Persistent Marine Debris in the North Sea, Northwest Atlantic Ocean, Wider Caribbean Area, and the West Coast of Baja California

A Report to the

Marine Mammal Commission

and the

National Ocean Pollution Program Office,
National Oceanic and Atmospheric Administration,
U.S. Department of Commerce

by

Burr Heneman
and the
Center for Environmental Education

July 1988

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WIDER CARIBBEAN AREA,
AND THE
WEST COAST OF BAJA CALIFORNIA

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Disclaimer

The views, ideas, and opinions expressed in this report are those of the authors and are not necessarily shared by the Marine Mammal Commission, its Committee of Scientific Advisors on Marine Mammals, or the National Ocean Pollution Program Office.

DEDICATION

This report is dedicated to the memory of Archie Carr.

"The fluid dynamics of advection and diffusion are well understood by physical oceanographers; and the role of currents, gyres, and rings in transporting debris is well documented; but the gathering action of down-welling in worsening the effect of pollutants on animals in driftline habitats has had little attention from marine ecologists. Neglect of this fundamental aspect of marine ecology can probably be attributed to the formidable arithmetic of advection and diffusion. But differential equations are not needed to understand that the driftlines, slicks, rips, and windrows that form along fronts, large and small, are an essential feature of the surface water of the ocean. They are the hedgerows of the epipelagic environment.

"The importance of these zones as marine habitat is well known to pelagic fishermen and to a scattering of marine zoologists, but the role of downwelling in the ecologic organization of the surface waters of the ocean has been generally overlooked. With the present volume of biologically injurious flotsam in the sea, and the probability that the spread of these materials will increase, it seems appropriate to examine the ecological threat posed by persistent plastic materials in driftlines along which biologic activity is at a maximum."

Archie Carr,
Marine Pollution Bulletin, June 1987

FOREWORD

The North Sea

"As another seaside holiday season gets under way, the accident toll begins to rise. Feet sliced by half-buried bottles and cans; beach clothes soiled by clods of oil; young fingers scorched by dumped distress flares and corrosive chemicals. Each lapping of the ocean brings with it a new surge of muck and hazard, ton after ton casually tossed overboard from ships to add yet further layers of nastiness to Britain's beleaguered coastline."

Richard Girling,
The Sunday Times, 29 June 1980

The Northwest Atlantic

"The sargasso is laced with trash. For sixty days the ocean has been pristine, a world that might never have been touched by man. Ships and a single chunk of Styrofoam have been the only evidence that humans still inhabit the earth. Suddenly my surroundings are full of their excrement - *our* excrement, I remind myself. Old bottles, baskets, clotted clumps of oil, bobbing bulbs, flasks, fishnet webs, ropes, crates, floats, foam, and faded fabric. The highway of trash stretches from south to north as far as I can see."

Steve Callahan,
from *Adrift*, 1986

The Wider Caribbean Area

"This place would be paradise if it weren't for all the trash and tar."

Tourist,
on a beach near Cancun, Mexico, 1988

The West Coast of Baja California

"The beaches along Baja's Pacific side collect flotsam from the entire northern Pacific Ocean. It is possible to find giant redwood logs from the northwest United States, white cedar stumps from Canada and Alaska, hatch covers from the ships of the world, bottles - old and new. Occasionally, a glass net float will survive the journey from the Japanese fishing grounds. Here, too, is evidence of man's carelessness in the many plastic cups, bags and egg cartons scattered about."

Tom Miller and Elmar Baxter,
The Baja Book, 1980

CONTENTS

EXECUTIVE SUMMARY

This report reviews available published and unpublished information on the sources, amounts, types, distribution, and effects of persistent debris in the marine environments of the North Sea, the northwest Atlantic Ocean, the Wider Caribbean Area, and the west coast of Baja California, Mexico. It also identifies local, national, regional, and international efforts to control, reduce, and eliminate marine debris in these study areas. Finally, the report draws conclusions about the status of marine debris in the study areas and makes specific recommendations on information that is needed and on mitigation actions that should be taken. A summary of major findings and recommendations for each study area follows.

North Sea

The report concludes that marine debris creates substantial problems in the North Sea study area, primarily by aesthetic degradation of coastal areas and the resultant costs of cleaning recreational beaches. Threats to human safety from hazardous wastes were also frequently reported. Entanglement of marine life, particularly seabirds, was widely reported, but mortality does not appear to be affecting populations. Plastics, glass, metal, and dunnage all contribute substantially to the debris load on beaches. Tar occurs at moderately high levels in some locations. Vessels appear to be the major source of debris, although land-source litter can be significant near urban areas and river mouths. Fishing gear was reported to be significant in very few locations.

With the possible exception of derelict fishing gear, there appears to be adequate information on the sources, amounts, types, distribution, and effects of marine debris in this study area.

The North Sea has a more highly developed framework of regulations that attempt to control marine pollution than any of the other study areas. Lacking until the entry into force of MARPOL 73/78 Annex V, however, have been international standards for regulating disposal of garbage from ships, the main source of debris in the North Sea. Therefore, implementation of Annex V after it enters into force at the end of 1988 should help considerably. All North Sea nations should be encouraged to ratify and implement Annex V. Special Area status, which we also recommend, would be required to solve problems created by nonplastic debris from vessels, such as glass, metal, and dunnage.

The North Sea suffers from a disturbing amount of hazardous marine debris, a problem that is inadequately dealt with by existing international agreements.

Some nations, notably the United Kingdom, have well-developed public awareness and educational programs to encourage voluntary compliance with the objective of reducing marine debris.

Northwest Atlantic

Major sources of marine debris were more numerous in the northwest Atlantic study area than in other areas, a fact that complicates mitigation efforts. The most serious effects were aesthetic degradation of the coast and clean-up costs. Several times in the past decade, there have been significant economic losses from debris-related beach closures in the New York Bight area. Impacts of debris entanglement and ingestion on sea turtle populations is unacceptably high since all of these species are either threatened or endangered. Additional information is needed to determine the impact of ghost fishing by derelict nets and traps, particularly off New England and eastern Canada.

Our principal recommendation for this study area is that Canada and the United States consider joint action to make their Atlantic coasts an international model for marine debris mitigation.

Wider Caribbean

Tar was easily the most serious marine debris problem in the Wider Caribbean study area, although other types of debris are commonly well-represented as well. There was disagreement on the relative contributions of tar by the various sources: tanker operations, fuel oil sludge, offshore oil production, terminal operations, and natural seeps.

Merchant marine and commercial fishing vessels and solid waste disposal methods on land appeared to be the major sources of plastics, glass, and metal on Caribbean beaches.

The most heavily affected coastal areas in the Wider Caribbean were generally downwind from major currents or shipping lanes. Land-source litter accumulates on some leeward beaches. The Texas coast had the worst debris problems of any area covered in this report.

Conflicts with tourism, an extremely important Wider Caribbean industry, are greatest in the western Caribbean, where many tourist areas are on windward coasts, than in the eastern Caribbean. The conflicts likely will become greater as tourist development spreads to the windward sides of eastern and central Caribbean islands, and growing populations generate more debris.

The Wider Caribbean area provided some new and more detailed information on the effects of debris, particularly tar and plastics, on sea turtles.

Major recommendations for this area include:

- More nations in the region, particularly oil producing countries, should ratify MARPOL 73/78 (with Annex I's mandatory restrictions on oil discharges from vessels) and optional Annex V;
- The Wider Caribbean should be designated a Special Area under MARPOL;

- More information should be collected on the most important sources of tar;

- Additional port reception facilities for fuel oil sludge are needed;

- Better regional coordination of research, planning, and management activities is needed, using the framework of the Cartagena Convention.

- The international community must recognize that Wider Caribbean nations with fragile, developing economies will require substantial assistance in implementing marine debris mitigation programs;

Baja California

Very little information was available for the Baja California study area. What information we found indicates that debris problems are negligible. One possible exception could be derelict gear from the rapidly growing set net fishery. We recommend periodic aerial surveys to monitor the situation.

General Comments

The report also makes general recommendations applicable to the three study areas with significant marine debris problems (North Sea, northwest Atlantic, and Wider Caribbean). We recommend the following:

- Regional and international communication and collaboration should be increased substantially by conferences and through other means.

- Marine debris programs should emphasize mitigation. Research should focus on filling critical information gaps, evaluating mitigation efforts, and monitoring long-term debris trends.

- To prevent costly and duplicative research, an international consensus should be reached on what additional information is needed on the effects of marine debris on seabirds, marine mammals, and sea turtles, and to evaluate the effects of ghost nets and traps on marine resources.

- Successful implementation of MARPOL Annex V should be given high priority in mitigation programs in the near term.

- Mitigation programs should give high priority to educational efforts and development of new technologies and procedures to reduce or dispose of solid wastes.

- There should be an international commitment to studying the role of oceanic fronts in concentrating marine debris and the animals, such as sea turtles, that likely are seriously affected by this debris.

- Funding should be provided to publish several sets of useful existing data from these study areas.

INTRODUCTION

Background of the Marine Debris Issue

The past 40 years have witnessed an explosive growth in the manufacture and use of inexpensive, durable plastics for countless products. One result has been an expanding annual mountain of this material and other persistent solid wastes to dispose of. Landfills are increasingly overburdened, and inevitably, as Cousteau, Heyerdahl, and a few marine scientists began to tell us in the 1960s, so too are the world's oceans.

Of the various kinds of human-generated, peristent solid waste that increasingly clutters the seas and beaches, plastics have recently received the most attention. But glass and metal items, as well as tar balls, often occur in greater number and volume than plastic waste.

A wide variety of debris is commonly observed in all seas and on coasts as remote as Antarctica's. A wealth of anecdotal information, and increasingly, research data, now exists on the sources, amounts, occurrence, and known or potential effects of this relatively nondegradable solid waste. Litter is dumped from merchant shipping, naval, commercial fishing, and recreational vessels and drilling rigs. The National Academy of Sciences (1975), in what remains the most comprehensive worldwide report on marine litter, estimated garbage and trash from all ocean sources to be 6,400,000 metric tons annually, with plastics comprising 44,800 metric tons of that total. Lost and discarded nets, traps, and other fishing gear, which the Food and Agricultural Organization of the United Nations estimated at 150,000 metric tons for 1975 (FAO 1985), is another important ocean source of debris because of its potential impacts on wildlife.

Tar balls result from accidental oil spills, tanker and other merchant vessel operations, and offshore oil production, as well as from natural seeps. Estimates of substantial discharges exist for various parts of the world. The National Research Council of the United States estimated that 1,100,000 metric tons of tar and heavy oils enter the marine environment each year as the result of human actions, excluding accidental spills (National Academy of Science 1985).

Land sources of marine debris include domestic and commercial solid wastes and by-products of manufacturing that enter the oceans through rivers and from coastal landfills. Data cited by Bean (1987) suggested that perhaps 600,000 tons of plastic waste may find its way annually to oceans from the United States alone. Solid waste disposal practices in many other countries contribute substantially to the world marine debris total.

The costs of these pollutants to humans and wildlife range from the obvious to the obscure. Discarded fishing nets ensnare marine mammals and sea turtles. In the best documented case, Fowler (1987) said the evidence suggests that entanglement in lost and discarded trawl webbing and packing bands may be the principal cause of the steady decline in northern fur seal numbers on the Pribilof Islands, Alaska, since the mid-1970s.

Seabirds swallow plastic pellets and other plastic debris. Day *et al.* (1985) reported that these materials have been found in the gizzards of at least 50 species of seabirds. Recent research indicates that ingestion of plastic may reduce reproductive success and be fatal to chicks in some species (Fry 1987).

Sea turtles eat tar and plastic sheeting, and A. Carr (1987) stated that "there is massive evidence that entrapment, entanglement, and impaction of the alimentary canal by ingested plastics have become major threats to sea turtle survival."

The growing tide of solid wastes has direct economic implications, as well. Plastics, tar, and other solids accumulate on recreational beaches, resulting in aesthetic degradation that often must be offset by expensive beach cleaning programs. Los Angeles County beachgoers leave behind roughly 75 tons of trash each week (CEE 1987), and the annual cost of cleaning a few kilometers of beach in Bermuda was reportedly $100,000 a decade ago (Carpenter 1978). Small vessels are damaged in collisions with large pieces of debris, and propellers and engine cooling intakes are fouled by fragments of net and plastic sheeting. Fishermen suffer losses when their nets become snagged on large pieces of sunken debris.

Plastics and other solid wastes are the subject of various international agreements such as the London Dumping Convention and the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78). MARPOL 73/78 is also concerned with petroleum and, therefore, tar pollution. Various regional agreements (the Oslo, Paris, and Helsinki conventions, for example, and the UNEP Regional Seas Programme) seek to reduce plastic, petroleum, and other marine pollutants.

Persistent debris in the marine environment has received increasing international attention in the 1980s. The international Workshop on the Fate and Impact of Marine Debris held in November, 1984, emphasized the North Pacific. The *Proceedings* from that conference provided the first major overview of the subject (Shomura and Yoshida 1985). Plastic in the marine environment was a major theme of the Sixth International Ocean Disposal Symposium in April, 1986. Several papers focusing on sources, quantities, and distribution of plastic debris, its impacts on marine animals, and legal approaches to reducing plastic pollution comprise a special issue of the *Marine Pollution Bulletin* (Wolfe 1987). A report to the United States Environmental Protection Agency by the Center for Environmental Education, *Plastics in the Ocean: More Than a Litter Problem*, reviews information on plastic debris along all United States coasts (CEE 1987a). A more recent report provides a brief summary of information on the sources, types, and effects of marine debris; an excellent review of current federal, state, and private mitigation efforts; and an assessment of degradable technologies (NOAA 1988). We recommend these publications as the most complete general reviews of the subject.

Objectives of This Study

Although there is a general understanding of sources, types, and effects of persistent marine debris, and more detailed information is available for a few areas such as the North Pacific, existing information on the North Sea, northwest Atlantic, Wider Caribbean Area, and west coast of Baja California had not been summarized prior to this report. The purpose of this study is to fill that void by:

- o obtaining published and unpublished information on the sources, amounts, types, and effects of marine debris in these areas;
- o identifying programs being undertaken to define and mitigate problems caused by marine debris.

This project is also intended, primarily through this report, to make relevant conservation organizations and governmental agencies in these study areas aware of international concern about marine debris problems and steps being taken by the United States and others to address them.

Staffing of This Project

This project and report for the Marine Mammal Commission and the National Ocean Pollution Program Office are in fulfillment of contract MM3309598-5 between the Marine Mammal Commission and Burr Heneman.

Elements of the project were completed under a subcontract with the Center for Environmental Education (CEE). Allen Blume of CEE conducted the main literature searches, coordinated the mailed survey, and made most of the follow-up contacts for the North Sea and northwest Atlantic study areas. Suzanne Iudicello assembled information on international agreements relating to marine debris and drafted an early version of Chapter VII. Natasha Atkins directed the efforts of CEE.

Burr Heneman conducted supplemental literature searches, made the follow-up contacts for the Wider Caribbean Area and Baja California and supplemental contacts in the North Sea and northwest Atlantic, made personal observations in the Wider Caribbean and Baja California study areas, and wrote the report.

O'Brien Heneman edited the report. Sarah Griffin prepared the study area maps.

I. METHODOLOGY

The Scope of Work for this project sought information concerning the sources, fates, and effects of nondegradable marine debris in the North Sea, the Northwest Atlantic, the Gulf of Mexico and Caribbean Sea, and the west coast of Baja California. Another objective was to report on programs related to marine debris in those areas. Consequently, our first steps included defining the study areas, deciding what types of non degradable marine debris to consider, and developing an approach that would assure our finding the relevant literature and reaching the appropriate academic, industry, government, and environmental representatives.

Definition of Study Areas

We defined our North Sea study area, quite traditionally, as the shallow, continental shelf largely encircled by England, Scotland (including the Orkney and Shetland islands), Norway, Sweden, Denmark, the Federal Republic of Germany, the Netherlands, Belgium, and France. We included the English Channel to the westerly extensions of Cornwall and Brittany, and the Skagerrak between Denmark, Norway, and southwestern Sweden. We included some information for the west coasts of England and Scotland when it was difficult or impossible to separate it from data relevant only to their North Sea coasts.

Our definition of the Northwest Atlantic was somewhat more arbitrary. We included the Atlantic coasts of Canada and the United States as far south as Fort Pierce, Florida (as explained below). We also included the Bahama Islands because of their close relationship with the Antilles Current. The eastern boundary of the study zone was not defined but did not include the Azores.

We combined the Caribbean Sea and Gulf of Mexico into one zone, the Wider Caribbean Area, following the example of the United Nations Regional Seas Programme in designating the Caribbean Regional Sea (see Chapter VI). Currents and winds, the sources and fates of marine debris, and existing research programs also argued for our treating these areas that have two names on the map as one study area. We defined the area as the waters virtually enclosed by Venezuela, Columbia, Panama, Costa Rica, Nicaragua, Honduras, Guatemala, Belize, and Mexico on the south and west; by the United States on the north; and by the Lesser Antilles on the east. We included in this area the southeast coast of Florida roughly as far north as Fort Pierce, which is located at the northern terminus of the Straits of Florida, just west of the northern end of the Bahamas. Various factors, such as currents and sources of debris, make the southeast Florida coast an extension of the Wider Caribbean for the purposes of this project.

Our definition of the west coast of Baja California is the area between the Baja/United States border in the north, Cabo San Lucas in the south, and Isla de Guadalupe to the west.

Types of Debris Included in This Study

The term "nondegradable," while absolute by definition, is actually relative when applied to marine debris; even persistent plastic degrades over some period of time. We elected to be liberal in picking a point on the time continuum of degradability in order to include more rather than fewer types of debris. The criteria that we adopted were that the debris be human-manufactured, that it take at least months to degrade in the marine environment, and that it be perceived by at least some interested people as a problem or potential problem. We gave our highest priority to plastic debris in all four study areas, and that emphasis in the literature search, mailed survey, and interviews made it easy for us to develop information on glass and metal debris since data on all three were frequently included in the same sources.

Athough many marine debris studies have focused only on litter and lost or discarded fishing gear, the information we developed indicated that those categories were either irrelevant or too narrow in portions of our four study areas. For instance, we found that oil in its various forms, including tar, overshadowed all other marine pollution concerns in the Wider Caribbean Area. Since tar fit our definition, we gave equal importance to it there. Similarly, hazardous debris (e.g., munitions, containers of toxic chemicals) was a serious concern in portions of the North Sea study area but not mentioned elsewhere.

We sought information on marine debris originating from any source: from maritime sources such as merchant shipping, commercial fishing, recreational boats, naval vessels, cruise ships, and oil drilling platforms; and from land sources such as industry and sewage and solid waste disposal systems. Because of concerns that have emerged in recent years over the effects of lost and discarded fishing gear in the North Pacific, we were especially alert to evidence of that form of debris in all four study areas.

We concerned ourselves with any identifiable economic, aesthetic, and wildlife effects caused by marine debris and with threats to human safety.

Sources of Information

There were three general sources that we relied on for most of our information: literature searches, a mailed survey, and personal contacts by telephone, by correspondence, or in person. In addition, one of the project participants (Heneman) made personal observations on the west coast of Baja and in the Wider Caribbean Area.

1. Literature Searches

We conducted multilingual keyword and subject literature searches in the United States through the Library of Congress and the libraries of the departments of Commerce (including the National Marine Fisheries Service and the National Technical Information Service), the Interior (including the Fish and Wildlife Service, Transportation (including the U.S. Coast Guard), State, and Agriculture. Additional literature searches were conducted at the International Monetary Fund, the Organization of American States, the United Nations Food and Agriculture Organization, the United Nations Environment Programme, the International Maritime Organization, and the International Development Organization. Finally, we conducted literature searches through the databases of the DIALOG and INFOLINE information systems.

Keywords and subjects used included plastics, plastic wastes, plastic waste disposal, plastic waste management, marine biology, marine ecology, marine debris, marine pollution, hazardous materials, hazardous wastes, oil pollution, tar, pelagic tar, nondegradable waste, marine mammals, marine fisheries, waste disposal in the ocean, water pollution, solid wastes, environmental monitoring, marine protection, coastal zone management, and coastal research.

Our literature searches were for material published since 1970.

Finally, important additional sources of titles were the reference sections of publications already known to us or acquired through the literature searches mentioned above.

Most of the non-English language literature we found was also available in English translation or had English summaries or abstracts. We translated several key articles or had them translated for us (Chaussepied 1983, 1985; FRG 1985; Moxnes 1985).

2. Mail Survey

Following the literature searches, a one-page survey was sent to 368 individuals or organizations representing governments, industry, the academic community, and environmental organizations. This list was compiled with the help of personal contacts, the Library of Congress, and the embassies of relevant nations in Washington, D.C. The list also included participants at relevant conferences and representatives to the Intergovernmental Oceanographic Commission and the United Nations Environment Programme.

The survey (see Appendix A) asked for the name, address, and telephone number of respondents and of people the respondents would recommend that we contact. It also provided space for very short answers to a few questions on the respondents' knowledge of marine debris in their areas. Our intent was to encourage returns by using a short questionnaire that could be filled out in a few minutes. The main purpose of the survey was to give us contacts to follow up with in the next stage of the project. The survey was not intended to develop complete information on marine debris.

Included with the mailed surveys were: a cover letter, a background article on plastic marine debris from *Natural History* magazine, and a summary of marine debris activity in the United States.

One response to the survey (Mauvais) was not in English. We translated that personal communication.

3. Personal Contacts

We had personal contact by correspondence, by telephone, or in person with at least 91 individuals. Most of these were respondents to the survey or people whose names were given to us by survey respondents. The rest were people known to the project participants or investigators selected from the literature search.

4. Personal Observations

Finally, Heneman made personal observations of marine debris in the Wider Caribbean Area and on the west coast of Baja California on several occasions. He visited Isla San Martin (northern Baja California) and Isla Cedros, Islas San Benito, and the Laguna San Ignacio area (all in central Baja California) in January 1983, February 1985, and March 1987. He also made spot checks of approximately 75 kilometers of beach between Todos Santos and Cabo San Lucas (southern Baja California) in March 1984. He was specifically concerned with marine debris only on the 1987 visit.

Heneman also visited five islands in the Lesser Antilles in May 1987: Barbuda, Antigua, Guadeloupe, Dominica, and St. Lucia. He was able to visit the leeward (western) coasts of all islands. He was able to visit the windward (eastern) coasts on Barbuda, Dominica, and St. Lucia. He also interviewed residents who represented government, the tourist industry, and environmental organizations.

Finally, Heneman made beach surveys and interviewed government and tourist industry representatives on the Caribbean, Gulf of Mexico, and Bay of Campeche coasts of the Yucatan Peninsula in January 1988.

II. RESULTS

We developed useful information for this project from the four sources described in the previous chapter: literature searches, mailed survey, personal contacts, and personal observations.

Literature Searches

We reviewed approximately 300 popular and scientific articles, reports, and other documents, which are roughly categorized in the following table.

Table 1. Analysis of literature searches.

Number, by study area:	
North Sea	73
Northwest Atlantic	36
Wider Caribbean Area	27
Baja California	0
Non-study Area	15
Number, by type of debris:	
Ocean- and land-generated litter, all kinds	88
Plastic pellets	68
Fishing gear	80
Pelagic tar, tar on beaches	54
Number, by type of effect:	
Ingestion	71
Entanglement (including ships, divers)	65
Aesthetic, effects on tourism	62

The single most useful source was the journal *Marine Pollution Bulletin*. A wide variety of other scientific journals contributed one or more articles. Governmental and international agency documents were also very important sources. Popular articles rarely had information that was not covered elsewhere.

Mailed Survey

Eighty-four of 368 surveys (22.8%) were returned to us. The following table gives a break-down by study area.

Table 2. Analysis of 84 survey returns by study area.

Area	Number	% of surveys mailed	% of surveys returned
North Sea	31	8.4	36.9
Northwest Atlantic	18	4.9	21.4
Wider Caribbean	19	5.2	22.6
Baja California	5	1.3	6.0
Non-study area	11	3.0	13.1
Total	84	22.8	100

Personal Contacts

We interviewed 91 individuals, most of whom were identified through the survey. The following table gives a breakdown by study area.

Table 3. Analysis of 91 interviews by study area.

Area	Number	% of total
North Sea	20	22.0
Northwest Atlantic	17	18.7
Wider Caribbean Area	29	31.8
Baja California	7	7.7
Non-study area	18	19.8
Total	91	100

Personal Observations

Personal observations provided useful, general impressions of five areas on the west coast of Baja California on four occasions between 1983 and 1987. They provided more detailed impressions as well as useful information from contacts on the five Lesser Antilles islands visited in 1987. Finally, a 1988 visit to the Yucatan Peninsula yielded, besides valuable interviews, the opportunity for debris surveys that provided quantitative information from the Caribbean, Gulf of Mexico, and Bay of Campeche coasts on amounts, types and sources of debris. The personal observations, as well as the interviews occasioned by these site visits, were particularly useful since they were made in study areas or sub-areas for which we had minimal information from other sources.

III. DISCUSSION: THE NORTH SEA AREA

Description

The North Sea is a shallow extension of the North Atlantic Ocean defined by the coasts of several of the most densely populated and industrialized nations in the world: the United Kingdom, Norway, Sweden, Denmark, the Federal Republic of Germany, the Netherlands, Belgium, and France.

The 54,000 km^3 of water in the North Sea is renewed roughly every two to three years by the 20,000 km^3 of relatively clean Atlantic Ocean water flowing in between Scotland and Norway. The English Channel (2,000 km^3/year) and the Baltic Sea (less than 1,000 km^3/year) provide much smaller in-flows. Fresh-water in-flow from rivers is estimated at only 125 km^3/year. The entire area is one of strong winds and currents and great tide ranges (Weichart 1973; UNEP 1982).

Types, Quantities, Sources, and Distribution of Marine Debris

We have organized this discussion by major types of debris we encountered references to: general land- and ocean-source litter, fishing gear, hazardous debris, and tar.

1. General Land- and Ocean-source Litter

The most information we found on North Sea marine debris from any single country came from the **United Kingdom**. In one of the earliest studies for any of the four study areas, Scott (1972) noted rapidly increasing amounts of plastic litter on two remote beaches he censused in Scotland in 1971. Detergent, bleach, oil, and cosmetic containers, plastic sheeting, and buckets made up nearly 80% of the roughly 40 plastic items he found per 50 yards of beach.

Scott (1975) returned to one of the sites in 1974 and found 213 plastic items/50 yards, a 500% increase. He also surveyed several beaches on other islands and found a wide range in the amount of debris, with the most on coasts unprotected from the prevailing winds. The winds made it difficult for him to assess the amount of litter in some areas since significant quantities had been blown inland. For example, he found 22 bleach and detergent containers in one area of 20 square yards some 2,000 feet from the coast.

The types of plastic litter Scott found and its location on and behind inaccessible beaches on windward coasts led him to conclude that "most of the plastic litter found on the seashore is sea-borne and wind-driven. Its location and nature suggests that it comes predominantly from shipping and not from local inhabitants or visitors."

T.R. Dixon (1978) found a similar pattern of debris on the Scottish coast in 1977 and also concluded that ships were the source of most of it. He

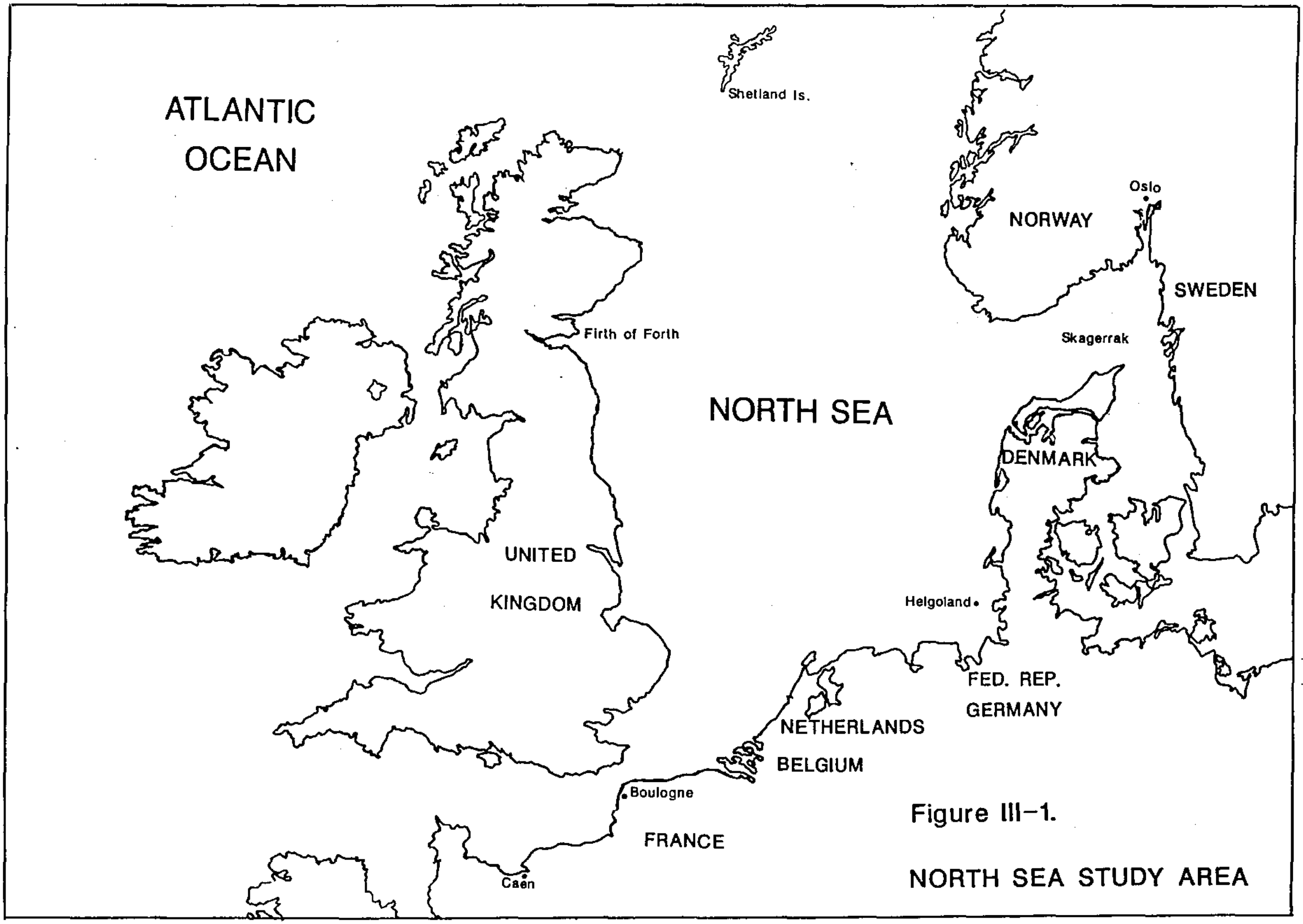

Figure III-1.

NORTH SEA STUDY AREA

found that plastics accounted for 32% of the debris volume, glass 12%, and metal 8%.

The experience of Caulton *et al.* (1987) inside Scotland's Firth of Forth was quite different from what Scott and Dixon found on exposed outer coasts. Most of the litter was of local origin, from beach-goers or a nearby coastal landfill, and there was little debris that could be attributed to shipping.

T.R. Dixon and the Keep Britain Tidy Group, the United Kingdom's litter abatement agency, have been responsible for the longest-term and most extensive marine debris research in the North Sea area. Dixon and Cooke (1977) began observations at Sandwich Bay in Kent in 1973, and that site is still being surveyed monthly as a reference monitoring location (Keep Britain Tidy 1986). Since 1973, there has been a marked increase in the amounts of litter there.

From 1973 to 1976, Dixon and Cooke (1977) made 116 surveys of three 1.6 km sections of beach and collected 2950 containers of which 1134 (38%) were plastic, 960 (33%) were glass, 739 (25%) were metal, and 117 (4%) were paper. Nearly half of the plastic containers were for lavatory and household cleaning agents, with mineral water, dairy product, and cosmetic containers contributing lesser percentages (Table III-1). Glass was probably under-represented in these figures because of breakage.

T.R. Dixon also reported on the geographic origins of the plastic containers (Table III-2). Although production sites can often be different from marketing areas, Dixon concluded there was enough evidence to indicate that waste disposal by ships accounted for a major portion of the beach litter.

T.J. Dixon and T.R. Dixon (1983) also conducted a pilot series of at-sea debris surveys in the North Sea in 1979 and 1980 that revealed widespread distribution of all litter types. Plastic was seen in more survey areas than any other debris type; nylon netting and rope was the least widespread.

Dixon and Dixon (1981b) commented on the pros and cons of various marine debris estimating techniques: estimating types and quantities of debris generated by ships and pleasure craft (see page III-5, Golchert), at-sea observations of floating debris, and beach surveys. Drawbacks of the first approach include the large number of assumptions and extrapolations that must be made about the numbers of ships and crew members in a given area, how much litter is created by them, and how much of that is dumped from the vessels. At-sea observations are costly, depend on suitable weather and sea conditions, and miss any items that do not float. The Dixons conclude that beach surveys, despite some negatives, provide the best approach. Beaches can be readily surveyed; litter accumulates, providing reasonable sample sizes; and at least some nonfloating debris can be expected to wash up and get counted. About the Keep Britain Tidy Group's program, the Dixons (1981b) write,

> "The aim of this research, with special reference to the British Isles, is to provide systematic data showing qualitatively and quantitatively the

nature and scope of the problem...The immediate objectives of the programme are: (1) The development of standardized field survey techniques and analytical methods for the surveillance of marine litter by beach surveys; (2) The identification of major trends in the composition, distribution and origin of litter occurring in the coastal and oceanic waters of Western Europe."

T.R. Dixon and the Keep Britain Tidy Group greatly expanded their beach clean-up and survey program in 1979 with a nationwide volunteer effort, the National Shoreline Refuse Survey, co-sponsored by *The Sunday Times*. In reporting the results of that survey (*The Sunday Times* 1979), the newspaper wrote, "Britain's coastline is filthy, dangerous and getting worse with every tide." Of 19,000 containers collected from 700 sites, 42% were plastic, a result similar to Dixon's 1973-1976 study. More of the plastic and metal containers (Table III-2) were of British origin, reflecting debris collected on Britain's west coast, away from the international flavor of the Channel coast.

Following the 1981 National Shoreline Refuse Survey, *The Sunday Times* (1981) reported on a new plague on British beaches: plastic tampon applicators, 20,000 of them from just 20 sites in Norfolk. They were assumed to have passed through sewage treatment plant filters in the United Kingdom.

Over the past several years, the Dixons and the Keep Britain Tidy Group have developed standardized procedures and forms for conducting beach litter surveys. Information is collected on numbers of items, weight, material, color, age, original container contents, country of origin, and markings. Large numbers of volunteers have made nationwide data collection possible, greatly increasing the value of the National Shoreline Refuse Survey.

The Dixons and others have applied these techniques elsewhere in the North Sea area. The Dixons (1981b) reported on beach surveys on the Cherbourg Peninsula, France, and in West Jutland, Denmark, in 1978 and 1979. They found a wide variety of litter types, as in the United Kingdom, the main constituents of which were "containers of all types and sizes, polyethylene sheeting, rope, wire, fibreboard, paperboard, light bulbs, fishing gear, out-dated pyrotechnics, packaged hazardous goods and occasionally partly used drugs." Containers made of plastic, glass, metal, or wood made up 80% of the beach litter by weight, with 44% of this total plastic, primarily bottles. They found plastics in 94% of transects in France and Denmark. The types of containers and their countries of origin for these surveys and two in the United Kingdom are summarized in tables III-1 and III-2.

Dixon and Dixon also analyzed the age of some 2184 containers from these four studies, finding that 62% were less than two years old and 85% less than four years old. They also found that a high proportion of older plastic containers and of those collected higher on the beach or behind the beach were fragmented. They concluded that some plastics, especially those made of high-density polyethylene, are photodegradable out of water and that fragmentation occurs within about two years of exposure to sun.

Table III-1. Original contents of plastic containers by percent of sample (from Dixon and Dixon 1981b).

	Sandwich Bay, Kent 1973-1976	Cherbourg Peninsula 1978	West Jutland 1979	U.K. National Survey 1978-1979
Sample size	1134	1378	1259	8381
Lavatory and household cleaners	46.8	33.5	34.8	23.6
Mineral waters	9.4	9.1	5.1	2.2
Dairy products (excluding milk)	3.8	5.1	3.1	7.2
Cosmetics & toiletries	6.8	4.3	3.6	3.1
Milk	4.5	8.5	7.0	3.6
Wine	5.5	7.5	2.3	0.3
Other & unidentified	23.2	32.2	44.3	60.3
Total	100	100	100	100

Table III-2. Geographic origin of identifiable containers (from Dixon and Dixon 1981b).

Sample size	989*	1619	2079	6410†
United Kingdom	28.6	36.3	51.5	71.0
France	24.2	34.7	10.4	10.5
Benelux	21.5	8.8	8.3	5.1
Fed. Rep. of Germany	12.6	7.7	8.5	4.4
Other Europe (not USSR)	10.6	6.6	12.2	5.9
Other	2.5	5.9	9.1	3.2
Total	100	100	100	100

*Plastic containers only.
†Plastic and metal containers only.

The Keep Britain Tidy Group, in an effort to identify sources of marine litter, interviewed crews of merchant ships and recreational boaters in 1977 and 1978 in south Wales (outside of the North Sea, but relevant to the United Kingdom's North Sea coast). Nearly 20% of the merchant ships dumped engine room and cargo wastes overboard. Only 13.5% used port receiving facilities for disposal of domestic trash. In contrast, over 75% of small boat and yacht owners said they diposed of trash on shore. It was not determined, however, what disposal methods another 20% used (KBTG newsletter).

Golchert (1986) attempted the difficult task of estimating the amount of litter dumped by ships into the North Sea each year. He calculated that (excluding food wastes, dunnage, and litter from pleasure craft and fishing vessels) ships put 45,000 m^3 of litter weighing 9,000 metric tons and composed of 90,000,000 pieces into the North Sea environment each year. Using his data for the composition of this debris, the total should include 22 million pieces of plastic debris, 34 million of glass, and 6 million of metal.

The potential problem of persistent marine debris was brought before the Paris Commission in 1978 after Denmark, the Netherlands, and other governments reported their concerns. (See Chapter VII for a discussion of the Paris Convention.) The Commission "recognized that the matter was of considerable importance and that the waste concerned was covered by the 'black list' of the Convention. The Commission therefore decided that Signatories and Contracting Parties should complete a questionnaire, which had been devised by France, so that the matter could be examined in further detail by [the Technical Working Group]." The issue next came before the Commission in 1985-1986, when the Federal Republic of Germany and the United Kingdom reported on coastal litter surveys that indicated the vast majority of the debris was being discarded from ships (Hayward pers. comm.).

The **Federal Republic of Germany** (FRG 1986b), at this and other forums, has reported that its North Sea coast is heavily polluted by litter from ships. Results of three studies conducted in that country are summarized in Table III-3. On Helgoland, a small island in the German Bight, a 60 meter site on the southwest coast was surveyed 106 times. At Scharhorn, on the mainland near the mouth of the Elbe River, 54 surveys were conducted along a 100 meter stretch of shoreline. At Norderoogsand, a sand bank on the seaward side of the North Frisian islands, six counts were made at a 550 m site. All the surveys were conducted in 1983 and 1984.

Table III-3. Composition of debris from 3 sites in the Federal Republic of Germany by percentage of items and percentage of weight (from FRG 1986b).

	Helgoland		Scharhorn		Norderoogsand	
	items	weight	items	weight	items	weight
Total debris	8539	1360 kg	3306	898 kg	124	328 kg
Plastic	75%	12%	55%	12%	44%	13%
Glass	3	4	14	12	16	5
Metal	4	10	2	3	6	18
Fishing gear	1	6	2	7	6	11
Wood	12	65	14	62	23	53
Other	5	3	13	4	5	0
Total	100	100	100	100	100	100

The largest amounts of debris were found on the southern coast of Helgoland, the site closest to major shipping lanes and most exposed to prevailing local currents and winds. Helgoland also had the highest percentage of plastic items, and Norderoogsand, the site most remote from shipping lanes, the lowest. Plastics as a percentage of weight, however, were similar at the three locations. Fishing gear was a minor debris component at all three sites.

Roughly 90% of the identifiable debris at Helgoland was manufactured in six nations bordering the North Sea, with the bulk of that from Germany (39.5%), the United Kingdom (17.8%), the Netherlands (16.5%), Denmark (9.6%), and France (3.5%). The remaining 10% originated in 20 other countries.

In **France**, largely because of aesthetic considerations and the costs of debris removal at tourist beaches, the Institut Francais de Recherche Pour l'Exploitation de la Mer carried out research on beach pollution for the French Ministry of the Environment (Chaussepied 1985). The 1982 study, including sites on the English Channel, Atlantic, and Mediterranean coasts, was intended to develop a methodology for evaluating marine debris on beaches. Chaussepied considered such factors as number of pieces, weight, volume, type, material, and geographic origin.

He chose two very different sites in the English Channel: one just south of Boulogne, an exposed location very near the Strait of Dover, and the other at the more protected River Orne estuary, near Caen, in the Bay of the Seine. The first site would seem to have the greatest possible exposure to shipping lanes and prevailing winds and currents. The second site, while more removed from the Channel, was in a bay that received the flows of the Seine, the Orne, and several other rivers.

At the Boulogne location, in 221 surveys, 0.4 kg of debris/linear meter of beach was found of which 47.5% was plastic. At the Caen site, in 265 surveys, 1.8 kg/linear meter beach of which only 23% was plastic. The weights of both glass and metal debris were much higher at the Caen site. The differing results for country of origin were similar to those for the exposed Scottish coast (Scott 1972, 1975; Dixon 1978) and the Firth of Forth (Caulton *et al.* 1987). At Caen, 94% of the identifiable debris was of French origin; at Boulogne, 50% was French, 23% British, and the other 27% was from 22 other countries. Chaussepied concluded that most of the debris not of French origin was from ships, including fishing vessels.

The amounts of debris collected at the other French sites were similar to what was found at the Caen and Boulogne beaches, slightly less in the Mediterranean, slightly more on the Atlantic coast. Composition of the debris was similar in all three areas although, in regard to country of origin, Spain was in second place behind France at the Atlantic sites, and Italy was in second place at the Mediterranean sites.

Chaussepied (1983) considered tar to be marine debris and collected data on it as well (see page III-10).

The studies described above are the most detailed that we found for the North Sea area. There are other reports of interest, however, including one of particular note from **Denmark**. The Ministry of the Environment reports that, since the disposal of all wastes was prohibited in the Baltic Sea (see the discussion of the Helsinki Convention, page VII-11), the North Sea entrance to the Baltic and the adjacent Danish coast has become a "trouble spot" (Skou pers. comm.). Ships apparently dispose of trash just before entering or after leaving the Baltic.

In the **Netherlands**, Carpenter (1978) mentioned Van Banning's having found large numbers of man-made articles (packing materials, bottles, metal drums) on the sea floor off the Netherlands. Van Franeker (1983) found all types of plastic debris on a Dutch beach (pellets, sheeting, cups, bottles, nets, toys). Two respondents to our survey, Kuiper (pers. comm.) and Dankers (pers. comm.), reported problem levels of plastic debris (bottles, crates, bags, miscellaneous litter), netting, glass bottles, and tar. Both attribute the debris to ships.

In **Norway**, the State Pollution Control Authority reports problem levels of debris, predominantly plastic, on recreational beaches and attributes it primarily to shipping and fishing vessels, but to pleasure craft and household waste as well (Koefoed pers. comm.).

The Norwegian Institute for Aquatic Research sent a questionnaire to coastal towns, community leaders, and outdoors organizations asking for quantitative assessments (Moxnes pers. comm.). Responses (57%) indicated annual accumulations of debris varied widely among areas surveyed, from 0.1 to 6.0 cubic meters/100 meters of beach, with most areas reporting 0.3-2.0 cubic meters/100 meters/year. Interestingly, of the three areas reporting the highest levels, 4.0-6.0 cubic meters/100 meters/year, two were near major cities (Oslo and Trondheim), and the third was on the remote northern coast (Trondheim and the north coast site are outside our North Sea study area). Most of the debris was attributed to shipping and fishing vessels, with household litter escaping from landfills, and recreational boaters and hunters considered responsible for significant contributions in certain areas. Household wastes and fishing gear were combined in the analysis, and that category varied from 30-80% of the total volume.

2. Lost and Discarded Fishing Gear

One report on fishing gear debris in Scotland is interesting because it was unusual in the North Sea area literature. Bourne (1977), who found 48 pieces of netting, at least one piece as large as 25 square meters, on 250 meters of beach, wrote that "small and large fragments of net are now becoming one of the major components of the flotsam washed up along...the east coat of Scotland." More recently, Bourne wrote (letter to Arnaudo, 1986) that "stray fragments of fishing net sometimes figure prominently amongst the appalling array of rubbish that washes up when we get onshore winds."

T.R. Dixon has observed that it is unusual to find nets washed ashore and that fishing nets and debris are a minor part of the United Kingdom's, and probably Europe's, marine debris problem (Arnaudo, pers. comm.).

Van Franeker (1983, 1985), research on the German North Sea coast (FRG 1986b; Schrey and Vauk 1987; Vauk and Schrey 1987), and personal communications from Moxnes, Kuiper, and Dankers all allude to the presence of fishing gear, particularly net fragments. None of them suggests that such debris is a major component of marine debris by volume, weight, or number of items. In fact, several of these investigators indicate that fishing gear is a minor element.

We found no reports of efforts to quantify lost and discarded nets and other fishing gear entering the North Sea environment. Major sources appear to be both trawl and gill net fisheries. Bourne (1977) says many net fragments also come from lobster pots made of nylon netting.

3. Hazardous Debris

In the 1980s, the attention of the Dixons and the Keep Britain Tidy Group has increasingly shifted to this category of marine debris in the **United Kingdom.** In the literature, an early warning of this problem was T.R. Dixon's report (1981a) on three 1980 incidents in southern England: "a metre long yellow canister found on the shore" (a 12-year old boy lost a finger when it exploded), a syringe and three Atropine capsules, and four dozen packets of phospine (a toxic and inflammable fumigant).

Dixon and Dixon (1981a) reported on two large-scale series of hazardous debris incidents in which 3,500 packages of chemicals, at least 956 of which contained hazardous substances, washed ashore in southern England over a six-month period. Much of this material is known to have come from the *Aeolian Sky*, which collided with another vessel and sank in the English Channel in November 1979. As much as half of the debris may have been deck cargo lost by another vessel, the *Tozeur*, in a Channel storm in late January 1980. Perhaps the most hazardous of the 956 identified items were 32 canisters of arsenic trichloride.

These events led to a 1982-1983 nationwide study by the Keep Britain Tidy Group. They surveyed all local coastal authorities as to stranded packages known to contain dangerous substances and packages which, because of lost or inadequate labels, were handled as dangerous. Dixon and Dixon (1986) reported on 254 packages of chemicals found in the 12-month period, of which 131 were known to be dangerous, 42 contained petroleum products judged nonhazardous, 36 with inadequate markings were treated as dangerous, and 45 had not been identified before reports were submitted. The most hazardous chemicals included ether and acetaldehyde. Other packages contained butane, ethylene oxide, methanol, phosphorus, benzyl chloride, hydrochloric acid, phosporic acid, sulfuric acid, and sodium hydroxide, among other substances.

Another large category of hazardous materials reported in the same study included munitions and pyrotechnics (Keep Britain Tidy Group, 1985). A total of 2,204 items were found, mostly ship distress signals and military smoke and flame generating devices. Of the items identified, 28% were of milirary origin.

T.R. Dixon (1987) reported eight hazardous debris incidents in 1986 involving 26 drums of hydrochloric acid, 21 drums of sodium nitrate and sodium nitrite, three mines (two of which exploded), two boxes of detonators, 300 anti-invasion mine fuses, and 80 military pyrotechnics.

The National Agency of Environmental Protection in **Denmark** had about 110 reports of "pollution incidents, other than pollution with oil" of which about 95% involved gas ammunition caught by fishermen, although this is primarily a Baltic Sea problem (Skou pers. comm.).

Similarly, **Sweden** reports mines and mustard gas bombs in fishing nets as its most important marine debris problem (Norby pers. comm.). Again, this problem occurs primarily in the Baltic Sea.

4. Tar

UNEP (1982) estimates that 1.4 million metric tons of oil enter the North Sea annually, of which 575,000 metric tons are from urban run-off and 300,000 metric tons are attributable to shipping and terminal operations.

Weichart (1973) gives a figure of 50,000-100,000 metric tons/year from ships and reports that, for "the past decade, in the bathing season at North Sea German beaches, light to middle oil pollution was ascertained on 50 percent of all days and heavy oil pollution was ascertained on 34 percent of all days."

In 1975, the Norwegian Institute of Marine Research took neuston net samples from 24 transects distributed along the entire coast of Norway (Smith 1976). Highest average tar concentrations (0.32 mg/m^2) were found in 41 samples taken in the Skagerrak, but even those were considered low compared to other northern ocean areas that had been investigated.

Chaussepied (1983) developed a methodology for collecting and analyzing tar balls which he applied on the English Channel, Atlantic, and Mediterranean coasts of **France** as well as in Africa and Indonesia. He concluded that amounts of tar on beaches correlates with levels of tanker traffic and proximity to tanker routes. In 1982, he found an average of 30 gm/linear meter of beach at his English Channel sites, which compared favorably with most other locations he investigated. His Mediterranean sites were slightly lower (20 gm/linear meter), but the Atlantic sites had a much higher average (170 gm/linear meter). (His sites in the Bay of Jakarta averaged 800 gm/linear meter. The northern Gulf of Guinea easily topped the list with 9,100 gm/linear meter.)

The only other reference to tar pollution we found was by Kuiper (pers. comm.), who mentioned it, along with all other types of debris, as a problem on beaches in the Netherlands.

Effects of Marine Debris

This discussion is organized into four sections, reflecting the major categories of effects we enountered in the North Sea area: aesthetic effects, economic effects, hazards to humans, and hazards to wildlife.

1. Aesthetic Effects

This category of impact is implicit in most of the concern expressed about marine debris in the North Sea area. Occasional comments addressed the issue directly. As Dixon and Dixon (1981b) put it, "The most obvious impact is the aesthetic degradation of coastal amenities, particularly leisure and recreational beaches." In the United Kingdom, the very name, Keep Britain Tidy Group, reflects aesthetic concern. Similarly, Weichart (1973) found that, besides oil residues, "other waste material from shipping is also washed up sporadically on the beaches in such large quantities that seaside amenities are seriously affected."

The unsightliness of litter and tar is at the heart of the World Tourism Organization's involvement with the marine debris issue (Shackleford pers. comm.). In spite of a German poll in which most beachgoer-respondents said aesthetics was a minor concern, the investigators assumed that debris impaired recreational enjoyment, even if only subconsciously (FRG 1985).

Perhaps the best demonstration of aesthetic concern is the widespread practice of beach clean-up at recreational beaches (see below).

2. Economic Effects

We became aware of three classifications of economic effects: costs of debris removal (including hazardous packages), damage to property, and lost fishery catches.

- Debris removal - Mention of the necessity of general beach clean-up and attendant costs was a universal refrain among those commenting on effects of marine debris in the North Sea area. Staff of the Paris Commission reported that by 1985, the Commission recognized that, in many areas, plastic debris was a growing nuisance that interfered with legitimate uses such as recreation (Hayward pers. comm.).

The Danish National Agency of Environmental Protection provided the only direct cost figures. Skou (pers. comm.) said that, in 1985, 16 local governments sharing 337 km of coast spent nearly $200,000 cleaning their beaches, or roughly $600/km.

Chaussepied (1985) reported that plastic debris and tar "has an important impact on tourism in coastal regions and thus obligates municipalities in these areas to clean these beaches at great expense." He and Mauvais (pers. comm.) agreed that their research was a direct result of the clean-up costs.

Moxnes (1985) in Norway and Kuiper (pers. comm.) in the Netherlands confirm the presence of clean-up programs in those countries.

Debris removal is a requirement not only for recreational beaches. Storm-driven high water washes debris onto North Sea dikes and dunes in amounts heavy enough to smother vegetation that prevents erosion. An annual average of 60,000 m^3 of debris, one-third of it human-generated, is removed at "considerable" cost along a 100 km section of coast in Schleswig-Holstein (FRG 1985).

One type of debris clearing in the North Sea area requires special mention. Hazardous debris handling has special safety requirements that add to the cost of this problem. For instance, following the *Aeolian Sky* incident (Dixon and Dixon 1981a), clearing operations of local authorities included: establishing emergency control centers in each county to collect and publicize information on the chemical packages (notices at beach entrances, informing schools); systematic beach searches by police, coast guard, and others (suspected chemical packages were handled by specially trained people in gas suits); identification of materials; storage of chemical packages after identification.

About half of the packages recovered had no labels with information on contents. These packages were assumed to be potentially hazardous, which meant employing all safety procedures in their subsequent handling. This problem substantially increased the cost of the operations. The total cost of this series of hazardous substance incidents was estimated at over $130,000.

Routine removal of dangerous or potentially dangerous packages from beaches on the Isle of Wight alone have cost roughly $18,000 in one year (Dixon and Dixon 1981b). These expenses generally are not recoverable because the source of the debris usually can not be positively identified.

- Damage to property - Economic effects in this category include damage to or loss of fishing nets that become fouled on large bottom debris, blocking of fish processing plant and vessel water intakes by plastic sheeting, fouling of propellers by plastic sheeting and line, and damage to small craft through collisions with floating debris (Dixon and Dixon 1981b; *The Sunday Times* 1979; Koefoed pers. comm.).

One of the grimmest accounts of boating hazards was published recently in a British yachting mazazine (*Yachting Monthly* 1986). The article included a collection of anecdotes from readers. One yachtsman had fouled his propeller on five of eight North Sea crossings. Other readers had collided with debris ranging from telephone poles to oil drums to a discarded freezer. Various kinds of plastic sheeting received the most blame.

- Lost fishery catches - This economic effect was mentioned only by Norby (pers. comm.) in conjunction with netting of mines and mustard gas bombs and fouling of nets on wrecks and large pieces of bottom debris in Sweden.

The issue of ghost nets' causing economic loss to fishermen by continuing to catch fish was addressed indirectly by one British report (Ministry of Agriculture, Fisheries and Food undated). It referred to two British studies of ghost nets, both of which concluded that the nets do not continue to fish indefinitely. The report indicated that currents usually cause nets to ball up, thereby reducing their ability to fish, and that nets, especially in shallow water, soon become fouled with weeds or weighted down with crabs.

3. Hazards to Humans

This catergory included two types of problems: hazards from toxic chemicals packages and explosives, and injuries caused by general debris such as glass and metal.

• Hazardous debris - The Keep Britain Tidy Group and T.R. Dixon have recorded details of various incidents in which hazardous debris actually harmed people or in which people received medical examinations because of potential exposure to toxic chemicals on beaches. In 1976, 43 people were taken to the hospital for examinations after they breathed ethyl mercaptan fumes (Dixon and Dixon 1981b). During the *Aeolian Sky* incident, 20 people received precautionary medical examinations after they came in contact with open chemical packages (Dixon and Dixon 1981a). In another 1980 incident, a 12-year old boy lost one finger and suffered damage to two others after a metal canister he found on the beach exploded.

In 1985, the Keep Britain Tidy Group said it knew of at least 100 adults and children who had received check-ups or treatment in similar cases since 1976. In one instance, "the contents of a drum of inflammable liquid exploded close enough to a beach user to singe the fur of her dog" (KBTG 1985).

T.R. Dixon (1987) reports on two cases in 1986 in which mines or bombs exploded. In one, the crew of a fishing vessel escaped injury although the explosion lifted their vessel "more than 4 m out of the water" according to witnesses. A dredger was damaged and a crewman injured in the other incident.

Finally, Norby (pers. comm.) told us that human injuries were one of the main problems resulting when net fishermen "caught" mines and mustard gas bombs.

• General debris - Injuries from miscellaneous debris was reported infrequently, but it clearly is a widespread and continuing occurrence. German investigators report a surprising statistic, that "every fifth visitor to the beach complains about injuries caused by broken glass, electric bulbs, fluorescent neon tubes, and nails in washed up pieces of wood" (FRG 1985). *The Sunday Times* learned that "a hospital in Kent reports that discarded aluminum ring-pulls are one of the commonest causes of foot laceration on holiday beaches."

4. Hazards to Wildlife

This discussion is organized into three sub-sections: ghost nets, seabirds, and marine mammals.

• Ghost gill nets - Minor sections of two large reports on net fisheries in the United Kingdom attempted to deal with the question of ghost fishing by lost nets. Both considered only entire set nets that, although lost, still were anchored at at least one point.

Millner (1985) said that the length of time that untended nets will continue to fish depends on such factors as current speed, amount of sea weed, weight of fish in the net, and the presence of crabs. When sea weed is present, nets rapidly become fouled, stop fishing efficiently, and eventually sink. "Nets which have torn free of one anchor soon become wrapped in a tight ball round the remaining anchorage point." If both ends remain anchored, a net will fish until it fills with weed or the weight of fish and crabs attracted by the fish causes it to sink. Millner's report was based on diver observations in waters shallower than 15 m off the Devon coast.

The second report (undated Ministry of Agriculture, Fisheries and Food report) concludes from Millner and a Canadian study (Way 1976; see Chapter IV) that "the presence of strong tidal currents, floating weed and an abundance of crabs in the shallow waters around the British Isles probably mean that lost netting presents little threat to populations of fish, marine mammals or sea birds. In addition, the potential dangers of lost gill nets must be viewed in the context of the large quantities of other synthetic materials, including ropes, fishing lines, trawl netting and industrial and domestic waste that are found in the sea."

• Seabirds - As with marine mammals and sea turtles, seabird interaction with marine debris can entail ingestion or entanglement. Survey respondents in the Netherlands (pers. comms. from Kuiper and Dankers) and Norway (Koefoed pers. comm.) mentioned the general impacts of debris on seabirds without specifying the kind of involvement or levels of mortality.

We found more references to ingestion than entanglement. Day *et al.* (1985), in their review of records of plastic ingestion by marine birds, listed North Sea reports from the 1970s and 1980s involving northern fulmars, greater shear-waters, sooty shearwaters, shags, gannets, skuas, and the Atlantic puffin. Most of these species reportedly had eaten nylon or elastic threads. Some had ingested plastic pellets or foamed plastic.

One of the reports in Day *et al.* was by Parslow and Jefferies (1972) on Atlantic puffins. Four of six birds they examined had eaten elastic threads, two of them enough to form a ball. The authors point out that the threads are potentially injurious since they remain tangled in the crop. The birds, however, had died from causes other than debris ingestion. It was unclear what the source of the rubber threads was.

We found two references to seabird ingestion of debris in the North Sea since the Day *et al.* article. In 1983, Furness (1985) looked at gizzard and proventriculus contents of four seabird species that breed on islands of the north coast of Scotland (St. Kilda, the Hebrides, and the Shetlands). Of 21 British storm petrels, none contained plastic. However, 10 Manx shearwaters averaged 0.4 pellets/bird, 17 Leach's storm petrels averaged 2.9 pellets/bird, and 21 northern fulmars averaged 8 pellets/bird. The maximum number of pellets in one bird (a fulmar) was 40; they were estimated to occupy 15% of the distended volume of the gizzard and 59% of the relaxed volume. Seventy-six percent of the fulmars had ingested pellets. Furness concluded that the levels he found had little effect on body condition.

Van Franeker (1985) examined stomach contents of 65 northern fulmars that washed ashore dead in the Netherlands and 51 collected from two Arctic sites. Ninety-two percent of the Dutch birds had ingested at least one plastic item, while only 80% of the Arctic birds had. The North Sea birds averaged nearly 12 plastic items/bird; the Arctic birds fewer than 5. There was no apparent pattern in what was consumed, although somewhat more than half of the items found for all birds were pellets. Thread, molded plastic, foam, and sheeting made up most of the rest of the ingested material. Based on his own work, on that of Furness, and on a 1976 report by Bourne, Van Franeker concluded that plastic ingestion by fulmars had increased sharply over a period of a few years.

German investigators (FRG 1985) have conducted the only study we found on seabird entanglement in debris. They collected data on 42 debris-related seabird deaths along the mainland and Helgoland coasts between 1978 and 1984. The study was not an attempt to quantify such deaths, but it does provide information on types of debris involved and on species composition of debris-related mortality:

- Great crested grebe (2) - both entangled in fishing line
- Gannet (13) - 5 entangled in net fragments, 7 in some form of line, twine, or rope, 1 in plastic sheeting
- Eider (5) - 5 had 6-pack yokes around their necks, 1 strangled by wire
- Great black-backed and herring gulls (12) - 4 entangled in fishing line, 3 in 6-pack yokes, 2 in plastic sheeting, 2 in thread
- Black-legged kittiwake (4) - 3 entangled in fishing line, 1 in net
- Common murre (6) - 4 encirled by some type of ring, 2 entangled in net fragments.

Ducks and gulls apparently became entangled while searching for food on shore. Murres presumably swim into items such as rings intentionally while feeding and are unable to extricate themselves. Gannets, the species most affected, have two common means of becoming entangled. They dive from considerable height on their prey and presumably sometimes mistake debris for food. They also collect netting and other debris to build their nests, where it can entangle young birds (Bourne letter to Arnaudo).

The FRG report concluded the section on seabird mortality by stating that, in the region of the German Bight, the species included in the survey were "not endangered by the debris burden of the North Sea."

Some of the same investigataors from the Instituts fur Vogelforschung have published a longer (1976-1985) study just of gannets on Helgoland (Shrey and Vauk 1987). In that period, 28 entangled gannets were found either alive, and were freed with human assistance, or dead. Of these, 8 (29%) were entangled in fishing gear or some other type of debris, 6 others (21%) were oiled, and 14 (61%) died of unknown causes.

In 1984 and 1985, Shrey and Vauk observed 313 living gannets visiting Helgoland, 8 of which (2.6%) "were entangled in net but still able to fly." (They point out that the 2.6% figure is probably low since there likely were duplicate counts of some unentangled gannets.) Nonetheless, the authors conclude from both sets of observations that "the species is not currently endangered from the impacts of litter or oil pollution."

- Marine mammals - Observations of marine debris effects on marine mammals in the North Sea seem to be uncommon. Impacts on marine mammals were mentioned as occurring, but not at problem levels, by several investigators (pers. comms. from Dankers and Kuiper in the Netherlands; Mauvais in France; Harwood, Bourne, and T.R. Dixon in the United Kingdom; FRG 1985). Harbor seals and grey seals were the only species identified.

Northridge (1986) reported that numbers of seals in British areas appear to be stable or, in a few areas, increasing. He also speculated as to why bottlenose dolphins and harbor porpoise have disappeared from southern North Sea areas where they were once abundant. His list of possible causes included boat traffic and human disturbance, competition with fisheries, incidental take in nets, and pollution. Marine debris was not on the list as a factor.

Mitigation

Marine debris mitigation in the North Sea has been of two general types:

- efforts to remove debris or reduce its effects after it has entered the marine environment

- efforts to reduce the amount of debris that goes into the North Sea.

After-the-fact mitigation is the rule in most coastal areas, particularly at recreational beaches. Beach clean-up of general litter as a routine practice is done in the United Kingdom (KBTG 1987; Dixon 1981b), France (Mauvais pers. comm.; Chaussepied 1983), the Federal Republic of Germany (Weichart 1973; FRG 1986), the Netherlands (Kuiper pers. comm.), Belgium (Jacques pers. comm.), Denmark (Skou pers. comm.), and Norway (Moxnes 1985). Dixon and Dixon also reported elaborate procedures for handling hazardous materials on beaches (1981a, 1986).

Other efforts to reduce the effects of debris include devices that reduce the propeller and rudder fouling on small boats (*Yachting Monthly* 1986), removal of entangling debris from marine mammals when the animals can be captured (Harwood pers. comm.), and research on the development of photo-degradable and biodegradable plastics (Scott pers. comm.).

The principal North Sea area references to degradability of plastic containers and sheeting as a means to reduce plastic litter are by Professor Gerald Scott of the Department of Chemical Engineering and Applied Chemistry at Aston University, Birmingham, United Kingdom. Scott (pers. comm.) argued that,

> "It is not possible for the polymer industries to continue to argue that plastics with controlled biodegradability are not feasible. The agricultural industry has pioneered the development of plastics with precisely controlled photo-degradability and the packaging industry is now well placed to take advantage of this when the necessary legislation is enacted which will introduce the new era of biodegradable packaging." Scott noted, however, that "the packaging industry has so far shown little interest in this solution to the plastics pollution problem."

Efforts to change behavior to prevent debris from entering the marine environment center on the complex interrelationships between research, education, regulation, and enforcement. The United Kingdom has had the greatest success; the government has adopted an active role in all aspects of the issue in partnership with the private sector. The Department of the Environment, for example, has stated that,

> "The Government consider public education on the problem of marine litter to be a matter of importance. Through our annual grant to the Keep Britain Tidy Group, we support the Group's Marine Litter Research Programme. The Group's litter abatement activities are aimed at educating and persuading the public not to create litter, and lay particular emphasis on education in schools and the involvement of all sectors of the community (local authorities, voluntary groups, industry and commerce) in changing attitudes by raising environmental awareness" (UK 1984).

The Keep Britain Tidy Group sees its research role as contributing to regulation, as well. Among their achievements they say, with justification, that they have "provided researched evidence to help persuade both the UK and foreign Governments of the need to ratify measures for controlling the disposal of waste overboard" (Hardwick pers. comm.).

The Marine Litter Research Programme is viewed as continuing to have a role after regulations such as those in MARPOL Annex V go into effect. Dixon and Dixon (1981b) considered it important that a marine litter surveillance system monitor the effectiveness of regulations.

Many of the Keep Britain Tidy Group's educational programs have focused on children and schools. For example, the Group gave prizes to children in a beach cleaning competition. The winners collected 88 kg in one hour, and a group of 38 children removed a total of 0.6 tons from a single beach (T.R. Dixon 1978). In addition, the Group's National Shoreline Refuse Survey was co-sponsored by *The Sunday Times* and WATCH, that newspaper's environmental club for young people (*The Sunday Times* 1979). Frequent articles on marine debris by one the newspaper's columnists were useful for reaching adults, as well.

Caulton (1987), whose students conducted a 1984 study of litter in Scotland's Firth of Forth, has provided one of the more thoughtful analyses of the role of education combatting litter:

> "Whether or not litter is local or foreign in origin, its dumping appears to be the result of negative motivation - lack of concern for and respect of the environment by the individuals concerned. In the context of maritime litter, much of it stems from the traditional view of the sea as an endless sink. This view has been untenable since the introduction of man-made materials such as plastics...The present state of gross pollution of the maritime zone pinpoints the urgency of an ongoing programme of environmental education, beginning in the primary schools or indeed, earlier at the pre-school stage, continuing through the secondary school and on into the adult population, via the media, to make everyone litter conscious. Thus the careless disposal of litter would be regarded as anti-social behaviour...The occasional national or local anti-litter campaign, laudable though it may be, is insufficient if a breakthrough is to be realized...Teachers of environmental studies, whether they approach the subject via geography, ecology or economics, all have a vital role to play in this educational objective. Litter as a major form of pollution, its impact on the natural environment, its social and economic consequences and the challenge at community and individual levels that its control represents, should all be important components built into education syllabuses...Well organized litter studies can provide an excellent opportunity for environmental field projects at all levels of education."

The results of research and education efforts in the United Kingdom are evident in that nation's ratification of Annex V of MARPOL in May 1986. Voluntary steps provide another example of successfully altering public consciousness on the marine litter issue:

> "The Marine Directorate of the [U.K.] Department of Transport has stressed to the British shipping industry the need to avoid the disposal of garbage at sea and has recommended that the industry voluntarily comply with the provisions of Annex V pending its entry into force. The ship owners have responded positively and UK passenger vehicle ferry owners operating from UK ports have issued standing orders banning the disposal of garbage into the sea" (Harding pers. comm.).

Ferry operators such as Sealink have cooperated despite the cost of fitting their vessels with specially designed waste handling equipment such as compactors. They have also taken such additional steps as switching from plastic to paper cups (*Yacht and Boat Owner* 1979).

All eight North Sea nations have ratified Annex V of MARPOL, which will enter into force at the end of 1988 (MMC 1988). Annex V will prohibit disposal of plastics from the vessels of signatory nations, or in the national waters of signatory nations. More recently, all eight have agreed to seek Special Area status for the North Sea under Annex V, which would reduce the disposal of glass, metal, and other persistent debris. (MARPOL and other global and regional approaches to the regulation of marine debris are discussed in Chapter VII.)

International agreement and regulation has been the principal approach to the problem of tar in the marine environment. All of the nations that border the North Sea study area are signatories of MARPOL, which automatically means they subscribe to the strict limitations in Annex I on the discharge of oil from tankers and other merchant ships.

Summary and Conclusions

That there are substantial aesthetic and economic problems of marine litter on recreational beaches is an inescapable conclusion of our North Sea investigation. The number of observers who made this point and the strength of their evidence leaves no room for doubt. The patterns of occurrence are consistent. The worst trouble spots, predictably, were sandy beaches with gentle slopes close to shipping lanes and exposed to prevailing winds and currents.

There was similar unanimity in attributing most of this debris to ships and boats, and this evidence is also convincing.

A great majority of the sources that commented on mitigation urged ratification of Annex V of MARPOL. Given the evidence, successful implementation of Annex V, after it enters into force at the end of 1988, should solve much of the North Sea marine debris problem (see Chapter VII for a more detailed discussion of MARPOL) .

A significant number of sources also called for Special Area status under Annex V for the North Sea, and in November 1987 the eight North Sea nations agreed to seek that additional level of protection (IMO 1987). Special Area status would go beyond the Annex V prohbition on disposal of plastics at sea from vessels by adding similar restrictions on the disposal of glass, metal, and other persistent debris in the Special Area.

A second category of problem area included portions of protected beaches near population centers, or near rivers that drain regions of high population density. Attribution of these localized concentrations to land sources is doubtless correct. Solutions to these problems lie in changing solid waste disposal methods and behavior patterns of beachgoers.

We found few references to the occurrence, amount, and source of plastic pellets, a debris component that has received more attention elsewhere (see Chapter IV). Two investigators had looked at pellet ingestion by seabirds (van Franeker 1985; Furness 1985). Neither study demonstrated harmful effects.

The work of the Dixons and the Keep Britain Tidy Group has adequately documented the existence of hazardous debris problems, as well, particularly in the English Channel. They have made a series of recommendations, some of them since adopted, concerning:

- Completeness of information in hazardous package labels
- Length of time that labels will remain on containers when in the sea
- Systems to assign liability and render compensation
- Mandatory (rather than recommended) reporting of the loss of hazardous materials at sea in order to alert coastal areas where the debris may strand.

These regulations could be incorporated in the International Maritime Dangerous Goods Code of the 1974 International Convention for the Safety of Life at Sea and guidelines under Annex III of MARPOL 73/78. However, the code is only a set of recommendations, and optional Annex III has not yet entered into force (Dixon and Dixon 1981a, 1986).

We found much less information on fishing gear and tar as components of North Sea debris. Both occur and may cause at least local problems (Weichart 1973; Bourne 1977). We have found it difficult to evaluate whether these sources of marine debris are insignificant in the North Sea, whether they are significant but under-investigated, or whether relevant information exists that we failed to locate. The sources that we did find that evaluated the effects of tar and fishing gear ranked them low, either absolutely or compared to other areas of the world (Chaussepied 1985; FRG 1986; Ministry of Agriculture n.d.; Arnaudo pers. comm.).

Several knowledegeable investigators (T.R. Dixon pers. comm.; Bourne 1983; FRG 1986; Millner 1985; Northridge 1986) de-emphasized the impacts of marine debris, including fishing gear, on seabirds and marine mammals. Nonetheless, further monitoring seems to be desirable. As Northridge suggests, much greater use could be made of stranded animals. Observations at breeding sites should reveal severe problems for some species relatively easily.

Most countries seem to be doing as much after-the-fact mitigation as is practicable. On the other hand, there is no upper limit to the amount of preventive effort that could be made, particularly in education, persuasion, and other forms of behavior modification. The United Kingdom provides and outstanding model for these approaches.

IV. DISCUSSION: THE NORTHWEST ATLANTIC OCEAN

Description

This study area is an arbitrary sub-division of the Atlantic Ocean. Its western boundary is the east coast of Canada and the United States. On the north, east, and south it is ill-defined by land masses or submarine features except for the Bahama and Caicos banks, Puerto Rico, and the Virgin Islands. It includes the North American, Newfoundland, and Labrador basins and most of the North Atlantic's central gyre, that great clock-wise movement of the Gulf Stream, the North Atlantic Drift, and the Canary, North Equatorial, and Antilles currents.

The St. Lawrence is the largest river flowing into the northwest Atlantic. It and other major fresh water sources such as the Hudson, Delaware, Susquehanna, Potomac, and James rivers drain highly industrialized population centers of Canada and the United States. Incomplete retention of solids by sewage treatment systems, dumping of wastes, and industrial solid waste discharges all are or have been major contributors to the debris load of the northwest Atlantic, either directly or via rivers (UNEP 1982).

Types, Quantities, Sources, and Distribution of Marine Debris

We have organized this discussion according to major types of debris we encountered references to: general land- and ocean-source litter, fishing gear, and tar.

1. General Land- and Ocean-source Litter

Canada has conducted little research into the subject of persistent marine debris, but there has been a growing realization in recent years that Canada's Atlantic coast has both known and potential marine debris problems (Bradford, Barchard pers. comms.). Plastic, glass, and metal litter probably accounts for the greatest volume, weight, and numbers of items of debris.

There is little certainty as to sources, however, and research will not easily provide answers. The Department of Fisheries and Oceans and Environment Canada both recognize that there are multiple sources. There is heavy shipping between Europe and North America off eastern Canada. There are several major fisheries involving Canadian and foreign vessels. Offshore oil platforms and support vessels have been active in the area. Both ocean- and land-source litter can reach the Canadian Atlantic coast from distant sources, carried by the St. Lawrence River or eddies from the Gulf Stream. Local sewage and solid waste disposal methods contribute debris to the marine environment (Bradford pers. comm.). These multiple sources, combined with the international nature of much debris, make it especially difficult to determine sources of litter on the Canadian Atlantic coast.

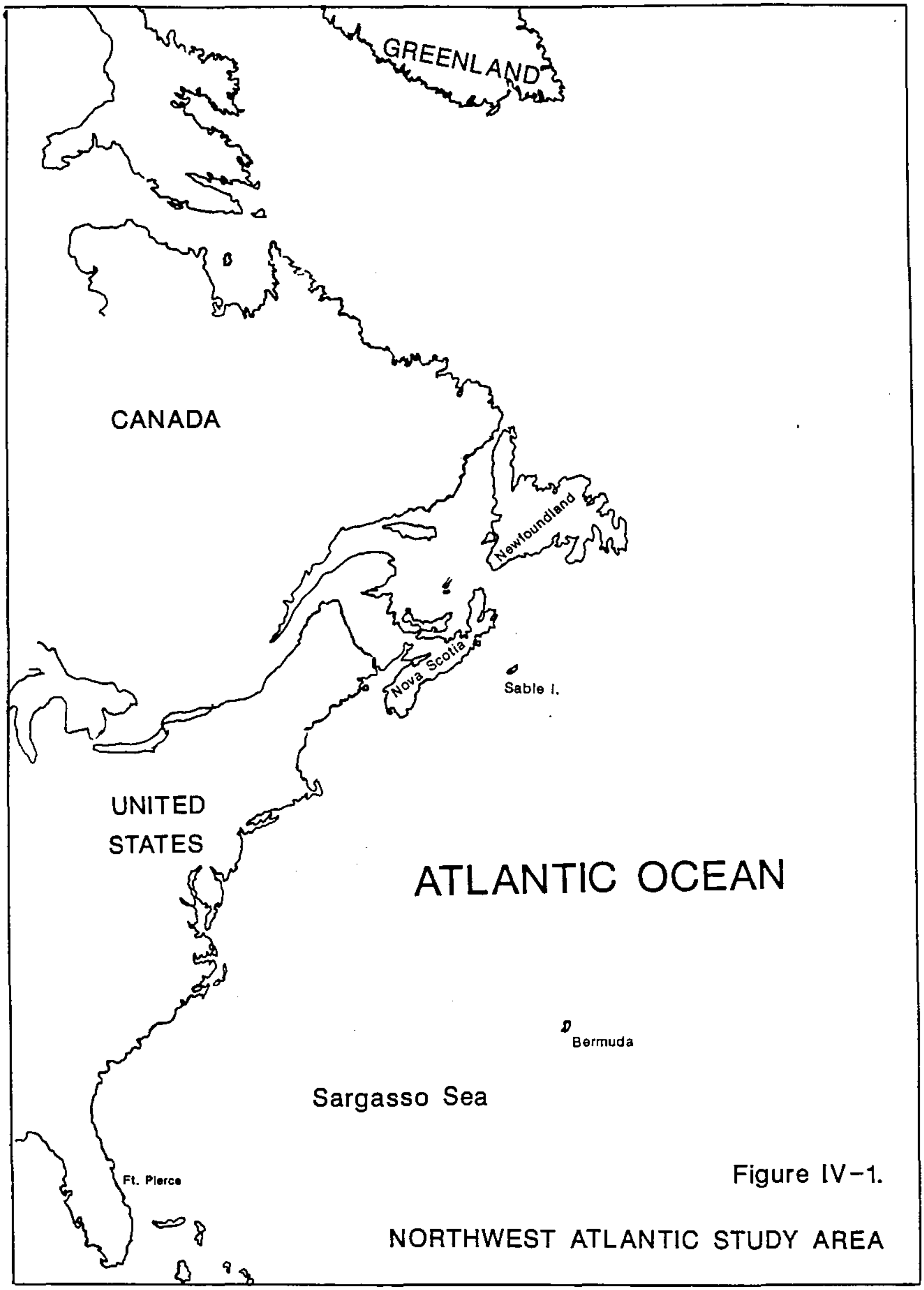

Figure IV-1.

NORTHWEST ATLANTIC STUDY AREA

Land-source litter may contribute relatively more to eastern Canada's marine debris than is true in similar sparsely-populated areas in the North Sea. Halifax-Dartmouth, the largest population center east of Quebec, is typical for the area in having no sewage treatment (Barchard pers. comm.), and Elliott (pers. comm.) reports debris is commonly disposed of over the cliffs in Newfoundland. Finally, the St. Lawrence River drainage is both densely populated and highly industrialized.

The only structured study of plastic litter in eastern Canada has been the three-year (1984-1986) volunteer effort by Lucas on Sable Island, 160 km off the coast of Nova Scotia (Bradford pers. comm.). The island, a treeless sand bank 43 km long by 1.5 km wide, receives debris from the major North Atlantic shipping lanes as well as the discharge of the Gulf of St. Lawrence. Lucas chose six 0.5 km sites on the north side of the island (where the greatest amounts of debris accumulated). She removed all debris in late April each year and then conducted surveys and collected debris at roughly 40-day intervals through November. She recorded weight, material, and, when possible, country of manufacture and whether or not the debris was attributable to fishing operations (Lucas pers. comm.).

In three seasons, Lucas collected 11,183 items, which she divided into categories such as fishing equipment, rope, strapping, plastic (other than fishing equipment and rope), glass, and metal. Fishing equipment, primarily net fragments, accounted for roughly 35% of the items. Nearly 96% of the pieces of netting were smaller than 30 cm on a side. Plastics represented nearly 94% of the total, metal was less than 1%, and the balance was glass. Most of the plastic items were containers or container fragments, sheeting, and bags. About 30% of the material with identifying marks on it was manufactured in Canada, with 7% from the United States (Lucas in prep.).

Lucas made two particularly useful calculations of accumulation rates that should be a routine part of beach litter monitoring but have not been. For example, plastic items accumulated at rates of 139 pieces/km/month and 8 kg/km/month in 1985-86 (Lucas in prep.).

Researchers in the **United States** became interested in plastic in the marine environment in about 1970. Carpenter *et al.* (1972) reported clear and white polystyrene spherules to be abundant in New England coastal waters. Their analyses revealed that the spherules contained polychlorinated biphenyls as plasticizers in concentrations of 5 parts/million. They assumed the source of the spherules was a raw plastics producer in southern New England.

At about the same time, in 1971, Hays and Cormons (1974) noticed white polystyrene spherules in regurgitated gull and tern pellets collected on Great Gull Island in Long Island Sound (many bird species regurgitate indigestible items in the form of pellets). The following year, in an effort to locate the sources of the plastic, they collected handfuls of mud, sand, and leaf litter near the sewage outlet pipes of plastics factories in Massachusetts, Connecticut, New York, and New Jersey. They found large numbers of spherules down-stream from all the plants they checked. In samples near plants in Massachusetts and Connecticut, they found as many as 2034 polystyrene and polyethylene spherules/inch^3 (2.5 cm^3). They assumed the sources of the spherules were the manufacturing plants.

The spherules (and other shapes, such as cylinders) described in these two reports have since become well-known as pellets in the marine debris literature. The plastics industry calls them nibs. They are the raw product of plastic manufacturers and are produced as small pellets to make them easy to ship as bulk cargos (Wilber pers. comm.). They apparently can enter the marine environment through waste systems of plants located near rivers, through careless loading or unloading of ships, and from flushing out cargo areas on ships.

Carpenter and Smith (1972) found a wide variety of plastic particles while taking surface samples in the Sargasso Sea in 1971. They made 11 tows totaling nearly 98 km with a 1 m diameter neuston net. They collected 228 plastic items with a total weight of 14.75 gm. Carpenter and Smith reported average concentrations of 3537 items/km^2 and 286.8 gm/km^2. However Wilber (pers. comm.) seems to be correct in pointing out that these figures are based on a miscalculation and that the correct values should be 2330 items/km^2 and 151 gm/km^2.

"Most of the pieces were hard, white cylindrical pellets, about 0.25 to 0.5 cm in diameter," but there were also green, blue, and red pieces and fragments of clear sheet plastic. "Several larger pieces could be identified as a syringe needle shield, a cigar holder, jewelry, and a button snap." It is not clear from Carpenter and Smith's article what proportion of the pieces were raw plastic pellets and how many were fragments of manufactured items, which makes it difficult to compare their data with later studies that make that distinction.

Also using neuston net tows, Colton *et al.* (1974) systematically sampled the continental shelf and Gulf Stream off the Atlantic coast of the United States, the Antilles Current, the Caribbean Sea, and the eastern Gulf of Mexico in 1972 as part of a multi-ship ichtyoplankton survey. (Their results are summarized in Table IV-1.) They noted the occurrence of five categories of plastic particles:

- White opaque polystyrene spherules, 0.2-1.7 mm in diameter, were found only north of Cape Hatteras with the greatest concentrations in coastal waters off Rhode Island and eastern Long Island and a secondary concentration offshore off Delaware Bay.

- Translucent to clear polystyrene spherules, 0.9-2.5 mm in diameter, were found in a pattern very similar to the opaque spherules.

- Opaque to translucent polyethylene cylinders or disks, 1.7-4.9 mm in diameter, were, again, found in greatest concentrations off southern New England, eastern Long Island, New Jersey, and Delaware, with much lower concentrations just south of Cape Hatteras and in the Yucatan Channel.

None was found in the Straits of Florida, the eastern Gulf of Mexico, or the coastal or Gulf Stream waters south of Cape Lookout, North Carolina.

- Pieces of Styrofoam were concentrated off eastern Long Island and in an area centered 130 km east-southeast of Delaware Bay.

- Sheets of wrapping material and pieces of hard and soft, clear and opaque plastic (assumed to be fragments of containers and other manufactured items) were the most abundant and widespread items collected, with greatest concentrations over the continental shelf between Virginia and Rhode Island. These were the only plastics found in a majority of the Caribbean and Antilles Current tows.

Colton *et al.* suggest that their results understate the amount of these small, plastic items in the areas they sampled. They used neuston nets with a mesh of 0.947 mm and collected polystyrene spherules with a mean diameter of 1.3 mm. Carpenter *et al.* (1972) used 0.333 mm mesh nets and collected polystyrene spherules with a mean diameter of only 0.5 mm. Colton *et al.* concluded that significant numbers of smaller particles passed through their nets. Furthermore, many of the polystyrene spherules they collected were slightly denser than water and thus "could only be maintained in the surface layers in areas of strong vertical mixing...Obviously, these opaque spherules and other plastic particles of similar density must also occur in subsurface waters."

Table IV-1. Mean abundance of plastic particles found on MARMAP cruises. Numbers of Styrofoam pieces and plastic sheets and pieces were not given because of extreme variation in the sizes of these particles (from Colton *et al.* 1974).

Plastic Type	Number/tow	Grams/tow	Number/km^2	Grams/km^2
Continental shelf and Gulf Stream: N. Florida-Cape Cod, 143 stations.				
Raw plastic	25.8	0.060	8317.5	19.9
Plastic & Styrofoam pieces		0.179		57.8
Total		0.239		77.7
Antilles Current: Virgin Islands-N. Florida, 40 stations.				
Raw plastic	0.5	0.007	148.4	2.2
Plastic & Styrofoam pieces		0.049		15.9
Total		0.056		18.1
Caribbean Sea and eastern Gulf of Mexico: 64 stations.				
Raw plastic	0.2	0.004	60.6	1.4
Plastic & Styrofoam pieces		0.028		9.1
Total		0.032		10.5

Colton *et al.* concluded from their own and others' work that most of the sheets and pieces of plastic and Styrofoam were litter dumped from vessels, that most of the raw plastic pellets in northern United States waters were from plants in southern New England and the mid-Atlantic states, and that the larger, differently-shaped, and less-weathered raw plastic found in the Caribbean and in the Antilles Current must have come from some other, unknown source.

Colton *et al.* found very low concentrations of pellets in shelf and Gulf Stream waters off the Atlantic coast of the United States south of North Carolina. In 1973-75, however, van Dolah *et al.* (1980), using neuston nets with the same mesh size in shelf and slope waters off the southeastern United States, found concentrations (30-80 g/km^2, average, 44 g/km^2) comparable to those that Colton *et al.* found off New England. Because van Dolah *et al.* found lower concentrations in shelf waters (<200 m) than in deeper waters, and because they failed to find increased concentrations near industrial centers, they concluded that "the primary source of pollution is through entrainment from other areas via currents and shipping."

Gregory (1983) looked for pellets on beaches in eastern Canada. He found the most (about 10/linear meter) near Halifax.

In 1984, the Sea Education Association began long-term monitoring of the occurrence of plastic debris both at sea and on beaches (Wilber pers. comm.). The study so far includes 468 neuston net tows from the *R/V Westward* in the northwest Atlantic Ocean, the Caribbean Sea, and the eastern Gulf of Mexico (Figure IV-2, Table IV-2), and more than 150 beach surveys in Bermuda, the Bahamas, the Lesser Antilles, the Florida Keys, and Cape Cod (Table IV-3).

As with the earlier studies, Wilber found plastic pellets and pieces in every area of the ocean sampled, with by far the greatest concentrations in the northern Sargasso Sea. The southern Sargasso yielded the next highest concentrations (Wilber 1987). Also noteworthy is that the values for the Sargasso Sea are significantly higher than those found by Carpenter and Smith in 1971.

Thirty-seven more recent tows (1987) in shelf and slope waters and the Sargasso Sea yielded density values for both pieces and pellets that were higher than those in Table IV-2 (Wilber pers. comm.).

Wilber's beach survey data focus on pellets (Table IV-3); however other plastic debris was observed as well. Plastic litter was particularly heavy in the same areas of high pellet density: more in Bermuda than in the Bahamas, and more in the Bahamas than in the Antilles (Wilber 1987). Beach litter was particularly heavy on the windward side of the Florida Keys (Wilber pers. comm.).

Gregory (1983) found similar numbers of polyethylene pellets in Bermuda (5000-10,000/linear meter).

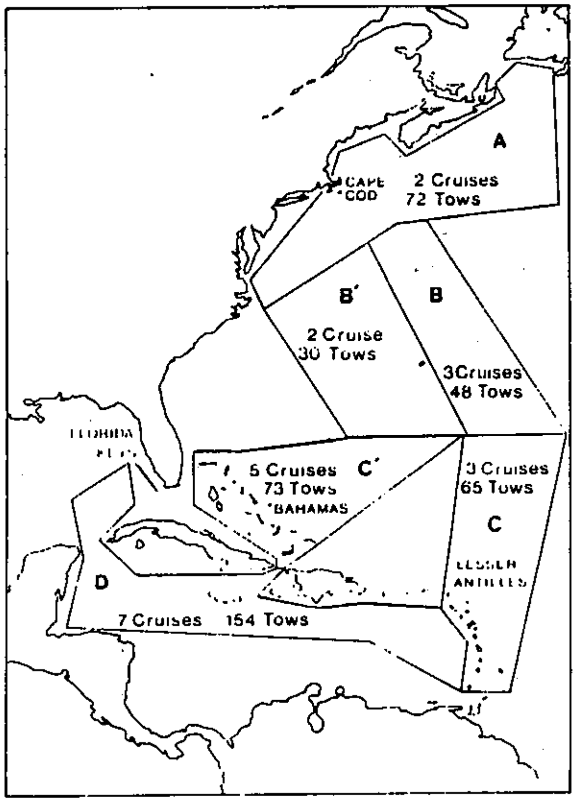

Figure IV-2. Four oceanic areas where *R/V Westward* made 431 neuston net tows (from Wilber 1987, reproduced with the permission of *Oceanus* magazine).

Table IV-2. Summary of data from *R/V Westward* tows in the four areas outlined in Figure IV-2 (from Wilber 1987).

Oceanic Region	# tows	% tows with plastic	pieces/ km2	% tows with pellets	pellets/ km2
(A) Shelf and slope	72	50	700	8	77
(B) Northern Sargasso Sea	78	100	11,000	76	1,700
(C) Southern Sargasso Sea	127	67	2,500	28	360
(D) Caribbean/eastern Gulf	154	60	1,400	14	150
Total/mean	431	68	2,100	28	490

Table IV-3. Summary of beach survey data (from Wilber 1987).

Area	# sites		pellets/m2
Cape Cod	20		100-1,000
Bermuda	20		2,000-10,000
Florida Keys	60		100-1,000
Bahamas	50	windward	500-1,000
		leeward	200-500
Antilles	25	windward	100-500
		leeward	50-100

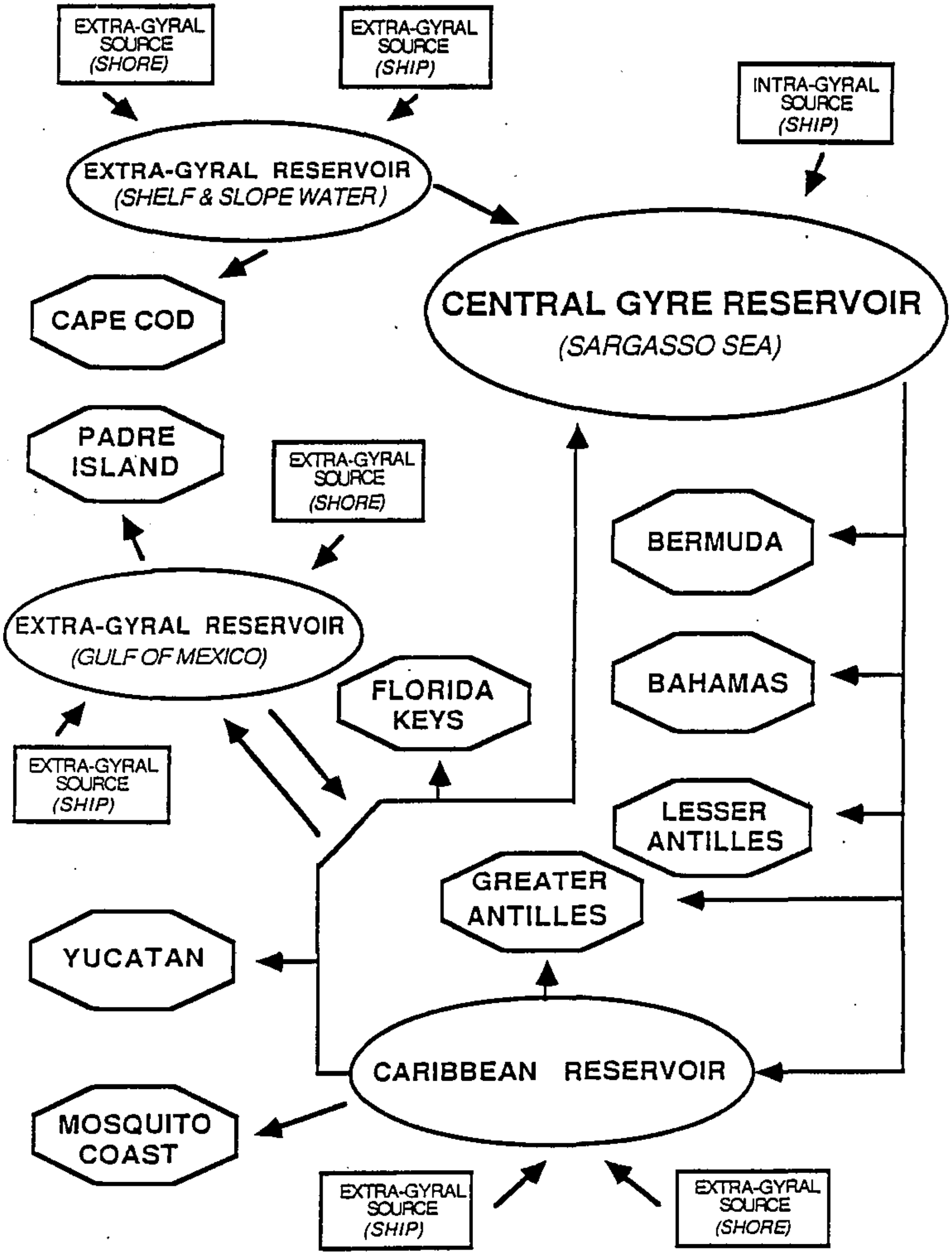

Figure IV-3. Flow diagram for plastic pollution in the northwest Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico (from Wilber 1987; reproduced with permission of the author and *Oceanus* magazine).

Wilber said that the low densities of pellets on beaches of the northeastern United States, where vast quantities of the pellets are produced, implicates shipping as a major source of this debris (Wilber pers. comm.). He also attributed most of the general plastic litter in the central gyre to dumping of trash from vessels (Wilber 1987).

Wilber, after quoting Carpenter and Smith's 1972 forecast of increasing concentrations of plastic particles in the ocean, pointed out that his data indicate a 1,000% increase in total plastic pieces/km^2 and a 200-400% increase in pellets/km^2 in the northern Sargasso Sea. Extrapolating from the densities he found in that area yields a pellet load for the northern Sargasso of something like 16 billion (Wilber pers. comm.).

The results of Wilber's work seem to support the general model he has elaborated for the introduction and removal of debris in the northwest Atlantic Ocean, Caribbean Sea, and eastern Gulf of Mexico (Figure IV-3). At the heart of this model is the North Atlantic central gyre and the Sargasso Sea. Just as the clockwise current system concentrates sargassum, the gyre also produces the highest densities of floating plastic pollution.

Material enters the system from multiple sources, such as the currents that form the gyre or ships within it. Some material escapes the gyre by beach deposition paraticularly in Bermuda, the Bahamas, and the Antilles, with amounts decreasing with distance from the center of the gyre. These islands, either in or adjacent to the major circulation pattern, "act as natural sieves or strainers for the accumulated flotsam" with those on the periphery of the system, such as the Antilles, receiving much less debris than a coast such as Bermuda's in the center (Wilber pers. comm.).

Although Bermuda's beaches had the highest densities of plastic because of the island's central location, the absolute amount of plastic Bermuda removes from the system is small since its coastline is relatively short. The Bahamas, however, have thousands of kilometers of sandy, shallow gradient, windward beaches facing the Antilles Current. All of the Bahamas visited by Wilber had heavy concentrations of plastic debris, leading him to conclude that the Bahamas "are probably the major removal site for the entire Atlantic Ocean" (Wilber pers. comm.). (The high levels of debris in the Bahamas were confirmed by a personal communication from Minns.)

Wilber suggests that the distribution of plastic debris in the central gyre is governed, on the largest scale, by the major currents that define the gyre (the Gulf Stream and the Canary, North Equatorial, and Antilles currents). On a smaller scale, rings or eddies generally less than 100 km across are constantly breaking off of the main currents and drifting through the gyre, often retaining their identities for months. On the smallest scale, Langmuir bands, parallel windrows caused by strong, steady winds, also concentrate flotsam (Wilber 1987; Carr 1986a, 1986b, 1987).

Wilber's model supports that of Archie Carr, who, concerned with the survival prospects of young sea turtles, adds an important perspective on the pelagic distribution of debris at or near the surface:

> "I belatedly came to appreciate the prevalence and diversity of convergences where downwelling gathers and aligns buoyant material, including the dispersed food resources of the surface waters. Galt (1985) enumerated the many ways in which fronts of all dimensions and configurations may originate. They range in magnitude from driftlines along the walls of major border currents down to local rips over reefs and sea mounts, off capes and river mouths, and at the downcurrent ends of bars. The sinking and advection that they generate also occurs at the borders of the warm- and cold-core Gulf Stream rings, and it builds the fields of raggedly parallel multiple bands generated by wind-action in Langmuir circulation. In all these and many other kinds and sizes of fronts, the mobilization of flotsam by the vertical component generated by the horizontal collision of water bodies gathers in both the hatchlings and the resources that they require" (A. Carr 1986b).

> "Besides providing useful resources, the convergences may become, in a way, a trap for marine life. In addition to the food and shelter, the animals that come in find themselves in close association with lethal floating objects and toxic substances. Persistent plastics are often the most conspicuous visible flotsam in a rip, and ghost gear and tar pellets are also often present" (A. Carr 1987).

The large subject of currents, fronts, and downwelling and their influence on the distribution of debris bridges our northwest Atlantic and Wider Caribbean study areas. We discuss it further in the Effects and Summary and Conclusions sections of this chapter as well as in Chapter V.

Carpenter and Smith (1972), Colton *et al.* (1974), and Wilber (1987) all generated precise data on amounts and distribution of plastic in the northwest Atlantic, primarily pelagic debris. In the past three years, growing interest in the subject has resulted in several projects of a different sort in the United States. Many of them have been conducted by the Center for Environmental Education, and that organization has described most of them in a comprehensive report on plastic marine debris for the Environmental Protection Agency (CEE 1987a). (A summary is included in a 1986 report on development of marine debris education programs by Centaur Associates and the Center for Environmental Education for the National Marine Fisheries Service. The following outline of sources, types, and amounts of marine debris on the Atlantic coast of the United States is based substantially on those two reports.) These projects generally take one or more of the following approaches:

- Description of known or potential sources of marine debris.
- Estimation of amounts of debris that may enter the marine environment from various sources.

- Beach clean-ups as a tool for public education and as a source of information on types, sources, and amounts of debris.

- Reviews of local, national, and international legal authorities relevant to the control of marine litter.

Much of the following is a summary of information contained in the EPA report, and the reader is referred to that publication for more detail.

Ocean sources affecting the Atlantic coast include merchant shipping, commercial fishing, naval vessels, passenger ships, and recreational vessels.

Merchant shipping is known to be a major source of marine debris. Most ships dump solid wastes overboard. There are no estimates of how much of that litter might strand on the Atlantic seaboard of the United States, but the National Academy of Sciences (1975) estimated that the world's merchant fleet of nearly 20,000 vessels annually dumped 5.6 million metric tons of cargo-associated wastes and 110,000 metric tons of domestic litter. In 1986, there were 734 merchant ships (over 1,000 gross tons) registered in the United States. Most of them operate abroad, but additional foreign vessels operate in United States waters. Many assumptions must be made to estimate the effect of this source on the United States. Most investigators concerned with plastic pellets have concluded that merchant shipping is the main source of raw plastics in the oceans.

Commercial fishing vessels dispose of both domestic waste and fishing-related gear, equipment, and packaging. Based on National Academy of Science and Department of Commerce data, United States registry fishing vessels may dump 25,000 metric tons of all varieties of solid waste annually. There have been no estimates made of amounts of debris contributed by foreign fishing vessels in United States waters.

The 600 United States **Naval vessels** with their population of 285,000 crew members dump garbage and trash overboard when at sea. No estimate has been made of the annual amount dumped.

The National Academy of Sciences (1975) estimated that **passenger ships** serving United States ports produced 28,000 metric tons of litter per year, 1.8% of which is plastic.

Recreational vessels present even greater problems of estimation. In 1984, there were approximately 2 million recreational vessels (on both fresh and salt water) with Coast Guard registration in the Atlantic coast states. The Coast Guard has estimated that each person on a recreational boat discards roughly 0.7 kg of garbage and trash a day into coastal waters (Duerr 1980).

Land sources of marine debris include sewage systems, solid waste disposal, littering, and plastics manufacturing.

Both primary and secondary **sewage treatment plants** routinely fail to retain all solid items. Even under normal operating conditions, most urban sewage treatment systems fail to separate all plastic items from sludge that is dumped in the ocean. Substantial amounts of plastic can escape from outfalls and from ocean dumping of sludge. Common items associated with this source include plastic tampon applicators, condoms, and disposable diapers.

Sewer systems and storm drains are combined in many cities. Thirty of the 100 highest volume systems in the United States are between Massachusetts and Virginia and have combined sewers and storm drains (NOAA 1988). High rainfall periods frequently overburden the sewage treatment plants, and sewage and large amounts of plastic escape into waterways. This source is considered to be particularly important in the Boston area and the New York Bight. The infamous "floatables incident" of May and June 1976 in the New York Bight is an example. Sewage treatment failed, resulting in the daily discharge of sewage and up to 13,000 cubic feet of floatable material, especially plastic (CEE 1987a). Similar discharges resulted in other beach closures in 1987 in New York and New Jersey (NOAA 1988).

Plastics and other debris regularly escape from **solid waste disposal** operations. For instance, a landfill on Staten Island received 700 tons of trash from barges each day in 1986 debris from solide waste disposal. Considerable quantities of lightweight litter blow off the barges while they are in transit and during loading and unloading (CEE 1987a). For the entire United States, some 9,000,000 tons of solid waste are believed to end up in the sea, much of that on the Atlantic coast (Bean 1987), and the EPA estimates that 7.2% of municipal solid waste is plastic (NOAA 1988).

Illegal dumping of land source trash contributes an unknown amount of marine debris. Presumably such deliberate dumping was responsible for the closure of New Jersey beaches in August 1987 when garbage, trash, and syringes and other hospital wastes washed ashore (NOAA 1988).

As demonstrated by the Hays and Cormons study (1972), the **plastics manufacturing** industry can be a direct source of plastic pollution. Outfall pipes of manufacturing plants apparently discharge pellets into rivers and coastal waters, although Wilber (1987) and others have suggested that this source is minor compared to what escapes during transportation of raw plastics.

Littering by the public is assumed to be a major source, especially at heavily-used recreational beaches. Quantifying such debris is extremely difficult, and little effort has been made to do so. Even when beach debris has been counted, weighed, and analyzed, the source of much of it can not be determined. A pioneering exception was Cundell (1973), who surveyed plastic material on a private beach in Narragansett Bay, Rhode Island. He concluded that most items resulted from recreational activities within the bay and was related to eating and drinking, boating, and fishing. He recorded deposition rates of about 1 gm/m^2/month.

In trying to assess types, amounts, and occurrence of debris, the EPA and Centaur/CEE reports were forced to rely heavily on anecdotal accounts from knowledgeable individuals and on data from beach clean-ups. Volunteers conducted beach clean-ups in several states in 1985, 1986, and 1987 (Table IV-4).

The data from these clean-ups reveal the problems of relying on this activity, as it has been conducted, for anything but the most general impression of marine debris occurrence. Effort can not be assumed to be standardized. Methodology for collection and analysis of debris varies from state to state and sometimes from year to year. There is no information on rates of accumulation. Nonetheless, it is possible to draw some useful conclusions about sources, types, and amounts of debris from the beach clean-ups, particularly in comparing one region to another. (The shortcomings of the beach clean-ups as research in no way diminishes their value as tools for public education, which is discussed below in the Mitigation section of this chapter.)

The most detailed information for two years of clean-ups is from Maine (Table IV-5), and we have included these results as an example. We do not know whether or not the 69.5 miles covered in 1986 overlap the 30 miles of 1985. Total glass (12.9-31.4%) and total Styrofoam and plastic (30.2-55%) varied widely from year to year. Within the Styrofoam and plastic categories, only plastic bags and sheeting were at all consistent.

With minor variations, the results from the other beach clean-ups were similar. Personal communications to CEE served to confirm the same picture in other Atlantic coast states. In response to our survey, personal communications from Beck (Narragansett Bay), Christoffers and Blair (Chesapeake Bay), and White (North Carolina coast) described the same situation. Styrofoam items tended to be higher on or near recreational beaches. Tampon applicators occurred in larger numbers near urban centers. In general, the debris consisted mostly of a wide variety of domestic waste: plastic, glass, and metal containers, plastic bags and sheeting, six-pack yokes, Styrofoam cups and packaging, plastic eating utensils, tampon applicators, plastic diapers, rope, monofilament line, fragments of plastic, and a vast miscellany of other items.

The sources of the material were only generally determinable. Sewage and solid waste disposal methods were more suspect near urban centers (Boston, New York/New Jersey), merchant vessels near shipping lanes and ports (Boston, New York Bight), fishing vessels in coastal areas near fisheries (northern New England, Chesapeake Bay), beachgoers at recreational beaches (New England, Long Island, Virginia), and recreational boats where they are most numerous (Long Island Sound, Chesapeake Bay, mid-Atlantic states).

Amounts of debris varied significantly, were greatest near urban-industrial areas (Boston and New York City), and were great enough everywhere to cause concern about the aesthetic degradation of beaches.

Table IV-4. Summary of three years of Atlantic coast beach clean-ups (from CEE data).

	Pounds of debris/mile		
State	1985	1986	1987
Maine	52	86	190
New Hampshire			133
Massachusetts	167	50	95
Rhode Island	113		
Connecticut	60		200
New York			1500
New Jersey			800
Delaware			60
North Carolina			133
Georgia			200
Florida			160

Table IV-5. Summary of items collected in the 1986 and 1985 Maine beach clean-ups (from Centaur/CEE 1986).

1986 Rank	Debris Category	# items 1986	% items 1986	% items 1985
1	Styrofoam	6453	27.4	11.6
2	Plastic containers	3068	13.0	6.1
3	Glass pieces and bottles	3032	12.9	31.4
4	Fishing gear	2692	11.4	8.4
5	Plastic sheeting and bags	2440	10.4	10.5
6	Household items	2183	9.3	11.2
7	Cans	1541	6.6	8.2
8	Clothing	1131	5.4	-
9	Plastic strapping	724	3.1	1.4
10	6-pack yokes	260	1.1	0.6

2. Fishing Gear

Fishing gear was one of the most widely reported types of debris on the Atlantic coast, but, as in the North Sea, it was a significant portion of total debris on beaches only in the far north where the most commercial fishing occurs. Roughly 35% of the debris Lucas found on Sable Island was fishing gear, primarily net fragments less than 30 cm on each side (Lucas pers. comm). Nettleship and Bowen (pers. comms.) said lost and discarded monofilament netting and lengths of line were common components of debris in Canada. In the United States, the highest value reported for fishing gear debris on beaches was 11.4% of the items in the 1986 beach clean-up in Maine. No more than three pieces of trawl webbing were found, with most of the rest of the fishing gear being buoys and line. A similar amount of fishing gear was found in 1985 (Centaur/CEE 1986).

Fishing gear was an insignificant portion of debris items reported in other states (Centaur/CEE 1986), but perhaps because of increasing public awareness of wildlife entanglement, it may have become more noticeable to knowledgeable observers. Fishing gear was the only type of debris mentioned by all United States Atlantic coast respondents to this project's survey (e.g., pers. comms. from Beck, Christoffers, Blair, White, and Minns). Net fragments, monofilament line, ropes, and buoys were the most commonly mentioned.

The sources of this debris varies with the fisheries common to a particular area (no sources suggested that the debris had come from a great distance). Cod trap and set net and salmon drift net fisheries are the main sources in Canada. Groundfish set net and lobster fisheries predominate in northern New England. There is a major crab trap fishery in Chesapeake Bay. A variety of nearshore net fisheries occur in the mid- and south-Atlantic states. Recreational fishermen contribute surprisingly large amounts of discarded or lost monofilament line along much of the Atlantic coast.

Fishing gear becomes debris through various routes. Unuseable gear is often discarded. Storms result in lost nets and traps. Nets may become irretrievably snagged on bottom features. Gear conflicts between trawl nets and stationary gear such as set nets and traps result in accidental and even intentional loss of gear (Way 1976; CEE 1987a).

Concern over lost nets and traps and their ability to keep fishing has increased in recent years as this gear has increasingly become constructed of nondegradable materials. Way (1976) said that storms, ice, and deep trawlers cause the loss of thousands of nets each year in Newfoundland. His study evaluated methods of finding and retrieving nets, but did not attempt to estimate amounts of lost gear. He dragged retrieval gear at 1-1½ knots for a total of about 50 hours in two known gill netting areas and recovered 147.5 nets. About 100 of the nets were in good condition. All that remained of the rest were head and foot ropes and useless fragments of netting. The striking result was that, in about 2½ hours of towing/day, Way recovered an average of nearly 8 nets/day. Way did not give a total length for the retrieved nets. Ninety-one meters (60 fathoms) is a standard length in that area, however, and assuming that length, the total for the 147.5 nets would be about 13 km.

In 1984, Carr and Cooper (1987) began a three-year study to determine the amount and effects of lost set nets in two areas of the Gulf of Maine. They used submersibles to conduct transects to find, survey, and videotape "ghost" nets on Jeffries Ledge and Stellwagen Bank. Based on the number of nets they found and the area they surveyed by submersible, they estimated (with low confidence limits) that the 64 nmi^2 of gill net grounds contained a total of about 203 km of lost net. They concluded that that amount was not substantial. The evidence also suggested to them that all the nets found were at least four and most at least seven years old. Carr and Cooper further concluded that most of these nets were lost about 1980 when the commercial gillnet fishery was most active and consisted mostly of inexperienced fishermen. Gillnet losses have since declined. Those that have occurred more recently were caused by conflicts with trawlers.

The EPA report (CEE 1987a) provided known amounts of lost gill net and estimated numbers of lost lobster traps off New England. Under the federal Fishing Vessel and Gear Damage Compensation Fund of the Fisherman's Protection Act, fishermen may be compensated, in certain circumstances, for gear loss or damage caused by foreign fishing activities. The administration of the law by NMFS is such that fishermen are compensated even when the cause of the loss or damage is unknown (Bean 1984). CEE examined two years of claims for the New England groundfish set net fishery. They found 21 cases with 48 km of gill net reported lost for 1985, and 15 cases and 29 km of lost net for 1986. Neither the CEE report nor this one has attempted to determine what percentage of lost net those claims represented nor whether ghost fishing from these lost nets constitutes a serious threat to any resources.

The EPA report (CEE 1987a) attributes most fishing gear debris on beaches in northern New England to the lobster fishery, which is understandable given the estimate it quotes of at least 500,000 lost lobster traps each year. Each standard-size trap represents a float, a long length of line, four square feet of nylon or polypropylene netting, and the wooden framework.

These reports of lost fishing gear in the northwest Atlantic provide more information than is available for the North Sea, but the picture still remains fragmentary. The estimates are only for parts of a few domestic commercial fisheries. We have virtually no information on several large commercial fisheries nor on sport fishing.

3. Tar

• Pelagic Tar - Reports of pelagic tar were not commonplace until the neuston net became a standard tool of oceanic research in the mid-1960s, and the first reports were not of quantified amounts. A 1968 Woods Hole research cruise encountered heavy tar pollution en route to the Sargasso Sea. From the cruise descriptions, Butler *et al.* (1973) subsequently estimated the concentrations in that small area to have been about 100 mg/m^2.

In the following two years, Heyerdahl's two *Ra* expeditions reported heavy oil pollution in the North Equatorial Current between northwest Africa and the Lesser Antilles. The following descriptions were typical:

> "There would be days...when only a very few...lumps could be seen from sunrise to sunset, whereas in exceptional cases the water was so polluted

that a bucket could not be filled with water without some floating lumps being caught at the same time...From early that morning until the evening of the following day, *Ra II* was drifting very slowly through calm water that was thickly polluted by clusters of solidified oil lumps which were commonly of the size of prunes or even potatoes. Many of these lumps were dark brown and pitted, more or less densely overgrown by barnacles, whereas others were smooth and black, with the appearance of being quite fresh. Multiped crustaceans were repeatedly seen riding on such lumps, as were sometimes also pelagic crabs and marine worms" (Heyerdahl 1971).

This account suggests how colonized tar might appear to be an attractive food source to sea turtles and other creatures. And the observations on the patchy occurrence of tar are echoed by virtually all subsequent investigators.

In 1969-70, the Bermuda Biological Station and Woods Hole Oceanographic Institution initiated a series of important studies of tar at a station near Bermuda and on cruises in the Sargasso Sea and elsewhere in the northwest Atlantic. Results were similar to later investigations: values averaging roughly 1-2 mg/m^2 in the northern Gulf Stream and along the North American coast; an average of 10 mg/m^2 in the Sargasso Sea. Butler *et al.* (1973) made observations on their methodology that are relevant to the general subject of pelagic debris studies:

"Since *Sargassum* and tar, as well as any other floating material, tend to line up in windrows in the direction of the wind because of Langmuir circulation of surface water, this automatically introduced inhomogeneity. ...To minimize the possibility of collecting either a windrow or the space between a windrow, the neuston net was generally towed in a circle, or perpendicular to the windrows...It is clear [from the results] that even with these precautions, the variation in sampling in the same place on a time scale of hours is quite large, with standard deviation of the same order of magnitude as the sample mean itself...We may assume that geographical variations, or variations between the results of different workers, of a factor of three to five are probably not statistically significant. This result also implies that extremely careful quantitative work does not improve the reliability of an acceptable survey of pelagic tar distribution."

In their review of available information on tar, Butler *et al.* (1973) concluded: "It seems clear that in the Atlantic Ocean, at least, virtually all pelagic tar originates from tanker operations."

In 1970, Polekarpov *et al.* (1971) (as cited in Butler *et al.* 1973) found concentrations averaging nearly 10 mg/m^2 in the North Equatorial Current just south of the Sargasso Sea, near the area Heyerdahl drifted through.

The three 1972 NOAA MARMAP cruises that resulted in Colton's articles on plastic pollution (page IV-4) also led to media reports of "vast areas of the Atlantic Ocean stretching from Cape Cod to the Caribbean that were befouled by floating oil, tar and plastics" (Lyons 1973). The largest area of oil and tar pollution was in the Antilles Current east of the Bahamas. J.N. Butler concluded that the tar was crude oil sludge from tanker cleaning. He noted: "Sightings of tar at sea were almost negligible off the Atlantic coast until 1968." He pointed out that closure of the Suez Canal in 1967 caused tanker traffic to be diverted around Africa. In a subsequent publication, he also observed that the amount of crude oil moved over the world's oceans each year increased more than tenfold between 1950 and 1970 (Butler *et al.* 1973).

Along the Continental Shelf between Nova Scotia and north Florida, the MARMAP cruises consistently found average concentrations well under 1 mg/m^2, with lower values closer to the coast and higher values offshore. Northern Gulf Stream samples averaged over 2 mg/m^2; the Antilles Current roughly 4 mg/m^2; and the Sargasso Sea over 9 mg/m^2 (Butler *et al.* 1973; van Dolah *et al.* 1980).

Cordes *et al.* (1980), and, as cited in NAS (1985), Levy (1977), McGowan *et* al. *(1974), Sherman* et al. (1974), and Sleeter *et al.* (1974) have since found the same general pattern.

• Tar on beaches - The American Petroleum Institute pioneered beach studies of tar in 1958. Dennis (1959) found heavy deposits at sites in New Jersey (19 g/linear meter), Cape Cod (45 g/m), and near Chesapeake Bay (81 g/m). Other sites yielded less than 5 g/m, except southeast Florida (see Chapter V).

A more recent study of beach tar on the Atlantic coast of the United States in our study area was by Romero *et al.* (1981). In 1979-80, they sampled tar at four locations on the Florida coast between Fort Pierce and the Georgia border and found decreasing concentrations, south to north (a relatively pristine 3.4-0.0 gm/m^2).

Because Bermuda had begun to suffer high levels of tar on its beaches, and in order to test a method other than neuston tows for gauging oceanic tar, the Bermuda Biological Station collected stranded tar on beaches in 1971-72 (Butler *et al.* 1973). Knap *et al.* (1980) and Smith and Knap (1985) used similar methods in follow-up sampling in 1978-79 and 1982-83.

Comparing the results of the three series of samples requires considerable interpretation because methodologies varied between the first project and the latter two. Nonetheless, Knap *et al.* (1980) were able to conclude that the high levels of tar reported from 1971-72 had increased by perhaps 15% despite estimates by other investigators that improved tanker operations had decreased pollution by 27%. By 1982-83, however, Smith and Knap (1985) found a significant decrease compared to 1978-79 — values that were at least comparable to, and possibly lower than, 1971-72. In 1982-83, Smith and Knap (1985) found 50-106 gm of tar/linear meter of beach on two beaches, a decrease of 78-87% from the 1978-79 study. (Chaussepied found 30 gm/linear meter of beach at his two English Channel sites. See Chapter III.) They attributed the decrease to fewer tanker spills and platform blow-outs and cleaner tanker operations as a result of international oil pollution regulations such as MARPOL Annex I (see Chapter VII). They also cited evidence that pelagic tar in the Sargasso Sea had begun to decrease.

Minns (pers. comm.) and Wilber (pers. comm.) report problem levels of tar on the windward coasts of the Bahamas.

Personal communications from Lucas, Nettleship, and Levy all noted tar on Canadian beaches. Lucas (pers. comm.) found tar periodically, at intervals of up to several weeks, on Sable Island. Her descriptions of the amounts of tar indicated much lower levels than on Bermuda.

We found only one group of investigators who attempted the difficult task of estimating inputs of tar into the northwest Atlantic. Van Vleet *et al.* (1983) concluded that approximately 7000 metric tons of pelagic tar enter the Atlantic each year from the Gulf of Mexico via the Florida Straits. Of that amount, about half may enter the Gulf from the Caribbean Sea via the Yucatan Channel while the other half originates in the Gulf. Roughly half of the tar samples they analyzed had bimodal *n*-alkane distribution characteristic of crude oil sludge from tanker cleaning (Van Vleet *et al.* 1984).

Effects of Marine Debris

This discussion is organized into three sections, reflecting the major categories of marine debris effects we encountered in the northwest Atlantic area: aesthetic effects, economic effects, and hazards to wildlife. Unlike the North Sea study area, we found no references to hazards to humans.

1. Aesthetic Effects

There is little we can add to our comments on the North Sea study area (page III-11). Concern over aesthetic degradation is often an unspoken assumption in both literature and personal communications. Aesthetics is the obvious motivation for both volunteer and nonvolunteer beach clean-ups.

Several personal communications made explicit reference to this impact, however, including Beck (Narragansett Bay), Blair (Chesapeake Bay), White (North Carolina), Wilber (Bermuda), and Minns (the Bahamas).

The EPA report (CEE 1987a) cited aesthetic concerns from all parts of the United States Atlantic coast. Perhaps a fitting symbol for the beach litter problem is the response of Cape Cod residents to the plague of tampon applicators in the past several years. This debris item has come to be known as "beach whistles," and a local artist who draws attention to their unwanted presence by making sculptures of them has formed an organization he dubbed TACKI (Tampon Applicator Creative Klubs International).

2. Economic Effects

As with the North Sea study area, we have divided this discussion into costs of debris removal, of damage to property, and of lost fisheries catches.

- Debris removal - Beach clean-up is the nearly universal response to marine debris accumulation on Atlantic coast recreational beaches (CEE 1987a). Local, state, and federal governments pay for routine removal from public beaches.

Few figures have been compiled for the area, but a few examples indicate the massive cumulative cost involved. As long ago as 1931, debris removal per kilometer on southern Long Island cost $10,000 annually (Carpenter 1978). Carpenter also learned that, in the 1970s, Bermuda spent $100,000 to clean 1 to 3 kilometers of beach. As Wilber (pers. comm.) reports, this activity is essential since "those beaches which are not groomed have an almost unbelievable accumulation of tar and plastic."

The classic example of the economic costs of marine debris is the summer 1976 "floatables incident" on Long Island beaches. The usual load of debris from commercial and recreational vessels, landfills, sewer outfalls, ocean dumping of sewage sludge, and litter left by beach-goers was augmented when heavy rains overwhelmed sewage treatment plants. Large quantities of debris began washing up on beaches on June 14, and within nine days all beaches were closed to swimming and the governor had declared most of Long Island a disaster area. Plastics exceeded all other materials and consisted mainly of tampon applicators (1 per 3 meters of beach), condoms, sanitary napkin liners, and disposable diapers. Other common items included Styrofoam cups and packaging, toys, straws, bottle caps, and cigar mouthpieces. By July 1, with the help of the Job Corps, the beaches had been cleaned, at a cost of $100,000, and reopened (CEE 1987a). The cost in lost business was considerably higher. The pier fishing industry and bait and tackle shops lost 30% of their business. Restaurants suffered 20% losses. Beach attendance was down by 30-50%. The total economic impact was estimated at $30,000,000 (Swanson *et al.* 1978).

Although this incident was exceptional, it illustrates how easily debris can reach crisis proportions in urban areas. It also serves as a startling reminder that clean beaches are no longer free.

- Damage to property - The only examples of property damage we found were allusions to navigational hazards and propeller fouling by plastic sheeting, ropes, and other debris. Personal communications from Beck (Narragansett Bay) and Blair (Chesapeake Bay) were typical. They and the references in the EPA report (CEE 1987a) for Massachusetts, Virginia, and South Carolina indicate that such incidents occur, but the implication is that they are uncommon.

U.S. Coast Guard records showed about 1000 debris-related cases of vessel disablement in a 2½-year period in the 1980s, the vast majority of which involved large, floating debris such as logs. The Coast Guard does not code these data to indicate which were caused by items such as netting, rope, or plastic sheeting (CEE 1987a).

Underlying concern over vessel disablement, besides financial cost, is the potential threat to human safety.

- Lost fishery catches - Ghost fishing by lost gear is the primary factor in this type of impact. The first study of ghost fishing in the northwest Atlantic was Way's (1976) work in eastern Canada. Table IV-6 gives the catch of the 147.5 set gill nets of unreported length that he found off Newfoundland. Presumably, most of this catch was from the 102 nets in relatively good condition. Way speculated that the catch would have been considerably higher at a time of year when more fish were present. He was not able to estimate the total impact of ghost fishing.

Way concluded that one or more of the following patterns occurs after nets are lost:

- Strong currents cause the headrope and footrope to twist together.
- The weight of the catch forces the headrope to the bottom where debris eventually buries the net.
- In areas of high crab concentrations, crabs infest the net in such numbers that groundfish avoid it (retrieved nets with many crabs had caught few fish).
- In areas of low crab concentrations, untwisted nets continue to fish effectively for at least one or two years (retrieved nets with many fish contained few crabs).

Way thought it likely that crabs were able to free themselves from the nets but did not indicate how.

Table IV-6. Summary of catch from 148 ghost gill nets retrieved off eastern Newfoundland (from Way 1976).

Species	Weight (lbs.)	% Alive	% Dead
Cod	425	81	19
Turbot	4335	80	20
Flounder	99	86	14
Catfish	1662	84	16
Skate	196	90	10
Crab	3220	99	1
Total/Average	9937	86	14

Carr and Cooper (1987) reported on catches in the ghost set nets they found in the Gulf of Maine. Most interesting was one net found in June 1984 and resurveyed in June 1985 and June 1986 (Table IV-7).

No cod, an important commercial species, were seen in any nets. Lobster were the one important commercial species found. Although the lobster were all alive, Carr and Cooper assumed they would not be able to extricate themselves from the nets, in which case a continuing catch of this species at the level observed might be cause for concern. Carr and Cooper, however, give no estimates of total impact on fish or shellfish species. Similarly, the EPA study (CEE 1987a) provides no information on the possible take of the lost New England groundfish set nets it reported on.

Table IV-7. Species catch in a 470 m ghost gill net on Jeffries Ledge (from Carr and Cooper 1987).

Species	1984	1985	1986
Dogfish	48	23	5
Skate		2	1
Wolffish	4		1
Sea Raven	4		2
Pollock		1	
Bluefish		1	
Flatfish		2	
Unidentified		14	
Lobster	4	3	7
Cancer crabs			61
Spider crabs			1

The EPA report does give a 1976 estimate of 1.5 million pounds of lobster in traps at the time the traps were lost. At a 1976 ex vessel price of $1.66/pound, the loss to lobstermen was about $2,500,000. However, there is no estimate of the effect of continued fishing by lost traps.

Lost gill nets are also blamed for causing further fishing gear losses in the Gulf of Maine. According to the Interstate Party Boat Association, some $50,000 worth of lures and line become snagged on lost nets each year, and these incidents were estimated to add $1,000,000 in party boat operating expenses (CEE 1987a).

Finally, one source for the EPA study said dumping sites in the New York Bight were affecting the ability of commercial fishermen to fish.

3. Hazards to Wildlife

For the northwest Atlantic study area, we have organized this discussion into four sections: fish, seabirds, marine mammals, and sea turtles.

• Fish - The first reports of possible marine debris hazards to wildlife involved the ingestion of raw plastics by fish. Carpenter *et al.* (1972) examined the gut contents of 270 larvae of 14 fish species in Long Island Sound. Larvae of eight species contained polystyrene spherules. For two species (white perch and silversides), one-third of the sample had ingested the debris. The authors assumed the spherules might cause intestinal blockage since the diameter of some of the beads (0.5 mm) was half the fishes' width.

As a result of the report from Carpenter *et al.*, Colton *et al.* (1974) tried to assess the effect of plastic ingestion on larval fish and juvenile fish; however, they found no plastic particles in the guts of over 500 fish of 22 species collected in the area of maximum abundance of the spherules (page IV-4). Subsequently, they were unable to induce plastic bead ingestion in larvae and juveniles of six species kept in aquaria. The authors concluded that adverse biological consequences of plastic pellets in the marine environment were minor.

• Seabirds - While people may become numbed to the occurrence of litter on beaches, entanglement of wildlife, particularly birds, seems to have become the sort of visible, sympathy-engendering reminder that jars sensibilities and alerts the public to a problem. More respondents to our study reported entanglement of seabirds, and there were more references to it in the literature, than any other effect of marine debris. From Canada (Nettleship, Lucas, and Bradford pers. comms.) to Rhode Island (Beck pers. comm.) to North Carolina (White pers. comm.), we found passing references to entanglement of seabirds in debris. The EPA study (CEE 1987a) reports entanglement in every Atlantic seaboard state.

Although gulls appear to be, by far, the group most frequently entangled, other birds mentioned included ducks, geese, ospreys, and wading birds. Six-pack yokes and monofilament line are almost the only entangling agents reported. Quantification is practically nonexistent, although one source in Virginia estimated that about eight gulls per year were entangled at one area. None of these anecdotal reports gives the impression of significant numbers of birds being involved.

The scientific literature has several references to seabird ingestion of plastic debris. One of the early reports was that of Rothstein (1973), who found polyethylene pellets in the gizzards of many Leach's storm-petrels nesting off Newfoundland in the 1960s. He did not detect any ill effects for the birds, but speculated about intestinal blockage and PCB poisoning.

In 1971, Hays and Cormons (1974) found white polystyrene spherules in a few gull and tern pellets collected on Great Gull Island, New York, at the eastern end of Long Island Sound. They, also, found no evidence that the pellets harmed the birds.

Day *et al.*'s compendium (1985) of seabird ingestion references includes several records from Canada involving northern fulmars, greater shearwaters, and sooty shearwaters. They also list a Massachusetts record of greater shear-waters having ingested plastic pellets. Of these species, only fulmars had shown any evidence of physical impairment, and those reports were not from the northwest Atlantic.

Elliott (pers. comm.) found plastic pellets and fragments (2-10 mm) in the stomachs of 60 of 1200 thick-billed murres sampled off Newfoundland. The material included bits of fishing line, net, bottles, and rope. He was concerned about possible blockage of the gut, but saw no evidence of ill effects.

The most recent specific case was reported by Dickerman and Goelet (1987). They found a dead, emaciated northern gannet off Long Island, New York, whose stomach was "occluded" by a 9 cm piece of a Styrofoam lobster trap float. The bird's plumage was lightly oiled, also, and it was found with several other birds of three species that had been heavily oiled.

Finally, several recent articles on seabird conservation are negative evidence of marine debris as a threat to seabirds in the northwest Atlantic. Bourne (1982, 1983) in two editorials on human threats to seabirds, one of which focused on Canada, never mentioned debris entanglement or ingestion as a possible factor. The International Council for Bird Preservation's encyclopedic publication *Status and Conservation of the World's Seabirds* has four relevant articles. Brown and Nettleship (1984) list competition with fisheries, chemical pollution, hunting, net-drowning, predation by gulls, and disturbance of breeding sites as the seabird conservation concerns in northeastern North America. Buckley and Buckley (1984) list human disturbance, organochlorine effects, and habitat destruction as the concerns in the north and middle Atlantic United States. And Clapp and Buckley (1984) list oil and organochlorine pollution, habitat destruction, human-induced predation, and human disturbance for the southeastern United States. Sprunt (1984) lists egging and other direct exploitation and possibly oil pollution as concerns in the Bahamas. None of these authors mentions debris entanglement or ingestion.

• Marine mammals - We found a few examples of marine mammal entanglement or ingestion, most of them involving harbor seals. In Canada, one harbor seal had been caught in the ghost nets Way (1976) retrieved. Bowen, Nettleship, and Lucas (pers. comms.) alluded to occasional entangled seals in Canada. Lucas' reports were of both grey and harbor seals on Sable Island. Entanglement has had no observable effect on their populations: harbor seals are stable and grey seals increasing.

The EPA study (CEE 1987a) reported occasional seals entangled in Maine and one entangled seal in Massachusetts.

The levels of these observations suggest entanglement is a minor problem for seals in the northwest Atlantic.

The EPA study also included one reference to a manatee entangled in rope from a crab trap and monofilament line. Another manatee had ingested a piece of rope.

We found no evidence of debris entanglement of cetaceans in the northwest Atlantic study area (Mead, Odell pers. comms). Cetaceans are seen caught in rope and netting, but these incidents are generally assumed to be the result of encounters with actively fished, rather than derelict, gear (Lien, Mayo pers. comms.).

There are a few records of cetaceans ingesting debris (Table IV-8). Since necropsies are not performed on most stranded cetaceans, the actual rate of debris ingestion may be much higher. The complete examinations that have been performed resulted in interesting observations. The necropsy report on the Gervais beaked whale states, "stomach completely filled with plastic bags." However, Mead (pers. comm.) cautions that he has seen no conclusive evidence that ingestion caused harm or death in any of these animals.

Table IV-8. Smithsonian Institution records of cetacean ingestion of plastic bags in the northwest Atlantic as of 2/11/86 (from CEE 1987a).

Species	Date	Sex	Length	Locality
Dwarf sperm whale	12/4/74	F	170 cm	Corolla, NC
Cuvier's beaked whale	1/? /81	F	580 cm	Assowam, VA
Grampus	5/6/82	M	230 cm	Martha's Vineyard, MA
Striped dolphin	3/22/83	M	220 cm	Cape Point, NC
Gervais beaked whale	12/18/83	F	371 cm	Cape May, NJ
Pygmy sperm whale	5/17/85	M	320 cm	Brevard Co., FL
Sperm whale	7/1/85	?	510 cm	Seaside, NJ
Minke whale	8/7/85	M	370 cm	Acoaxet, MA

We found two additional records of sperm whales taken in commercial harvests having ingested debris. Labertsen and Kohn (1986) found a crushed three-gallon bucket in the small intestine of an animal taken off the west coast of Iceland in 1982. Martin and Clarke (1986) found various nonfood objects in the stomachs of fewer than 10% of the 221 sperm whales killed between 1977 and 1981. Debris items were usually less than 0.2 m in length. They mention drinking cups, toys, and a newspaper. They also found five large items, all of them pieces of fishing net, the largest of which weighed 63 kg and was stuck between the second and third stomach compartments. The authors suggest such a blockage could cause starvation and death.

- Sea turtles - Archie Carr and his colleagues have gradually been formulating an explanation of the developmental stage of sea turtles and their relation to oceanic current systems in the Atlantic, Caribbean, and Gulf of Mexico. Of particular relevance to our northwest Atlantic study area are their observations of loggerheads:

> "It thus appears that from the time U.S. loggerhead hatchlings enter the sea...they either are making repeated transatlantic crossings in the main Gulf Stream system or are circling in rings and minor eddies, feeding at and near the surface along fronts...The Azores data provide strong evidence that young loggerheads are oceanic migrants not just as post-hatchlings, but for a protracted period of their early development. It seems necessary, therefore, to give serious consideration to the likelihood that the initial developmental regimen of western Atlantic loggerhead hatchlings is...a period of three years or longer, and that during that time the Atlantic juveniles drift in the Gulf Stream system and feed on pelagic forage along the frontal walls of eddies and gyres" (Carr 1986b).

> "In a way, driftlines are like English hedgerows or like the zones along which terrestrial habitats meet. The comparisons are superficial, though, because the rips draw in not just organisms and their food but everything else that floats as well. And of all the driftline inhabitants, little sea turtles seem the most vulnerable to the pollution the fronts gather" (Carr 1986a).

> "When heavy seas wash the Florida East Coast in the fall, little loggerheads, dead or moribund, are often thrown ashore, sometimes in great numbers. The stomachs of the dead ones often contain pellets of tar and the ubiquitous plastic beads that are delivered to the sea by the millions in industrial waste water. Both the tar pellets and the beads are suggestively similar in size and shape to sargassum floats, and this likeness may account for the turtles' misguided feeding" (Carr 1987).

Carr then referred to the accounts of sea turtles and debris compiled by Balazs (1985), the most complete record of sea turtle entanglement and ingestion. Balazs reported numerous incidents from Florida to Massachusetts of green, loggerhead, hawksbill, leatherback, and Kemp's ridley turtles that had ingested tar, monofilament fishing line (180 m in one case), plastic sheeting (15 eight-quart bags in one case), and plastic fragments. Balazs included several other references to stranded turtles found entangled in fishing line, rope, and netting along the Atlantic coast of the United States and in Bermuda.

Several investigators whom Balazs quoted attributed death to the effects of the debris, especially when an animal's jaws were stuck together with tar, or line restricted its movement or had severed a flipper. Negative effects of ingestion (blocked intestines, reduced absorption of nutrients, absorption of toxic chemicals) were normally difficult to determine.

Plastic bags and sheets were the most common ingested debris (32.1%) followed by tar balls (20.8%) and plastic particles (18.9%).

Since 1980, the Sea Turtle Stranding and Salvage Network has collected information on strandings of marine turtles on the United States Atlantic and Gulf of Mexico coasts (Schroeder 1987a). As with any large volunteer project, effort varies among areas and from year to year. The completeness and accuracy of data also vary. Since necropsies are rarely performed, data on debris ingestion are normally absent (Schroeder pers. comm.). Nonetheless, the effort has provided a valuable data base that, if maintained with some consistency, could be a useful tool for monitoring sea turtle/debris encounters. (See the Effects section of Chapter VI for a discussion of recent research on tar and plastic ingestion by sea turtles.)

Data from all years have not yet been edited, coded, and written up, a job that should be completed by the end of 1988 (Schroeder pers. comm.). At that point, it will be possible to retrieve more detailed information on debris-related strandings from the data base. For instance, final and preliminary annual reports (Schroeder 1987a, 1987b) break down strandings geographically by units as small as counties, but factors such as entanglement and tar are reported only for the entire Maine-Texas study area. As a result, it is only possible at this time to report the annual levels of strandings for both coasts (ca. 1000-2100/year, 1980-1986); the portion of the total occurring in our northwest Atlantic study area for 1986 (1063 or 57%) and the first nine months of 1987 (preliminary figure of 1032 or 62%); the percentage for both coasts involving entanglement in 1985 (1%), 1986 (2.4%), and the first nine months of 1987 (preliminary: 2.3%); and the percentage for both coasts involving tar for 1985 (0.3%) and 1986 (0.5%) (Schroeder pers. comm., 1987a, 1987b). Most of the turtles with tar on them were from southeast Florida, which is outside our northwest Atlantic study area (Schroeder pers. comm.).

Schroeder (1987a) stressed that stranding figures represent minimum mortality since not all turtles strand and not all stranded turtles are observed. She reported carcass tagging studies in South Carolina that resulted in a 27.3% stranding rate. Despite the uncertainties in the data, however, the low rates reported for entanglement and tar are noteworthy for our study.

Mitigation

As with the North Sea study area, marine debris mitigation in the northwest Atlantic study area has been of two general types:

- efforts to remove debris or reduce its effects after it has entered the marine environment, and

- efforts to reduce the amount of debris that enters the northwest Atlantic.

The most obvious activity is, of course, direct removal of debris from coastal areas, primarily recreational beaches. Beach grooming is universal, as reported in the section of this chapter on effects of marine debris. We found more different approaches to reducing the amount of debris in the environment in the northwest Atlantic area than in any other study area. Most of these activities are in the United States.

Canada has long had legislation such as the Ocean Dumping Control Act and the Canada Shipping Act that prohibit at-sea disposal of plastics and other ship-generated trash (Waldichuk pers. comm.), but organized concern about marine debris appears to be a new phenomenon. The government is currently developing a mitigation plan whose general outline will likely include four elements: public education, enforcement of existing regulations, participation in international bodies engaged in drafting new regulations and procedures, and research into the impacts of marine debris on organisms (Bradford pers. comm.).

The first major and visible step the United States government took in regard to marine debris was organizing the International Workshop on the Fate and Impact of Marine Debris in Honolulu in November 1984. As a direct result of concerns identified at the workshop, as well as urging from nongovernmental organizations, Congress appropriated fiscal year 1985 funds for the National Marine Fisheries Service, with guidance from the Marine Mammal Commission, to begin a marine debris research, education, and management program (the Marine Entanglement Research Program). Congress has appropriated additional funds each year since 1985.

In addition, the Coast Guard and the Department of State were the lead agencies in gaining United States ratification of MARPOL 73/78 Annex V in late 1987 (Annex V is discussed on page VII-8). Congress then passed and the President signed into law the Marine Plastic Pollution Research and Control Act of 1987 as a first step in implementing Annex V (MMC 1988). Transmission of the United States' instrument of ratification to the International Maritime Organization on December 30, 1987 fulfilled the requirements for entry into force: 31 nations whose merchant shipping tonnage represented more than 50% of the world's merchant fleet had ratified Annex V. These countries are obligated to begin enforcing its provisions at the end of 1988.

The Marine Plastic Pollution Research and Control Act, besides incorporating into United States law the Annex V prohibitions on garbage discharge from ships, also establishes procedures for determining the adequacy of port reception facilities and for certifying them, and requires periodic reports to Congress on compliance with Annex V. It also mandates an EPA study of methods to reduce plastic pollution, a program of public education on the harmful effects of plastic pollution and the need to reduce such pollution, a study of plastic debris in the New York Bight, and development of a plan to reduce pollution from various sources in the New York Bight.

In the Department of Commerce, under the National Oceanic and Atmospheric Administration, the National Ocean Pollution Program Office is responsible for preparing and revising five-year plans for ocean pollution research and monitoring. The most recent plan was completed in 1985, and a revised plan is scheduled for completion in September 1988. The plan includes an inventory of relevant federal programs, analyses of the extent to which significant marine pollution problems are being addressed, and recommendations for making federal efforts more effective (National Marine Pollution Program Office 1985).

In 1987 at the urging of several senators, the President's Domestic Policy Council asked NOAA to establish and chair an Interagency Marine Debris Task Force with representation from such relevant federal agencies as the Coast Guard, the Council on Environmental Quality, the Department of Agriculture, the Department of the Interior, the Department of State, the Environmental Protection Agency, the United States Navy, and the Marine Mammal Commission. The Task Force was charged with preparing an assessment and recommendations on research and management for the Domestic Policy Council (NOAA 1988).

The Marine Entanglement Research Program has funded a wide variety of research, education, and management projects aimed at assessing effects of marine debris and finding educational and technological approaches to minimizing the problems. Research projects relevant to this report include studying such subjects as the effects of plastic ingestion on seabirds and sea turtles, the relationship between debris and stranded sea turtles in the Gulf of Mexico, the association of debris and oceanic fronts, and amounts and sources of debris at selected National Seashores. The program has initiated an education project for the Atlantic and Gulf coasts aimed at reducing debris from such sources as domestic wastes, commercial fisheries, merchant shipping, recreational fishing and boating, and the petroleum and plastics industries. Management programs include studies of shipboard and port waste management, and investigations with the plastics industry of degradable plastics for various products that are common components of marine debris. Finally, the program will fund a second International Workshop on the Fate and Impact of Marine Debris to be held in early April 1989 (Coe and Bunn 1987; Coe pers. comm.).

Several United States laws are applicable, or potentially applicable, to regulating persistent marine debris. These include the Act to Prevent Pollution from Ships; the Fishery Conservation and Management Act; the Marine Protection, Research, and Sanctuaries Act (Ocean Dumping Act); the Outer Continental Shelf Lands Act; the Resources Conservation and Recovery Act; and the Rivers and Harbors Act. The interested reader may refer to discussions of them in Bean (1984, 1987) and the EPA report (CEE 1987a). Similarly, detailed summaries of other federal agencies' activities (including the departments of State, Defense, Agriculture, and the Interior) can be found in NOAA (1988).

Various state governments in the United States have adopted laws or regulations intended to reduce debris or its effects on the marine environment. One group of these is directed at fishing gear, primarily traps. Maine, for example, requires a biodegradable vent to be incorporated in all lobster traps to minimize ghost fishing. North Carolina has also adopted regulations to reduce the number of lost traps (CEE 1987a).

Several states in this study area (Connecticut, Delaware, Maine, Massachusetts, New Jersey, New York, and Vermont) have prohibited nondegradable plastic six-pack yokes. And in 1987, a bill to ban the sale of tampons with plastic applicators was introduced in the Massachusetts legislature (CEE 1987a).

Since serious marine debris pollution closed many New Jersey beaches in the summer of 1987, that state has attacked the problem with a variety of programs involving beach clean-up funding, anti-litter education, land-source debris research, and enforcement.

Many governmental agencies (especially local, state, and federal parks and wildlife refuges) and nongovernmental organizations are more or less involved with public education efforts (CEE 1987a; White pers. comm.). These include media campaigns and annual Coast Week beach clean-ups, whose educational value is greater than the dent made in debris.

As in the North Sea study area, international regulation has been the approach taken to tar pollution. All four nations in the northwest Atlantic study area — Canada, the United States, Bahamas, and the United Kingdom (Bermuda, Turks and Caicos) — are signatories to MARPOL, Annex I of which limits allowable oil pollution from ships, particularly tankers (see Chapter VII for a discussion of MARPOL).

Summary and Conclusions

Although there are gaps in information, aesthetic degradation and the concomitant costs of beach cleaning appear to be the most serious effects of marine debris in this study area. Entanglement of wildlife is perceived as a problem by many people, but there is no evidence of threats to any species or populations with the likely exception of sea turtles. Enough is now known about the association of sea turtles and debris that these species should receive high priority for research and mitigation (see Chapter V, as well).

The striking difference between marine debris as a problem in the northwest Atlantic compared to the North Sea is the much greater number of major sources in the former, particularly on the United States Atlantic coast. The variety of sources in both areas was similar. In the North Sea, however, merchant shipping is, by far, the largest single source, and implementation of Annex V of MARPOL should solve most of the problems in that area.

Similarly, in the northeastern Pacific, there is a principal source of marine debris to focus on: the fishing industry.

Solving marine debris problems in the northwest Atlantic is significantly complicated by the diversity of major sources. Merchant shipping is clearly a significant source, but domestic wastes from land sources, recreational boating and fishing, and commercial fishing are more important contributors in many areas. Tar pollution from vessels appears to be at least a minor problem. Successfully reducing debris from this constellation of sources will require several industries to develop and adopt new technologies, and millions of people to alter deeply ingrained behavior patterns.

V. DISCUSSION: THE WIDER CARIBBEAN AREA

Description

The Wider Caribbean study area includes the Caribbean Sea, the Gulf of Mexico, the Straits of Florida, and the coastal lands of 25 nations with coasts on those bodies of water (figures V-1 and V-2). Much of the Wider Caribbean littoral constitutes a developing region with modest levels of industrialization and urbanization. On the immediate coast, there are 24 cities with populations over 100,000, including nine over 500,000 and one (Havana) over 1,000,000 (UNEP 1984).

Rivers flowing into the Caribbean and Gulf, including two of the world's largest, drain about 7,500,000 km^2. The Mississippi and the Orinoco alone drain over 4,000,000 km^2. (The mouth of the Orinoco lies just east of the Caribbean, but the powerful westward drift of the North Equatorial Current carries most of its outflow into the Caribbean.) Total freshwater inflow from the 18 largest rivers averages about 66,000 m^3/second, a figure that is dwarfed by the 30,000,000 m^3/second entering from the North Atlantic (UNEP 1984).

The hydrography of the Caribbean Sea is dominated by the flows of the North Equatorial Current and, to a lesser degree (near Trinidad and Tobago), the South Equatorial Current, which filter westward through the Lesser Antilles. This combined flow, as the Caribbean current, eventually bends northwestward toward the Yucatan Channel. The southwest Caribbean gyre is a subsidiary, cyclonic pattern in the large embayment formed by the coasts of Nicaragua, Costa Rica, and Panama (UNEP 1984).

The hydrography of the Gulf of Mexico is more complex. The Caribbean Current enters the Gulf via the Yucatan Channel and exits to the east through the Straits of Florida as the Gulf Stream. In between, the Gulf Loop Current may take a variety of routes. At times, most of the flow through the Yucatan Channel immediately turns east along the north coast of Cuba. Most of the year, the Loop Current flows north from the Yucatan Channel for several hundred kilometers before turning sharply to the east and south on its way to the Straits of Florida. Except for periodic intrusions off western Florida, this flow remains seaward of the broad continental shelf of the United States Gulf coast (Van Vleet *et al.* 1983).

Circulation in the western Gulf of Mexico is less well understood. The main body of the western Gulf is dominated by an anti-cyclonic gyre off Louisiana, Texas, and northern Mexico. Although eddies from the Loop Current occasionally pinch off and enter the western Gulf, there seems to be little exchange between the two areas, especially from the western to the eastern Gulf. The Bay of Campeche is a sub-area with its own cyclonic gyre (Van Vleet *et al.* 1983b; Atwood *et al.* 1987b).

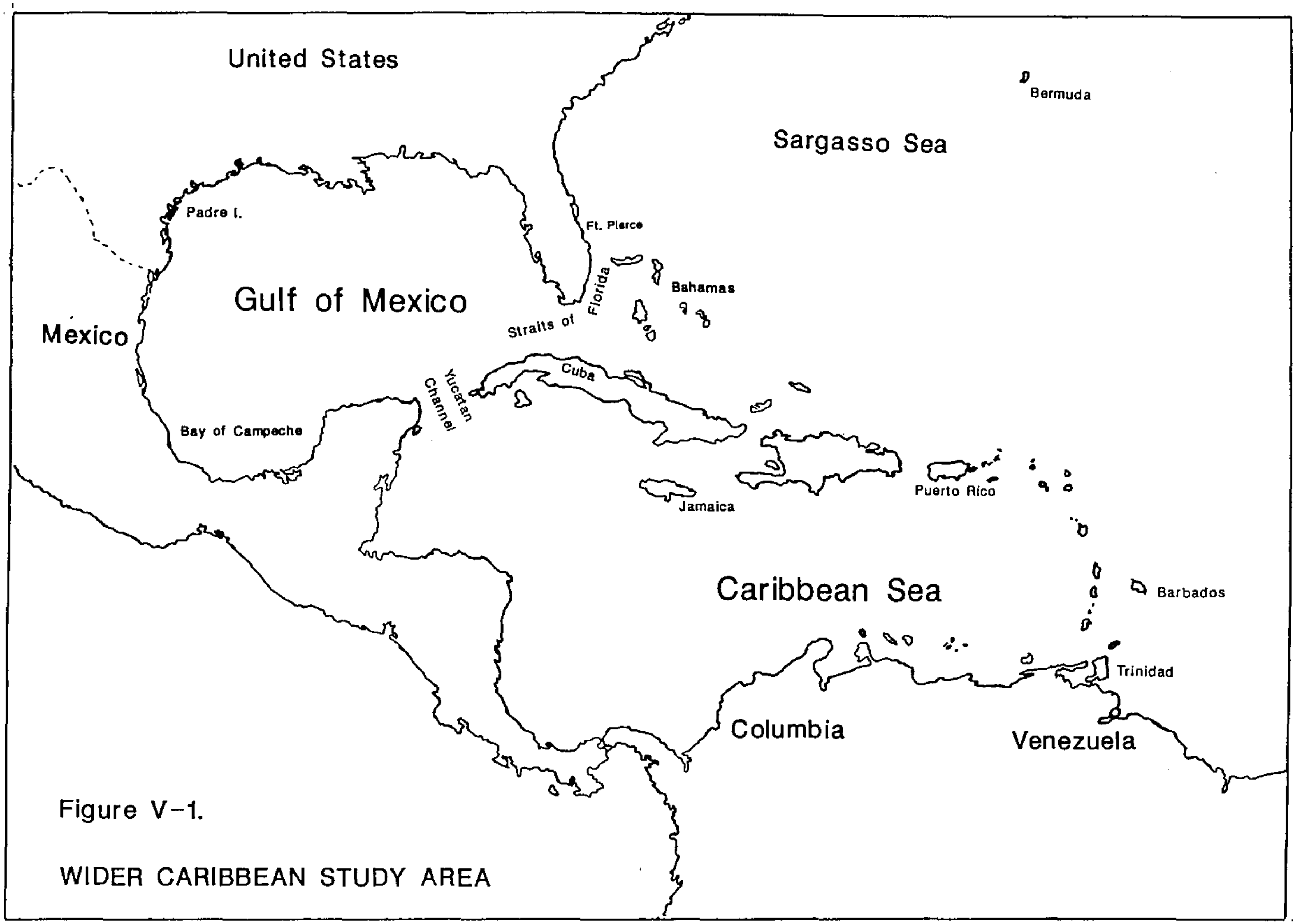

Figure V-1.

WIDER CARIBBEAN STUDY AREA

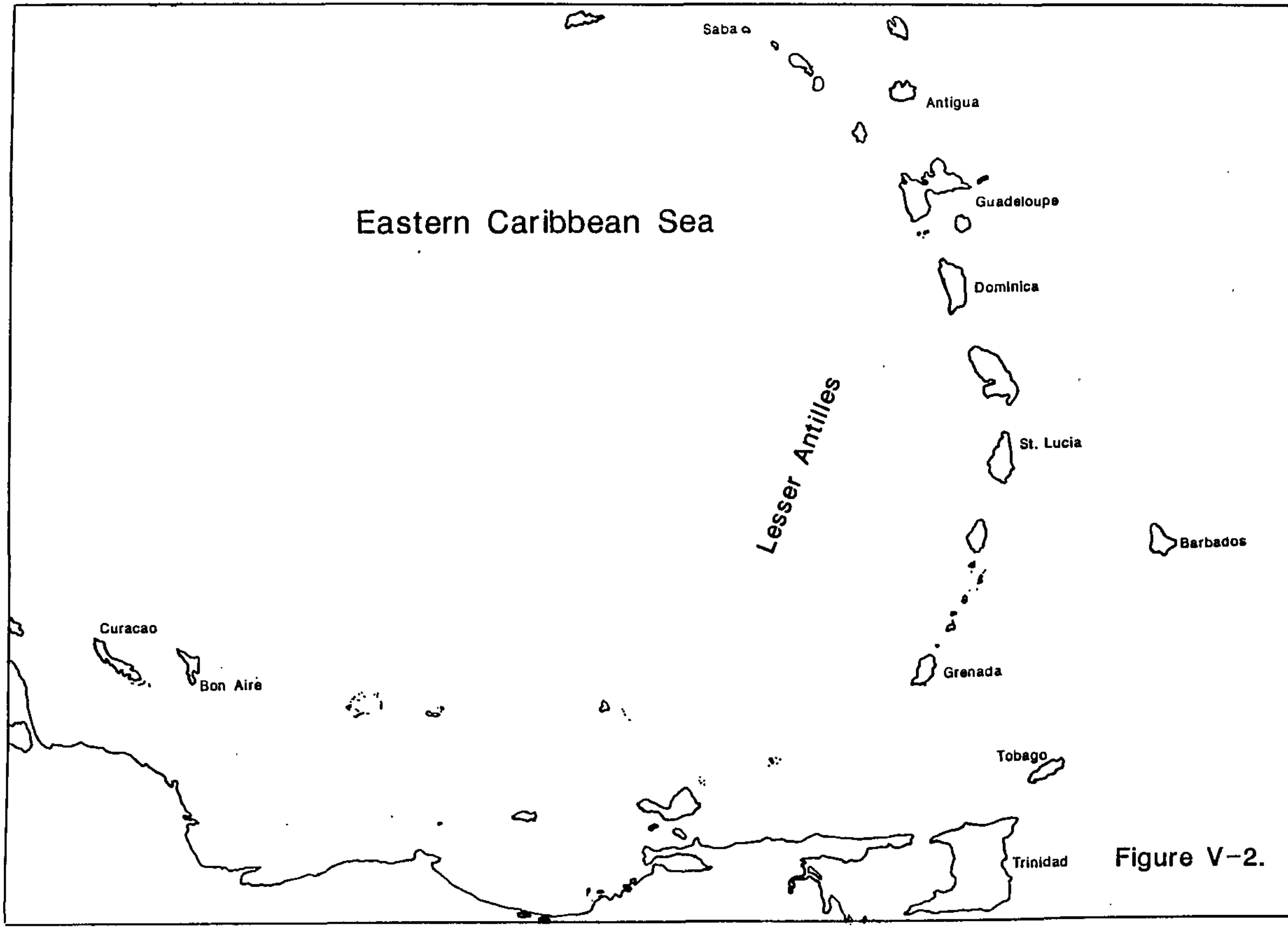
Eastern Caribbean Sea
Lesser Antilles
Saba
Antigua
Guadeloupe
Dominica
St. Lucia
Barbados
Grenada
Tobago
Trinidad
Curacao
Bon Aire

Figure V-2.

With the exception of storm systems (tropical storms, hurricanes, and *el nortes*), southeast, east, and northeast tradewinds prevail in most of the Wider Caribbean all year (Atwood *et al.* 1987b; Georges and Oostdam 1983).

The wind and current information about the Wider Caribbean summarized above, and its relationship to the distribution of marine debris in the area were made graphic by a surface drifter study (not related to debris) for the Office of Naval Research in 1975-1977. The two series of launches represented in Figure V-3 are typical of their results. The predictive value of this work by Parker *et al.* (1979) has since been confirmed by other investigators directly concerned with the occurrence of various kinds of debris, including tar and plastic. This study provides the experimental underpinnings in the Wider Caribbean for the model Wilber (page IV-8) elaborated from his pelagic and beached plastic studies in the North Atlantic and eastern Caribbean: it demonstrates what happens to debris in the southern periphery of the North Atlantic gyre that drifts into the Caribbean, rather than being carried northeast toward the Gulf Stream with the Antilles Current.

The general picture that emerges, of debris entrained in major currents until the stronger influence of easterly tradewinds deposits it on windward beaches, helps to explain much of the following section of this chapter. With localized exceptions, east-facing beaches throughout the Wider Caribbean, but especially in the Lesser Antilles, the Yucatan, Texas, and southeast Florida, are the ultimate dumping grounds for our oceanic litter and tar.

No comparable model has been elaborated for the North Sea, although there are obvious patterns of debris occurrence (e.g., downwind from shipping lanes). The North Atlantic Gyre and the current system of the Wider Caribbean are interrelated, but winds are far less regular in the North Atlantic, and giant, long-lasting eddies there make the effects of currents less predictable. Two areas are exceptions and reliably follow a pattern similar to that in the Wider Caribbean: Bermuda's coast presents a small barrier that collects floating material headed for the Sargasso Sea, and the Bahamas are far enough south to be influenced by the tradewinds, which sweep part of the Antilles Current's debris load onto their windward beaches (see pages IV-6 through IV-10).

Within this larger framework, Archie Carr described other key processes that determine the distribution of marine debris:

> "I came to realize that the fundamental factor in the pelagic stage of sea turtle development is...the gathering of resources that takes place at a front, a convergence where different bodies of water come together. Apparently, horizontal friction or collision there generates sinking, or downwelling, and this mobilizes and aligns anything buoyant in the vicinity...Convergences range in magnitude from trivial disruptions to the shears and collisions of the big geostrophic currents and midocean gyres. To a casual observer, they may be conspicuous only when flotsam is present. Anybody who has done a lot of looking down at sea from an airplane at moderate altitude may have noticed areas of the sea surface

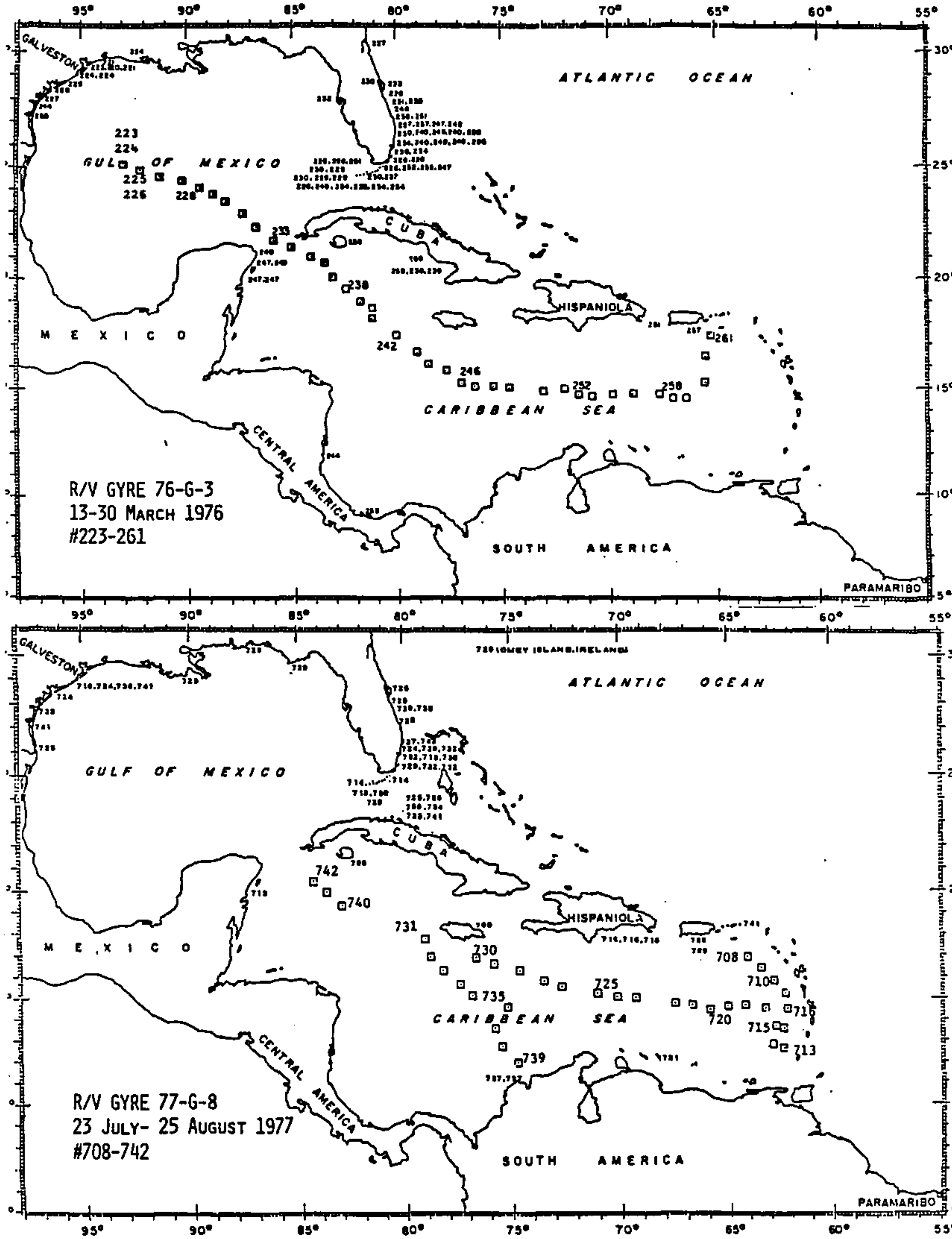

Figure V-3. Locations of launches (squares with batch numbers) and recoveries (small numbers along coasts) of surface drifters (Parker *et al.* 1979, reproduced with authors' permission.)

striated with ragged, roughly parallel lines of floating stuff. These are known as Langmuir bands. They are produced, I am told, when wind blows steadily at seven knots or more. This somehow sets up a series of evenly spaced counterrotating vortices, the axes of which run...in the direction the wind blows. Along the line where each pair of these opposing eddies collide, the water sinks, and anything afloat is drawn in...It is not a cheering thought that these days Dr. Langmuir's bands are made more conspicuous in the seas of the world by the abundance of styrofoam scraps and plastic bags and other human garbage that they hold" (A. Carr 1986a).

Types, Quantities, Sources, and Distribution of Marine Debris

We have organized this discussion according to the major types of debris we encountered references to: tar, general land- and ocean-source litter, and fishing gear. Unlike the chapters on the other study areas, we have chosen to discuss tar first because it is perceived in the Wider Caribbean as the most important marine debris issue, and because there is much more information available on tar than on other types of persistent marine debris.

1. Tar

According to UNEP (1984), the petroleum industry is the most significant economic activity in the Wider Caribbean, and "contamination by petroleum hydrocarbons seems to be the most serious marine pollution problem of the region." Transportation and production contribute the most to the problem. Corredor (1987), chairman of the steering committee of the CARIPOL petroleum pollution monitoring project in the Wider Caribbean, has written:

> "Petroleum pollution is an issue of major concern in the region...Floating and stranded tar balls are ubiquitous...Not only do tar aggregations pose a considerable problem to commercial development of the coastal zone, especially to the use of beaches for tourism; the work here presented points to the serious threat that tar aggregations pose to marine life."

Major Wider Caribbean petroleum production areas include Louisiana, Texas, the Bay of Campeche, Venezuela, and Trinidad and Tobago, all of which are classified as production accident high-risk zones. In 1982, more than 2000 offshore United States structures accounted for nearly 15% of the world's offshore production (UNEP 1982). Mexican petroleum development has grown rapidly in the past 15 years. Total offshore production in the Wider Caribbean was over 400,000 metric tons/day in 1978, and significant expansion is expected. Nonetheless, the National Research Council (NAS 1985) estimated that, worldwide, offshore production is responsible for less than 3% of the tar in the marine environment (50,000 metric tons/year).

Transportation of oil, as well as other merchant shipping, are thought to account for a major portion of oil pollution through deballasting and disposal of fuel oil sludge and bilge oil. The National Research Council (NAS 1985) estimated that, of the various sources of tar in the marine environment worldwide, normal merchant shipping operations (excluding accidental spills from tankers) contributed over 55% (about 1,000,000 metric tons/year). Van Vleet *et al.* (1984) estimated that at least 50% of the floating tar in the eastern Gulf of Mexico and Straits of Florida was from tank cleaning and ballasting operations. Atwood *et al.* (1987b) concluded that perhaps half the tar in the Caribbean originated in the Atlantic and that most was from tanker operations.

About 700,000 metric tons of oil/day were transported through the Wider Caribbean in 1983. Most of the traffic was on three major routes: between the Middle East and Africa and refineries on the United States Gulf Coast, between Venezuela or the Netherlands Antilles and various world markets, and between Panama and the United States Atlantic and Gulf coasts and the Virgin Islands. There are also many minor routes for transportation of crude oil and refined petroleum products within the Caribbean (UNEP 1984). According to Hayes (pers. comm.), however, almost all of the few Wider Caribbean locations where tankers are loaded now have shore reception facilities for oily ballast, although these terminals may not be equipped to receive fuel oil sludge from tankers. Furthermore, thousands of general cargo vessels call at the 70 ports in the region, many of which lack reception facilities for increasing quantities of fuel oil sludge and other oily waste being generated by diesel-powered merchant ships. (See the more detailed discussion of tar from vessels in the Mitigation section of this chapter and in the section on MARPOL in Chapter VII.)

The Wider Caribbean Area is also one of the more important locations of natural seeps in the world. These are located primarily along the Gulf Coast of Texas and Mexico, the coast of Venezuela, near Trinidad, and on the Barbados Ridge (NAS 1985; Speed pers. comm.). Their relative contribution to Wider Caribbean tar is unknown, but a few investigators have suggested it may be significant in some areas such as the western Gulf of Mexico (NAS 1985), Trinidad, and Barbados (Speed pers. comm.). The National Research Council (NAS 1985) estimated that seeps represented about 14% of the total tar entering the world's seas (250,000 metric tons/year).

A few attempts have been made to estimate the amount of tar entering the Wider Caribbean (Van Vleet *et al.* 1984). The range in these estimates is enormous, and the assumptions necessary to make them are daunting. We have chosen to ignore these estimates rather than try to reconcile them.

In 1976, the Intergovernmental Oceanographic Commission's (IOC) Regional Program for the Caribbean and Adjacent Regions (IOCARIBE) set marine pollution monitoring as one of its highest priorities. Subsequently, petroleum was selected as the pollutant of greatest immediate concern. In 1979, IOCARIBE started a pollution research program, CARIPOL. Its first project was monitoring of floating tar (neuston net samples reported as milligrams per square meter of sea surface), tar on beaches (collected from the water line to the back of the beach from 1-m wide transects and reported as grams/linear meter of beach front), and dissolved/dispersed hydrocarbons. The program, designed to allow participation from throughout the region without sophisticated equipment, was sponsored by IOC/IOCARIBE and the United Nations Environment Programme (UNEP) Caribbean Action Plan (CAP). CARIPOL was modeled on the Marine Pollution Monitoring Project (Petroleum) (MAPMOPP) conducted by the IOC and the World Meteorological Organization (Atwood *et al.* 1987c, 1987d).

By the end of 1986, investigators representing 13 governments had made over 7500 observations of beach tar and floating tar (this report does not summarize the work on dissolved/dispersed hydrocarbons). Most of the following discussion of tar in the Wider Caribbean is based on the CARIPOL study.

- Floating tar - There is less information, from all sources, on floating tar than on tar on beaches. Table V-1 summarizes most of the information developed in the CARIPOL project.

Table V-1. Summary of results of CARIPOL floating tar study, 1979-1984. Values are percentages of observations (from Atwood *et al.* 1987b).

Area	Number of Observations	Tar Concentrations (mg/m^2) 0-0.1	0.1-1.0	>1.0
Eastern Caribbean	138	81%	10%	9%
Northwest Caribbean	95	71	16	13
Western Gulf of Mexico	36	72	19	9
Bay of Campeche	39	92	3	6
Eastern Gulf of Mexico	332	58	24	17
Straits of Florida	43	35	28	37

An important point in interpreting such data is that floating tar is extremely patchy in occurrence and variable in amount (Van Vleet *et al.* 1984). As a result, the sample sizes from some of the CARIPOL areas were small enough that they may be highly unrepresentative and misleading. (We did not include three observations from the southwest Caribbean in Table V-1.) The data give an indication of tar concentrations, however, and where there is overlap with the earlier MAPMOPP study, concentrations are similar (Atwood *et al.* 1987b).

The Straits of Florida had by far the highest percentage of observations of floating tar in amounts greater than 1 mg/m^2, and that area and the eastern Gulf of Mexico had the lowest percentage less than 0.1 mg/m^2. Some of the data are perplexing. For example, the low concentrations found in the Bay of Campeche (Cortes-Vazquez *et al.* 1987) seem to contradict the very high tar levels found on beaches on the west side of the bay (see page V-15).

Van Vleet *et al.* (1983a, 1983b, 1984) originally reported the floating tar results for the northern and eastern Gulf and Straits of Florida. Their data are summarized in Figure V-4, Figure V-5, and Table V-2. Van Vleet *et al.* made 416 neuston tows in the eastern Gulf, Straits of Florida, and Yucatan Channel in 1980 and 1981. The highest levels (Figure V-4) were associated with the

Loop Current and in the Straits of Florida. (The results for the Straits of Florida were anticipated in 1972 by the Coast Guard study of tar in United States coastal waters. The highest average levels found were in nearshore waters off Miami and Fort Lauderdale, Florida.) On average, tar concentrations associated with the main current system (areas C, F, and G in Figure V-5) were more than an order of magnitude greater than those from over the Shelf (areas A, B, D, and E). These investigators predicted that the southeast Florida coast, from Key West to Fort Pierce, was the area most likely to be affected by the tar. Atwood *et al.* concluded that the relatively low value for floating tar in the northern Straits of Florida indicated that prevailing southeast winds had already deposited most tar farther south on the Florida coast and on the Florida Keys. (See Romero *et al.* 1981 in the discussion of tar on beaches on page V-15.)

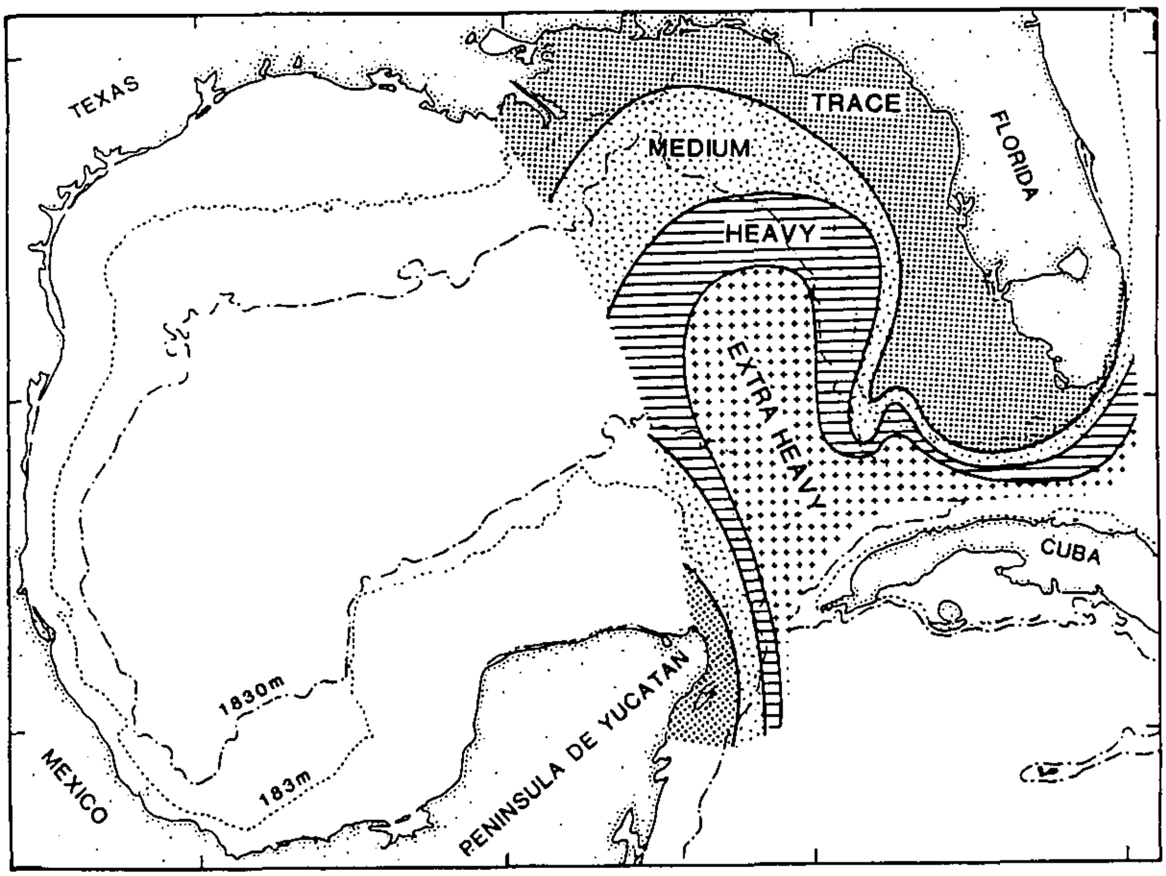

Figure V-4. Average distribution of floating tar in the eastern Gulf of Mexico. Contours represent probabilities of various concentrations. All concentrations are given as wet weights.

Trace = < 0.1 mg/m^2
Medium = 0.1-1.0 mg/m^2
Heavy = 1-5 mg/m^2
Extra heavy = >5 mg/m^2

(Reproduced from Van Vleet *et al.* 1984 with permission of the author.)

Figure V-5. Geographic areas sampled for floating tar by CARIPOL project. Results are summarized in Table V-2. (Reproduced from Atwood *et al.* 1987a, with permission of the *Caribbean Journal of Science*.)

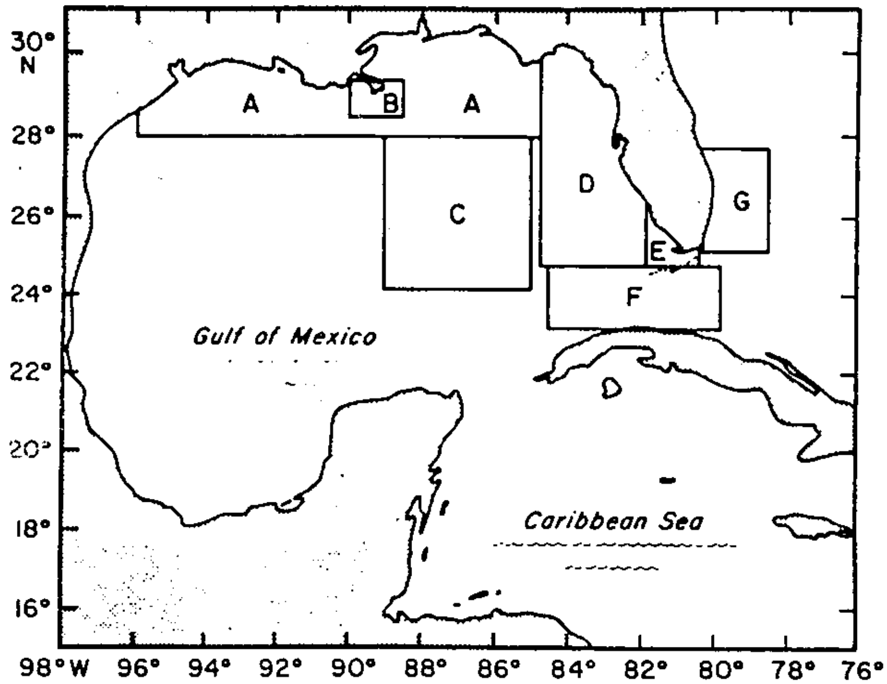

Table V-2. Floating tar concentrations (wet weight) in the northern and eastern Gulf of Mexico and the Straits of Florida. Letter codes refer to areas in Figure V-5 (from Atwood *et al.* 1987a).

Geographic Areas		Number of Observations	Average Concentration (mg/m^2)
A	Northern Gulf of Mexico	69	0.6
B	Mississippi Outflow	19	0.2
C	Gulf Loop	44	2.3
D	Florida Shelf	153	1.1
E	Florida Bay	18	0.4
F	Southern Straits of Florida	52	4.7
G	Northern Straits of Florida	22	1.1
	All areas	393	1.8

The low levels of tar in Shelf waters included the Florida Panhandle and the Louisiana coast, where samples were taken in the Mississippi River discharge and near concentrated offshore oil development activity. Van Vleet *et al.* (1984) concluded that the contributions of the Mississippi River and offshore rigs to tar in the Gulf were negligible.

Based on the information presented above and on samples they and other investigators took in the Yucatan Channel, they estimated that a substantial portion (up to 50%) of tar in the eastern Gulf enters from the Caribbean, and that the remainder originated within the Gulf.

From analysis of tar samples, Van Vleet *et al.* estimated that about half of the tar in the eastern Gulf was attributable to tanker discharges. (The samples had *n*-alkane distributions thought to be characteristic of either crude oil from tanker washing or refined No. 6 fuel oil.) The rest may or may not have been from tankers: the sources could not be identified. In addition to the Mississippi River and offshore oil rigs, they ruled out natural seeps as likely sources of significant amounts of tar in the eastern Gulf.

Van Vleet *et al.* (1983a) found the highest tar concentrations associated with sargassum, which suggests the influence of downwelling. However, they cite other investigators who found a poor association between sargassum and tar in the North Atlantic.

The average values Van Vleet *et al.* found for the eastern Gulf (<2mg/m^2) were comparable to concentrations reported for parts of the northwest Atlantic (Chapter IV). Average values different investigators have found for the Caribbean have varied from 0.2-1.35 mg/m^2 (Butler *et al.* 1973; NAS 1985).

Other results of the CARIPOL floating tar study deserve comment. In the eastern Caribbean, Corredor *et al.* (1983) found a strong correlation between tar ball abundance and wind direction off the southwest coast of **Puerto Rico**. Tar concentrations were greatest in periods of south winds, suggesting sources in the central and southern Caribbean. When the original 1980-82 data collection was continued into 1985, Morell and Corredor (1987) discovered a strong correlation between tar pollution and tanker traffic to a petrochemical complex at Guayanilla, Puerto Rico. Both tanker traffic and floating tar diminished after several plants in the complex closed.

Wade *et al.* (1987) sampled floating tar in Kingston Harbor (**Jamaica**) and its approaches from 1980 through 1983. Amounts of tar from 112 samples were negligible in the harbor, while 119 samples from the approaches averaged about 5 mg/m^2 (wet weight). Most of the fresh tar analyzed was similar to the Venezuelan crude that Jamaica normally imports. Some tar balls had apparently been in the water for a considerable period, however, since they were heavily weathered and showed barnacle growth.

Between 1980 and 1983, Burton (1987) found an average of 0.045 mg/m^2 (wet weight) of floating tar in 30 samples off **Grand Cayman**. He also received reports from aircraft of 12 oil slicks (February 1982-October 1985). Nine of the sightings were early in the morning with no vessel nearby, suggesting that the discharges occurred at night. Ships were associated with the other three slicks: an oil tanker cleaning tanks, another tanker discharging oily ballast, and an ore carrier discharging light oil. All slicks were less than 0.5 km wide. The longest was about 100 km.

Finally, little was learned about floating tar concentrations in the western Gulf (north of the Bay of Campeche) since the few samples taken in that large area (Table V-1) were concentrated in the eastern portion (Atwood *et al.* 1987b). Van Vleet *et al.* (1983b), the National Research Council (NAS 1985), and Scalan and Winter (1980) cited earlier work attributing some floating tar off the Texas and Mexican coasts to natural seeps.

- Tar on beaches - Most of the CARIPOL data on tar on beaches are summarized in Table V-3. Although tar on beaches is much less ephemeral than floating tar, several investigators have commented on the extreme variability of its occurrence, even from sites that are adjacent to each other and in samples taken close together in time. Atwood *et al.* (1987b) also point out that information is lacking for some locations, such as the northern Gulf of Mexico. Nonetheless, the data confirm a serious beach tar problem in many areas, particularly on windward coasts:

> "Experience throughout the region indicates that when beach tar values reach 10 [gm/linear meter of beach], persons using the beach commonly get tar on their feet. At values approaching 100 [gm/linear meter] the beaches become virtually unusable for tourist purposes" (Atwood *et al.* 1987b).

The following discussion of beached tar information, from the CARIPOL project and other sources, begins in the eastern Caribbean and generally follows the main current system on its route to the Straits of Florida. (Where available, values are reported in Table V-3). In general, there was a pattern of windward coasts being much more heavily tarred than leeward coasts, and highest levels being associated with major currents and tanker traffic routes.

The ranges of values for **Barbados** in Table V-3 illustrate this windward-leeward pattern; however the picture on Barbados is complicated by significant natural seeps on and near the island on the Atlantic side. According to Speed (pers. comm.) there may be seeps on much of the Barbados Ridge, which begins north of Barbados and ends near Trinidad. This nonvolcanic formation is east of, and parallel to, the volcanic chain of islands that begins with Guadeloupe in the north and ends with Grenada in the south. The volcanic archipelago has a very low potential for seeps. Speed also said it would be easy to distinguish between naturally occurring and anthropogenic tar based on the distinctive mineral content of tar from seeps. Horrocks (pers. comm.) reported soft tar balls 5-30 cm across (thought to come from tankers) commonly occur every few hundred meters on the Atlantic coast. More common are hard, 0.5 cm weathered lumps that, in heavily oiled areas, may occur about every 15 cm.

Table V-3. Summary of results of CARIPOL tar on beaches study in the Wider Caribbean Area. Some values are approximate (derived from Corredor *et al.* 1987; Atwood *et al.* 1987b).

Area and (Number of Sites)		gm/linear meter	gm/m^2	Range (gm/linear meter)
Barbados	windward			10-100
	leeward			<1.0
Trinidad & Tobago (108)	windward	45-50		
	leeward	0.2-3.1		
Grenada	windward			10-100
	leeward			1-10
Turrumote Key,	windward	3-13		
Puerto Rico (4)	leeward	24-58		
Jamaica (32)	windward	38-243	27	
	leeward	5		
Grand Cayman (6)	windward	70-607		
	leeward	0.3		
Bonaire (7)	windward	56-278	3-55	
	leeward	0	0	
Curacao (2)	windward	44-363	12	
	leeward	0		
Venezuela				<10
Columbia				<10
Costa Rica (9)		0-0.5		
Yucatan (east & north)				10-1000
Bay of Campeche (8)	windward		32-179	
	leeward		0-3	
Florida (26)	windward		10	
	leeward		0.3	

The Atlantic coasts of **Trinidad and Tobago** had tar values comparable to coasts elsewhere in the world that are located close to petroleum transport routes or significant natural seeps, according to Georges and Oostdam (1983). Various factors led them to attribute most of the Atlantic coast tar to tanker operations somewhere upstream in the South Equatorial Current, although the presence of natural oil seeps and offshore oil development nearby complicated the picture. The Caribbean coast of Trinidad was "practically pristine" despite being adjacent to a second major offshore oil production area.

The windward and leeward coasts of **Grenada** exhibited the typical Wider Caribbean pattern.

Elsewhere in the Lesser Antilles, Heneman, in 1988, found both windward and leeward beaches to be almost devoid of tar on St. Lucia and Dominica. He observed moderate amounts of tar on the rocky, Atlantic coast of Barbuda, the northernmost of the islands visited.

Ogden (pers. comm.) reported that tar pollution is an infrequent annoyance on **St. Croix** despite tanker traffic associated with an oil refinery on the island. When tar does appear on beaches, it may be either fresh or weathered.

In Table V-3, the data for Turrumote Key in **Puerto Rico** is anomalous since the higher concentrations were on the leeward side. Otero *et al.* (1987) suggest that wave refraction at this 500 m long islet explains the anomaly.The important point for this location was the presence of significant amounts of tar. They also found that peak occurrences of tar on Turrumote coincided with peaks of floating tar offshore (as reported by Morell and Corredor 1987).

As can be seen in Table V-3, tar was significantly heavier on windward beaches in **Jamaica**. Analysis showed that most of the tar from the exposed, southern beaches was similar to the Venezuelan crude oil typically imported by Jamaica (Wade *et al.* 1987). Tar from the protected, north coast was from an unknown source. Experiments at one windward beach near Kingston Harbor yielded a rate of tar deposition of 1.4 gm/linear meter/day, although following "documented near-shore tanker washing," the rate was as high as 400 gm/linear meter/day. Wade *et al.* attributed most of the tar to tanker operations.

Burton (1987), who found much heavier tar concentrations on the windward side of **Grand Cayman** during his 1980-83 CARIPOL sampling, said most of it was from crude oil (Table V-3). Various tests of different samples suggested similarities to Alaskan, Arabian, and Mexican crudes. Burton found no significant increase or decrease in tar when he compared results for the first 11 months of the study with the second 11 months on Grand Cayman. However, qualitative reports from Little Cayman indicated a substantial reduction in beached tar there after an area near that island ceased being used as a center for oil lightering operations in 1982.

In **Bonaire** (Newton 1987) and **Curacao** (Richardson *et al.* 1987) in the southern Netherlands Antilles, the typical pattern of high tar concentrations on windward beaches and low values for leeward beaches was evident (Table V-3).

Venezuela and **Columbia** showed similar levels of beach tar. Most sampling sites had low levels. There were a few problem areas in each country, but these generally were not closely associated with oil production areas. The pattern of low tar values in these two countries reflects the fact that the heaviest beach pollution in the Wider Caribbean was downwind from major currents and tanker routes.

We found two conflicting reports for the west coast of the southwest Caribbean gyre. Mata *et al.* (1987), in 74 samples from two locations in **Costa Rica** in 1981-85, found virtually no tar (Table V-3). However, Kilar (pers. comm.), in a non-CARIPOL project at Galeta Point in Panama, continuously sampled over 100 meters of reef front and recorded high tar accumulation rates: 10 gm/linear meter/day. Kilar's site, Galeta Point, was six km east of the Caribbean entry to the Panama Canal.

Most of the sampling sites on the eastern and northern **Yucatan Peninsula** coasts had average values over 100 gm/linear meter of beach (Table V-3). In 1988, Heneman observed tar levels on the eastern coast high enough to require daily grooming for reasonable use by beachgoers. Hotels and resorts in this major tourist area routinely provide solvents for vacationers to clean tar from their feet.

Cortes-Vazquez *et al.* (1987) took a total of 31 samples from eight sites in the **Bay of Campeche** in 1983-84 and found very low values on the east coast and high average values on the west coast (Table V-3). (They found very high values in one sample on Cayo Arcas - an islet in the bay used as an offshore terminal - which is not included in Table V-3.) The high levels on beaches in the southwestern Bay of Campeche seemed to be contradicted by the low levels of floating tar found in the Bay of Campeche in the CARIPOL study (Atwood *et al.* 1987b, and see Table V-1). The authors attributed the high levels of beach tar to petroleum activities in the Gulf of Mexico, particularly offshore oil development and related tanker and terminal operations in the Bay of Campeche.

Several investigators have observed significant hydrocarbon seeps in the Bay of Campeche, but their reports have been more of gas and liquid petroleum than of tar (Scalan and Winters 1980).

In 1988, Heneman surveyed five 200 m sections of beach on the east coast of the Bay of Campeche, between Sabancuy and Champoton, and found no evidence of tar. These observations included one of the CARIPOL sites that yielded low tar levels. However, Rodriquez (pers. comm.), a resident of Campeche who studies the effects of oil on fish for the Mexican national fisheries agency, reported that tar was a frequent and serious problem on recreational beaches south of the city of Campeche. This contradiction might be explained by the fact that the CARIPOL project sampled the three eastern Bay of Campeche sites only two or three times each. Nonetheless, it seems clear that beach tar is much heavier on the western coast of the bay: all eight eastern Bay of Campeche samples had zero tar levels; none of the 23 western samples had zero tar, and 12 of them had concentrations of over 25 gm/m^2.

Hildebrand (pers. comm.) also reported that the worst areas on the Mexican coast are along the southwest Bay of Campeche coast, especially near Tampico, Tuxpan, Alvarado, and Coatzacoalcos. He reported there are some natural seeps, but attributed most tar to sloppy procedures in transferring crude oil to tankers from both onshore and offshore production facilities. According to his observations, there has been less tar near Tampico and Tuxpan in recent years. Oil fields on shore in that area had become less productive, and the transfer of crude oil to tankers has virtually ended. He also suggested that spills have decreased because of increasing sensitivity of residents to oil on beaches.

Atwood *et al.* (1987a) knew of no quantitative studies, but reported that **Texas** beaches are reputed to be heavily oiled. Unfortunately, there were no CARIPOL participants anywhere on the Gulf coast between the Bay of Campeche and

Florida. Hildebrand (pers. comm.) reported that, with local exceptions, beaches in Texas are more heavily tarred than those in Mexico. As mentioned above, the National Research Council (NAS 1985) and Van Vleet *et al.* (1983b) cited reports of significant natural seeps contributing to floating tar in the western Gulf of Mexico. However, Pace (pers. comm.) reported that, according to his observations, tar concentrations on Padre Island were much lower 40-50 years ago than currently, suggesting a source other than natural seeps. Scalan and Winter (1980) cited earlier studies showing fewer hydrocarbon seeps off of Texas than in the Bay of Campeche. Pace and Whistler (pers. comm.) also said the problem is generally worse in spring and summer when onshore winds are most consistent.

The only quantitative study of beach tar in Texas that we became aware of is one Amos and Plotkin are conducting on Mustang Island. Once a week in March-November 1987, they collected and weighed all tar on three 10 m wide transects. They found tar in 100% of the 30 surveys they conducted. Tar concentrations averaged 40 gm/linear meter of beach, with the heaviest occurrences in May and July (Amos and Plotkin unpublished data), four times the level at which Atwood *et al.* (1987a) said that beachgoers commonly get tar on their feet. Knowledgeable observers generally thought tar concentrations were even higher on Padre Island and South Padre Island.

Amos has collected and frozen tar samples from Mustang Island for nearly ten years, but has not yet found funding to have them analyzed. These samples might help identify sources of the tar on Texas beaches.

Van Vleet (in press) reported heavy concentrations of beach tar in the **Dry Tortugas**, levels comparable to those Romero *et al.* found in the Florida Keys (see below).

In 1971-72, at a beach north of Miami, **Florida**, the Coast Guard sampled tar from five transects with a total width of about 140 m on a beach about 380 m long. They collected all tar from the transects five days weekly for one year. The average daily deposition rate for the year was over 7 gm/linear meter of beach, a result that was comparable to what Romero *et al.* found nearly a decade later in the same general area.

Romero *et al.* (1981) took 177 beach tar samples at 26 sites on the Atlantic and Gulf coasts of Florida in 1979-80 (Figure V-6). All but the four northernmost sites on the Atlantic coast are in our Wider Caribbean study area. Table V-3 gives values for the 12 windward (Atlantic) coast sites south of Fort Pierce and the 10 leeward (Gulf of Mexico) sites. The six sites on the Atlantic side of the Florida Keys averaged about 16 gm/m^2, while many of the Gulf Coast sites were pristine, a result that fits neatly with the floating tar data reported by Van Vleet *et al.* (page V-8). The beached tar study found even higher tar levels in the Florida Keys than in the Miami-Fort Pierce area, a pattern that corresponded to the higher levels in the southern Straits of Florida than in the northern straits in the floating tar study.

Romero *et al.* suggested the high tar levels on the southeast coast were attributable to a combination of southeast winds, heavy shipping in the Straits of Florida, and tar carried by the Caribbean and Gulf Loop currents. They also reported that there is no evidence tar is increasing or decreasing on Florida beaches in the past 30 years. Their data was comparable to American Petroleum Institute studies in 1958 and 1971-72. Atwood *et al.* (1987d) suggest that the lack of change may indicate that reductions in tar entering the oceans because of improved tanker operations may have been roughly balanced by the large increase in petroleum being transported.

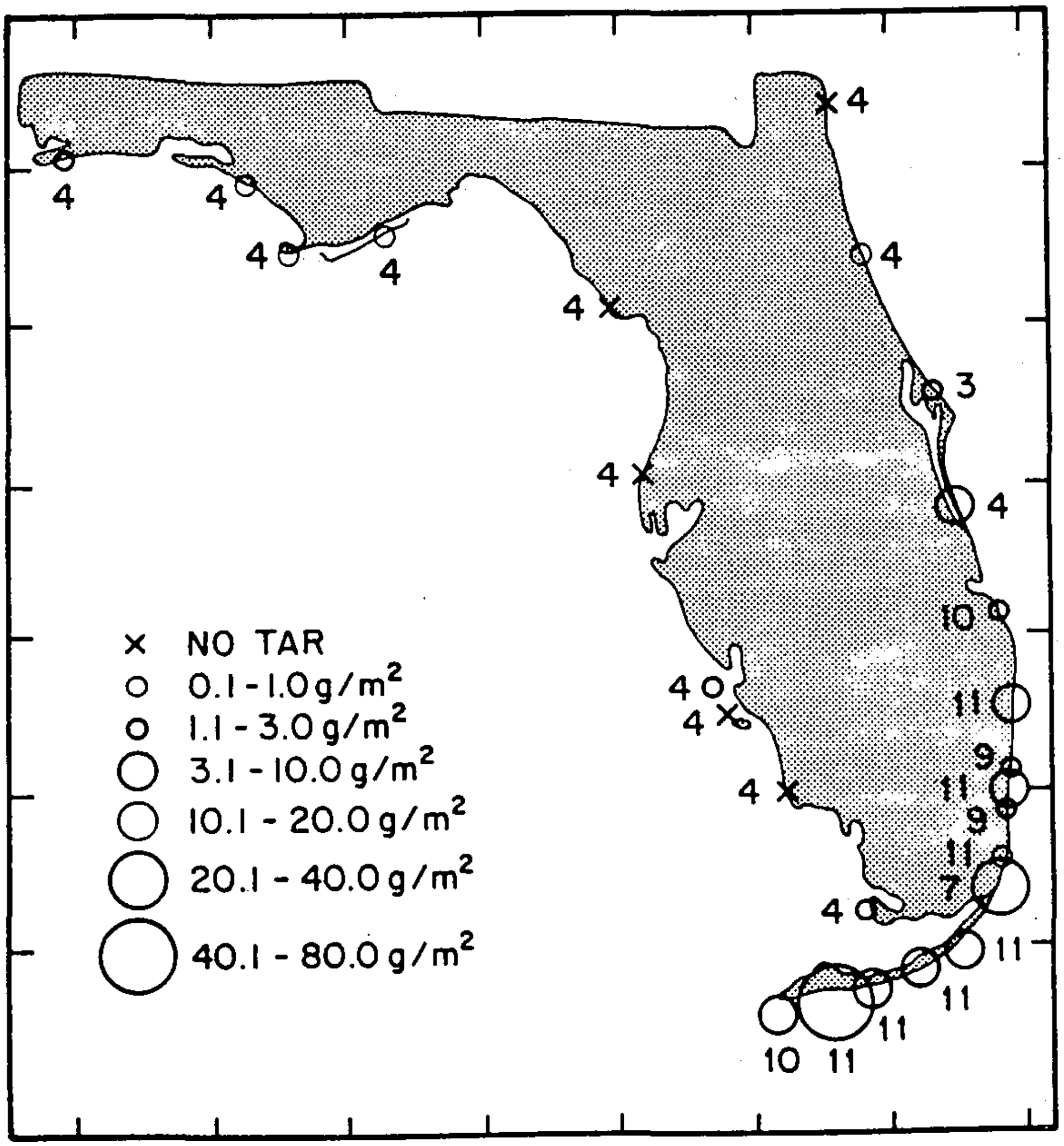

Figure V-6. Location of CARIPOL beach sampling sites in Florida. The size of the circles indicates the range of mean amounts of tar found at each site. The number near each site is the number of surveys. (From Romero *et al.* 1981. Reprinted with permission of *Marine Pollution Bulletin* and the authors.)

2. General Land- and Ocean-source Litter - A wide variety of major litter sources contribute persistent debris to the Wider Caribbean marine environment; however, there is little other than anecdotal information available on sources, amounts, or occurrence. This situation should improve dramatically in coming years since the CARIPOL steering committee has decided to collect data on plastic debris on beaches (Corredor pers. comm.).

In general, we can say little more about the distribution of plastic and other litter than that the mechanisms apparently are similar to those for tar. As a result, coasts downwind from major currents and shipping lanes are most vulnerable: the Lesser Antilles, the Caribbean coast of the Yucatan Peninsula, southeast Florida, and, above all, Texas. Offshore, the downwelling areas along fronts concentrate debris. Archie Carr (1986a) cited the example of a tanker bound from Corpus Christi, Texas, to Jacksonville, Florida, that "cruised for 30 miles in a crowded land of garbage."

- Land sources - From land, sewage and solid waste disposal practices are significant sources. UNEP (1984) reported that fewer than 10% of sewage systems around the Caribbean had treatment facilities, and that the untreated sewage and accompanying plastic debris generated by 30,000,000 people flows into that sea. The situation is better in the Gulf of Mexico since United States sewage generally is treated and most debris is filtered out. Most sewage from coastal Mexican cities is untreated, however (UNEP 1984; Rodriguez pers. comm.).

Solid waste disposal and littering are even less well quantified, but likely significant, land sources. Solid waste in many areas is deposited in or near streams and in low-lying coastal areas. Water courses eventually carry debris to the sea, and storm tides and waves wash out dumps (Towle pers. comm.; Cambers pers. comm.; Heneman pers. obs.).

Another mechanism is the result of the widespread problem of shoreline erosion in the eastern Caribbean (Cambers pers. comm.; Towle pers. comm.). Junked cars and other large items are used to stabilize eroding areas, and the presence of rubble is seen as an invitation for dumping trash.

Littering, particularly of recreational beaches, is a common problem in the Wider Caribbean.

- Ocean sources - Just as tar enters the Caribbean entrained in the north and south equatorial currents, so the Atlantic is also one of the largest ocean sources of debris in the Wider Caribbean area (Colton *et al.* 1974; Wilber 1987). Most debris found on the Atlantic coasts of the Lesser Antilles is likely from this source (Heneman pers. obs.; Wilber pers. comm.; Horrocks pers. comm.; Siung-Chang pers. comm.), and even more must pass between the islands into the Caribbean. At-sea sources within the Wider Caribbean include merchant shipping, cruise ships, commercial fishing, recreational boating, and, to a much greater degree than in the North Sea or northwest Atlantic, offshore oil operations.

Merchant shipping is a major activity in the Wider Caribbean. UNEP (1984) lists nearly 70 major ports in the region, including three of the five largest United States ports. Merchant ships generate both crew wastes and cargo-associated debris. **Cruise ships** are less numerous, but each vessel produces much greater quantities of waste. As in other parts of the world, ocean disposal is the rule for both. Worldwide estimates of quantities have been made (NAS 1975), but none exist for the Wider Caribbean.

After tourism, **commercial fisheries** are the most important economic activities that depend on the marine environment (UNEP 1984). Again, the National Academy of Sciences (1975) estimated litter generated by commercial fishing vessels worldwide, but there are no regional breakdowns. Using data in the EPA report (CEE 1987a), it appears that the 16,000 United States' Gulf coast commercial fishing vessels (1977 registration data) may have dumped some 25,000 metric tons of domestic wastes, a small percentage of which was plastic and other persistent debris.

Recreational boats probably represent a significant source in some areas, particularly along the Gulf coast of the United States where nearly 2,000,000 were registered in 1984 (CEE 1987a). Duerr (1980) estimated that the average boater dumps about 1.5 pounds of waste for each day on the water, a significant portion of which is persistent debris.

Offshore oil activities in the United States, Mexico, Venezuela, and Trinidad and Tobago are thought to contribute significant amounts of domestic waste and industrial debris (CEE 1987; Amos pers. comm.; Siung-Chang pers. comm.; Hildebrand pers. comm.). In 1985, there were about 1000 platforms off the United States Gulf coast. These platforms were serviced by roughly 1000 vessels and staffed by about 27,000 people. A small number of vessels is engaged in seismic testing. Waste disposal from the platforms is strictly regulated, but much of the debris on the Texas coast has been attributed to these sources (CEE 1987).

• Distribution - Colton *et al.* (1974) and Wilber (1987) have done the only quantitative studies of floating plastic debris in the Wider Caribbean, and their results contradict each other in part (Table IV-1, page IV-5; Table IV-2, page IV-7; Figure IV-2, page IV- 7). Both studies yield much lower levels of raw and manufactured plastics in the Wider Caribbean than in the Sargasso Sea (Wilber's southern Sargasso Sea corresponds roughly to Colton's Antilles Current). Wilber, however, found significantly higher levels in the Wider Caribbean than in continental shelf and slope waters. Colton *et al.* reported higher concentrations, especially of pellets, in Shelf and Gulf Stream areas. Perhaps more significant is the comparison of pellets/km^2, which were 250% higher in the Wider Caribbean in the later study. (Unfortunately, one can not compare other results since Colton *et al.* did not report pieces/km^2, and Wilber did not report gm/km^2.)

The rest of this section reports available information on plastic and other persistent litter on beaches. As in the section on tar, we begin in the

Lesser Antilles and generally follow the current system around the Wider Caribbean to the Straits of Florida. With only local exceptions, heavier debris loads are the rule on windward coasts throughout the eastern Caribbean (Cambers pers. comm.; Wilber pers. comm.; Heneman pers. obs.).

Wilber (pers. comm.) reported that even windward coast beaches in the Lesser Antilles had much less debris than those in the Bahamas and on Bermuda (Table IV-3, page IV-7 summarizes his data for plastic pellets). He gave two explanations for these observations. The first relates to the North Atlantic Gyre, which concentrates floating material in the Sargasso Sea. Since, in general, concentrations of this material diminish with distance from the center, there should be the least in the southern portion of the North Equatorial Current where it enters the Caribbean Sea. His second point is that, unlike the flat, sandy beaches of the Bahamas, the windward coasts of most of the Lesser Antilles are steep and rocky. As a result, many debris items "literally 'bounce off' the rocky shores of the Antilles and keep going into the Caribbean." (Other investigators — Dixon and Cooke 1977, Moxnes 1985, Heneman pers. obs. — have recognized this same phenomenon.)

Horrocks (pers. comm.) reported that plastic bags (particularly ice bags), plastic cups, and rope occasionally wash up in large amounts on the east coast of **Barbados**. Caribbean beaches are littered by land-source debris after heavy rains.

On **Trinidad** in 1984, Siung-Chang (pers. comm.) found heavy litter loads (74 g/m^2) on 15 recreational beaches she surveyed, with accumulation rates of over 1 kg/week on four beaches. Only 40% of the debris was thought to have washed onto the beaches; the rest was left by beachgoers. Of the identifiable items, 42% were metal soft drink cans and pull tabs, 30% were plastic items, and 4% were glass.

In 1987, Heneman observed generally light levels of debris on the windward coasts of **Barbuda**, **Dominica**, and **St. Lucia**; however, there are few beaches and most of those are narrow and cliff-backed, making them poor sites for accumulating litter. Much of the debris was fishing gear (see following section), and all identifiable material appeared not to have originated on the islands.

Even ungroomed beaches on the Caribbean coasts of these islands were clean except near river mouths or population centers, where land-source litter was often very heavy. For example, on a small beach near the mouth of the Castries River in St. Lucia, the sand above the high tide line was completely obscured by glass, plastic, and metal containers and the blue plastic bags used in large numbers in growing bananas, the principal crop. Charles (pers. comm.) said that so many of these bags got into streams that they often interfered with domestic water treatment filters. Gregoire and Butler (pers. comms.) confirmed that the pattern Heneman observed was typical for Dominica and St. Lucia.

Heneman also observed leeward beaches on **Antigua** and **Guadeloupe** in 1987. Most Antiguan beaches are groomed regularly; others had moderate amounts of locally generated litter. Largely because trash collection is universal and effective on Guadeloupe, even ungroomed beaches there were virtually pristine.

Trash dumps are commonly located on the coast in the Lesser Antilles, and they are sources of debris on beaches and in the water. Towle (pers. comm.) reported 29 of 33 dumps in the islands are on or near shorelines. Cambers (pers. comm.) gave an example of a coastal landfill in **Grenada** from which much of the material escapes.

In the **Netherlands Antilles**, Van 't Hof (pers. comm.) and Sybesma (pers. comm.) said plastic bags, bottles, cups, and six-pack yokes are common beach litter. Van 't Hof attributed debris on Saba to ships and to land-source litter from St. Eustatius, directly upwind from Saba. Sybesma reported that, until recently, domestic solid wastes on Curacao were dumped into the sea, and sewage was untreated.

Towle (pers. comm.) surveyed about one quarter (120 m) of the windward shore of **Isla de Aves**, which is located nearly 250 km west of Dominica. He estimated that what he found was no more than a 10-month accumulation, since fall storms sweep the island clean. Debris included 92 plastic items such as bottles and lids (plus an additional pound of plastic fragments), 39 metal cans, and 111 glass bottles. All the itemized debris averaged over 2 objects/ meter of beach surveyed.

Hurst (pers. comm.) conducted field work on the south (windward) coast of Jamaica in 1983-84. He reported: "The only debris I encountered on the beaches were minor amounts of trash from freighters, except that along some beaches, trash from tourists and local businesses was the only debris. No beaches were observed with substantial amounts of debris."

Morel (pers. comm.), who takes samples 80 km south of **Puerto Rico** for the CARIPOL floating tar survey, reported that he has seen a substantial increase in plastic at sea in the past five years. He often sees large plastic bags of domestic waste, presumably from ships. He also reported substantial amounts of debris in the water after heavy rains.

Kimmel (pers. comm.) and Detres (pers. comm.) reported the usual sorts of litter on Puerto Rican beaches, which they attributed to merchant shipping, recreational boaters, and garbage dumps.

In January 1988, Heneman surveyed several sites on the Caribbean, Gulf of Mexico, and Bay of Campeche coasts of the **Yucatan Peninsula** (Table V-4). The heavy debris load on the Caribbean coast south of Cancun (one 2 km site, one survey) consisted predominantly of plastic, glass, and metal containers, and trawl net webbing and rope. The most common containers were for bleach, orange juice, cleansers, cosmetics, cooking oil, beer, and outboard motor oil. About half of the material was plastic, with glass and metal accounting for equal parts of the other half. Of the items that could be identified as to country of manufacture, most came from Mexico, followed by the United States, Jamaica, Colümbia, Venezuela, and the Netherlands. England, France, Germany, Belgium, Canada, and Barbados were also represented. Most of the items from Jamaica, Venezuela, and Columbia were small cooking-oil bottles and small orange juice containers, which suggests that they may have been land-source litter. Most debris was in the back-beach area, indicating that it was an accumulation of at least several months. Avalos (pers. comm.) confirmed that the general level of debris was typical. At the uppermost high tide line, Heneman also found 50-100 raw plastic pellets/linear meter of beach in a 20 m site.

Table V-4. Summary of 1988 beach debris surveys on the Yucatan Peninsula.

Coastal Area	Items/ 100 m	Country of Manufacture Mexico	United States	Other
Caribbean	>150	50%	20%	30%
Gulf of Mexico	45	80%	10%	10%
Bay of Campeche	15	100%	-	-

The Gulf of Mexico location (one 1 km site, one survey), about 80 km west of the Yucatan Channel, probably had more debris on it than normal since a northerly wind had been blowing for several days and almost all debris was located just above the high tide line rather than on the upper beach. Roughly 80% of the material was plastic, and most of the remainder was metal. Containers for outboard motor oil, cooking oil, fruit juice, and insect spray were the most common items. Uncommon items included syringe bottles and chemical light sticks used in long-line fishing. After Mexico and the United States, the most identifiable items were manufactured in Venezuela. Jamaica, Germany, and Trinidad were also represented. There were no fishing nets.

The Bay of Campeche sites (five locations totaling 1 km along 60 km of coast, one survey) were very clean. Nearly 100% of the debris items were plastic outboard motor oil containers. Rodriguez (pers. comm.) confirmed that, unlike the situation with tar on the Campeche coast, plastic and other persistent debris is not a problem.

From all accounts, **Texas** has the highest levels of marine debris in the Wider Caribbean (Amos pers. comm.; Pace pers. comm.; CEE 1987a, 1987b). Hildebrand (pers. comm.) said that persistent debris is much worse on the Texas coast than in Mexico. All possible sources of debris appear to be well represented. Eddies from the Gulf Loop Current and southeast tradewinds carry debris from the Caribbean into the western Gulf of Mexico. Longshore currents have two general regimes. From March through August, there is a weak but constant flow up the coast from the south, carrying debris from the Bay of Campeche. In fall and winter, a strong but intermittent current from the north brings with it debris from the Louisiana coast and the Mississippi River discharge. During most of the year, east and southeast winds beach floating material from virtually any part of the western Gulf (Amos pers. comm.). Large commercial fisheries for shrimp and swordfish support thousands of boats and their crews. Both Mexico and the United States are offshore oil producers in the western Gulf, and petroleum exploration, production, and transport all generate debris. Major ports in the area attract merchant vessels that routinely dispose of shipboard waste by dumping.

The vulnerability of the Texas coast was amply demonstrated in the 1985, 1986, and 1987 beach clean-ups. In 1985, surveys at Padre Island National Seashore indicated that roughly 2.5 tons of litter per mile had accumulated on 57 miles of beach. The National Park Service estimated that 800,000 plastic one-gallon milk jugs alone wash ashore each year. Other common items were large pieces of plastic sheeting, seismic marker buoys, drilling pipe thread protectors, and oil and air filters. The Park Service estimated that no more than 10% of the debris was left by visitors to the National Seashore.

In 1986, for which the most detail is available, 2800 volunteers collected 124 tons from 122 miles of beach (CEE 1987a). Of the 171,496 items tallied, there were 21,880 plastic containers of all kinds (5308 milk jugs alone), 15,579 plastic bags, 12,491 beverage cans, 11,837 glass bottles, and 10,358 six-pack yokes. Plastic and Styrofoam accounted for 67% of the items, metal 13%, glass 12%, and paper and wood 8%. The worst areas — between Bay City and South Padre Island — yielded 1.8 tons/mile.

In 1987, 7100 volunteers cleaned over 306 tons of debris from 154 miles of Texas beach, or roughly 2 tons/mile (CEE 1987c).

Hundreds of 30- and 55-gallon drums wash ashore in Texas each year, and in some areas as many as half of these contain hazardous chemicals (CEE 1987b).

Determining the sources of debris is often impossible, but clean-up organizers in Texas were able to break about 19% of the items down into categories such as cargo wastes (large plastic sheets, pallets, etc.: 3.7%); galley wastes (plastic egg cartons, milk jugs, vegetable sacks: 5.2%); operational goods (plastic write-enable rings for seismic testing, hardhats, light bulbs, drums, strapping bands: 7.6%); fishing industry debris (nets, buoys, fishing line, light sticks, gloves: 2.1%).

Once a week in March-November 1987, Amos and Plotkin (in press) censused debris on 12 km of Mustang Island beach. The entire 12 km normally was groomed each week, so their data represented weekly accumulations. In 31 censuses, plastics of all kinds averaged 638 items/kilometer. Most of these items were plastic bags and sheeting, bottles of all kinds, miscellaneous bits of plastic, and polypropylene line. Since 1983, they also made over 1000 observations of the 12 km study area using a 0-5 subjective rating system for 40 categories of debris. As to sources, Amos and Plotkin reported:

"Manufactured items from at least [45] countries...have washed up on Mustang Island beach in the past three years...The bulk of the foreign "household" (galley) materials have come from fishing boats, or more often, merchant marine vessels. Except for the U.S.-originated litter of this type, oil and gas platforms and rigs cannot be the source of such materials...By far the greatest amount of galley material is of U.S. origin: one-gallon milk jugs, egg cartons, styrofoam forzen-food packs. The great majority of these are typical Texas supermarket brands...This leaves shrimping, commercial fishing, U.S. merchant marine transport, and oil and gas operators and their service industries as potential culprits. [We] exclude the recreational fishing industry from this list because of the institutional container sizes and product labels frequently found.

"One category...is definitely attributable to offshore oil and gas activities. Under this category come 55-gallon drums and the more abundant 5-gallon plastic pails and carboys of chemicals used in exploration and drilling. A decrease in these items has occurred in the past two years [which] coincides with the downturn in drilling rigs operating in the Gulf and an increase in the companies' campaigns to educate offshore oil workers and to tighten littering regulations. Debris peculiar to associated activities, such as seismic surveying and the service and supply boats, continues to be found on the beach. These include write-protect rings and marker floats and large plastic sheeting used to cover palletted cargo.

"Rubber gloves, shrimp baskets, onion and sea-salt sacks and Mexican bleach bottles can be attributed to the shrimping industry while cold-chemical light sticks come from the longline fishing industry. Beverage cans, glass beer and liquor bottles, fast-food containers and disposable picnic supplies may come from recreational fishing boats, or may originate on the beach itself...Certain items like cans, bottles, and food containers could have come from any or all of these sources."

Amos (pers. comm.) also reported that debris is much heavier at Padre Island National Seashore than on Mustang Island.

Smaller beach clean-ups were conducted in **Alabama** (no data available), **Mississippi** (0.7 tons of litter/mile on five miles of beach), and Louisiana (200 tons of litter on an unreported length of beach) (CEE 1987a).

As with tar, debris is light along most of the Gulf coast of **Florida** (CEE 1987a; Heneman pers. obs.).

Wilber (1987 and pers. comm.) conducted surveys of plastic pellets and general debris in the Florida Keys and the mainland coast of southeast Florida (Table IV-3, page IV-7). Densities of pellets were roughly comparable to those on Cape Cod and the windward Bahamas shores. He estimated that the total deposited on the small Keys archipelago amounted to 800 million to 4 billion pellets.

Wilber concluded that the Keys act as an "island sieve" downwind from the Straits of Florida, just as the Lesser Antilles and Bahamas collect debris (and tar) from the North Equatorial and Antilles currents. As for general litter, he pointed out, "The Key West—Cape Canaveral stretch of shore was one of two major areas implicated as the 'trash ground' for the entire Caribbean/GOMEX system" in the surface drifter study referred to above (Figure V-3, page V-5), and added: "I was quite frankly astounded by the quantity of plastic which I found along the Keys' beaches. Some of these areas...have concentrations which rival Bermuda sites and are greater than the Bahamian shores" (Wilber pers. comm.).

3. Fishing Gear - Reports of fishing gear debris in the Wider Caribbean were infrequent and rarely quantitative. The most frequently reported items were traps, net fragments, and monofilament line.

Many factors result in the loss of fishing gear. Storms relocate or destroy gear. In 1985, for example, Hurricane Kate caused the loss of an estimated 25,000 lobster traps in Florida (CEE 1987a). Dragged gear such as trawl nets tear when they snag on bottom features. Gear conflicts between fisheries, such as the operation in the same area of stationary and dragged gear, result in accidental, and sometimes intentional, loss of gear. For instance, shrimp trawl nets in some parts of the Gulf of Mexico have been snagged on barbed wire and cinder blocks placed near stone crab traps (Centaur/CEE 1986). Some gear is thrown overboard when it is no longer serviceable.

In 1987, Heneman observed moderate amounts of heavy, green net fragments on **Barbuda** and on the Atlantic coast of **St. Lucia**. This netting was abundant enough and in large enough pieces that it was commonly used to reinforce fences containing goats and other livestock on Barbuda. The netting was not from local fisheries, and Fuller (pers. comm.) attributed it to Japanese tuna fisheries in the Atlantic. The same material doubtless beaches on the other islands in the Lesser Antilles.

Corredor, Kimmel, and Detres (pers. comms.) reported fishing gear, especially nets, lines, and floats, on Puerto Rican beaches but did not indicate that these were major debris components compared to general litter. Again, the netting was not from local fisheries. From Corredor's description, it appears to have been the same type of netting Heneman observed in the Lesser Antilles.

In 1988, Heneman observed moderate amounts of similar net fishery debris on the Caribbean coast of the **Yucatan Peninsula**. Often, there was little netting: most of the item consisted of a length of head- or foot-rope. Again, the netting was not from local fisheries, which use only monofilament nets. Heneman saw no net fragments on the Gulf of Mexico or Bay of Campeche coasts.

In 122 miles of the 1986 Texas beach clean-up, volunteers found 1435 pieces of netting (roughly 7/km) and 315 pieces of monofilament fishing line (CEE 1987b).

The EPA study (CEE 1987a) reported that since 1979 in Louisiana, the Fishermen's Vessel and Gear Damage Compensation Fund had received 3,200 claims for lost or damaged gear, the majority of which involved shrimp trawl nets.

Browder (pers. comm.) reported that lost fish, lobster, and stone crab traps are a serious problem on the Gulf coast of Florida as well as in Puerto Rico and the United States Virgin Islands. She also said there is a trend toward using plastic instead of wooden traps. In 1985 there were records of claims to the Fishermen's Vessel and Gear Damage Compensation Fund for the loss of 16,611 stone crab traps in the Gulf of Mexico, an unknown percentage of which were made of plastic. These lost traps represented an equal number of lost floats and an estimated 253 km of synthetic line. In the lobster fishery on the Florida Gulf coast, 25% of the 96,000 traps in use were estimated to have been lost in 1985 (CEE 1987a).

Effects of Marine Debris

This discussion is organized into three sections, reflecting the major categories of marine debris effects we encountered in the Wider Caribbean area: aesthetic effects, economic effects, and hazards to wildlife. Usually, the one element common to all three was inadequate substantiation, even where impacts were said to be high.

1. Aesthetic Effects

We found almost universal concern about the aesthetic degradation of Wider Caribbean coasts because of tar, general litter, and even fishing gear. The level of comment from any area usually was a reflection of two factors: the amount of debris, and the importance of tourism and recreational beaches to the local economy.

There is not much to add to what we have said about aesthetic concerns in the North Sea and northwest Atlantic study areas. However, tourism is a much more important industry in the Wider Caribbean, and there is general agreement that tourism suffers when the aesthetic environment deteriorates (UNEP 1984). Finding explicit support for this concern in the words of tourists is uncommon. One example is the vacationer who said of the Caribbean coast of the Yucatan, "This place would be paradise if it weren't for all the trash and tar" (see the Foreword of this report). Another is the experience of the National Park Service at Padre Island National Seashore in Texas. Since 1962, 99% of visitor complaints have been about beach litter, and Park Service personnel almost daily hear visitors say they will never return because of the "filthy beaches" (CEE 1987a). The World Tourism Organization, which has "drawn attention to the risks of pollution of tourist beaches by oil, plastics, and other marine debris," demonstrates a professional recognition of this sensibility of coastal visitors (Shackleford pers. comm.).

2. Economic Effects

We found references to four types of economic effects of marine debris in the Wider Caribbean: threats to tourist economies, costs associated with debris removal, damage to property, and lost fishery catches.

• Threats to tourist economies - The potential for adverse economic impacts of marine debris on tourism was raised by several sources. Two factors make this situation worse in the Wider Caribbean than in the North Sea and northwest Atlantic study areas. First, many local and national Caribbean economies are much more dependent on tourism than is true in the other study areas. And second, tar heavily pollutes many tourist areas and potential tourist areas, which was not the case in the other study areas. Tar undoubtedly is a more unpleasant form of debris than litter, which only looks offensive. Tar looks bad, small pieces of it are impossible to clean up, and it sticks to people's feet and clothing. Atwood *et al.* (1987b) pointed out that many beaches in the Wider Caribbean have tar concentrations at which beachgoers commonly get tar on their feet, or which even render a beach unuseable. Corredor (1987), in his foreword to the Caribbean Journal of Science issue devoted to results of the CARIPOL project, said that tar aggregations already "pose a considerable problem to commercial development of the coastal zone, especially to the use of beaches for tourism."

The conflict between tourism and tar and litter pollution has been less than it would have been if tourist development were not generally concentrated on leeward coasts and debris were not worse, as a rule, on windward coasts. That situation is changing as tourism expands into new coastal areas. South-eastern Florida, with some of the heaviest debris loads reported, has long been a center for tourism, of course. In recent decades, coastal tourism has become a $5,000,000,000-a-year industry in Texas (CEE 1987a), which arguably has the worst marine debris problem in the Wider Caribbean. In the past 15 years, Mexico has encouraged major tourist industry development of the Caribbean coast of the Yucatan Peninsula, another area with heavy debris loads.

The trend toward development of new areas, including debris-laden windward coasts, will likely continue in such areas as Barbados (Horrocks pers. comm.), St. Lucia (Heneman pers. obs.), Jamaica (Hurts pers. comm.), Grand Cayman (Burton 1987), and the Yucatan (Heneman pers. obs.). UNEP (1982 and 1984) pointed out that many countries that rely on visitors for foreign exchange plan to develop tourism even further. Throughout the region, and particularly in the insular Caribbean, tourism development will be oriented toward the coast. At the same time, urbanization of the coastal zone and increased petroleum development and transportation will carry the risk of increased tar and litter pollution of a marine environment that a successful tourism industry depends upon.

• Debris removal - Regular removal of litter and tar from recreational beaches is, of course, the necessary mitigation for aesthetic degradation. The cost of these clean-ups must be substantial since they are nearly universal, but quantification is almost nonexistent. The only figures we found were for Texas, where the state estimated coastal cities and counties spend more than $14,000,000 a year to clean debris from beaches (Mauro 1987). In 1985, the National Park Service spent $10,000 on beach clean-up, most of it on the half-mile of beach most visited by the public (CEE 1987a).

• Damage to property - As in the North Sea and northwest Atlantic study areas, a few reports alluded to damage to vessels when rope or plastic sheeting fouled propellers or cooling water intake systems. There was no quantification of these incidents.

• Lost fishery catches - Trap fisheries are widespread in the Caribbean and Gulf of Mexico, and there is concern about ghost fishing by lost traps (Browder, Hurst pers. comms.; Heneman pers. obs.). Although degradable materials have traditionally been used to make traps for fish, lobster, and stone crabs, metal and plastic-coated wire traps are now the rule in many areas. We found only one estimate of trap loss rates in the Wider Caribbean. Sutherland and Harper (1983) estimated reef fish trap loss in southern Florida to be 20-100%/year. These investigators also said that lost traps would probably continue to fish for more than six months. Sutherland *et al.* (1983) reported that 18 of 23 lost traps (78.3%) they found and observed contained no fish. The traps either were disabled and no longer caught fish, or else fish had entered and then escaped through random movements. The other five traps, which appeared to be less than six months old, contained eight grouper, 14 lobster, and six fish of noncommercial species, all of them alive.

In 1982, because of concern about the high rates of trap loss reported above, the National Marine Fisheries Service conducted laboratory studies on the behavior of Florida reef fish in traps and field research on the fishing life of lost traps (Harper and McClellan 1983). The laboratory tests involved traps and 45 species of fish in an 8000-gallon tank. After entering a trap, all species except the larger predators learned to use the exit within a few days, and "an equilibrium state occurs with frequent movements in and out of the trap." After a 6"X6" escapement panel was removed, all individuals of all species escaped.

During the field study, divers observed several traps set off Key Biscayne, Florida, over a period of a few months. As few as 5.5 days and as many as 157 days were required for traps to become incapable of catching fish. Four traps lost their ability to retain fish when the metal prongs in the opening were bent, presumably when large predators escaped. Escape windows opened on four traps, allowing fish to escape. Seams parted on two traps when large fish struggled to escape. Dense algal growth obscured another trap, and fish no longer entered it. Storm damage also caused traps to become less effective. During 97 observations, 130 fish were observed in eight traps, 25 of which died. Most of the dead fish were large predators such as barracuda, yellow jack, and lemon sharks. The report drew no conclusions about the over-all impact of ghost fishing by lost traps.

3. Hazards to Wildlife

For the Wider Caribbean Area, we have organized this discussion into three sections: seabirds, marine mammals, and sea turtles.

• Seabirds - As was true in the North Sea and northwest Atlantic study areas, entanglement of seabirds, particularly gulls, was the most frequently reported consequence of marine debris for wildlife (CEE 1987a; Amos, Causey, and Corredor pers. comms.). Other birds mentioned included terns, brown pelicans, waders, and shorebirds. The usual culprits were six-pack yokes and monofilament fishing line. All of these reports were from the United States Gulf coast and Puerto Rico. With the exception of brown pelicans and royal terns (see below), none of these reports suggested debris might have caused levels of mortality that would effect a species or population.

The only quantitative studies were reported in the International Council for Bird Preservation's *Status and Conservation of the World's Seabirds*. Clapp and Buckley (1984), citing a study in Florida in the early 1970s, reported that 80% of brown pelicans showed signs of injury from entanglement with fishing gear. Another study they cited indicated that entanglement in fishing lines might have caused significant mortality of juvenile royal terns. The authors' recommendations for seabird conservation in the southeastern United States, however, dealt only with what they considered to be more important conservation threats, such as habitat loss, disturbance by humans, and predation. In the same work, van Halewyn and Norton (1984) listed egging and other human disturbance, habitat loss, introduction of predators, and oil pollution as concerns in the Caribbean, but did not mention ingestion of or entanglement in debris.

Wilber (pers. comm.) mentioned that seabirds ingest plastic pellets and pieces, but that possible negative impacts on birds and other animals are only recently being addressed.

• Marine mammals - We found few references to the effects of debris on marine mammals in the Wider Caribbean. The Smithsonian had records of two pygmy sperm whales since the early 1970s known to have ingested plastic bags; one of them stranded in Texas, the other in Florida (CEE 1987a). Estevez (pers. comm.) reported that ingestion of plastic sheeting may have contributed to the death of a bottle-nosed dolphin on the Florida Gulf coast.

We found two references to manatees having been entangled in lost fishing gear (Huff pers. comm.; CEE 1987a). Laist (1987) cited a report of a manatee in Florida that died from the effects of ingesting a large sheet of plastic. Since 1974, the Southeast Stranding Network has recorded the entanglement of a Bryde's whale that stranded on the Florida Gulf coast (Odell pers. comm.).

• Sea turtles - Sea turtles may be the animals most seriously affected by marine debris (see the Dedication and discussions of fronts and effects on sea turtles on pages IV-9 and IV-24). As Archie Carr has described their situation:

"The juvenile pelagic stage may last for a period of 3-5 years, according to the species. During this time of early development the young turtles are passive migrants in driftlines in the surface water of the open sea. Here they come into intimate contact with buoyant debris, and there is massive evidence that entrapment, entanglement, and impaction of the alimentary canal by ingested plastics have become major threats to sea turtle survival" (A. Carr 1987).

Ogren (pers. comm.) reported that, while direct human exploitation of turtles for eggs and meat, and incidental take in fisheries are the major causes of human-induced mortality in adult sea turtles, marine debris ingestion and entanglement may be a new, significant cause of death, especially for juveniles.

Balazs (1985) compiled dozens of records of sea turtle debris ingestion and entanglement worldwide, a large percentage of which came from the Wider Caribbean Area. The reports, of green, loggerhead, hawksbill, and Kemp's Ridley turtles, came primarily from Florida and Texas. Costa Rica (where Carr had reported a mass mortality of green turtles from ingestion of plastic banana bags in the 1950s) and Barbuda also were mentioned. Tar was the most common item ingested. Turtles also were found to have eaten monofilament line, plastic sheeting, Styrofoam, and pieces of plastic. (The largest item ingested by a turtle was a piece of plastic sheeting 3X4 m.) Entanglement usually involved fishing line or netting.

The Sea Turtle Stranding and Salvage Network (see page IV-27) has collected data on United States Atlantic and Gulf coast strandings since 1980. In our Wider Caribbean study area, 784 turtles (43% of the total) were reported stranded in 1986, and 613 (38%) in the first nine months of 1987. Only 1% of the reports for all areas involved entanglement in 1985, 2.4% in 1986, and 2.3% in the first nine months of 1987. Most of the turtles that had ingested tar (0.3% in 1985 and 0.5% in 1986) stranded in southeast Florida. Again, these data represent minimal figures since not all turtles strand or are reported if they strand, observers may not report all evidence of entanglement, and they generally miss ingestion since necropsies rarely are done (Schroeder 1987a, 1987b, pers. comm.).

In 1986-87, Plotkin and Amos (1988) necropsied 76 turtles that stranded on Mustang, Padre, and South Padre islands in Texas. Nearly half (35) had ingested either plastic bags (74.3%), pieces of plastic (20%), Styrofoam (11.4%), monofilament line (11.4%), plastic pellets (8.6%), plastic strapping (5.7%), balloons (5.7%), aluminum foil (5.7%), tar (2.8%), glass (2.8%), or other items. The debris was present in loggerheads, greens, and one hawksbill. Debris ingestion was unquestionably the cause of death in two animals; cause of death could not be positively determined in the other 33 turtles. The weight of ingested debris constituted only a small proportion of the total weight of gut contents in most of the turtles. (These data confirm Schroeder's contention that the stranding network results underreport debris ingestion in sea turtles.)

Plotkin and Amos also examined stranding network data on 287 turtles for the same area and time. Seven (2.4%, the same value that Schroeder reported for the entire United States Atlantic and Gulf coasts) had died as the result of debris entanglement, usually in fishing gear.

Several investigators have recently developed a useful chain of evidence on the effects of tar on sea turtles. Laboratory experiments by Lutz (pers. comm.) and Vargo *et al.* (1986) indicated that turtles readily ingested tar (sublethal quantities), which resulted in significant physiological effects. Van Vleet and Pauly (1987) analyzed tar scraped from nine sea turtles that stranded in Florida and Texas. All nine samples appeared to have been crude oil with characteristics that indicated they came from tanker discharges (bimodal *n*-alkane distribution). Van Vleet *et al.* (1984) had earlier concluded that at least half of the tar load in the eastern Gulf of Mexico and Straits of Florida was attributable to tanker discharges.

Van Vleet and Pauly (1987) then looked at the implications for sea turtles of what was known about tar occurrence and wind and current patterns. Based on the surface drifter studies (Figure V-3), floating tar studies by Van Vleet *et al.* (Figure V-4), and the beached tar study by Romero *et al.* (Figure V-6), they concluded that turtles would be exposed to high concentrations of floating oil residues along the southeast Florida coastline. They found that data from the Florida Department of Natural Resources on tar-related turtle strandings (Figure V-7) appears to confirm that conclusion. As a result of this evidence, Van Vleet and Pauly suggested that discharges of crude oil from tankers were having a significant effect on sea turtles in the eastern Gulf of Mexico.

In a project for the NMFS Marine Entanglement Research Program, Lutz (1987) offered 10X10 cm pieces of plastic sheeting to green and loggerhead turtles that weighed 1-16 kg. The most any turtle ingested was 7 pieces. (Exposure to the plastic was set at low levels to ensure that the effects would be sub-lethal.) When compared with controls, the turtles that ingested plastic showed no differences in food consumption rates, gut passage time, food absorption, dive time, oxygen consumption, blood gases and acid base balance, blood GTP levels, blood cortisol levels, blood ions and osmotic pressure, and hematocrit and white blood cell volume. There was a fall in blood glucose levels, but it was much lower than in turtles that were starved for two weeks.

Lutz concluded that turtles will actively seek out and consume plastic sheeting but that, at the quantities of plastic he used, the effects were negligible. Lutz added:

> "We can say nothing about what might happen at higher levels of ingestion, and it would be most unfortunate if our study was used to support the position that the ingestion of nonbiodegradable debris at a level less than gut strangulation is without consequence to sea turtles. It is very possible that an increased burden will cause harm since in vertebrates in general a partial blockage of the gut can cause interference with nutrition, loss of electrolytes, and blood in the feces. Very much higher

levels of plastics than we used in this study have been found in nature, including large pieces of plastic bags twisted throughout the intestine."

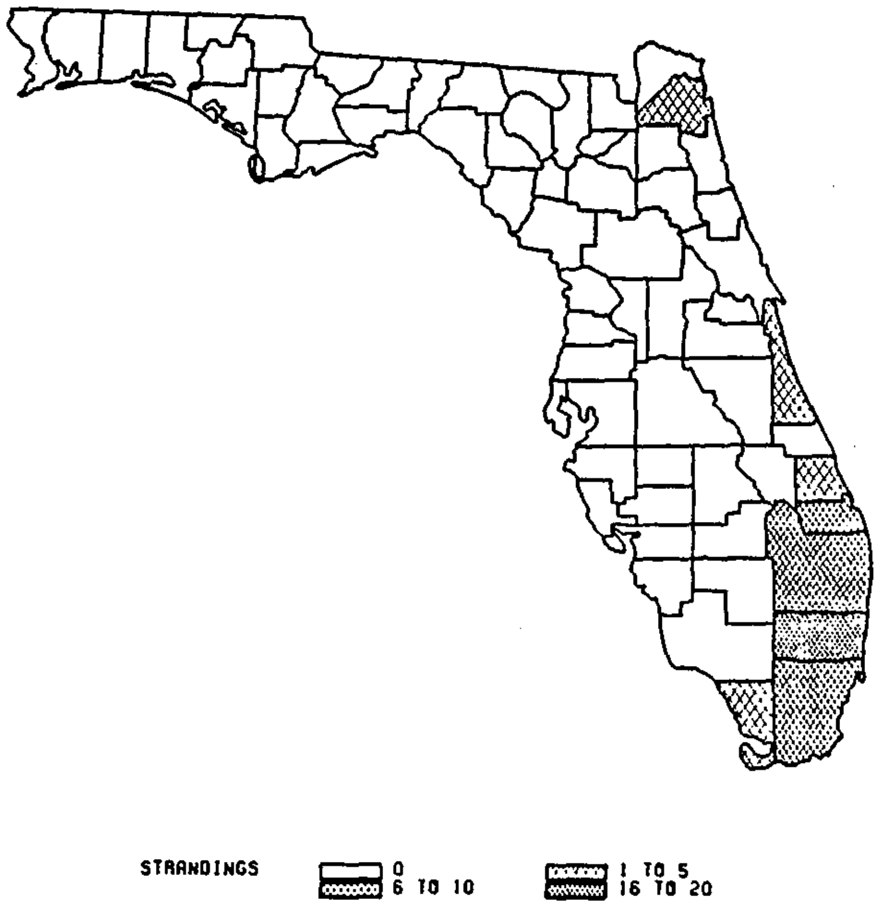

Figure V-7. Florida Department of Natural Resources data (1980-84) on petroleum-related sea turtle strandings. (Reproduced with permission of the Florida Department of Natural Resources.)

Mitigation

As in the North Sea and northwest Atlantic study areas, marine debris mitigation in the Wider Caribbean has been of two general kinds:

- efforts to remove debris or reduce its effects after it has entered the marine environment, and
- efforts to reduce the amount of debris that goes into the Caribbean Sea and Gulf of Mexico.

The most obvious activity, again, was direct removal of debris from recreational beaches. Beach cleaning was reported in Trinidad & Tobago (Siung-Chang pers. comm.), Barbados (Horrocks pers. comm.), Antigua, Dominica, St. Lucia (Heneman pers. obs.), the Netherlands Antilles (Sybesma, van 't Hof pers. comms.), Grand Cayman (Burton 1987), Jamaica (Hurst pers. comm.), the Yucatan Peninsula (Heneman pers. obs.), Texas (CEE 1987a), and Florida (Atwood *et al.* 1987b; Heneman pers. obs.). It undoubtedly occurs in other tourist areas as well. Texas has instituted an innovative "Adopt-a-Beach" program in which civic groups commit to cleaning a beach at least three times a year.

NMFS regulations in the south Atlantic and Gulf of Mexico require escapement panels in fish traps, which appear to function well according to the limited research conducted so far (Browder pers. comm.).

Archie Carr suggested an important step in reducing the impact of debris, especially tar, on headstarted sea turtles. In 1983, after head-start Kemp's ridley turtles were released off Mustang and Padre islands, Texas, 91 later stranded and were found to have ingested oil or tar. As a result, Carr recommended great care in choosing release sites:

> "One important tactical rule-of-thumb...is to refrain from releasing hatchlings or head-start turtles on any shore off which no convergence is available, where an onshore drift prevails in the season of release, or where a longshore driftline is likely to be loaded with pollution" (Carr 1986b).

A great variety of approaches is being tried to reduce the amount of debris that enters the marine environment. In the United States, every coastal state in the study area has a coastal management program that speaks generally to protecting coastal resources. With the exception of Texas, however, we found no state policies or regulations that specifically address marine debris.

The Texas General Land Office, which administers the state's offshore oil leasing program, now prohibits discharges of solid wastes from oil and gas drilling and production platforms, and from seismic vessels operating in state waters. Oil and gas operators now must develop detailed solid waste management plans, and state inspectors routinely check for compliance (Mauro 1987).

Texas also appeared to be taking the lead among U.S. states in educational programs. A "Don't Mess with Texas" anti-litter campaign by the Department of Highways and Public Transportation includes public service television advertisements filmed on beaches. The Texas General Land Office launched its own "Don't Mess with Texas Beaches" campaign. Both of these are aimed at the individual beach-goers, who generate a significant amount of the total debris.

At the national level, the United States government has paid increasing attention to the marine debris issue (page IV-28). Several of the projects of the Marine Entanglement Research Program listed in Chapter IV are relevant to the Wider Caribbean study area (Coe and Bunn 1987; Coe pers. comm.).

Elsewhere in the Wider Caribbean Area, two factors have militated against the solution of marine debris problems. First, all evidence indicates that, on the heavily polluted windward coasts throughout the region, the sources of most debris are upwind and often distant. As a result, the debris is beyond the ability of individual governments to control, as Atwood *et al.* (1987b) pointed out. Second,

> "Many Caribbean countries have not fully developed the managerial and custodial ethics or the policies needed to protect adequately or to use wisely the assets of the sea. The most important reasons for this situation are that: (a) national economic problems often overshadow environmental considerations so that costs or, alternatively, loss of potential revenue are perceived as outweighing benefits; [and] (b) marine pollution has not been adequately identified as a major problem in the Caribbean area which, in turn, is partly due to the lack of systematic studies on environmental quality...Therefore, one of the problems confronting the Wider Caribbean Region is the general lack of policy concerning marine pollution, especially on a regional basis...In recent years this situation has been changing gradually" (UNEP 1984).

As evidence of change, UNEP (1984) mentioned the Barbados Territorial Waters Act of 1977, the Grenada Territorial Waters Act of 1978, several laws adopted by Jamaica, and an oil spill clean-up plan adopted by Trinidad & Tobago in 1977. All of these address some forms of marine pollution, but none deals directly with the routine generation of persistent debris. Many other specific steps have been taken. Officially, Curacao has stopped dumping garbage and trash into the sea (Sybesma pers. comm.). The Dominican Republic, St. Lucia, and St. Vincent & the Grenadines all have broad environmental education programs aimed at children and adults that include concern for litter (Charles and Butler pers. comms.).

UNEP (1984) also pointed out the important role that must be played by the various marine laboratories scattered through the region. Although their work commonly has focused on basic marine research, they need to be incorporated into coordinated efforts to assess marine pollution problems, including marine debris. The IOCARIBE CARIPOL project on petroleum pollution (and, eventually, plastic debris) has been an excellent example of how international organizations (such as UNEP, the IOC, and IMO), national governments, and independent laboratories can cooperate. Another hopeful sign was the 1987 Seminar on the Control of Dumping and Other Waste Disposal Methods in the Caribbean Sea sponsored by the IMO, UNEP, the IOC, and Mexico (Caribbean Conservation Association 1987).

An example of the useful work that independent organizations can undertake on their own is the research the Caribbean Conservation Corporation is conducting "at sites where developing sea turtles...come intimately into contact with injurious flotsam" (Archie Carr pers. comm.).

The essential umbrella for regional approaches to marine debris and other marine resource problems is already in place. Since the adoption of an action plan in 1981, the Wider Caribbean Region has been one of the UNEP Regional Seas (UNEP 1985). One important result has been the adoption in 1983 of the Cartagena Convention (Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region), which entered into force in October 1986 after being ratified by nine states. Antigua & Barbuda, Barbados, Britain, France, Grenada, Jamaica, Mexico, the Netherlands, Saint Lucia, the United States, and Venezuela had ratified the Convention by the end of 1987 (Wecker 1987). Signatories to the Convention are committed to controlling pollution from, among other sources, land, dumping, and vessels. (See Chapter VII for a more detailed discussion.)

At the global level, the entry into force of Annex V of MARPOL at the end of 1988 (see Chapter VII) should lead to a reduction in plastic litter from vessels and offshore platforms in the Wider Caribbean marine environment. Some nations and the state of Texas have already proposed seeking Special Area status for the Caribbean Sea, the Gulf of Mexico, or the Wider Caribbean Area. This additional level of protection would reduce the amount of persistent debris such as glass and metal from vessels.

Because of the high levels of floating tar and tar on beaches, the international agreements to limit oil and tar pollution from the normal operations of tankers and other vessels are of particular importance to the Wider Caribbean area. The most recent of these is Annex I of MARPOL, which replaced earlier, less stringent restrictions when it went into effect in 1983. As of January 1988, nine nations in the Wider Caribbean study area had ratified MARPOL (and, automatically, Annex I): Antigua & Barbuda, Bahamas, Britain, Columbia, France, the Netherlands, Panama, St. Vincent & the Grenadines, and the United States.

The 16 nations in the area that had not ratified MARPOL included three significant producers of offshore oil: Mexico, Trinidad & Tobago, and Venezuela (Kershaw pers. comm.). Mexico and Venezuela have ratified the Cartagena Convention, which commits them to conforming to international law and to applying internationally recognized rules in preventing and reducing normal or accidental discharges from ships (Edwards 1985). The relevant provisions of the Cartagena Convention, however, are really a statement of intent and are much more general than the detailed standards of Annex I of MARPOL. (See Chapter VII for a more detailed discussion of the provisions and effects of Annex I of MARPOL and the Cartagena Convention.)

Summary and Conclusions

As with the northwest Atlantic study area, marine debris in the Wider Caribbean comes from a wide variety of major sources: merchant shipping, commercial fishing, offshore oil development, solid waste disposal practices. Significant amounts are generated within the region, but the North Atlantic also contributes heavily to the debris load.

Floating tar and tar on beaches are clearly more serious problems than in the preceding study areas, especially considering the importance of tourism to the region's economies. For at least a decade, tar and other forms of petroleum pollution have been perceived as the worst pollution problem in the Wider Caribbean; the CARIPOL project and other observations now have provided the data to confirm that perception.

Although tar pollution is clearly a serious problem, successful mitigation will require more information on its sources, amounts, and trends in the Wider Caribbean study area. In some areas with significant tar pollution, such as Barbados, Trinidad & Tobago, and Texas, there was disagreement about the relative contributions of natural seeps and vessels. For the entire study areas, there also was disagreement on the impacts of tanker de-ballasting versus discharge of fuel oil residues from tankers and other merchant ships. Mitigation measures for these two are not the same. Other sources, without data to support their claims, said that tar pollution from routine offshore oil development operations was underestimated in the National Research Council study (NAS 1985). Finally, we found disagreement on trends. Towle and Wilber (pers. comms.) saw evidence of a decline in tar pollution similar to the evidence reported for Bermuda (see Chapter IV). Romero *et al.* (1981) concluded that tar levels had remained roughly the same over 30 years on southeast Florida beaches.

Generally, the locations most affected by debris are downwind from major currents or shipping lanes. The conflict between debris occurrence and tourist expectations of pristine beaches is probably the best understood problem caused by tar and litter, although it is not well documented. The correlative effect, of course, is the cost of mitigation: cleaning beaches. Without substantial mitigation efforts, the conflict will deepen as coastal tourist development, urbanization, and exploitation and transportation of oil increase.

The Wider Caribbean study area provided more information suggesting that the effects of debris on sea turtles, particularly by ingestion of tar and plastics, may be extremely serious. There was no evidence of impacts on other wildlife at levels that should cause concern. (The studies on ghost fishing by lost traps were reassuring as far as they went, but they looked at a very limited section of the region's trap fisheries.)

With the entry into force of Annex V of MARPOL and the potential of the Cartagena Convention, prospects for mitigating debris problems in the Wider Caribbean would appear to be excellent. The best remedies, however, such as education, compliance with regulations on oil discharge and litter disposal from vessels, and better handling of land-source litter, will be expensive for small, fragile economies. Such solutions as port reception facilities for fuel oil residues and trash may only be possible if they are planned and funded regionally. Reduction in the amounts of debris from one major source — the Atlantic Ocean — is the only mitigation that Wider Caribbean nations will not have to bear the cost of. It is also the one that they will have to rely on the efforts of other nations to implement.

VI. DISCUSSION: THE WEST COAST OF BAJA CALIFORNIA, MEXICO

Description

The Baja California study area comprises the roughly 1300 km of Pacific Ocean coast between the Mexico-United States border in the north and Cabo San Lucas in the south (Figure VI-I). We include islands as far offshore as Isla de Guadalupe, some 280 km west of the Baja peninsula. Most of the coast on the peninsula consists of broad, sand beaches. Many of the island coasts are cobble or cliff with no beach.

During most of the year, the California Current flows south along the Baja coast and the northwest winds are normally brisk. In December-March, there is a weak northerly drift, the Davidson Current. Winter storms are accompanied by winds out of the south.

Types, Quantities, Sources, and Distribution of Marine Debris

The only information we found on any aspect of marine debris in Baja California was from anecdotal accounts of individuals who had made periodic visits to the region for, with one exception, purposes unrelated to debris.

Mate (pers. comm.) provided the most comprehensive observations. In 1974-75, he flew most of both Baja coasts looking for stranded marine mammals. He also walked several Baja beaches in 1979, 1980, and 1983. He estimated that pieces of large debris (tires, balls of netting, large cans or drums, pieces of boats or aircraft) occurred on the west coast at least every mile. Some areas had much higher concentrations: Miller's Landing near Guerrero Negro, Punta Abreojos, Punta Eugenia, and areas just north and south of Bahia Magdalena.

He saw little small debris, although his aerial surveys were at an altitude low enough to distinguish items as small as cups and six-pack yokes.

His impression was that there was more debris on the Pacific coast than in the Sea of Cortez.

Mate did not see ghost nets along the Pacific coast although he frequently saw them from the air in the Sea of Cortez. Ghost nets have likely increased on the Pacific coast, however, since net fisheries have expanded rapidly there since Mate flew the coast (Grabowski, Klein, Schwartz pers. comms.).

Heneman made spot checks along the 75 km of coast between Todos Santos and Cabo San Lucas in 1983 and found the entire stretch to be virtually pristine. He found light concentrations of debris on the beaches north of the mouth of Laguna San Ignacio in 1983 and 1985. In the same area in 1987, he observed fewer than 20 debris items per 100 linear meters of beach, on a section of beach that was over 100 m wide. The small amounts of debris appeared to be general land- or vessel-generated trash that had drifted a

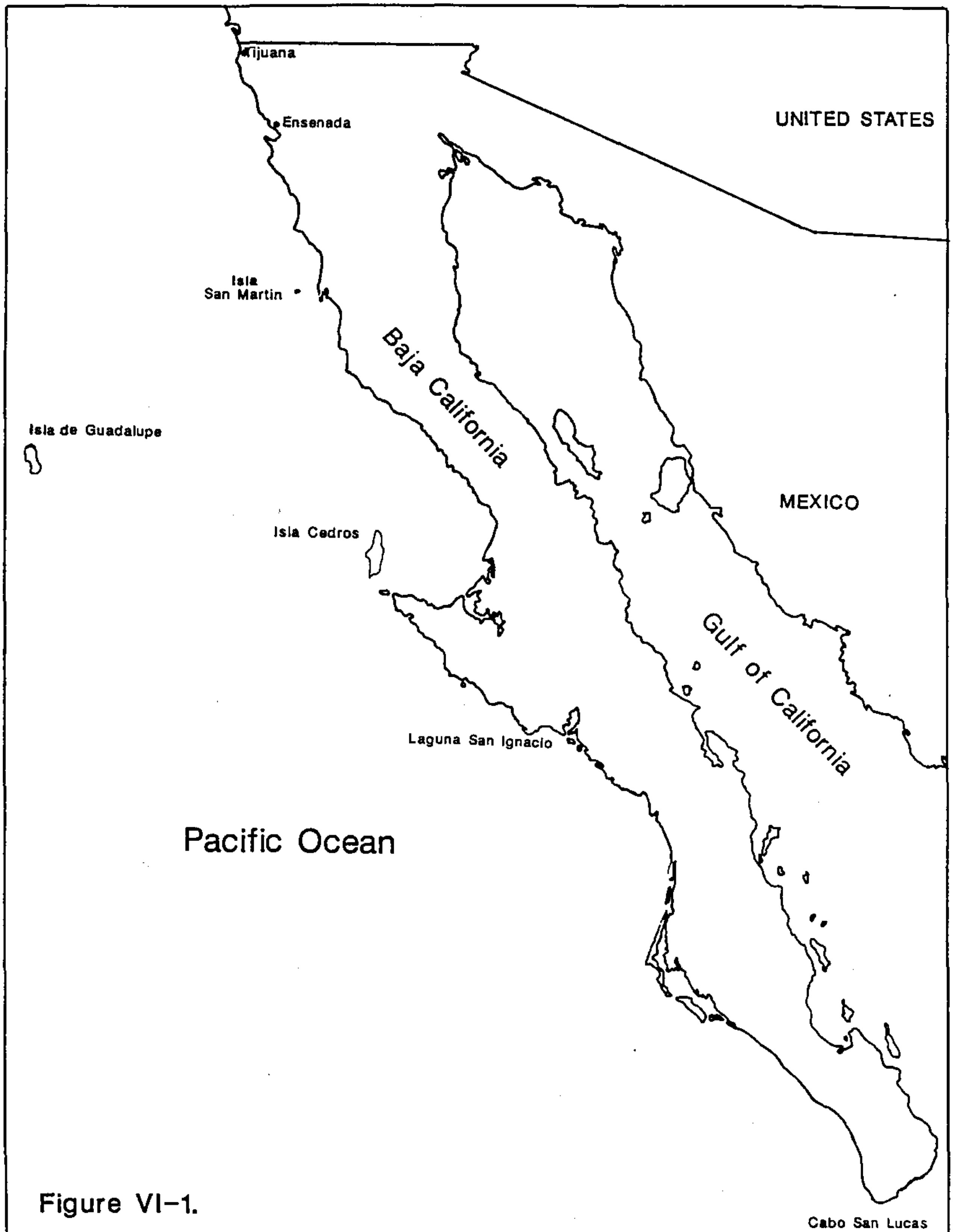

Figure VI-1.

WEST COAST OF BAJA CALIFORNIA STUDY AREA considerable distance. He also visited Isla Cedros, Islas San Benito, and Isla San Martin the same three years and found little debris. Most of what there was — shoes, food containers, plastic outboard motor oil bottles — appeared to have been generated locally by seasonal fishing camps.

DeLong (pers. comm.) surveyed most of the east side of Isla de Guadalupe in August 1984 looking for debris and entangled Guadalupe fur seals. On roughly 30 km of coast he found one small net fragment and one plastic oil container. DeLong was impressed by how clean the coast was, but also pointed out that it was on the leeward side of the island.

Debris likely is heavier along the northernmost section of the Baja coast since it is near the population centers of Ensenada, Tijuana, and southern California. Escofet (pers. comm.) reported plastic on beaches near Tijuana, which she attributed to vessels. During periods of high rainfall, Tijuana's sewage treatment plant discharges untreated sewage (*Marine Pollution Bulletin* 1986), likely including plastic material, into the Tijuana River and the ocean. Much of that material probably drifts north along the coast, however, since the flooding takes place during winter storms when winds are from the south.

Effects of Marine Debris

Mate (pers. comm.) reported that he occasionally saw birds and marine mammals entangled in six-pack yokes or net fragments, but not in numbers that should cause concern.

DeLong (pers. comm.) observed roughly 1600 Guadalupe fur seals on Isla de Guadalupe, none of which were entangled.

Storro-Patterson (pers. comm.) reported having seen occasional California gray whales and pinnipeds entangled in polypropylene line along the Pacific coast from Baja California to Alaska, and several entangled gray whales are reported in southern California each year through the California Marine Mammal Stranding Network (Lecky pers. comm.). Most of these animals probably became entangled in actively fished gear, and there usually is little indication whether the entanglement occurred in Mexican or United States waters.

Stewart and Yochem (1985) reported that about 0.08% of California sea lions, northern elephant seals, and harbor seals on San Nicolas and San Miguel islands off southern California were entangled, but concluded that most of these entanglements were the result of encounters with actively fished gear. There was no indication whether any of the small number of animals entangled in debris had encountered the material in Mexican waters.

Mitigation

The only mitigation that we became aware of is an agreement between Mexico and the United States to plan and build facilities to contain sewage that overflows into the Tijuana River during heavy rainfall. According to the

Marine Pollution Bulletin (1986), however, the planned retention basins will be only a temporary solution to the problem.

Summary and Conclusions

Clearly, there is little information available on marine debris on the Pacific coast of Baja California, Mexico. Systematic observations are almost nonexistent. Many visitors to the region could provide their informal observations. The individuals we asked reported no evidence of problem levels of debris with two exceptions: possible debris "hotspots" such as Mate and Escofet mentioned, and the likelihood of increased gill net debris as a result of the growth of the set gill net fishery in the past decade. Otherwise, the reports we received indicated that marine debris is not a problem in this area.

VII. DISCUSSION: INTERNATIONAL AGREEMENTS TO REGULATE MARINE DEBRIS

Since the 1950s, the international community has developed several global and regional approaches to the study, reduction, and control of pollution of the marine environment. The focus initially was on oil, chemical, and sewage pollution, but in the past few years increasing attention has been paid to the kinds of persistent debris that are the subject of this report. This chapter provides a brief analysis of these efforts after first introducing the various international bodies currently involved with marine debris issues.

International Organizations

The United Nations and agencies in the UN system are the principal international organizations concerned with marine pollution. The UN itself is the ultimate forum for the discussion of international issues. Although agencies in the UN system conduct most programs related to marine pollution, one exception within the UN itself is the Secretariat Office for the Law of the Seas Affairs. It is responsible for following the progress of the Convention on the Law of the Seas (see page VII-9) toward ratification, and for implementing it when ratified (Mensah 1984).

As a result of the 1972 Stockholm Conference on the Human Environment, the UN General Assembly created the United Nations Environment Programme (UNEP). UNEP has a broad charge of promoting international cooperation on the environment, reviewing the world's environmental situation, conducting research, and providing policy guidance for other UN agencies. Of particular relevance to this study is the UNEP Regional Seas Programme, established in 1974 to encourage regional approaches to protecting the marine environment. The Wider Caribbean is one of 11 such areas in the world (Mensah 1984; UNEP 1984).

The International Maritime Organization (IMO), which began operations in 1959, was established as a special agency of the UN. IMO and its Marine Environment Protection Committee (MEPC) work with other international agencies and shipping and oil industry associations in developing international standards for, among other things, prevention and reduction of pollution from ships. The MARPOL Convention and Protocol are examples (see below). IMO provides advice and assistance to developing countries for implementation of its international conventions (Mensah 1984). It also reviews proposals to create Special Areas requiring greater protection from pollutants from vessels.

The Intergovernmental Oceanographic Commission (IOC) is an independent group operating within the United Nations Educational, Scientific, and Cultural Organization (UNESCO). The IOC conducts, funds, encourages, and coordinates marine research and international exchange of information as part of its Global Investigation of Pollution in the Marine Environment (GIPME) program. GIPME has the objective of providing a scientifically sound basis for regulating marine pollution (IOC 1985). GIPME relies heavily on national and regional research efforts that collectively constitute a global Marine Pollution Monitoring

System (**MARPOLMON**). The IOC often collaborates with other international agencies. An example is the IOCARIBE program, including the CARIPOL petroleum pollution monitoring project, sponsored jointly by the IOC and UNEP (see Chapter V). The monitoring activities conducted under the Oslo, Paris, Helsinki, and London conventions also provide data for MARPOLMON. To help in implementation of GIPME, the IOC formed a Group of Experts on the Effects of Pollution (**GEEP**), which is concerned with biological impacts of pollution, and a Group of Experts on Methods, Standards, and Intercalibration (**GEMSI**), which develops standards and research protocols, and evaluates data from national and regional research programs for quality and comparability (IOC 1985). For example, GEMSI helped develop the IOCARIBE *CARIPOL Manual for Petroleum Pollution Monitoring* (IOCARIBE 1980). GEMSI is sponsored jointly by the IOC and UNEP (Kullenberg 1986).

Another IOC program, the Marine Pollution Monitoring Programme (Petroleum) (**MAPMOPP**), which is co-sponsored by the World Meteorological Organization, tracks surface oil pollution in the world's seas (GESAMP 1984).

The Food and Agricultural Organization (**FAO**), because of its interest in world fisheries, has recently become involved in assessing amounts of lost and discarded fishing gear and its effects on marine life (FAO 1987).

Eight UN agencies (including IMO, UNESCO, IOC, and FAO) established the Group of Experts on Scientific Aspects of Marine Pollution (**GESAMP**) in 1969. It advises the sponsoring agencies on such subjects as the effects of pollutants, and helps evaluate proposed mitigation. A major, continuing GESAMP project is revision of its review, *The Health of the Oceans*, which was first published in 1982.

Outside the UN, governing bodies for such regional agreements as the Oslo, Paris, Helsinki, and Cartagena conventions, and the London Dumping Convention all are directly concerned with persistent marine debris. Several nongovernmental organizations participate actively in the negotiation of conventions to control marine pollution and the development of implementing guidelines. Industry associations include the International Chamber of Shipping, the Oil Companies International Marine Forum, the International Association of Independent Tanker Owners, the International Petroleum Industry Environmental Conservation Association, and the Oil Industry International Exploration and Production Forum. A few environmental organizations, such as the International Union for Conservation of Nature and Natural Resources, play similar roles (Mensah 1984).

Global Agreements

This discussion reviews the coverage and limitations of three international agreements with global application that regulate or, in the case of the Law of the Sea Convention, potentially regulate the types of marine pollution covered in this report. Annexes I and V of MARPOL 73/78 deal with tar, with hydrocarbons that might weather into tar, and with plastics and other garbage such as glass and metal. The London Dumping Convention covers ocean dumping including, of relevance to this report, of hydrocarbons and plastics. In regard to hydrocarbons, our discussion is limited to agreements to regulate operational discharges of petroleum from vessels. Efforts to control the effects of accidental spills from tankers and offshore oil development facilities are beyond the scope of this study.

1. MARPOL 73/78 — Annex I

The 1973 International Convention for the Prevention of Pollution from Ships and the Protocol of 1978 (MARPOL 73/78) are "the primary international regime aimed at preventing unnecessary and uncontrolled discharges of pollutants into the oceans of the world from ships" (Kime 1986). Although MARPOL now covers a wide variety of pollutants, its origins lie in international concern, dating to before World War I, about oil pollution of the oceans; however, no international agreement to control oil pollution from ships was reached until the 1950s (IMO 1986). In order to understand the regulations adopted over the past 30 years, it is useful to have a general picture of how ships generate wastes that result in tar pollution.

A variety of normal ship operations result in discharges of hydrocarbons that are tarry when they enter the marine environment or soon weather to the consistency of tar. The vast bulk of these discharges are from two sources: tanker ballasting operations and fuel oil sludge (Hayes pers. comm.). The National Research Council estimated that these two sources accounted for about 92% of such discharges (NAS 1985). Consequently, we have limited our discussion of tar pollution from ships to these two sources.

- Tanker ballasting operations — After unloading a cargo of crude oil, some amount of the crude, called clingage, remains on the bottom and sides of the tanks. The tanker then must take on water ballast so that the vessel will handle properly on its return voyage to a loading terminal. The ballast mixes with the clingage, but given time and calm enough seas the combination forms a tarry layer on top, a layer of "clean" water on the bottom, and between them, a "gray" layer of water and small oil particles.

The ballast tanks must be emptied before taking a new cargo, but loading ports have long prohibited discharge of the oily ballast in harbors. And without the steps now being taken to reduce its volume, the amount of oil ballast formerly was too great to be handled by port reception facilities, if they existed. As a result, before the oil pollution regulations of recent years, the oily ballast was discharged at sea and replaced with clean ballast water that could be discharged in port (Wardley-Smith 1976).

Several mitigating measures have reduced the amount of oily ballast discharged into the world's oceans. Some tankers, particularly newer ones, have segregated ballast tanks (SBT), used only for water ballast (Hillyard pers. comm.). The obvious disadvantage of this system for the ship owner is that the ballast tanks can not be used to carry cargo.

Another new technique is used while the tanker is unloading. Crude oil is sprayed onto the tank surfaces, washing off much of the clingage. The result of crude oil washing (COW) is less oily ballast to be disposed of subsequently (Hillyard pers. comm.).

A third technique, load on top (LOT), is now routinely combined with COW on the vast majority of the world's tankers (Hayes pers comm.). In this system, an unloaded tanker takes on water ballast in some tanks. While the vessel is under way, other tanks are thoroughly cleaned with heated water under pressure, and the oil and water residue from that process is pumped into a "slop tank." The cleaned tanks can now be filled with clean ballast water. Meanwhile, oil in the dirty ballasted tanks floats to the top, permitting the relatively clean water underneath it to be decanted into the sea. Gauges monitor the amount of oil in the discharged water so that pumping can be halted when the oil content is above acceptable limits. The oily ballast that can not be discharged is then pumped into the slop tank. The slop tank also undergoes a continuous settling and decanting process. The next cargo is loaded on top of the residue in the slop tank, the one tank that still contains a residue of crude oil and some water.

The LOT system requires trips long enough, and weather calm enough, for the settling and decanting process to work. For short trips, tankers must discharge their oily ballast into reception facilities at the loading terminal, an extra step in port that delays loading (Wardley-Smith 1976).

- Fuel oil sludge — The world's merchant fleet, including tankers, has increasingly shifted from steam power to low-speed diesels that burn low-grade oil. Before being used as fuel, this bunker oil must be partially purified on board. The sludge that results is mixed with much smaller amounts of machinery space (bilge) oil. One large, high-horsepower vessel generates as much as 300 metric tons of sludge per year (Hayes pers. comm.). Especially on nontankers, sludge holding tanks may not be large enough to hold all the sludge generated between visits to ports with reception facilities. Disposal overboard is the only alternative (NAS 1985).

The first international agreement to limit these sources of tar in the marine environment was the International Convention for the Prevention of Pollution of the Sea by Oil, 1954, as amended in 1962, 1969, and 1971 (IMO 1985). The original convention and the 1962 amendments prohibited the deliberate discharge of oil or water containing more than 100 ppm of oil from all vessels (except tankers less than 150 tons gross and other ships under 500 tons gross) within 50 miles of land (with higher distance requirements in some areas outside the scope of this report). The contracting parties agreed to provide reception facilities for oil residues. The convention also required the first record keeping for oil transfer and ballasting operations (IMO 1985, 1986).

The 1969 amendments prohibited all oil discharges from tanker cargo spaces within 50 miles of land, limited the rate at which oil could be discharged outside prohibited zones to 60 liters/nautical mile, limited the total amount of oil that a tanker could discharge on a ballast voyage to 1/15,000 of the ship's total cargo carrying capacity, and limited the oil content of machinery space residue discharges from all vessels to 100 ppm (IMO 1985, 1986). The 1971 amendments were not relevant to this study.

By the time the 1969 OILPOL amendments were adopted, the growth in the transport of hydrocarbons, other chemicals, and hazardous materials, events such as the *Torrey Canyon* spill, and a heightened environmental awareness led IMO to sponsor a conference to write an entirely new agreement. The result was the 1973 International Convention for the Prevention of Pollution from Ships (MARPOL), the five annexes of which cover all types of marine pollution from ships except dumping (see page VII-7 for a discussion of the London Dumping Convention). Annex I, on pollution by oil, and Annex V (see page VII-8), on pollution by garbage from ships, are relevant to this report (IMO 1985, 1986).

Annex I of MARPOL 1973 maintained the discharge requirements of OILPOL, but reduced the total amount that tankers can discharge from cargo spaces to 1/30,000 of total capacity. An important new feature (Regulation 10) was the concept of "Special Areas" where oil discharges are totally prohibited (the Baltic and Mediterranean seas, for example, were so designated). This mechanism is discussed further in the section on regional approaches to controlling marine debris.

All tankers were required to be able to employ the LOT system and retain all cargo space oil residues on board. The convention specifies the discharge monitoring and control equipment, filters, slop tanks, and plumbing necessary for a tanker to employ LOT. New tankers larger than 70,000 tons deadweight are required to have enough SBT capacity so that the vessel need not carry ballast water in cargo spaces. Equipment to remove machinery space oil from water that is discharged, to monitor and control these discharges, and to retain machinery space residues on board are specified for all vessels larger than 400 gross tons. To aid in enforcement, each tanker larger than 150 gross tons must be surveyed and certified every five years (IMO 1985, 1986).

For a variety of reasons, the MARPOL Convention did not enter into force in its original form. It was added to and revised by the MARPOL Protocol of 1978, and the two instruments, as one, entered into force in October 1983. The 1978 Protocol lowered the threshold for requiring SBT on new tankers from 70,000 to 20,000 deadweight tons. The Protocol also made COW an alternative to SBT on existing tankers and required it on new tankers (IMO 1985, 1986).

One set of amendments (1984) to Annex I entered into force in 1986, but they represent refinements generally not relevant to this discussion.

By the end of January 1988, 49 nations representing over 95% of the world's tanker tonnage had ratified MARPOL 73/78, although not all of these had acceded to Annex V (IMO 1988; Office of Technology Assessment 1975). IMO and the National Research Council have said that OILPOL, MARPOL Annex I, and a few other factors have already brought about great improvement in tanker design and equipment and a significant reduction in tar pollution of the marine environment (Hayes pers. comm.; IMO 1986; NAS 1985). Several reasons are offered for the improvement:

- Before OILPOL's 1969 amendments went into effect in 1973, oil discharges were unrestricted outside the prohibited zones (normally 50 miles from land);

- OILPOL and MARPOL have been accompanied by design and technology improvements such as SBT, LOT, COW, and port reception facilities;

- Because the cost of modifying a ship is very expensive, tankers built after new standards were adopted generally conformed to those standards even before the agreements entered into force;

- Ship owners, operators, officers, and crew have all become more aware of the desirability of conforming to new international standards;

- Monitoring for compliance with regulations has become more effective;

- The rise in the price of crude oil has encouraged the reduction of waste;

- In the 1980s, transport of crude oil has declined more than 25%.

The improvement is expected to continue as older tankers are retired (IMO 1986).

It may be, however, that a disproportionate share of any decrease in tar pollution from ships is attributable to improved tanker operations. Tar from nontankers, the vast majority of the world's merchant fleet, may even have increased as steam ships have given way to diesel-powered vessels that generate large amounts of fuel oil sludge.

The implications of this question, for this report, are greatest for the Wider Caribbean study area. Although producer countries such as Mexico, Venezuela, and Trinidad & Tobago are not signatories to MARPOL, almost all of their small number of loading terminals have facilities for unloading slop tanks. In contrast, few ports in the Wider Caribbean, including crude oil loading terminals, are equipped to handle fuel oil sludge and machinery space residues. The same problem exists in many other parts of the world. Therefore, an increasing proportion of marine tar pollution should be from nontankers (Hayes pers. comm.). However, most of the investigations we have reviewed for the northwest Atlantic and Wider Caribbean attributed tar primarily to tanker operations and, to a lesser extent, to offshore oil production and natural seeps. Several possible explanations for this contradiction suggest themselves, at least two of which seem worth mentioning.

First, in the tar studies we reviewed, the last samples of any size to be analyzed were collected in 1981 by Van Vleet *et al.* (1984). Since then the opposing trends of tanker compliance with MARPOL Annex I and the shift to diesel and heavy fuel oils have been continuing. Hayes (pers. comm.) suggested that the National Research Council's estimates (NAS 1985), which were based primarily on 1980 information and attributed more than twice as much oil pollution worldwide to tanker operations as to fuel and bilge oils, is seriously out of date.

Second, an obvious question is whether the standard gas chromatagraphic analyses of tar balls can positively discriminate between oil from deballasting operations and fuel oil sludge. We were unable, through the very limited effort possible for us in the scope of this project, to find out whether that question can be answered with certainty. As we have recommended, however, since the mitigation measures differ, more information is needed on the relative contributions of tankers, nontankers, offshore oil production, and natural seeps to marine tar pollution, particularly in the Wider Caribbean Area.

2. The London Dumping Convention

The first IMO agreement to deal with persistent marine debris other than tar was the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention, or LDC), which was adopted in 1972 and entered into force in 1975.

Dumping was defined as "any deliberate disposal of wastes or other matter from vessels...platforms or other man-made structures at sea" (Article III). Excluded from this definition, however, was "the disposal of wastes or other matter incidental to, or derived from the normal operations of vessels...platforms, or other man-made structures at sea and their equipment" (Article III). Article IV prohibits "the dumping of wastes or other matter listed in Annex I." Annex I includes "persistent plastics and other persistent materials, for example, netting and ropes, which may float or may remain in suspension in the sea in such a manner as to interfere materially with fishing, navigation or other legitimate uses of the sea" as well as "crude oil, fuel oil, heavy diesel oil...and any mixtures containing these, taken on board for the purpose of dumping." The LDC clearly prohibits the dumping of all types of persistent debris generated on land and taken to sea for disposal, and the Convention appears to have succeeded in that intent.

For some years there has been discussion of how far the Convention can be stretched to cover debris such as discarded fishing nets and wastes generated on vessels (Bean 1984, 1987; Gosliner 1985; Lentz 1986, 1987). That issue has become moot since MARPOL Annex V will enter into force at the end of 1988 (see below). The regulations of the LDC and MARPOL Annex V apparently will complement each other since, as Bean (1984) pointed out, the MARPOL Convention defined "discharges" in a way that excludes acts defined as "dumping" under the LDC. On the other hand, in a statement that added weight to the general intent of both agreements, the Ninth Consultative Meeting of the LDC declined to draw a sharp line between the two, and concluded that:

"the deliberate disposal of ship-generated persistent plastic and synthetic material, including fishing nets, whether or not such deliberate disposal is covered by Annex V of MARPOL 73/78 or constitutes dumping under the [London Dumping] Convention, is a source of marine pollution which the [London Dumping] Convention calls upon all Contracting Parties to control" (Lentz 1986).

This statement apparently refers to Article XII of the LDC, in which Contracting Parties pledge to promote measures to protect the marine environment from pollution caused by, among other things, "wastes generated in the course of operations of vessels...platforms and other man-made structures."

3. MARPOL 73/78 — Annex V

When the International Convention for the Prevention of Pollution from Ships was adopted in 1973, it included three optional annexes. Annex V, Regulations for the Prevention of Pollution by Garbage from Ships, has received increasing attention in the past several years as concern over plastics pollution and other persistent marine debris has mounted. Ratification by the United States in December of 1987 meant that the requirements for entry into force had finally been met, and Annex V will enter into force at the end of 1988 (IMO 1985; MMC 1988).

Garbage Type	All Vessels		Offshore Platforms and Associated Vessels***
	Outside Special Areas	Inside Special Areas**	
Plastics, includes synthetic ropes and fishing nets and garbage bags	Dumping Prohibited	Dumping Prohibited	Dumping Prohibited
Floating dunnage, lining, and packing materials	>25 miles offshore	Dumping Prohibited	Dumping Prohibited
Paper, rags, glass, metal bottles, crockery, and similar items	>12 miles	Dumping Prohibited	Dumping Prohibited
Paper, rags, glass, etc., comminuted or ground*	>3 miles	Dumping Prohibited	Dumping Prohibited
Food waste not comminuted or ground	>12 miles	>12 miles	Dumping Prohibited
Food waste comminuted or ground*	>3 miles	>12 miles	>12 miles
Mixed refuse types	More stringent requirements apply	More stringent requirements apply	More stringent requirements apply

* Comminuted or ground garbage must be able to pass through a screen with mesh size no larger than 25 mm.
** Special areas are the Mediterranean, Baltic, Red, and Black Seas areas and the Gulf area.
*** Offshore platforms and associated vessels include all fixed or floating platforms engaged in exploration or exploitation of seabed mineral resources and all vessels alongside or within 500 m of such platforms.

Table VII-1. Summary of garbage discharge limitations under MARPOL 73/78. (Reproduced from the *Annual Report of the Marine Mammal Commission, 1987.*)

As with Annex I, the restrictions in Table VII-1 apply to all ships of signatory nations anywhere in the world, to all ships of nonsignatory nations while they are in the territorial waters of signatory nations, and to "fixed and floating platforms engaged in the exploration, exploitation and associated offshore processing of seabed mineral resources" in the territorial waters of signatory nations (MARPOL 73/78).

Signatory nations are also bound to undertake "to ensure the provision of facilities at ports and terminals for the reception of garbage, without causing undue delay to ships, and according to the needs of the ships using them" (MARPOL 73/78).

One exception to Annex V is relevant to this study. As with the LDC, "the accidental loss of synthetic fishing nets" is not regulated (MARPOL 73/78).

The Special Area provisions of Annex V are discussed in the section of this chapter on regional agreements.

The IMO, as secretariat for MARPOL 73/78, is currently developing guidelines for the implementation of Annex V. Within IMO, the Marine Environment Protection Committee and its Working Group on Optional Annexes are drafting the guidelines (IMO 1987; MMC 1988).

How effective Annex V will be remains to be seen. It still has many fewer signatory nations than either Annex I or the LDC. It applies to many tens of thousands of vessels; therefore, monitoring and enforcement will be more difficult than for other agreements. Compliance will be impossible without significant investments in port reception facilities and shipboard compactors, incinerators, and comminuters. Perhaps most important, Annex V's success will require education to change outlooks and behavior patterns.

4. The United Nations Convention on the Law of the Sea, 1982

The Law of the Sea Convention (LOS), another indirect result of the 1972 Stockholm Conference, has not yet entered into force. As of early 1987, only 26 of 159 signatory nations had ratified it, with 60 nations required. Provisions relevant to this report include the commitment of signatory states to adopt laws and regulations to prevent, reduce, and control dumping, pollution from vessels, and pollution from land-based sources. Other provisions contain even more general statements on protecting marine resources and on the powers of coastal states to regulate activities in their territorial seas (CEE 1987a). Much of the language of these provisions is borrowed from other international agreements. Therefore, as Bean (1984) concluded, "Although...it has not yet come into force, most of its provisions enjoy wide support as customary international law."

Regional Agreements

A host of regional agreements dealing with various aspects of marine pollution have been adopted in the past 20 years. They have the advantages of concerted action to address problems beyond the power of individual nations to solve, while having provisions tailored to the circumstances of the specific region. They also can enter into force when the nations of one region agree; there is no need to wait for global support. Perhaps most important, a regional agreement provides a forum for discussing regional problems, a necessary focus on the local marine environment, and a framework for multilateral cooperation.

1. The Oslo Convention

The Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft (the Oslo Convention), which was adopted in 1972 and entered into force in 1974, was the first regional agreement for pollution prevention, rather than for dealing with the results of an oil spill. It covers the north-east Atlantic Ocean and North Sea, and has been ratified by all the maritime states of Europe bordering the bodies of water covered by the Convention except the Soviet Union (Hayward 1984; CEE 1987a).

The Oslo Convention, among other things, prohibits the dumping of "persistent plastics and other persistent synthetic materials which may float or remain in suspension, or sink to the bottom, and which may seriously interfere with fishing or navigation, reduce amenities, or interfere with other legitimate uses of the sea" (Annex I). The wording is almost identical to that in the subsequent London Dumping Convention. The parties also agreed to cooperate on monitoring the effects of pollutants and on research into "alternative methods of disposal of harmful substances" (Articles 12 and 13).

The Convention provides for regulated dumping of other listed substances, including "tar-like substances," according to a permit system that takes into account amounts to be dumped; characteristics of the wastes; and location, condition and characteristics of the proposed dump site.

2. The Paris Convention

The Convention for the Prevention of Marine Pollution from Land-based Sources (the Paris Convention), adopted in 1974, has been ratified by all the contracting parties to the Oslo Convention except Finland, and with the addition of the European Economic Community. This Convention also covers the North Sea and northeast Atlantic Ocean.

The Paris Convention tackles the more difficult job of controlling land-source pollution, and its approach is necessarily more complex. It recognizes that pollution can reach the seas "through watercourses, from the coast, including through underwater or other pipelines [outfalls], from man-made structures" off the coast. Of relevance to this report, it commits Contracting Parties to implementing programs and measures "for the elimination...

of pollution of the maritime area from land-based sources by substances listed in Part I of Annex A," which include, among other things, "persistent synthetic materials which may float, remain in suspension or sink, and which may seriously interfere with any legitimate use of the sea," and "persistent oils and hydrocarbons of petroleum origin" (Article 4 and Annex A, Part I).

The substances in Part I of Annex A were included, "because they are not readily degradable or rendered harmless by natural processes; and because they may either give rise to dangerous accumulation of harmful material in the food chain, or endanger the welfare of living organisms causing undesirable changes in the marine eco-systems, or interfere seriously with the harvesting of sea foods or with other legitimate uses of the sea; and because it is considered that pollution by these substances necessitates urgent action" (Annex A, Part I).

The complexity of the Paris Convention lies in its commitment to ending not *discharges* of proscribed substances, but *pollution* by such discharges. As a result, the Convention signatories are also pledged to cooperative efforts to assess levels of pollution and the effectiveness of measures to reduce pollution (Article 11), and to conducting joint research into new methods of reducing land-source pollution (Article 10).

So far, the Paris Convention has not been used as a mechanism for reducing land-source litter that reaches the coast (Hayward pers. comm.). The problem of beach litter came before the Paris Commission (governing body for the Convention) in 1978. The Commission then sought information from its Contracting Parties. Based on data provided by the Federal Republic of Germany and the United Kingdom, the Commission concluded that the vast majority of beach litter was attributable to ships, and therefore was within the scope of MARPOL 73/78 Annex V. As we reported in Chapter III, however, Caulton *et al.* (1987) and Chaussepied (1985) have demonstrated that land-source material can be the major component of beach debris in some areas of the North Sea coast, particularly near cities or river mouths.

3. The Helsinki Convention

The Convention on the Protection of the Marine Environment of the Baltic Sea Area (the Helsinki Convention) was adopted in 1974 and entered into force in 1980. It is the only regional agreement that has attempted to cover marine pollution from all sources, including ship-generated wastes, dumping, land sources, and exploration and exploitation of the seabed (Hayward 1984).

The comprehensive approach of the Convention makes it of interest here, although the Baltic Sea is beyond the scope of this report. Moreover, the Convention's ban on pollution from ships may have had unintended negative consequences for the North Sea study area. As we mentioned in Chapter III, ships may be disposing of trash just before entering or just after leaving the Baltic Sea (Skou pers. comm.), a problem that should end with the entry into force of Annex V or MARPOL 73/78.

4. The UNEP Regional Seas Programme

The UNEP Regional Seas Programme is a consequence of the importance the 1972 Stockholm Conference attached to regional pollution control (UNEP 1985). Initiated in 1974, it now includes 11 regions and over 120 coastal nations. Only one of these, the Wider Caribbean, is within the scope of this report (see the section on the Cartagena Convention below).

The approach has been similar in all regions (UNEP 1985; Edwards 1985; Hayward 1984; Lentz 1986, 1987). UNEP, at the request of governments in a region, coordinates the efforts of the countries involved and of relevant global and regional organizations in drafting an action plan. The action plan emphasizes assessment of sources, impacts, and trends of marine pollution; guidelines for controlling pollution and protecting and managing marine resources; review of socio-economic activities with impacts on the environment; and development of public awareness and training programs.

The action plan is followed by a convention that includes objectives and general statements of the signatories' obligations. Among these obligations are prevention or control of pollution from various sources, including dumping and discharges from ships.

The conventions are to be "umbrella agreements" accompanied by individual protocols dealing with specific issues, such as reducing pollution from a particular source, or cooperative measures on some aspect of environmental management. The protocols also enumerate the responsibilities of the various parties. Obviously, the success of a regional seas program depends on the scope and substance of the protocols adopted and implemented.

Although UNEP and other agencies initially provide funding and institutional help, the signatories are expected eventually to assume administration of each regional program.

5. The Cartagena Convention

Various Caribbean states and the Economic Commission for Latin America and the Caribbean, with assistance from UNEP and other agencies in the UN system, began drafting a regional seas program action plan for the Wider Caribbean in 1977. The action plan was finally adopted in 1981, and drafting of a convention and a protocol on oil spill cooperation began. The Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region (the Cartagena Convention) was adopted in 1983 (UNEP 1985), and it went into force in 1986 (Wecker 1987). By the end of 1987, 13 states had ratified the convention (Antigua & Barbuda, Barbados, France, Grenada, Jamaica, Mexico, the Netherlands, Panama, Saint Lucia, Trinidad & Tobago, the United Kingdom, the United States, and Venezuela) and 33 states were participating (MMC 1988).

The Convention states, always in general terms, that the signatories will "endeavor to conclude bilateral or multilateral agreements...for the protection of the marine environment" and will take "all appropriate measures" to prevent, reduce, and control pollution from ships, by dumping, and by coastal disposal and discharges from internal waters (CEE 1987a). It also commits its members to the principle of sustainable development (Wecker 1987).

Several projects are being implemented under the action plan, most of them concerned with oil spill preparedness, public awareness, and environmental training. Of particular relevance to this report was the training of participants in the CARIPOL petroleum pollution monitoring program (UNEP 1985).

Clearly, programs to actually prevent, reduce, or control marine debris will depend on the adoption and implementation of specific protocols, as is the intent of the Regional Seas Programme. Nonetheless, the action plan and the Convention provide mechanisms for the region to begin to identify issues and plan mitigation in the area. An important early achievement of the Cartagena Convention has been the shared recognition of the need for reliable information, careful planning, and joint action in solving marine resource issues.

6. MARPOL 73/78 Special Areas

In Annexes I and V, MARPOL 73/78 provides for a higher level of protection for five designated "Special Areas" (page VII-5 and Table VII-1). Designation of a region occurred "for recognized technical reasons in relation to its oceanographical and ecological condition and to the particular character of its traffic" (Regulation 1). The standards are, in effect, zero discharge for hydrocarbons and nondegradable solid wastes.

Interests in two areas within the scope of this project have proposed amending MARPOL to designate additional Special Areas. The State of Texas has asked the United States delegation to IMO to propose the Wider Caribbean Area, or, failing support from Caribbean nations, the Gulf of Mexico as a Special Area (Mauro 1987). And environmental ministers of the North Sea nations have voted to seek Special Area status for the North Sea (IMO 1987).

MARPOL includes procedures for the signatories and IMO to amend the agreement; however, there are no criteria beyond those quoted above for selecting Special Areas. Furthermore, the "recognized technical reasons" referred to are not defined. It is clear, however, that enough support would assure amendment even if the exact process for adding Special Areas is not yet clear.

What protection would MARPOL Special Area status add to the basic Annex V provisions? Disposal of all plastics is prohibited outside Special Areas. Glass, metal, paper, cloth, crockery, and dunnage are the categories that would be added to the total ban. These materials represented a substantial amount of the beach litter in both the North Sea and the Wider Caribbean. Implementation of the requirements would be much the same in that port reception facilities could handle the additional materials as well as plastic. In fact, less shipboard sorting would be required under the Special Area regulations since only two categories of waste remain: food and nonfood.

Implementation of Annex I Special Area status would be technically more difficult. A substantial increase in the number of ports with reception facilities would be necessary to achieve zero discharge.

An alternative for the Wider Caribbean Area that could include regulations tailored to the region would be specific protocols negotiated under the Cartagena Convention.

Summary and Conclusions

Most of the global and regional agreements relevant to persistent marine debris are relatively new; their histories are too short to permit much evaluation. One of the major tools, Annex V of MARPOL, has not even entered into force yet. The Regional Seas program for the Wider Caribbean is in its infancy; its success depends on protocols that are yet to be drafted.

The necessary framework of international agreements seems to be in place. What is needed is more implementation and continued monitoring and evaluation.

VIII. CONCLUSIONS AND RECOMMENDATIONS

We have organized this chapter into five sections: conclusions and recommendations generally applicable to the three study areas with significant marine debris problems (North Sea, northwest Atlantic, and Wider Caribbean), and conclusions and recommendations specific to each of the four study areas. These five sections are each subdivided into sections on information and mitigation.

General

1. Information

Research versus Mitigation

□ Conclusion — Existing information from the four study areas and other parts of the world clearly documents the existence of social, economic, and wildlife impacts caused by various types of persistent marine debris that enter the marine environment from several sources. More information is definitely needed about types, sources, quantities, distribution, and effects of marine debris in particular instances (as noted below), but care should increasingly be exercised to avoid committing scarce resources to duplicative research.

■ Recommendation — The limited resources available for dealing with marine debris problems should be shifted as much and as rapidly as possible from research to mitigation. Evaluation of future research projects should be based on how the information to be generated will either identify a new problem or contribute materially to the elimination of a known problem. In general, expenditures on research should emphasize the following needs:

- Filling critical information gaps. Critical information could be defined as being essential either for determining whether a problem exists, or for mitigation to proceed.

- Evaluating mitigation efforts. It is necessary to know whether local, national, and regional approaches are accomplishing what is expected of them.

- Monitoring debris trends. Carefully selected sites should be used for long-term monitoring of global trends.

Information Exchange

□ Conclusion — Cost-effective information gathering and mitigation both require greater communication and cooperation than currently exist. In spite of clear evidence of improvement in recent years, we found numerous examples of the remoteness of policy centers from problems, of researchers unfamiliar with the work of other researchers in related fields, and of lack of involvement of logical participants in the development of research and mitigation programs.

These problems are complicated by distance and language differences, but they occur even within fairly small circles. As just one illustration of the communication difficulties to be overcome, we mention our learning of two offices within NOAA, both responsible for developing a protocol for monitoring plastic pollution on beaches, each unaware of the other's project.

Another casualty of poor communication is comparability of data. For instance, there is no agreement in the literature on the choice between using square meters or linear meters of beach for reporting concentrations of beach tar or litter. Another example we encountered was the reporting of tar weights using at least three different methods of measurement (dry weight, wet weight, and toluene extractable material).

We found little evidence of international exchange of information on education programs targeted on debris generators such as the general public, specific user groups, or industries. Lack of communication also results in needed work not being done, while other projects duplicate each other. Finally, there is no single source to turn to for information on persistent marine debris.

■ Recommendations — Communication and cooperation need to increase dramatically. More information needs to move in both directions on the axis from local, through national and regional, to global agencies. At each level of discussion, greater effort must be made to involve the right people from the relevant policy bodies, scientific organizations, industries, and citizen groups.

A burst of interchange and activity followed the first international Workshop on the Fate and Impact of Marine Debris in Honolulu in 1984. Fortunately, a second workshop is now scheduled for April 2-8, 1989, also in Honolulu. Such gatherings need to occur more frequently, they should be held at regional and industry-wide levels as well, and they must be funded well enough to ensure the attendance of those who have useful information to share and those who can most effectively apply information gleaned from conferences in their own countries.

In addition, the relevant agencies in the UN system such as IMO, IOC, FAO, and UNEP can do even more than they are in fostering communication and cooperation. One of these organizations, presumably UNEP or IOC, should become the clearinghouse for marine debris information, able to refer an inquirer to the best sources on any aspect of the issue. All of these agencies should regularly assess whether they are soliciting advice from all relevant sources, and disseminating information as widely as possible.

Implementation of MARPOL Annex V

□ Conclusion — Entry into force of Annex V of MARPOL at the end of 1988 holds the promise of significantly reducing persistent debris in the marine environment if it is implemented successfully.

■ Recommendation — Industry, port authorities, international groups (such as IMO's MEPC), and national groups (such as NOAA and the Interagency Task Force on Persistent Marine Debris in the United States) need to continue to develop the information required to implement Annex V. For example, what is the status and adequacy of existing port reception facilities? What technologies are appropriate for handling ship-generated trash? What procedures could reduce the amount of waste generated?

Effects on Wildlife

□ Conclusion — Although there is clear evidence that marine debris affects individuals of many species, evidence of serious population level effects on marine wildlife is inconclusive. For example, few studies have been done on derelict nets and traps. Of these, some suggest there *might* be significant impacts on some commercial species in some areas. Other studies indicate that ghost traps and nets usually cease fishing effectively after a matter of months. Similarly, while there is 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. The effects of debris ingestion by seabirds are still largely unknown, although recent studies on a few species that do not normally occur in our study areas indicate that chick survival is affected, at least in those species.

In the case of marine mammals, there is little evidence in our study areas of the effects of marine debris ingestion or entanglement. Additional information on ingestion could be available by performing more necropsies on stranded animals.

Convincing evidence indicates that ingestion of tar and plastics can be fatal to individual sea turtles. We know nothing about such impacts on sea turtle populations, except that with these endangered or threatened species, any level of impact is significant. Of increasing concern, we know very little about the potentially serious effects of debris on entire age classes of young sea turtles still in their pelagic stage of development.

Considering the state of our information and the resources available, the important question to answer for all of these examples is, How much information is needed to decide whether or not mitigation programs are justified?

■ Recommendation — There should be international discussion (see Information Exchange above) that includes any agencies and organizations that might fund research on such projects to decide what additional information is necessary on the effects of marine debris on seabirds, marine mammals, and sea turtles, and to evaluate the effects of ghost nets and traps on marine resources.

In some instances, the consensus might be that there is no problem. In others, the decision could be that there is clear evidence of serious effects or that the evidence falls short of absolute certainty but is sufficient to justify mitigation. In these cases, further research on the effects should become low priority, and resources should be concentrated on mitigation. Or, the consensus might be that more information is needed, in which case the next steps should be deciding what research is to be done, who will do it, and which agencies will fund it.

Driftlines

□ Conclusion — Archie Carr (1986a, 1986b, 1987) has eloquently drawn attention to the role of downwelling along fronts in creating driftline habitat, and what the implications are for the animals that live there now that driftlines have become accumulators of debris:

> "The growing evidence for a more protracted stage, during which the juvenile turtles are passive migrants in fronts that are increasingly invaded by debris and toxic wastes, emphasizes the need for a better understanding by marine biologists of the organization of the driftline habitat and the behavioral ecology of its occupants...Until that sampling [of physical and biological factors of fronts] is done we are bound to remain peculiarly ignorant of the ecologic organization of three-fifths of the surface of the earth" (A. Carr 1986b).

■ Recommendation — Studying the role of fronts in concentrating both driftline habitat animals and debris is logistically difficult, but the questions Carr has raised surely are worth answering. The United States Marine Entanglement Research Program has made a small beginning on this task; it deserves international attention.

Recreational Beaches

□ Conclusion — The aesthetic effects of marine debris and the concomitant costs of routine beach clean-up are considerable and universal on recreational beaches, but information to support this conclusion is largely anecdotal, rather than quantitative.

■ Recommendation — Additional information on these effects of marine debris should not be gathered except as is useful for public awareness campaigns.

Unpublished Data

□ Conclusion — There are several sets of potentially useful, unpublished data for the North Sea, northwest Atlantic, and Wider Caribbean study areas (Amos, Horrocks, Lucas, Moxnes, Plotkin, Speed, Towle, Wilber pers. comms.).

■ Recommendation — Relevant agencies should fund publication of these existing data.

2. Mitigation

Public Awareness

□ Conclusion — Altering people's behavior by changing their outlook on waste and acceptable means of disposing of it will be the most effective means of solving persistent marine debris problems in the long run.

■ Recommendations — Public awareness programs and education components of other mitigation measures should receive extremely high priority for funding. Educational programs should be directed at the general public, as well as segments of the public, such as beachgoers, recreational boaters, and sport fishermen. Other targets for encouraging voluntary compliance should include industries, such as commercial fishing, merchant shipping, oil transportation, and offshore oil exploration and production.

Education programs for key groups should be pervasive. In merchant shipping, for example, appropriate programs should be aimed at ship owners. Crewmembers and officers should learn the legal and technical aspects of waste disposal in their initial training and at maritime colleges and technical schools, and shipboard review and educational posters could provide continual reminders about correct procedures. Special attention should be paid to naval architects, maritime professional societies, and port officials and operating staff. Such education programs should be developed with industry assistance.

A similar approach should be used with other industry and public groups that generate large quantities of persistent marine debris.

New Technolgies

□ Conclusion — New or improved technologies and systems for applying them are needed to significantly reduce marine debris, as has been noted by many investigators and agencies. These requirements are especially relevant to debris generated by merchant ships, fishing vessels, sewage treatment systems, and offshore oil exploration and production.

■ Recommendations — Port authorities and the merchant marine, commercial fishing, and oil production industries, in cooperation with other relevant industries (plastics manufacturing and packaging, fishing gear manufacturing, naval design, etc.) and national, regional, and international agencies, must develop new technologies, improve and more widely apply existing technologies, and develop systems for effectively applying these technologies to reducing persistent marine debris.

Vessel owners and operators, both merchant marine and commercial fishing, and offshore platform owners and operators need to reduce the amount of persis tent debris they generate, improve garbage handling techniques, and improve garbage processing technology (comminuters, incinerators, and compactors).

Port authorities in most ports will have to make substantial improvements in garbage reception facilities to allow vessels to comply with Annex V conveniently and effectively.

The fishing industry and fisheries management agencies need to make progress in reducing both the amounts and the ghost fishing potential of derelict gear. For example, escapement panels should be universally required in traps made of otherwise nondegradable materials. Nets and other gear could be made of degradable materials without losing their effectiveness (Andrady 1987). To reduce the amounts of floating derelict netting, nets should be made of negatively buoyant material and be attached to headropes with degradable material. The benefits and practical difficulties of gear marking should finally be determined. The idea of bounties to encourage shore disposal of gear should receive further attention (FAO 1985). The Canadian experience with retrieving ghost nets from heavily fished areas should be considered for application elsewhere (Way 1976).

The plastics manufacturing industry, the industries that use plastics in forms that commonly become marine debris, and relevant policy bodies and management agencies should cooperate in reducing the use of nondegradable materials (especially plastics), and increasing the potential for recycling and resource recovery (power generation by burning). This process likely will involve technological improvements, shifts among currently available products, and, in some cases, regulation.

North Sea Study Area

1. Information

□ Conclusion — With the possible exception of derelict fishing gear, there appears to be adequate information documenting the sources, amounts, types, distribution, and effects of persistent marine debris to justify mitigation.

■ Recommendation — Existing monitoring of the effects of derelict fishing gear (as with stranded marine mammals in the United Kingdom) should continue and be augmented by observations in other countries. Methodologies should be standardized and information shared through some mechanism such as an informal stranding network.

2. Mitigation

□ Conclusion — Most persistent marine debris in the North Sea study area appears to be domestic wastes from merchant shipping and fishing vessels. Plastic, glass, metal, and dunnage all represent substantial fractions of this debris.

■ Recommendation — North Sea nations that have not yet ratified Annex V of MARPOL 73/78 should be encouraged to do so since implementation of this agreement offers the greatest promise of reducing marine debris in the area.

Furthermore, although implementation of the basic provisions of Annex V would reduce debris, especially plastics, Special Area status for the North Sea would provide a significantly greater degree of protection by reducing glass, metal, dunnage, and other debris as well.

Northwest Atlantic Study Area

1. Information

□ Conclusion — Although adequate data on the sources, types, and effects of marine debris are generally available, there are important information gaps in addition to those mentioned above under general information needs:

- In the New York Bight region, the increasingly common episodes of beach pollution by land-source debris of uncertain origin points to the need for more precise information. Portions of the Canadian coast may have a similar problem.

- Several studies suggest that there are substantial quantities of lost traps and nets, but stop short of estimating the ghost fishing potential of this gear.

■ Recommendations — More information is needed on the Canadian coast and in the northeastern United States on the specific sources of marine debris that originates on land. The problem of illegal disposal should be included in this topic.

There should be further evaluation of the effects of ghost fishing by nets and traps, particularly off eastern Canada and New England.

2. Mitigation

□ Conclusion — The northern portion of the northwest Atlantic study area has more major sources of marine debris than any of our other study areas. The coast is heavily urban and industrial, and rivers (the largest of which is the Saint Lawrence) drain urban and industrial centers as far away as central Canada and the United States Midwest. Landfills for solid wastes are under extreme pressure. Sewage treatment systems are inadequate for keeping some forms of persistent debris from escaping. Several large ports (including some on the Great Lakes) are the terminus of major shipping routes. The western North Atlantic supports several major net and trap fisheries. Vast numbers of recreational beachgoers and boaters use the coast and nearshore waters. Beaches near urban areas accumulate debris loads higher than anywhere but Texas. New York and New Jersey have suffered more severe economic losses from debris-related beaches closures than have been reported anywhere else.

■ Recommendation — Canada and the United States have an opportunity to turn their northeast coasts into models for the mitigation of marine debris problems for other parts of those countries and the world. Concentrated in this region are multiple sources of debris; human, technical, and financial resources to address debris problems; the necessary industries and policy bodies to conduct the mitigation process; and information centers to communicate successful approaches to much of the world. The New York Bight plastics study and restoration plan mandated by the Marine Plastic Pollution Research and Control Act, as well as other steps being taken to implement MARPOL 73/78 Annex V, could serve as the nucleus for United States efforts in such a collaboration.

Wider Caribbean Study Area

1. Information

Sources of Tar

□ Conclusion — Tar causes the most significant marine debris problems in the Wider Caribbean area. Tanker operations have generally been blamed for most floating and beached tar; however, we consider the relative contributions of tankers, nontankers, offshore oil production, terminal operations, and natural seeps still to be an open question.

■ Recommendation — Since mitigation measures differ for tar from different sources, more information is needed to determine which are the most serious sources in the Wider Caribbean. The Cartagena Convention signatories, with the assistance of IMO, the merchant shipping industry, the tanker industry, the oil industry, and the scientific community, should undertake studies that would include chemical analysis of tar samples taken at the sources, chemical analysis of tar samples from beaches, analysis of tanker and nontanker traffic, and analysis of the adequacy of port reception facilities for both tanker slops and fuel oil sludge.

Coordination of Effort

□ Conclusion — Of the four study areas, the Wider Caribbean has the most nations (25) and the least developed communications network. While there are many marine research organizations, they usually have little connection with the national agencies concerned with the management of environmental problems, and few of their projects are devoted to applied research related to marine debris pollution. Furthermore, while marine laboratories may communicate with each other, other than the IOCARIBE project, "there is no effective regional coordination for data gathering, exhange, and integrated marine pollution monitoring and research programmes" (UNEP 1984).

■ Recommendation — The Cartagena Convention should become the framework for development of regional planning and coordination of marine debris monitoring involving national environmental management agencies, marine research organizations in the region, and relevant international bodies. This approach should include initiation of a regional clearinghouse for information on marine debris and other pollution.

Land Sources

☐ Conclusion — Although plastic, glass, and metal marine debris is taken for granted in much of the Wider Caribbean, it is a serious problem in many areas. With growing populations and urbanization, these problems are likely to become worse since land sources contribute heavily to the total. Some of the worst problems are in areas that already have substantial tourism. Other areas that currently accumulate large amounts of debris are expected to become targets for tourist development.

■ Recommendation — More information is needed on how landfills and other land-based litter disposal in the region contribute to marine debris. If, as is expected, these turn out to be significant sources, national agencies, with regional and international assistance, should investigate alternative methods of solid waste disposal.

2. Mitigation

Ratification of MARPOL

☐ Conclusion — Many Wider Caribbean nations, including oil producing countries such as Mexico, Venezuela, and Trinidad & Tobago, have not yet ratified MARPOL 73/78, which includes mandatory restrictions on tar pollution.

■ Recommendation — Wider Caribbean nations should be encouraged to ratify and implement MARPOL 73/78 and optional Annex V.

Special Area Designation

☐ Conclusion — The primary conclusion of *The State of Marine Pollution in the Wider Caribbean Region* (UNEP 1984), with which we entirely concur, states:

> "The pollution problems of the Caribbean Sea may not have reached the magnitude of those in the Baltic and the Mediterranean...but the similarity of land-locked configuration of the Caribbean with the potential for retention of pollutants from a developing region warrants early preventive action. If the countries of these regions are to benefit from the exploitation and sharing of the resources of the Caribbean Sea, it becomes imperative that immediate action is taken to arrest the trend towards destruction of marine life which is so essential to the maintenance of the marine ecological balance and to the sustenance of our people."

■ Recommendation — The quotation above, along with the information summarized in this report, make a strong case for designation of the Wider Caribbean Region as a Special Area under MARPOL 73/78 Annex I and Annex V.

Port Reception Facilities

□ Conclusion — The Wider Caribbean has inadequate port reception facilities for vessel fuel oil sludge.

■ Recommendation — National governments, the Cartagena Convention organization, international agencies, and the shipping industry should review the needs of the region for port reception facilities for oil, and develop and implement a mitigation plan.

Costs of Mitigation

□ Conclusion — The Wider Caribbean, many of whose nations are developing, includes some of the most fragile economies in the world. Although every nation in the area is able to take some steps toward reducing the region's marine debris problems, financial and technological capacities are severely limited in many of the 25 countries.

■ Recommendation — The international community must be prepared to assist many of the nations of the Wider Caribbean in their individual and regional efforts to combat marine debris problems.

The West Coast of Baja California Study Area

1. Information

□ Conclusion — The small amount of information we found on the west coast of Baja California did not indicate the existence of problem levels of marine debris. We conclude that debris problems likely are insignificant with the possible exception of entanglement in derelict gill nets from the growing set net fishery.

■ Recommendation — Aerial surveys, such as Mate conducted in the 1970s, should be repeated in order to obtain baseline information on amounts, types, and distribution of debris, with particular emphasis on derelict fishing gear. These should be conducted two times a year — in late winter and late summer — to observe conditions during the two annual oceanic regimes.

2. Mitigation

□ Conclusion — We found no evidence to justify mitigation other than that mentioned in Chapter VI.

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Appendix A: Materials Included in the Mailed Survey

The mailed survey (see chapters I and II) was intended to:

- o briefly acquaint the survey's recipients with recent international activity in regard to marine debris concerns,
- o acquaint the recipients with the current project, and
- o elicit as many responses as possible.

The survey (pages A-2 and A-3) was short enough to be answered in a few minutes, a format we chose to increase the number of responses. We wanted the survey to be a source of names of relevant individuals to follow up with. It was not intended to be a source of detailed information itself.

Four other items were included with the survey form. A two-page letter described the project, asked for responses, and described the sort of information and materials that would be useful to us.

A four-page article (Plastics at Sea, by D.H.S. Wehle and F.C. Coleman, printed in *Natural History* in February, 1983) presented a summary of marine debris effects, with an emphasis on wildlife.

A four-page report (Plastics in the Ocean) by the Center for Environmental Education described volunteer beach clean-up efforts in the United States.

And a two-page summary (pages A-4 and A-5) listed United States government efforts leading up to and following the first international Workshop on the Fate and Impact of Marine Debris, held in Honolulu, Hawaii in November, 1984.

Center for Environmental Education

624 9th Street, NW
Washington, DC 20001

REQUEST FOR INFORMATION

NONDEGRADABLE DEBRIS IN THE MARINE ENVIRONMENT

Please complete and return this form to the Center for Environmental Education not later than December 31, 1986. Use reverse side for additional comments.

NAME OF RESEARCHER/ORGANIZATION:

Address:

Telephone/Telex:

TYPE(S) OF DEBRIS YOU HAVE OBSERVED OR ARE FAMILIAR WITH:

Sources:

Problems:

Mitigating Measures Being Taken:

Are you currently, or would you be interested in, undertaking research related to marine debris?

Are you aware of any written material (reports, newspaper accounts, vessel logs, etc.) on the marine debris problem in your geographic area?

OTHER RECOMMENDED CONTACTS:

Name:

Address:

Telephone/Telex:

Area of Investigation/Type of Information:

Name:

Address:

Telephone/Telex:

Area of Investigation/Type of Information:

Name:

Address:

Telephone/Telex:

Area of Investigation/Type of Information:

Please return this form to:

Allen D. Blume
Center for Environmental Education
624 Ninth St., N.W.
Washington, D.C. 20001
(907) 737-3600 or (703) 979-3439

Center for Environmental Education

624 9th Street NW
Washington, DC 20001

PLASTICS IN THE MARINE ENVIRONMENT

A Summary of U.S. Work in Progress*

Early 1970's	Standing Scientific Committee of the North Pacific Fur Seal Commission raises concerns over net fragments, packing bands and other debris in fur seals in the Pribilof Islands of the Bering Sea.
Late 1970's	Despite public information effort, seal population noted in decline at rate of 4-8% per year.
1982	National Marine Fisheries Service data indicate high seas mortality of seals 3-4 years old. Actual causes unknown, but evidence suggests primary death rate due to entanglement. Other data indicates Hawaiian monk seals similarly affected. Data collected on ingestion of plastic bags, resin pellets and other plastics by marine turtles and seabirds indicate global problem.
	Marine Mammal Commission recommends that National Marine Fisheries Service convene assessment workshop on nature and extent of problem, identify research and management measures to resolve problem.
1983	Marine Mammal Commission and National Marine Fisheries Service meet with governments of Canada, Japan, Korea, Taiwan and USSR; MMC develops reference points on need for international research; develops recommendations for international conference.
1984	MMC contracts for assessment of domestic and international law applicable to entanglement problem.
	<u>Workshop on the Fate and Impact of Marine Debris</u> held in Honolulu, Hawaii. Purposes: (1) Review the state of knowledge on the source, fate and impact of marine debris; (2) identify and make recommendations on possible mitigating actions; (3) identify and make recommendations on future research needs.

1985 Congress appropriates $1,750,000 to NMFS for FY85 and FY86 to begin definition and resolution of the marine debris problem, and directs the Service to consult with the Marine Mammal Commission to develop a plan of activities.

Marine Pollution Program Office (NOAA) provides funds to MMC to help support study to compile available information on marine debris in the Northwest Atlantic Ocean, the North Sea, the Gulf of Mexico, and coastal waters along the west of Baja, California and adjacent islands.

Other funds are allocated to support surveys of lost and discarded fishing gear; to organize and carry out beach clean-up and public awareness campaigns; and evaluation of available information and ongoing studies relevant to the marine debris problem in Australia and New Zealand.

1986 Sixth Annual International Ocean Disposal Symposium held 21-26 April at the Asilomar Conference Center, Pacific Grove, California to review information and analyses received since the 1984 Honolulu Conference.

Center for Environmental Education issues report to U.S. Environmental Protection Agency on USE AND DISPOSAL OF NONDEGRADABLE PLASTICS IN THE MARINE AND GREAT LAKES ENVIRONMENTS.

* Excerpts from testimony by David W. Laist, Senior Program Analyst, Marine Mammal Commission, 12 Aug. 1986.

Appendix B: Abbreviations Used in This Report

CARIPOL	IOCARIBE Caribbean marine pollution research and monitoring program
CEE	Center for Environmental Education
COW	Crude oil washing
EPA	Environmental Protection Agency (United States)
FRG	Federal Republic of Germany
GEEP	Group of Experts on the Effects of Pollution (within IOC)
GEMSI	Group of Experts on Methods, Standards and Intercalibration (within IOC)
GESAMP	Group of Experts on the Scientific Aspects of Marine Pollution
GIPME	Global Investigation of Pollution in the Marine Environment
IMO	International Maritime Organization
IOC	Intergovernmental Oceanographic Commission
IOCARIBE	IOC Regional Program for the Caribbean and Adjacent Regions
KBTG	The Keep Britain Tidy Group
LDC	Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Dumping Convention)
LOS	Law of the Sea
LOT	Load on top
MAPMOPP	IOC/WMO Marine Pollution Monitoring Project (Petroleum)
MARPOL 73/78	International Convention for the Prevention of Pollution from Ships, 1973, and the Protocol of 1978
MARPOLMON	Marine Pollution Monitoring System
MEPC	Marine Environment Protection Committee (within IMO)
MMC	Marine Mammal Commission (United States)
NAS	National Academy of Science (United States)
NMFS	National Marine Fisheries Service (United States)
NOAA	National Oceanic and Atmospheric Administration (United States)
pers. comm.	personal communication
pers. obs.	personal observation
SBT	Segregated ballast tanks
UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
WMO	World Meteorological Organization