Marine Debris Monitoring and Assessment: Recommendations for Monitoring Debris Trends in the Marine Environment

NOAA Marine Debris Program
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
Technical Memorandum NOS-OR&R-46
November 2013

Photo taken by U.S. National Park Service, Kenai Fjords National Park

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Recommendations for Monitoring Debris Trends in the Marine Environment

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The suggested citation for this document is:
Lippiatt, S., Opfer, S., and Arthur, C. 2013. Marine Debris Monitoring and Assessment. NOAA Technical Memorandum NOS-OR&R-46.

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Contents

EXECUTIVE SUMMARY

Marine debris is defined by the National Oceanic and Atmospheric Administration (NOAA) and the United States Coast Guard (USCG) as any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or the Great Lakes (33 USC 1951 et seq. as amended by Title VI of Public Law 112-213). Marine debris has become one of the most recognized pollution problems in the world's oceans and waterways today.

In recent years, research efforts have significantly increased knowledge of the topic of marine debris. However, the field as a whole has not adopted standardized monitoring procedures or debris item categories. Standard methodology and reporting is necessary in order to compare marine debris source, abundance, distribution, movement, and impact data on regional, national, and global scales.

The NOAA Marine Debris Program (MDP) has developed standardized, statistically valid methodologies for conducting rapid assessments of the debris material type and quantity present in a monitored location. The monitoring guidelines in this document focus on abundance, types, and concentration rather than analyzing by potential source, as in many cases it is very difficult to connect a debris item to a specific debris-generating activity. These techniques are intended to be widely applicable to enable comparisons across regional and global scales.

This document includes guidelines for estimating debris concentrations on shorelines, in surface waters, during visual surveys at sea, and in the benthos. Background information is provided for each environmental compartment (i.e., shorelines, surface waters, and the seafloor), in addition to guidelines for survey design, required equipment, the survey techniques, and study implementation considerations. The appendices include a brief literature review for each compartment, survey data sheets, a debris item photo guide, frequently asked questions for shoreline surveys, and a summary of work completed by Versar, Inc. to test the methodologies.

The techniques described in this document were developed over the course of a number of years, based on a review of the literature, discussions with experts, and field testing by the MDP and contractors. For shoreline monitoring, the MDP benefited from feedback from partner organizations who implemented these methods prior to the official publication of these guidelines.

The guidelines in this document are intended for use by managers, researchers, citizen scientists, and other groups conducting marine debris survey and assessment activities, especially those requiring a rapid assessment. Monitoring and assessment of marine debris is essential to understanding the problem and being able to mitigate, prioritize, and prevent the most severe impacts. The effort to develop this document was rooted in the need to standardize methodologies and facilitate comparisons across time, space, and environmental compartments. These guidelines are provided to the marine debris community at large in order to guide the development of integrated monitoring programs nationwide.

1.0 INTRODUCTION

Marine debris, in some form, has been addressed by NOAA since the early 1980s and officially recognized as a problem by the federal government since the passing of the Marine Plastic Pollution Research and Control Act (MPPRCA) in 1987 (Public Law 100-220, Title II). This legislation was one of the first to provide research prioritization and authorize federal funding for marine debris in the United States. The NOAA Marine Debris Program (MDP) was initiated as a program in 2005 within the National Ocean Service's Office of Response and Restoration and was legally established by the Marine Debris Act (33 U.S.C. 1951 et seq., as amended by Title VI of Public Law 112-213). The act provides specific mandates to the program including mapping, identification, impact assessments, removal and prevention activities, research and development of alternatives to gear posing threats to the marine environment, and outreach activities.

Standardized marine debris monitoring and assessment can be used to evaluate the effectiveness of policies to mitigate debris, such as recycling incentives or extended producer responsibility measures, and provide insight into priority targets for prevention and mitigation (NRC 2008). For example, in the Gulf of Alaska, the NOAA Alaska Fisheries Science Center conducted shoreline monitoring prior to and following the implementation of the International Convention for the Prevention of Pollution from Ships (MARPOL); results indicated a significant decrease in the abundance of derelict fishing gear debris, in the form of nets from ships (Maselko and Johnson, 2011). Similarly, debris monitoring in Washington DC and other areas with recently-enacted policies on single-use shopping bags are indicating fewer plastic bags in rivers and in riverine "trash traps" (e.g., Anacostia Watershed Society, unpublished data).

The complicated nature of the distribution of marine debris in the environment calls for a clear and defined approach to characterizing and assessing the problem. Marine debris enters the marine environment through many pathways, and the extensive size of the ocean, patchiness in the distribution of debris, and spatial and temporal variability in the drivers of debris add to the complex life cycle of marine debris (Ryan et al., 2009, Cole et al., 2011, Doyle et al., 2011). This document updates and expands upon marine debris assessment guidelines developed by the NOAA Marine Entanglement Research Program in 1992 (Ribic et al., 1992). The guidelines outlined here incorporate modern technologies and sampling equipment and focus on standardization of data and reporting for a statistically robust analysis which can address all types of debris. Guidelines are included for estimating debris concentration on shorelines, in surface waters, during visual surveys at sea, and in benthic surveys. The shoreline survey technique described here is available in a user-friendly version in the *NOAA Shoreline Survey Field Guide* (Opfer et al., 2012).

1.1 Objectives and Method Development

The guidelines in this document are intended to serve as a basis for nationwide monitoring and assessment of marine debris, and were designed with four main objectives in mind:

- Estimate the quantity of debris at local and regional levels according to land use or other correlating parameter
- Determine types and concentration of debris present by material category (plastic, metal, glass, rubber, paper/processed lumber, cloth/fabric, other)
- Examine the spatial distribution and variability of debris
- Investigate temporal trends in debris types and concentration

This report includes guidelines for four survey techniques developed and/or modified by the MDP:

- Shoreline techniques: Guidance for assessing debris concentration on shoreline segments, including both macro- (> 2.5 cm) and meso-debris (5 mm–2.5 cm)
- Surface water techniques: Guidance for assessing floating debris concentration, including macro-debris (>2.5 cm), meso-debris (5mm–2.5cm) and micro-debris (≤ 5 mm in length)
- At-sea visual techniques: Guidance for conducting ship-based visual surveys of floating macro-debris (> 5cm or 2 in)
- Benthic techniques: Guidance for evaluating debris concentration on the seafloor

The methods detailed in this report take into consideration lessons learned from studies listed in Section 7.1. Additionally, shoreline methods were developed with input from an established advisory group. The advisory group consisted of established researchers in the debris monitoring field, other federal agencies involved in marine debris efforts, and internal NOAA MDP staff (Section 7.2).

The techniques for shorelines, surface waters, and at-sea visual surveys were tested and refined by NOAA MDP staff during a pilot project in summer and fall 2009 - 2010 in the Chesapeake Bay (Arthur et al., 2011). In 2011, the refined techniques were used during monthly surveys in various tributaries of the northern Chesapeake Bay to test the hypothesis that debris concentration is correlated with land-use (Lippiatt et al., 2012). Additionally, rigorous bi-weekly shoreline and surface water sampling completed by Versar, Inc. from July through December 2011 at two sites in the mid-Atlantic informed statistical considerations described in Sections 2.0 and 3.0 of this document. The shoreline technique was also extensively used and tested by regional and local groups along the U.S. west coast, Alaska, and Hawaii to monitor for the arrival of marine debris generated by the 2011 Japanese tsunami.

In 2009, the United Nations Environment Program (UNEP) published a debris assessment framework with the major goal of management and integration of debris monitoring activities across broad geographic regions (Cheshire et al., 2009). The UNEP framework includes a set of survey methods for beach, benthic, and floating debris assessment based on existing techniques used in the Oslo and Paris Convention for the Protection of the Marine Environment of the

North-East Atlantic (OSPAR), the Northwest Pacific Action Plan (NOWPAP), Australian Marine Debris Status (AMDS), and the National Marine Debris Monitoring Program (NMDMP) (Cheshire et al., 2009). The approach taken in this document is modeled after UNEP's framework with a few key differences: NOAA techniques focus on item count and concentration (in units that count debris items per square meter of shoreline, # items/m^2) rather than both count and weight information; NOAA shoreline survey techniques focus on assessment of debris standing-stock rather than flux rate (however, the NOAA shoreline survey can be adapted for accumulation surveys, see discussion in section 2.0, below); and the debris classification systems vary between the two methods.

The application of these guidelines to discrete studies will be most informative when study design and site selection address clearly stated objectives.

1.2 Debris Classification

Although previously published guidelines have focused on documenting the primary source of debris (e.g., Sheavly, 2007), the methods described here emphasize material type.

Debris source information is an excellent educational tool, however many debris items are difficult to identify as either land- vs. sea-based or industrial- vs. consumer-based debris. The source of a piece of debris found in the open ocean cannot necessarily be attributed to the manufacturing origin or country of consumption. Even when the debris has markings that can be used to identify where it was produced, the exact point of loss to the environment is unknown. Original sources of floating marine debris in the oceans can be difficult to identify, given the persistence and potential for long-range transport of lightweight buoyant materials (Ryan et al., 2009).This makes it difficult to evaluate controls on the land- or ocean-based sources of marine debris. Guidelines in this document take a tiered approach whereby every piece of debris is recorded according to material category and then by specific item or product (as recommended in Ribic et al., 1992). The material categories included are plastic, metal, glass, rubber, paper/processed lumber, cloth/fabric, and other or non-classifiable debris. There is also the allowance of "other" items that are locally important and may not be currently listed on the data sheets. Further, these items can be catalogued and tracked in the www.md-map.net online database (see Section 2.6). In this way, these guidelines allow for regional customization of important debris items. Information on debris source can be obtained during data analysis if indicator items are identified (e.g., plastic fishing floats are assumed to be sea-based debris). Furthermore, this approach enables analysis of variability in the composition and quantity of debris over time and space. The NMDMP effort (described in further detail in section 2.0), which collected information on specific indicator items, was designed to evaluate debris trends on a regional scale and was not suitable to local-scale assessments of spatial and temporal variability in debris types and quantities (Sheavly, 2007, NRC 2008, Ribic et al., 2010, Sheavly, 2010, Ribic et al., 2011, Ribic et al., 2012).

The methods described here do not include debris weight information. Debris weight can be challenging to measure and dependent on water content; reporting in units of debris counts (e.g.,

#items/m^2 of shoreline or #items/m^3 of water) provides more reliable and consistent data and techniques that are more accessible to organizations that may not have means of accurately weighing debris. Other programs that are not meant to be part of a rapid response technique or wish to factor in how physical properties such as weight, density, and form affect debris hydrodynamics and fate, may want to collect weight data.

Debris items encountered during these surveys is differentiated based on size class. Both the shoreline and surface water sampling strategies distinguish between large (>30cm) and small debris items (<30cm). Large debris items have a larger surface area and therefore have a greater potential to disturb valuable habitat. Additionally, large debris items may be less mobile in the environment and may be encountered more than once in reoccurring surveys. Having a record and location of these items will limit the potential errors in duplication. Figure 1, below, indicates the debris size ranges sampled by the techniques described here.

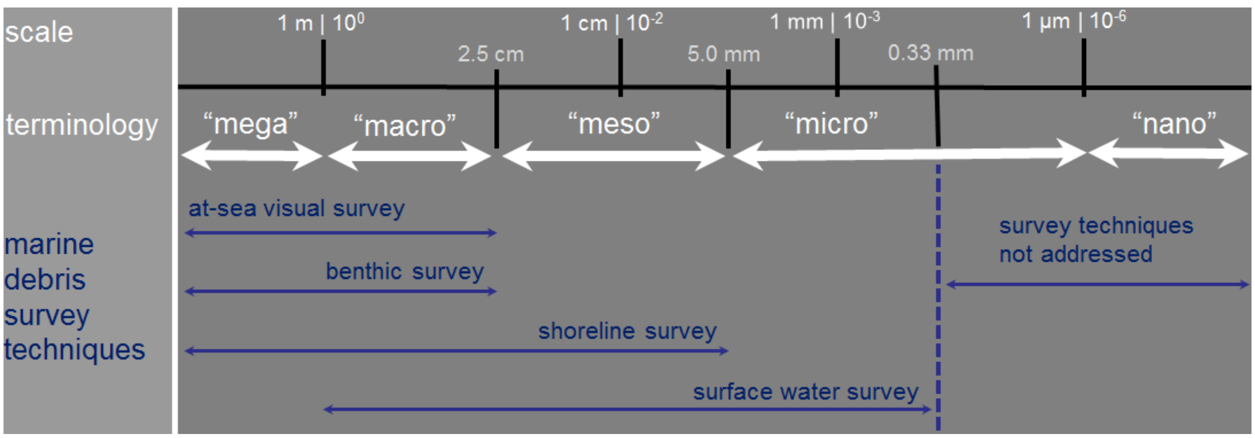

Figure 1. Size ranges sampled by the techniques suggested in this document.

1.3 Safety

Safety should be the number one priority during any survey activity. Because this work is carried out in the field, there are inherent hazards associated with these techniques. Use caution and follow general safety guidelines. The safety tips below are provided as general guidance, but it is imperative that project leads understand all risks associated with survey activities, always use caution, and conduct an operational risk assessment for the specific marine debris survey activity and location. Operational risk assessments should include resources (e.g., equipment, boats, communication, support, personal protective equipment), environmental hazards or considerations (e.g., remoteness, surf zones), personnel (experience, training, physical and mental fitness), weather, and mission complexity.

- Follow the buddy system when conducting shoreline surveys and other field operations.
- Let someone know where you are and when you expect to return.
- Carry a means of communication for emergencies, for example a cell phone or radio. If there is no reception use a GPS emergency responder or personal locator beacon.

- Always carry a first aid kit. The kit should include an emergency water supply and sunscreen, as well as bug spray.
- Understand the symptoms of heat stress and actions to treat it. For more information, see the OSHA website (https://www.osha.gov/SLTC/heatstress/heat_illnesses.html). Make sure to carry enough water.
- Be prepared for the weather and tides. Do not conduct field operations in severe weather and when tides could impede the survey area or block an access route.
- Wear appropriate clothing. Be sure to wear close-toed shoes and gloves when handling any non-hazardous debris as there may be sharp edges.
- Be aware of your surroundings and be mindful of trip and fall hazards.
- While on a vessel, always wear your life jacket and make sure it fits correctly.
- Large, heavy objects should be left in place. Do not attempt to lift heavy debris objects as they may have additional water weight and lifting them could result in injury.
- If you are conducting surveys in the United States and you come across a potentially hazardous material (e.g., oil or chemical drums, gas cans, propane tanks), contact local authorities (a 911 call), a state emergency response or environmental health agency, and the National Response Center at (1-800-424-8802) to report the item with as much information as possible. Do not touch the material or attempt to move it.
- When in doubt, don't pick it up! If unsure of an item, do not touch it. If the item is potentially hazardous, report it to the appropriate authorities.

2.0 SHORELINE METHODS

Marine debris monitoring on shorelines has become an increasingly common undertaking for academic, government, and environmental organizations. Shoreline surveys are usually more accessible, inexpensive, and straight-forward than monitoring in other environmental compartments. Often the highest debris concentrations are found on shorelines, which facilitates data analysis and trend assessment.

In addition to lessons learned from the studies listed in Section 7.1 and described below, these methods were developed with input from an established advisory group. The advisory group consisted of researchers in the debris monitoring field, other federal agencies involved in marine debris efforts, and NOAA MDP staff (Section 7.2). Data sheets modified here (Section 7.5) were adapted from UNEP and the Intergovernmental Oceanographic Commission (UNEP/IOC) debris monitoring guidelines (Cheshire et al., 2009).

2.1 Debris Assessment Methods

Numerous marine debris monitoring programs exist throughout the world. Most programs have unique objectives and employ a variety of region-specific methodologies, making across the board comparisons of debris estimates difficult (e.g., Barnes et al., 2009). For shorelines, some studies report number (or weight) of debris items per unit length of shoreline (e.g., Bowman et al., 1998, Barnes and Milner, 2005) or strandline (e.g., Velander and Mocogoni, 1999) while others report number (or weight) of items per unit area of shoreline (e.g., Acha et al., 2003).

In addition to the NOAA Marine Entanglement Research Program guidelines mentioned above (Ribic et al., 1992), lessons learned from previous marine debris monitoring efforts were considered during development of these guidelines. One key long-term, large scale monitoring program, the National Marine Debris Monitoring Program (NMDMP), was developed by an interagency working group consisting of the U.S. Environmental Protection Agency, NOAA, National Park Service, and United States Coast Guard following the ratification of MARPOL Annex V and the passage of the MPPRCA. NMDMP was designed to assess the magnitude of the marine debris problem in the U.S. and evaluate any regional or temporal trends according to a statistically valid design and sampling plan (Escardó-Boomsa et al., 1995). The NMDMP study, which consisted of monthly surveys conducted by trained volunteers at randomly selected sites along the U.S. coastline, used indicator items to identify the major sources of debris (Sheavly, 2007). Monitoring occurred from 1996 to 2006 and an analysis of data from a five year time period (2001 – 2006) is provided in Sheavly (2007). The five year analysis showed no statistical change in the prevalence of the indicator items for the nation as a whole (regional data analyses are found in Ribic et al. (2010), Ribic et al. (2011), and Ribic et al. (2012)).

This NOAA shoreline survey technique is designed as a rapid, quantitative beach assessment for collection of standardized and consistent data that can be applied to address policy and management needs at various spatial scales. The UNEP framework mentioned above (Cheshire et al., 2009) provides two different beach survey techniques – comprehensive and rapid beach assessments. This NOAA shoreline technique is designed to be useable by trained community volunteer organizations while simultaneously providing data that can be used to address key management questions. Table 1 provides a comparison of the two survey techniques.

	UNEP	NOAA
Removal of shoreline debris?	Yes	No/Yes*
Report item count or weight?	Both	Count only
Shoreline site length	100 – 1000 m	100 m sections
Site characterization included?	Yes	Yes
Minimum debris size	2.5 cm	2.5 cm
Recommended survey frequency	At least every 3 months	Every 28 days +/- 3 days
Smaller item protocol?	10-m wide transects	Sieve protocol
Large items recorded separately?	Yes	Yes
Specialized equipment required?	Scale for weight	No

Table 1. Comparison of NOAA and UNEP shoreline survey guidelines.
* NOAA standing-stock techniques can be adapted for shoreline cleanup efforts. See Section 2.3, below.

2.2 Standing-stock surveys

The shoreline technique described in this document is designed as a standing-stock assessment survey. Standing-stock surveys are used to measure the load or concentration of debris at a shoreline site over time. Each survey event is a snapshot of the concentration of debris at the site, and a series of these snapshots over time provides information on changes in the baseline concentration of debris. Knowing the concentration of debris (in units of #items/m^2 of shoreline) at various shoreline sites is necessary in evaluating the cumulative impact and conducting impact or risk assessments of debris at a given site and on a regional scale. In standing-stock surveys, the measured debris concentration reflects the long-term balance between inputs (land and sea based) and removal (through export, burial, degradation, etc.). An understanding of how the abundance of debris changes over time facilitates analysis of the drivers of debris deposition (e.g., weather, tides, tourism, prevention efforts).

In order to obtain a valid time-series of debris concentration, the natural flux of debris onto and off of the shoreline should not be altered by the survey activity. Integrity of the sample design should be maintained by not removing debris from the site during standing-stock surveys. If debris is removed from the shoreline site during a survey, the overall abundance of debris may be underestimated at subsequent surveys. Exceptions should be considered if an item poses a threat to human health or is potentially hazardous.

The standing-stock and residence time of marine debris on a given shoreline will vary with characteristics of the debris itself, deposition from land- and sea-based sources, local climate and seasonal weather patterns, and characteristics of the beach itself. Shoreline geomorphology, substrate, exposure, and coastal current patterns are some of the factors that will affect whether a given site tends to accumulate or capture debris.

2.3 Accumulation surveys

The shoreline survey technique described here can be modified for accumulation surveys (see Opfer et al., 2012). During accumulation surveys, marine debris is removed from the shoreline site. Accumulation studies require initial removal of all debris from the site followed by regular surveys to record and remove all debris. Because debris is removed from the site, the data collected over time provides an estimate of the flux of debris onto the shoreline (in units of #items/m^2/time), as opposed to the concentration or standing-stock of debris. Both types of data are useful for developing models of the life cycle and movement of debris among environmental compartments. Accumulation survey data indicate the *net* flux of debris onto the shoreline, and assume that the rate of debris accumulation is uniform between sample events. Debris flux data can be used to assess changes in at-sea debris loads, but cannot be used to evaluate the debris load or cumulative impacts of debris. Compared to standing-stock surveys, accumulation studies require more time and money as they are more thorough, require debris removal, and need to be conducted on a more frequent basis.

Accumulation survey frequencies must be identical for comparison between studies (Ribic et al., 1992). Shoreline sites may have a relatively rapid debris turnover rate, so in order to accurately estimate debris flux onto a shoreline site it must be sampled frequently. There is growing evidence that accumulation rates are underestimated by typical survey frequencies. Eriksson et al. (2013) found that daily accumulation rate measurements (i.e., surveys conducted on a daily basis) were an order of magnitude higher than those measured during monthly surveys, and Swanepoel (1995) suggested that daily accumulation rates were 100-600% higher than weekly accumulation rates. Eriksson et al. (2013) further suggested that 12 days of consecutive sampling at a given site may be more informative than monthly surveys over the course of one year. However, Ryan et al. (2009) argue that longer intervals between sampling events reduces variability in measured accumulation rates.

It is difficult to differentiate between factors that result in the deposition of debris onto the shoreline. Depending on the timing of sampling events (e.g., just prior to or following a storm event), the calculated net accumulation rate will likely vary. A debris marking study by Williams and Tudor (2001) found that “old” debris can reappear on the shoreline following strong wind events. Debris can become buried soon after deposition; in reality, accumulation studies are measuring the accumulation rate of visible debris items (Ribic et al., 1992). Accumulation data may also be affected by the lateral influx of debris from adjacent shoreline sites. Thus, conducting shoreline surveys may not be a suitable proxy for estimating debris loads in the ocean.

Given these considerations, accumulation studies may be appropriate based on study objectives. For example, accumulation surveys can be used to look for a spike in debris deposition from a major debris-generating event or variations due to climactic events (e.g., El Niño Southern Oscillation; Morishige et al., 2007). Debris flux measurements are important to understanding the life cycle of marine debris, and accumulation surveys will provide information on the relative abundances of different debris types. To reduce the impacts of marine debris in critical habitats, the benefit of more invasive accumulation surveys (with removal of debris) versus less intrusive standing-stock surveys should be considered in these locations.

2.4 Survey Design

Previous studies have shown that varying amounts and types of marine debris accumulate on shorelines depending on geographical location, oceanographic and meteorological conditions, climatological patterns (such as El Niño), and proximity to land-based or ocean-based sources (Morishige et al., 2007, Sheavly, 2007). To provide a more statistically relevant dataset, monitoring sites should be randomly selected from appropriate strata (e.g., land use, commercial and recreational fishing activities, political boundaries or management areas, storm water or sewage outfalls). Because there are various factors affecting debris deposition on shorelines, some studies have not detected significant differences in debris abundances between sites based on stratifying parameters. For example, van Cauwenberghe et al. (2013) found that sedimentary regime (i.e., accretion versus erosion) and tourism did not account for the debris loads they found on Belgian shorelines. Further, Versar, Inc. (2012) did not find differences in debris loads based on watershed land use.

The amount of sampling necessary to assess debris concentrations within a given region is dependent on the spatial variability in debris concentrations and the desired level of detection (i.e., in order to detect a smaller change in debris load, more sampling is required). Versar, Inc. (2012) used a nested survey design to test the utility of the shoreline and surface water survey techniques described here, which were developed based on a 100-m length of shoreline. At the coarsest level, two regions in the coastal mid-Atlantic United States were selected based on land use (urban vs. rural). Within each region, three 1000-m locations (stretches of shoreline) were identified. Locations were required to meet all site selection criteria (listed below) and were separated by at least 1200 m. Within each location, three 100-m shoreline sites were systematically selected and remained fixed for the duration of the study. Surveys at the site level were conducted on a bi-weekly basis for a period of six months in accordance with the standing-stock technique described below. Results of the study indicated that there was more variability (higher relative standard error) in debris concentrations among sites within a given location compared to the variability between locations at the regional level. This suggests that in order to decrease error in reported debris concentrations, shoreline surveys should be designed to assess debris at the scale of a 1000-m location (i.e., random selection of transects within a 1000-m location).

However, this technique was designed to be widely applicable, and it is recognized that in some cases it is not possible to find a suitable 1000-m stretch of shoreline for location-level assessment. Further, the European Union / Joint Research Centre Marine Strategy Framework Directive (MSFD) recommends a study design that includes more than one 100-m site on a given stretch of shoreline, or two sections of 50-m on heavily littered shorelines (MSFD, 2013). The technique explained below is based on assessment of debris at one 100-m site, but it should be noted that a study that includes more than one site on a given shoreline will provide more statistically powerful results.

2.4.1 Site Selection

An assessment of the impact of marine debris surveys on the local environment should be completed prior to commencement of any monitoring activities. In particular, monitoring should not be conducted where there is the potential for impacts to endangered or protected species or habitats. Organizations wishing to engage in marine debris monitoring activities are encouraged to contact local land owners or managers and wildlife authorities during the site selection process.

Shoreline survey sites should have the following characteristics:

- Sandy beach or pebble shoreline
- Clear, direct, year-round access (or seasonal access depending on physical conditions of the site)
- No breakwaters or jetties that affect local circulation and accumulate or inhibit debris deposition
- A minimum of 100 m in length parallel to the water (measured along the waters' edge)
- No regular cleanup activities. Sites do not need to be precluded solely because of annual or semi-annual cleanup events, but activities need to be tracked and noted in data analysis

These characteristics should be met where possible, but should be analyzed on a case-by-case basis and modified if appropriate for a particular region/location or shoreline type. The minimum length of shoreline was selected based on UNEP recommendations for rapid assessment (Cheshire et al., 2009). UNEP and MSFD (2013) suggest selecting shoreline sites that have a low to moderate slope (15 – 45º). Shallow tidal mudflat areas can be very wide at low tide, and marine debris is typically not very common in the intertidal. However, low-slope sites may still be appropriate for surveys.

2.4.2 Sample Frequency

Biweekly testing in the coastal mid-Atlantic indicated that in most instances, individual sampling events closely tracked monthly averages (Section 7.3). This finding suggests that sampling once every 28 days provides an accurate snapshot of debris concentration for the month. Following on recommendations from the National Marine Debris Monitoring Program (Sheavly, 2007), surveys should occur within a three-day window of the scheduled sampling event (i.e., shoreline standing-stock surveys should occur once every 28 ± 3 days).

2.5 Equipment

The following items are suggested for shoreline standing-stock assessments:

- Digital camera
- Hand-held GPS unit
- Extra batteries (suggest rechargeable batteries)
- Surveyor's measuring wheel
- Flag markers/stakes

- 100-foot measuring tape (fiberglass preferred)
- First aid kit (to include sunscreen, bug spray, drinking water)
- Work gloves
- Sturdy 12-inch ruler
- Clipboard for each surveyor
- Data sheets (printed on waterproof paper)
- Pencils
- For meso- and microdebris assessment:
    - 5-mm stainless steel sieve
    - Stainless steel tweezers/forceps
    - 32-ounce (~1 L) amber glass sample bottles with lids
    - Wide-mouth funnel (stainless steel) to fit glass bottles
    - Plastic bucket
    - Quadrat kit (1 m^2)
    - Small folding shovel
    - Waterproof paper for labels
    - Permanent markers

2.6 Pre-Survey Shoreline Characterization

Before any sampling begins, shoreline characterization should be completed for each 100 m site. Each survey site should be measured and marked for accuracy and repeatability using a surveyor's measuring wheel. This includes recording GPS coordinates in decimal degree format (DDD.DDDD N/W) at the start and end of each 100 m segment (note that locations in the southern or western hemispheres will have negative latitudes or longitudes). If the shoreline width is greater than 6 m, GPS coordinates at all four corners of the shoreline section should be recorded where possible. Additionally, a shoreline ID name should be created and used for the duration of the study (this name will be used for reference in the www.md-map.net database[1]).

Shoreline characteristics and surrounding land-use characteristics (*e.g.* primary land use, nearest town, nearest river, etc.) should also be recorded on the data sheets prior to survey activity. Shoreline characteristics include identification and uniformity of the primary substrate type (sand, cobble, etc.), the tidal range and distance (if applicable), a description of the first barrier at the back of the shoreline section (dunes, vegetation, etc.), and the aspect of the shoreline. It is important to record the distance to outfalls, rivers, and other potential sources of marine debris as well as local current patterns which can affect debris deposition. Digital photographs should be taken to document the physical characteristics of the monitoring site. Unless major changes occur to the shoreline, shoreline characterization only needs to be completed once per site per year. As mentioned above, changes in beach morphology (e.g., as a result of storm activity) may result in changes in debris deposition.

[1] At the time of publication, the NOAA MDP online database for shoreline survey data is housed at www.md-map.net. The database allows users to create custom debris items within the existing NOAA datasheet framework and facilitates data export and analysis. For information or access to the database, email MD.monitoring@noaa.gov.

2.7 Shoreline Survey Methodology for Macro-Debris (>2.5 cm)

In order to analyze the maximum width of the shoreline section during a relatively rapid beach assessment, sampling should be conducted within three hours of low tide. This constraint is made for the following reasons:

- Basing surveys on tides provides a consistent starting point at the waters' edge. Wrack lines are inadequate reference points as they move and change throughout the year.
- Some shoreline sites are inaccessible at high tide.
- Low tide heights typically exhibit less variability than high tides, which allows for a larger window of time to conduct surveys.
- Surveys conducted just prior to high tide may miss debris deposited on the wrack line at high tide.
- Surveying the entire shoreline (including the intertidal) at all sites facilitates comparisons of debris concentrations across sites. Data is representative of the entire shoreline site and is not biased by a small sample size (Rees and Pond, 1995; Burnham et al., 1985).
- Low tide provides a simple gauge of area surveyed. If a survey team does not have the ability to measure beach width at a given survey, it may be a valid assumption that approximately the same area of shoreline is being surveyed (we highly suggest testing this for a given shoreline site prior to accepting this assumption).

Before arriving on site, select four numbers from the random number table (Section 7.4) to eliminate any bias from visual inspection of the shoreline section. These four numbers correspond with four transects of 5 m in length within the shoreline section that will be sampled at this particular survey. The number of transects chosen for each sampling event correspond with a 20% coverage of the shoreline section. Thus, on any sampling day 20 m of the 100 m shoreline section is analyzed for debris.

Transects run perpendicular to the shoreline section from water's edge, at the time of sampling, to the back of the shoreline (Figure 2). The back of the shoreline is defined as the location of the first barrier or primary substrate change. There might be a change in substrate within the intertidal zone; in this instance the back of the shoreline should be defined such that it extends to at least the high tide wrack line. Further, if there is evidence that storm or wave action is pushing debris beyond the back of the shoreline, surveyors may be interested in recording these debris items separately (e.g., in Alaska debris is commonly found in the wooded region behind the shoreline). In this case, debris beyond the back barrier is recorded on a second data sheet and tracked separately from debris on the shoreline.

Upon arrival at the site at low tide, use the surveyor's measuring wheel to mark the selected transects with flags and record transect GPS coordinates in decimal degree format. Depending on the width of the shoreline section, the coordinate information can be recorded either at one point in the middle of each transect (shoreline width <6 m or < ~19.5 ft) or at both the water's edge and back of each transect (shoreline width >6 m or ~19.5 ft; Figure 2). This designation is due to the error associated with the operation of handheld GPS units. The GPS coordinates of each transect are recorded for quality assurance and to track any changes of beach morphology over the course of the study. For surveys conducted at high latitude locations, include information on the GPS datum used in the notes section of the data sheet. In addition to GPS locations, record ancillary data prior to the debris survey, which includes the length of each transect from water's edge to first barrier, the time, season, and date of last survey, description of recent storm activity, current weather conditions, and the number of individuals conducting the transect survey. If these characteristics are consistent between transects on a given survey event, they only need to be recorded on one data sheet.

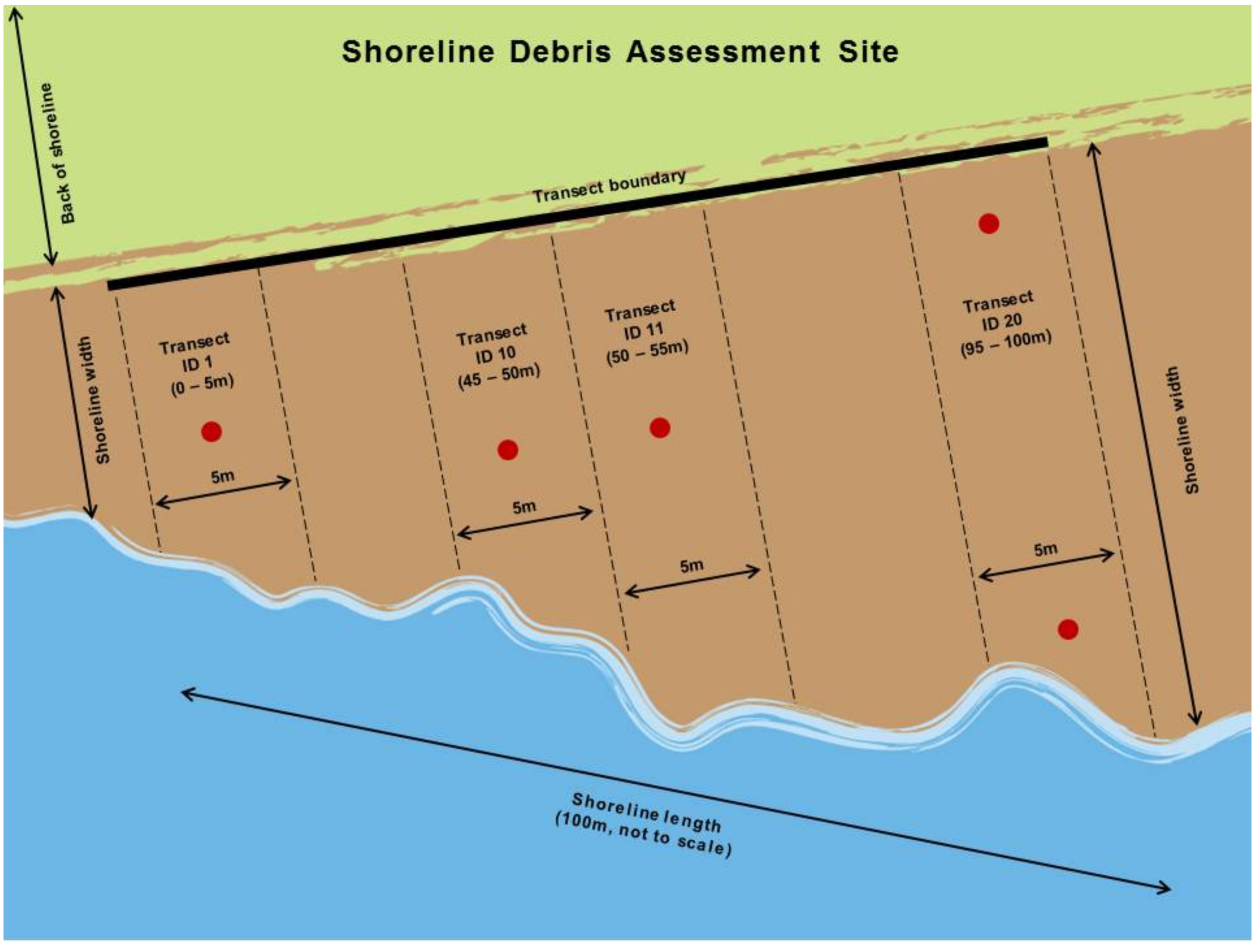

Figure 2. Shoreline section (100 m) displaying perpendicular transects from water's edge at low tide to the first barrier at the back of the shoreline section. Red circles indicate marked GPS coordinates. Shoreline width determines location and number of GPS coordinates. Figure not to scale.

Once ancillary data are recorded, surveyors should walk each transect tallying debris items according to material type and subcategory (see data sheets in Section 7.5). Debris items should only be recorded if they are at least 2.5 cm in size on the longest dimension (Figure 3). This standard length (approximately the diameter of a typical beverage bottle cap) was chosen to ensure that the same size items are counted across surveys and to maintain consistency in survey results. Data on debris < 2.5 cm has limited accuracy due to its small size compared to the transect area. In practice, surveyors will inevitably miss a significant fraction of debris below this size cutoff. This size cutoff for macro-debris surveys has also been adopted by UNEP (Cheshire et al., 2009) and the MSFD (MSFD, 2011, MSFD, 2013). Recognizing that small items represent an important size fraction of marine debris that may pose an even greater threat to marine life (e.g., through ingestion), this technique suggests the use of subsampling within transects for the assessment of meso- and micro-debris. The challenges with this approach, given the variability in small debris concentrations within a shoreline transect, are discussed below.

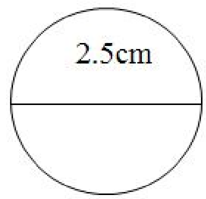

Figure 3. The minimum debris size to be counted is 2.5 cm.

Large macro-debris items (> 30 cm or about 1 ft) are recorded on a separate section of the debris data sheet. Large items should only be recorded in the large items section. Information recorded should include the debris type, the status of the large item (sunken, stranded, or partially buried), the latitude and longitude of the item, and the approximate debris size. This information is important in determining the footprint of large debris items.

Any item that is partially within a transect should be tallied (however, items should not be tallied twice if randomly selected transects are adjacent). If an item is blown into a transect mid-survey, it is tallied only if the surveyor has not yet surveyed the section of the transect where the item is located. Multiple fragments of what may have originally been a whole item should be tallied separately. Capturing information on the total number of fragments present is a better reflection of the debris impacts and effort required for cleanup. If one fragment is recognizable as a specific item, for example a remnant of a plastic beverage bottle, it should be recorded as such provided that the remnant is at least 50% of the original item (Tangaroa Blue Foundation, 2012).

Items that do not fall under a specific subcategory can be entered into the "other" category at the end of each material section. In order to ensure that these standardized methods are widely applicable, NOAA's online shoreline survey database allows users to create custom debris categories[1]. This allows researchers to track locally-relevant debris items within a nationally-standardized format.

If a surveyor is unsure of an item's material type, it is tallied in the other/non-classifiable category at the end of the data sheet. Include a brief description of the item in the notes section for clarification. Items that are composed of multiple material types should be recorded according to the most abundant material that makes up the surface of the item. For example, a tire with a metal rim would likely be recorded as a large rubber item. A debris item photo guide is included in Section 7.6. Digital photographs should be taken of unidentifiable items, as well as other debris items or markings of interest. Place a lined ruler next to the debris item to establish a size reference. It is also a good practice to take a photo of each transect surveyed, and record photo ID numbers on the data sheet.

The macro-debris item concentration (number of debris items/m^2) per transect is calculated as follows:

$$C = \frac{n}{(w \times l)}$$

C = concentration of debris items (# of debris items/m^2)
n = # of macro-debris items observed
w = width (m) of shoreline section recorded during sampling (i.e, transect width)
l = length (m) of shoreline sampled = 5 m

Note that the shoreline width that is measured at each transect is essential for calculating debris concentrations. For a given sampling event:

1. Calculate debris concentrations for each individual transect surveyed (a minimum of four per survey).
2. Take the mean of the concentrations at each transect to calculate an overall site concentration (± standard deviation) for that date.

The previously mentioned online database exports survey data (counts) and concentrations per debris item category, material type, large debris, and total debris.

2.8 Sampling for Meso- (5 mm – 2.5 cm) and Micro-Debris (≤5 mm)

Random samples can be collected from sandy beach locations for analysis of meso- and micro-debris. For random sampling within a shoreline segment, use a random number table (Section 7.4) to select the placement of a 1-m^2 quadrat. The placement of the number on the random number table determines the location of the sample. For example, if random number seven was chosen, the placement of the quadrat would be on the right side of the transect in the wrack line.

Because shoreline meso- and micro-debris concentrations are very patchy, random quadrat placement may not always be the preferred method. During field testing in the coastal mid-Atlantic, meso-debris was very rare in randomly selected samples (meso-debris occurred in only 2-3% of sample events; Versar, Inc. 2012). Therefore, depending on study objectives, it may be appropriate to focus meso-debris sampling on sections of the shoreline where small debris is more likely to accumulate. Previous studies have suggested sampling along the wrack line, where less re-suspension and thus higher debris concentrations are expected to occur, and to avoid the effect of tidal height on the deposition of debris of various sizes and densities (Browne et al., 2010). Van Cauwenberghe et al. (2013) found significantly higher concentrations of microplastic at the high-water mark compared to the low-water mark on Belgian shorelines. However, if samples are collected in a non-random fashion (i.e., focused on the wrack line), results cannot be extrapolated over larger spatial scales.

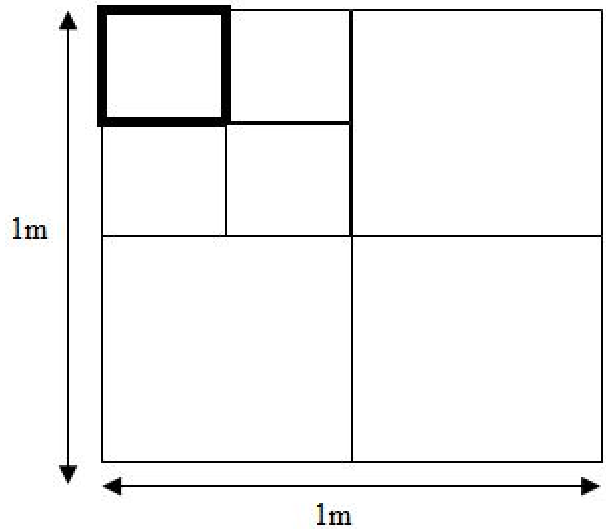

Figure 4. Randomly placed 1 m^2 quadrat with area of sand to be sieved (0.0625 m^2) in bold.

Once the quadrat placement is selected, remove any pieces of debris from the surface that are larger than 2.5 cm (and should have been counted in the macro-debris survey). Use a small stainless steel shovel to collect the top 3 cm of sand from 1/16 of the quadrat (0.0625 m^2). This is done by dividing the quadrat into fourths and then dividing one of the quarters into fourths (Figure 4). Sieve the collected sand through a stainless steel 5 mm mesh sieve above a bucket or funnel and sample jar. If the sand is wet, use a water rinse to facilitate the sieving process (seawater that has been sieved through a 0.33-mm screen is sufficient for this purpose). Transfer the sieved micro-debris samples to labeled amber glass bottles for further analysis back in the lab (Baker et al., 2013). If it is not possible to properly identify meso-debris items (> 5 mm) in the field they should be collected and analyzed back in the lab. Repeat this process for each of the four transects that were sampled for macro-debris.

Meso- and micro-debris item concentration (# of debris items/m^3) is calculated as follows:

$$C = \frac{n}{(a \times h)}$$

C = concentration of debris items (# of debris items/m^3)
n = # of debris items observed
a = area sampled = 0.0625 m^2
h = depth of sample = 0.03 m

Provided that samples are collected randomly, meso- and micro-debris concentrations for a given sampling event can be calculated according to the same approach as for macro-debris (Section 2.7).

2.9 Quality Control

To ensure that all of the appropriately sized debris items within a transect are recorded, quality control estimates should be conducted by a second surveyor before the collection of the meso- and micro-debris sample. The second surveyor should assess 20% of the total number of transects sampled per site over the course of the study (e.g., one site visited monthly will have a total of 48 transects and 10 quality assurance / quality control samples). Quality assurance sampling should be distributed among different sampling events and include consideration of debris classification.

2.10 Considerations

Shoreline surveys are the most accessible and cost-effective mode of marine debris monitoring and assessment. Depending on study objectives, additional data collection needs may be identified, for example debris location on the shoreline, number of beach visitors, or information on debris biofouling. This information can be included in the notes section of the data sheets or on a separate form. Surveys can be conducted by appropriately trained and managed volunteers to reduce costs, but as with any citizen-science effort, volunteer coordination is a major (and often overlooked) task. Site selection, proper debris classification, and survey schedule often prompt questions from new volunteers. A frequently asked questions document is provided in Section 7.7.

As mentioned above, care should be given to avoid threatened or endangered species and habitats during site selection and while conducting surveys. While removal of debris from the environment is an important endeavor, it is not a long-term solution. The distinction between standing-stock and accumulation surveys, and the information gleaned from each, is important. Leaving debris on the shoreline allows surveyors to assess the variation in debris loads over time, which is essential information for quantifying the impacts of debris on the marine environment and making the case for increased prevention and mitigation efforts.

3.0 SURFACE WATER METHODS

Floating marine debris has been noted by research and other vessels since 1971 (Carpenter et al., 1972; Carpenter and Smith, 1972). However, few systematic quantification surveys have been conducted throughout the oceans to develop a cohesive understanding of the extent and degree of pollution from floating marine debris.

Reported debris concentrations range from less than 1 piece/km^2 to 20,328 ± 2324 pieces/km^2 in the subtropical Atlantic Ocean (Law et al., 2010), to potentially higher concentrations in the North Pacific Ocean (NRC 2008; see Section 7.1). In addition to a lack of standard sampling methodologies, metrics vary by study objective which complicates debris concentration comparisons. Weight and number of items are used to measure debris items, while area and volume measure the matrix sampled (Section 7.1).

This section provides rigorous, standardized methodologies for assessing the amount and type of floating anthropogenic debris and guidance for the development of a robust survey design for coastal and offshore waters. Guidelines were developed to be flexible enough to conduct both coastal and offshore assessments. A goal for these guidelines is to increase the amount of surface water marine debris data that can be leveraged from tangentially-related organizations and projects that routinely conduct surface trawling. Data collected can facilitate comparisons to assess where floating debris is most prevalent and contribute to assessments of the eventual fate and risk posed by the debris.

3.1 Floating debris survey techniques

Floating marine debris and debris suspended in surface waters has been documented across the world in the open ocean and in coastal waters. In general, efforts to monitor oceanic marine debris have been informal, with many anecdotal reports, few scientific expeditions that included floating debris sighting surveys, and even fewer scientific expeditions dedicated to collection and quantification of floating marine debris samples. Early marine debris sampling was often conducted with pelagic plankton sampling. Methods have varied over the years to include oblique plankton tows (Carpenter et al., 1972) and Neuston nets towed across surface waters (Colton et al., 1974, Yamashita and Tanimura, 2007). In the North Atlantic Ocean, the Sea Education Association used Neuston nets towed by a sailing vessel in a standard procedure to produce a 22-year data set (Law et al., 2010). Moore et al. (2001b, 2002) published some of the first reports that demonstrate the use of a manta net in conducting debris trawls. Brown and Cheng (1981) note an advantage of the manta net is the two paravanes that attach to the frame and allow the net mouth to skim the surface of the water. Thompson et al. (2004) determined plastic fragment concentrations in archived samples collected with a continuous plankton recorder.

Variability in the physical construction of nets, towing conditions, and overall technique make it difficult to interpret temporal and spatial trends of floating debris concentrations. These studies demonstrate a large variability in the physical construction of nets used in surface water debris surveys, in terms of aperture, mesh size, and net length. Towing conditions, such as tow speed and trawl length, vary depending on the overall study objective (Section 7.1). Reported mesh sizes have ranged from 150 to 947 µm (NRC 2008) and though studies have not yet targeted floating nano-sized debris particles, it is possible that these could be sampled with various whole-water sampling techniques. Marine debris was investigated in new and archived surface water plankton tow samples from the CalCOFI program (Gilfillan et al. 2009, Doyle et al. 2011), which uses a manta net equipped with a flowmeter and 0.505 mm mesh for 15 minutes at a speed of approximately 1.0-1.5 knots. These methods have been employed in standard plankton tows for decades, and proved effective for sampling debris in surface waters.

We evaluated the methodology from published literature to develop the guidelines presented in this document, which are heavily influenced by the California Cooperative Ocean and Fisheries Investigations (CalCOFI). The surface water debris sampling technique and study design described in this section were tested in a pilot sampling effort conducted in the Chesapeake Bay, as well as in a more rigorous testing of nearshore coastal waters in the Delmarva Peninsula (Versar, Inc. 2012).

3.2 Survey Design

Few studies have repeatedly sampled an area for marine debris using a standardized technique; often measurements are tangential to primary study objectives and debris data are not published. Even when long-term data exist, the patchiness of debris distribution may obscure expected trends (Law et al., 2010).

To test the utility of the surface water guidelines described here, Versar, Inc. developed a nested survey design (Versar, Inc. 2012; see Section 7.3). As discussed in Section 2.4, at the coarsest level, two regions in the coastal mid-Atlantic United States were selected based on land use (urban vs. rural). Within each region, three 1000-m locations (stretches of shoreline) were identified. Adjacent to each location, nine surface water sampling stations were selected and remained fixed for the duration of the study. To avoid tow direction bias, direction of the tow was randomly assigned for each trawl. Surveys were conducted on a bi-weekly basis for a period of six months in accordance with the sampling technique described below. Results of the study indicate that floating macro-debris abundances in urban and rural locations did not differ significantly, but differences among locations and temporal trends were detected using this survey design.

Given the widely variable debris concentrations noted by published reports and during testing by Versar, Inc., it is difficult to provide strict recommendations about survey design. Survey design should consider the following suggestions while tailoring the study to address specific questions about floating marine debris.

3.2.1 Site Selection

The coastal sampling design presented here pursues a regional perspective on floating debris and its relationship to shoreline debris. Additional considerations for offshore sampling include oceanographic conditions; known currents, eddies, convergence patterns, mixing, and seasonal fluctuations therein; known or potential sources of marine debris; shipping lanes; and the bathymetry and geomorphic structures that may influence the generation and eventual fate of floating debris. Groups conducting offshore sampling are strongly encouraged to conduct surveys in conjunction with ongoing marine research and/or water quality assessments.

To provide a statistically robust dataset, selected sites for coastal surface water sampling should be stratified based on appropriate parameters, for example land use (e.g., urban, rural) associated with nearby shorelines, fishing activities, or storm water or sewage outfalls. Random site selection from each stratum (stratified random sampling) is a useful tool to assess temporal and spatial variability while controlling for some of the expected variability and reducing sampling error. In order to compare shoreline and adjacent surface water debris concentrations, shoreline site selection should occur before any surface water site selection takes place.

Additionally, sites should have the following characteristics:

- Direct, seasonal or year-round access, depending on location
- Located within one nautical mile from shore for comparison to shoreline debris loads
- No stationary or transient in-water barriers to ship transect path
- Preferably areas that have not seen recent changes or manmade alterations to hydrographic patterns

These characteristics should be met where possible, but should be analyzed on a case-by-case basis and modified if appropriate for a particular region/location. This technique may be adapted or modified to monitor riverine, coastal, and offshore locations.

3.2.2 Sample Number and Frequency

In addition to standardizing the technique and equipment used, it is equally important to complete enough sampling to account for heterogeneity in debris concentration (e.g., Pichel et al., 2007). Depending on study objectives, detecting significant trends or making regional comparisons may require an infeasible sample size (Ryan et al., 2009, Versar, Inc., 2012). It may be advantageous to conduct surveys initially more frequently to understand the spread of the data and factors affecting variability (MSFD, 2013). To increase confidence in debris concentration estimates, balance spatial distribution of sampling and the number of floating debris transects within a location with the amount of replication required at the shoreline site level (Versar, Inc., 2012).

Once location is determined, at least ten transects are identified, plotted in mapping software, and randomly numbered. Three numbers are selected from a random number table to determine which transects are evaluated on a sampling event. At least three transects should be completed within two nautical miles parallel to the adjacent shoreline site and within one nautical mile perpendicular to the shore (Figure 5). We suggest surveyors pair the surface water sampling frequency with adjacent shoreline assessments. And, where possible, groups are encouraged to conduct surveys in conjunction with ongoing marine research and/or water quality assessments.

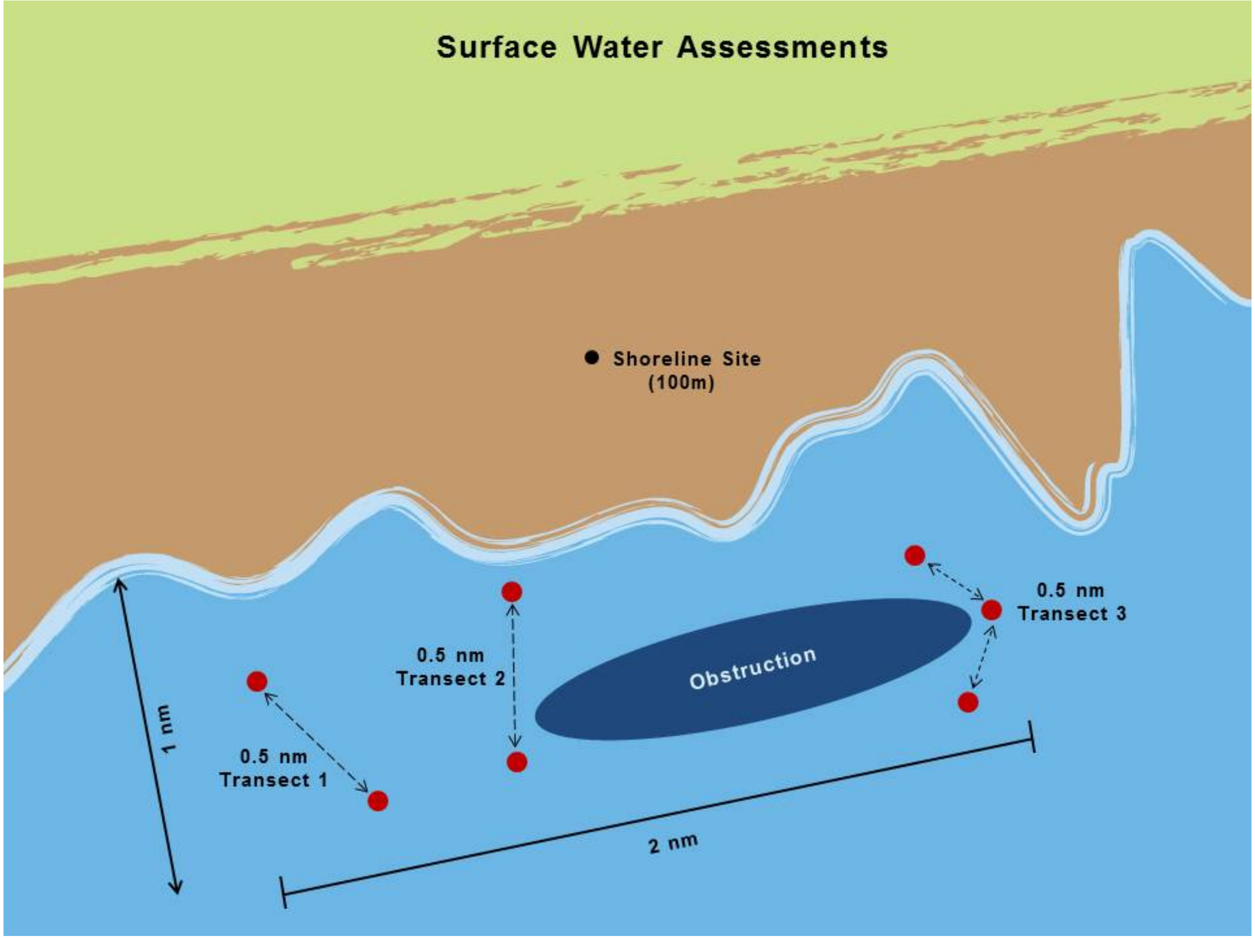

Figure 5. Shoreline and pelagic sampling should be coordinated so that the pelagic trawl transects occur within two nautical miles of the shoreline assessment sites (here, denoted as a single 100 m section of beach). Three trawls, each approximately 0.5 nm, will be conducted at each site. Red circles represent points at which to note GPS coordinates. If obstructions are present, it is necessary to take GPS coordinates whenever the vessel changes heading and not only at the beginning and end of each trawl transect.

3.3 Equipment

The following equipment is suggested to perform surface trawls for floating marine debris:

- Nautical charts
- Digital camera
- Hand-held GPS unit
- Extra batteries (suggest rechargeable batteries)
- Manta net
- Detachable cod end (+ one spare)
- Bridle for manta net
- Weights to attach to frame, if in offshore or choppy waters
- Flowmeter
- Stopwatch

- Squirt bottles
- Plastic buckets with handles (two 5-gallon)
- Stainless steel sieves (5-mm and 0.30-mm mesh)
- Calipers
- First aid kit (including sunscreen, bug spray, drinking water)
- Work gloves for hauling the net
- Latex gloves (or appropriate alternative) for handling the sample
- Stainless steel forceps, 6-inch, angled tip, for picking out larger debris items
- 32-ounce (~1 L) amber glass sample bottles with lids
- Wide-mouth funnel (stainless steel) to fit glass bottles
- Clipboards
- Data sheets (on waterproof paper)
- Waterproof labels for jars, pre-labeled and affixed to jars prior to trawls
- Pencils
- Permanent markers
- White trays, 12-inches square (or equivalent) for sorting debris
- Stainless steel spatula, ~8-inches in length, with tapered and rounded ends for sorting debris
- Sealant to repair net holes
- Bags for large debris items
- Instrument to measure water quality parameters (optional)

3.4 Pre-Survey Site Characterization

Before completing floating debris surveys, shoreline characterization is completed for each 100 m site. See Section 2.0 of this document for the methodology.

For surveys of coastal waters adjacent to shoreline sites, current bathymetric maps should be obtained for the area within two nautical miles of the chosen shoreline site. Several potential sites for trawls are chosen based on ease of access and strata described in the survey design section. It is ideal to complete a survey of the surrounding surface waters before any sampling begins. For studies with concurrent shoreline surveys, any pertinent information on hydrography, bathymetry, and in-water barriers is also described in the "notes" section of the shoreline characterization data sheet.

Select transects prior to arrival at the site. Each data sheet captures ancillary data and data pertaining to a single trawl event. Ancillary data may be recorded before arrival at the site.

Each trawl transect has a unique identification in this suggested format:

Site ID_year-month-day_transect #

An example is [MD-MR_2010-01-07_T1] for a trawl completed in Maryland's Middle River on January 7, 2010 along the first transect (identified as T1 in mapping software).

3.5 Surface Water Trawl Survey Methodology (> 0.30 mm)

3.5.1 Trawling technique

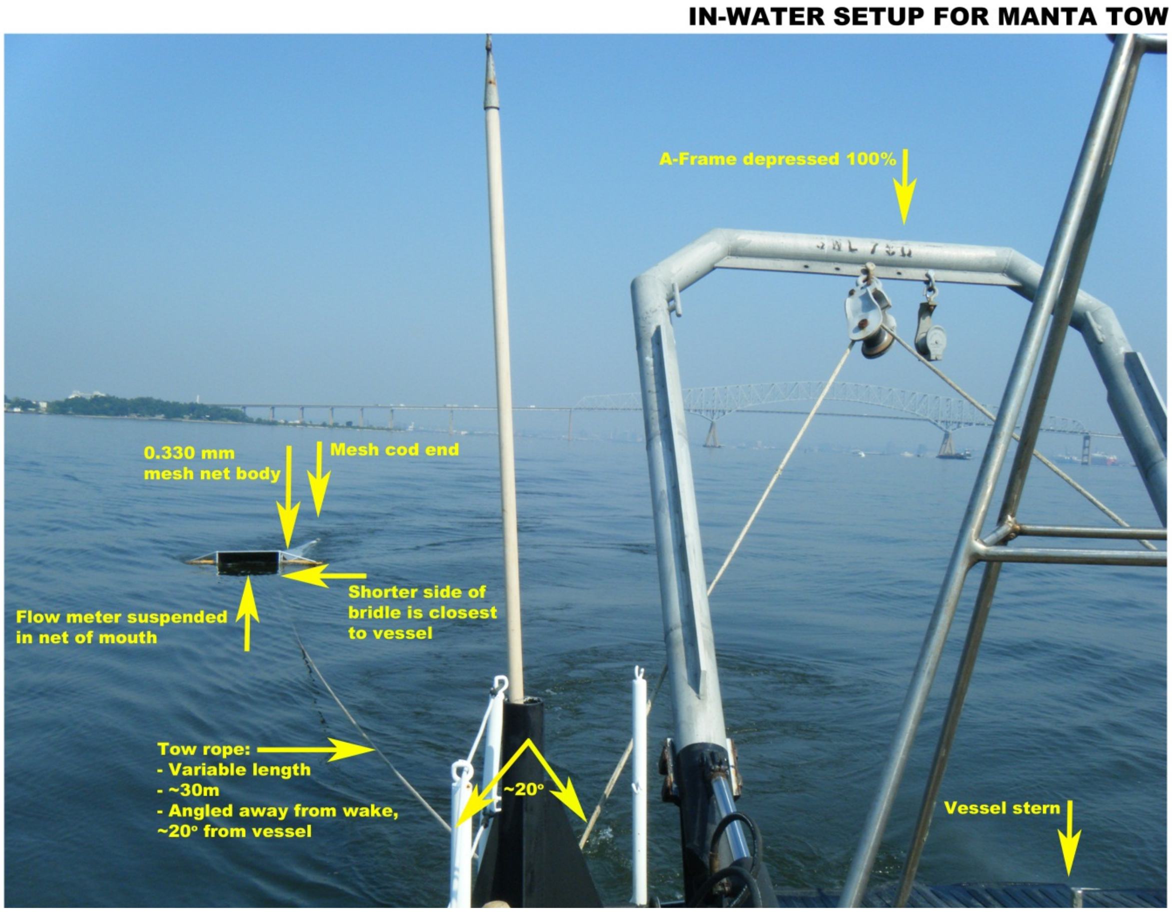

Figure 6. In-water setup for a manta tow. The vessel shown has an A-frame at the stern that is fully depressed, which supports a tow rope that is cleated to achieve and angle of ~20° between the vessel and the net to minimize interaction with the vessel's wake. The shorter side of the bridle should be closer to the vessel to help facilitate avoidance of sampling the wake.

All transects follow the same trawling technique. A manta net, with a body composed of 0.330 mm nylon mesh and measuring approximately 3 m in length, is towed horizontally at the surface (Figure 6). Depending on sea state, weights are added to the bridle to ensure balanced positioning and coverage of the surface waters. Alternately, weights may be added to a tow line that connects the bridle to the winch line. A swivel connects the tow rope to the manta net bridle, which is offset so that one side is slightly longer to encourage a towing angle that samples waters outside of the vessel's wake. A buoy is attached to the net for safety and retrieval purposes.

A digital or analog flowmeter is attached to the net frame and suspended in the center of the net mouth. An initial flowmeter reading is taken prior to deployment of the net apparatus; this reading should not change before placement in the water. The net is deployed from the back or the side of the vessel, with enough slack to allow the net to smoothly skim the surface of the water and avoid the vessel's wake. The side paravanes of the manta net should be on the water's surface. An angle of approximately 20 degrees between the line of the vessel and the net is desirable for minimizing interaction with the vessel wake. The shorter side of the bridle should be closer to the vessel to obtain the required towing angle (Figure 6).

The trawl is deployed for approximately 0.5 nautical miles at a speed of 1-3 knots, an approximately 15 minute duration. When noting the in-water time, include time for deployment and retraction when the net is submerged in the water and the flowmeter is recording volume. During the trawl, vessel speed and tow rope length may be adjusted to ensure the net is properly skimming the surface away from the vessel wake. One person watches the net and notes any large debris items that may be initially funneled into the net mouth. These should be detailed on a large debris data sheet.

GPS coordinates are recorded in degree decimal format at the beginning and ending point of each trawl transect. This can be done with a handheld GPS unit or by marking coordinates of the vessel's transect path in mapping software. If obstructions are present in the area and require alteration of the original transect, GPS coordinates should be recorded when the vessel changes heading (Figure 5).

3.5.2 Sample Processing

The flowmeter reading is recorded as soon as the net is recovered. Contents of the net are gently washed with natural seawater from the outside, into the cod end. If possible, ambient seawater is filtered through a 0.333 mm mesh sieve to remove particles that could bias the sample. The cod end is detached and its entire contents are rinsed with seawater. Digital photos document the process throughout, especially the cod end contents at the end of each trawl.

Samples may be processed on the vessel or transferred to labeled sample jars for laboratory processing. Any obvious large debris items, >30 cm, are counted on a separate large debris data sheet, rinsed to collect any small attached particles, photographed, and then stored in bags or discarded appropriately. Large natural items can be discarded but should be rinsed to collect any small attached particles; items may be recorded on the data sheet and photographed depending on study objectives.

When processing samples on the vessel, the remaining sample from the cod end is rinsed into stacked stainless steel sieves (5 mm and 0.333 mm) to separate debris items into two size fractions, ($x > 5$ mm) and ($5 \text{ mm} > x > 0.333$ mm). Proper rinsing with squirt bottles filled with ambient seawater is essential to collect all natural and anthropogenic particles that may be attached to debris items and natural contents (e.g., floating leaves, woody stems, pine needles, jellyfish). Rinsing is important if samples will be analyzed for microplastic concentration; in that case, the study design may consider using deionized water for rinsing to decrease potential bias. Debris items larger than 5 mm are sorted by material category and tallied on debris data sheets. Macro-debris may then be discarded appropriately or archived depending on study objectives.

The size fraction smaller than 5 mm, composed of micro-debris, is carefully rinsed into glass sample bottles and stored frozen to prevent any sample degradation.

If samples are not processed on the vessel, steps are taken to condense the sample by minimizing rinsing and cataloging any large debris items. Large items are processed as described above and removed from the sample. Trawl contents are rinsed into glass sample jars for sieving in the laboratory, following the sieving technique described above. Samples are processed as soon as possible to avoid the need for initial freezing or chemical preservation.

Analytical methods are available for processing water, sediment, and sand samples to quantify microplastic debris (Baker et al., 2013). When applicable, archiving frozen samples for further analyses is suggested.

3.6 Data analysis

Volume of water filtered during each trawl is calculated based on the flowmeter used. In general, distance is calculated per trawl by subtracting the initial and final readings of the flowmeter and applying a correction factor specific to the flowmeter. Distance is then multiplied by the area of the net mouth to determine a volume of water filtered. The concentration (#items/m^3) of macro-debris items is calculated as follows:

$$C = \frac{n}{V}$$

C = concentration of debris items (# of debris items/m^3)
n = # of debris items observed
V= volume of water filtered (m3) = [(net mouth width) × (net mouth height) × d]
d = distance traveled = (flowmeter final – flowmeter initial) × correction factor

For a given sampling event:

1. Calculate debris concentrations for each individual transect surveyed (a minimum of three per survey) using the equation above
2. Take the mean of the three concentrations to calculate an overall site concentration (with a standard deviation) for that date

3.7 Quality Control

Quality control procedures increase the efficiency, accuracy, and precision of floating debris assessments. Safety and data management plans should be in place before sampling begins. For accuracy in positioning of trawl transects, develop a survey design before sampling begins and use a GIS to label all potential transects. Naming conventions should be standardized for notation on sample labels and data sheets.

Consistently following a standardized procedure is essential. Trawling and processing techniques should be monitored for consistency. During trawling, watch the manta net to ensure that it is properly skimming the water's surface without creating excessive splashing of water in the net mouth that influences water sampling. If the manta net is not skimming properly, vessel speed (or other parameters) should be tweaked to provide appropriate positioning and water flow through the net. Debris counts should be confirmed by two individuals if possible; at least 20% samples should be analyzed separately by two people for quality assurance. Debris samples should be saved for additional testing if material type is not determined. For studies investigating micro-debris, rinsing standards are important and the suggestions listed here may be appended with additional controls such as using deionized or filtered water for rinsing, and conducting all rinsing within a controlled laboratory environment. Sieves and equipment should be thoroughly rinsed between trawl events. All instruments should be calibrated and cleaned regularly. Equipment and rigging should be cleaned and inspected after each sampling event.

3.8 Considerations

Assessing floating debris quantity and composition presents challenges and confounding factors. The recommended technique for floating debris surveys is meant to be robust to slight modifications depending on study objectives, and this has been noted in the text. This section presents additional considerations for employing the floating debris survey technique.

3.8.1 Survey design

As discussed in Section 1.2, debris sources and points of input are often impossible to determine. Several categories have been identified, including (1) larger pieces from land-based runoff or actual release; (2) larger pieces from ocean-based dumping or accidental release; (3) smaller pieces that result from the degradation of larger marine debris in the environment; and (4) small debris, for example, micro- and nano-plastics used in consumer products (e.g., plastic beads used as an exfoliant in soaps) that enter the waste stream from regular use and are likely discharged with wastewater (Fendall and Sewell 2009). Programs that seek to understand the source of debris should heavily consider survey design in terms of both selecting appropriate sites to monitor and adding enough replication to constrain the variability in debris concentrations attributed to environmental conditions.

Local weather, runoff, other potential point sources of debris, and oceanographic conditions will be important to consider in the study design. Where possible, groups are encouraged to conduct surveys in conjunction with ongoing marine research and/or water quality assessments. This may necessitate adjustment to the suggested study design, but more important is standardizing the techniques used to collect and process the floating debris samples, as well as the metrics used to report debris concentrations.

3.8.2 Technique

Note that, as a general rule, faster tow speeds and larger mesh sizes will exclude smaller particles and will bias the sample toward larger particles. The techniques recommended here provide an overview of the amount and type of debris present in surface waters at a given location, but due to operational constraints will not sample the entire water column or obtain all debris. Particles smaller than 0.33 mm (the suggested mesh size) will escape during trawling. Trawl transect lengths may be optimized based on local conditions. For example, during a phytoplankton bloom the mesh may become clogged and will not filter effectively. Techniques that diverge from the standard transect length or standard tow speed are especially encouraged to measure flow volume per trawl, in order to account for varying flow volumes in calculated concentrations.

Depending on study objectives, samples may be processed in a clean laboratory environment with slight changes to sieving technique such as a more thorough washing with deionized water, a more detailed sorting based on additional size classes (e.g., additional sieving through a 1-mm screen), drying the total sample, and weighing debris items. All visible debris items may be measured with calipers.

If study objectives involve correlating debris loads and water quality, parameters such as dissolved oxygen, pH, temperature, etc. should be recorded at the beginning and end of each transect.

3.8.3 Data analysis

The reporting unit is extremely important when making comparison to other comparable studies.

For macro-debris, count (debris pieces) per volume (water filtered) provides an accurate measurement. This is a departure from most historic and present-day conventions, but is commonly used in marine plankton studies, is fairly simple to obtain, and allows for comparison of macro-debris concentrations in other matrices such as sand and sediments. Volumetric measures of surface water debris are useful because debris, especially plastic debris, can be neutrally buoyant and exist at depth in the water column due to wind-driven mixing (Kukulka et al., 2012). In the future, it may be possible to use measurements of floating marine debris to integrate a measurement through the water column; and thus providing an estimate for the amount of water filtered in each trawl would enhance parameterization.

In some cases it may be useful to obtain mass measurements to estimate debris density within a given parcel of water (g/m^3). This measurement is informative for macro-debris, but is especially important for micro-debris particles that may not be easily counted. In addition, density estimates of micro-debris may be compared to density estimates of natural material in a given size class which provides an easily understood ratio of debris to the naturally occurring particles. Density is easily compared to whole water samples, benthic sediment grabs, and plankton abundance measurements that may be obtained in the same study. For very small particles (<1 mm), mass measurements will likely be more accurate than count.

3.8.4 Relevance

Given the high variability in floating debris concentration, it may not be cost-effective to conduct enough sampling to accurately compare locations or regions, or to understand which environmental variables most influence debris concentration (Versar, Inc., 2012). To address this reality and strive for relevance with these techniques, this document stresses the benefits of completing floating marine debris surveys in conjunction with ongoing marine research and/or water quality surveys for increased efficiency in data collection. In addition, these techniques sample both macro- and micro-debris. Particles smaller than 5 mm have been documented in many water samples that did not contain macro-debris. Understanding the factors that affect the size distribution and particle concentration of debris in the ocean is important to advance the state of the science regarding debris movement, distribution, and degradation. These floating debris assessment techniques may be applied to address additional research questions beyond those posed at the beginning of this section.

4.0 AT-SEA VISUAL SURVEY METHODS

4.1 Background

Ship-based visual surveys are a relatively easy, cost-effective method for crowd-sourcing open ocean marine debris sightings (i.e., from vessels of opportunity) and can provide useful information on the types of debris commonly encountered and spatial and temporal variability of floating debris. The accuracy of reports generated from ship-based debris sightings is affected by environmental factors (e.g., weather conditions, sea state) and variation between observers (Ryan et al., 2009) and vessel size and speed (Rees and Pond, 1995). On larger vessels, observers are typically situated higher above the water surface and farther from the bow (e.g., on the bridge), which causes items very close to the bow to go undetected (Thiel et al., 2011). To account for the likelihood of surveyors missing some debris items located on a transect (Ryan 2013) apply a correction factor to measured debris counts based on item size and distance. Line transect sampling methods (where the perpendicular distance to each item is recorded) may reduce bias (Burnham and Anderson, 1984), but is not recommended for novice observers. It is important to recognize that although the majority of debris floating on the ocean surface is from the smaller size fractions (e.g., Law et al., 2010, Doyle et al. 2011, van Cauwenberghe et al., 2013), visual sightings will be skewed toward larger debris items. Further, unlike surface water trawls which will capture debris just beneath the surface (i.e., debris that has been subjected to wind mixing), visual surveys will only account for debris that is visible at the surface. Visual survey data should be interpreted as a low-end estimate of the total concentration of floating debris.

A number of confounding factors must be taken into consideration for accurate comparisons of floating debris concentrations across time and space. Similar to marine debris in other environmental compartments, there is a lot of variability and patchiness in the abundance of floating debris. Large-scale convergence zones (e.g., the North Pacific High Pressure Zone), as well as small and meso-scale circulation features, may concentrate floating debris and create ephemeral debris patches. Areas of concentrated debris (which often also include natural debris) can be difficult to quantify from a moving vessel. One data analysis technique is to pool sightings from very long transects to account for debris patches (e.g., Ryan 2013 used 50 km transect lengths).

Quantitative comparisons of different visual survey efforts noted in the literature are difficult to make due to the differences in reporting units (e.g., #items/km or #items/km^2), minimum debris size (studies have varied from 1.5 – 10 cm (Section 7.1)), and transect width (up to 100 m; e.g., Morris, 1980, Shiomoto and Kameda, 2005). Relative to debris classification systems used for other types of marine debris monitoring, a simplified data sheet should be used for visual surveys as it is difficult to collect detailed and accurate information on debris types from a ship-based observer. Thus, the visual survey data sheet provided in Section 7.5 does not cover the same level of detail as data sheets for shoreline sampling and surface water trawls. Given the uncertainty in detection and patchiness of large debris items, data collected through visual surveys may be most useful for qualitative assessments of the types and relative abundances of floating debris.

4.2 Survey Design

Cheshire et al. (2009) provides methods for setting up a prescribed visual survey pattern in a given area and also for transect sampling. Given the widely variable debris concentrations noted by published reports, it is difficult to provide strict recommendations about survey design. Survey design should consider the suggestions put forth in the surface water trawl technique (Section 3.2), while tailoring the study to address specific questions about floating marine debris. Visual surveys may complement surface water trawl surveys and shoreline surveys. A survey design that includes visual surveys of floating debris conducted in conjunction with other survey types will lead to a more robust data set. Where possible, groups are encouraged to conduct surveys in conjunction with ongoing marine research and/or water quality assessments. This may include vessels of opportunity as well as structured studies that monitor at standard intervals. When vessels of opportunity are used as the platform for visual debris surveys, a structured study design is unlikely. This must be stated when data and results are reported (Ribic et al., 1992).

4.3 Equipment

The following equipment is suggested to perform visual surveys of floating marine debris:

- Clipboard
- Pencil
- Survey forms printed on waterproof paper
- GPS unit
- Binoculars
- Digital camera

4.4 At-Sea Visual Survey Technique

Visual surveys should be conducted along strip transects at least 0.5 nm in length. Ancillary data, including environmental conditions and GPS locations of transect beginning and end points should be recorded on the visual survey form (Section 7.5). Any changes in heading during individual transects should be recorded in the space provided. If possible, two surveyors should conduct surveys from the bow of the vessel, and data from the port and starboard sides can be pooled from two separate data sheets. If only one surveyor is available, the surveyor may want to conduct the survey from the glare-free side of the vessel (Ribic et al., 1992). Each surveyor is responsible for visually scanning the sea surface and recording all debris > 2.5 cm that passes either the port or starboard side of the vessel (Figure 7). MSFD (2013) recommends that visual surveys not be conducted when environmental conditions are such that this minimum debris size cannot be detected, and provides suggested transect widths (ranging from 3 to 15 meters) based on vessel speed and height of the observer above the water (reproduced in Table 2). It is important to note that these suggested transect widths need to undergo further testing, and should be used only as a starting point. Binoculars may be used to verify the identity of items.

Observer height above water	Ship Speed		
	2 knots	6 knots	10 knots
1 m	6 m	4 m	3 m
3 m	8 m	6 m	4 m
6 m	10 m	8 m	6 m
10 m	15 m	10 m	5 m

Table 2. Suggested visual survey transect widths based on observer height above water and ship speed. Adapted from MSFD (2013). Note that these suggestions are preliminary and will be further reviewed by the MSFD.

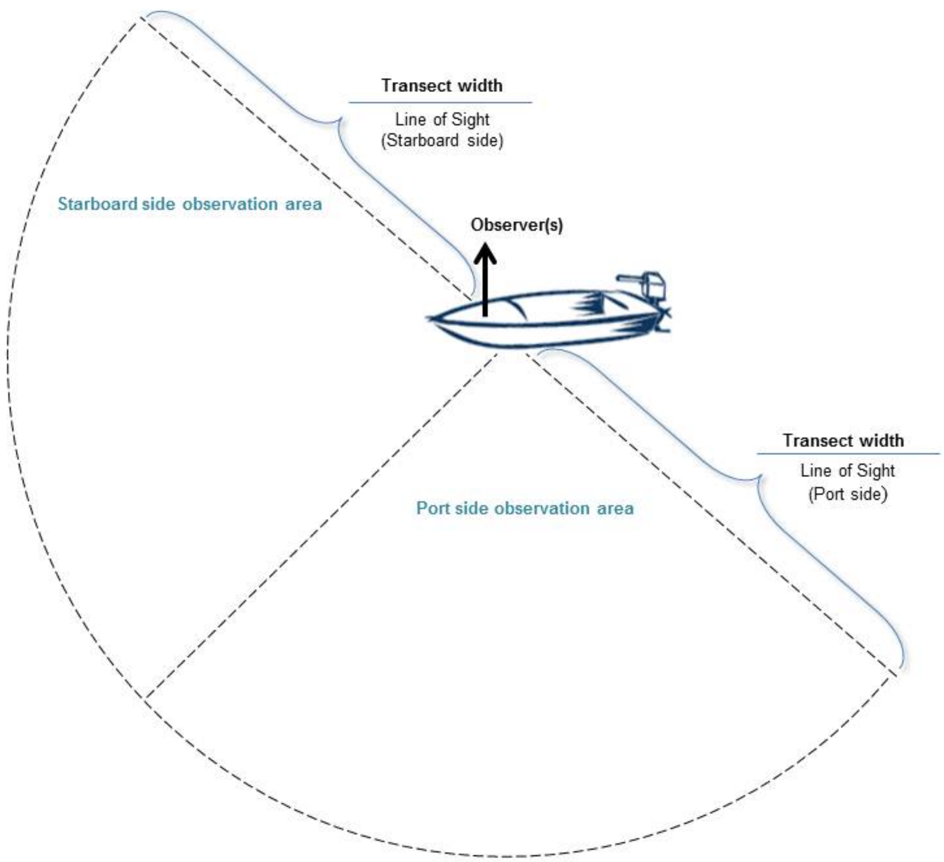

Figure 7. During visual surveys, observers are responsible for visually scanning the sea surface on either the port or starboard side of the vessel, within a defined transect width.

Visual survey data should be reported in terms of # items/km^2, based on the transect width and length (determined from latitude and longitude of transect start and end points). To get an understanding of variability in detection from different observers, quality control surveys should be conducted on 20% of survey transects, by a second visual observer on the same side of the vessel. Quality control surveys should be distributed among different sampling events and include consideration of debris classification and total count.

4.5 Considerations

As discussed above, ship-based debris observations can provide useful information on the abundances and types of debris floating at the sea surface. However, given the patchiness of surface water debris and uncertainty in debris classification during visual surveys, researchers must give careful consideration to survey design and standardization between observers and platforms in order to develop robust estimates of floating debris concentrations.

5.0 BENTHIC METHODS

The information provided in this section is intended to guide development of benthic surveys to ensure that data and results can be integrated with surveys in other environmental compartments. Integration and standardization of survey efforts between shorelines, surface waters, and the benthos is important to understand and model the life cycle and behavior of debris. We suggest that groups interested in developing a benthic survey program follow the guidelines below and refer to more detailed protocols provided by the MSFD (MSFD, 2013).

5.1 Background

Historical methods for detection and survey of benthic debris vary according to vessel capabilities and available equipment, target debris type and size, location, personnel (e.g., availability, skill level, training, technical abilities), and environmental conditions (e.g., depth, water clarity, current strength). Benthic monitoring efforts are often cost-prohibitive and more logistically challenging than some other types of marine debris monitoring (namely, shoreline monitoring), and there is often a lot of spatial variability in benthic debris concentrations. However, the seafloor is recognized as a potentially significant debris sink that should not be ignored.

MSFD (2013) provides suggested methods based on depth, divided between shallow (< 20 m; SCUBA), shelf (up to 800 m; trawls), and deep sea floor environments; the sections that follow provide a general overview of the MSFD (2013) suggested approach. It is recognized that there is no single technique that will work across survey efforts in diverse environments and with different objectives and available resources. The guidelines presented here should be used as a guiding framework during the planning process, during which operation-specific protocols and safety measures will be developed.

Benthic debris items should be catalogued according to the same classification system used for other environmental compartments. That is, debris should be tallied according to the material types and item categories captured on shoreline and surface water data sheets (Section 7.5). Further, to ensure comparability with data collected on shorelines and in surface waters, the focus should be on debris abundance (count and concentration) rather than weight. However, from a management perspective it might be informative and efficient to concurrently collect volume, size, and/or weight estimates. In instances where debris is not collected during surveys, there will be a lower degree of confidence in accurate item classification (e.g., diver or submersible surveys). A list of the benthic marine debris survey literature reviewed is provided in Section 7.1. Side scan sonar is not considered here given that it is only feasible for detection of large debris items, for example derelict crab pots (Stevens et al., 2000; Morison and Murphy, 2009).

Although assessment of micro-debris (< 5 mm) is not a focus of this document, it is worth noting that concurrent sampling of this small size fraction during macro-debris assessment requires the use of sediment grabs or trawls with a fine mesh size (e.g., Cole et al., 2011).

5.2 Survey Design

5.2.1 Site Selection

Survey locations are dependent on accessibility, study objectives, and available resources and equipment. Sensitive habitats or species and underwater hazards should be avoided. This includes sites that may contain unexploded ordinance or have features that may pose an entanglement hazard to divers or gear. Given the patchiness of benthic debris, sampling should focus on areas where debris is suspected to accumulate and may be stratified by factors such as land use, proximity to river mouths, substrate, tourism, fishing pressure, or oceanic current patterns. Bathymetry and hydrodynamics should be considered during site selection as there is growing evidence of their influence on benthic debris accumulations (e.g., Galgani et al. 1996; Keller et al. 2010). Acha et al. (2003) show that salinity fronts associated with river mouths tend to trap debris and may be common accumulation areas.

5.2.2 Sample Frequency

Survey frequency for benthic debris assessments should be determined based on study objectives, available resources, and expected seasonal or annual variability. In the Bay of Biscay (France), Galgani et al (1995a) found a greater abundance and more spatial variability in benthic debris trawls during the winter / early spring compared to other times of the year when debris concentrations were more uniform. The authors suggest that this variation may be due to seasonal changes in coastal currents and water levels. Quarterly or biannual sampling may be appropriate in regions that exhibit less seasonality (e.g., tropical regions with wet / dry seasons) and sampling may be further restricted by weather conditions and accessibility in high latitude areas.

5.3 Shallow Environments (< 20 m)

Based on proximity to source, shallow nearshore regions are more likely to accumulate seafloor debris. In areas where there are strong bottom currents or intense storm activity, debris may be pushed farther out on the continental shelf, accumulate around rocky ledges or outcrops, or be deposited in offshore canyons or other depressions (e.g., Galgani et al., 1996, Bauer et al., 2008, Kendall et al., 2007, Wei et al., 2012, Schlining et al., 2013).

Dive surveys along line or strip transects are often the preferred method for assessment of seafloor debris in shallow or coastal environments. The ability to detect debris is a significant concern during underwater visual surveys, and the dimensions of each sampling unit (e.g., transect length and width) should be based on estimated debris concentration, detectability, and environmental conditions. Diver experience may also affect the degree of detection (Ribic et al., 1992). MSFD (2013) provides a range of transect lengths (20 – 200 m) and widths (4 – 8 m) based on environmental conditions and debris concentration (based on Katsanevakis, 2009; see

Table 3). In order to double the areal coverage of surveys, the UNEP survey technique employs a pair of divers, one on each side of the transect line (Cheshire et al., 2009). Further, MSFD recommends the use of a distance sampling method, where divers record the distance of each debris item from the line so that a degree of detectability can be applied during debris concentration calculations. A minimum debris size must be identified prior to any survey activities. The minimum debris size should be based on study objectives but should not be smaller than the lower limit of detection (Donohue et al., 2001, Timmers and Kistner, 2005); ideally all items > 2.5 cm are detectable. Selecting a smaller minimum debris size cut-off will require more time and resources. Results of dive transect surveys are expressed in terms of #items/m^2.

Debris Density	Environmental Conditions	Sampling Unit (length x width)
0.1 – 1 items / m^2	Low turbidity & high habitat complexity	20 m x 4 m
0.1 – 1 items / m^2	High turbidity	20 m x 4 m
0.01 – 0.1 items / m^2	In every case	100 m x 8 m
< 0.01 items / m^2	In every case	200 m x 8 m

Table 3. Suggested dive survey transect lengths and widths based on environmental conditions and debris concentration. Adapted from MSFD (2013) and Katsanevakis (2009).

To ensure that all of the appropriately sized debris items within a transect are recorded, quality control estimates should be conducted by a second surveyor on 20% of the total number of transects sampled per site over the course of the study. Quality assurance sampling should be distributed among different sampling events and include consideration of debris classification.

Both SCUBA and snorkel free-dive techniques have been used for shallow water benthic debris assessments (e.g., Donohue et al., 2001, Bauer et al., 2008; see Section 7.1). Existing biological monitoring programs that employ diver surveys may provide an opportunity for collaboration. Debris surveys would be more economical and efficient if combined with existing benthic ecology or other monitoring efforts.

For any diving activities or other use of compressed gas as a breathing medium (e.g., surface supplied air), safety is the number one priority and divers must be trained to a level commensurate with the type and conditions of the diving activity being undertaken. Project leads are responsible for understanding all aspects of dive safety regulations and required trainings (e.g., OSHA distinctions between scientific and commercial diving) and must ensure that their organization has the capacity to oversee all planned diving activities (e.g., appropriate insurance, safety policies, etc.).

5.4 Continental Shelves (up to 800 m)

In locations where it is too deep for dive surveys, debris assessments can be combined with ongoing trawl surveys, for example benthic ecology studies or fish stock assessments (e.g., Keller et al., 2010). Although debris loads are likely underestimated with trawls, not all debris is captured and debris may be lost while the net is returned to the vessel; (Spengler and Costa, 2008), trawl surveys can provide an idea of the relative types and abundances of benthic marine debris, which is informative at a local or regional level. It should be noted that trawling activities are largely limited to smooth and flat areas of the seafloor, which are not indicative of typical debris accumulation areas (Galgani et al., 1995a). Ribic et al. (1992) point out that variability in the vessel, crew, net type (including footrope), depth sampled, and weather will affect the accuracy of measurements.

UNEP (Cheshire et al., 2009) provides a benthic trawl survey design. The suggested approach is to select a 5 km by 5 km survey area, create a grid of 25 km^2, randomly select three sub-blocks of 1 km^2, and conduct five parallel trawls of 800 m each within each selected sub-block. Trawls should be separated by at least 200 m and data from all transects should be aggregated to report an overall debris concentration. Trawl equipment should have a fixed mouth width (e.g., otter trawls) such that debris concentrations can be reported in units of #items/km^2 based on the distance trawled.

To ensure that all of the appropriately sized debris items within a sample are recorded, quality control assessments should be conducted by a second individual on 20% of the total number of samples per site over the course of the study. Quality assurance sampling should be distributed among different sampling events and include consideration of debris classification.

It is important to consider the impacts of any trawling activity on benthic ecosystems, and sensitive or protected habitats and species should be avoided. Marine debris trawl surveys are more affordable and less destructive if combined with existing sampling programs. Van Cauwenberghe et al. (2013) applied the UNEP trawl survey design on the Belgian continental shelf and argue that the trawls were an inefficient use of time and resources.

5.5 Deep Sea Floor

There is a paucity of data available on debris in the deep sea, particularly in areas where trawling is not a viable option. Debris is expected to accumulate in relatively calm areas with high sedimentation rates, and studies have shown that debris tends to accumulate near outcrops and in offshore canyons or channels (e.g., Galgani et al., 1996, Kendall et al. 2007, Wei et al., 2012, Schlining et al. 2013). In regions of the seafloor with varying topography (e.g., outcrops, canyons, steep slopes), submersibles are the only viable option for marine debris surveys. Remotely operated vehicles (ROVs) and manned submersibles have previously been used for debris surveys (Section 7.1), but are restrictively expensive in many cases. Detectability is a significant concern for surveys that employ submersibles, and in some cases the vehicle may purposely avoid debris due to entanglement hazards. Further, the color, size, shape, fouling, and degree of burial in sediments will affect detectability (Ribic et al., 1992). In Monterey Bay, CA a 22-year archive of ROV video footage was recently analyzed for marine debris sightings (Schlining et al., 2013). The study added to our understanding of typical accumulation regions but no estimation of debris concentration was provided.

5.6 Considerations

Benthic debris has been shown to inflict negative impacts on marine species and habitats, particularly corals (e.g., Schleyer and Tomalin, 2000, Bauer et al., 2008, Yoshikawa and Asoh, 2004). Thus, it may be worthwhile to identify relationships between bottom communities and marine debris in various environments (Bauer et al., 2008). Benthic debris typically has a very patchy distribution, so surveys may be a necessary first step to prioritize debris cleanup efforts, but considerable effort is required in order to cover large regions of the seafloor (Galgani et al., 1996). As mentioned above, although the benthos is likely a significant sink for marine debris, surveys are often prohibitively expensive and logistically complicated compared to other types of monitoring.

When designing a study, it is important consider and report the lower size limit for detection, which will be based on the equipment used, habitat type, and in some cases water clarity. In addition, information on the depth range over which sampling occurs and total area of seafloor sampled is important (Spengler and Costa, 2008). Regardless of the benthic survey technique employed, #items/unit area is the suggested basic reporting unit.

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This section contains references cited within the main text of this document and in literature review tables (see Section 7.1).

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7.0 APPENDICES

7.1 Literature Review Tables[2]

Shoreline survey literature reviewed:

Citation	Location	General Metrics
Alkalay et al. 2006	Israel	Debris count, concentration
Cauwenberghe et al 2013	Belgian shelf and shoreline	Debris concentration, weight
Edyvane et al. 2004	Anxious Bay, Australia	Debris count, weight, source, and entanglement
Eriksson et al 2012	Two islands south of Australia	Debris concentration/day
Frost & Cullen 1997	New South Wales, Australia	Debris concentration, weight, source
Jambeck et al., 2009	New Hampshire, USA	Debris count, source, entanglement
Kusui & Noda 2003	Sea of Japan (Japan & Russia)	Debris count, weight, and source
Liu et al. 2013	Taiwan - southwest coast	Debris concentration
Moore et al., 2001a	Orange County, California	Debris concentration, weight, source
Morishige et al. 2007	Northwest Hawaiian Islands	Climate/weather, Debris count
Oigman-Pszcsol & Creed 2007	SE Brazil	Debris count, concentration
Rees & Pond 1995	United Kingdom	Debris count, source
Ribic et al 2010	Nationwide USA	Debris count, source, entanglement
Ribic et al 2011	Caribbean and Gulf of Mexico	Debris count, source, entanglement
Ribic et al. 1994	Nationwide	Debris count, source
Rosevelt et al 2013	Monterey Bay, California	Debris concentration
Sheavly 2007	Nationwide USA	Debris count, source, entanglement
Thiel et al., 2013	North-central Chile	Debris concentration

Visual survey literature reviewed:

Citation	Location	Transect width (distance from ship)	Metric
Day et al 1990	North Pacific	50 m	items / km^2
Matsumura and Nasu, 1997	Japan	no limit	items / km^2
Ryan, 2013	Bay of Bengal / Straits of Malacca (Indian Ocean)	50 m	items / km^2
Shiomoto and Kameda, 2005	nearshore Japan	100 m	items / km^2
Thiel et al 2003	SE Pacific (near Chile)	10 m	items / km^2
Thiel et al 2011	German Bight, North Sea	20 - 70 m	items / km^2

[2] These publications were reviewed during development of NOAA survey techniques, and do not necessarily represent an exhaustive literature review.

Surface water trawl literature reviewed:

Citation	**Location**	**Depth Range**	**Method**	**Metrics**
Carpenter et al., 1972	coastal North Atlantic Ocean	surface to unspecified depth	oblique plankton net using 0.33-mesh	$\#/m^3$
Carpenter and Smith, 1972	Sargasso Sea	surface	neuston net tows using 0.33-mm mesh at 2 knots	$\#/km^2$ and g/km^2
Colton et al., 1974	North Atlantic Ocean Caribbean	surface	neuston net tows using 0.947-mm mesh at 5 knots	$\#/km^2$ and g/km^2
Day et al., 1990	North Pacific Ocean, Bering Sea, Japan Sea	surface	ring net or Sameoto net tows with 0.50-mesh	$\#/km^2$ and g/km^2
Day and Shaw, 1987	North Pacific Ocean	paper?		
Doyle et al., 2011	Bering Sea; California Current	surface (10-15 cm) and subsurface (California) to 212 m	Sameoto neuston net tows using 0.505-mm mesh at 1.5-2.0 knots; manta net using 0.505-mm mesh; subsurface cruises used Bongo nets with 0.505-mm mesh	$\#/m^3$ and mg/m^3
Gilfillan et al., 2009	California Current	surface	manta net tows using 0.505-mm mesh at 0.5-0.75 m/s	$\#/m^3$ and mg/m^3
Goldstein et al., 2012	North Pacific Ocean	surface	ovoid and rectangular plankton net tows using 0.505-mm mesh at 2 m/s; manta net tows using 0.333-mm mesh at 0.7-1 m/s	$\#/m^3$ and mg/m^3
Lattin et al., 2004	California Current	surface to 5m	neuston net tows (manta) using 0.333-mm mesh; bongo net tows using 0.333-mm mesh; both at 1.0-2.3 m/s	$\#/m^3$ and g/m^3
Law et al., 2010	North Atlantic Subtropical Gyre	surface	neuston net tows using 0.335-mm mesh at 2 knots	$\#/km^2$
Moore et al., 2001(b)	North Pacific Ocean	surface	manta net tows using 0.33-mesh at 1 m/s	$\#/km^2$
Moore et al., 2002	coastal North Pacific Ocean; California Coastal Current	surface	manta net tows using 0.33-mesh at 1 m/s	$\#/m^3$ and g/m^3
Moret-Ferguson et al., 2010	North Atlantic Ocean	surface	neuston net tows using 0.335-mm mesh at 2 knots	average count (#), size (mm), mass (g), density (g/mL)
Ogi et al., 1999	coastal Japan	surface	neuston net tows using 0.3-1.8 mm mesh at 2 knots	$\#/km^2$ and g
Ryan et al., 2009	review	comprehensive	n/a	n/a
Thompson et al., 2004	North Sea; North Atlantic Ocean	10m	continuous plankton recorder using $127mm^2$ aperture onto 0.280-mm mesh	$\#/m^3$
Yamashita and Tanimura, 2007	North Pacific Ocean; Kuroshio Current	surface	manta net tows using 0.33-mm mesh at 2 knots	$\#/km^2$

Benthic survey literature reviewed:

Citation	Location	Depth Range	Method	Metrics
Donohue et al 2001	Northwestern Hawaiian Islands	> 10 m	snorkel	items / km^2
Bauer et al 2008	Grey's Reef, South Atlantic Bight, USA	16 - 20 m	SCUBA	# items / 100 m^2
Chiappone et al 2004	Florida Keys	< 8 m	SCUBA	# items / 100 m^2
Acha et al 2003	Rio del la Plata, South America	6 - 23 m	trawl	items / km^2
Cauwenberghe et al 2013	Southern North Sea, Belgium	not reported	trawl	items / km^2
Galgani et al 1995a	Seine Bay and Bay of Biscay, France	0 - 100 m	trawl	# items / hectare
Galgani et al 1995b	Northwestern Mediterranean	up to 750 m	trawl	# items / hectare
Galgani et al 1996*	Gulf of Lions, France	100 - 1600 m	trawl	# items / hectare
Galgani et al 2000*	European Seas	at least 2200 m	trawl	# items / hectare
Hess et al 1990	Kodiak Island, AK	not reported	trawl	items / km^2
June 1990	Oregon and Bering Sea	7 - 675 m	trawl	items / km^2
Keller et al 2010	US West Coast	55 - 1280 m	trawl	items / km^2 and kg / km^2
Lee et al 2006	East China Sea and South Sea of Korea	not reported	trawl	kg / km^2
Stefatos et al 1999	Ionian Sea, Greece	not reported	trawl	items / km^2
Wei et al. 2012	Gulf of Mexico	359 - 3724 m	trawl	# items / hectare
Galgani et al 1996*	offshore Marseille and Nice, France	40 - 1448 m	manned submersible	# items / 100 m
Galgani et al 2000*	European Seas	50 - 2700 m	manned submersible	# items / km
Watters et al 2010	Monterey Bay and Southern California	20 - 365 m	manned submersible	# items / 100 m
Schlining et al 2013	Monterey Bay, CA	25 - 3971 m	ROV	# items (normalized debris counts - relative abundance)

* Studies listed twice because they employed more than one survey method.

7.2 Shoreline Survey Advisory Group

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7.3 Versar, Inc. Executive Summary

The text below is the executive summary of the final report compiled by Versar, Inc. (Versar, Inc., 2012) based on comprehensive testing of the shoreline and surface water survey techniques presented in this document. The complete report can be accessed at www.clearinghouse.marinedebris.noaa.gov.

> Developing standardized protocols to quantify marine debris is critical for the protection of natural resources and for evaluating debris removal programs and policies designed to reduce marine debris. The National Oceanic and Atmospheric Administration (NOAA) Marine Debris Division (MDD) developed a suite of sampling protocols to quantify marine debris on coastal shoreline habitats and in nearshore pelagic surface waters. We developed a large scale pilot project to test the ability of the protocols to quantify marine debris, monitor changes in debris density, and assess factors correlated with changes in debris density on short and long-term timescales. The overall goal of the pilot project was to provide feedback to the MDD on the level of sampling effort required to implement the protocols in a larger assessment program. Two sampling regions representing urban and rural land use in the coastal zone of the mid-Atlantic Bight were chosen to conduct the pilot project. Within the urban and rural regions, three locations consisting of three sampling sites each were sampled for marine debris along the shoreline and in the ocean using visual shoreline transect surveys and pelagic net sampling methods designed by the MDD. Each region was sampled bi-weekly from June 27th to December 08th, 2011 for a total of 12 sampling events per region over the 24 week survey.
>
> MDD sampling protocols were successfully employed to sample debris and make estimates of debris densities. Debris was more common in the shoreline compared to the pelagic portion of the survey for each size class of debris. Plastic was the most common form of debris observed. Shoreline macrodebris varied over time and at each level of spatial resolution except for the region level. The urban and rural region had similar debris densities. Differences among shoreline locations were best explained by the sampling event on which the location was sampled, the number of people per site, and the total debris density. Shoreline macrodebris was weakly correlated with densities of people and the week of sampling. Both debris density and the number of people decreased over the course of the survey. Relative standard errors for shoreline macrodebris at the region, location, and site levels indicate that reasonably precise estimates were made (RSE<=30% in most instances). Pelagic macrodebris varied among locations but was similar between regions, among transects, and over time. Pelagic macrodebris was positively correlated with surface water temperature. Differences among pelagic locations were best explained by the sampling event during which the location was sampled and the surface water temperature. Relative standard errors for pelagic macrodebris at each spatial resolution indicate that estimates are imprecise due to high spatial and temporal variability of debris in the water. Sample size analyses indicate that sample size would have to increase exorbitantly to distinguish urban from rural due to the high degree of similarity between regions. Overall we found the sampling protocols employed in this survey are consistent and repeatable and based on our assessment would have the flexibility to serve as a guide for standardized methods for quantifying marine debris in small or large scale marine debris monitoring and assessment surveys. To further enhance these sampling protocols and future surveys we recommend (1) that a critical evaluation be conducted to determine the value of comparing differences in marine debris

between land use types, (2) additional protocol testing be conducted in other shoreline habitat types, (3) readily available GIS and location specific data from U.S. regions be identified and compiled into a comprehensive GIS, and (4) that shoreline sampling continue in the location of the current pilot survey using a stratified random sampling rather than fixed sampling approach.

7.4 Random Number Tables

Transect Selection Random Number Table					
	1	2	3	4	5
1	4	8	17	9	1
2	7	19	2	12	20
3	18	14	6	16	11
4	3	5	15	10	13

Micro-Debris Random Number Table					
	1	2	3	4	5
1	6	2	14	17	19
2	8	10	13	5	9
3	16	18	15	4	7
4	1	3	20	12	11

5m

Each column represents 1m of transect width. Rows represent zones of a shoreline section.

white = above the wrack line (closer to the first barrier)
light gray = at the wrack line
dark gray = below the wrack line (closer to the water)

Transect ID # from start of 100 m shoreline section		
1	0-5m	0-16'4"
2	5-10m	16'4"- 32'9"
3	10-15m	32'9" - 49'2"
4	15-20m	49'2" - 65'7"
5	20-25m	65'7" - 82'
6	25-30m	82' - 98'5"
7	30-35m	98'5" - 114'9"
8	35-40m	114'9" - 131'2"
9	40-45m	131'2" - 147'7"
10	45-50m	147'7" - 164'
11	50-55m	164' - 180'5"
12	55-60m	180'5" - 196'10"
13	60-65m	196'10" - 213'3"
14	65-70m	213'3" - 229'7"
15	70-75m	229'7" - 246'
16	75-80m	246' - 262'5"
17	80-85m	262'5" - 278'10"
18	85-90m	278'5" - 295'3"
19	90-95m	295'3" - 311'8"
20	95-100m	311'8" - 328'1"

7.5 Data sheets

7.5.1 Shoreline data sheets

SHORELINE DEBRIS **Site Characterization Sheet** **Standing-Stock Surveys**	Organization		Name of organization responsible for collecting the data
	Surveyor name		Name of person responsible for filling in this sheet
	Phone number		Phone contact for surveyor
Complete this form **ONCE** for each site location	Date		Date of this survey

SAMPLING AREA

Shoreline name			Name or ID by which this section of shoreline is known (e.g., beach name, park)
State/County			State and county where your site is located
Coordinates at start of shoreline section	Latitude	Longitude	Recorded as XXX.XXXX (decimal degrees) at start of shoreline section (in both corners if width > 6 meters)
Coordinates at end of shoreline section	Latitude	Longitude	Recorded as XXX.XXXX (decimal degrees) at end of shoreline section (in both corners if width > 6 meters)
Photo number/ID			The digital identification number(s) of photos taken of shoreline section

SHORELINE CHARACTERISTICS

Length of sample area (usually 100 m)		Length measured along the midpoint of the shoreline (in meters)
Shoreline slope (°)		Slope above horizontal (between 0 – 90°)
Substratum type		For example, a sandy or gravel beach
Substrate uniformity		Percent coverage of the primary substrate type (%)
Tidal range		Max & min vertical tidal range. Use tide chart (usually in feet).
Tidal distance		Horizontal distance (in meters) from low- to high-tide line. Measure on beach at low and high tides or estimate based on wrack lines.
Back of shoreline		Describe landward limit (e.g., vegetation, rock wall, cliff, dunes, parking lot)
Aspect		Direction you are facing when you look out at the water (e.g., northeast)

LAND-USE CHARACTERISTICS			
Location & major usage	Urban		Select one and indicate major usage (e.g., recreation, boat access, remote)
	Suburban		
	Rural		
Access			Vehicular (you can drive to your site), pedestrian (must walk), isolated (need a boat or plane)
Nearest town			Name of nearest town
Nearest town distance			Distance to nearest town (miles)
Nearest town direction			Direction to nearest town (cardinal direction)
Nearest river name			If applicable, name of nearest river or stream. If blank, assumed to mean no inputs nearby
Nearest river distance			Distance to nearest river/stream (km)
Nearest river direction			Direction to nearest river/stream (cardinal direction from site)
River/creek input to beach	YES	NO	Does nearest river/stream have an outlet within this shoreline section?
Pipe or drain input	YES	NO	Is there a storm drain or channelized outlet within shoreline section?
Notes (including description, landmarks, coastal hydrography, offshore barriers, etc.):			

SHORELINE DEBRIS Survey Data Sheet	Organization			Name of organization responsible for data collection
	Surveyor name			Name of person responsible for filling in this sheet
	Phone number			Phone contact for surveyor
Complete this form during **EACH** transect	Email address			Email contact for surveyor
	Date			Date of this survey
ANCILLARY INFORMATION				
Shoreline name				Name for section of shoreline (e.g., beach name, park)
Transect # and photo ID				Transect # (1-20) and digital photo number of transect
Coordinates of start of shoreline site	Latitude	Longitude		Recorded as XXX.XXXX (decimal degrees). Record in both corners if width > 6 m. If transect, record at water's edge.
Coordinates of end of shoreline site	Latitude	Longitude		Recorded as XXX.XXXX (decimal degrees). Record in both corners if width > 6 m. If transect, record at back of shoreline.
Width of beach				Width of beach at time of survey from water's edge to back of shoreline (meters)
Time start/end	Start	End		Time at the beginning and end of the survey
Time of low tide				Time of the most recent or upcoming low tide.
Season				Spring, summer, fall, winter, tropical wet, etc.
Date of last survey				Date on which the last survey was conducted
Storm activity				Describe significant storm activity within the previous week (date(s), high winds, etc.)
Current weather				Describe weather on sampling day, including wind speed and % cloud coverage
Number of persons				Number of persons conducting the survey
Large items	YES	NO		Did you note large items in the large debris section?
Debris behind back barrier?	YES	NO		Is there debris behind the back barrier of the site (if yes, do not include it in tallies below)
Photo ID #s				The digital identification number(s) of debris photos taken during this transect.

Notes: Evidence of cleanup, sampling issues, etc.

DEBRIS DATA: (continued on back)

ITEM	TALLY (e.g., IIII)			TOTAL
	PLASTIC			
Plastic fragments	Hard	Foamed	Film	
Food wrappers				
Beverage bottles				
Other jugs or containers				
Bottle or container caps				
Cigar tips				
Cigarettes				
Disposable cigarette lighters				
6-pack rings				
Bags				
Plastic rope/small net pieces				
Buoys & floats				
Fishing lures & line				
Cups (including polystyrene/foamed plastic)				
Plastic utensils				
Straws				
Balloons				
Personal care products				
Other:				
	METAL			
Aluminum/tin cans				
Aerosol cans				
Metal fragments				
Other:				
	GLASS			
Beverage bottles				
Jars				
Glass fragments				
Other:				

ITEM	TALLY (e.g., ~~IIII~~)	TOTAL
	RUBBER	
Flip-flops		
Gloves		
Tires		
Rubber fragments		
Other:		
	PROCESSED LUMBER (no natural wood)	
Cardboard cartons		
Paper and cardboard		
Paper bags		
Lumber/building material		
Other:		
	CLOTH/FABRIC	
Clothing & shoes		
Gloves (non-rubber)		
Towels/rags		
Rope/net pieces (non-nylon)		
Fabric pieces		
Other:		
	OTHER/UNCLASSIFIABLE	

LARGE DEBRIS ITEMS (> 1 foot or ~ 0.3 m)

Item type (vessel, net, etc.)	Status (sunken, stranded, buried)	Approximate width (m)	Approximate length (m)	Description / photo ID #

Notes on debris items, description of "Other/unclassifiable" items, etc:

7.5.2 Trawl data sheets

PELAGIC DEBRIS **Trawl Data Sheet**	Organization		Name of organization responsible for data collection
	Surveyor name		Name of person responsible for filling in this sheet
	Phone number		Phone contact for surveyor
Complete this form during **each** trawl	Email address		Email contact for surveyor
	Date		Date of this survey

ANCILLARY INFORMATION				
Body of water, location				Name of the water body and the approximate location of the trawl (sketch map below)
Date of last survey				Date on which the last survey was completed
Current weather	Wind	Cloud cover	Sea state	Describe current weather including wind speed, % cloud cover, sea state
Storm activity				Describe significant storm activity in previous week (e.g., date, high winds)
Number of persons				Number of persons conducting trawl
Latitude/longitude start	Latitude	Longitude		Record as XXX.XXXX at start of the sample transect (decimal degrees)
Latitude/longitude end	Latitude	Longitude		Record as XXX.XXXX at end of the sample transect (decimal degrees)
Time	Start	End		Record as HH:MM. Record when flowmeter starts / stops turning.
Time (adjusted)	Start	End		Any adjustments to the actual trawl time, in seconds, based on eployment/recapture of net.
Flowmeter	Start	End		Flowmeter reading (xxxxxx) before and after trawl
Average ship speed				Record in knots
Photo ID #s				The digital identification number(s) of debris photos taken during this transect.

Map: **Space provided below for sketching a map of the site, including important bathymetric or hydrographic features.**

DEBRIS DATA:

ITEM	TALLY (e.g., ~~IIII~~)			TOTAL
PLASTIC				
Plastic fragments	Hard	Foamed	Film	
Food wrappers				
Beverage bottles				
Other jugs or containers				
Bottle or container caps				
Cigar tips				
Cigarettes				
Disposable cigarette lighters				
6-pack rings				
Bags				
Plastic rope/small net pieces				
Buoys & floats				
Fishing lures & line				
Cups (including polystyrene/ foamed plastic)				
Plastic utensils				
Straws				
Balloons				
Personal care products				
Other:				
METAL				
Aluminum/tin cans				
Aerosol cans				
Metal fragments				
Other:				
GLASS				
Beverage bottles				
Jars				
Glass fragments				
Other:				
RUBBER				
Flip-flops				
Gloves				
Tires				
Rubber fragments				
Other:				
PROCESSED LUMBER (no natural wood)				
Cardboard cartons				
Paper and cardboard				
Paper bags				
Lumber/building material				
Other:				

ITEM	TALLY (e.g., ~~IIII~~)	TOTAL
	CLOTH/FABRIC	
Clothing & shoes		
Gloves (non-rubber)		
Towels/rags		
Rope/net pieces (non-nylon)		
Fabric pieces		
Other:		
	OTHER/UNCLASSIFIABLE	

***LARGE DEBRIS ITEMS* (> 1 foot or ~ 0.3 m)**				
Material type (e.g., plastic)	Item type (e.g., net)	Approximate width (m)	Approximate length (m)	Description / photo ID #

Notes on debris items, description of "Other/unclassifiable" items, etc:

<u>Sea state</u>: BEAUFORT WIND FORCE SCALE: Specifications and equivalent speeds for use at sea

FORCE	EQUIVALENT (miles/hr)	SPEED (knots)	WAVE (m)	DESCRIPTION	
0	0-1	0-1	0	Calm	Sea like a mirror
1	1-3	1-3	.1	Light Air	Ripples with the appearance of scales are formed, but without foam crests.
2	4-7	4-6	.2	Light Breeze	Small wavelets, still short, but more pronounced. Crests have a glassy appearance and do not break.
3	8-12	7-10	.6	Gentle Breeze	Large wavelets. Crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.
4	13-18	11-16	1	Moderate Breeze	Small waves, becoming larger; fairly frequent white horses.
5	19-24	17-21	2	Fresh Breeze	Moderate waves, taking a more pronounced long form; many white horses are formed. Chance of some spray.
6	25-31	22-27	3	Strong Breeze	Large waves begin to form; the white foam crests are more extensive everywhere. Probably some spray.
7	32-38	28-33	4	Near Gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.
8	39-46	34-40	5.5	Gale	Moderately high waves of greater length; edges of crests begin to break into spindrift. The foam is blown in well-marked streaks along the direction of the wind.
9	47-54	41-47	7	Severe Gale	High waves. Dense streaks of foam along the direction of the wind. Crests of waves begin to topple, tumble and roll over. Spray may affect visibility.
10	55-63	48-55	9	Storm	Very high waves with long over-hanging crests. The resulting foam, in great patches, is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes on a white appearance. The 'tumbling' of the sea becomes heavy and shock-like. Visibility affected.
11	64-72	56-63	11.5	Violent Storm	Exceptionally high waves (small and medium-size ships might be for a time lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.
12	73-83	64-71	14+	Hurricane	The air is filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.

PELAGIC DEBRIS **Large Debris Data Sheet**	Organization		Name of organization responsible for collecting the data
	Surveyor Name		Name of person responsible for filling in this sheet
	Phone Number		Phone contact for surveyor
Completed for large items collected OR lost (excluded) from net tows	Date		Date of this survey
	Body of water, location		Name by which the body of water is known

Large Debris Data:

Item Type (vessel, net, etc.)	Status (CAPTURED in net vs. EXCLUDED from net in ship path)	Trawl #	Trawl Latitude (nnn.nnnn N)	Trawl Longitude (nnn.nnnn W)	Approximate Area		Photo ID/#	Description
					Length (ft)	Width (ft)		

7.5.3 Visual survey data sheets

This data sheet is also available on the NOAA website.
http://www.corporateservices.noaa.gov/~noaaforms/eforms/nf75-103.pdf

Shipboard Observation Form for Floating Marine Debris

DIRECTIONS:

1. Determine transect width based on observer height above water and ship speed (see Table)
2. Record ancillary data and start and end lat/long and time.
3. Log debris (> than 2.5 cm) spotted on one side of the vessel (port or starboard) within transect width.

Date: Month/Day/Year	**Vessel Name:**
Observer Name:	**Vessel Speed:**
Height of obs. above water (m):	**Transect width:**

Transect line START: Time (01:00-24:00 UTC): ___________ Heading: ________°

Latitude: _______°____.____' N Longitude: _______°____.____' W

Transect line END: Time (01:00-24:00 UTC): ___________ Heading: ________°

Latitude: _______°____.____' N Longitude: _______°____.____' W

Did your heading change between your start and end time? ☐ YES (Note heading changes below) ☐ NO

Heading change #1: Time of change (01:00-24:00 UTC): ___________ Heading: _____________°

Heading change #2: Time of change (01:00-24:00 UTC): ___________ Heading: _____________°

Heading change #3: Time of change (01:00-24:00 UTC): ___________ Heading: _____________°

Observer height above water	Ship Speed		
	2 knots	6 knots	10 knots
1 m	6 m	4 m	3 m
3 m	8 m	6 m	4 m
6 m	10 m	8 m	6 m
10 m	15 m	10 m	5 m

	Fishing/Boat Gear				Plastics						Glass		Other	Wildlife			SPEED / WEATHER / SEA STATE					NOTES	
Observations from PORT or STARBORD side?	Buoys/ Floats	Misc Line	Misc. Nets	Other Fishing Gear	Plastic Fragment	Bags, Sheeting, Tarp	Bottles (Beverage)	Jugs/ Buckets	Styrofoam	Other Plastic Item	Glass Bottle	Other Glass Item	**Describe* **(e.g., processed lumber)**	Turtles? (Y or N)	Jellyfish? (Y or N)	Seabirds? (Y or N)	Avg wind speed (knots)	Avg boat speed (knots)	Weather (describe)	Cloud cover (% of the overhead sky covered in clouds)	Avg sea state (describe)	**Include info on:** Any disruption, stops, changes in speed, dense patches of debris, etc.	**Did you take any photos?** **File naming:** VesselName_Date_PhotoNumber
P	*I*	*0*	*0*	*0*	*III*	*0*	*I*	*0*	*I*	*0*	*II*	*0*	*--*	*N*	*N*	*N*	*5*	*10*	*sunny/ clear*	*5%*	*calm*	*No stops or disruptions; straight course*	*Y - buoy*

7.6 Marine Debris Survey Photo Manual

NOAA Marine Debris Program

Marine Debris Monitoring and Assessment Project

www.MarineDebris.noaa.gov

Marine Debris Survey Photo Manual

Plastic

Plastic fragments will have a similar texture to their original condition, but may be more deteriorated due to exposure to the environment. Polystyrene (PS) can be hard or foamed, but may change with exposure to the environment. Pieces of plastic film or sheeting can be found shredded into strips.

Hard Plastic:

Foamed Plastic:

Plastic Film:

Plastic Film:

Food wrappers come in a variety of types and sizes. Food packaging can be made of polypropylene (PP), polystyrene (PS), or polyethylene (PE). Food wrappers are distinguished from plastic films by identifiable labels.

Beverage bottles for soft drinks, water, juice, sports drinks, and beer. Made in a variety of sizes (e.g. 6 oz. to 2 L), colors vary (translucent, green, brown, light blue, etc.). Usually made of polyethylene terephthalate (PET or can be made of PETE).

Other jugs/containers include a variety of packaging types ranging from the common milk jug to a food container to an oil lube bottle to cleaner bottle to a 5-gallon bucket. Most are made of polyethylene.

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Bottle & container caps come in various sizes and colors. Caps and closures for beverage bottles are usually made of polypropylene (PP) and high density polyethylene (HDPE) with other container lids being made of low density polyethylene (LDPE) or linear LDPE (LLDPE).

Cigar tips are provided on a few brands of cigars and are considered disposable filters.

Cigarettes/cigarette filters can be hard or fibrous (both are made of a synthetic polymer – cellulose acetate); some cigarettes may not have filters and are composed of only tobacco and paper.

Disposable cigarette lighters have a casing made of a rigid plastic (usually with a metal top). May or may not contain fluids.

Bags (film) used for dry cleaning, newspapers, bread, frozen foods, bulk ice, fresh produce, household garbage, etc. Bags are usually made of HDPE or LDPE

Plastic rope & small net pieces are composed of synthetic material rather than cloth or fabric. Net pieces can be distinguished from rope pieces if knots are present. Plastic rope and net is composed of polypropylene and/or nylon.

www.MarineDebris.noaa.gov

Buoys & floats are usually associated with fishing and boating activities. A buoy floats at the surface and is moored to the bottom. Floats (some are also called bobbers) can 'float' at various depths or rest at the surface. These come in various sizes, shapes and colors. Most mooring buoys are made from HDPE. Rope floats are made of compression molded polyvinyl chloride (PVC). Some floats can be made of rigid polystyrene (PS-foamed plastic).




Fishing line & lures can be found in a variety of forms based on fishing type. Fishing lures come in a variety of shapes, sizes and materials dependent on their function. Modern types are made of plastic with metal hooks and eyes for line. Fishing line types are mostly available in three varieties – monofilament, braided and fluorocarbon. Fishing line is usually made of nylon or PET/PETE, with monofilament being the most popular.






Cups (including polystyrene) are usually made of either PP or foamed plastic / PS. However, some cups have been made of HDPE and PET, with most paper cups being coated with a plastic film.

Straws come in various sizes ranging from shorter ones (~ 4 inches) used in cocktail drinks to a variety of beverage types (~8-10 inches). Straws that are made of paper will deteriorate faster, even if wax-coated. Straws found on the beach or floating on the water will most likely be made of polypropylene (PP).

Balloons (mylar balloons) have a seam and are made of a metal (foil) coated plastic such as polyethylene or nylon.

Personal care products is a very broad plastic debris category. This includes various products including health and beauty aids ranging from deodorants (usually with a roller-ball applicator as most aerosol containers are made of metal) to suntan or body lotion bottles to combs/ brushes to toothbrushes. This debris can be "left" at the beach or is deposited from storm water drainage or washed in from offshore sources. This debris is usually made of polypropylenes and polyethylenes (including HDPE).






Pellets (for use in pelagic and microdebris analysis) Resin pellets are raw plastic material used to produce plastic products. They come in a variety of basic shapes (e.g. round, cylindrical, ovoid), can be translucent or may be in color, but are usually white, black or clear. Once the pellets have been exposed to the environment, their color will change. Most pellets are less than 5 mm in size.




Metal

Aluminum/tin cans are used for beverages (sodas, juice, beer) and food stuffs. Exposure to the environment will cause these containers to deteriorate – aluminum cans become brittle over time and collapse. If dumped at sea, they will most likely sink out before being deposited on the shore. Tin cans can rust when exposed to the environment. These are usually associated with household trash, but larger cans (6 inch diameters or larger) are usually related to ship galley food products.



Aerosol cans have an outer shell of metal (aluminum or steel) and compressed contents. The spray valve will be made of plastic and the cap is also usually plastic. The spray valve and cap will most likely not be attached to the canister.


Metal fragments can vary in size and may be located with a metal detector. Metal pieces that have been exposed to the environment may rust depending upon their material.

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Glass


Beverage bottles are used for sodas, water, liquor, beer, and wine and come in assorted colors (clear, green, brown, blue, and other colors). Most glass beverage bottles have metal caps.



Jars for condiments and other foods can be made of glass. This type of debris is usually associated with household waste (land) or galley waste (ocean). The lids are usually metal. If these are dumped at sea without their lid, they most likely will sink.


Glass fragments care should be taken in collecting this debris. Use gloves and/or use a slotted scooper to remove pieces of glass.

Rubber

Flip-flops/shoes found as debris may consist of the entire article or part of it, such as the bottom of a flip flop or the sole of a shoe. Shoes may be made of leather, canvas or nylon. Boots used for fishing operations and are usually rubber with heavy soles and steel toes.






Gloves are used for numerous water-related activities (both recreationally and commercially). Work gloves used for fishing may be made of natural rubber latex, Nitrile (synthetic rubber compound), neoprene (polychloroprene), polyvinyl alcohol (PVA), polyvinyl chloride (PVC), polyurethane (PUR), or butyl rubber (synthetic). NOTE: In some geographic areas, evidence of sea turtles attempting to feed on discarded gloves can be seen with diamond-shaped bites in the gloves.

Tires can come in various sizes (trucks, cars, trailer, bicycle, recreational vehicles, lawn mower, etc.) and may have the wheel rim still attached (metal), hub cap (metal) covering lug nuts (metal). If an inner tube is found, it will be made of rubber but will be from a much dated vehicle as current styles do not use inner tubes.

Rubber fragments may not feel like "rubber" due to their degradation when exposed to the environment. Due to oxidation, rubber may even feel brittle.

Balloons are traditionally made of a liquid rubber (natural latex). NOTE: Most toy balloons are made of natural latex, but some are made from a synthetic polymer and are therefore considered plastic.

Processed lumber/paper

Cardboard cartons will begin to deteriorate the longer they are exposed to the environment. They absorb moisture and the layers that form the walls will start to fall apart, resulting in the box collapsing. The longer the cardboard carton is exposed, the faster it will deteriorate.

Paper & cardboard will consist of newspapers, magazines and books that may have been left on the beach or have been blown onto the beach or into the water. Card-board might be left behind as packaging for a case of beer cans or allowed to blown onto a beach from a waste bin. Both materials will most likely be deteriorated due to exposure to the environment.

Paper bags may have been left behind by a beach-user or allowed to blow on the beach or into the water. These may be the result of fast food that was consumed near or on the beach. The bags will begin to deteriorate the longer they are exposed to the environment. As bags absorb moisture the paper will fall apart.

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Building material may include a variety of material types depending upon the use and source. Plywood and lumber pieces can float and will be carried to other areas by the wind and waves. Other potential types of building materials could include PVC piping (polyvinyl chloride), rebar (metal) and polystyrene insulation.

Cloth/fabric


Clothing is usually left behind (lost) by beach goers or fishermen. Shorts, tops and often underwear have been collected.

Gloves (non-rubber) made of fabrics are most likely not used on boats or fishing activities.

Towels/rags have various sources based on usage. Towels are usually left behind by beach goers and rags might be used on boats for working with equipment and maintenance (cleaning) activities


Rope/net pieces that are not made of nylon can be identified by a "softer" feel in most cases. Natural rope material can also be tested using the flame of a lighter where the synthetic rope will melt when exposed to the rope fibers, natural fibers will ignite (provided they are relatively dry). Large (very thick) natural ropes are often used as mooring lines for ships when in port.

Fabric pieces are identified when the original object is no longer distinguishable due to deterioration. Fabric pieces usually tear when pulled on.

7.7 Frequently Asked Questions for Shoreline Surveys

Shoreline Survey Frequently Asked Questions

General

Q: Our volunteers cannot make the regularly scheduled survey. How should we reschedule the survey?

Q: How many photos should be taken at each survey?

Q: How do I keep track of the date on which photos were taken?

Q: My GPS is giving me lat/longs in the wrong format, how do I change it to decimal degrees?

Shoreline Characterization

Q: If my shoreline is greater than six meters wide, I need to record GPS coordinates at all four corners of survey site. How do I take GPS coordinates at the water's edge when waves are washing in and out?

Q: How do I determine the tidal distance?

Q: My shoreline site is longer than 100 m. How do I select a 100 m segment?

Q: How do I determine the back of the shoreline?

Survey Protocols

Q: I found an item of debris smaller than 2.5 cm in the longest dimension. Why can't I record it on the data sheet?

Q: I found an item that could become a large item (> 30 cm) if it became unraveled / unwound. How should I record it?

Q: Do surveys always need to be conducted at low tide?

Q: Why do we need to measure beach width at every survey?

Q: How do you record the width of the site if the back of the shoreline is not parallel to the water (e.g., a U-shaped site)?

Q: What should I do if I cannot determine the debris material type?

Q: I found a piece of natural driftwood. Should I record this on the survey sheet?

Q: I found an item that is coated in one material type, and composed of another. How do I record it?

Q: I found multiple pieces of a larger piece of debris. Should I record it as one item or multiple items?

Q: There is debris beyond the first barrier or change in substrate at the back of the shoreline. Can I record those items?

Q: What should I do if I find debris fouled with what might be invasive species?

Q: What should I do if I find a piece of hazardous debris?

Q: What should I do if I find a derelict vessel or other large object that may become a hazard to navigation?

Q: What should I do if I find an item that may be a valuable or significant memento?

Q: I am completing standing-stock surveys. Why do I need to take GPS coordinates of all four transects at every survey?

Q: I am completing standing-stock surveys, and at multiple surveys I have been encountering the same item. Should I tally this item at each survey (assuming it is in one of the random transects)?

Data Entry and Submission

Q: How do I get access to the NOAA MD-MAP database?

Q: How often should I upload data to the NOAA MD-MAP database?

General

Q: Our volunteers cannot make the regularly scheduled survey. How should we reschedule the survey?

A: Surveys should be conducted on a regular, every 28 day schedule. If you need to miss a survey it should be made up within a three day window of the original survey date (i.e., 28 days ± 3 days). That gives you a seven day window for completing the missed survey.

Q: How many photos should be taken at each survey?

A: Taking a photo of the entire site from the beginning and end points at each survey is a good way to visually capture changes in shoreline topography and other characteristics that may affect debris deposition. You may also want to take a photo of each individual transect. In addition, please take photos of interesting, unidentifiable, or fouled debris (organisms growing on or attached to debris).

Q: How do I keep track of the date on which photos were taken?

A: You should download the photos to your computer following each survey. Change the filename of the photos to include a date, location, and photo # (e.g., 06-10-2012_LongBeach#01.jpg). You can also write comments about the photos you've taken in the notes section of the data sheet.

Q: My GPS is giving me lat/longs in the wrong format, how do I change it to decimal degrees?

A: The lat/long units can be usually be changed in the general settings of the GPS. There are also many online tools to convert between units.

Shoreline Characterization

Q: If my shoreline is greater than six meters wide, I need to record GPS coordinates at all four corners of survey site. How do I take GPS coordinates at the water's edge when waves are washing in and out?

A: When you conduct your initial shoreline characterization it is important to arrive at the site at low tide so that you can capture the entire width of the beach. In order to record GPS readings at the water's edge, watch the breaking waves to try to determine the shoreward extent of the water. Record coordinates at that point. If a portion of the shoreline site is underwater at subsequent surveys do not try to enter the water to survey. Only survey the exposed area of the shoreline.

Q: How do I determine the tidal distance?

A: Tidal distance is the horizontal distance on the beach between the average low and high tide lines. Arrive at your site at low tide and measure the distance from the water's edge to the high tide wrack line. This measurement is different from the total width of the shoreline, which is measured from the waters' edge to the back barrier.

Q: My shoreline site is longer than 100 m. How do I select a 100 m segment?

A: Select your 100 m segment based on areas with relatively low public usage, little evidence of debris from day use (picnic debris), and areas that are not immediately adjacent to an obstruction to nearshore circulation (e.g., breakwater, point of land). Also consider landmarks or permanent features to assist in returning to the same segment at future dates. You may want to consider randomly selecting multiple 100 m segments within a larger shoreline site.

Q: How do I determine the back of the shoreline?

A: The back of the shoreline is defined here as the first major change in substrate, which may be a vegetation line, cliff, or other barrier. If you are interested in also monitoring debris that may be pushed back into vegetation behind the beach during storms, that debris should be tallied on a separate data sheet so that it's not included in the calculated debris standing-stocks. Data entered into the NOAA database should only reflect the debris to the first change in substrate. If the back of the shoreline is only a partial barrier, for example a patch of vegetation behind which there is more beach, then survey up to the first continuous barrier (include that vegetation patch and the area behind it). In some cases, shoreline sites may be too complex to clearly delineate a maximum landward limit where debris might be deposited. These types of sites, and shorelines that are very high energy or dominated by sedimentary deposits, may not be good shoreline survey candidates. For the same reason, barrier islands and other shifting substrates are not likely to be ideal survey locations.

Survey Protocols

Q: I found an item of debris smaller than 2.5 cm in the longest dimension. Why can't I record it on the data sheet?
A: The 2.5 cm size cutoff (about the size of a bottle cap) is used as a standard metric because it is the smallest size that can reliably and consistently be detected with the human eye.

Q: I found an item that could become a large item (> 30 cm) if it became unraveled / unwound. How should I record it?
A: Items should be recorded according to how they're found at the time of the survey. For example, if a circular strap or band is found enclosed and is < 30 cm in all dimensions it should be recorded as a regular-sized item, but if it is opened / detached and is longer than 30 cm, it should be recorded as a large item.

Q: Do surveys always need to be conducted at low tide?
A: The NOAA protocols ask for surveys to be conducted at low tide so that the entire area where debris may be deposited is surveyed. However, in some areas where tidal ranges are measured in 10's of meters, it may not be practical to survey at low tide when large mud flats or wave-cut platforms are exposed. If it becomes apparent that the vast majority of debris in the intertidal is ultimately pushed up to the high tide wrack line, surveyors may decide that it is valid to survey at times outside of the suggested window. However, this decision should be made carefully, backed up with data, and revisited on a regular basis.

Q: Why do we need to measure beach width at every survey?
A: Knowing the width of the shoreline allows NOAA to report debris densities in units of # of items per square meter of shoreline. NOAA asks for the shoreline width at each survey in order to evaluate the variability in shoreline width over the course of the project. Ideally, you could note the shoreline width at the average lowest tide of the day (tidal height 0' according to tide tables or graphs), referred to as Mean Lower Low Water (MLLW, more information available at: http://tidesandcurrents.noaa.gov/datum_options.html).

Q: How do you record the width of the site if the back of the shoreline is not parallel to the water (e.g., a U-shaped site)?
A: If the shoreline site is irregularly shaped, you will need to measure the width in a few different places in order to get an accurate estimate of total shoreline area. Please sketch the shape of the site in the data sheet notes section. Break the shoreline into a series of rectangles and measure the length and width of each. This does not need to be done at every survey.

Q: What should I do if I cannot determine the debris material type?
A: If you don't know whether an item is rubber, plastic, metal, etc., record it under "other", provide a description, and take photos.

Q: I found a piece of natural driftwood. Should I record this on the survey sheet?
A: No. Natural woody debris does not fall under the official definition of marine debris. Only processed or treated lumber should be recorded.

Q: I found an item that is coated in one material type, and composed of another. How do I record it?
A: Items should be recorded according to the primary material type on the surface of the item.

Q: I found multiple pieces of a larger piece of debris. Should I record it as one item or multiple items?
A: Record the item in the condition you found it. If the item was broken when you found it, record each piece separately. If it broke while you were examining it, record the debris as one item only.

Q: There is debris beyond the first barrier or change in substrate at the back of the shoreline. Can I record those items?
A: Items located beyond the first barrier can be noted and described in the notes section of the data sheet (or on a separate data sheet), but this data should be compiled separately from the shoreline debris data.

Q: What should I do if I find debris fouled with what might be invasive species?
A: If you suspect that you may have found debris with invasive species, please take clear photos of the item, attached organism, and any identifying marks on the object. Remove the item from the water or shoreline and place on dry land well above the high tide line. You may want to contact local taxonomic experts listed at http://www.anstaskforce.gov/Tsunami.html. In your report note the current location of the item.

Q: What should I do if I find a piece of hazardous debris?
A: If you encounter hazardous items such as oil or chemical drums, contact your local authorities (a 911 call), state environmental health agency, and the National Response Center 1-800-424-8802. Provide as much information as possible so the authorities can determine how to respond.

Q: What should I do if I find a derelict vessel or other large object that may become a hazard to navigation?
A: Contact your local authorities (a 911 call), state environmental health agency, and the U.S. Coast Guard Pacific Area Command at 510-437-3701. Provide as much information as possible so the authorities can determine how to respond.

Q: What should I do if I find an item that may be a valuable or significant memento?
A: If an item has unique identifiers and may be traceable to an individual or group, please take photos and report the item to DisasterDebris@noaa.gov (note that the item was found during a monitoring survey). Use your best judgment to determine what may or may not be valuable.

Q: I am completing standing-stock surveys. Why do I need to take GPS coordinates of all four transects at every survey?
A: Taking GPS coordinates of each transect helps NOAA to track the location of transects and to ensure that the survey site location is not changing over time (due to moving landmarks or shifting

beach dynamics). Additionally, it helps to ensure that site start/end points are located correctly and that equipment is functioning properly.

Q: I am completing standing-stock surveys, and at multiple surveys I have been encountering the same item. Should I tally this item at each survey (assuming it is in one of the random transects)?
A: Yes! This is part of the reason that standing-stock surveys are informative. They provide information on the density of debris on the shoreline and how it changes over time. Debris that remains on the shoreline for long periods of time is part of the "standing-stock." The persistence of the item can be noted in the notes section of the data sheet.

Data Entry and Submission

Q: How do I get access to the NOAA MD-MAP database?
A: Send an email to MD.monitoring@noaa.gov for questions about the database or to request a login.

Q: How often should I upload data to the NOAA MD-MAP database?
A: Please enter data into MD-MAP as soon as possible after each survey to ensure that data is entered accurately.

Penny Pritzker
United States Secretary of Commerce

Dr. Kathryn D. Sullivan
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Dr. Holly A. Bamford
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