National Marine Debris Monitoring Program
Lessons Learned

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I. Background on the National Marine Debris Monitoring Program

A. What is marine debris?

Marine debris was defined in 1975 by the National Academy of Sciences as "solid materials of human origin that are discarded at sea or reach the sea through waterways or through domestic and industrial outfalls." Marine debris has also been defined by some researchers as "any manufactured or processed solid waste material (typically inert) that enters the ocean environment from any source" and is one of the most pervasive and potentially solvable pollution problems plaguing the world's oceans and waterways (Coe and Rogers, 1997). In the 2008 Interagency Marine Debris Coordinating Committee report to Congress, the scope of marine debris was described as "persistent solid man-made debris from both land-based and ocean-based sources and its adverse impacts on the marine environment and navigation safety" in its review of the marine debris issue in the United States (NOAA, 2008).

Marine debris can degrade ocean habitats, endanger marine and coastal wildlife, interfere with navigation, result in economic losses, and threaten human health and safety. The types of marine debris range from discarded convenience and fast-food packaging; beverage containers; cigarette filters; disposable lighters and packaging; storm sewer effluents; building materials; tires and car parts; 55-gallon drums; fishing line; lost and abandoned fishing nets; ropes; and fish and shellfish traps. Products that are consumed or used in daily activities create wastes that have the potential to become marine debris when not handled or disposed of properly.

B. Where does it come from?

Determining where marine debris originates is an ongoing challenge. Debris and litter can travel long distances before being deposited on coastal beaches or riverbanks or settling on the bottom of the creek bed, bay, or seafloor. Marine debris sources are traditionally classified as either land-or ocean/waterway-based, depending on how the debris enters the water. Other factors such as ocean current patterns, weather and tides, and proximity to urban centers, industrial and recreational areas, shipping lanes, and fishing grounds influence the types and amount of debris that are found floating on the open ocean or collecting along beaches and waterways or under water. Adequate quantitative and qualitative knowledge of the sources of marine debris is extremely important because it can serve as the primary foundation for managerial decisions on actions to prevent, reduce, and control problems caused by marine debris.

Land-based debris can be blown, washed, or discharged into the water from land areas such as parking lots, culverts and storm sewers. The major land-based sources of marine debris can include wastes from dumpsites located along coastal areas or banks of rivers; industrial outfalls; materials manufacturers, processors, and transporters; shore-based solid waste disposal and waste processing facilities; sewage treatment and combined sewer overflows; tourism and recreational use of coastal areas; fishing industry processing activities; and natural storm-related events and floodwaters.

People can also generate marine debris at sea. The major ocean-based sources of marine debris include shipping (merchant, public transport, pleasure, naval and research vessels), and fishing (vessels, angling and fish farming) activities; offshore mining and extraction (vessels, and oil and gas platforms); undersea exploration; legal and illegal dumping at sea; abandoned, lost or otherwise discarded fishing gear; and natural disasters. Debris can end up in the water through accidental loss or system failure; poor waste management practices; or illegal disposal and indiscriminant littering.

C. Why is it a problem?

Marine debris is more than just an unsightly inconvenience for coastal vacationers or pleasure boaters; it is one of the world's most pervasive pollution problems affecting our oceans and inland waterways. It affects the economies and inhabitants of coastal and waterside communities worldwide. Over the past 50 years, organic materials – once the most common forms of debris – have yielded to the dominance of synthetic polymers as the most abundant material found in solid wastes. Durable and slow to degrade, plastic materials that are used in the production of containers and packaging for various beverages and food stuffs, made into packing straps and tarps for cargos and bulk packaging, and nylon materials used in fishing line, nets and gear all have the potential to become marine debris when not disposed of properly. In addition, many of these items are highly buoyant and when improperly handled can be carried in ocean currents for thousands of miles, damaging sensitive marine ecosystems and harming vulnerable wildlife due to entanglements and ingestion.

Marine debris collects along coastal beaches and inland waterways detracting from the aesthetic beauty and enjoyment of these areas, thus negatively affecting tourism. Debris can also be a human health and safety hazard. Discarded fishing line, rope, and plastic trash bags can wrap around and damage boat propellers, or be sucked into boat engines. Medical wastes and drug paraphernalia ending up on beaches can carry diseases, and broken glass and other sharp objects can be very harmful to unsuspecting beach goers, including young children.

Marine debris can also cause habitat destruction by affecting water quality and causing physical damage to fragile ecosystems. Coral reefs are very susceptible to the impacts of marine debris through abrasion and smothering. In addition, sea grass beds and bottom-dwelling species in benthic habitats are also susceptible. A variety of wildlife can have lethal encounters with marine debris. Many species accidentally ingest debris, mistaking it as food. Abandoned fishing nets and gear, discarded fishing line and other forms of debris can entangle marine wildlife – sea turtles, manatees, sea birds, and fish – maiming or even killing them.

The ubiquitous presence of marine debris, coupled with its physical, ecological, cultural, and socio-economic complexities, poses one of the most severe threats to the sustainability of sensitive habitats, wildlife, and people of the United States and the world as a whole. While there are laws regulating the dumping of trash at sea and on shore, the global nature of marine debris, its inability to be confined within territorial boundaries, and the complexity of identifying debris sources have made effective laws difficult to draft and even harder to enforce.

D. Why monitor marine debris?

Successful management of the marine debris problem requires a comprehensive understanding of the issue including identifying the dominant forms of marine debris, their abundance and potential sources, and ultimately, the human behaviors and activities producing it. Monitoring marine debris provides significant insight and understanding of this pollution problem and can function as an ongoing component of management strategies. Monitoring can be used to clarify the problem of marine debris – e.g. what are the types, what are the possible sources, how widespread is this problem? In addition, ongoing monitoring activities can be used to assess the effectiveness of management strategies, legislation, and other activities designed to control and abate this pollution problem (Coe and Rodgers, 1997 and Sheavly, 2005).

Conducting surveys to monitor marine debris that collects along beaches is an established technique for evaluating the status of the debris found on those beaches or providing an indicator of conditions in surrounding waters (Dixon and Dixon, 1981; Ribic *et al*., 1992; Rees and Pond, 1995; Alkalay *et al.,* 2007; Cheshire et al., 2009). However, there have been few large-scale and long-term programs available to fill information gaps for marine debris characterization and pollution management (UNEP, 2009; Cheshire *et al.,* 2009).

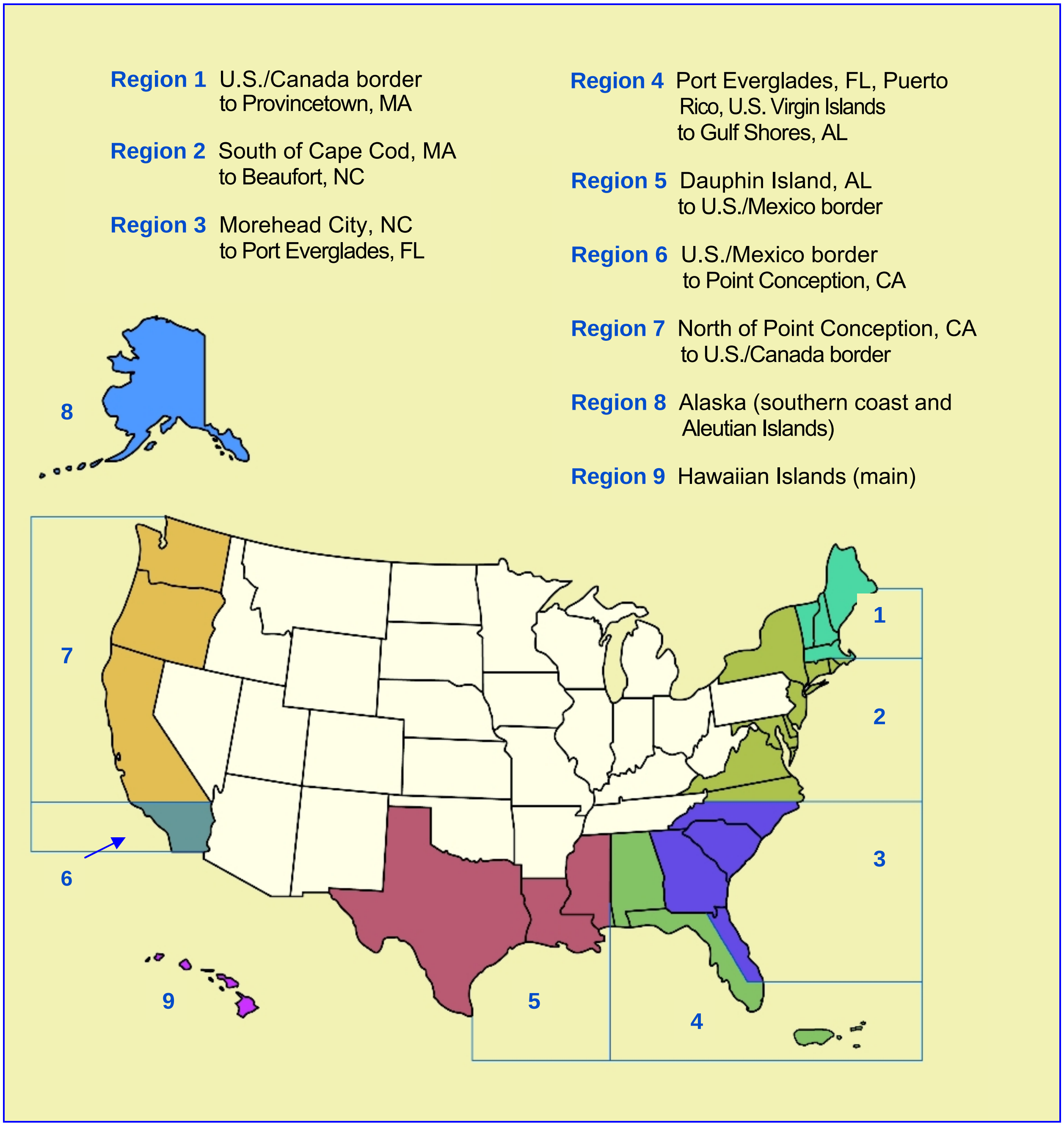
Years of informal beach cleanups and other debris research have shown that shorelines accumulate varying amounts and types of debris dependent upon their geographic location, oceanographic and meteorological systems, and proximity to land-based and ocean-based sources (Cole *et al*, 1990; Manski *et al*, 1991; Ribic *et al,* 1992; Corbin and Singh, 1993; Farris and Hart, 1995; Coe and Rogers, 1997; Debrot *et al,* 1999; De Mora, 2004; and UNEP, 2006). However, a recent National Academy of Sciences report on marine debris concluded that there was still relatively little quantitative information available on the amounts and sources of marine debris, thus encouraging the implementation of coordinated monitoring efforts to assess marine debris (Criddle *et al.,* 2008).

Conducting effective monitoring activities to assess the types and amounts of marine debris, combined with coordinated public education programs and effective solid waste management strategies, could help lead to the reduction and eventual abatement of the marine debris problems impacting the United States and its global neighbors.

E. What is the National Marine Debris Monitoring Program (NMDMP)?

The National Marine Debris Monitoring Program (NMDMP) was developed to provide statistical and policy assessment information related to marine debris. More specifically, NMDMP was developed to standardize marine debris data collection in the United States by using a scientifically valid protocol to determine marine debris status and trends. The United States was divided into nine regions based on the types of marine debris found in those areas, the prevailing currents, and logistical considerations of access and other parameters with identification of and random selection of 20 beach sites within each region. The purpose of this study was to answer the following research questions:

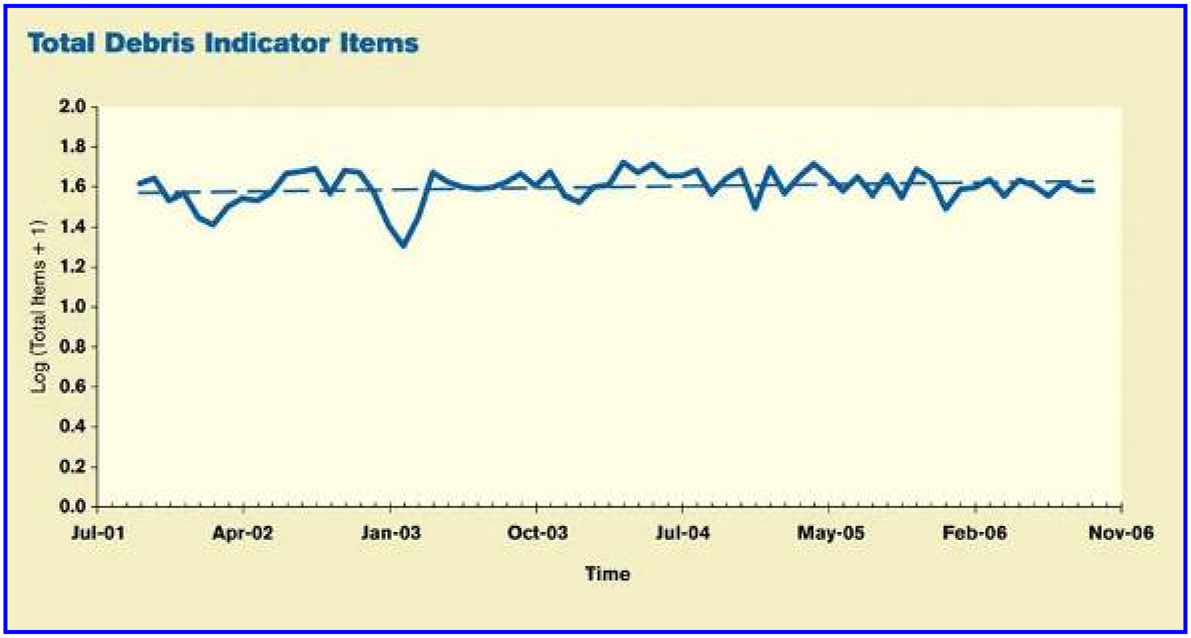
(1) Is the amount of debris on our coastlines changing?
(2) What are the major sources of the debris?



This study was characterized as a full-scale, national volunteer driven effort, where over 600 volunteers and volunteer groups devoted a considerable amount of time and effort in implementing and conducting the field monitoring for assessing the status of marine debris along the coastal areas of the United States.

Sheavly (2007) reported on the results of this study and revealed that nationally, no significant change in the total amount of debris was detected.

An average of 95.4 ± 22.6 (SE) indicator items was removed during each survey. The major sources of debris in the United States during this study indicated that land-based debris items made up the largest percentage of debris surveyed nationally, comprising 48.8% of all collected items, followed by general source items at 33.4% and ocean-based items at 17.7%.



		Average Number of Indicator Items	Percent of Total	CV	Average Annual Percent Change
United States	Total Items	95.4 ± 28.6		2.05	3.6%
	Ocean-based	16.9 ± 3.5	17.7%	1.42	-9.0%
	Land-based	46.6 ± 19.9	48.8%	2.91	8.8%
	General Items	31.9 ± 7.9	33.4%	1.68	5.4%

Regional analysis of the data revealed high variability among regions and among sites of an individual region, influenced by seasonal parameters and other activities. Total indicator debris in Regions 1 and 2 increased over the study period. The only region to display a significant decrease in debris was Region 9 (Hawaii). This decrease may have been influenced by the effects of weather patterns and other climatological factors.

The origin of the National Marine Debris Monitoring Program is rooted in the ratification of Annex V of the International Convention for the Prevention of Pollution from Ships (also known as MARPOL 73/78) on December 31, 1987 by the United States. Annex V prohibits the at-sea disposal of plastic wastes and regulates the distance from shore that ships may dump all other solid waste materials, which became effective on December 31, 1988. The Marine Plastic Pollution Research and Control Act (MPPRCA) of 1987 (Public Law 100-220, Title II) is the national legislation implementing Annex V. MPPRCA directed the Administrator of the EPA, along with the Secretary of Commerce, and the U.S. Coast Guard to conduct a program to encourage the formation of volunteer groups to assist in the monitoring, reporting, cleanup, and prevention of ocean and shoreline pollution.

II. Lessons learned from the research protocol, methodology, and results

A. Research protocol development and field testing

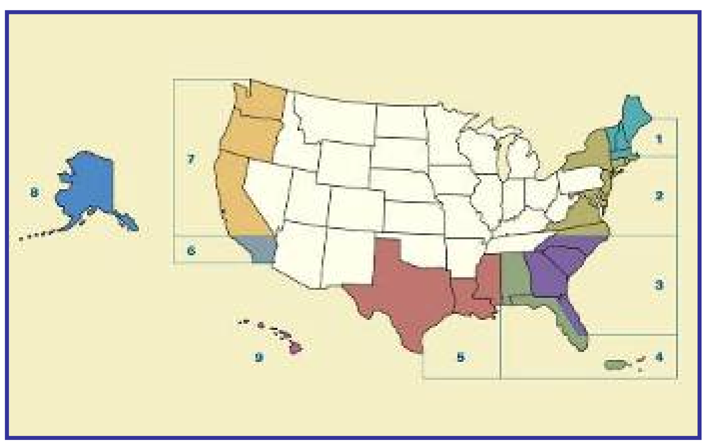
The research protocol was developed through the collaboration of a federal workgroup and proved to be an effective approach. The design of the protocol was led by Dr. Christine Ribic (USGS/University of Wisconsin) and implementation of the protocol was conducted by the Ocean Conservancy. Members of the Marine Debris Monitoring (MDM) Federal Workgroup brought varying interests and expertise to the table including technical expertise in designing field collections of marine debris, organizing beach cleanups and cataloguing marine debris, experience with the effects and impacts of marine debris related to fisheries and marine wildlife, and regulating the controls for marine debris on land and at sea.

Pilot studies were implemented to evaluate the practicality of the marine debris survey protocol that was designed by Dr. Ribic in collaboration with the MDM Federal Workgroup. Pilot sites were first selected on the East Coast (Maryland and New Jersey) and subsequent sites were chosen along the Gulf of Mexico (Alabama and Texas). The New Jersey monitoring sites surveys were successfully completed over a two and a half-year period, but the Maryland survey site, unfortunately, was impacted by a severe winter storm that washed away the beach study site during the first year. The New Jersey pilot program yielded a wealth of marine debris information and provided insights into the feasibility and practicalities of conducting a long-term national study. The New Jersey pilot data also exhibited seasonal variability and indicated that there was little autocorrelation structure in the data. This meant that the New Jersey data could be treated as independent observations and more familiar statistical tests (e.g., analysis of variance) could be used for the future, five-year national study. The Gulf of Mexico data were used to identify gaps and trends, as well as determine amounts and variability between sites and regions (Ribic, 2001a, b, and c).

These pilot studies presented the opportunity to test and refine the study protocol and statistical design. The results of these initial studies yielded the base information necessary to determine the number of required monitoring sites, the frequency of the surveys, the required duration of the national study, and the strength of the planned statistical analysis.

B. Selection of survey regions and monitoring sites

Due to the jurisdiction of MARPOL Annex V, this study focused on monitoring marine debris only along open-coastal areas of the United States. The coast of the United States was divided into seven separate regions based on current patterns such as the Alaska Current, California Current, Loop Current of the Gulf of Mexico, Florida Current, Gulf Stream, and Labrador Current. Two additional regions were established for the states of Alaska and Hawaii for a total of nine monitoring regions. The nine study regions are presented in this map.



A comprehensive listing of potential survey site locations for each region was compiled based on the recommendations of local natural resource managers from state and national parks; coastal programs managed by state and federal agencies; national, regional, and local conservation programs; NGOs, state programs, and civic associations (e.g. Adopt-A-Beach) who coordinate International Coastal Cleanup events nationwide; and project staff, through their own investigations and field surveys. Each potential site was required to meet the following criteria:

- Length of at least 500 meters (≈ 0.31 miles),
- Low to moderate slope (15° to 45°),
- Composed of sand to small gravel,
- Clear, direct access to the sea (not blocked by breakwaters or jetties),
- Accessible to volunteers year round,
- Does not receive any routine municipal or community cleaning during the study; and
- Site will not impact any endangered or protected species such as sea turtles, sea/shorebirds, marine mammals, and sensitive beach vegetation.

A number of sites were randomly selected for survey activities in each region. Each site was measured and marked with semi-permanent start and end markers (if allowable), photographed for visual identification, and GPS coordinates were recorded. During the course of the study, several monitoring sites became unusable as the result of shoreline changes due to storm activities such as hurricanes, Nor'easters, and other meteorological events. In addition, a few of the monitoring sites were on federal property and following the events of September 11, 2001, access was denied to the volunteers resulting in termination of those sites.

Although the original protocol called for identifying additional monitoring areas at each end of the monitoring site in case the primary site became inaccessible, we found that if the primary monitoring site was washed away due to a storm, so were the alternate sites. It is imperative that an adequate number of monitoring sites are established for a long-term study such as this to account for losses in sites for whatever reason.

C. Identification of debris indicator items and probable sources

The MDM Workgroup reviewed data from the International Coastal Cleanup and other current research on debris types and sources (Ribic, 1989 and Escardó-Boomsma *et al.*, 1995). A total of 31 common debris items were selected for monitoring based on their ability to provide the information needed to measure the changes and trends in the amount of debris washing ashore. The list included items that could indicate land-based and ocean-based sources and items of particular concern because of biological or other potential impacts. The list included the following:

- *Ocean-Based Source Indicator Items*: gloves, plastic sheets (≥ 1 meter), light bulbs/tubes, oil/gas containers (>1 quart), pipe-thread protectors, nets (≥ 5 meshes), traps/pots, fishing line, light sticks, rope (≥ 1 meter), salt bags, fish baskets, cruise line logo items, floats/buoys.

- *Land-Based Source Indicator Items*: syringes, condoms, metal beverage cans, motor oil containers (1-quart), balloons, six-pack rings, straws, tampon applicators, cotton swabs.

- *General Source Indicator Items:** plastic bags (<1 meter), plastic bags (≥ 1 meter), strapping bands (open), strapping bands (closed), plastic beverage bottles, plastic food bottles, plastic bleach/cleaner bottles, other plastic bottles.

  **These items represent debris that originates from unspecified ocean- or land-based sources.*

The specific source of individual forms of debris is not easily determined due to multiple uses of products by a variety of user-groups. However, careful analysis of behaviors and activities associated with the presence of marine debris can provide information to assign source. The indicator items for ocean-based sources included articles that were used in offshore drilling and extraction (gloves, light bulbs/tubes, and pipe-thread protectors), fishing (gloves, light bulbs/tubes, oil/gas containers > 1 quart, nets, traps/pots, fishing line, light sticks, rope, salt bags, fish baskets, and flouts/buoys), and marine transport (plastic sheets, light bulbs/tubes, and cruise line logo items).

Land-based indicator items were associated with combined sewer overflows (motor oil containers, syringes, condoms, tampon applicators, and cotton swabs) and shoreline recreation (metal beverage cans, six pack rings, straws, and balloons). Metal beverage cans could be tossed off a boat, however, it was determined that the metal cans would sink before they would most likely make it to shore, thus a land-based source was indicated.

General source indicator items demonstrate the multiple uses of items that can end up as debris. For example, plastic bags can be blown into the water from land, or dumped at sea by improper garbage disposal. Strapping bands can be used on cargo ships as well as building materials on land. Plastic beverage and food bottles (depending on size) can be used in picnics on land or in the galley of a boat or ship. Other plastic bottles also have duplicitous functions on land and at sea.

During the course of this study, questions arose about other debris items that were present on the survey beaches. It was explained to the public that this listing was not inclusive of all the various types of debris that could be found on beaches around the country. The indicator items were chosen to provide information on the research questions: (1) Is the amount of debris along our coastlines changing over a five-year period? (2) What are the major sources of the debris? This study was not an effort to document all the types of debris.

Problems in identification occurred from time to time among the volunteer groups related to language issues (Puerto Rico) and other miscommunications. The project team used a quarterly newsletter to point out discrepancies to all the volunteers, but followed up with specific re-training to those experiencing the problems. Volunteers sent samples of unknown debris forms to project staff in the early days of the study and later sent digital photos for clarification of debris questions. In future monitoring efforts, it is suggested that photographs be used in all manuals to properly identify all debris items.

Additional debris items could be added to the monitoring list if accommodations are made for that activity in the protocol and in data processing. During this study, no additional debris items were added.

D. Program implementation

The National Marine Debris Monitoring Program was implemented sequentially due to restricted federal funding. The decision was made to implement NMDMP regions in this order: Regions 4 and 5, Regions 3, 2, and 1, followed by Regions 6 and 7. Regions 8 and 9 were the last to come on board based in part to their location (distance from the mainland) and the costs associated with travel of project staff to those areas as well as seasonal restrictions (Alaska).

The sequential method of implementing the monitoring program resulted in some regions and sites being active for over 10 years, with some not being able to stay in full force during the final stages of program. In hindsight, simultaneous implementation of the regions would have been more effective and economical in the long run. It would have also provided a tighter set of national data.

E. Volunteer management

The use of volunteers for a national research study of this magnitude was an experiment in and of itself. Could a "volunteer" group of relatively novice field researchers be successful? The answer is YES, but with some considerations! NMDMP volunteers were composed of a plethora of backgrounds, including retired corporate executives, technicians, educators, local conservation organizers, middle and high school science classes, college students, U.S. Naval and Coast Guard offices, and other members from the private sector. NMDMP proved that these diverse groups could be effective field researchers if they were properly trained and had the support needed to keep the monitoring teams on schedule and reporting their data in a timely fashion. These efforts could be more successful if local management and coordination was integrated into the program utilizing regional EPA offices and state or municipal/county programs. Project staff could not physically visit with the 100+ monitoring groups often enough to keep all the volunteer groups on track. Local management would increase the output of this type of study and provide a synergy for ongoing programming and community feedback.

As stated above regarding the sequential implementation of the NMDMP regions, the volunteers were the most impacted. Some sites were actually monitored over a period of more than 10 years by the end of the study. This represented a significant time investment by the groups that signed onto this program. It also resulted in necessary replacement efforts for teams that had to resign because of other organizational interests and obligations. In the future, it is essential that a monitoring program of this nature be realistic as to expectations for volunteers related to overall labor and length of time needed to conduct this type of research.

For the most part, the volunteers participating in this effort did not receive monetary support to cover transportation expenses related to their efforts. Some support was provided to school groups that rented buses or groups that needed ferry transport to reach offshore barrier island sites. The volunteers and their organizations and/or businesses contributed the majority of the overall financial resources used to conduct the monthly surveys. Future research efforts should consider offering a monetary stipend to offset some of the monitoring teams' transportation costs and other expenses.

NMDMP volunteers were very successful in implementing the survey protocol and benefited from effective training programs and the well developed and thorough support materials used with the volunteers, along with site visits by project staff when possible. As the additional regions were implemented, the availability of project staffs (and travel funds) to conduct site visits became more restricted. Other means of communicating with the volunteers were implemented through conference calls (usually conducted after office hours by project staff), regional workshops for survey directors, distribution of a quarterly newsletter, and routine emails and individual phone calls. Regular and frequent communications are a key to any volunteer program and significantly influence the quality of their participation.

F. Data collection

Data collection in the field was overseen by the survey directors who reported directly to project staff monthly. A reminder and check-in system was developed by project staff to help survey directors stay on task and in soliciting the data collected each month. Survey directors were provided stamped and addressed envelopes to submit their monthly data to Ocean Conservancy. Calendars produced by Ocean Conservancy were marked with each NMDMP survey and sent out to the volunteers to support the timing of their surveys.

The process of data collection, processing and storage was managed by CMC/Ocean Conservancy through its project staff, including a data manager. The data was recorded by the volunteers on a standardized data card developed by CMC/Ocean Conservancy and approved by the MDM Workgroup. Upon receipt at CMC/Ocean Conservancy, the data was entered into an Access database into structured forms built around a relational database maintained by the NMDMP data manger. The data, region and site information, and volunteer roster were routinely backed up on an external hard drive for archiving. At the time of implementation of this study, an offsite and secure data backup program was not very accessible. In the future, offsite backups would be recommended as they are readily available and relatively inexpensive. As mentioned above, utilizing online data submission should be used along with appropriate QA procedures for qualifying data entry, thus streamlining the data process and speeding up data submissions and processing.


Items Collected

You may find it helpful to work with a buddy as you clean the area, one of you picking up trash and the other taking notes. An easy way to keep track of the items you find is by making tick marks. The box is for total items; see sample below.

Example:

Balloons ~~||||~~ ~~||||~~ ~~||||~~ || 17

Ocean-Based

Gloves
Pl. sheets ≥ 1 meter
Light bulbs/tubes
Oil/gas containers (> 1 quart)
Pipe-thread protectors
Nets ≥ 5 meshes
Traps/pots
Fishing line
Light sticks
Rope ≥ 1 meter
Salt bags
Fish baskets
Cruiseline logo items
Floats/Buoys

Land-Based

Syringes
Condoms
Metal beverage cans
Motor oil containers (1 quart)
Balloons
Six-pack rings
Straws
Tampon applicators
Cotton swabs

General Sources

Plastic bags with seam < 1 meter
≥ 1 meter
Straps: Open
Closed
Plastic bottles: beverage
food
bleach/cleaner
other pl. bottles

Comments:

When a data card was received, a notice was sent to the survey director (an email or phone call) that it had been received. As the data was entered by project staff, any questions on the NMDMP data were immediately addressed via email or phone calls. QA procedures were an integral part of the survey protocol and were managed by the survey directors randomly, four times within 13 surveys each year. The QA performance improved as the experience of the volunteers progressed. Quarterly data summations were prepared and uploaded onto the NMDMP website (maintained by Ocean Conservancy). Volunteers were excited and pleased to see the progression of their monitoring activities online.

A key improvement would be made in online submission of the data collected in a study of this type. At the implementation of this study, online capabilities were limited at Ocean Conservancy and by many of the volunteers. Not all of the volunteers had access to a computer in all regions.

G. Data analysis and results

The protocol developed for NMDMP required that surveys be conducted every 28 ±3 days at each of the monitoring sites. However, over the course of the five-year study a number of surveys took place outside of the 28 ±3 day window for various reasons (e.g., holidays, volunteer time, weather). There were two concerns with surveys conducted outside the established survey window – surveys done in advance of the established window may not collect as much debris, and surveys done beyond the prescribed survey window may have too much debris (more time to accumulate) or too little debris (more of a chance to be washed off). In order to maximize the use of the data collected, the data gathered outside the established window were evaluated using two different statistical tests to determine if they were statistically valid and could be included in the analysis. The first evaluation compared the total number of items collected from valid surveys (those done within the ±3 day window) and off-target surveys (those done outside the ±3 day window) using a Mann-Whitney test (Conover, 1999). The second assessment compared the valid surveys with those done less than 25 days apart and those done more than 31 days apart using a Kruskal-Wallis test (Conover, 1999). The evaluations indicated that there was no significant difference between data collected for valid and off-target surveys ($p>0.10$ for all tests). Therefore, all surveys for an individual site were used in the data analysis. As a result, 47 survey sites were included in the analysis.

To investigate change in total indicator items over the five-year study period, a linear regression model was fit to total debris items over time at each study site (i.e., slope of the series). Previous analyses showed that there was a strong seasonal effect in abundance of marine debris (Ribic, 1998); therefore, a seasonal variable was added into the regression model to adjust for any seasonal effects. Data were log transformed to meet the assumption of normality and down weight extreme observations (Draper and Smith, 1981). In sites where zero items were collected during at least one survey, slopes were calculated using log (debris items + 1) transformed data. The slope from the regression model for each site was used to compare changes in indicator items over time at the national and regional levels using a Wilcoxon signed-rank test comparing deviation of the slopes from zero at $\alpha = 0.10$. Regression models were constructed for totals of ocean-based, land-based, and general debris items, again using slopes from each site to test for deviation from zero at both the national and regional level using the Wilcoxon signed-rank test at $\alpha = 0.10$.

Descriptive statistics were calculated for national, regional, and site level data, including the mean number of debris items and standard error. Bias adjusted coefficient of variation was calculated for each survey site (Sokal and Braumann, 1980). The coefficient of variation allows for comparison of variation across sites, with values close to one having high variation over time and values closer to zero with less variation over time. For changes in debris over time, the average percent change each year was calculated based on:
[(mean debris items in year_{i+1} – mean debris items in year_i)/mean in year_i].

Other monitoring research and analysis of the debris patterns in this study indicates that there is a seasonal effect in debris accumulation and there was evidence of seasonal patterns within the regional analyses.

Tidal cycles could also have an effect. The monitoring protocol required that surveys be conducted at the low tide stage to expose the largest amount of beach area. We suggest that future monitoring efforts at the regional level investigate seasonal patterns for debris deposition. In more temperate and warmer areas where the seasonal changes are less dramatic than those experienced in the Northeast and Northwest, less frequent sampling activities may provide an adequate amount of data for analysis. In more tropical areas, seasonal sampling based on wet and dry seasons may provide adequate information. It should also be noted that while the use of volunteer efforts can be effective, expecting volunteers to sustain frequent sampling efforts over an extended period (several years) might not be practical.

The results of this study revealed that nationally, no significant change in the total amount of debris was detected. An average of 95.4 ± 22.6 (SE) indicator items was removed during each survey. The major sources of debris in the United States during this study indicated that land-based debris items made up a greatest percentage of debris surveyed nationally, comprising 48.8% of all collected items, followed by general source items at 33.4% and ocean-based items at 17.7%.

Regional analysis of the data revealed high variability among regions and among sites of an individual region, influenced by seasonal parameters and other activities. Total indicator debris in Regions 1 and 2 increased over the study period. The only region to display a significant decrease in debris was Region 9 (Hawaii). This decrease may have been influenced by the effects of weather patterns and other climatological factors.

A baseline of data has been developed in this study using the randomly selected sites meeting specific criteria. It may be appropriate to revisit the design to take advantage of advances in selecting sites in a spatially balanced manner or to consider stratification of sites such as by known sources of debris producing activities – outfall pipes, river mouths, recreational beaches, shipping/marina operations, and other locales. Being able to connect specific activities to specific forms of debris would greatly enhance the development of programs for reduction and prevention of debris. Alternately, collection of variables, such as distance to known debris-producing activities, could be used in future analyses.

The statistical analysis component of this program was one of the most important elements of this study and the most underserved. A statistician needs to be a significant part of the early development of this program and in subsequent analysis of the pilot studies used to field test the monitoring protocol. It is recommended that a statistician be a fully integrated member of the project team so that adequate adjustments can be made in the sampling protocol and to assess the data collected during the monitoring program.

H. Summary

The National Marine Debris Monitoring Program was an experiment designed to standardize marine debris data collection in the United States using a scientifically valid protocol to assess marine debris status and trends. This was the first significant national study on marine debris amounts and sources and has served as a model for development of other programs around the world. A workforce of over 600 volunteers in 21 coastal states, territories, and islands successfully conducted a national monitoring program and produced a statistically valid database on marine debris for the United States. In reviewing the “lessons learned” during this 10+ year process, a great deal was learned by project staff and federal agency managers.

Securing a strategy for ongoing funding of a national-scale project is essential for effective and timely completion. Due to the limited funds, the program initially progressed in stages, but in the end that decision was counterproductive because it took too long and strained program development and volunteer management efforts.

Monitoring efforts need to be managed at the local level so that someone is available to interface with monitoring volunteers and provide support for training and data processing. This local support would increase the efficiency of the monitoring and result in a greater synergy for ongoing programming and community feedback. The use of volunteers should be considered carefully based upon the required commitment and the expectations of the study.

It is imperative that an adequate number of monitoring sites are established for a long-term study to account for potential losses in sites. In addition, it may be appropriate to design a protocol that selects sites based on known sources of debris producing activities – commercial fishing, outfall pipes, river mouths, recreational beaches, shipping/marina operations, and other activities. Being able to connect specific activities to specific forms of debris would greatly enhance the development of programs for reduction and prevention of debris. Alternately, collection of variables, such as distance to known debris-producing activities, could be used in future analyses.

Photographs should be used in training manuals to ensure the proper identification of debris items. Online data submission and appropriate QA procedures would streamline the data process and would enhance data management.

And last, but most importantly, a statistician should be a fully integrated member of the project team so that adequate adjustments can be made in the sampling protocol and to assess the data collected during the monitoring program.

III. Based on the National Marine Debris Monitoring Program, considerations for developing other/future marine debris monitoring activities for coastal areas

A. Identify the purpose for monitoring debris in your project area

Beach surveys have long been the primary tool for measuring the amount of marine debris in coastal and marine systems, and they also provide an effective vehicle for education and building community understanding and awareness. Ultimately, in order to effectively manage and eventually mitigate the impacts from marine debris, it is necessary to develop an understanding of the types and sources of marine debris and the behaviors that produce this pollution problem. There are many questions which can be answered through the use of different protocols; however, these questions must be identified based on the information being targeted, so that it effectively fits with the selected protocol. Additionally, there is also a need to ensure that good quality data are available that will allow appropriate analyses of the types and sources of debris in the selected environments and how these may vary seasonally and in response to management strategies and interventions.

Marine debris monitoring activities need to be planned to ensure that they will support a specific resource management framework and are conducted using valid protocols that are replicable statistically. The monitoring protocol must include the definition and specification of the survey sites, size of monitoring sites, survey frequency, classification and quantification of debris, and a process for data integration, analysis, and reporting of results. In other words, know where and why you are surveying an area, what are you collecting and documenting and how often, how will the data be processed and analyzed, and who will receive this information.

B. Determining areas to monitor – setting site criteria

Identification of appropriate sampling "locations" is a precursor to establishing the basic survey sites within any debris monitoring program. Accordingly, there is a need to consider the process by which survey sites are chosen. Ideally, sites should be selected with reference to regional management or resource arrangements, as well as their utility in providing meaningful data about debris dynamics.

Sites should be selected in a spatially balanced and stratified manner, such as by known sources of debris producing activities – outfall pipes from municipal sewers, creek and river outfalls and plumes, beach uses (recreational), local (or regional) shipping/marina operations, fishing activities, and other activities that may influence the deposition of debris on the monitoring sites. Being able to connect specific activities to specific forms of debris would greatly enhance the development of programs for reduction and prevention of debris. Alternately, collection of variables, such as distance to known debris-producing activities, could be used in data analyses. Information on current patterns and other oceanographic processes are needed to effectively understand the possible influences for the selected monitoring sites.

Be sure to choose suitable beach areas that will accommodate the establishment of adequate survey sites (i.e. long enough to provide an adequate distance to survey an adequate amount of debris). Selection criteria should include:

- A minimum length of 100 m, although beaches with smaller amounts of debris may need to be longer (e.g. 1 km);
- Low to moderate slope (15° – 45°), which precludes very shallow tidal mudflat areas that may be up to a half a mile wide or more at low tide;
- Clear access to the sea (not blocked by breakwaters or jetties) so that marine debris is not screened by man-made structures;
- Accessible to the survey teams year-round; however, some consideration needs to be given to sites that are iced-in during the winter and the difficulty in accessing very remote areas (e.g. barrier islands);
- Ideally, the site should not be subject to any other cleanup activities, although it is understood that many coastal communities conduct routine beach maintenance/cleaning, especially during the summer months in tourist areas; in such cases, the timing of non-survey related beach cleaning must be known so that the debris accumulation rate can be calculated properly;
- Monitoring activities should be conducted so as not to impact any endangered or protected species such as sea turtles, shore birds, marine mammals or sensitive beach vegetation; in many cases this would exclude national parks, but this may vary depending on local management arrangements and access; and
- Beach areas composed of a sand or small gravel substrate will provide the best interface for washed in debris, however, some areas may need to be studied that are rocky. Be aware that these areas require more effort for debris removal.

C. Identify and document various geographic/physical processes and human activities that affect the areas selected for monitoring

Oceanographic processes such as currents and tidal ranges have a direct impact on the accumulation of debris on coastal beaches. Understanding the current patterns offshore to the monitoring site will provide information on possible sources and effects on accumulation of marine debris in that area. Conducting surveys at low tide, for example, will ensure greater access to the beach area for collecting and documenting the accumulated debris. Tide tables are easily accessed to identify the best times for surveys.

Shoreline debris monitoring also needs to include the compilation of information related to sources of debris producing activities – outfall pipes from municipal sewers, creek and river outfalls and plumes, beach uses (recreational), local (or regional) shipping/marina operations, fishing activities, and other activities that may influence the deposition of debris on the monitoring sites. This information must be collected during the course of the monitoring program at each site and updated as needed – in the case of recent shoreline development (e.g. construction of a building or home).

At each location, data needs to be collected relating to the depositional environment and proximity to debris sources including:

- Slope (angle of incline from 1 m of fall from mid-point of beach).
- Aspect (compass direction perpendicular to the beach facing the sea).
- Prevailing wind (direction of wind for beach site, from meteorological data).
- Beach curvature (horizontal shape of beach – concave, convex, sinusoidal, or straight).
- Total beach length.
- Nearest river – name, distance, direction, and whether or not it inputs directly to the beach.
- Nearest town – name, distance, and direction.
- Estimated number of person visits per year.
- Main beach usage (i.e. recreational – swimming and sunbathing, fishing, surfing, boat access, or remote/not accessed by public on a regular basis).
- Access (vehicular, pedestrian, and/or boat only).

On the day of the survey, additional information should be recorded related to the conditions of the beach site including:

- Weather conditions the week before the survey (note inclement weather events-rain, storm activity)
- Weather conditions on the day of the survey (wind speed and direction, air temperature)
- Any changes to the beach area due to meteorological events or human activities.

D. Designing a monitoring strategy

The research questions associated with debris monitoring will determine why, what, and how you are to monitor marine debris in your area.

- Indicator items can be used to determine sources and activities leading to the deposition of marine debris. The amount of debris (counts and/or weight over time) can be used to assess management or mitigation strategies for a reduction or prevention of marine debris.
- The measurement of the *standing crop* (i.e. [unit quantity of debris] per [unit length of beach]) or total debris on a beach relates to the marine debris load and time between clearances (either natural storm deposition and removal or human clean up operations).
- In order to measure the *flux rates* of marine debris, one must calculate the rate at which debris accumulates (i.e. the amount of debris arriving on a specific length of beach over a

given period of time expressed as [unit quantity of debris per [unit length of beach] per [unit time]).

The NMDMP study was a flux study examining the accumulation of debris (number of pieces) over a specific length of beach (500 m) over a specific period of time (monthly/28 days ± 3 days) using indicator items identified as debris related to specific sources.

Use of the NMDMP existing protocol, standardized data card, and survey procedures can be used to determine if the amount of debris is changing in your area. The indicator debris items identified in NMDMP can be used to determine marine debris sources. If a NMDMP monitoring site is in close proximately to your survey area, a baseline of data for comparison exists and can be used to determine temporal changes in debris patterns.

Modifications might be useful in your monitoring efforts if you have additional information on the types of debris you want to study – additional indicator debris items are possible if you understand how those items have become marine debris. There is additional marine debris data available in the United States collected annually through the International Coastal Cleanup. That database could provide a baseline of information on the various types of debris collected in your area. From that listing, surveys could be conducted to assess the basic debris composition of your monitoring area. Use of the NMDMP protocol (sampling frequency, survey site criteria, etc.) could be useful in developing your monitoring strategy.

E. Working with volunteers

There are a number of key issues that need to be considered when engaging volunteers in marine debris monitoring efforts and these include:

- Volunteers need to be properly trained with hands-on training exercises and supportive training materials and program manuals that detail responsibilities and procedures.
- Local coordination and management is needed to ensure that volunteers are available when needed and monitoring schedules are followed.
- Effective and frequent communication is a key element in keeping volunteers engaged and up-to-date with the monitoring activities, including how their efforts are supporting resource and conservation management programs and interventions. Effective strategies include the use of e-newsletters, individual and group emails, conference calls, and webinars. Do not fail to give a personal touch to your volunteers with individual phone calls when possible.
- Strategies are needed to ensure that as some volunteers leave your program, new volunteers are trained to provide replacements. This may include identifying new groups to participate in your program.
- Regular recognition of the volunteers and their efforts can be effective in maintaining their involvement in the monitoring program (e.g. media coverage, presentations by monitoring group members and/or management groups at local civic meetings, thank you notes, and various incentives including t-shirts, hats, etc.).
- The monitoring program needs to be realistic in terms of the expectations of labor and the length of time needed from the volunteers to conduct this type of study.
- Program managers need to make regular site visits to ensure that training is relevant and appropriate to the needs of the monitoring effort. Follow-up visits should be scheduled to coincide with re-training efforts and other activities.

- Volunteer survey directors, who may often be volunteers themselves, need appropriate training to ensure that they have the skills to manage a volunteer team.
- Local partnerships may be developed with state or municipal agency staff to facilitate the monitoring and integration of volunteer management, training, and program delivery.
- Where appropriate, typically for remote surveys or where local volunteers are limited by financial or other resources, monetary support may be required to cover transportation expenses related to their monitoring efforts.
- While the very nature of a volunteer is not to expect anything in return for his/her efforts, people do like to know that their efforts are meaningful and appreciated.

F. Develop/adopt basic program components

Suggested program components to aid in operating a successful monitoring program include the following:

- Development of comprehensive training materials that employ both text and pictorial presentations accessible online and in print format. Utilize existing manuals as a guide and incorporate those strategies into your program.
- Development of a photo-library for debris identification which incorporates a measurement component, and, if necessary, an additional photo of an entire debris item. This photo-library must be accessible via the Internet and made available to monitors in laminated, print form if they are without Internet access.
- Development of a strategy to help identify unknown debris items collected by your volunteers using digital photo exchanges or by sending debris pieces to you for identification.
- Conducting local (new or refresher) workshops with your staff and volunteers on your monitoring program.
- Engaging other professionals in collaborating with local groups and volunteers involved in monitoring activities.
- Soliciting the involvement of an oceanographer/researcher to help correlate information about the offshore current patterns that may affect your study area.
- Development of a web presence of your monitoring activities for access in other areas and creating program links related to managing marine debris.
- Conducting regional workshops or participating in conferences to present information on monitoring efforts and how this data is being used for management strategies.

IV. Additional considerations for marine debris monitoring

A. Counts and weights of debris

Debris item counts are relatively easy to make and they do not require any specialized equipment. In relation to debris items, such as plastic drink bottles or plastic bags, counts provide a quantitative indicator of relative importance.

Problems arise, however, when there are debris items within the same category that may differ substantially in terms of size. Counts of derelict fishing nets will grossly underestimate the significance of larger nets which may vary in size from less than 1 m^2 to 100s or even 1000s of m^2. In such cases, counts are much less useful than a measurement of weight. Similarly, counts can skew the data results due to heavily fragmented debris items.

Weights of marine debris by categories are relatively easy to obtain and provide a very quick method for quantifying large numbers of items that have been collected during a survey. Furthermore, by aggregating items within a debris category and measuring the weight, it is possible to rapidly deal with broken or fragmented material (e.g., glass bottles or plastic bags). In some cases (e.g., cloth or fishing net), the weight will be affected by whether the material is wet or dry and this is a source of error.

Not all types of marine debris can be weighed; heavily fouled fishing nets or pieces of timber may weigh several tons. Most likely, these cannot be weighed unless the survey team has access to specialized equipment.

Where feasible, incorporate both counts and weights into your monitoring activities, as this information will allow you more interpretation of the basic debris data.

B. Adequate sampling units

There is no formula to calculate the minimum length of a survey site. In monitoring programs around the world, the range is from 10 m to 1 km and greater, with some conducting transects through the monitoring sites. The key factor is that the survey site must be long enough to allow an adequate sampling of debris. Add to that the balancing of total area covered and the amount of time needed to conduct the survey.

In the development of the NMDMP protocol, a kilometer was initially considered, but in discussions with MDM Workgroup members familiar with volunteer programs, concern was expressed about the ability of volunteers to handle long distances in the hot sun. A compromise was achieved for NMDMP of 500 m, along with an analysis of the pilot data to determine if adequate data had been collected.

A minimum of 100 m is encouraged based on additional research and work with the UNEP Marine Litter Technical Work Group (Cheshire *et al*., 2009).

C. Coordinate/support other marine debris programs – e.g., local adopt-a-beach campaigns, the International Coastal Cleanup and other activities.

It might be prudent, as well as effective, to become acquainted with existing marine debris activities in your study area so as not to cause confusion or interfere with ongoing activities. Suggested programs to research would include a local Adopt-a-Beach program, usually managed by civic and conservation organizations. They may already be involved in a marine debris monitoring effort or may be interested in participating in your monitoring program. An annual event is the International Coastal Cleanup, which takes place on the 3rd Saturday in September. It may be possible to integrate participation for that annual event into your monitoring plans.

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Lessons Learned Photo Identification

Page	Photo Description	Photo Credits
Cover	left beach shot	Ocean Conservancy
	center beach shot	Ocean Conservancy
	right beach shot	Ocean Conservancy
Page 1	pile of debris	UNEP Regional Seas
	stormwater	Ocean Conservancy
	beach	stock footage
Page 2	storm drain	Ocean Conservancy
	container ship	stock footage
	beach debris	Ocean Conservancy
Page 3	dead albatross	NOAA
	dead green sea turtle	NOAA
	dead pygmy sperm whale calf	NOAA
Page 4	NMDMP volunteer	Ocean Conservancy
	NMDMP volunteers	Ocean Conservancy
	NMDMP volunteers	Ocean Conservancy
Page 9	beach site (marker)	Ocean Conservancy
Page 10	fish light sticks	Ocean Conservancy
	fishing line	Ocean Conservancy
	fishing buoys	Ocean Conservancy
	syringes	Ocean Conservancy
	metal beverage cans	Ocean Conservancy
	grocery bag	Ocean Conservancy
	plastic beverage bottles	Ocean Conservancy
Page 12	NMDMP volunteers on beach	Ocean Conservancy
	NMDMP volunteers sitting	Ocean Conservancy
Page 17	Debris in water	CA Coastal Commission
	NMDMP volunteers on beach	Ocean Conservancy

Stock footage included photos available on the web, open domain.
The photos from the Ocean Conservancy were part a grant report prepared for EPA on the National Marine Debris Monitoring Program in 2007.