Impacts of Marine Debris: Research and Management Needs

David W. Laist[1] and Michael Liffmann[2]

[1] Marine Mammal Commission, 4340 East-West Highway, Rm 905, Bethesda, MD 20814
[2] Louisiana State University, Louisiana Sea Grant College Program, Baton Rouge LA

Background

Although societies have altered natural environments since time immemorial, the magnitude, intensity, and rate of change have increased dramatically in the last 75 years. Nowhere is this more evident than in coastal areas, where growing populations, increased demands on natural resources, and powerful modern technologies have combined to bring about far-reaching changes in coastal and marine environments, not all of them favorable. Human-induced changes have been profound and continue to increase in scope, yet we have had neither the time nor resources to pause, study, and reflect on the remarkable impacts and how to mitigate them.

Marine debris is a good example of such change. Significant marine debris impacts can be traced to the 1940s when new synthetic materials began replacing natural fibers in the manufacture of fishing nets, line, and all sorts of everyday items. The low cost, light weight, and long life of new synthetic materials have resulted in more items being discarded, their transport to the most remote ocean shorelines and waters, and a much longer hazard life for marine species.

Although the roots of marine debris pollution date to the mid-1900s, its impacts on marine life were largely unrecognized until 1984 when the National Marine Fisheries Service (NMFS), at the recommendation of the Marine Mammal Commission, hosted the Workshop on the Fate and Impact of Marine Debris (Shomura and Yoshida (1985). Data compiled at the workshop revealed that marine debris was affecting far more species in many more areas than previously realized. Its biological impacts were found to have two principal forms: (1) entanglement of animals in loops and openings of derelict line, nets, strapping bands, etc., and (2) ingestion of plastics causing damaged or blocked digestive tracks. Both are potentially lethal to marine life. In addition, human safety problems caused by fouling and disabling of vessel propulsion systems were noted.

The 1984 workshop spurred national and international efforts to investigate, monitor, and mitigate marine debris impacts (Laist *et. al.* 1999). With regard to biological impacts, studies over the following decade documented entanglement and ingestion impacts in all the world's oceans. Interactions were reported in all but one of the world's sea turtle species, 74% (138 species) of all seabird species, 37% (28 species) of all cetacean species, 58% (19 species) of all pinniped species, and Florida manatees (Laist 1996a). Many affected species were listed as endangered or threatened under national and international conservation programs. Entanglement was found to be more likely than ingestion to injure or kill marine life, and most entanglements involved fishing nets, monofilament fishing line, rope, and strapping bands lost or discarded by

commercial and recreational fisheries. Some seabirds and sea turtles, however, were especially prone to ingesting debris, such as plastic bags, cigarette lighters, light sticks, and small plastic fragments that were confused for floating prey. Potentially significant impacts to commercial fish stocks were also identified due to ghost-fishing (*i.e.*, derelict fishing gear that continues to catch fish and shellfish for years after being lost or discarded [Laist 1996b]).

Other studies focused on the types and amounts of debris in ocean areas (Pruter 1987 and Ribic *et. al.*, 1997). They found that plastic items comprised the majority of marine debris, and that, in some areas, up to 90% of all debris was made of plastics. Still other studies focused on economic impacts, particularly those measured by diminished opportunities to use the marine environment for pleasure (see for example, Faris and Hart 1995). Beaches, rivers, wetlands, and bays are used extensively by recreationists, and thus the consequences of aesthetic degradation, beach clean-ups, and human health and safety impacts associated with marine debris may impose some of the highest economic impacts (Hoagland and Kite Powell 1997; Holdnak 1992; Smith et al. 1997). Over the years, countless news articles and anecdotes have been reported illustrating how marine debris, most notably sewage, medical items, and bottles and cans, threaten human health and safety and affect coastal communities.

Beginning in the mid-1980s, many notable actions were taken to address these problems. Among these were the following: (1) the U.S. Congress authorized funding for the Marine Entanglement Research Program in the National Marine Fisheries Service to improve understanding of marine debris problems and coordinate responsive federal actions; (2) in 1987, parties to the International Convention for the Regulation of Pollution from Ships 1973 and its 1978 protocol, (jointly known as MARPOL 73/78) took steps to implement Annex V, a convention annex for regulating the discharge of garbage from ships and prohibiting all at-sea discharges of plastics; (3) also in 1987 the U.S. Congress passed the Marine Plastics Pollution Research and Control Act (MPPRCA) to enact domestic authority for implementing Annex V; (4) the U.S. Navy implemented a program to develop and retrofit solid waste handling technology for all of its vessels; (5) a series of international meetings, workshops and symposia were held to review information on marine debris impacts and to identify priority research and management needs; and (6) the Center for Marine Conservation and other non-governmental groups organized a national beach clean-up campaign, that was expanded into an international program in 1990.

One region of the world that received intensive attention during the 1990s for its marine debris problems was the Caribbean. Twenty-two developing nations in that region received technical and financial support to implement the MARPOL 73/78 Convention and to help fulfill the requirements associated with the designation of the Wider Caribbean Region as a Special Area under Annex V of the Convention. The Special Area designation, adopted by the International Maritime Organization (IMO) in 1993, prohibits all at-sea discharges of vessel-generated garbage from ships, with the exception of ground food wastes that could be discharged beyond three miles from land (WCISW 1997). Assistance for these nations became available in 1994 when the Wider Caribbean Initiative on Ship-Generated Waste Project (WCISW) was funded by the Global Environment Facility through the World Bank and implemented by the IMO. Through the Project, half a dozen countries not already party to MARPOL 73/78 acceded to the Convention during the course of four years. Technical support was also provided to (1)

draft and implement marine pollution legislation in several countries, (2) develop regional and national strategies for handling vessel-generated wastes, (3) identify land-based waste management options (including reuse and recycling), and (4) increase and strategically place shore-based waste reception facilities.

Summary of Recommendations from Previous Conferences, Meetings and Reports

As indicated above, several international meetings on marine debris were held during the 1980s and early 1990s to review and evaluate information on marine debris. Among these was a special session on marine debris at a 1986 ocean disposal symposium (Wolfe 1987), a 1987 fishing industry conference on marine debris (Alverson and June 1988), and two international conferences organized by the Marine Entanglement Research Program of the National Marine Fisheries Service in 1989 and 1994 (Shomura and Godfrey 1990, Coe and Rogers 1994) to follow up on the initial workshop convened in 1984. Participants at those meetings made recommendations on priority research needs, as well as steps to coordinate and guide mitigation work. Many of those recommendations remain unaddressed or only partly addressed.

With regard to assessing marine debris impacts, participants at the 1984 Workshop on the Fate and Impact of Marine Debris(Shomura and Yoshida 1985) recommended steps to:

1 assess marine debris impacts on living marine resources, including fish, northern fur seals, Hawaiian monk seals, seabirds, and marine turtles;

2. determine impacts of ingestion of debris by seabirds and turtles;

3. determine the severity of debris problems in areas other than the North Pacific Ocean;

4. expand existing stranding networks for marine mammals, birds, and turtles to collect data on interactions with marine debris;

5. obtain data on the amounts of gear lost by commercial fisheries, particularly high seas gillnet fisheries;

6. determine the impact of marine debris on the sea floor; and

7. obtain worldwide data on vessel disablement as a result of interactions with marine debris.

In 1987 commercial fishing organizations sponsored the North Pacific Rim Fishermen's Conference on Marine Debris. The purpose of the conference was to identify research needs and industry outreach priorities from the fishing industry's perspective. Proceedings from the Conference (Alverson and June 1988) urged that international efforts be expanded to quantify population- level impacts of marine debris on marine species. It also recommended work to quantify economic impacts on commercial and recreational fisheries, and the development of

fishing gear and fishing practices that would minimize ghost-fishing. Recognizing the long-term nature of work needed to address marine debris issues, conference participants also recommended that the National Oceanic and Atmospheric Administration provide long-term funding support to the National Marine Fisheries Service for its Marine Entanglement Research Program.

Also in 1987, President Reagan, at the request of 30 members of the U.S. Senate, directed the Office of Domestic Policy to establish an Interagency Task Force on Marine Debris to develop a coordinated strategy to address marine debris issues. Chaired by the National Oceanic and Atmospheric Administration, the task force completed its report in May 1988 (Office of Domestic Policy 1988). The report called on all federal agencies to assess and mitigate marine debris impacts in cooperation with state and local governments, industry, academia, and private groups. It embraced advice developed at the earlier meetings, including recommendations for long-term support of the National Marine Fisheries Service's Marine Entanglement Research Program and for quantifying deleterious marine debris impacts on fish and wildlife and vessels. The task force report also recommended greater emphasis on (1) documenting and resolving the aesthetic impacts of marine debris and its associated economic effects on coastal communities, and (2) determining and monitoring marine debris impacts on endangered, threatened, and depleted species. It also called for developing standards on the use of biodegradable plastics and for removing marine debris from beaches and other marine areas.

On 2-7 April 1989 and 8-13 May 1994, the National Oceanic and Atmospheric Administration convened the second and third international conferences on marine debris in Honolulu, Hawaii, and Miami, Florida respectively. Building on results of earlier meetings, participants at the 1989 conference recommended:

1 the preparation of a marine debris survey manual to standardize methodologies for monitoring marine debris on beaches;

2. forming an international committee to coordinate collaborative efforts for collecting entanglement data and removing hazardous debris from habitats used by species, such as Hawaiian monk seals, sea turtles, and northern fur seals;

3. studying potential lethal effects of plastic ingestion among sea turtles and seabirds, including studies to correlate ingestion of plastics and the occurrence of lesions in sea turtles, and to assess pseudo-satiation and possible toxic effects among seabirds;

4. instituting measures to record and track the numbers of gillnets and traps lost during commercial fishing, to estimate ghost fishing rates in lost gear over time, and to develop mechanisms for reducing the length of time lost fishing gear could continue to catch fish and shellfish; and
5. evaluating economic impacts from vessel disablement, ghost fishing, cleaning debris off beaches, and reduced tourism.

The third international conference in 1994 made similar recommendations, but also noted needs to investigate the role of floating debris in transporting invasive, non-indigenous species to

new marine areas and the potential for large-scale impacts from debris accumulations on the sea floor. They also reiterated the need to recover lost fishing gear in areas where it accumulates, to develop a system to record losses of commercial fishing gear, and to evaluate the types and amounts of fish and shellfish caught in lost gear.

In 1995, the National Research Council's Marine Board published the results of a comprehensive two-year study on actions needed to develop a national strategy for implementing MARPOL Annex V (National Research Council 1995). Among other things, the report recommended that:

1. The National Oceanic and Atmospheric Administration, with help from the Environmental Protection Agency, establish a national program to monitor the flux of marine debris on beaches and benthos and marine debris impacts on wildlife;

2. The Environmental Protection Agency develop an overall framework for requiring and monitoring garbage discharges from ships and the availability of adequate port receptions facilities for ship-generated garbage;

3. The International Maritime Organization develop a garbage treatment technology program to develop new garbage handling technology;

4. Congress fund a foundation to coordinate a sustained, long- term program to educate and train the maritime sector in actions needed to properly handle and dispose of ship-generated garbage; and

5. Congress establish a permanent national commission to provide consistent, independent oversight and coordination of actions to implement Annex V and the provisions of the Marine Plastic Pollution Control Act.

Progress Since 1994

Since 1994, there has been a marked decline in efforts to address marine debris pollution. For example, despite progress made in the Wider Caribbean Region under the WCISW Project, funding for work ended abruptly in 1998 and the Wider Caribbean Special Area has not yet entered into force. Such designation will become effective only when countries and territories in the region notify the IMO that their ports, terminals, and marinas have adequate reception facilities. There is little likelihood of this taking place in the near term. There are many remaining organizational constraints, the necessary physical infrastructure in the form of reception facilities and solid waste management systems is, by and large, woefully inadequate, and operational aspects associated with national implementation and enforcement have not been formulated in many countries.

Attention to marine debris pollution in the United States also decreased sharply after 1994. In 1995, Congress eliminated funding for the Marine Entanglement Research Program as part of efforts to reduce deficit spending. In doing so, it effectively terminated the only national-level program in the United States designed to coordinate and support federal activities to assess

and mitigate marine debris pollution. Funded at between $600,000 and $750,000 per year, the program was the only source of federal funding available to investigate and mitigate the full range of marine debris impacts. In 1996, Congress amended the Marine Plastic Pollution Research and Control Act to direct that the National Oceanic and Atmospheric Administration convene a federal marine debris coordinating committee to oversee cooperative work by involved agencies to address marine debris pollution issues. However, no steps have been taken to convene such a committee. As a result, with three notable exceptions, most conference and report recommendations have received little or no attention over the past six years.

One area in which progress has continued is the development of a National Marine Debris Monitoring Program. In 1995, the Environmental Protection Agency, in cooperation with the Center for Marine Conservation, developed a national marine debris monitoring plan. Since 1996, the Agency has provide $100,000 per year to the Center to develop and implement a monthly sampling program to monitor derelict fishing gear and other marine debris at selected beaches around the nation. Although limited by funding, the program has established monitoring sites in several regions. Over time, the program will provide a means of assessing trends in the amounts of marine debris fouling the nation's shorelines. As a companion effort, with support principally from corporate sponsors, the Environmental Protection Agency, and the Coast Guard, the Center also has continued to coordinate international beach clean-ups with volunteers annually removing trash from hundreds of beaches worldwide.

A ten-year study of beach trash along the 68-mile Padre Island National Seashore was completed in 1998 by researchers affiliated with the National Park Service and Texas A&M University-Corpus Christi. Padre Island, a barrier island located on the south coast of Texas, is annually visited by approximately one million persons. The marine debris monitoring project, the most extensive of its type in the United States, used a variety of data collection methodologies, including quarterly beach transects and daily surveys over extended periods of time. During the decade, researchers collected nearly 400,000 trash items and concluded that most of the debris was from U.S. sources. The U.S. Gulf of Mexico shrimping fleet, and to a much lesser extent, the offshore oil and gas industry, were identified as the primary "point source" contributors to the problem (Miller and Jones 1999).

The third area where efforts have been maintained concerns marine debris impacts on endangered Hawaiian monk seals and coral reefs in the Northwestern Hawaiian Islands. Since the early 1980s, the Honolulu Laboratory of the National Marine Fisheries Service has documented more than 200 monk seal entanglements, including a record high of 25 entangled seals in 1999. To address the problem, Service field crews routinely disentangled monk seals whenever necessary and possible, and removed hazardous debris from pupping beaches. To assess entanglement risks in surrounding waters, the Service conducted a dive survey for derelict fishing gear on reefs adjacent to pupping beaches in the winter of 1996-1997. Based on the results, it was estimated that there were 94 net fragments per square kilometer in waters less than 10 fathoms deep at French Frigate Shoals alone (Bowland 1997). In response to the findings, the Service coordinated cooperative reef cleanup efforts in 1998 and 1999 with other federal, state, and local agencies and private groups. Six tons of submerged net debris was removed from the reefs in 1998 and about 25 tons were removed in 1999. Most of the netting was from trawl nets that apparently had drifted into the area from distant fishing grounds. In addition to finding

several monk seals entangled in net debris hung up on reef outcrops, the nets also were found to be damaging reef corals and other reef species. Because of the remote origin of the netting (there is no trawl fishing in the Hawaiian Islands), the State Department brought the problem to the attention of governments officials in key fishing nations around the North Pacific rim.

The few studies done to assess impacts on other species suggest that marine debris problems continue to exist. In one case, studies suggest that marine debris may provide a conduit for transferring toxic chemicals to marine life. Studies of plastic debris and plastic ingestion by albatrosses at Kure Atoll in the Northwestern Hawaiian Islands suggest that plastics, particularly cigarette lighters and light sticks, continue to be ingested frequently by albatrosses. Albatrosses in the Northwestern Hawaiian Islands also have high levels of PCB contamination. Recent studies suggest that this contamination may come from floating fish eggs and plastics that adsorb toxic chemicals as they bob through the surface micro-layer of the ocean, which may receive PCBs from contaminated land-based dust as it settles on the ocean. If such a transfer occurs, it could represent a significant, previously unrecognized concern for species that commonly ingest plastics and floating marine life. A recent study of plastic ingestion by sea turtles also concluded that post-hatchling sea turtles have an extremely limited ability to compensate for dietary dilution caused by debris in their digestive tracks and that they would experience sublethal effects from decreased energy and nitrogen intake (McCauley and Bjorndal 1998).

A few studies have attempted to determine if ingestion and entanglement rates declined after MARPOL Annex V entered into force at the end of 1988. Shaver and Plotkin (1998) examined plastics in the digestive tracks of 473 sea turtles stranded along Texas between 1983 and 1995. They found ingested plastics in more than half of the turtles sampled, with no significant difference in the proportion of affected turtles before and after Annex V went into effect; ingested items were the primary cause of death for at least seven turtles. Arnould and Croxall (1995) examined entanglement rates of Antarctic fur seals at South Georgia Island in the Southern Ocean between 1988/1999 and 1993/1994. They found the incidence of entanglement declined by half after Annex V went into effect although the decline may have been related to a decline in fishing activity in the area. It was noted, however, that a decline in strapping band entanglements probably was related to education efforts urging fishers to cut strapping bands before discarding them. This conclusion was supported by a finding that all strapping bands found washed ashore on South Georgia during the 1993-1994 survey had been cut. Long-term efforts to monitor entangled northern fur seals on the Pribilof Islands also suggest a decrease in entanglement rates since MARPOL Annex V went into effect (Robson *et. al.*, 1999). Although funding decreases have reduced sampling efforts in recent years, work now is carried out largely by the local Native community during annual subsistence harvests. The results suggest that entanglement rates among juvenile male fur seals on haul-out beaches declined from a high of about 0.7% in the mid-1970s to about 0.4% in the 1980s and about 0.2% between 1988 and 1997. As with Hawaiian monk seals, most net entanglements of northern fur seals have involved derelict trawl net.

Several studies to assess potential impacts from ghost fishing by derelict gear were undertaken prior to 1994 (Laist 1996), some of which suggested significant impacts were possible. Since 1994, however, no further studies have been done to assess ghost fishing rates or

to estimate ghost-fishing impacts on commercially valuable fishery stocks. Other than the monk seal disentanglement work and related reef clean-up efforts in the Northwestern Hawaiian Islands, no efforts have been undertaken to mitigate entanglement impacts from derelict fishing gear.

Unresolved Issues

Information on trends in the types and amounts of marine debris continues to be poorly understood. To detect statistically significant trends in the composition and quantities of marine debris, long- term monitoring studies, such as the U.S. National Marine Debris Monitoring Program supported by the Environmental Protection Agency and the National Park Service, need to be continued, refined, and expanded to cover new areas. Currently, monitoring programs comparable to the U.S. program do not exist in other countries. Such programs are needed to help determine which types and sources of marine debris require priority attention.

Other than ongoing studies to monitor entanglement of Hawaiian monk seals and northern fur seals on breeding beaches, little work is currently being done to monitor or assess impact of marine debris on living marine resources. The greatest unknown in this regard is the numbers of animals entangled and killed at sea that are never recorded by shore-based monitoring programs. One of the only instances where work has been undertaken to assess and mitigate entanglements away from shore is the above noted work in the Northwestern Hawaiian Islands to survey and remove debris in reef habitats adjacent to monk seal breeding beaches. Because of logistical challenges, the impacts of marine debris on living marine resources at sea remain poorly understood and documented. Currently there are no systematic studies to monitor long-term entanglement trends among pinniped populations other than Hawaiian monk seals and northern fur seals; nor are there systematic efforts to assess or monitor ingestion of marine debris by species, such as sea turtles or albatrosses, that frequently ingest large quantities of plastics. Although recommended at past marine debris meetings, no work has yet been done to correlate debris ingestion by sea turtles with the occurrence papilloma tumors in turtles.

Although several studies to assess and mitigate impacts of ghost-fishing were undertaken prior to 1994 (Laist 1996), little appears to have been done since then. In some cases, ghost-fishing impacts may be significant. For instance, ghost fishing losses for the sablefish trap fishery off British Columbia, Canada, have been estimated as high as 30 percent of actual landings (Faris and Hart 1995). Carr *et. al.* (1992) monitored ghost-fishing by two 100 m gillnets over a two-year period off New England and recorded a catch of 172 lobsters during just 14 dive observations over that period. Considering the number of gillnets and other fishing gear lost in New England, such findings suggest that lost nets could catch and kill a significant number of lobsters. The study also tested biodegradable float releases to minimize ghost fishing by reducing the net's vertical profile. Despite such work, no efforts have been made to gather data on the numbers or location of lost fishing gear, to estimate potential region-wide economic impacts, or to further develop potential mitigation measures.

Navigation hazards posed by marine debris, particularly for small craft, also remain poorly documented. Anecdotal reports of entangled motors, clogged water intakes, and propeller and hull damage are common. Despite several recommendations to compile data on such

hazards, no systematic study of the economic costs of such damage has been conducted (Kirkley and McConnell 1996).

A scan of the most recent literature on the benefits associated with a reduction of marine debris also indicates that the true social and economic costs remain unknown (Hoagland and Kite-Powell 1997). For example, we do not have a complete picture of the magnitude of economic damages associated with the ecological effects of marine debris. No studies have been conducted to estimate the economic losses associated with the entanglement of marine mammals, turtles, birds and other aquatic wildlife and, as noted above, little has been done to estimate economic costs of ghost fishing. More in-depth investigations are also needed concerning costs to coastal tourism and recreation, as well as marine debris hazard costs to boat and ship owners. Investigations into economic costs to fisheries stemming from reduced public appeal for the products due to pollution from trash and inadequately treated sewage also have not been done.

Opportunities for Improvement and Actions Needed

To mitigate marine debris pollution, it is essential to document and monitor its occurrence. The National Marine Debris Monitoring Program supported by the Environmental Protection Agency and carried out by the Center for Marine Conservation has been designed to address this need on a national level. Its continuation as a long-term funding priority should be a fundamental component of any effort to resolve marine debris issues. Further work is needed to establish monitoring sites in all regions of the country, and conference participants should consider work done to date to develop this program as an opportunity to gather baseline data on regional marine debris problems and trends. In some cases additional surveys may be needed to identify particular problem areas, such as has been done in the Northwestern Hawaiian Islands.

There also is a need for further work to assess and monitor biological impacts of marine debris. Ongoing monitoring of entanglement rates for Hawaiian monk seal and northern fur seal populations should be continued, and opportunities may exist to develop similar programs for species in other areas. Further work also is needed to assess and monitor ingestion of plastics by species, such as sea turtles and albatrosses, that frequently ingest large quantities of marine debris. Recent improvements in regional marine mammal and sea turtle stranding programs and fishery observer programs provide an opportunity to collect data on ingestion of plastics, and consideration should be given to supporting routine collection and analyses of stomach samples from these sources. As a related matter, studies may be needed to determine whether floating plastics adsorb toxic chemicals that could be transferred to marine life via ingestion.

The impacts of ghost-fishing by derelict fishing nets and traps merit particular attention. In most cases, past recommendations to address its effects have received little or no funding. Studies of submerged fishing debris in the Northwestern Hawaiian Islands illustrate the type of problems that may exist and similar work should be considered for other locations where derelict fishing gear may accumulate (*e.g.*, major fishing grounds or coastal waters where floating debris can be deposited). In addition to determining densities of lost gear in particular areas, such studies could be designed to assess (1) the types and quantities of marine life, particularly commercially valuable crab and lobsters, caught in submerged derelict gear, and (2) the feasibility of dedicated clean-up efforts to remove lost gear from sea floor areas where it is most

concentrated. Further work on gear modifications that would render lost gear less harmful to marine life also would appear to merit consideration. Long-term studies similar to Carr *et. al.* (1992) to monitor interactions between marine life and derelict gear also should be considered. Their purposes could be twofold: (1) documenting the catch rates by different types of derelict gear in different areas over multi-year periods, and (2) testing gear modifications that could make lost gear less hazardous to marine life (*e.g.*, the use biodegradable materials). Fishing industry grants made available by the National Marine Fisheries Service provide an opportunity to support such work; however, to date, grant applications in this area have received low priority and gone unsupported. Establishing a higher priority for work to resolve derelict gear issues in fishing industry grants could help address funding limitations.

Other actions that may merit consideration relative to ghost fishing include requirements for reporting when and where gear is lost, and the institution of fishing gear deposit systems to create an economic incentive for recovering and properly disposing of old or derelict fishing gear at land-based disposal sites. Because many land-based disposal sites discourage, or even prevent, disposal of fishing gear in landfills, steps may be needed to identify or arrange for disposal sites for fishing gear.

Although some studies have been conducted on the public's willingness to pay for the control of marine debris and a clean marine environment, more research in this field should be considered. A survey of users and nonusers of beaches and estuarine reserves in North Carolina and New Jersey concluded that individuals were willing to pay twice as much to clean up a beach than they were to clean up an estuary (Zhang 1995). Also, incentive systems consisting of bounties, taxes, deposits, rebates, etc., may merit investigating in some locales. Hoagland and Kite-Powell (1997) recently concluded that the Gulf of Maine had seen modest reductions in bottle debris over time, and that this coincided with the adoption of bottle deposit and refund legislation. As noted above, incentive-based solutions may be particularly helpful for marine debris problems in fisheries and fishing communities. A Canadian study found that commercial fishermen, if adequately informed, are more likely to return garbage to port when waste collection facilities are readily available (Topping 1997). Others have concluded that tax/subsidy systems are economically viable, but that they should be limited to selected items in the waste stream (Dinan 1993; Palmer and Walls 1994; Fullerton and Kinnaman 1993). One such item might be fishing gear, particularly the netting, traps, and cordage that have been traditionally discarded or lost at sea.

To help address all of these issues, consideration also should be given to funding and coordination needs. For example, based on conference results, consideration should be given to recommending that (1) Congress reinstate funding for a national marine debris research and management program similar to the former Marine Entanglement Research Program to help fund the broad range of projects needed to assess and mitigate marine debris impacts, and (2) the National Oceanic and Atmospheric Administration convene a national marine debris coordinating committee pursuant to directives of the Marine Plastic Pollution Research and Control Act.

Topics for Further Discussion

Based on information presented at the conference, participants should consider recommended actions in the following areas.

1. Monitoring studies to determine the types, amounts, and accumulation trends of derelict fishing gear and other forms of marine debris:
    - continued support for the National Marine Debris Monitoring Program;
    - additional studies to identify and document regional areas where marine debris accumulations may occur.

2. Assessing, monitoring, and mitigating impacts of derelict fishing gear and other marinedebris on living marine resources:
    - continuation of shore-based studies to document and disentangle Hawaiian monk seals and northern fur seals;
    - studies to document other entangled marine species;
    - collection and analyses of ingestion data on albatrosses, sea turtles, and other species;
    - assessment of the adsorption of toxic chemicals by marine debris likely to be ingested by marine species.

3. Assessing and mitigating ghost-fishing impacts:
    - conduct underwater surveys to document densities of derelict net debris and traps in major fishing areas or areas where drifting debris may concentrate, and to test feasibility of dedicated clean-up work;
    - conduct multi-year studies of species and catch rates in different types of derelict fishing gear in different areas;
    - collect or require reporting of data on the when and where fishing gear is lost during commercial fishing operations; and
    - study potential gear modification that would reduce the probability of fishing gear being lost, increase the probability of lost fishing gear being found, and reduce the hazard life of lost gear not recovered.

4. Considering economic incentive-based solutions for marine debris problems. A range of policy approaches should be investigated, including those that:
    - establish deposits, refunds, or bounties for gillnets, fish traps, light sticks, and other items frequently or occasionally lost during commercial fishing;
    - ensure convenient and affordable solid waste management systems are available to accept commercial fishing wastes, including old fishing gear;
    - consider that economically inefficient fishing effort has accompanied open access to most species. We need to investigate whether taxation designed to limit effort, and thus reduce the likelihood of gear losses, overboard disposal, etc., would result in societal benefits;
    - investigate higher taxation possibilities for items that cannot be recycled and subsidies for those that can be recycled; and
    - determine whether penalty mechanisms, such as fines, are effective at controlling the problem or if there are better and more cost-effective options.

5. Continuing to support studies designed to assess the economic and social costs of marine debris to coastal tourism and recreation and navigation interests. This information can be used to continue educating policy-makers and stakeholders.

6. Establishing a framework to support and coordinate marine debris impact assessment and mitigation activities:
   - request that the National Oceanic and Atmospheric Administration or some other agency establish and secure funding for a national marine debris research and monitoring program similar to the former Marine Entanglement Research Program;
   - request that the National Oceanic and Atmospheric Administration convene a national marine debris coordinating committee pursuant to provisions of the Marine Plastic Pollution Research and Control Act.

References

Alverson, D. L. and J. A. June (eds). 1988. Proceedings of the North Pacific Rim Fisherman's Conference on Marine Debris, Kailua-Kona, Hawaii, October 13-16. Natural Resources Consultants. Seattle Washington. 460p.

Arnould, J. P. Y. and J. P. Croxall. 1995. Trends in Entanglement of Antarctic Fur Seals (Arctocephalus gazella) in Man-Made Debris at South Georgia. Mar. Poll. Bull. 30(11):707-712.

Bowland, R. 1997. A preliminary surveys of the underwater accumulations of derelict nets at French Frigate Shoals. Southwest Fisheries Science Center Administrative Report J-97-13. National Marine Fisheries Service. Honolulu, HI. 9p.

Carr, H. A., A. J. Blott, and P. G. Caruso. 1992. A study of ghost gillnets in the inshore waters of southern New England. pp 361-366 in MTS '92 Global Ocean Partnership: Proceedings of the Marine Technology Society Conference, 19-21 October 1992. Marine Technology Society.

Coe, J. M. and D. B. Rogers. 1996. Marine Debris Sources, Impacts and Solutions. Springer-Verlag, New York, N. Y. 432p.

Dinan, T. 1993. Economic efficiency effects of alternative policies for reducing waste disposal. Journal of Environmental Economic and Management. 25: 242-256.

Faris, J. and K. Hart. 1995. Seas of debris: a summary of the Third International Conference on Marine Debris. UNC-SG-95-01. North Carolina Sea Grant College Program. Raleigh, N.C.

Fullerton, D. and T.C. Kinnaman. 1993. Garbage recycling and illicit burning or dumping. National Bureau of Economic Research. Paper No. 4374. Pittsburgh, Penn. And Charlottesville, Virginia. Carnegie-Mellon University and University of Virginia.

Hoagland, P. and H.L. Kite-Powell. 1997. Characterization and mitigation of marine debris in the Gulf of Maine. Report to the U.S. Gulf of Maine Association. Woods Hole Research Consortium, Duxburry, Mass.

Holdnak, A. 1992. The impacts of marine debris, weather conditions, and unexpected events on recreational boater satisfaction on the Delaware inland bays. Ph.D. Dissertation. College Station, Penn. The Pennsylvania State University.

Kirkley, J. and K. McConnell. 1996. Marine debris: benefits, costs, and choices. Pp. 161-171 in J. M. Coe and D. R. Rogers (eds.) Marine Debris Sources, Impacts and Solutions. Springer-Verlag, New York, N. Y.

Laist, D. W. 1987. Overview of biological effects of lost and discarded plastic debris in the marine environment. Mar. Poll. Bull.18:319-326.

Laist, D. W. 1996a. Impacts of marine debris: Entanglement of marine live in marine debris including a comprehensive list of species with entanglement an ingestion records. Pp 99-139 *in* J. M. Coe and D. R. Rogers (eds.) Marine Debris Sources, Impacts and Solutions. Springer-Verlag, New York, N. Y.

Laist, D. W. 1996b. Marine Debris Entanglement and Ghost Fishing: A cryptic and significant type of bycatch? Pp 33-39 *in* Proceedings of the Solving Bycatch Workshop: Considerations for Today and Tomorrow. 25-27 September 1995, Seattle, Washington. Report No. 96-03. Alaska Sea Grant College Program.

Laist, D. W., J. M. Coe, and K. J. O'Hara. 1999. Marine Debris Pollution. Pp 342-366 *in* J. R. Twiss, Jr. and R. R. Reeves (eds.) Conservation and Management of Marine Mammals. Smithsonian Institution Press. Washington, D.C.

McCauley, S. J. and K. A. Bjorndal. 1998. Conservation implications of dietary dilution from debris ingestion: sublethal effects in post-hatchling loggerhead sea turtles. Conserv. Biol. 13(4):925-929.

Miller, J. and E. Jones. 1999. A study of shoreline trash: 1989-1998, Padre Island National Seashore. U.S. Department of the Interior, National Parks Service, Denver, Colorado.

National Research Council. 1995. Clean Ships Clean Ports Clean Oceans: Controlling Garbage and Plastic Wastes at Sea. National Academy Press. Washington, D.C. 355p.

Office of Domestic Policy. 1988. Report of the Interagency Task Force on Persistent Marine Debris. May 1988. Washington. D.C. 170p + Appendices.

Palmer, K. and M. Walls. 1994. Materials use and solid waste disposal: an evaluation of policies. RFF Paper No. 95-02. Washington, D.C. Resources for the Future (October).

Pruter, A. T. 1987. Sources, Quantities and distribution of persistent plastics in the marine environment. Mar. Poll. Bull. 18(6B):305-310.

Ribic, C. A., S. W. Johnson, and C. A. Cole. 1997. Distribution, type, accumulation, and source of marine debris in the United States, 1989-1993. Pp 35-47 in Coe, J. M. and D. B. Rogers (eds.) Marine Debris Sources, Impacts and Solutions. Springer, New York.

Robson, B. W., R. G. Towell, M. Kiyota, C. M. Stepetin, and G. E. Merculief. 1999. Northern fur seal entanglement studies: St. Paul and St. George Islands, 1997. pp 33-54 in Sinclair, E. H. and B. W. Robson (eds.) Fur Seal Investigations 1997. NOAA Technical Memorandum NMFS-AFSC-105. National Marine Fisheries Service, Alaska Fisheries Science Center. Seattle, WA.

Shaver, D. J. and P. T. Plotkin. 1998. Marine Debris Ingestion by sea turtles in south Texas: pre and post-MARPOL Annex V. P. 124 *in* Proceedings of the 16th Symposium on Sea Turtle Biology and Conservation. NOAA Technical Memorandum SEFSC-412.

Shomura, R. S. and H. O. Yoshida (eds.). 1985. Proceedings of the Workshop on the Fate and Impact of Marine Debris 27-29 November 1984, Honolulu, HI. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFC-54. 580p.

Shomura, R. S. and M. L. Godfrey (eds.). 1990. (Proceedings of the Second International Conference on Marine Debris 2-7 April 1989, Honolulu, HI. U.S. Department of Commerce. NOAA Technical Memorandum NMFS-SWFSC-154. Vol I. 774p.

Smith, K., X. Zhang, and R. Palmquist. 1996. The economic value of controlling marine debris. Pp. 187-203 in J. M. Coe and D. R. Rogers (eds.) Marine Debris Sources, Impacts and Solutions. Springer-Verlag, New York, N. Y.

Topping, P. 1997. Environment Canada's Marine Debris Program: a progress report. Working Paper. Ottawa: Marine Environment Division, Environment Canada.

Wider Caribbean Initiative for Ship-Generated Waste. 1997. Strategy and action plan for source reduction, recycling, and recovery of ship-generated waste. International Maritime Organization. London, England. WCISW Report No. 4

Wolfe, D. A.(ed). 1987. Plastics in the Sea: Selected Papers from the Sixth International Ocean Disposal Symposium. Mar. Poll. Bull. 18(6b):303-365.

Zhang, X. 1995. Integrating resource types, access conditions, and preference differences into models for use and non-use values: the case of marine debris. Ph.D. dissertation. Raleigh, North Carolina, North Carolina State University.