lancetfish stranded on the shore between 1971 and 1973. Of these, four lancetfish had two bottles each in their stomachs in addition to food items.

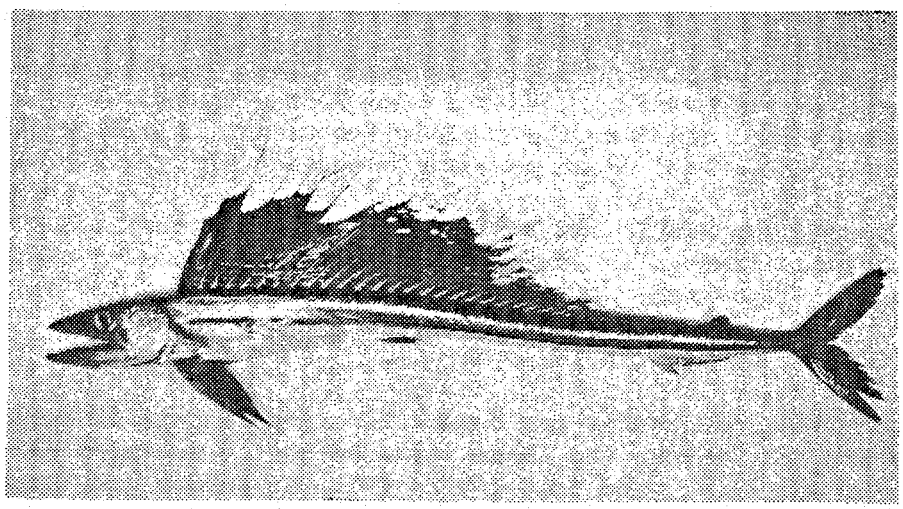

Figure 1. --A longnose lancetfish collected from Suruga Bay. Date collected: 27 April 1967, body length: 887 mm. Scale in figure indicates 300 mm.

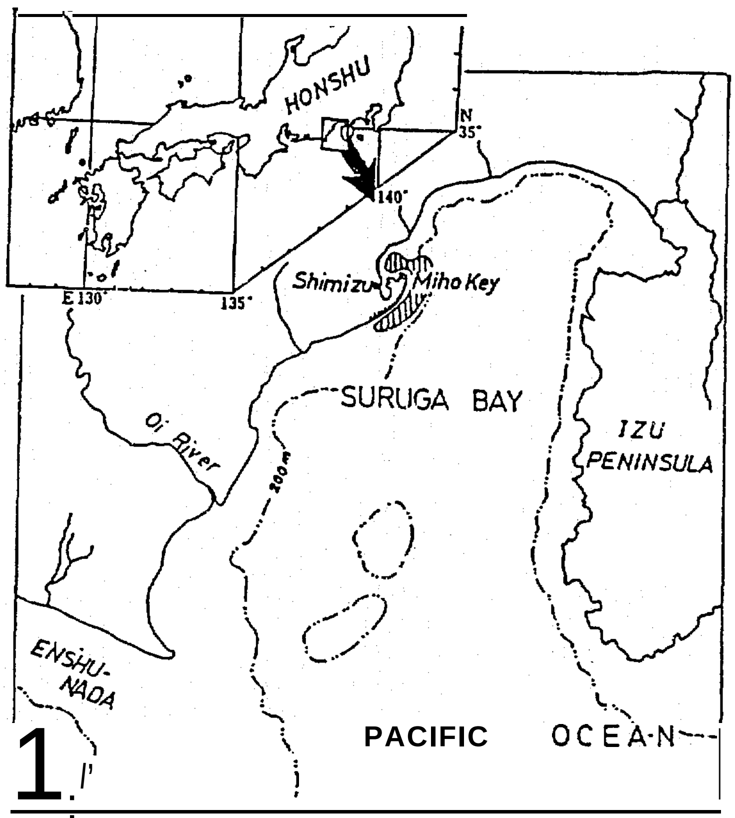

Figure 2. --Suruga Bay, central Japan. The shaded portion of Miho Key is the beach where longnose lancetfish have been stranded and the shaded area off Miho Key indicates a gillnet fishing ground.

Figure 3. --Synthetic materials from stomachs of longnose lancetfish stranded on the beach of Miho Key. Date collected: May 1971. Scale in figure indicates 100 mm.

The feeding ratio of synthetic materials to food was examined for each year. The feeding ratio for 184 of the 296 specimens that were stranded on the shore was 62.2%, whereas the feeding ratio for 48 specimens among 76 caught with gillnets was 63.2%. The average amount of synthetic material per specimen for each year was also studied. The average amount of synthetic materials per specimen was 3.1 pieces for specimens stranded on the shore and 2.2 pieces for those caught in gillnets.

The results from stranded specimens cover a long time period. Therefore, the study period was divided into two parts, 1964-75 and 1978-83. The feeding ratio of synthetic materials in stomachs of lancetfish was 58.0% in the period 1964-75, and it increased to 72.0% in 1978-83. The average amount of synthetic material per specimen increased from 2.2 pieces in 1964-75 to 4.5 pieces (more than double) in 1978-83 (Tables 1 and 2).

For the samples that had synthetic materials in their stomachs, the frequency of the amount of synthetic materials was studied to see how many pieces were eaten per specimen.

Of those fish on the shore, 112 specimens did not have synthetic materials in their stomachs at all. Thirty-six samples had one piece. Of 184 fish, 135 (73.4%) ate 1 to 6 pieces of synthetic material. One lancetfish ate 17 pieces.

Table 1.--Number of synthetic pieces found in the stomachs of longnose lancetfish stranded on the beach of Miho Key.

Year	Number of lancetfish	Number of lancetfish with pieces of synthetic materials	Total number of pieces of synthetic materials	Average number of pieces of synthetic materials
1964	2	1	5	2.5
1965	2	1	7	3.5
1966	2	1	15	7.5
1967	9	2	10	1.1
1968	19	12	33	1.7
1969	19	11	29	1.5
1970	18	9	38	2.1
1971	56	30	99	1.8
1972	21	15	70	3.3
1973	24	17	72	3.0
1974	2	1	3	1.5
1975	2	1	1	0.5
1976	--	--	--	--
1977	--	--	--	--
1978	57	39	281	4.9
1979	37	24	145	3.9
1980	16	12	76	4.8
1981	--	--	--	--
1982	--	--	--	--
1983	10	8.	38	3.8
Total	296	184	922	

For the fish caught with gillnets, 28 did not have any synthetic material pieces and 12 fish ate only 1 piece. One specimen had 15 pieces in its stomach. All the others contained 10 or fewer pieces (Tables 3 and 4).

These results show that synthetic material in the stomachs of longnose lancetfish is increasing. This is from the increase in synthetic materials being discarded by people into rivers and the ocean.

DISCUSSION

The longnose lancetfish is a voracious feeder. It has nonselective food habits and will catch anything in the ocean it can swallow. In most cases, the stomach contents can be identified to the species level. The feeding habits of lancetfish are the same in other areas (Haedrich 1964; Haedrich and Nielsen 1966; Fourmanoir 1969; Rancurel 1970; Fujita and Hattori 1976). Therefore, it is possible to identify the organisms in the

Table 2. --Number of synthetic pieces found in the stomachs of longnose lancetfish caught by gillnet.

Year	Number of lancetfish	Number of lancetfish with pieces of synthetic materials	Total number of pieces of synthetic materials	Average number of pieces of synthetic materials
1969	1	1	1	1.0
1970	14	6	12	0.9
1971	33	23	74	2.2
1972	21	12	63	3.0
1973	5	4	10	2.0
1974	1	1	3	3.0
1975	1	1	5	5.0
Total	76	48	168	

Table 3. --Number and frequency of synthetic pieces found in each stomach of longnose lancetfish stranded on the beach of Miho Key.

Number of pieces of synthetic materials found in each stomach	Number of lancetfish
0	112
1	36
2	29
3	25
4	16
5	16
6	13
7	6
8	9
9	6
10	5
11	4
12	4
13	3
14	4
15	3
16	4
17	1

Table 4.--Number and frequency of synthetic pieces found in each stomach of longnose lancetfish caught by gillnet.

Number of pieces of synthetic materials found in each stomach	Number of lancetfish
0	28
1	12
2	9
3	8
4	7
5	4
6	3
7	2
8	0
9	1
10	1
15	1

habitat where lancetfish live using stomach analysis. The distribution of nonfood items such as synthetic materials can also be determined.

Results showing that polyethylene and vinyl pieces found in the stomachs of lancetfish have increased over time imply that fairly large quantities of synthetic materials are present in the waters near Miho Key. In the last few years, the author has observed water surfaces of the area from the innermost part to the central part of Suruga Bay from on board a research vessel, and has seen large floating vinyl pieces. These items were not seen at all in the sea 8 years ago. This study documents the notion that quantities of discarded synthetic materials have increased in recent years. Synthetic materials mass-produced to meet the consumer demands will continue to contaminate the seas around Japan because they are discarded from houses and factories as waste and enter the sea through rivers.

Because of their feeding habits, lancetfish can serve as a biological monitor of synthetic pollution in the ocean.

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ECOLOGICAL ASPECTS OF MARINE TURTLES IMPACTED BY OCEAN DEBRIS: A 1989 PERSPECTIVE

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ABSTRACT

Authenticated reports of debris entanglement and ingestion by marine turtles have continued to accumulate since a comprehend ive, worldwide list of such events was first assembled in 1984. Although fragmentary, available evidence indicates that ingestion of man-made debris floating on the high seas has the greatest potential for adversely impacting sea turtle populations. A major problem in gathering detailed information on this phenomenon is the inability of researchers to locate and study pelagic habitats used by juvenile turtles of all species. Consequently, those cases of debris ingestion that do become known should be considered as the tip of the iceberg. Due to the insights of the late Archie Carr, pelagic habitats used as foraging sites by sea turtles are not believed to be frontal systems (convergence, rips, drift lines) where buoyant food and debris are drawn together by advection. International concern for the impact of buoyant wastes in the ocean is heightened by the fact that many sea turtle populations are endangered and have experienced serious declines from overfishing and other adverse factors.

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

STUDIES ON THE INGESTION OF PLASTIC AND LATEX BY SEA TURTLES

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ABSTRACT

Small pieces of latex and plastic sheeting were offered to sea turtles on different occasions and the turtles' feeding behavior was noted, as well as the time taken for the turtles to pass ingested materials. The physiological and clinical status of turtles that had consumed plastic sheeting was also monitored. We observed that green sea and loggerhead turtles actively seek out and consume the offered material. Some color preference was shown, clear plastic having the lowest acceptance rate. The amount consumed was influenced by appetite. At the low feeding levels allowed in these experiments, we detected no effects of plastic ingestion on gut function, metabolic rate, blood chemistry, liver function, or salt balance. However, blood glucose declined for 9 days following ingestion, indicating a possible interference in energy metabolism or gut function. The sojourn of the ingested latex material in the gut ranged from a few days to 4 months. Moreover, some of the turtles passed multiple pieces all bound together, although they had ingested the individual pieces at different times. Since the gut clearance time for food is in the order of days, it appears that some of the latex pieces were being held up in the intestine. Latex pieces that had been retained for the longest time in the gut showed evidence of deterioration.

INTRODUCTION

As man's use of nonbiodegradable products increases, so does the amount of such material dumped into the ocean. Offshore garbage dumping by ships at sea was legal until recently and the ocean is considered by some (e.g., Osterburg 1986) as "nature's trash basket." However, one consequence of this practice is that contact by marine animals with nonbiodegradable refuse such as plastic bags and Styrofoam products also increases. Hopefully, the ratification of the MARPOL V agreement will help

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to alleviate the problem, but recent incidents of entanglement and ingestion in marine mammals and seabirds (Cawthorn 1985) suggest that harmful contact with refuse may occur much more frequently than previously thought.

It is becoming increasingly recognized that the ocean dumping of plastic waste presents a particularly serious hazard for sea turtles. Sea turtles consume a wide variety of debris and, in the man-made category, plastic bags and sheets appear to be the most prevalent material ingested (Balazs 1985). In some instances, the level of contamination can be very high. For example, plastic bags were found in 23% of a sample of green sea turtles in Peruvian waters (Hays de Brown and Brown 1982), and in one analysis 44% of adult nonbreeding leatherbacks were found to have plastic in their stomachs (Mrosovsky 1981). It has been suggested that one cause for ingestion is that turtles mistake the plastic for their natural jellyfish prey (Fritts 1982). More *recently* concern has been expressed over spent balloon material in the ocean, the result of increasing popularity of massive balloon launches.

Is the ingestion of plastic and latex by sea turtles any cause for concern? Clearly, if sufficient material is swallowed to cause a complete stoppage of the gut, death will result from starvation. However, there are only a few such documented cases (Balazs 1985; Cawthorn 1985), and most of the evidence for turtles swallowing plastic comes from butchered turtles (Balazs 1985). In domestic vertebrates, persistent partial blockage of the intestine can interfere with gut function (Fraser 1986). In the sea turtle, a coating of the gut wall by plastic could cause a reduction in absorption efficiency and also cause mechanical damage to the gut lining. Sublethal ingestion, therefore, where complete intestinal blockage does not occur, may be quite common and could adversely affect behavior, growth, reproduction, and general homeostatic physiological. functioning and lead to other potentially lethal situations.

There is, unfortunately, no information on whether the ingestion of such material is accidental or deliberate, or information on the effects of sublethal ingestion of plastics by sea turtles. Given the critical position of most sea turtle populations and the huge magnitude of ocean dumping (van Dolah et al. 1980; Horsman 1982), it is clearly important to determine if the swallowing of such inert material by sea turtles is harmful. and to establish the seriousness of any harm.

The purpose of this study was to document the mode of plastic and latex ingestion in sea turtles and to give a first estimate of how serious the resultant harm might be.

MATERIALS AND METHODS

This is the first study of its kind, and since there were no previous data to use as a guide, and as we did not wish to cause any lasting harm to the experimental sea turtles, we were particularly careful and cautious in designing our experimental protocol.

Animals

Green sea and loggerhead turtles were kept in tanks of approximately 3,785 L (1,000 gal) capacity. Each tank was supplied with running, filtered seawater. The turtles were fed a specially formulated feed for sea turtles (Purina sea turtle chow) each day during the experiments unless otherwise noted.

Ingestion

In the initial experiment, green and loggerhead yearlings (ea. 1 kg weight) and juvenile (10 to 18 kg) turtles were allowed to consume a small single piece of plastic sheeting (1 to 10 cm^2) and were observed for about 2 weeks during which time various behavioral. (yearling and juvenile) and physiological (juvenile) measurements were taken. The animals were fed turtle chow daily during this experiment. Since a preliminary examination of the data showed no adverse effects, a second set of experiments was undertaken at an increased (but still modest) level of plastic ingestion. Seven loggerheads weighing 13 to 18 kg were used in this section (four experimental, three control) and were fed five to seven small pieces of plastic. They were also fed daily and observed for 2 weeks. In these experiments the initial measurements before feeding plastic served as individual controls. In order to understand the effects of simple food limitation per se, a third set of turtles was starved for 2 weeks and the various physiological parameters were monitored. This set also served as a control for those turtles in the previous experiments that occasionally refused food for a few days.

An additional study on latex was undertaken in order to determine whether the ingestion of balloon material was accidental or deliberate and if the latex material was altered on passage through the gut. Five turtles were isolated in separate tanks and were offered small (ea. 1 cm^2) pieces of colored latex and clear plastic sheeting under different conditions. The turtles' feeding behavior was noted, as well as the time taken for the turtles to pass ingested materials. The passed material was collected for examination.

Gut Function

Food consumption was measured as the number of pellets consumed each day. The pellets weighed on average 0.918 ± 0.085 g. Feces were collected in plastic bags attached to the turtles and stored frozen at -20°C. It was noted that defecation usually started 1 to 2 h after feeding. Samples of food and feces were dried at 67°C for 48 h and their calorific value measured using a Parr 1241 Adiabatic Calorimeter.

The ash content of food and feces was estimated by weighing samples before and after being heated in a muffle furnace at 600°C for 24 h. Ash was used as a digestibility marker (Conover 1966). Although this method has been criticized because of its unproven assumption that ash-forming materials are neither added nor absorbed as food passes through the gut (Bjorndal 1985; Newman et al. 1985), it is used fairly commonly in studies of digestibility in marine organisms, and gives values in reasonable agreement with the acid insoluble method in sea turtles (Vargo et al. 1986) . It also has value as a comparative estimate.

Gut passage time was determined from the first appearance in the feces of the plastic sheets and of small plastic markers (Teflon disks, 2-3 mm diameter) that had been included in the food.

Occult blood in the feces was tested for using the benzidine reaction (Henry 1974).

Dive Time

Dive time was recorded on a stopwatch while observing the turtles' diving behavior in the tank. Surface time was not measured since the interval was, almost without exception, less than 3 sec (usually one breath).

Oxygen Consumption

A closed circuit method was used for oxygen consumption measurements. The turtle was placed in a sealed humidified air chamber connected to an Applied Electrochemistry oxygen analyzer. Chamber air was pumped through the analyzer and returned to the chamber. Carbon dioxide and water vapor were removed from the analyzer input line by chemical scrubbers (Ascarite and Dririte). The experiments were run for approximately 1 h, and the minimal chamber partial oxygen pressures (PO_2) were always >100 torr.

Blood Chemistry

Blood was taken from the dorsal cervical sinus as previously described (Bentley and Dunbar-Cooper 1980).

Blood gases (PO_2, PCO_2) and pH were determined immediately on whole blood using a Radiometer BMS Mk 2 blood-gas analyzer set to the experimental temperature (22°C). Plasma bicarbonate was calculated from the pH and PCO_2 data using *the* temperature- and pH-dependent CO_2 volubility and dissociation constants of Severinghaus (1965).

The blood *was* then centrifuged and the plasma divided into two parts. One part was deproteinized with 8% chilled perchloric acid and served for plasma lactate and urea measurements using the Sigma kit No. 826-uv for lactate and the Sigma kit No. 640 for urea. The untreated plasma was analyzed for osmotic pressure using a Wescor 6100 osmometer and saved frozen for measurement of ions and metabolizes. Plasma chloride was measured by an Aminco chloride titrator and plasma cations by atomic absorption spectrophotometry (Perkin Elmer PE 403). Column chromatography was used to estimate plasma cortisol, and glutamic pyruvate transaminase levels were measured by spectrophotometry using Sigma kit No. 505. The hematocrit and the percentage volume of white blood cells were read after centrifugation.

RESULTS

Feeding and Digestion

Ingestion

During normal feeding, green sea turtles were each offered, on different occasions, five pieces of pink, blue, and yellow latex, and clear plastic (Fig. 1). Each turtle had its own preference: No. 1, blue; No. 2, pink; and No. 3, yellow; Nos. 4 and 5 refused all. Surprisingly, none of the turtles accepted the clear plastic. On offering yellow material to turtles that had been fasted for 3 days, there was a substantial increase in the amount of ingestion. Turtles No. 1, No. 2, and No. 3 consumed all of the material offered, but turtle No. 5 continued to hold itself aloof from this experiment (Fig. 2). In two additional sets of experiments on fasted turtles, turtle No. 1 ingested clear plastic but the others continued to ignore it (Fig. 3).

Gut Passage Time

The ingested material started appearing in the tank water after a few days and then declined over the next few weeks (Fig. 4). This time course corresponded with normal gut passage time as measured by the Teflon markers (11.3 days, range 10 to 13 days, n - 3). Quite unexpectedly, latex material continued to appear in the tank for up to as long as 4 months, peaking at about 8 weeks. Some of the turtles passed multiple pieces all bound together, although they had ingested the individual pieces at different times. The latex pieces that had been held for the longest time in the gut showed evidence of deterioration.

Food Consumption

In the loggerheads, daily food consumption did not vary much on an individual basis and when changes occurred they were fairly smooth (Fig. 5A). There was no noticeable pattern after feeding plastic. The average daily rate of consumption (grams of food per kilogram body weight per day) for individual loggerheads was 5.07 ± 1.97, n - 7; 5.9 ± 3.08, n- 7; 9.2 ± 1.59, n - 11; 9.3 ± 2.06, n = 8. In the green sea turtles, the average rates were similar, i.e., 6.7 ± 3.8, n- 8; 10.9 ± 1.93, n - 8; 11.82 ± 2.8, n - 9. However, in one of the green sea turtle consumption gradually diminished to zero on day 4 and then recovered (Fig. 5B). The consumption patterns for the other two turtles were similar to those observed in the loggerheads.

Energy Adsorption

The calorific value of the feces showed no consistent change with time in either the green sea turtles or the loggerheads (Fig. 6). Interestingly, the green sea turtle feces had a higher calorific content than the loggerhead (loggerhead feces 3,328 ± 145 cal/g, n - 10; green 4,126 ± 324 cal/g, n - 9). These differences were statistically significant ($P < 0.01$). It can be calculated that an amount of loggerhead food containing 1 g of ash

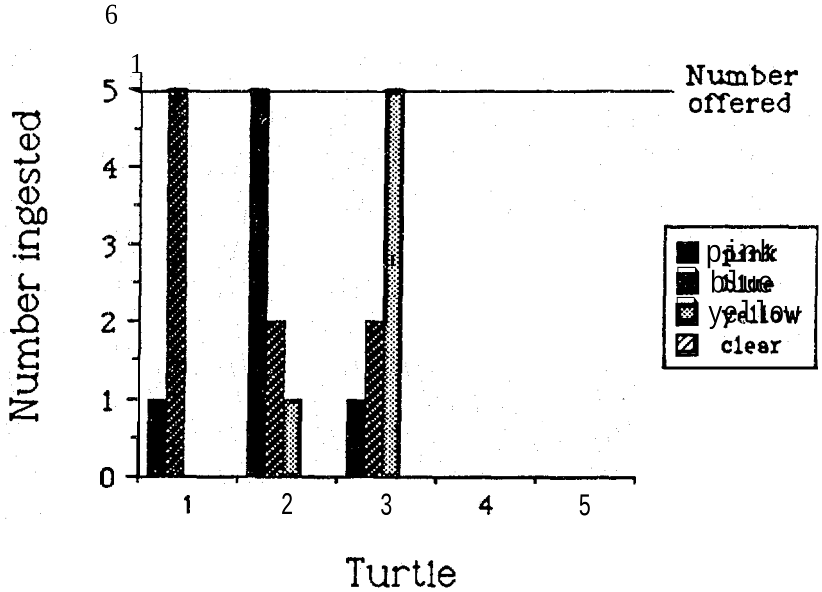

Figure 1. --Voluntary ingestion of latex pieces in green sea turtles.

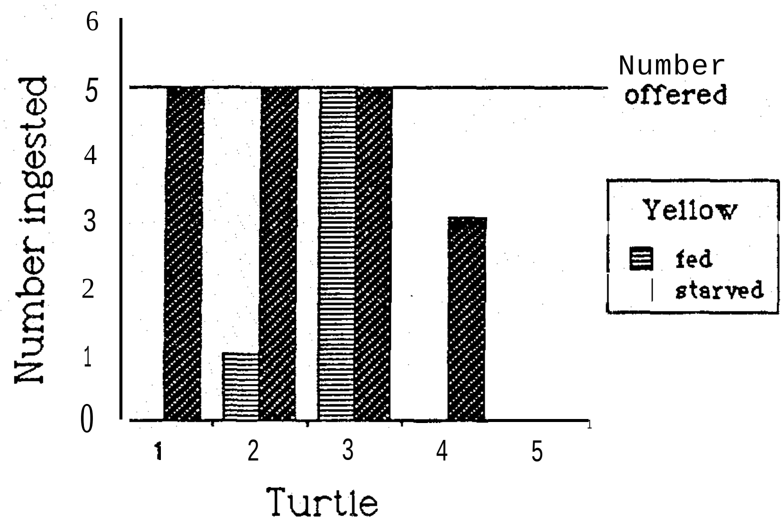

Figure 2. --Effect of 3 days fasting on latex ingestion in green sea turtles.

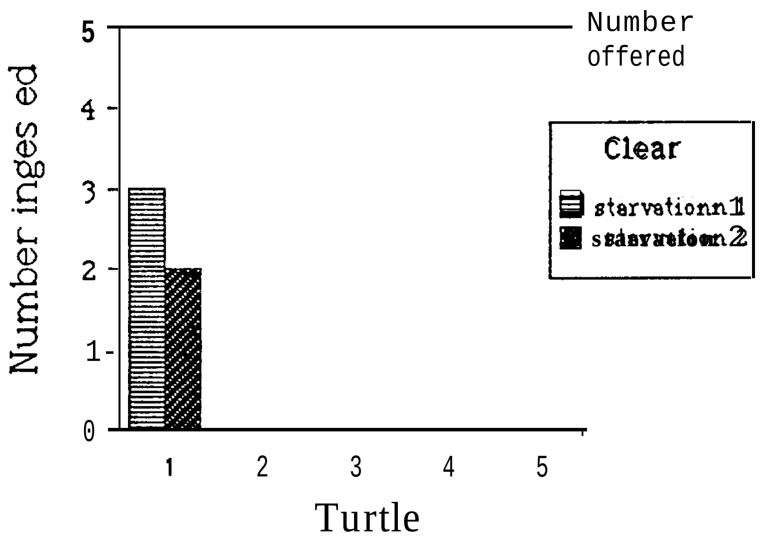

Figure 3.--Effect of 3 days fasting on the ingestion of clear plastic in green sea turtles.

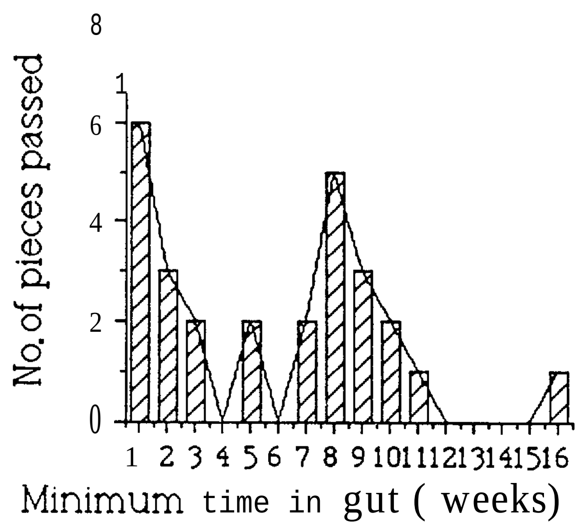

Figure 4. --Gut passage time for ingested pieces of latex in the green sea turtle.

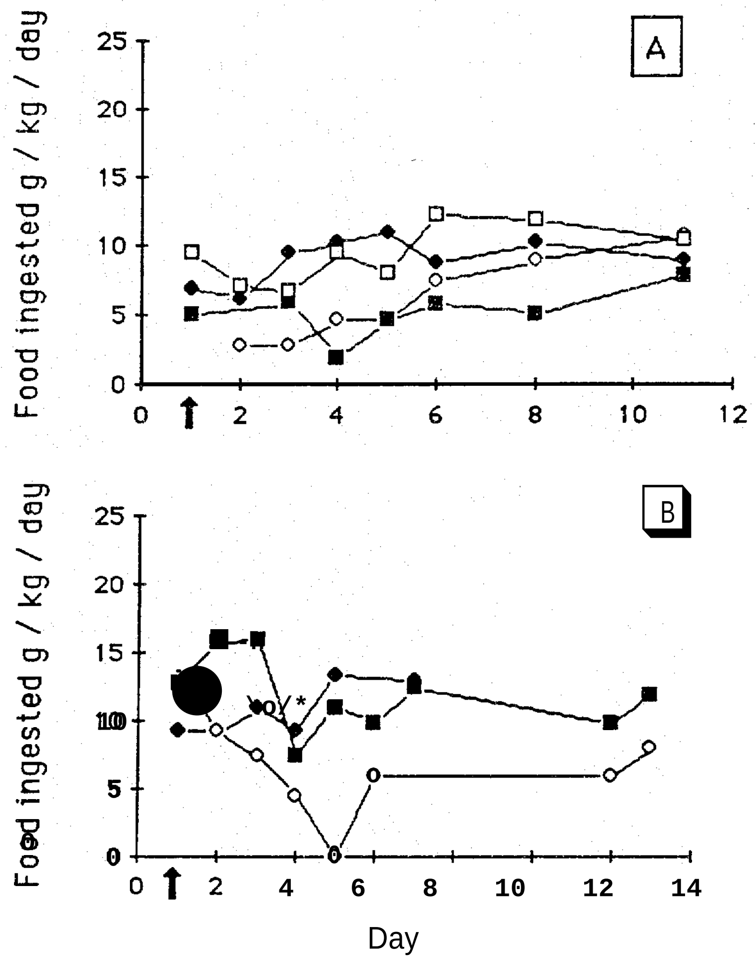

Figure 5. --The effect of plastic ingestion (↑) on food consumption in four individual loggerhead (A) and three green sea turtles (B).

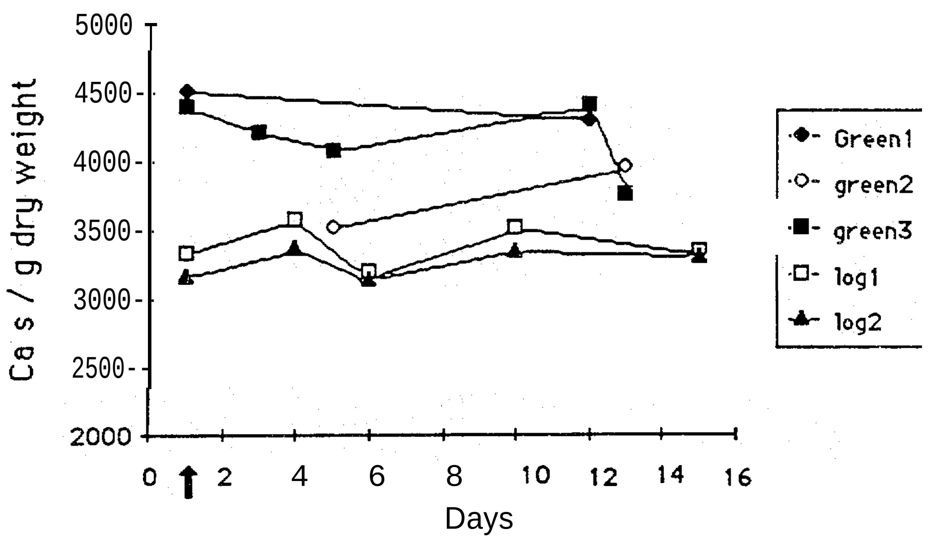

Figure 6. --The calorific value of green and loggerhead turtle feces after being fed plastic (↑).

would have a gross energy content of 51,381 cal, while feces with the same amount of ash would have 12,743 cal. Assuming constancy of ash, this indicates a digestible energy adsorption efficiency of 75.2%.

Stool Culture

In the two control loggerheads, the fecal flora was respectively 99% g positive, 1% g negative; and 98% g positive, 2% g negative. In three turtles that had been fed plastic bags, the fecal floral composition was as follows: 100% g positive; 85% g positive, 15% g negative; 100% g positive. The gut bacterial composition was, therefore, substantially gram positive in nature and this feature was not altered by plastic ingestion.

Occult Blood

No occult blood was observed in any of the fecal samples examined either in the control or the experimental animals. The plastic ingestion, therefore, had not caused intestinal bleeding.

Respiration

Oxygen Consumption

Plastic ingestion had no apparent effect on the *oxygen* consumption of either the green sea or the loggerhead turtles, and on an individual basis they were remarkably constant over the 2 weeks of monitoring. Metabolic rates for the green sea turtles ranged from 47.9 to 73.8 ml/kg/h, and the loggerhead values showed an almost identical range of from 38.1 to 70.2 ml/kg/h. Similar oxygen consumption have been obtained for green sea turtles (70.8 ml/kg/h at 25°C, Kraus and Jackson 1985) and loggerheads (62.0 ml/kg/h, Lutz and Bentley 1985) measured in air.

Blood Chemistry and Acid Base Balance

Oxygen

Venous oxygen levels remained relatively constant in both the experimental turtles and in the starved group. There was no significant difference between groups. Since venous oxygen levels are determined by the difference between oxygen supply and tissue use, and since oxygen consumption did not change, it seems likely that the mechanisms for oxygen transport have not been affected by plastic ingestion. The mean venous value for all of the data (PO_2 = 56.69 ± 1.59, n - 38) is very similar to that found in an earlier study on the same animals (Lutz and Dunbar-Cooper 1987).

Carbon Dioxide

Venous carbon dioxide remained similarly constant over the course of the experiment, and no statistical difference was found between the control and the experimental groups. The mean value for all of the data is PO_2v - 24.79 ± 0.976, n = 38.

Blood pH

For the group of experimental turtles fed plastic, venous blood pH appeared to decline on the first day after feeding plastic ($P \leq 0.5$) and continued to fall in two turtles on day *2* and in one until day 3 (Fig. 7A). No such trend was noted for the starved controls (Fig. 7B). However, the range in pH shifts was very narrow, and for the whole set the average pH was 7.550 ± 0.008, n - 38, close to the predicted normal venous pH for the prevailing body temperature (25°C, pH - 7.442, Lutz et al. 1988).

Bicarbonate

There was no change in venous bicarbonate on the day following plastic ingestion. The overall bicarbonate concentration was 22.6 ± 0.971 mM, n = 38.

Glucose

In the loggerheads fed plastic, blood glucose levels declined for 10 days (Fig. 8), but recovered to initial values by day 14, about the time plastic was expelled from the gut (see below). A least squares linear regression of the relationship between blood glucose (G) and days after plastic ingestion (T) produced the following equation illustrated in Figure 8.

$$G\ (mM) - 6.683-0.445\ T \qquad r - 0.866,\ n = 12$$

The average rate of decline in blood glucose was therefore 0.45 mM/day. Interestingly, starvation by itself caused a marked fall in blood glucose levels (Fig. 9). In both the loggerhead and green sea turtles, blood glucose levels declined sharply on the second day of starvation at much greater rates than the fed loggerheads who had consumed plastic viz., 2.52 mM/day in the green and 2.42 mM/day in the loggerhead.

Glutamic Transaminase

The initial concentration of loggerhead glutamic transaminase plasma (GTP) was 1.67 ± 0.608, n = 7, international units/ml. The GTP values varied somewhat in both the control turtles and the plastic-fed turtles for the first 3 days of the experiment (Fig. 10), but after the fourth day there was a marked decline in values in both groups, possibly related to the fall in plasma glucose.

Cortisol

In all samples tested, the blood cortisol levels were extremely low (4.0 μg/dl), indicating that the turtles were not stressed by the experimental protocol. Blood cortisol levels have been seen to increase in stressed loggerheads from similar low initial levels (l-3 μg/dl to as high as 37 μg/dl (D. Owens pers. commun.).

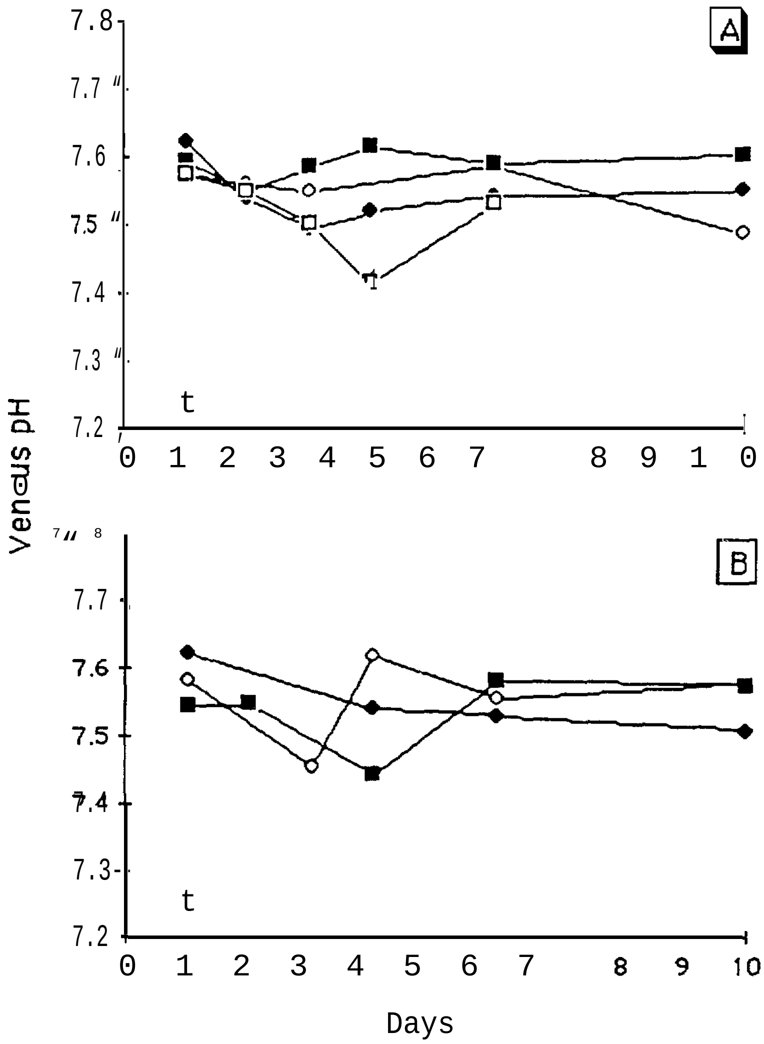

Figure 7. --The effect of plastic ingestion (A, t) and starvation (B, t) on the loggerhead turtle venous pH.

Hematocrit

The hematocrit values did not change over the course of the experiments in either the loggerhead or the green sea turtle. The loggerhead mean value (28.6%) is less than that found for loggerheads sampled in the wild (35.5%, Lutz and Dunbar-Cooper 1987) and less than that found for the green sea turtle (33.3%); the latter difference is significant ($P < 0.01$).

White Blood Cells

No change was seen in white blood cell volume following plastic ingestion. In the loggerheads, the white blood cells initially made up about 0.2% of the whole blood, and with one exception the values were reasonably constant, ranging between 0.2 and 0.4% for 10 days after plastic ingestion.

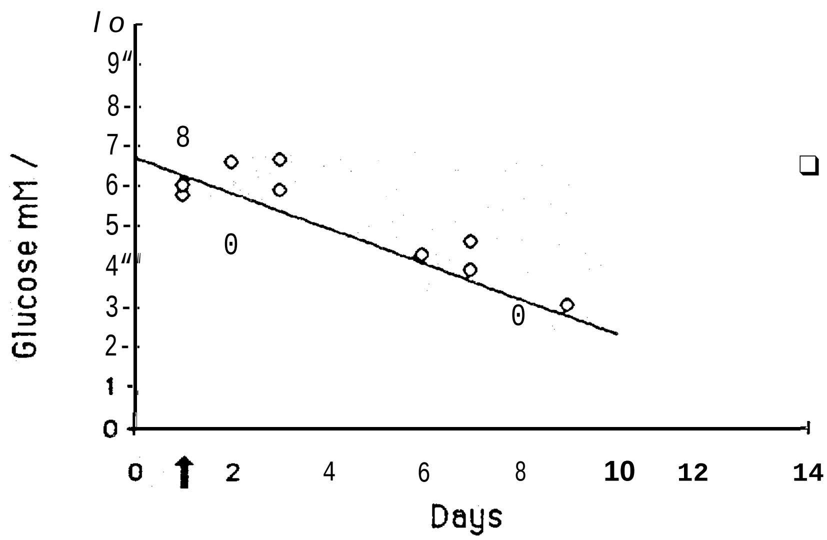

Figure 8. --The effect of plastic ingestion (t) on blood glucose levels in the loggerhead turtle.

DISCUSSION

We have been able to demonstrate that both green sea and loggerhead turtles do not discriminate against plastic sheeting when they engulf food intermingled with plastic. The experiments with latex ingestion in loggerheads demonstrated that if their appetite is sufficient, they will actively swim towards and ingest latex materials, that all colors are acceptable, and that the amount ingested will depend on their nutritional state. Indeed, it was our impression that hungry sea turtles will swallow almost any material of a suitable size and consistency and will continue to do so until satiation.

No clear evidence of ill effects from plastic ingestion was found in this set of experiments though it should be noted that the turtles were only allowed to consume very small amounts. In fact, the constancy of many of the physiological parameters over the 2 weeks of monitoring is evidence that the experimental setup was not, by itself, a perturbing influence.

Further evidence of a lack of stress is seen in the low blood cortisol levels. The values are similar to those reported for resting blood cortisol levels for vertebrates in general which are around 1-5 μg/100 ml (rainbow trout, 3.8 μg/100 ml, Donaldson 1981; loggerhead, 1-3 μg/100 ml, Owens pers. commun.; dog, 1-5 μg/100 ml, Fraser 1986). For many animals, stress produces a surge in blood corticosteriods, often within hours of the stress, that will persist during the stress and sometimes for days afterwards (Fraser 1986). Compared to resting values, the expected increases in blood cortisol concentrations under stressful conditions can be substantial (16 μg/100 ml in the stressed rainbow trout, Donaldson 1981).

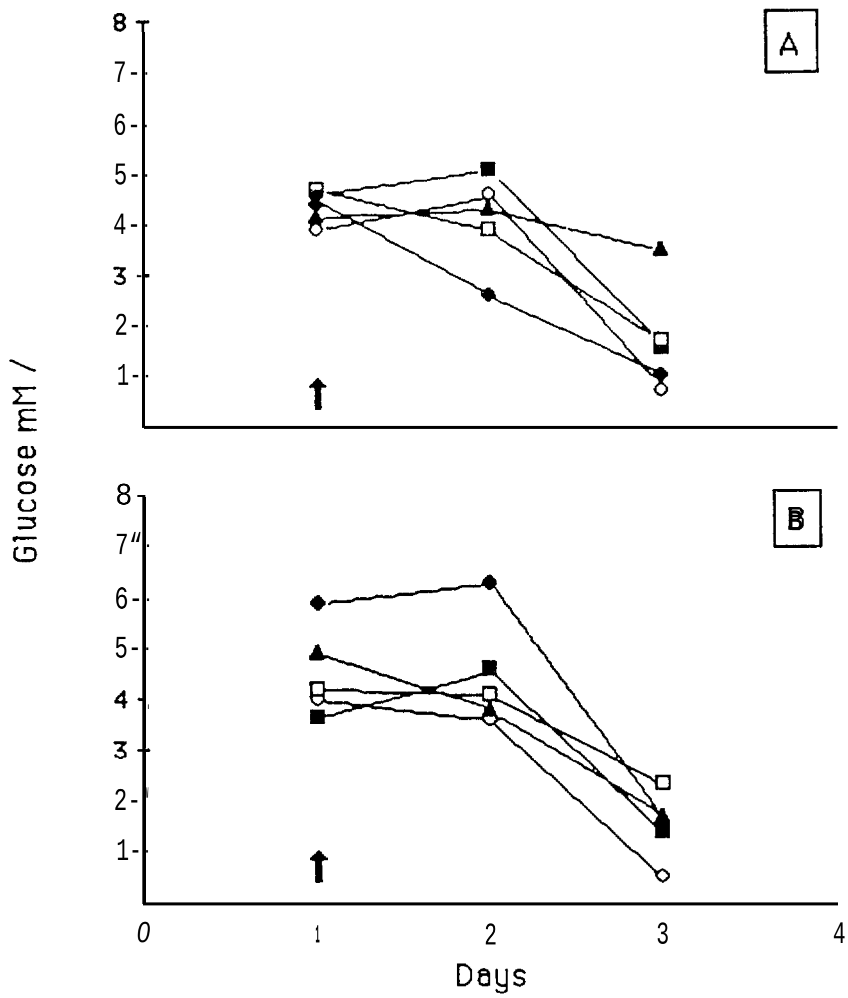

Figure 9. --The effect of starvation (t) on blood glucose concentrations in the loggerhead (A) and green sea turtles (B).

There was no evidence of plastic ingestion affecting feeding and the handling of food. The rate of food consumption did not change after eating plastic in either the loggerhead or the green sea turtles, and the average daily consumption was similar for both species (9.79 g/kg/day, green; 7.37 g/kg/day, loggerhead). Wood and Wood (1981) found a similar food intake for green sea turtles fed pellets (8 to 12 g/kg/day). The food consumption rates found in this study are equivalent to a calorific intake of 44.2 kcal/kg/day for the green and 33.3 kcal/kg/day for the loggerhead.

The efficiency of food adsorption and the calorific value of the feces were unaltered, and the bacterial composition of the gut was not changed. There was no evidence of blood in the feces, pointing to an absence of mechanical damage as plastic passed through the gut.

No effect of plastic ingestion was detected with respect to any of the measured parameters that are directly associated with respiratory

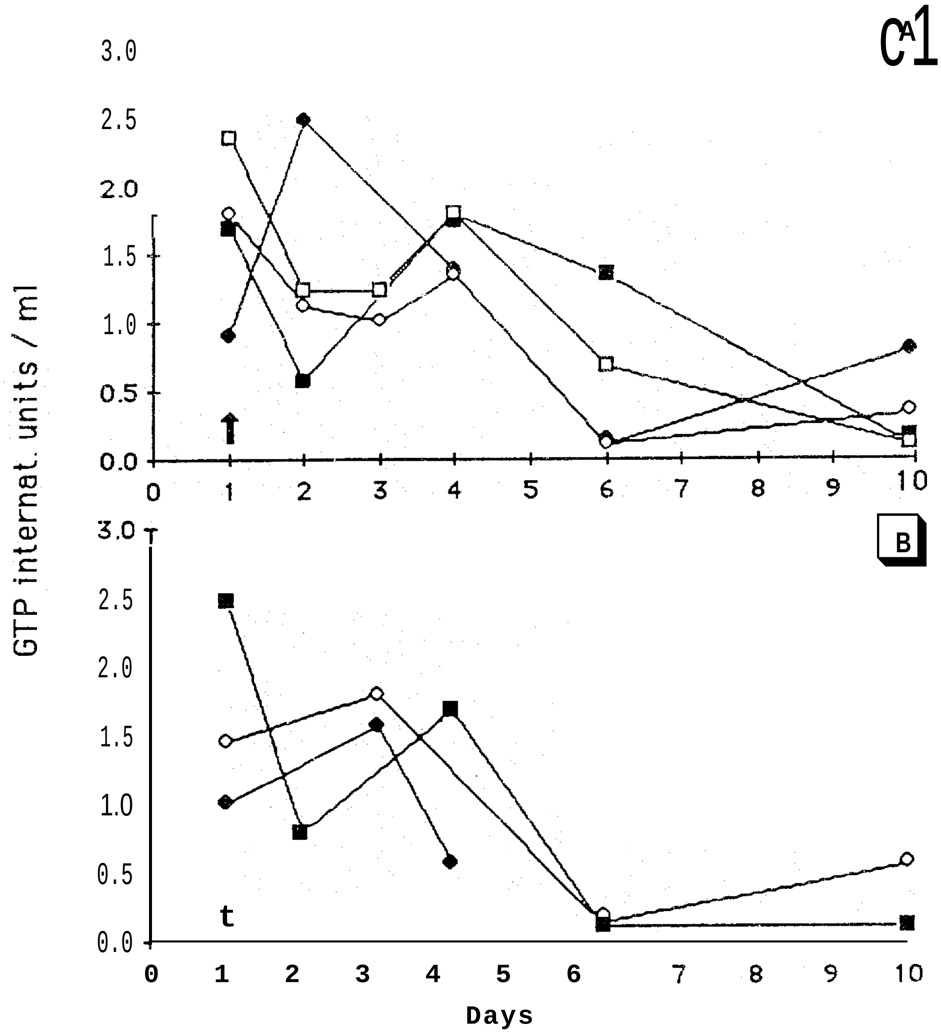

Figure 10. --The effect of plastic ingestion (t, A) and starvation (t, B) on glutamic transaminase levels in loggerhead plasma.

physiology, viz., metabolic rate, blood oxygen and carbon dioxide levels, blood acid base status.

The hematocrit was remarkably constant, an indicator of health, and no marked changes were seen in the proportion of white blood cells. A very substantial increase in white blood cell numbers (400%) was one of the most notable features of sea turtles affected by oil pollution (Vargo et al. 1986). No evidence of liver malfunctioning was seen in the lack of increase in plasma glutamic pyruvic transaminase (Fraser 1986).

The rates of change in blood glucose are a possible exception to this pattern. The key observation was that blood glucose declined rapidly in loggerheads that were starved and also fell, although at a lesser rate, in turtles that had been fed plastic sheets. The implication is, therefore, that blood glucose levels in sea turtles are especially sensitive to nutrient uptake from the gut and that this process had been interfered with in those animals that had consumed plastic. Interestingly, the blood glucose concentrations for the control fed loggerheads in this study (5.23 mM ± 1.279 mM, n- 10) were much higher than those recorded in the wild from loggerheads sampled in the Port Canaveral ship channel (ea. 1 mM, Lutz and Dunbar-Cooper 1987) evidence perhaps that the Canaveral turtles had not been feeding. Blood glucose levels, therefore, may serve as a sensitive index of nutritional status for turtles both in the laboratory and in the wild.

The study did point to some interesting differences in the physiology of green sea turtles and loggerheads. On average the green sea turtles had a higher hematocrit than the loggerheads (33.3%, green; 28.6%, loggerhead) and a higher proportion of white blood cells (0.2%, loggerhead; 1.02%, green) . In the green sea turtles, the average daily food consumption of the pelleted food was about 32% higher. On the other hand, this was offset somewhat by green sea turtles having a higher feces energy content (24% higher in the green) and, therefore, a lower efficiency in extracting energy from the food.

In summary, when hungry, sea turtles will actively consume plastic and latex material. Except for a possible interference in energy metabolism (declining blood glucose levels), at the levels allowed in this study ingestion produced no measurable changes in the physiological parameters that were measured. However, the observation that pieces of latex can gather up in the gut and remain there for considerable periods of time should be viewed with some concern and certainly needs more detailed investigation.

ACKNOWLEDGMENTS

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EFFECTS OF ANTHROPOGENIC DEBRIS ON SEA TURTLES IN THE NORTHWESTERN GULF OF MEXICO

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ABSTRACT

Reports of sea turtles ingesting and becoming entangled in marine debris and the adverse effects associated with these encounters exist worldwide, but the magnitude of this problem has yet to be determined. Data collected from sea turtles stranded on the south Texas coast from 1986 through 1988 indicate that they are significantly affected by ingestion of and, to a lesser extent, by entanglement in marine debris. All five species of sea turtles found in the Gulf of Mexico, both male and female, posthatchling through adult, had eaten or were ensnared by debris. Plastics discarded at sea were involved in the majority of these incidents. The offshore oil industry, cargo ships, research vessels, commercial and recreational fishing boats, and other seagoing vessels are primarily responsible for the trash discarded at sea which threatens sea turtles in the Gulf of Mexico.

INTRODUCTION

Because of their widespread intentional exploitation by man in the past, sea turtle populations in the United States have declined and all species are currently considered either threatened with or in danger of extinction. The greatest threat to their survival today is man's incidental exploitation. Every year thousands of sea turtles are incidentally caught and drowned in the net trawls of shrimp fishermen, beach front development encroaches on valuable sea turtle nesting beaches and threatens their reproductive efforts, newly hatched sea turtles are run over by cars or die from heat and exhaustion after they are enticed to crawl from their nests towards the bright lights of a condominium instead of towards the comparatively dimly lit sea, and an unknown number of sea turtles die when they become entangled in or ingest nonbiodegradable anthropogenic marine debris.

Balazs (1985) was the first to examine the widespread effects and impacts of marine debris on sea turtles. He compiled reports from the literature and through personal communication on the incidence of

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entanglement in and ingestion of marine debris by sea turtles worldwide. Collectively, these reports painted a rather grim picture for the recovery of sea turtle populations. But precisely how much of a threat marine debris poses to sea turtles has not yet been determined. Because sea turtles spend most of their lives at sea and are generally inaccessible to researchers, it has been difficult to assess the magnitude of this problem on any population. The objective of the present study was to determine the extent of entanglement and ingestion for sea turtles found stranded on the south Texas coast.

METHODS

Data were collected from sea turtles found stranded on Mustang Island, North Padre Island, and South Padre Island, Texas, from 1986 through 1988.

Entanglement

Stranding forms submitted to the Texas Sea Turtle Stranding and Salvage Network coordinator were used to obtain information on entangled sea turtles. Information culled from these forms included species stranded, date stranded, condition of the turtle (i.e., alive or dead), size of the turtle (curved carapace length (CCL)), type of entanglement, and fate of the turtle.

Ingestion

Stranded turtles were necropsied following Wolke and George (1981). Prior to necropsy, the species was identified and CCL and width ❑easurements were recorded. During necropsy, the sex of the turtle was determined by visual examination of the gonads. The esophagus, stomach, and intestinal tract were removed from the body cavity and all organs were examined for abnormalities: lesions, ruptures, and parasites. The contents of the digestive tracts were emptied onto a fine-meshed sieve and rinsed with water. Anthropogenic debris was separated from the other food items, cataloged, and saved for later analysis. The remaining food items were preserved in 10% buffered formalin.

RESULTS

Entanglement

Sea turtles became entangled when their head, limbs, or entire bodies accidentally were ensnared in debris or active fishing gear. During the 3-year study, 30 (7.5%) of the 400 sea turtles reported stranded were entangled (Table 1). All of the sea turtle species found in the northwestern Gulf of Mexico had been ensnared. These included 13 Kemp's ridleys, *Lepidochelys kempi*, 7 loggerheads, *Carettacaretta*, 6 hawksbills, *Eretmochelys imbricata*, 3 green turtles, *Chelonia mydas*, and 1 leatherback, *Dermochelys coriacea*. Commercial and recreational fishermen and their lost or discarded gear were responsible for the majority of these incidents. Sea turtles *were* found entangled in fishing line or hook (9), shrimp trawl (7), net or rope (5), plastic woven produce sacks (4), tar (3), trotline

Table 1.--Incidence of entanglement in sea turtles found stranded on the south Texas coast from 1986 through 1988.

Year	Number of turtles entangled (%)	Total number of turtles stranded
1986	14 (7.8)	179
1987	11 (10.1)	109
1988	5 (4.5)	112
All years	30 (7.5)	400

(1), and crab pot (1). Injuries resulting from their entanglement were responsible for the deaths of seven of these' turtles. The remaining 23 turtles were rehabilitated at the University of Texas Marine Science Institute and, with the exception of 1 permanently injured (blind) turtle, were released back into the Gulf of Mexico.

Ingestion

Marine debris was found in the stomachs or intestinal tracts of 60 (54.1%) of the 111 turtles necropsied (Table 2). It was present in 52.3% of the loggerheads, 46.7% of the green turtles, and 87.5% of the hawksbills (Table 3). (No leatherbacks were necropsied during the study.) Shaver (pers. commun.) examined the gut contents of Kemp's ridleys stranded within the same study area and found debris in *29.8%* of those turtles (Table 3). Plastic materials were most frequently eaten (Table 4). Most of this material (ea. 60%) was buoyant in nature, but some was not, indicating that sea turtles not only feed on debris floating on the surface of the water, but also feed on debris that is suspended in the water column or is on the bottom.

The incidence of debris ingestion was highest in those turtles stranded during December and lowest in turtles stranded during August (Fig. 1). However, seasonal trends should not be interpreted from these data because recent work by Lutz (pers. commun.) has revealed that sea turtles have the ability to retain plastic in their digestive tracts for prolonged periods of time.

Our ingestion data support Carr (1987), who warned that the young, advanced pelagic stage sea turtles were most vulnerable because they spend the first few years of their life in the open ocean, dependent upon drift lines (areas of high debris concentrations) for their food supply and shelter. Information on the size (carapace length) at which sea turtles become sexually mature (adult) is based-upon data collected from females at their nesting beaches. The size at sexual maturity differs among the sea turtle species, varies geographically within a species, and is unknown for male sea turtles. For the purposes of this study, we defined posthatchling

Table 2. --Incidence of debris ingestion in sea turtles found stranded on the south Texas coast from 1986 through 1988.

Year	Number of turtles with debris (%)	Total number of turtles necropsied
1986	10 (40.0)	25
1987	32 (59.3)	54
1988	18 (56.3)	32
All years	60 (54.1)	111

Table 3. --Incidence of debris ingestion by the different sea turtle species found stranded on the south Texas coast from 1986 through 1988.

Species	Number of turtles with debris (%)	Total number of turtles necropsied
Loggerhead, *Caretta caretta*	46 (52.3)	88
Green, *Chelonia mydas*	7 (46.7)	15
Hawksbill, *Eretmochelys imbricata*	7 (87.5)	8
Kemp's ridley, *Lepidochelys kempi*[a]	31 (29.8)	104

[a]D. J. Shaver pers. commun.

Table 4.--Types of debris (and their occurrence) collected from the intestinal tracts of sea turtles found stranded on the south Texas coast from 1986 through 1988.

Type of debris	Number of turtles that had ingested that type	Percent (N- 111)
Plastic bag, pieces	39	35.1
Styrofoam	17	15.3
Plastic, hard pieces	15	13.5
Plastic, line or rope	10	9.0
Plastic beads or pellets	8	7.2
Balloons	7	6.3
Tar	7	6.3
Glass	2	1.8
Paper or cardboard	2	1.8
Aluminum	2	1.8
Stainless steel hook	1	0.9
Latex or rubber	1	0.9
Heat-sealed drink tab	1	0.9

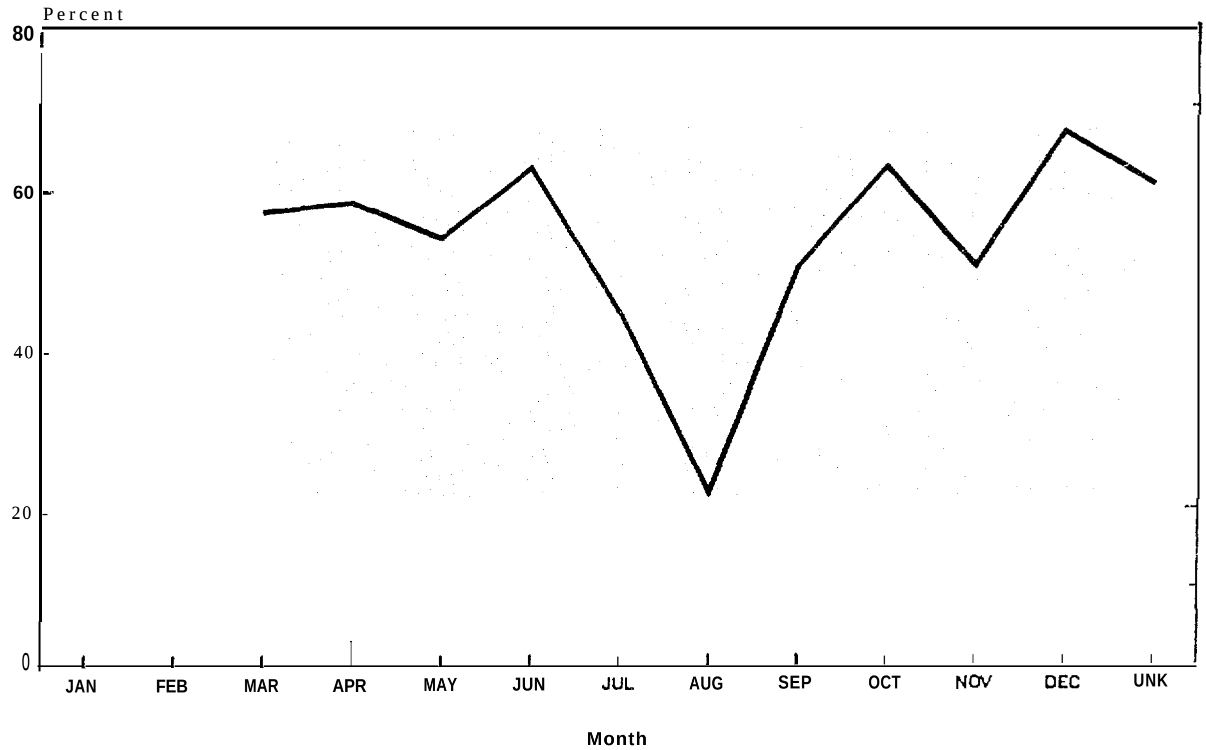

Figure 1. --Percent occurrence (by month) of anthropogenic debris found in the digestive tracts of sea turtles stranded on the south Texas coast.

to 40-cm CCL as advanced pelagic stage turtles, 40-80 cm CCL as subadult turtles, and ≥80-cm CCL or greater as adult turtles. We found debris in 70.8% of the advanced pelagic stage turtles, 55.4% of the subadult turtles, and 31.8% of the adult turtles (Fig. 2).

Debris ingestion resulted in the deaths of four of the turtles necropsied during this study (a noticeable obstruction or blockage in the digestive tract was observed), but could not be implicated in the deaths of the remaining 56 turtles. It was difficult to determine if the debris eaten had caused a turtle's death. For most cases observed, only small quantities of debris were present, and they were usually well mixed in the digestive tracts with the other food items and. probably did not contribute to death.

DISCUSSION

A number of the turtles that washed ashore during the study were already missing a limb. Many of these losses were suspected to be the result of a prior entanglement, but because there was no proof, these turtles were not counted as having been entangled. Therefore, we feel that our entanglement numbers may be too small. The reasons why sea turtles become entangled remains unclear. Their natural curiosity towards objects

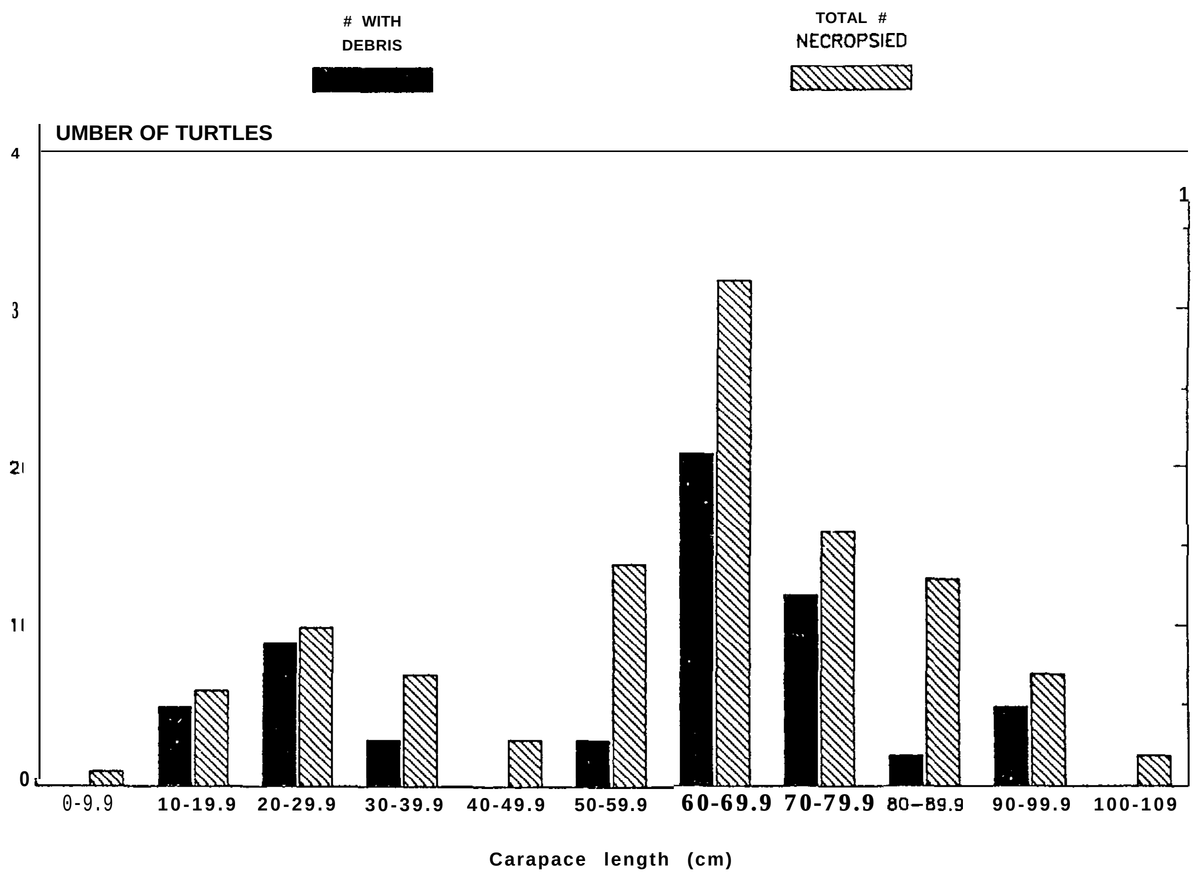

Figure 2. --Occurrence of anthropogenic debris found in the digestive tracts of sea turtles stranded on the south Texas coast from 1986 through 1988 (by carapace length (cm)).

adrift in the water is most often cited as the reason for their propensity for probing near and becoming ensnared in debris. It is likely that sea turtles are attracted to these floating objects because they are seeking food or shelter.

An unusual relationship was found between hawksbills and plastic woven produce sacks (onion sacks). The four incidents of entanglement in those sacks reported here all involved advanced pelagic stage hawksbills (their CCL ranged from 19.4 to 28.5 cm) had their head or limbs caught in the plastic fibers of a produce sack. In addition to our four reports, we know of two other hawksbills that were found entangled in the exact same manner. In 1988, one was found stranded on Galveston Island, Texas (M. Duronslet pers. commun.), and the other was found in April 1989 on the beach at Rancho Nuevo, Mexico (R. Byles pers. commun.). What affinity, if any, hawksbills have for onion sacks is unknown. More behavioral studies of all of the sea turtle species are necessary before we can explain how and why they become involved in these situations.

Debris was eaten by more than half of the turtles necropsied during this study, and while this ingestion did not appear to result in the deaths of the majority of these turtles, its presence in the digestive tracts of so many is indicative of the pervasiveness of anthropogenic debris in the northwestern Gulf of Mexico. It has been suggested that sea turtles eat debris because it resembles their natural prey or perhaps because epizoic or epiphytic growth on the debris has attracted the turtle. Before man began discarding his nonbiodegradable wastes into the oceans, sea turtles did not have to differentiate between what was edible and what was not, because essentially everything was edible. In the Gulf of Mexico, the offshore oil industry, cargo ships, research vessels, commercial and recreational fishing boats, and other seagoing vessels are primarily responsible for the trash discarded at sea which eventually is consumed by many sea turtles. Prevailing currents and winds drive virtually all of the trash that is dumped into the Gulf of Mexico (and to a lesser extent the Caribbean) to the northwestern Gulf of Mexico and onto the Texas coast.

Annex V of MARPOL (implemented domestically by the Act to Prevent Pollution. from Ships) came into effect on 31 December 1988. This annex prohibits the dumping of plastics at sea and regulates how far from shore other anthropogenic debris may be discarded. The passage of this law probably will not deter the many who have grown accustomed to dumping their trash overboard. This law needs to be enforced at sea and at the ports, and those who are guilty should be fined as one means of controlling the oceanic debris problem. Most importantly, people need to be educated and convinced to save their refuse until they can properly dispose of it on land.

Certain bodies of water such as the Mediterranean Sea were given special designation under Annex V of MARPOL. These areas have been afforded extra protection because of their unique oceanographic or ecological conditions, and it is now illegal to discard any type of debris in these waters. The Gulf of Mexico was considered a candidate for this special protection, but was not designated as such when Annex V was passed. The semienclosed nature of the Gulf of Mexico, the prevalence of marine debris in these waters and on adjacent beaches, and the importance of this area as a habitat for sea turtles (in particular the critically endangered Kemp's ridley sea turtle) should be enough justification for its designation as a special area. The likelihood that a sea turtle inhabiting the Gulf of Mexico will come into contact with anthropogenic debris is quite substantial.

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ON THE SYNTHETIC MATERIALS FOUND IN THE DIGESTIVE SYSTEMS OF, AND DISCHARGED BY, SEA TURTLES COLLECTED IN WATERS ADJACENT TO JAPAN

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ABSTRACT

It has been recognized that five species of sea turtles are common in waters adjacent to Japan: *Caretta caretta*, *Chelonia mydas*, *Eretmochelys imbricata*, *Lepidochelys olivacea*, and *Dermochelys coriacea*. Stranded, live turtles collected along the coast of central and southern Japan were examined, and most were found to have ingested synthetic materials into their systems during the research period. The main types of plastics found were transparent bags or sheeting, monofilament fishing line, and rope parts. Large plastic sheets were ingested particularly by the leatherback turtle, *D.coriacea*. It is concluded that most of the sea turtles found in waters adjacent to Japan have a high frequency of plastic ingestion.

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PLASTIC INGESTION IN A PYGMY SPERM WHALE, *KOGIA BREVICEPS*

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ABSTRACT

An adult female pygmy sperm whale, *Kogiabreviceps*,(2.9 m body length) and a young male (1.8 m body length) thought to be her calf stranded alive on Galveston Island on 1 January 1984. Both animals were transported to a holding tank for observation and treatment. The female was extremely weak and died on the third day of captivity. Severe multiple mucosal ulcerations were found throughout all stomach chambers during necropsy. In contrast, the calf initially appeared to be thriving. He was able to swim unassisted and eventually began to make shallow dives. Force feeding was begun, and on the eighth and ninth days he voluntarily accepted squid placed in front of him. However, on the tenth day he suddenly weakened, lost interest in feeding, and died. On necropsy, the first two stomach compartments (forestomach and fundic chamber) were found to be completely occluded by a plastic garbage can liner, a bread wrapper, a corn chip bag, and two other pieces of plastic sheeting. The small third stomach chamber (connecting channel) prevented passage of the debris farther along the gastrointestinal tract. A severe inflammation within the abdominal cavity was also found which was diagnosed as the immediate cause of death and thought to be secondary to the gastric obstruction. The primary food item for this species is squid, and it is feasible that suspension of this debris in the water column may have been mistaken as prey by the inexperienced calf.

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INGESTION OF PLASTIC DEBRIS BY STRANDED MARINE MAMMALS FROM FLORIDA

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ABSTRACT

Ocean pollution in the form of plastic debris has been recently recognized as a major threat to marine wildlife. Injuries and fatalities caused by entanglement and ingestion of floating and submerged debris have been documented for an increasing number of marine vertebrates (mammals, birds, turtles, fish). Ingested plastics may cause a false sensation of fullness, decreasing feeding bouts, or may obstruct normal passage of food through the digestive tract.

Ingestion of plastic material is reported here for five species of marine mammals stranded along the Florida coast. These include four cetacean species (bottlenose dolphin, *Tursiops truncatus*; false killer whale, *Pseudorca crassidens;* pygmy sperm whale, *Kogia breviceps*; dwarf sperm whale, *K. simus*) and the sirenian, *Trichechus manatus* (West Indian manatee), from both coastal (*Tursiops truncatus*, *T. manatus*) and pelagic (*P. crassidens, K. breviceps*, *K. simus*) habitats. Debris included plastic jugs, disposable surgeon gloves, plastic bags, and monofilament lines. Plastic debris was usually found with food items (vegetation, and fish and cephalopod remains). On at least one occasion (an emaciated *T. truncatus*), ingestion of such material is believed to have contributed to death. With the increasing littering of the Florida coastline, plastic impact on marine mammal populations may be much more widespread than previously reported.

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

SURVEY OF MARINE DEBRIS INGESTION BY ODONTOCETE CETACEANS

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ABSTRACT

Odontocete cetaceans are affected to an unknown degree by the ingestion of oceanic debris. Published accounts discuss primarily the sperm whale, *Physeter macrocephalus*.

The pathologic effects of foreign body ingestion on captive cetaceans are well documented, and provide background information on the potential effects of debris ingestion on wild, free-ranging animals. A survey of major institutions reveals 40 incidence of debris ingestion in 16 species of stranded odontocete cetaceans. Plastic debris was prevalent, with a total occurrence of 80.0%. Evidence indicates ingestion of debris may be secondary to the stranding syndrome. A survey of prior food habits analyses on 10 species of odontocete cetaceans was conducted. All species combined, a total of 1,790 stomachs were examined. Marine debris was encountered only in Baird's beaked whale, *Berardius bairdii*, taken at two localities in the coastal waters of Japan. In *B. bairdii* taken off the Pacific coast of central Japan, debris incidence in 86 stomachs was 26.7%. Plastic debris made up 39.1% of the foreign material ingested. Off northern Hokkaido, in the southern Okhotsk Sea, incidence of debris in 20 stomachs was 15.0%. Food habits data indicate that the lower frequency of debris ingestion is related to differences in feeding strategy in the northern region.

In the wild state odontocete cetaceans are probably discriminating feeders. Evidence indicates that the high occurrence of debris in *Physeter macrocephalus* and *B. bairdii* is due primarily to incidental ingestion along with benthic prey.

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INTRODUCTION

The quantity of increasingly diverse marine litter discarded into the world's oceans is reaching enormous proportions. Billions of pounds of debris are dumped into the sea each year (Carpenter and Smith 1972; Venrick et al. 1973; Wong et al. 1974; Morris 1980a, 1980b; Van Dolah et al. 1980; Eldridge 1982; O'Hara et al. 1988). Recent studies reveal this to be more than an aesthetic problem. Debris, particularly nonbiodegradeable plastics, is accumulating in the marine environment and causing significant mortality in some marine animals (Wallace 1985).

In 1984, the first Workshop on the Fate and Impact of Marine Debris was held in Hawaii. Papers presented confined their data on ingestion of marine debris largely to marine birds (Day et al. 1985) and turtles (Balazs 1985; Cawthorn 1985). The potential problem of debris ingestion by marine mammals was not addressed, with only anecdotal accounts appearing in the proceedings (Cawthorn 1985; Mate 1985).

Ingestion of debris by cetaceans does occur. Early accounts of an impressive array of nonfood items ingested by the sperm whale, *Physeter macrocephalus*, are well known (Turner 1903; Millais 1906; Hollis 1939; Pike 1950; Sleptsov 1952; Clarke 1956; Berzin 1959, 1971; Caldwell et al. 1966). Berzin (1971) discusses accounts of "several vinyl chloride bags" found in North Pacific sperm whale stomachs as early as 1961. More recent accounts of debris ingestion involve stranded cetaceans (Wehle and Coleman 1983; Cawthorn 1985; Mate 1985; Cowan et al. 1986).

It is evident that there is a need for research on the occurrence and potential impact of cetacean debris ingestion. This study, though confined to the toothed cetaceans (odontoceti), begins to address this subject. It is divided into three major areas of inquiry. 1) Investigate the effects of foreign body ingestion by captive cetaceans maintained by marine aquariums in order *to* assess the potential effects of debris ingestion in the wild. 2) Conduct a survey on incidence of debris ingestion in stranded cetaceans. 3) Survey incidence of marine debris in food habits analyses conducted on free-ranging cetacean populations.

METHODS OF DATA COLLECTION

Information on the pathologic effects of captive cetacean foreign body ingestion was derived from the literature and the senior author's personal experience as biologist and curator at Marineland of the Pacific during the period 1968-74.

Records of debris ingestion in stranded odontocete cetaceans were solicited from institutions and persons known to include stomach content examination as part of a coordinated stranded animal recovery program. Due to variation in recordkeeping and necropsy techniques imposed by a 24-year time frame (1963-86), frequency of occurrence data on debris ingestion could not be reliably derived. Accounts from the literature were not included unless sufficient information on time frame, locality, and nature of ingested debris was available.

Data on evidence of debris ingestion in free-ranging odontocete cetaceans were obtained from food habits studies conducted on animals collected at sea as a result of incidental fisheries interactions or directly taken for research or commercial purposes. In each case, personnel directly involved in the preliminary stomach content sorting procedures were interviewed. Unusual items encountered during this stage tend to be remembered (though not necessarily recorded). An "I don't recall" response during the interview resulted in elimination of the study from the data base.

In some instances determinations as to whether ingested objects constitute debris directly ingested or introduced secondarily through prey species presented a problem. Tiny bits of plastic and isolated fishhooks are particularly suspect. Fish are well known to be attracted to and ingest man-made objects. Recently ingestion of plastic particles by oceanic squid has been documented (Araya 1983; Machida 1983). For purposes of this study, animals containing only isolated fishhooks were noted but not included in the frequency data presented.

As this study progressed, it became apparent that there are probably more isolated incidence of debris ingestion in odontocete cetaceans than we were able to locate in the time allowed. We welcome any oversights brought to our attention so the records may be included in a future revision of this report.

RESULTS

Captive Cetacean Foreign Body Ingestion

Mortality in marine parks and zoos due to foreign body ingestion is well documented in the literature. Brown et al. (1960) described causes of mortality in a major oceanarium, Marineland of the Pacific, during the first 5 years of operation. *Three* of those years were summarized as follows: "The losses occurring during the years 1955 to 1958 were, with few exceptions, caused by animals swallowing indigestible foreign material and resulting *in* gastric and enteric impactions." Nakajima et al. (1965) reported that 18 of 92 (19.6%) dolphin casualties at Enoshima Aquarium in Japan between 1958 and 1965 had foreign material in their stomachs. Caldwell et al. (1965) described a simultaneous mortality of three trained bottlenose dolphins at Gulfarium in Florida. They died from ingesting plastic strips from the tank enclosure. "Balls of plastic up *to* four inches in diameter were found in the first stomach of these animals."

During the senior author's tenure at Marineland of the Pacific, numerous cetaceans died as a result of ingestion of foreign material. One trained Pacific bottlenose dolphin was particularly noteworthy in that it had ingested a piece of a polyethylene plastic bag ca. 0.19 m (2 ft square). Necropsy findings revealed that while the major portion of the bag remained in the forestomach, a small section extended through the sphincter and into the gastric stomach. Tissue pathology was extensive. Approximately one-half of the forestomach lining and submucosa had eroded away, with necrotic tissue and inflammation extending deep into the musculature of the stomach wall. The stomach wall and serosa adjacent to this lesion were edematous and thickened five to six times beyond normal. It was surmised that the effect of the plastic protruding through the sphincter into the gastric stomach caused an excess of digestive fluids to be released into the forestomach, severely injuring those portions of stomach lining insulated by plastic.

Captive cetaceans have been known to ingest a wide variety of foreign material. Objects such as cotton gloves, tin cans, plastic bags, bottles, pens, coins, flashbulbs, plastic combs, nails, steel wool cleaning pads, plastic toys, and women's jewelry are some of the articles reported (Brown et al. 1960; Amemiya 1962; Caldwell et al. 1965; Nakajima et al. 1965; Ridgway 1965, 1972; Brown et al. 1966).

The reasons for the high incidence of foreign body ingestion in captive cetaceans are not clear. The captive environment, due to its obvious spatial limitations, is at best an abnormal one. The social behavior of these animals has been severely altered (Caldwell et al. 1968). Ridgway (1972) suggested that since captive animals are taught to consume dead fish, they may consider any object entering the pool as edible. Excitement of training, performing, play behavior, and competition for food may also be contributing factors (Nakajima et al. 1965).

What is clear from the accounts on captive cetacean ingestion of foreign objects is that it has the potential for being a direct cause of mortality, or at least debilitating to a degree which could predispose animals to disease or predation in the wild state.

Stranded Animal Debris Ingestion

Case descriptions of stranded animal debris ingestion by species are presented in Table 1. A total of 43 accounts were available, spanning a period of time from 1963 to 1986. Sixteen species of odontocete cetaceans were involved.

Reports on debris ingestion came primarily from the east and west coasts of North America (37 and 58%, respectively). Only one record each was obtained from the Gulf of Mexico (Texas) and Hawaii. The differences in frequency probably reflect regional variation in stranded cetacean recovery and detailed necropsy techniques rather than true geographic differences in abundance of marine debris.

The kinds of debris ingested varied considerably. Plastic bags and plastic sheeting were the most prevalent items (62.5%). Other miscellaneous plastic articles such as drinking straws, bottle caps, discarded fishing net, synthetic rope, and a small container occurred in 17.5% of the cases. The total occurrence for all plastic debris was 80.0%. Nonplastic debris such as rubber balloons, asphalt, cellophane, cloth, paper, and metal articles (excluding fishhooks) was encountered in 37.5% of the cases reported. Fragments of marine plants, which are also abnormally ingested, were encountered in 32.6% of the stomachs examined.

Table 1.--Records of the ingestion of marine debris by stranded odontocete cetaceans.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
			Physeter macrocephalus, sperm whale			
--	6/79	Florence, OR	--	--	About 1 L of tightly packed trawl net in stomach. One of 38 stomachs examined from a mass stranding of 41 animals	Mate 1985.
Sp-1	6/7/79	Purgatory Bay, Bonavista Cove, Newfoundland, Canada	1,030	F	Small length of nylon rope and unidentified debris	U.S. National Museum.[e]
MME01362	7/1/85	Seaside, NJ	510	--	Mylar balloon	U.S. National Museum.[a]
			Kogia simus, dwarf sperm whale			
USNM504132	12/4/74	Corolla, NC	178	F	Plastic Wonderbread bread wrapper	U.S. National Museum.[a]
			Kogia breviceps, pygmy sperm whale			
CMNH0216	4/27/76	Sullivan's Island, SC	318	F	Two small pieces of thin plastic	Charleston Museum.[b]
MME00549	1/1/84	Galveston, TX	182	M	Pounds of plastic bags clogging its stomach chambers	U.S. National Museum;[a] Wehle and Coleman 1983.
MME01263	5/17/85	Brevard Co., FL	320	M	Plastic bag	U.S. National Museum.[a]

Table 1. --Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
			***Ziphius cavirostris*, Cuvier's beaked whale**			
JRH-087	11/20/80	San Diego, CA	526	M	Piece of asphalt	Southwest Fisheries Science Center.[c]
USNM550111	1/7/81	Assawaman, VA	580	F	Large plastic bag and plastic wrappers	U.S. National Museum.*
USNM550734	1/27/86	Seaford, VA	512	F	Plastic straw and a horse chestnut	U.S. National Museum.[a]
			***Mesoplodon europaeus*, Gervais' beaked whale**			
USNM550018	11/22/80	Hatteras Island, NC	311	M	Large piece of clear plastic bag	U.S. National Museum.[a]
USNM550362	12/28/83	Cape May, NJ	371	F	Stomach filled with plastic bag	U.S. National Museum.[a]
			***Mesoplodon densirostris*, Blainville's beaked whale**			
USNM550754	2/14/86	East Hampton, NY	420	M	One plastic bottle cap	U.S. National Museum.[a]
			***Globicephala macrorhynchus*, short-finned pilot whale**			
USNM550310	5/18/83	Corolla, NC	275	M	Small plastic container	U.S. National Museum.[a]
			***Steno bredanensis*, rough-toothed dolphin**			
USNM504462	6/28/76	Maui, HI	215	F	Plastic bag in stomach. This animal was one of nine mass stranded on 6/28/76.	U.S. National Museum.[a]

Table 1.--Continued,

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
USNM504486	10/12/76	Sandbridge, VA	206	M	Two pieces of heavy black plastic. This animal and one below are part of mass stranding of 13 on 10/12/76	U.S. National Museum.[a]
USNM504494	10/12/76	Sandbridge, VA	233	M	One large fishhook loose in stomach	U.S. National Museum.[a]
		Lagenorhynchus obliquidens, Pacific white-sided dolphin				
--	8/29/63	Santa Monica, CA	165	M	Piece of paper wadded into a 5.1 cm (2-in) ball along with seaweed, squid beaks, and roundworms.	Caldwell et al. 1965.
WAW-130	8/15/71	Santa Monica, CA	167	M	Stomach contained numerous small plastic bags, pieces of cardboard, and waxed paper, Numerous kelp fronds (*Macrocystis pyrifera*) also present. This animal had been observed inside a yacht harbor for 10 days prior to stranding. Necropsy diagnosed parasitic central nervous system pathology and hepatitis as cause of death.	W. Walker, unpubl. data; Cowan et al. 1986.
WAW-174	9/21/72	Long Beach, CA	176	F	Forestomach half full of four plastic bags, two plastic bottle caps, and numerous small sticks, twigs, leaves, and kelp fronds	W. Walker, unpubl. data. Pathology data from Cowan et al. 1986

Table 1.--Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
					(*Macrocystis* and *Egregia*). One No. 4 fishhook snagged in stomach lining. Necropsy diagnosed central nervous system pathology due to parasitism by the trematode, *Nasitrema* sp.	
WAW-192	7/18/83	Santa Monica, CA	188	F	Three small plastic bags, one plastic drinking straw, one Calif. Dep. Fish Game mackerel fish tag No. M-11283. Tag is 5.1 cm (2 in) long, yellow, spaghetti type. Necropsy diagnosed central nervous system pathology due to parasitism as cause of stranding.	W. Walker unpubl. data. Pathology data from Cowan et. al. 1986.
					***Delphinus delphis*, common dolphin**	
WAW-148	2/12/72	Malibu, CA	173	F	One 15 * 15 cm plastic bag, several kelp fronds (*Macrocystis pyrifera*). Cause of stranding diagnosed as parasitism of central nervous system.	W. Walker unpubl. data. Pathology data from Cowan et al. 1986.
WAW-172	9/8/72	Will Rogers State Beach, Los Angeles County, CA	190	M	Two 20-cm^2 pieces of cellophane; one small piece of black plastic plastic (approximately 3 cm^2), and portions of marine plants (*Macrocystis*, *Egregia*, and	W. Walker unpubl. data. Pathology data from Cowan et al. 1986.

Table 1. --Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
					Phyllospadix) . Cause of stranding diagnosed as parasitism of central nervous system.	
LACM72286	11/24/80	Hermosa Beach, CA	197	F	One rusted fishhook embedded in stomach wall. Necropsy revealed an apparently unrelated massive tumor or abscess in abdomen adjacent to left kidney.	Los Angeles County Museum of Natural History.[d]
JEH331	4/25/86	Will Rogers State Beach, Los Angeles County, CA	193	F	Stomach contained one partial red balloon (3 x 13 cm), one piece of clear plastic (8 x 13 cm), and kelp fronds (*Macrocystis pyrifera*).	Los Angeles County Museum of Natural History.[d]
			Tursiops truncatus, bottlenose dolphin (All southern California coastal population)			
WFP-559	2/5/77	La Jolla, CA	302	M	One rusted metal bottle cap beach sand, fragments of kelp fronds	W. Walker unpubl. data.
WAW-141	12/26/71	Huntington Beach, CA	207	F	Three approximately 20-cm^2 pieces of heavy clear plastic approximately 3 mil thick; several littorinid snail shells	W. Walker unpubl. data.
WFP-535	8/9/76	La Jolla, CA Diego County, CA	313	M	Two cellophane cigarette wrappers one rusted fishhook, kelp fronds (*Egregia* sp.)	W. Walker unpubl. data,

Table 1. --Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
WFP-537	8/31/76	Encinitas, CA	--	F	One blue vinyl plastic strip (3 x 30 cm); kelp frond fragments, one gastropod operculum.	W. Walker unpubl. data.
WFP-565	1/27/77	Del Mar, CA	267	M	One black rubber "bungie cord" with metal hooks at ends (2 x 1 x 40 cm), sand, mollusc shell fragments	W. Walker unpubl. data.
WAW-553	9/2/78	Huntington Beach, CA.	231	F	One partial shoelace, beach sand, mollusc shell fragments	W. Walker unpubl. data.
JRH-057	5/13/80	La Jolla, CA	251	F	Two plastic bags, one 20 x 20 cm, other partial 40 x 15 cm; kelp fronds (*Macrocystis pyrifera*), beach sand, gravel, shell fragments	W. Walker unpubl. data. data.
LJH-006	11/14/81	San Diego, CA	236	F	Metal spring (2.0 x 20 cm)	Southwest Fisheries Science Center.[d]
HJB-036	9/3/86	Solana Beach, CA	U	M	Two fishhooks ca. 2.5 cm (1 in) long	Southwest Fisheries Science Center.[c]
			Grampus griseus, Risso's dolphin			
SEAN7595	5/6/82	Martha's Vineyard, MA	230	M	Plastic bag in throat	New England Aquarium and U.S. National Museum of Natural History.[a]

Table 1. --Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
LACM47145	12/8/84	Manhattan Beach, CA	225	--	Blue balloon, partial (20x 2.5 cm)	Los Angeles County Museum of Natural History.[d]
			Stenella coeruleoalba, striped dolphin			
DAP-001	3/22/83	Cape Point, NC	220	M	Plastic bag in stomach	U.S. National Museum[a] of Natural History, Smithsonian Institution, Wash., D.C.
			Lissodelphis borealis, northern right whale dolphin			
WAW- 194	8/2/73	Will Rogers State Beach, Los Angeles County, CA,	211	F	One partial plastic bag in mouth, remainder 25 x 30 cm in forestomach; fronds of marine plants *Macrocystis*, *Cystoseira*, and *Egregia*; one honey bee (hymenoptera); three white bird feathers. Necropsy diagnosed parasitism of central nervous system as cause of stranding *Cystoseira*, and *Egregia*; one honey bee (hymenopteran); three white bird feathers. Necropsy diagnosed parasitism of central nervous system as cause of stranding	W. Walker unpubl. data.

Table 1.--Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
WAW- 209	10/4/73	Santa Monica, CA	225	F	Several small bits of blue vinyl plastic (ea. 2 cm^2); one rusted metal bottle cap; 10-12 pieces of kelp fronds (*Macrocystis pyrifera*). Cause of stranding undetermined.	W. Walker unpubl. data.
					***Phocoena phocoena*, harbor porpoise**	
USNM504220	3/1/75	Corolla, NC	--	--	Piece of cloth and plastic in stomach	U.S. National Museum.[a]
					***Phocoenoides dalli*, Dan’s porpoise**	
LACM54739	7/2/73	Venice Beach, CA	222	M	Stomach jammed with debris as follows: 13 pieces of clear plastic sheets ranging in size from 4 x 9 cm to 35 x 41 cm; 1 piece black plastic 5 x 16 cm; 3 heavy, clear plastic bags 20 x 39 cm; 2 sandwich bags both 14 x 20 cm; 2 plastic bread bags both 23 x 47 cm; 1 plastic drinking straw; 2 pieces of crumpled cardboard approximately 10 x 13 cm; kelp fronds (*Macrocystis pyrifera*). Necropsy not performed due to autolysed condition of tissues. Cause of stranding undetermined.	Los Angeles County Museum of Natural History[d] and Walker unpubl. data.

Table 1. --Continued.

Specimen No.	Date	Location	Length (cm)	Sex	Description	Information source
WAW-197	8/10/73	Santa Barbara Yacht Harbor, CA	190	F	One blue plastic bottle cap; one 20 x 20 cm plastic bag. The remainder of the forestomach is jammed with kelp, *Macrocystis pyrifera*. Necropsy diagnosed parasitic central nervous system disorder as cause of stranding. Animal had been observed in the harbor 3 days prior to stranding.	W. Walker unpubl. data; Cowan et al. 1986.
SBMNH 78-47	11/8/78	Carpenteria State Beach, Santa Barbara County, CA	204	M	Pieces of plastic bags and kelp in stomach	Santa Barbara Museum of Natural History, Santa Barbara, CA.

[a]Charleston Museum of Natural History, Charleston, S.C.
[b]U.S. National Museum of Natural History, Smithsonian Institution Washington, D.C.
[c]Southwest Fisheries Science Center, National Marine Fisheries Semite, La Jolla, Calif.
[d]Los Angeles County Museum of Natural History, Los Angeles, Calif.

In one case (WAW-192), a small spaghetti-type mackerel fish tag was found in the stomach. This item was undoubtedly introduced secondarily through ingested prey (*Scomber japonicus*).

Autopsy data were available in eight (18.6%) of the cases (WAW-130, 174, 192, 148, 172, 194, 197, and LACM 72286). Chronic pre-existing disease was present in all instances. In seven of these cases, brain parasitism by the trematode *Nasitrema* sp. was diagnosed as the primary cause of stranding. All these cases occurred in southern California. In two isolated instances (WAW-130 and 197), the animals were observed for up to 10 days inside a boat marina breakwater prior to stranding.

In the southern California area, brain parasitism due to *Nasitrema* sp. has proven to be a common pathologic factor in individual strandings of small cetaceans (Ridgway 1965; Ridgway and Dailey 1972; Dailey and Walker 1978; Cowan et al. 1986). Cowan et al. (1986) found 91% parasitized brains in 44 brains examined in 4 species of stranded cetaceans. No marine debris-related gastrointestinal pathology was evident in any of the 23 southern California strandings summarized in Table 1.

Naturally occurring disease factors may predispose these animals to ingest abnormal objects. The high incidence of pre-existing brain parasitism and the absence of debris-induced gastrointestinal pathology suggest that the significance of marine debris in stranded cetaceans should remain questionable unless accompanied by related pathologic changes and a complete necropsy and tissue analysis of all major organ systems.

Marine Debris Encountered in Food Habits Analyses of Free-Ranging Animals

Data on 10 species of odontocete cetaceans *were* available (Table 2). All species combined, a total of 1,790 stomachs had been examined. The geographic regions covered in the sample are diverse. Localities in the North Pacific and Bering Sea represented 81.5% of the sample. The Okhotsk Sea represented 5.9% and the remaining 12.6% were collected off the coast of Uruguay in the South Atlantic. Of the 10 species of cetaceans reported, only the Baird's beaked whale, *Berardius bairdii*, taken at 2 different localities in the coastal waters of Japan had ingested debris. In 86 *B. bairdii* taken off Chiba Prefecture, central Japan, the frequency of debris ingestion was 26.7%. A lower incidence of debris was evident in 20 *Berardius* examined from the southern Okhotsk Sea, where frequency of ingestion was 15.0%. Overall frequency for both areas sampled was 24.5%.

The nature of debris material ingested by *B. bairdii* from both regions was diverse (see Tables 3 and 4 for detailed accounts). Occurrence of plastic bags and sheeting was 30.8%. Other plastic articles including discarded fishing gear had a frequency of 11.5%. All plastic material combined was 42.3%. Miscellaneous nonplastic material such as vegetable refuse, wood boards, concrete fragments, pieces of glass, cigarette filters, cellophane, rubber material, a roof tile fragment, bottle caps, rusty hinge, aluminum can pull tabs, and a metal butane lighter top had an occurrence of *76.0%.* Observations made during collection of stomach content samples revealed no debris-associated lesions or evidence of impaction.

Examination of the data in Tables 3 and 4 reveals that the major portion of debris found in *B. bairdii* stomachs were negatively buoyant items probably ingested at or near the ocean bottom.

Differences in the frequency of debris ingestion between the Pacific coast of central Japan (26.7%) and the southern Okhotsk Sea (15.0%) are probably due to regional differences in feeding strategy. Off the Pacific coast of central Japan, *Berardius* are known to feed primarily on benthic prey. In this region they are documented to be feeding on bottom-dwelling morid and macrourid fishes (81.7%). Cephalopods represented only 18.0% of the consumed prey. In addition, stones and gravel were encountered in all stomachs examined and were undoubtedly consumed incidentally during bottom feeding (Walker and Mead 1988). In the southern Okhotsk Sea, *Berardius* feeding strategy changes considerably. In this region, cephalopod prey are dominant (87.6%) in the food habits sample. The predominantly benthic morid and macrourid fishes represent only 8.2% of the prey. Stones and gravel were encountered in only 10.0% of the stomachs examined (W. A. Walker unpubl. data).

The other nine species of cetaceans summarized in Table 2 are known *to* feed primarily in the epipelagic and mesopelagic zones in the upper water column. Debris occurrence in all 1,684 stomachs examined was 0. The stomach sample for these nine species is small compared to conservative, stock-level, population estimates. As a result, the absence of marine debris in the species summarized in Table 2 is inconclusive. However, some inference can be made from the Dan's porpoise, *Phocoenoides dalli*, samples from the northern North Pacific and Bering Sea. Both these regions are documented to have a high density of marine debris (Venrick et al. 1973; Feder et al. 1978; Shaw and Mapes 1979; Dahlberg and Day 1985). Eight hundred fifteen *Phocoenoides* stomachs were examined from these regions and no debris items were encountered.

DISCUSSION

Accounts of mortality and pathology caused by foreign body ingestion in captive cetaceans leave little doubt as to the potential effects of marine debris in wild, free-ranging cetaceans.

Most of the available records of debris ingestion are from stranded odontocete cetaceans. However, debris ingestion in singly stranded animals may be, in a large percentage of cases, part of the stranding syndrome. Pre-existing disease factors related to parasitism occurred in almost all cases accompanied by complete necropsy observations.

Debris ingestion data on free-ranging animals derived from previously conducted food habits studies were, with the exception of Baird's beaked whale, negative. Of the 10 species summarized in Table 2, *B. bairdii* is the only species of cetacean known *to* demonstrate regionally varying degrees of deepwater bottom-feeding strategy. All the remaining nine

Table 2, --Summary of ingested marine debris encountered in food habits analyses of free-ranging small cetaceans.

Species	Date	General location	Collection method	Sample size	Debris occurrence	Information source
Berardius bairdii	1988-89	Taken in the southern Okhotsk Sea off northern Hokkaido, Japan	Shore-based harpoon fishery	20	15.0%	W. Walker unpubl. data. For detailed summary see Table 4.
Berardius bairdii	1985-87	Taken off the Pacific coast of central Japan	Shore-based harpoon fishery	86	26.7%	W. Walker and J. G. Mead unpubl. data. Food habits data in Walker and Mead 1988. For detailed summary see Table 3.
Steno *bredanensis*	1977-87	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna fishery	16	0	W. Walker and J. G. Mead unpubl. data.
Lagenorhynchus obliquidens	1979-72	Collected off the coasts of Washington and California	Collected at sea for research purposes	44	0	C. Fiscus, food habits data presented in Stroud et al. 1981.
Delphinus delphis	1977-80	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna pursue seine fishery	32	0	Southwest Fisheries Science Center, La Jolla, CA, unpubl. data.
Tursiops truncatus	1972 87	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna purse seine fishery	35	0	W. Walker unpubl. data; food habits data presented (in part) in Walker 1981.
Stenella attenuata	1968-77	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna purse seine fishery	231	0	Southwest Fisheries Science Center, La Jolla, CA, food habits data (in part) published in Perrin et al. 1973.

Table 2, --Continued.

Species	Date	General location	Collection method	Sample size	Debris occurrence	Information source
Stenella coeruleoalba	1977-80	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna purse seine fishery	104	0	Southwest Fisheries Science Center, La Jolla, CA, unpubl. data.
Stenella longirostris	1968-80	Offshore waters of the eastern tropical Pacific	Incidental take in the yellowfin tuna purse seine fishery	78	0	Southwest Fisheries Science Center, La Jolla, CA, published (in part) in Perrin et al. 1973.
Phocoenoides dalli	1988	Okhotsk Sea, Japan ca. lat. 44#10'N, long. 144#30'E	Shore-based hand-harpoon fishery	86	0	W. Walker unpubl. data.
Phocoenoides dalli	1979-86	Northern North Pacific and Bering Sea	Incidental take of Japanese high seas salmon gillnet fishery	815	0	T. Crawford and L. Tsunoda, Northwest and Alaska Fisheries Center, National Marine Mammal Laboratory, Seattle, Wash. Food habits data presented (in part) in Crawford 1981.
Phocoenoides dalli	1958-72	Collected off the coasts of Washington and California	Collected at sea for research purposes	17	0	C. Fiscus; food habits data in Stroud et al. 1981.
Pontoporia blainvilli	1969-75	Off the coast of Uruguay, South America (ea. lat. 34#30'S)	Incidental take in local shark gillnet fisheries	226	0	R. Brownell, Jr. and W. Walker. Prey species accounts on 11 animals in Fitch and Brownell 1971.

Table 3.--Summary of ingested marine debris in 86 ***Berardius bairdii*** taken at Wadaura, Chiba Prefecture, Japan, 1985-87.

Specimen No.	Date	Length (m)	Sex	Age (year)	Description of debris
85-008	7/23/85	10.10	M	23	Vegetable refuse--approximately 1 dozen coffee beans.
85-015	7/28/85	9.85	M	73	Three small glass fragments (two clear, one brown) approximately 1.5 x 2 x 0.5 cm, edges worn; two cigarette filters.
85-017	7/29/85	10.05	F	23	One cigarette filter and a piece of tree bark.
85-018	7/30/85	10.43	M	31	One No. 2 size rusted fishhook.
85-021	8/1/86	10.00	M	51	One piece of wadded-up longline approximately 15 cm diameter with 15-20 rusted No. 2 size hooks. The main lines and branch lines are made up of braided No. 7 nylon net twine with hooks set approximately 120 cm apart. Condition of this object suggests recent ingestion of discarded fishing gear.
85-022	8/1/85	9.90	M	21	One piece of black plastic (25 x 15 cm) approximately 1.5 mil thick and vegetable refuse--two corn kernels, *Zea* maise.
85-023	8/2/85	10.70	F	54	One fishhook--only rusted shank and small portion of leader remain.
85-024	8/2/85	9.90	M	84	One piece of black vinyl plastic (130 x 135 x 0.3 cm).
85-026	8/3/85	9.65	M	8	One 45 x 3 cm mahogany stick with staples.
85-033	8/6/85	9.62	M	70	One 20 x 15 cm thin plastic sheet (food wrapper?); cellophane package material (8 x 6 cm). Vegetable refuse--one undigested potato (5 x 6 x 3 cm) two pieces of tree bark (3-4 x 5-6 cm).

Table 3.- -Continued.

Specimen No.	Date	Length (m)	Sex	Age (year)	Description of debris
85-031	8/5/85	9.50	M	60	One 8 x 10 x 0.5 cm irregular-shaped piece of clear plastic (PVC?).
86-004	7/27/86	10.75	F	22	One 10 x 15 x 1.0 cm piece of pine board.
86-011	7/29/86	10.40	F	53	One 12 x 2 x 1 cm piece of wood; one 20 x 30 cm black plastic sheet approximately 3 mil thick.
86-012	7/30/86	9.70	M	17	Two fragments of clear plastic 4 x 3 cm and 6 x 2 cm, both approximately 3 mil thick.
86-020	8/7/86	9.10	F	8	One 5 x 6 x 2 cm fragment of blue glazed roofing tile, two cigarette filters.
86-026	8/9/86	10.20	M	26	One 10 x 10 cm piece of concrete; one bottle cap; one 6 x 6 x 2 cm piece of tree bark.
86-028	8/10/86	9.70	M	38	One fragment of 20 x 15 x 0.3 cm rubber mat and 3-4 bird feathers.
87-013	7/29/87	10.32	M	56	Vegetable refuse--25-30 soybeans; one badly rusted metal hinge.
87-014	7/29/87	10.80	F	40	One 3 x 4 x 3 concrete fragment; two pieces of cellophane (both approximately 8 x 15 cm).
87-015	8/1/87	10.60	F	19	Vegetable refuse--10-15 soybeans, 8 corn kernels, *Zea maise;* 1 aluminum pull tab,
87-016	8/1/87	10.20	F	17	One corroded fishhook; one metal portion (top) of a butane cigarette lighter.
87-017	8/2/87	10.35	M	68	Four clear glass fragments 2 to 4 cm^2 and approximately 0.3 cm thick, all worn smooth on edges.

Table 3.--Continued.

Specimen No.	Date	Length (m)	Sex	Age (year)	Description of debris
87-021	8/10/87	10.40	F	51	One piece of wood with nail (not protruding) 17.5 x 4.5 x 7.0 cm (weight 130 g).
87-023	8/13/87	10.30	F	44	One large concrete fragment 9.5 x 6.5 x 3.0, weight 230 g; one piece of 3 mil thick black plastic 18 x 23 cm.
87-024	8/14/87	10.58	M	41	One fragment of brown glass, 4 x 2 x 0.3 cm, edges smooth, one piece of brown plastic sheet 30-35 cm^2.

species summarized are known to feed primarily in the epipelagic and mesopelagic zones.

Experimental evidence suggests that odontocete cetaceans are probably very discriminating feeders. Mistaken ingestion of oceanic debris due to its resemblance to preferred prey species is unlikely because of odontocete cetacean echolocation capabilities. In captive experiments, the bottlenose dolphin, *Tursiops truncatus*, has been shown to be capable of making fine discriminations in size, shape, texture, and composition of objects (Kellogg 1958, 1959a, 1959b; Norris et al. 1961; Evans and Powell 1967; Norris 1969). Kellogg (1959a) demonstrated the use of echolocation by *T. truncatus* to locate preferred food fish but avoid inedible objects. Selection between a water-filled 2-cm gelatin capsule and an equal-sized piece of cut fish has been demonstrated (Norris et al. 1961). Evans and Powell (1967) determined that T. *truncatus* could discriminate between identical-sized sheets of different metals, or even between sheets of the same metal but of different thicknesses. Monofilament about 1 mm in' diameter was determined to be at the threshold of detection for a captive harbor porpoise, *Phocoena phocoena* (Busnel et al. 1965).

The two species of free-ranging odontocete cetaceans documented to ingest marine debris are the sperm whale *Physeter macrocephalus*, and the Baird's beaked *B. bairdii*. Both these cetaceans are known to spend some time feeding at or near the bottom, particularly in coastal waters. This is verified by the behavior of preferred prey species and by the common occurrence of stones and gravel in examined stomachs (Betesheva and Akimushkin 1955; Nemoto and Nasu 1963; Tomilin 1967; Berzin 1971; Walker and Mead 1988). Ingestion of debris in these two species of cetaceans is very likely to be incidental, the debris being consumed along with bottom-dwelling prey.

Table 4. --Summary of ingested marine debris in 20 *Berardius bairdii* taken at Abashiri, Hokkaido, Japan, 1988-89.

Specimen No.	Date	Length (m)	Sex	Description of debris
Ab-88-03	8/28/88	10.70	M	One No. 2 size fishhook with short, approximately 15 cm, portion of leader attached.
Ab-88-08	9/7/88	10.10	M	Two No. 2 size fishhooks.
Ab-88-18	9/24/88	10.20	F	One badly rusted, partial No. 2 size fishhook.
89-HK-101	9/1/89	9.40	M	One cotton sleeve from rubber glove, black rubber fragments still attached to anterior edges.
89-HK-102	9/2/89	1.0.78	F	One No. 2 fishhook and three ca. 30 cm^2 portions of clear plastic sheeting. All appear to be portions of the same material and are ca. 3 cm thick. Vegetable refuse--three pieces of citrus fruit (orange?) peels.
89-HK-104	9/9/88	10.20	M	One ca. 10-cm diameter wad of thin, clear plastic sheeting ca. 1.5 mil thick.

Records presented in this report of marine debris ingested by *Berardius* off central Japan all came from off the Boso Peninsula, Chiba Prefecture, an area extending from the northern edge of the entrance to Tokyo Bay north *to* Choshi off the Pacific coast of Japan (lat. 34°39'-35°57'N). The animals were taken primarily along the 1,000-m depth contour line. Due to the proximity to Tokyo Bay and Choshi (a major fishing port), the entire area is subject to extremely heavy merchant and commercial fishing vessel traffic. The *Berardius* stomach samples from off northern Hokkaido were from two general areas in the southern Okhotsk Sea: 1) The immediate vicinity of the major commercial fishing port of Abashiri (ea. lat. 44°30'N, long. 144°30'E) and 2) Nemuro Strait between the Shiretoko Peninsula (Japan) and Kunashir Island (U.S.S.R.) (ea. lat. 44°15'N, long. 145°30'E). Both these areas are also subject to heavy commercial fishing activity.

Debris encountered in *Berardius* stomachs from both the Pacific coast of Japan and the southern Okhotsk Sea consisted almost exclusively of negatively bouyant material. The varied nature of the debris (e.g., broken glass, vegetable refuse, aluminum pull tabs, bottle caps) and the deep offshore location strongly suggest shipboard refuse as the primary source of the ingested debris.

It should be noted that the absence of debris-related pathology in the Baird's beaked whale sample does not rule out the occurrence of debris-related mortality in the study areas. To the contrary, the high incidence of ingested debris, the varied nature of the debris material, and records of debris-related mortality in captive cetaceans permit some speculation on the potential for incidental debris ingestion as a mortality factor in this species. *Berardius* is a large animal (up to 12.8 m in length). Death or debilitation through gastrointestinal impaction would probably require a relatively large volume of indigestible material. However, some of the debris material summarized in Tables 3 and 4 has considerable pathologic potential. Ingestion of relatively small items such as sharp metallic objects or freshly broken glass poses a real identifiable hazard and is a well-documented factor in human as well as veterinary disease. Complications through mechanical trauma to the gastrointestinal tract by such objects range from laceration and hemorrhage to perforation of the gut wall and acute bacterial peritonitis. These conditions are eminently life threatening. In the wild state, the elapsed time from onset to death would probably be short and accompanied by marked behavioral alterations. As a result, the probability of encountering these acute states in the fisheries sample would be very low. In the commercial fisheries sample we should expect only chronic, prolonged disease conditions to be manifest. Some bias toward the taking of chronically ill whales in commercial harpoon fisheries is suspected, Walker (1988) suggested, on the basis of a parasite survey, that the prolonged chase procedure in the Japanese *Berardius* fishery may involve selection toward the taking of some physically infirm individuals.

Wallace (1985) raised the question of whether sinking truly constituted debris removal. Results of this study indicate that negatively buoyant debris are not neutral, but still may pose a potential hazard to large predators feeding on benthic prey.

RECOMMENDATIONS

The worldwide trend toward curtailment of the commercial take of marine mammals restricts opportunities for future food habits sampling. In the future, food habits studies are likely to become more reliant on samples obtained from incidental fisheries' interactions and strandings. The following recommendations should be incorporated into future research:

- Develop and incorporate a consistent format for recording the presence as well as the absence of marine debris in stomach content analyses conducted on both free-ranging and stranded marine mammals. The recording of negative findings should also be emphasized, as they are crucial in establishing reliable information on the frequency of debris occurrence in future studies.

- Whenever possible, occurrence of ingested debris should be of the debris should also be kept (e.g. , size, shape, consistency) . In the case of stranded animals, the necropsy should include examination and evaluation of all major organ systems. Data presented in this report suggest that ingestion of debris may be secondary to other naturally occurring disease factors.

- The filter-feeding strategy of the baleen whales, Mysticeti, may make them particularly vulnerable to incidental debris ingestion in both the benthic zone and zones of the upper water column. Researchers should be encouraged to take advantage of the few remaining commercial fisheries to record evidence of ingested debris. The stomachs and oral cavities of stranded baleen whales should be examined whenever possible. Individuals involved in past food habit studies of baleen whale species should be interviewed.

- Research on marine mammal food habits as well as debris ingestion should continue in order to establish preferred prey species and feeding behavior, and increase the data base on debris ingestion.

- The data presented in this report are limited to gross observations on the acute effects of ingested debris (e.g. , gastrointestinal impaction, ulceration). Research into the potentially insidious effects of absorption of hydrocarbon contaminants such as plasticizers should be conducted.

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