Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Marine debris on the shoreline of Monterey Bay National Marine Sanctuary:

An assessment of activities contributing to marine debris, categories and composition, spatial distribution, and predictor variables

Monterey Bay National Marine Sanctuary

Final Report

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Cover photo: A shoreline cleanup event in Monterey Bay National Marine Sanctuary to assess how beach debris contributes to marine debris. Photo: Save Our Shores

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This publication does not represent an endorsement of any product or organization discussed within, but only represents the results, recommendations, and potential solutions for addressing the marine debris problem on the shoreline of Monterey Bay National Marine Sanctuary. Several actions contained herein also reference potential legislative options for addressing the issue of marine debris. These actions are solely options, to be carried out by other organizations interested in addressing marine debris policy, and are not affiliated with NOAA, NOAA's Office of National Marine Sanctuaries, or the NOAA Marine Debris Program.

Executive Summary

Marine debris is a concerning problem as it poses environmental, social, and economic threats to marine ecosystems and shoreline communities globally. Marine debris is more commonly composed of plastic than any other material. Plastic negatively affects marine ecosystems, degrades habitats, and impacts wildlife by entanglement, ingestion, chemical leaching, and toxicity which has caused untold numbers of deaths to seabirds, turtles, marine mammals, and other forms of ocean life. Shoreline communities are impacted by hazardous trash items, loss of tourism, and the challenges of implementing effective strategies to manage litter. California state and local governments spend over 420 million dollars ($420M) annually to clean up and prevent litter from entering the state's rivers and streams and polluting beaches and the ocean. Marine debris in the ocean is escalating exponentially, fueled by worldwide growing plastic production and demand. Tackling this pervasive global problem, will require the coordinated efforts of governments, plastic producers, municipalities, plastic user groups, researchers, and stakeholders, working together to strategize and implement solutions. Monterey Bay National Marine Sanctuary (MBNMS) adopted a Marine Debris Action Plan with an overarching goal to assess and reduce the amount of marine debris in, or entering the sanctuary.

Shorelines are the interface between the land and sea; thus, they represent an important geography for monitoring and assessing marine debris. Globally, approximately 80% of marine debris is transported to the ocean by rivers. From the ocean, marine debris can be washed ashore by wind, currents, waves, upwelling, and tides. Litter can also be directly deposited onto the shoreline by visitors or carried to the beach by winds. Thus, shoreline litter provides insight regarding the types of marine debris likely to be prevalent in the nearby ocean environment. Because shorelines are accessible, carry high debris loads, and are easier to study than marine debris found in the ocean and on the seafloor, beach litter surveys can provide a large and robust dataset for understanding predominant types of marine debris in a region. Furthermore, analyzing the distribution and density of marine debris on beaches, transport mechanisms, and sources of marine debris can inform and provide direction to preventative and corrective management measures.

This study analyzed data collected by five citizen science programs along the entire 276 miles (444 kilometers) of MBNMS shoreline over a five-year period from January 1, 2017 to December 31, 2021, providing a total of 4,725 survey points collected by more than 37,000 volunteers. Through developing harmonizing categories for marine debris and interpreting this large collective dataset, we identified three primary human activities that contributed nearly 95% of marine debris: Eating and Drinking, Smoking, and Various Activities. Various Activities refers to items not attributed to a specific activity because items collected were small fragments or could have originated from multiple activities, as in the case of packaging. Four additional activities contributed a smaller amount to marine debris: Personal Hygiene, Recreation, Dumping and Disaster, and Fishing. These four activities collectively contributed only 5% of the tallied marine debris items. Within each activity, several trash categories were identified.

Specific trash categories that contributed to the majority of marine debris by count (59%) were plastic fragments, cigarette butts, and wrappers. Efforts to reduce the amount of marine debris should be targeted at activities making the largest contribution to the problem, hence Eating and Drinking and Smoking. The high percentage of debris attributed to Various Activities (42.5%) indicates that efforts to reduce general marine debris are also important. General debris includes all items made from plastic such as plastic bottles, caps, cups, packaging, and wrappers. Because plastic breaks apart into smaller and smaller fragments that are harder to collect, but do not decompose, containment and careful disposal of plastic products as well as reducing plastic use are keys to reducing marine debris.

Hotspots for marine debris were identified by dividing MBNMS shoreline into 28 segments of equal length and summing debris counts for each. The number of debris items collected over the 5-year period in monitored segments ranged from 70 to 310,837 total items, and the items collected per cleanup event ranged from 53 to 473. The number of cleanups varied by segments. Some remote segments along the Big Sur Coast were never visited while 775 cleanups occurred in a popular beach segment in Santa Cruz. This Santa Cruz segment had the highest number of total items collected and a high number of items per event, along the shoreline from Natural Bridges to Hooper Beach including the Main Beach and Cowell Beach. Two other segments ranked as high to medium high for numbers of items collected and number of items per event: one segment in northern Santa Cruz County between Waddell Creek and Bonny Doon Beach and a second segment from Manresa State Beach in Santa Cruz County to Moss Landing in Monterey County. We suggest groups or individuals collecting marine debris intensify efforts in areas where a high number of items were collected per event as shown in maps in this report. Additionally, we hope municipalities or agencies managing parts of hotspot segments review policies, practices, and enforcement efforts for marine debris.

We compared marine debris density and the material composition of debris items along MBNMS shoreline with other regions of the globe. MBNMS average linear marine debris density was 2,150 items/km, relatively low on the world scale where density ranged from 0 to as high as 10,700 items/km. Material composition of MBNMS debris items was 72.7% plastic, 7.8% paper, 5% glass, 4.5% metal, 0.5% cloth, and 9.6% mixed materials. Plastic represents a large part of the debris load on beaches across the globe, up to 93% in some cases.

A specific type of plastic that is internationally problematic is cigarette butts, which are toxic to many organisms if swallowed; and, also leach toxic chemicals that can harm marine organisms. Cigarette butts made up nearly a quarter (23.1 %) of the debris load on MBNMS beaches. Disposal of cigarette butts in the environment is a pervasive and distressing problem across the globe. International Coastal Cleanup Day consistently reports cigarette butts as the most collected trash item from 2010 to 2020. The National Cancer Institute has found smokers do not benefit from the addition of acetate filters (cigarette butts) to cigarettes, finding cancer rates on par with users of cigarettes without filters. Our analysis found a decrease in the number of cigarette butts on California State Park beaches, following a ban on smoking imposed in October 2019. These results warrant further study of the effectiveness of smoking bans for reducing cigarette butt debris. Smoking bans coupled with educational campaigns to inform smokers of the serious harm of cigarette butts to marine organisms and to the ocean environment might reduce the number of cigarette butts on beaches and alleviate the harms caused by this toxic pollutant.

Using statistics to understand the sources and transport mechanisms for marine debris, we were able to determine that beach cleanups have an enormous impact on reducing trash on beaches. We also found that the proximity to river mouths, offshore wind and currents, the angle of intersection of the nearshore current with the beach, beach substrate (sandy or rocky), and percent of shoreline within a California State Park, all made a difference in the quantity of marine debris collected in specific shoreline segments.

Given the seriousness of the harm to marine life from plastic pollution and the projected escalation in plastic production, the dilemma of how to reduce plastic use and plastic trash deserves attention and decisive preventative actions from all sectors of society to prevent plastic from entering the ocean. California state and local policies have been adopted and enacted to replace or ban items of concern, such as single-use plastic bags, food-ware, straws, and cigarettes. Additional legislation (CA SB-54) is in process toward California's goal of recycling all single-use packaging and single-use food-ware products. As plastic users, all of us can contribute significantly to diminishing plastic waste that escapes to the environment through conscientiously managing the plastic we use and ensuring it is properly contained and disposed of, and by seeking ways to reduce, reuse, recycle, refuse, and replace plastic products. Joining beach cleanups and collecting marine debris data are important ways each of us can help understand and alleviate the growing marine debris problem.

Figure 1: How debris ends up on MBNMS beaches: (1) human action, including beach goers and commercial fishing; (2) waterways, including rivers and storm drain outfall pipes that discharges onto beaches; and (3) currents, including the direction of nearshore currents in MBNMS, seasonal currents on the West Coast (Davidson Current), and global currents and upwelling. Photos top row (left to right): Steve Lonhart/NOAA, Pam Krone/NOAA; middle row: Pam Krone/NOAA; Images bottom row: John Ryan/MBARI

Section 1: Introduction

The accumulation of trash on beaches and in the ocean across the globe, also called marine debris, creates economic, environmental, and social threats to marine ecosystems and shoreline communities. California state and local governments spend over 520 million dollars ($520M) annually to clean up and prevent litter from entering the state's rivers and streams and polluting beaches and the ocean (Stickel et al., 2012). NOAA's Monterey Bay National Marine Sanctuary (MBNMS) is motivated to reduce these threats and has developed a Marine Debris Action Plan with an overarching goal to assess and reduce the amount of marine debris in or entering MBNMS, as referenced in the 2021 Management Plan.

Marine debris is anthropogenically (human-sourced) and can include trash on beaches, microplastics in the ocean, floating plastic on the ocean's surface, ghost nets, and other humanmade objects. Marine debris encompasses items made from glass, plastic, cloth, metal, and paper/wood. However, marine debris does not include natural debris such as kelp, carcasses, and tree trunks. In this report, we use the terms marine debris, debris, litter, and trash interchangeably with no intended difference in meaning. We occasionally use the term shoreline debris to specifically denote marine debris occurring on the shoreline.

Marine debris ends up on the shoreline from land-based, shore-based, and ocean-based human activities. Debris is transported by people as they come to the beach to eat, play, fish, or engage in other shoreline activities. Debris from land-based activities is carried to the shore by natural forces such as wind or water flowing from rivers or storm drains. Marine debris from fishing or boating activities in the ocean can be transported to the shore by the action of ocean upwelling, tides, waves, and currents.

Depending on the local dynamics of marine debris transport, shorelines can be sources or sinks for marine debris. Most macroplastic (>5mm) entering the ocean from river mouths strands close to coastal entry points, with model simulations estimating that 65–75% of buoyant floating plastic material ends up on the beach (Onink, 2021). Thus, trash from land-based activities can be deposited into the ocean from rivers and then transported onto the beach from the ocean. The shoreline acts as a kind of net, reducing the amount of marine debris in the ocean, hence making beaches a sink for marine debris (Dubec et al., 2015; Onink, 2021). In other cases, trash left on the beach by beachgoers can be carried into the ocean, making the beach a source of marine debris entering the ocean (Tourinho and Fillman, 2011; Munari et al., 2018; Brabo et al., 2022). Local beach geography and dynamics in addition to human intervention by beachgoers and cleanup activities play an important role in the balance of inputs to outputs.

Once in the ocean, plastic marine debris is nearly impossible to collect and results in negative biological and ecological consequences, many of which are not currently well understood. Plastic marine debris is commonly misidentified and inadvertently eaten as food by fish, birds, turtles, and other marine inhabitants, resulting in malnourishment or gut blockage, physical entanglement, toxicity, and accumulation up the food web (Bergmann et al., 2015; Roman et al., 2020). Entanglement in debris and consumption has caused untold numbers of deaths in marine mammals, sea turtles, pelagic birds, fish, whales, and other ocean creatures (Wilcox et al., 2018; Thiel et al., 2018; Alexiadou et al., 2019; Roman et al., 2019; Horn et al., 2020; Roman et al., 2020; Senko, 2020; NASEM, 2022; Eisfeld-Pierantonio et al., 2022; Oldach et al., 2022).

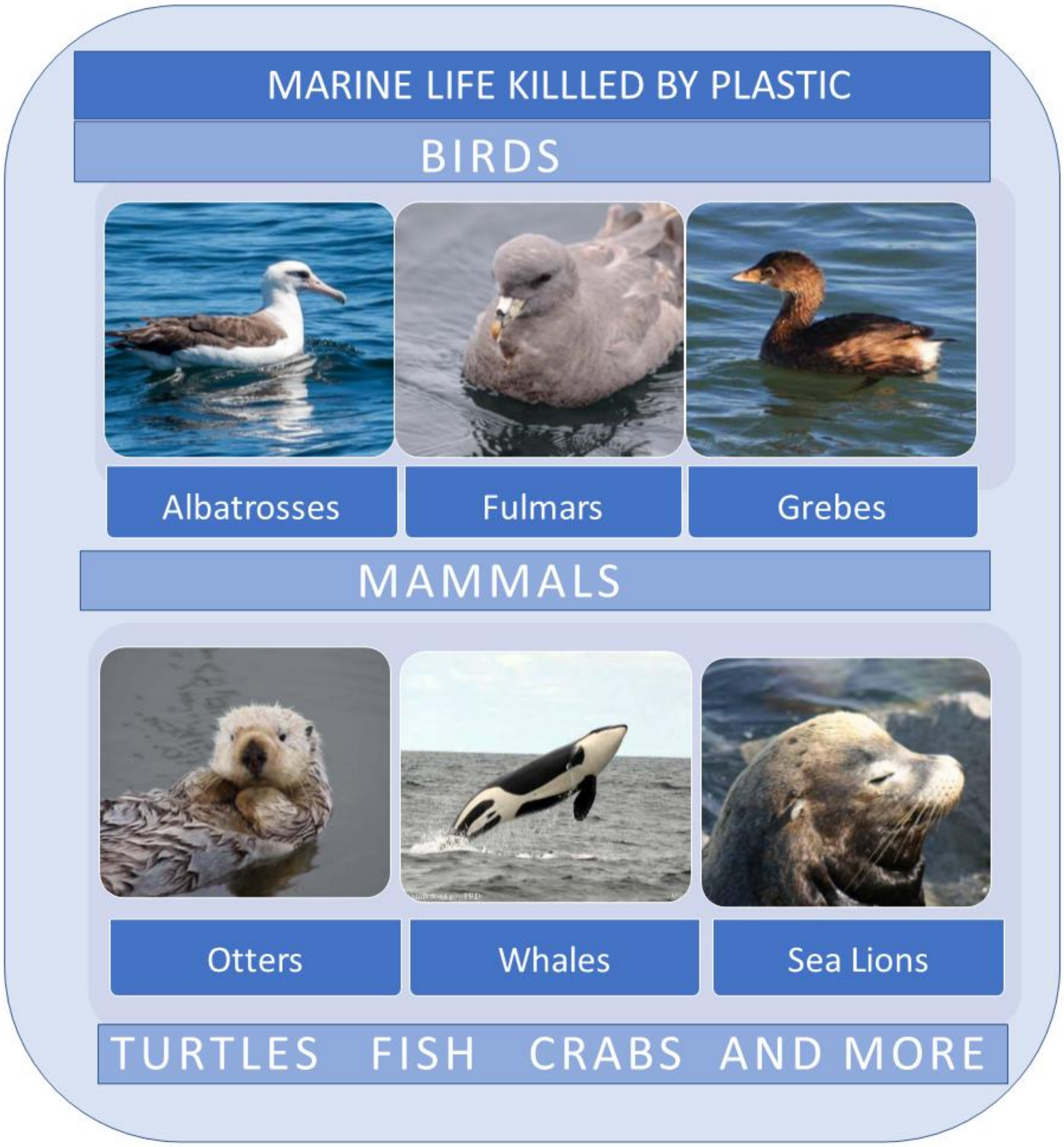

Figure 2: Examples of marine life injured or killed by plastic. Photos top row (left to right): Douglas Croft, Sophie Webb, Steve Lonhart/NOAA; bottom row (left to right): Steve Lonhart/NOAA, Michael Richlen/NOAA, Josh Pederson/NOAA

Because beaches serve as a collection point for marine debris, beach cleanups are a key mitigation strategy for removing debris before it can enter or reenter the ocean and cause further degradation and harm. Beach cleanups, when data is simultaneously collected, also build understanding of shoreline debris type and abundance, which is essential for understanding the marine debris issues that need to be addressed and for assessing whether conditions have improved subsequent to new policies or changes in management (Hutto and Belote, 2013). Shorelines are the most robust environment for studying marine debris due to their ease of access and greater number of observations that are possible when compared with ocean surveys (GESAMP, 2019).

Burgeoning interest in marine debris is leading to increasing research of the amount and distribution of debris on beaches, the sources and causes, transport to marine systems, and ecosystem effects, as well as strategies for prevention. Most scientists agree that the problem is generally worsening rather than improving (UNEP, 2021). The growing demand for plastic has led to a boom in production, increasing exponentially from 2 million tonnes in 1950 to 460 million tonnes in 2019 (Geyer et al., 2017). Unfortunately, increased production has resulted in an exponential increase of marine debris, as preventative measures have been inadequate. In 2019, an estimated 1.7 million tonnes of plastic leaked into the global ocean, adding to the estimated 30 million tonnes already present (OECD, 2022). The plastic pollution problem has been exacerbated by increasing amounts of plastic manufactured each year, lack of proper disposal or other end of life solutions, lack of education and social change needed to correct the problem, and insufficient social will to make producers fully responsible for the entire life cycle of the plastic in products they produce (Eriksen et al., 2014; UNEP, 2021; Rangel-Buitrago et al., 2022; NASEM 2022). Careful management of trash to prevent accidental escape, stewardship of plastic products including end of life solutions and strategies to reduce plastic waste at all stages of intervention have been proposed as means to provide relief from this escalating environmental catastrophe (NASEM, 2022; OECD, 2022).

Monterey Bay National Marine Sanctuary (MBNMS or sanctuary) staff is concerned with trash on beaches because of the possibility of transport to the ocean from wind, tides, and waves, in addition to the degraded state and appearance of beaches with trash. Within MBNMS, marine debris has been found in the deep trench off the coast of Monterey Bay (Schlining et al., 2013); trapped in geologic formations such as ledges and canyons (Corcoran, 2015); in the rocky intertidal areas (Weber et al., 2019); as macroplastic and microplastic particles and throughout the water column from the surface to the deep ocean strata at 1000 meters (Kashiwabara et al., 2021; Choy et al., 2019); and on beaches (Roosevelt et al., 2013).

In this report, we concern ourselves with a small part of the overall issue, specifically with marine debris collected and counted on the shoreline of MBNMS, the relationship of marine debris to human activities, and recommendations for local control and management of debris that is found on beaches. In our analysis, we utilized data collected by citizen scientists as well as research data collected for more formal analysis. We included the most recent five years of data: 2017 through 2021. Our objective was to address the following questions:

1. What beach activities and categories of trash represent the most prevalent trash problem on MBNMS shorelines?
2. What are the geographic hotspots, where trash density and accumulation are greater? Are these related to particular activities that vary by geography?
3. What are the predictor variables that influence marine debris density on the shoreline?
4. What strategies could be used to reduce the amount of debris on beaches?

1.1 Monterey Bay National Marine Sanctuary and its Shoreline

Monterey Bay National Marine Sanctuary (MBNMS) shoreline was the location of this study. It extends from Rocky Point in Marin County to Abalone Cove in San Luis Obispo County, with the exception of the San Francisco-Pacifica Exclusion Area. MBNMS has a coastline length of 276 miles (444 km), includes

6,094 square statute miles of ocean, and extends an average of 30 miles from the shore. The diversity of marine life is extraordinary, including 36 species of marine mammals, 180 species of sea birds and shore birds, 525 species of fishes and a variety of marine biota. Recreational activities are encouraged in the sanctuary and include boating, paddling, sailing, scuba, tide pooling, wildlife viewing, and beach activities (NOAA, 2012). Industrial and commercial uses of MBNMS include fishing, aquaculture, military activities, shipping, deployment of underwater cables, and mineral extraction (NOAA, 2012). MBNMS is important ecologically for ecosystems that support the rich diversity of sea life, and economically for industrial, tourism, and commercial fisheries benefits. For preservation purposes, activities that could harm the health of the marine ecosystem such as drilling, ocean dumping, or seabed mining are prohibited. Marine debris is a concern for MBNMS due to the impacts on the marine environment and sanctuary resources.

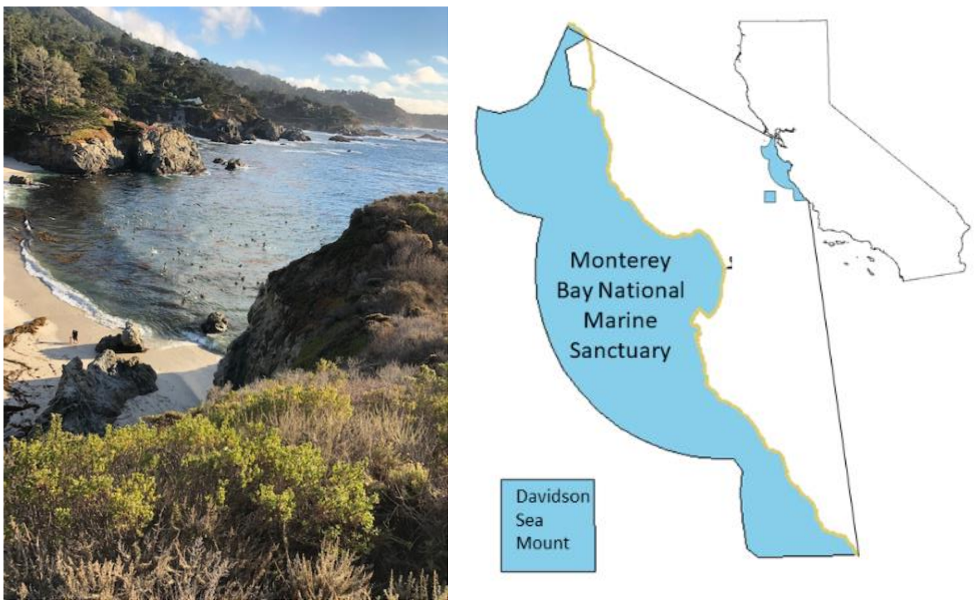

Figure 3: A view of the sanctuary coastline and an illustration of Monterey Bay National Marine Sanctuary boundary, including the Davidson Seamount Management Zone. Photo: Pam Krone/NOAA

The mission of MBNMS is to understand and protect the coastal ecosystem and cultural resources of MBNMS through education, monitoring, resource protection, and research. MBNMS shoreline is a valuable resource to the many individuals who enjoy the beautiful beaches and spectacular marine life as well as those organizations who benefit from the productive marine environment. Resource protection in MBNMS includes protecting natural resources to reduce detrimental human impacts to sanctuary resources and preserve its treasures now and for future generations.

1.2 NOAA’s Marine Debris Program

In 2006, Congress authorized the NOAA Marine Debris Program (MDP) as the U.S. federal government’s lead for addressing marine debris. The MDP achieves its mission through six main pillars: Prevention, Removal, Research, Monitoring and Detection, Response, and Coordination. MDP staff are positioned across the country in order to support projects and partnerships with state and local agencies, tribes, non-governmental organizations, academia, and industry. The MDP envisions the global ocean and its coasts free from the impacts of marine debris and its mission is to investigate and prevent the adverse impacts of marine debris. Both MBNMS and MDP fall under the authority of the US Department of Commerce, National Oceanic Atmospheric Administration (NOAA), and the National Ocean Service (NOS).

Section 2: Data Sets Used for Assessment of Marine Debris

Professional and citizen science debris data collection programs exist to assist researchers, non-profit organizations, and other stakeholders in better understanding the extent, distribution, origin, and types of marine debris found on beaches. Many of these programs are also leaders in public education regarding marine debris issues and solutions, and some also advocate for legislative changes or local actions that can be taken to lessen marine debris. Examples include the Save Our Shores program providing posters for public education and the Surfrider Foundation advocating for plastic bag bans in many cities. Some debris cleanup and data collection programs are designed by non-profit organizations coordinating beach cleanups using citizen scientists to collect and tabulate debris data. Marine debris apps allow individuals to collect and contribute debris data while engaging in self-directed beach cleanups. In some cases, data cards or checklists are still used by organizations when organizing beach cleanups for trash data collection. Other debris data programs require registration to enroll in the program and are more oriented toward marine debris researchers that study the accumulation or distribution of debris, such as the NOAA Marine Debris Program. These programs generally require more precise location and area information as well as offering some flexibility in the categories of data collected. Although often less precise in terms of area covered and effort expended, citizen science programs, using volunteer time, can collect a much larger amount of data in terms of spatial extent, number of events, and frequency of beach cleanups. In our analysis, we made use of data from both types of programs, from non-profit organization data collected by citizen scientists as well as research data collected for more formal analysis.

We settled on five data sets that were the most representative geographically for MBNMS shoreline and had the highest number of cleanup events where data was recorded. Additional information on the data sources, selection, cleanup, and harmonization processes are available in Appendix A.

NOAA Marine Debris Monitoring and Assessment Project:
NOAA Marine Debris Monitoring and Assessment Project (MDMAP) is a monitoring program of the NOAA Marine Debris Program. The MDMAP website provides a means to query marine debris data collected within countries, states, data collection organizations, or named beaches. Three different survey modes are included in MDMAP: standing stock data, accumulation data (2.5 to 30 cm), and accumulation data (>30 cm).

Debris Tracker:
Debris Tracker is an app designed to help citizen scientists contribute data on debris while doing cleanups at any location globally: inland, beaches, and ocean based. Debris Tracker, designed by the University of Georgia, allows for customization of data collected including debris items. It also allows for opting into data options such as number of people, duration, land use, and area covered, among others.

Trash Information and Data for Education and Solutions (TIDES):
TIDES is an online, open-access database hosted by Ocean Conservancy, containing the world's largest ocean trash dataset collected by volunteer cleanups. The app used for data collection is Clean Swell.

Save Our Shores:
For over 45 years, Save Our Shores (SOS) has been engaging community members in beach, inland, and river cleanups to remove harmful debris from the Monterey Bay Region in California. SOS hosts hundreds of events throughout the year and is also a regional coordinator for the Ocean Conservancy's International Coastal Cleanup Day (coordinated in California by the California Coastal Commission).

Surfrider Foundation:
Surfrider Foundation has a national network of chapters that convene beach cleanups in U.S. coastal state and engages in other activities to preserve beach access and protect the ocean.

We used as much data as possible to create a more comprehensive understanding of marine debris on MBNMS's coastline (Table 1).

Data Set	Start Date (all include 2021)	Number of Categories	Trash Weight	# People	Dimensions	Duration	Beach Name	lat & long
MDMAP: 2.5-30 cm	6/12/2012	48	NI	100%	length and width	100%	yes	yes
Save Our Shores	2/2/2008	75	77%	85%	31% (est. length)	79%	yes	NI
Debris Tracker	10/1/2014	53	NI	NI	0%	0%	0%	yes
TIDES	6/26/2015	50	100%	100%	distance	NI	NI	yes
Surfrider	1/9/2016	81	96%	96%	24%	45%	yes	yes

Table 1: Data sets used in this analysis are different in many ways (NI=Not Included).

Figure 4: Coastal cliffs and private land make some areas along the Big Sur shoreline inaccessible. Photo: Josh Pederson/NOAA

2.1 Data Source Geographic Scope

The geographic scope and distribution differed between datasets in terms of extent and number of events (Figure 5). All data sets analysis included cleanups along the northern shorelines of MBNMS, with Debris Tracker, TIDES, and Surfrider including further north to Marin County. TIDES data included the most cleanup events across the most dispersed geographic locations, including cleanups along the Big Sur Coast (Kasler Point, Plaskett Rock, Jade Cove, Sand Dollar Beach, Cape San Martin) and south to San Simeon (Point Piedras Blancas, San Simeon State Beach, Moonstone Beach, Abalone Cove). Save Our Shores (SOS) efforts were concentrated in the Monterey Bay area, extending south to include one event at Andrew Molera State Park in Big Sur, and six events north at Año Nuevo State Reserve. A large extent of Big Sur coastline between Point Lobos State Park and San Simeon had poor or no coverage as many of the beaches are inaccessible due to rocky cliffs as well as restrictions by landowners.

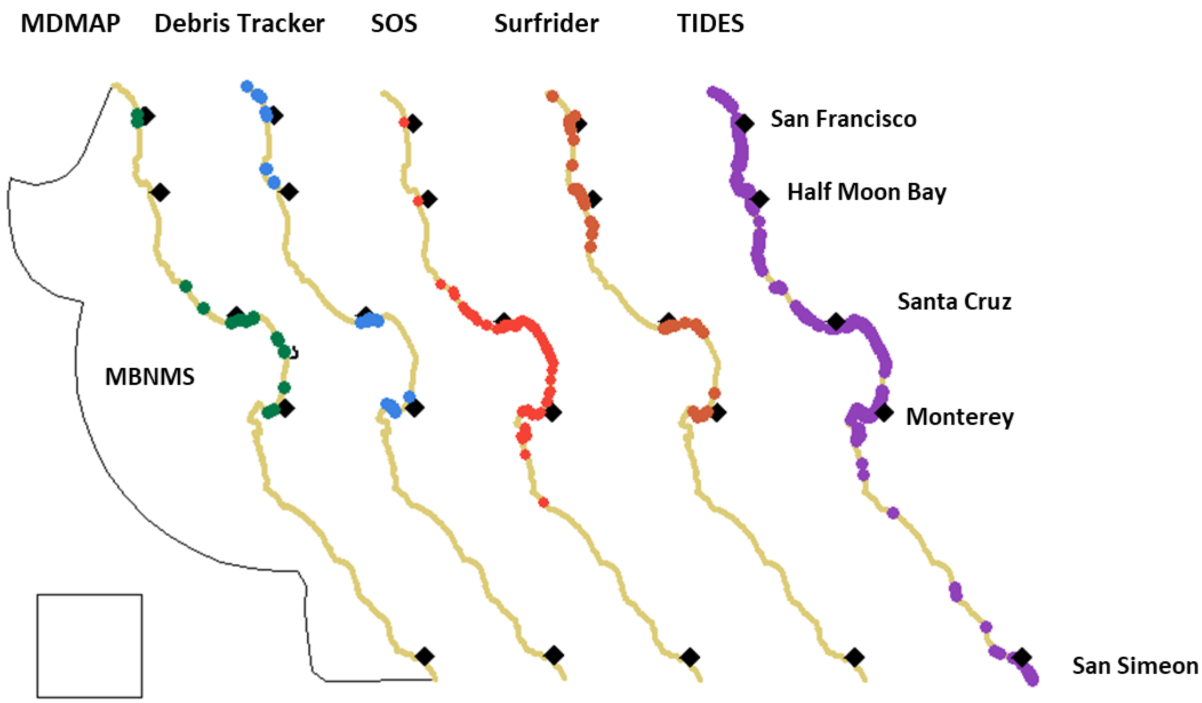

Figure 5: Cleanup locations for each of the five data sets used for analysis from 2017-2021. Some locations were visited for cleanups multiple times.

2.2 Number of Events by Data Source over a Five-Year Period

The total number of beach cleanup events where debris was tabulated and recorded in these five datasets on MBNMS shoreline increased year after year starting with 259 events in 2017 and increasing to 958 in 2021 (Figure 6). The number of events in the TIDES dataset increased each year, due in part to the increasing popularity of Coastal Cleanup Day, occurring each year on the third Saturday in September and organized by the Ocean Conservancy. This increase in TIDES data was assisted by SOS, who organizes groups for Coastal Cleanup Day and uses the TIDES app on this day. Events included in TIDES were eliminated from SOS data to avoid double counting. Although much of TIDES data (45%) is collected in the fall when Coastal Cleanup Day takes place, use of this app for tabulating trash increased each year during all other seasons as well. The number of cleanup events in the SOS dataset was consistent from 2018 through 2021, at about 200±50 events/year. MDMAP increased in use from 2017 (9) to a peak in 2019 (140) and then showed a decline in use from 2019 to 2021 (38). This time period coincided with a pause in promotion of MDMAP while the project underwent an evaluation and revamp. Debris Tracker had about the same number of events tracked in 2017 (81) as in 2021 (89), with less events in middle years. Surfrider, although reporting the fewest events, often consolidated the efforts of many people into a single event. More than half (54%) of Surfrider data was contributed by groups of 25 people or more. Along with Surfrider, other datasets (SOS and TIDES) also consolidated trash data for large groups into a single event, sometimes for efforts of more than 100 people.

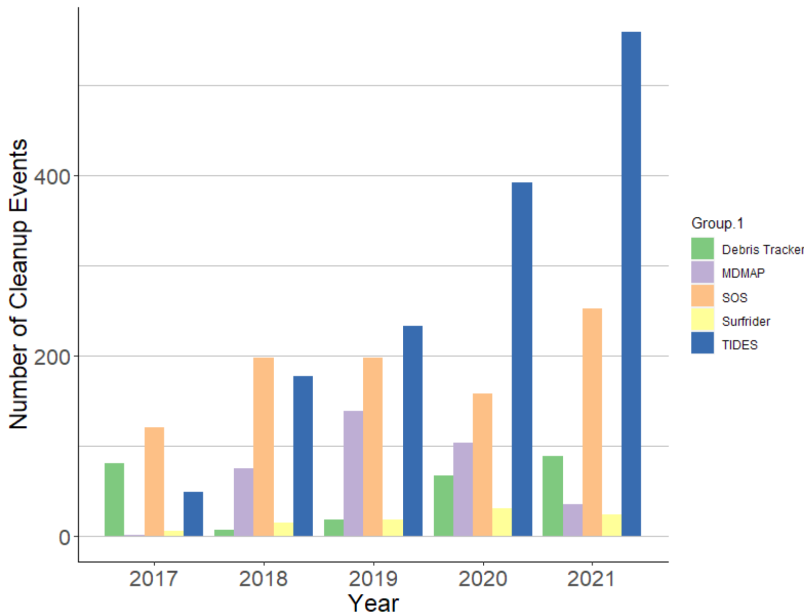

Figure 6: Number of cleanup events in each data set by year. Events are trash cleanups where debris is recorded. In cases when organizers used apps, the larger dataset was maintained, removing duplicate data from the smaller set. For example, Surfrider uses the Debris Tracker app and SOS uses the TIDES app.

2.3 Data Source Number of Collectors

The median number of collectors and of marine debris items collected per event vary by dataset, as shown by the central line in each colored boxes in the box and whisker plots (Figure 7). SOS, Surfrider, and the Ocean Conservancy (using TIDES) host large events, which explains the outliers (dots above the colored rectangles) on the plots. Due to the amount of effort put into the event by volunteers, SOS, and Surfrider also have higher median value for trash items collected per event when compared with the other datasets. Because the TIDES app is also extensively used by individuals, the median value for this dataset is lower. Debris Tracker does not track the number of people on the app and had the least number of events. As Surfrider uses this app, events included in the Surfrider dataset were omitted from the Debris Tracker data to avoid double counting, however skewing the plots of Debris Tracker to lower values. MDMAP is designed as a monitoring tool and restricts data collection to a particular shoreline length, thus the number of items per event is generally lower than programs that strive for large beach cleanups.

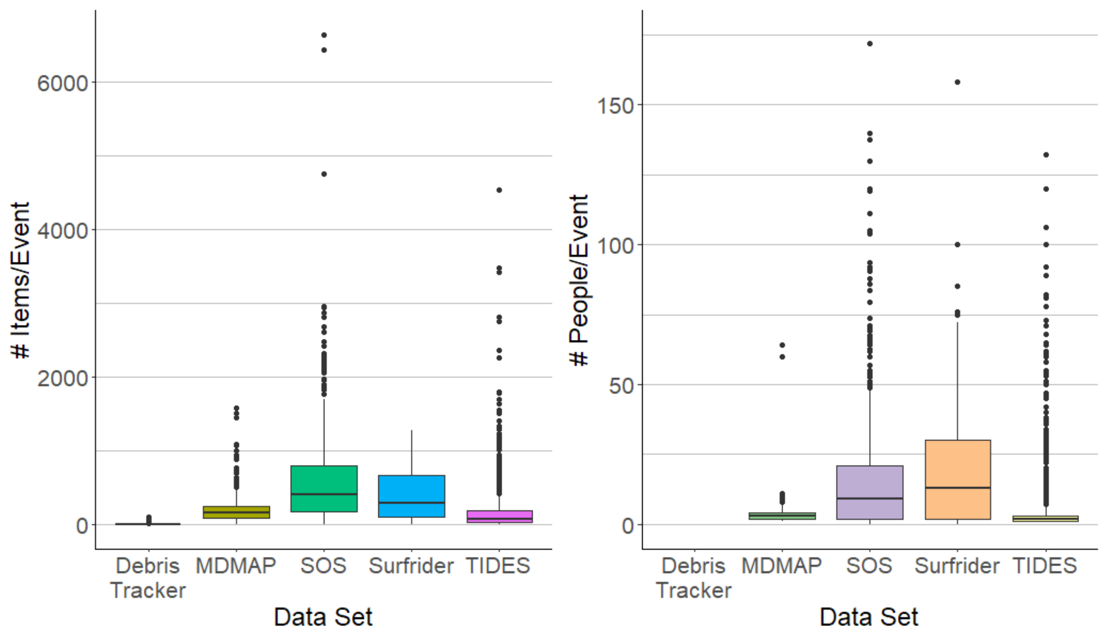

Figure 7: Plots showing the number of items and number of people per event by dataset reveal differences in trash data collection methods. SOS, Surfrider, and the Ocean Conservancy (using the TIDES app) organize cleanup events attended by large numbers of volunteers. TIDES is also extensively used by single individual or small group cleanups. Extreme outliers were not included on both plots: SOS reported items/event = 4752, 6440, 6640; TIDES items/event = 4530; SOS people/event = 200, 206; TIDES people/event = 200.

2.4 Discussion

Data used from multiple citizen scientist sources (TIDES, SOS, Surfrider, MDMAP, Debris Tracker) provided a more comprehensive estimate of the amount, type, and distribution of debris on MBNMS shoreline than use of a single dataset.

By using citizen science data, we reinforce the importance of public engagement in cleanup processes and validate the relevance of this mode of data collection. Beyond the values of data collection and cleaner beaches, the process of engaging citizen scientists can build their understanding of the problems and potential solutions which hopefully will encourage them to take action to solve this difficult socio-environmental issue (Nelms et al., 2017; Kawabe et al., 2022). Citizen science programs do more than gather knowledge inexpensively through volunteers, they impact the individuals involved. Through recognizing their contribution and building their understanding of science, a sense of responsibility and desire to become involved in civic change is sometimes ignited (Turrini et al., 2018). Citizen science can produce good quality data; however, limitations and biases should be considered. For example, citizen scientists tend to under report small items (<2.5 cm) in marine debris cleanups (Kawabe et al., 2022). Training citizen scientists prior to participation can improve data quality by reducing errors and overcoming biases resulting from differences in abilities (Bonney et al., 2016). The reliability of collected information can be increased by developing clear protocols, training volunteers, and onsite supervision, in addition to review and revision of data collected (Bergmann et al., 2015). Data source used in this study either are currently doing or planning to implement all recommended methods for increasing the reliability of data provided by citizen scientists.

Although we included five large datasets in our analysis, it remains incomplete because cleanups occur without data documentation. Finding a way to estimate marine debris from these unaccounted efforts, as well as from areas of the coastline not surveyed would provide additional insight into the amount, type, and location of marine debris along MBNMS shoreline. We encourage individuals and organizations to document the debris collected during cleanup events as more data provides more comprehensive information for building scientific understanding and decision making on the municipal and state level, as well as for use by governmental and non-governmental organizations wanting to be strategic in determining improvement efforts.

Figure 8: Contributing organizations for beach cleanup datasets. Logos and photos courtesy of Save Our Shores, Debris Tracker, Ocean Conservancy, Surfrider, and the NOAA Marine Debris Monitoring and Assessment Project.

Section 3: Activities Resulting in Trash on Beaches: What activities contribute most to beach litter?

Human activities result in mismanaged trash and debris found on beaches. We identified seven primary activities resulting in marine debris: , and . Activities contributing to marine debris may take place on the beach, inland, or out at sea.

Eating and Drinking: Eating and drinking activities included trash resulting from snacks, picnics, beach cookouts, parties, and carry-out food. Trash categories associated with eating and drinking included utensils and plates, take-out food containers, bottles, straws, and wrappers.

Smoking: Trash left behind from smoking cigarettes, cigars, and vaping included butts, packaging, containers, and other smoking items.

Dumping and Disaster: Industrial and household waste dumping includes trash that may originate from unintentional or illegal dumping. This category also includes items resulting from storm damage, coastal erosion, or degrading harbors. Items include appliances, construction material, and tires.

Fishing: Fishing included both recreational and commercial abandoned, derelict of otherwise lost fishing gear or equipment found on the beach such as buoys, fishing line, crab traps, or net material.

Personal Hygiene: Personal hygiene items included any personal protective or sanitary products used to keep safe and clean such as masks, gloves, condoms, and diapers.

Recreation: Items associated with recreation on the beach or elsewhere (other than sport fishing) included balloons, toys, clothing, and dog waste bags.

Various: Trash that could have originated from one of the other six activities, thus various activities. Examples include packaging that could not be identified with a more specific activity or fragmented pieces of plastic, glass, or metal.

3.1 Methods

We harmonized the trash categories used for recording trash data for each of the five datasets into seven activities and 41 common categories. For additional information on the harmonization process and the use of the Trash Taxonomy Tool as an aid, see Appendix A. Using the harmonized data from the combined datasets, we used R software for statistical computing and graphics (R Core Team, 2021) to summarize the counts for the total number of trash items for each activity and for each category of trash collected and tabulated during cleanups. We did not have a methodology for estimating “unreported” trash from cleanups performed regularly on beaches by municipalities or California State Parks or sporadically by individuals.

Although the harmonization effort allowed for the creation of common categories between datasets, categories did not perfectly align in all cases. Two types of alignment issues occurred: 1) combined items in a dataset were counted in only one category; or 2) not all datasets contained items in all of the categories developed (the item was likely counted during a cleanup in a more general category such as "other.") An example of combined items occurs in the Debris Tracker dataset, where cigarette butts and cigar tips were combined into a single item. In this case, we counted the combined item in the "cigarette butts" category, the larger of the two categories. We estimated the number of cigar tips undercounted based on the proportions in other data sets, finding this underestimation was only one cigar tip. The second type of alignment issue occurred when a category was not included in a data set. This occurred for "Take-Out Food Containers," which were not included in MDMAP, and "Fireworks," not included in MDMAP or in the Debris Tracker. We determined that we would correct for these differences if they were substantial by using the percentages from the other datasets to move items from where they would have been counted into the identified category. However, this correction was not applied because after the analysis, we found the differences were minor and would have been time consuming to compute. As a result, some of the categories are somewhat underrepresented.

3.2 Results

The three activities contributing to the largest counts of the trash items found on beaches were (42.5%), (27.9%), and (24.5%) (Figure 10, Table 2). The remaining four activities combined contributed to only 5% of trash items collected during beach cleanups: Personal Hygiene (1.7%), Recreation (1.4%), Dumping and Disaster (1.1%), and Fishing (0.8%).

Trash items were put into the Various activity class for three reasons: 1) the trash item could have resulted from more than one activity, 2) trash items not distinguished and classified as "other" were included in Various, or 3) the trash item was a broken piece of something and could not be further identified. An example of number one was the "packaging" category that included items such as foam, plastic, and paper packaging that could have resulted from eating (foam or plastic food packaging) or recreation (a toy box or broken bodyboard). As an example of number two, the term "other" was used as a catch all phrase in datasets for items not fitting listed categories and included items identified in the dataset as other plastic, other cloth, other glass, other metal, and other rubber. Examples of number three include broken pieces classified in the data sets as fragments, including plastic, foam, rubber, and glass fragments.

The largest number of surveyed trash items resulted from activities (# items=425,143, 42.5%). More than half the items included in this activity were "plastic fragments" (# items=260,613, 25.9%). Fragmentation suggests plastic items that have broken down and are no longer recognizable as an object. These items had been broken into pieces or fragments, through abrasion on beach sand, degradation as they traveled across the landscape, or tumbled through waterways to the ocean. Fragmented items may have traveled a long distance from the land or ocean-based activities where they originated as waste. These fragments are not classified as microplastics until they are smaller than 5 millimeters in size, about the size of a pencil eraser and smaller.

(# items=279,748, 27.9%) contributed substantially to marine debris. The top three categories were wrappers (# items=96,954), bottle caps (# items=48,982), and bottles (# items=30,756). Other categories that fit under this activity and contributed substantial amounts of trash were bags (# items=18,434), cans (# items=17,910), foodware (# items=17,397), straws and stirrers (# items=16,357), and take-out food containers (# items=16,506). Eating and Drinking includes food and drinks brought from home or purchased nearby for consumption at the beach. Disposability makes these items more likely to be left behind. Encouraging reusable, recyclable, or compostable foodware, cups, utensils, and containers through ordinances or as a voluntary measure is an approach many municipalities are taking. The city of Santa Cruz has targeted ordinances for the take-out food market to prevent single use disposable items from being discarded in the environment and on the beaches. The city of Monterey requires that take-out food be provided in biodegradable, compostable, or recyclable containers, so long as these are affordable (Ordinance 3426 cs). San Mateo County has an ordinance requiring that take-out foodware be composed of natural fiber-based materials. These types of restrictions on take-out food businesses could reduce take-out food containers, utensils, straws, and foodware (20% of the trash items in this activity).

The amount of trash contributed by (# items=245,431, 24.5%) was the most perplexing of the beach activities that contributed trash items. Although Smoking includes e-cigarettes, cigars, and cigarettes, plus packaging, containers, and lighters, by far the greatest contribution was from cigarette butts (94.4% of items in the Smoking activity). The population of cigarette smokers makes up 10% of adults in California (CDC, 2022) and yet contributes the single largest recognizable item (not a fragment) of beach debris, amounting to 231,735 cigarette butts over the five-year period. One volunteer who has participated in hundreds of cleanups over the years in the Santa Cruz area claimed that cigarette butts are most prevalent at particular sites with easy vehicle access (personal conversation Scheller, 2022). She said people at these locations commonly lunch or snack in their vehicle and toss out the cigarette butts, such that she can easily collect 150 butts in one location.

Other activities (and) contributed a small percent of the total trash items found on MBNMS shorelines.

Figure 9: Different human activities that can produce marine debris in the ocean.

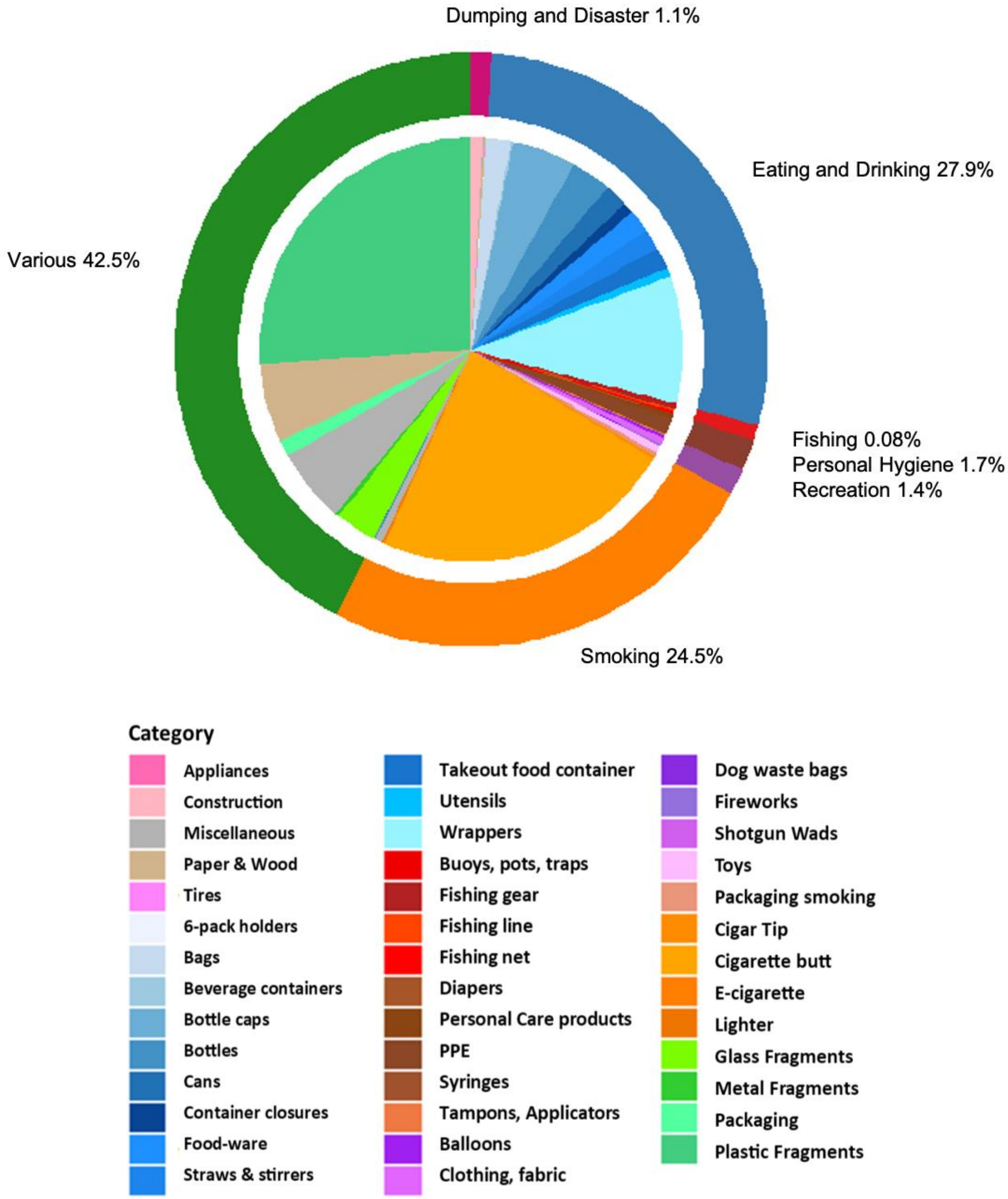

Figure 10: Diagram of seven major activities contributing to marine debris and the 41 categories of trash associated with activities.

Trash items from the five data sets were harmonized into seven activities and 41 common categories of marine debris. The percent of items counted during cleanup events from 2017–2021 were computed for each activity and category (Table 2).

Table 2. Numbers and percentages of marine debris for each activity and category during the 5-year period.

Category	listed in data sets			
Bottle (non-food)	non-beverage bottles, oil bottles, bleach bottles, etc.	428	0.1%	0.0%
Can (non-food)	aerosol cans, other metal cans	91	0.0%	0.0%
Glass fragments	glass pieces, glass fragments, glass other	31,622	7.4%	3.1%
Metal fragments	metal pieces, metal fragments, metal other	2,887	0.7%	0.3%
Miscellaneous	Other trash, tarps, plastic string, other	56,381	13.3%	5.6%
Packaging	strapping bands, other packaging, cardboard cartons, zip ties, Styrofoam packaging, paperboard container	12,484	2.9%	1.2%
Paper and wood products	cardboard, paper pieces, other paper/wood items	60,167	14.2%	6.0%
Plastic fragments	plastic or polystyrene pieces, plastic fragments, plastic or foam pieces, film fragments, nurdles, rubber fragments	260,613	61.3%	25.9%
Wrappers (non-food)	non-food plastic film/wrapper	470	0.1%	0.0%
Foodware	plates, cups, bowls, napkins	17,397	6.2%	1.7%
Straws and stirrers	straws, stirrers	16,357	5.8%	1.6%
Take-out food container	take-out/away containers, food box, street food bowl, food to-go containers, foam/plastic food container	16,506	5.9%	1.6%

Category	listed in data sets			
Utensils	forks, knives, spoons, utensils	6,479	2.3%	0.6%
Six-pack holders	six-pack rings, six-pack holders	164	0.1%	0.0%
Bags	grocery bags, plastic bags, paper bags, Ziplock or trash bags, shopping bags	18,434	6.6%	1.8%
Beverage containers	beverage sachets, juice boxes, jugs, glass jars	1,769	0.6%	0.2%
Bottle cap	bottle caps	48,982	17.5%	4.9%
Bottle	bottles (except non-beverage bottles)	30,756	11.0%	3.1%
Can	cans (except aerosol cans or other metal cans)	17,910	6.4%	1.8%
Container closure	lids, bottle caps or lids	8,040	2.9%	0.8%
Wrapper	food wrappers, aluminum foil, plastic film	96,954	34.7%	9.6%
Smoking packaging	tobacco packaging/ wrap, cigarette boxes, other tobacco, tobacco lighters, single use weed containers	3,268	1.3%	0.3%
Cigarette butts	cigarette butts	231,735	94.4%	23.1%
Cigar tip	cigar tips	1,943	0.8%	0.2%
e-cigarette	vape cartridges, e-smoking devices, e-cigarettes	1,331	0.5%	0.1%
Lighter	lighter	1,003	0.4%	0.1%
Miscellaneous smoking	cigarettes, various smoking items, tobacco (not e-waste or butts)	6,151	2.5%	0.6%

Category	listed in data sets			
Diapers	diapers	283	1.7%	0.0%
Personal care products	Band-Aids, personal hygiene, wipes, toothbrushes, floss, condoms, personal care products	3,265	19.2%	0.3%
PPE	gloves, masks, personal hygiene, personal care products	12,336	72.6%	1.2%
Syringes	syringes, needles	515	3.0%	0.1%
Tampons applicators	tampons, applicators, feminine hygiene products	601	3.5%	0.1%
Balloons	balloons	2,653	18.4%	0.3%
Clothing	clothing, fabric gloves, flip flops, clothes, towels, rags, plastic fiber, fabric pieces, shoes	5,040	35.0%	0.5%
Dog waste bags	bagged pet waste, dog poop bags	239	1.7%	0.0%
Fireworks	fireworks	701	4.9%	0.1%
Miscellaneous (recreation)	light sticks	5	0.0%	0.0%
Paper (recreation)	magazines, newspapers,	616	4.3%	0.1%
Shotgun wads	shotgun wads	0	0.0%	0.0%
Toys	toys and beach accessories	5,131	35.7%	0.5%

Category	listed in data sets			
Appliances	appliances, refrigerators, washers, etc.	96	0.9%	0.0%
Construction	construction materials, building materials, lumber, nails	8,773	78.2%	0.9%
Miscellaneous (dumping)	batteries	699	6.2%	0.1%
Paper, and wood (dumping)	wood pallets, treated wood	1,401	12.5%	0.1%
Tires	tires	252	2.2%	0.0%
Buoys, pots, traps	buoys, pots, traps, floats	232	2.8%	0.0%
Fishing line	fishing line, lures, and line	1,518	18.5%	0.2%
Fishing net	fishing net & pieces, rope-net pieces, and nets	2,367	28.8%	0.2%
Fishing gear	fishing gear, bait bags, hooks, sinkers, lures, rope	4,100	49.9%	0.4%

3.3 Discussion

We developed a classification system that allowed us to create a set of common activities and categories for marine debris from items listed in five large citizen science datasets. This classification system allowed us to harmonize the items between datasets, giving us the ability to analyze the collective dataset as a whole, rather than analyzing each dataset separately. The purpose of classification systems is to allow for comparisons across regions and on a global basis and to provide relevant information for the management of marine debris issues. Despite their relevance, classification systems are imprecise and eliminate details that can be useful for understanding sources and pathways of marine debris (Falk-Andersson, 2021). Our classification system was imprecise and somewhat undercounted items not included in all datasets. Our classification system included seven activities related to marine debris found on MBNMS beaches, which although independently initiated, resulted in a striking resemblance to “marine litter by source” developed by the Ocean Conservancy for the International Coastal Cleanup Campaign. The only difference was that their scheme combined Eating and Drinking with Recreation under a single umbrella termed “Shoreline and Recreational Activities,” and did not include Various Activities or a substitute (UNEP, 2015).

Eating and Drinking was the activity with the largest number of categories (n=12) in our classification system, and contributed to more marine debris items than any other recognizable activity (not including Various) on MBNMS shoreline, resulting in 27.9% of debris. A United Nations Environment Programme (UNEP) study of Mediterranean beaches in 16 countries over a four-year period ending in 2010 found that 52% of marine debris related to “shoreline and recreational activities,” which included eating and drinking (UNEP, 2011). UNEP identified the pathway to the beach for shoreline and recreational waste as coming from beach activities such as fast-food consumption and picnics, litter washed from parking lots and storm drains, and accidental releases from coastal landfills. Smoking contributed the next highest amount of marine debris in our study, amounting to 24.5% of waste items, as well as in the Mediterranean study, where it contributed 40% (UNEP 2011). Smoking is recognized globally as an activity contributing substantial amounts of marine debris. Cigarette butts are commonly the predominant item picked up during International Coastal Cleanup Day, followed by plastic beverage bottles and food wrappers (Ocean Conservancy, 2021).

Directed actions at the state or municipal level as well as by concerned citizens and organizations that lead to a reduction in debris from Eating and Drinking and Smoking activities could significantly reduce beach litter. A range of solutions are suggested in Section 8 of this report. Because Various activities, those unattributable to a single activity, made up 42.5% of debris, overall efforts to remove trash at the source before it fragments and to manage general trash items such as packaging, wrappers, cans, and bottles are also needed to reduce marine debris.

Some reports caution using item abundance as the primary criteria for strategizing what marine debris issues to confront and how to direct efforts to reduce debris. For example, consideration should be given to potential threats to human and marine life, the likelihood of success through building connections and partnerships, the desired impact, and the adoption of general approaches that build public awareness of the overall marine debris problem and its effects (UNEP/MAP, 2015; Falk-Andersson, 2021; TFSA 2017). Managing threats to humans from focused efforts to address Personal Hygiene items might reduce transmissible human disease. Fishing debris represents a special threat to marine life from entanglement or ingestion and to marine ecosystems from the destruction of sensitive habitat, spread of disease, and colonization by invasive species (Donohue, 2001; Watson et al., 2022). Items related to Dumping and Disaster, including construction materials, tires, and appliances, represent a greater issue when weight is considered. Materials in this category can pose health risks, especially to children, who are vulnerable to protruding nails and to harmful fluids (USEPA, 1998). Furthermore, dumping creates unsightly conditions that leads to more dumping, so taking actions to clean up sites before the issue escalates can potentially abate growth of the problem (USEPA, 1998). Local knowledge is important to direct efforts toward reducing marine debris from these activities. Strategies should be developed in-light-of the severity of the issue and further investigating the concerns at particular shoreline locations.

Section 4: What categories of trash are most prevalent on MBNMS shoreline and what percent is plastic compared with other materials?

4.1 Methods

For each item in each category of marine debris, we identified the material it was made of. The seven materials were identified as glass, metal, cloth, wood or paper, plastic, polystyrene, or a mix. In most cases the material was listed for the item in the originating dataset. Some trash categories included a combination of items that were composed from different materials. For example, the category Personal Protective Equipment (PPE) is a combination of several items: cloth masks, plastic gloves, and syringes. Take-out food containers were composed of plastic, polystyrene, or paper, each counted separately in some datasets. The dots in Figure 11 (following page) display the total counts for each category, with different colored dots showing the cumulative amount by type of material.

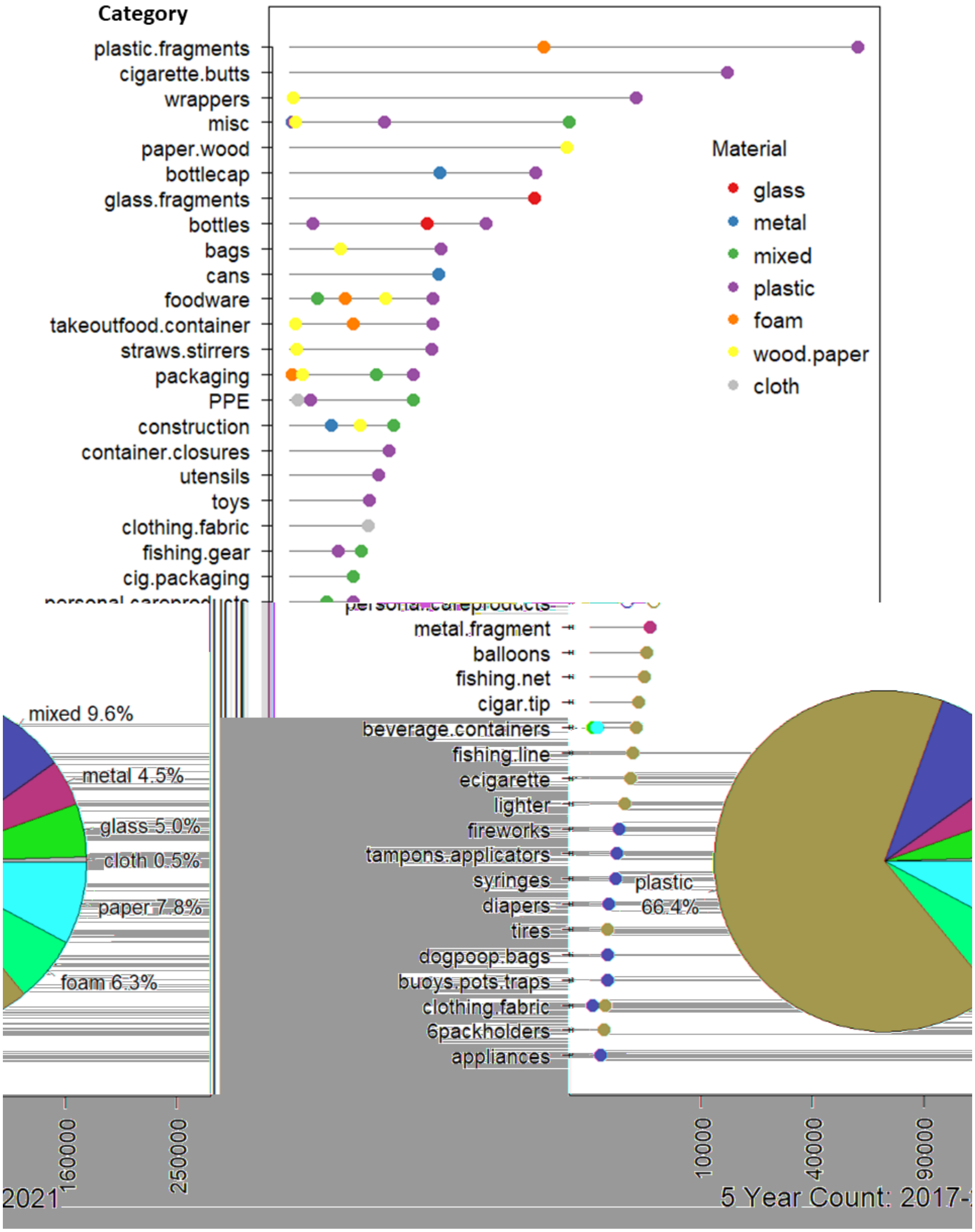

Figure 11: Item count for each trash category and material type by color. Note the count is plotted on a square root scale. The pie diagram shows that the most prevalent material was plastic, representing 66.4% of the trash items.

4.2 Discussion

The majority of marine debris was composed of plastic, either in the form of multiple plastic types (66.4%) such as those found in wrappers (polypropylene), soft drink bottles (polyethylene terephthalate), food foils (polyvinyl chloride), sachets (high density polyethylene), and others. We differentiated polystyrene, a plastic commonly called foam, from other plastics to discover whether bans on polystyrene are continuing to have an impact. Foam (expanded polystyrene) has been banned in many counties and municipalities in California (CAW, 2022). In June 2022, the California legislature passed the Plastic Pollution Prevention and Packaging Producer Responsibility Act that requires a ban on polystyrene in California if recycling rates do not reach 25% by 2025. Many cities and counties in California have already banned polystyrene or some uses of it. These include counties within MBNMS watersheds: Santa Cruz, San Mateo, San Luis Obispo, Monterey, and Santa Clara. Specific bans by county and city can be found the Californians Against Waste website. The city of Monterey, as an example, bans the use of polystyrene containers for take-out food packaging. These bans, along with increased public awareness of polystyrene as a pollutant, may have had an effect, as the proportion of polystyrene items compared with overall plastic items collected per event decreased from 13% in 2017 down to 7% in 2021. In addition to banning polystyrene, other plastic bans passed in several California municipalities include straw bans, plastic bag bans, and reusable foodware ordinances when dining-in or, in some cases, for take-out food.

Three items, all composed of plastic, represented more than half of all items collected. Plastic fragments (25.9%), cigarette butts (23.1%), and wrappers (9.6%) were the most common litter items found on MBNMS shoreline. These same items are the common debris items in California and globally. Plastic fragments (hard plastic, foam, and film) made up a large percent of the total items found across the U.S. in a baseline study, representing about 40% of items using MDMAP data and 16% using International Coastal Cleanup Campaign data (Hardesty et al., 2017). International Coastal Cleanup Day reported the top three items collected in 2021 were food wrappers, cigarette butts, and plastic pieces (Ocean Conservancy, 2022). For the first time in a decade, food wrappers exceeded cigarette butts (Ocean Conservancy, 2022). The consistency of these three items being at the top of lists over time and across the globe make them an obvious target for developing reduction strategies.

Improper cigarette butt disposal is a ubiquitous problem across the globe, yet many smokers do not consider butts to be litter and lack awareness of the toxicological harm butts and their chemical leachate pose to marine biota (Rath et al., 2012; Novotny and Slaughter, 2014; Katarzyte et al., 2021). Cigarette butts can be ingested during feeding by marine organisms, including fish, sea turtles, whales, and birds (Marcedo et al., 2011; Rebischung et al., 2018). The chemicals contained in the ingested butts can be toxic, as well as chemicals that leach from the butts into fresh or saltwater. Toxic chemicals found in the leachate include formaldehyde, metals, polyaromatic hydrocarbons (PAHs), and other carcinogens (Dobaradaran, 2021). This toxicity can affect growth, reproduction, or survival of various marine and freshwater organisms including fish species, tidepool snails, frogs, worms, and bivalves (Slaughter et al., 2011; Dobaradaran, 2021).

In a review of 22 papers, Araujo and Costa (2019) reported cigarette butts relative contribution to marine debris on continental coasts ranged between 3% on the British coast to 87% of litter in Rio de Janeiro, Brazil. Four locations reported results in the 20–30% range: the Chilean coast, Bulgarian coast, Mediterranean coast of Morocco, and Slovenian coast. Many ideas have been proposed and tried to reduce cigarette butt litter including efforts to change voluntary behavior of the smoker, extending cigarette producer responsibility, and legislative action. Educational campaigns use infographics and beach signage to inform the public and smokers regarding the dangers, both to people and to the environment. These measures directed to change smoker behavior, are sometimes coupled with beach receptacles for butts (Figure 12). Although some anti-cigarette butt campaigns have failed to make a difference in reducing beach litter in the short term (Katarzyte et al., 2021), anti-littering messages have proven to increase awareness and knowledge among smokers and firm up their intentions to refrain from littering (Morgan et al., 2021). Educational campaigns can also be a means of increasing public awareness and eliciting peer pressure, often a more effective way to bring about change (Rosenberg, 2012). Extended producer responsibility could activate solutions such as different filter types that biodegrade, recycling/reusing take-back cigarette butt programs, educational packaging, holding producers responsible for cleanup costs, and industry responsibility to debunk false impressions regarding the safety of filters (Healton et al., 2011; Novotny and Slaughter, 2014; Shen et al., 2021). Bans of smoking on beaches is another means to reduce cigarette butt pollution; however, bans may not be effective unless accompanied with other actions to increase awareness, along with enforcement and fines (Currie and Stack, 2021).

The state of California passed a law in October 2019 (CA SB-8) prohibiting smoking on most California State Parks and Beaches, along with a $25 fine. Following this smoking ban, the shoreline segments within a state park (n=14) showed an 84% drop in cigarette butts from 2019 to 2020; whereas segments absent of a state park (n=17) dropped by only 52%. In 2021 there was a slight rebound in cigarette butts in state parks, however numbers of cigarette butts remain far below previous years (Figure 12). Additional information and solutions related to plastic fragments and cigarette butts can be found in Section 8.

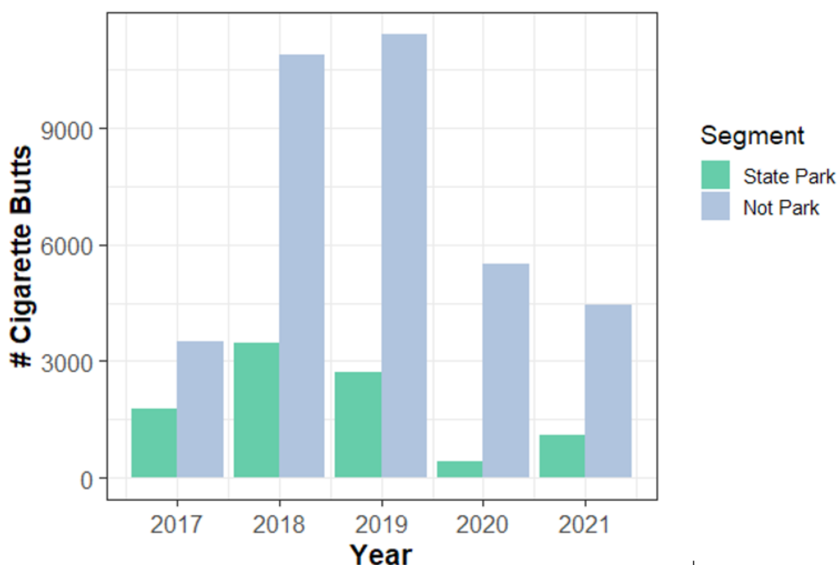

Figure 12: Number of cigarette butts collected at state park beaches and non-state park beaches by year from 2017-2021.

Figure 13: Educational campaigns coupled with receptacles near beaches target voluntary behavior change by smokers to reduce cigarette butt trash. Photos top left: Surfrider; top right: California Department of Public Health; middle: Superior Watershed Partnership; bottom: NOAA's Marine Debris Program.

Section 5: Temporal Changes: What trash categories showed the greatest change over the five-year period and during the COVID-19 pandemic?

5.1 Methods

We evaluated whether there was a steady consistent increase or decrease in the relative amount of marine debris contributed by each of the 41 trash categories over the study period from January 1, 2017 through December 31, 2021; and whether there was a distinctive change during 2020, when there were many beach closures and/or restrictions on activities and group gatherings during the COVID pandemic (NY Times 05/01/2020).

1) We reviewed each trash category to see if there was a steady increase or decrease in the relative percent of that category compared with all other categories each year from 2017–2021.
2) We reviewed the 2020 year (during beach closures and restrictions due to the COVID pandemic) to evaluate whether particular trash categories declined or increased in terms of relative percent compared with the other four years.
3) We evaluated changes in the material composition of trash over the five-year period.
4) We reviewed changes in cleanup surveys (number of surveys and number of collectors) conducted over the five-year period.

5.2 Results

We did not find steady changes in the relative amounts contributed by 38 out of 41 of the debris categories observed over the five-year period. The only trash category that demonstrated consistent annual relative increases all five years was Personal Protective Equipment (PPE). In terms of total count, PPE increased from 2017 (# items=41) to 2021 (# items=2,577), showing the strongest increase between 2019 and 2020 of 77%. Two other trash categories, e-cigarettes and dog waste bags, were not reported the first three years, then had relative increases the last two years with respective counts of 246 in 2020 and 170 in 2021. PPE is included in all five data sets; however, dog waste bags and e-cigarettes are only included in two or three datasets respectively out of the five (see Appendix Figure A1). All other categories showed no consistent relative change.

Several trash categories exhibited relative increases or decreases during 2020 when beach closures and restrictions on large group gatherings occurred on California beaches from mid-March through October due to the COVID pandemic (CA Coastal Zone Beach Restrictions due to COVID-19). When compared with all other years, relative fractional decreases occurred for counts of the following categories: appliances, buoys, pots and traps, cigarette butts, cigar tips, diapers, fireworks, lighters, syringes, tampons and applicators, wrappers, and plastic fragments. Increases relative to other years occurred for the following categories of debris: beverage containers, cigarette packaging, container closures, fishing nets, and metal fragments. Of special interest, the three most prevalent trash categories on MBNMS beaches (plastic fragments, cigarette butts, and wrappers) all decreased relative to other trash items in 2020. The changes in human behavior in 2020, probably related to COVID, resulted in changes in the categories of trash that were most prevalent on beaches; however, these behavioral changes may have taken place on the beach, as well as in other inland areas where deposited trash eventually finds its way to the shoreline.

The largest shifts in material composition of marine debris over the five-year period were increases in the percent of items composed of mixed materials (from 2% to 13%) and decreases for glass (from 6% to 3%) and foam (from 10% to 5%; Figure 14). The relative amount of plastic (not including foam) varied between 66% and 70%, with no clear pattern. The mixed material class includes items that are composed of more than one material, as well as items that were classified as "other" in a dataset, thus the material was unknown. The items made of mixed materials that showed an increase in 2020 and 2021 compared with earlier years were gloves, masks, personal hygiene, other packaging, and construction materials.

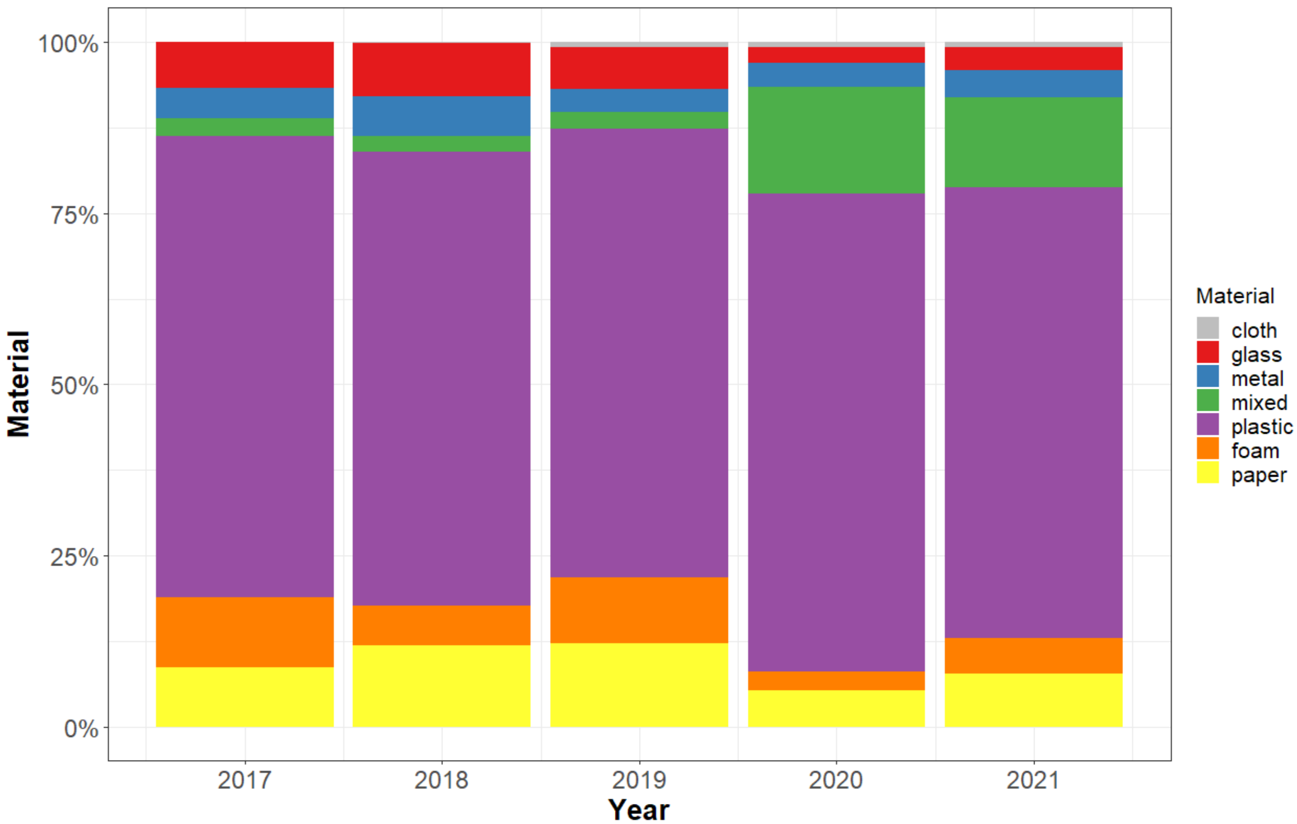

Figure 14: The material composition of marine debris over the five-year period showed percent increases in items made from mixed materials and decreases in items made from foam and glass. Plastic remained relatively constant.

Assessing changes in the amount of marine debris over the five-year period was complicated by the differences in number of cleanups and group size for cleanups as the COVID pandemic effected the country and changed the way people related to one another and to the environment. Response to COVID brought about a reduction in the number of large group cleanups (>30 participants) in 2020 and 2021; however, the number of small group cleanups continued to increase each year (Table 3). Interestingly, the average number of items collected per person during small group events increased in these two years, perhaps as people were spending more time outdoors and as trash may have accumulated due to the absence of large group events. Again, we emphasize the importance of recording number of people and time spent in datasets, so that information can be interpreted. The number of reported items in Table 3 includes only events where the number of people were reported, as we consider the effort involved in cleanups.

	Large Events > 30 People			Small Events <= 30 People			All Events
Year	Number of Events	Average # Items/ Person	Total # Items	Number of Events	Average # Items/ Person	Total # Items	TOTAL # ITEMS
2017	47	22.0	57580	126	58.2	53418	110998
2018	67	18.7	65698	390	66.0	127090	192789
2019	60	24.1	72885	522	54.1	145945	218830
2020	12	14.9	8874	622	125.4	127201	136076
2021	23	16.9	19158	820	73.6	164559	183717

Table 3: Changes in the group size of cleanups during the COVID pandemic show a drop off in large events in 2020 and 2021 and an increase in the number of items/persons collected during small group cleanups.

The year with the most trash items collected and reported was pre-pandemic in 2019, followed by a 47% decline in the number of items reported during the first year of the COVID pandemic in 2020. Having fewer beachgoers and a decrease in group gatherings with different activities, such as eating and drinking, can partially explain the lower total shoreline marine debris in 2020.

Section 6: Geographic Analysis: Where are marine debris hotspots along MBNMS shoreline?

6.1 Methods

MBNMS shoreline was divided into 28 segments of equal length, each representing a 14.5 km (9 mile) stretch. In some areas, the shoreline is twisty and the shoreline length does not cover the same difference in latitude as in other areas, such as seen along the ragged coast of Point Lobos State Park (Figure 15). Using non-overlapping geographic information system (GIS) bounding boxes around each segment, we summarized the data from the five harmonized trash data sets for each of the 28 segments. For each segment, we computed trash items per kilometer, by dividing the total number of trash items by the segment length of 14.5 km. We also computed average trash items per cleanup event by dividing the total number of trash items by the number of cleanup events along that segment. Cleanup events were those reported for the same day and same area in the dataset, with group size varying between 1 to 709. Large cleanup events with 100 to 709 volunteers (n=62) were counted as a single event, as was a cleanup reported by one person (n=1,830). We mapped the findings using R statistical software and the sf, ggplot2, and tmap packages (R Core Team, 2021). Segments were ranked as hotspots based on the outcomes from both the trash density (items per kilometer) and the items per event.

For comparison purposes between methods and with regard to other studies, we also computed linear trash density in the more conventional way using only the TIDES dataset. The conventional method is to compute trash items per unit of distance surveyed. Survey distances are recorded using the GIS phone interface with the Clean Swell app in some cases, and in other cases are estimated by citizen scientists when data is recorded on a paper data card. With TIDES data, we calculated items/km by dividing the total items collected by the distance recorded for each cleanup event and averaged this result for each segment. We also computed items/km-person to include an effort variable. Additionally, we developed a marine debris weight map including effort (kg/person).

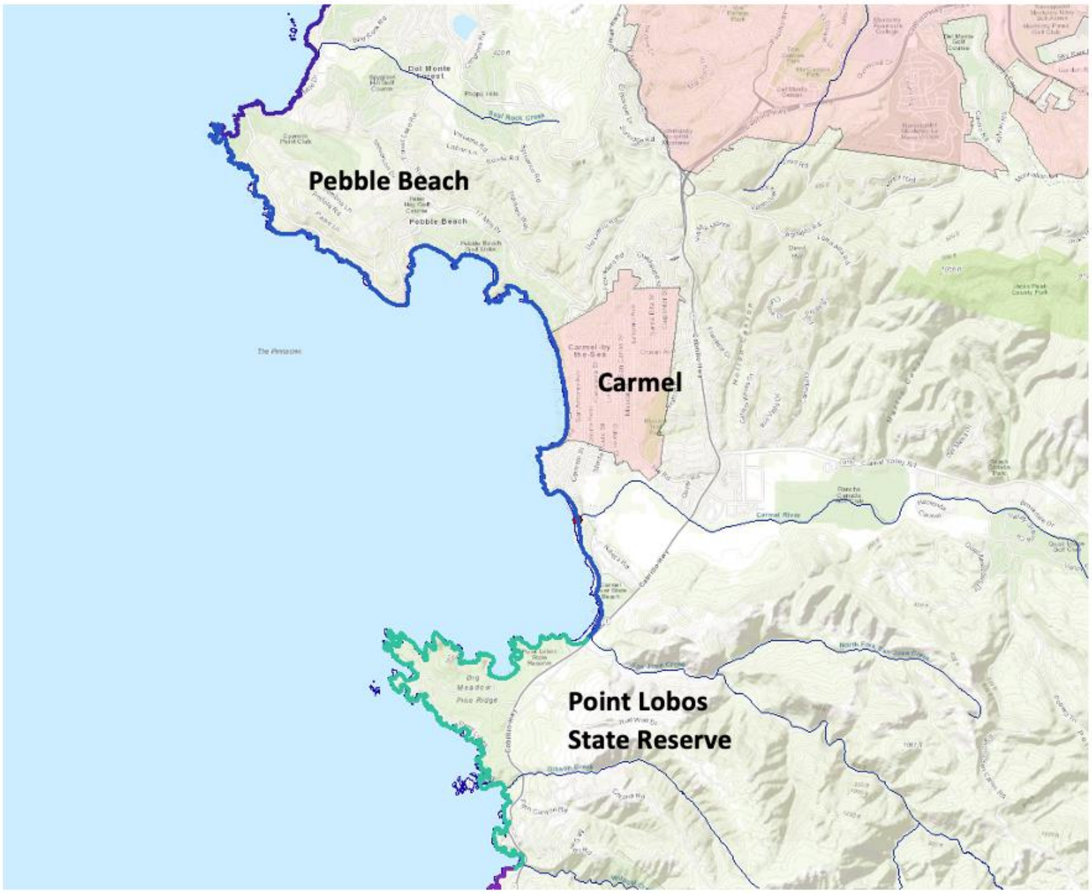

Figure 15: The jagged shoreline of Point Lobos State Reserve (green) is equal in length (14.5 km) to the shoreline from Cypress Point in Pebble Beach to the Carmel River Beach (blue). Each represents one of the 28 segments of MBNMS shoreline included in the hotspot analysis.

6.2 Results

Large differences in the amounts of marine debris collected over the five years were seen between segments (ranging from 70–310,837 items), however numbers of surveys also varied greatly (ranging from 1–775 surveys) and thus lead to ambiguity regarding whether segments with larger amounts of debris collected actually had higher trash densities or were just sampled more times (Figure 16). Some segments had both a large number of items collected and high numbers of items collected per event (Table 4). Using both numbers to determine hotspots probably more accurately represents where debris deposition is highest. Unaccounted cleanups further obscure this question.

We ranked trash density and trash collected per event, a measure of effort, into five and four classes respectively, as shown on the map in Figure 16 and Table 4. Because trash density in one segment (S9) was more than twice as high as any other segment, it was ranked separately as very high. Segment S9 includes many popular Santa Cruz Beaches including Natural Bridges, Cowell Beach, Main Beach, and Pleasure Point. Three segments ranked very high or high for both density and effort: S9, S7 and S11.

Segment S7 includes popular beaches north of the City of Santa Cruz (Greyhound Rock Beach, Davenport Beaches, Panther Beach, and Bonny Doon Beach) and Segment S11 includes Manresa, Sunset, Pajaro River, Zmudowski and Moss Landing State Beaches. Eight segments ranked high or medium high in both density and effort: S1, S8, S10, S12, S13, S14, S16 and S28. All segments surrounding Monterey Bay were ranked in one of these two worst classes for marine debris along the MBNMS coastline, along with the northern and southern most segments on the MBNMS shoreline (S1 & S28) and Point Lobos State Park (S16). Segments that ranked high or medium high on either trash density or effort and low or medium low on the other measure were Segment IDs: S2, S3, and S27. Segments that ranked medium low on one measure and low or medium low on the other measure were S4, S6, S15, S17, S18, and S24. Segments with a low ranking for both measures were one on the southern San Mateo coast and three on the Big Sur coast: S5, S19, S21 and S26. Four segments did not have any cleanup surveys.

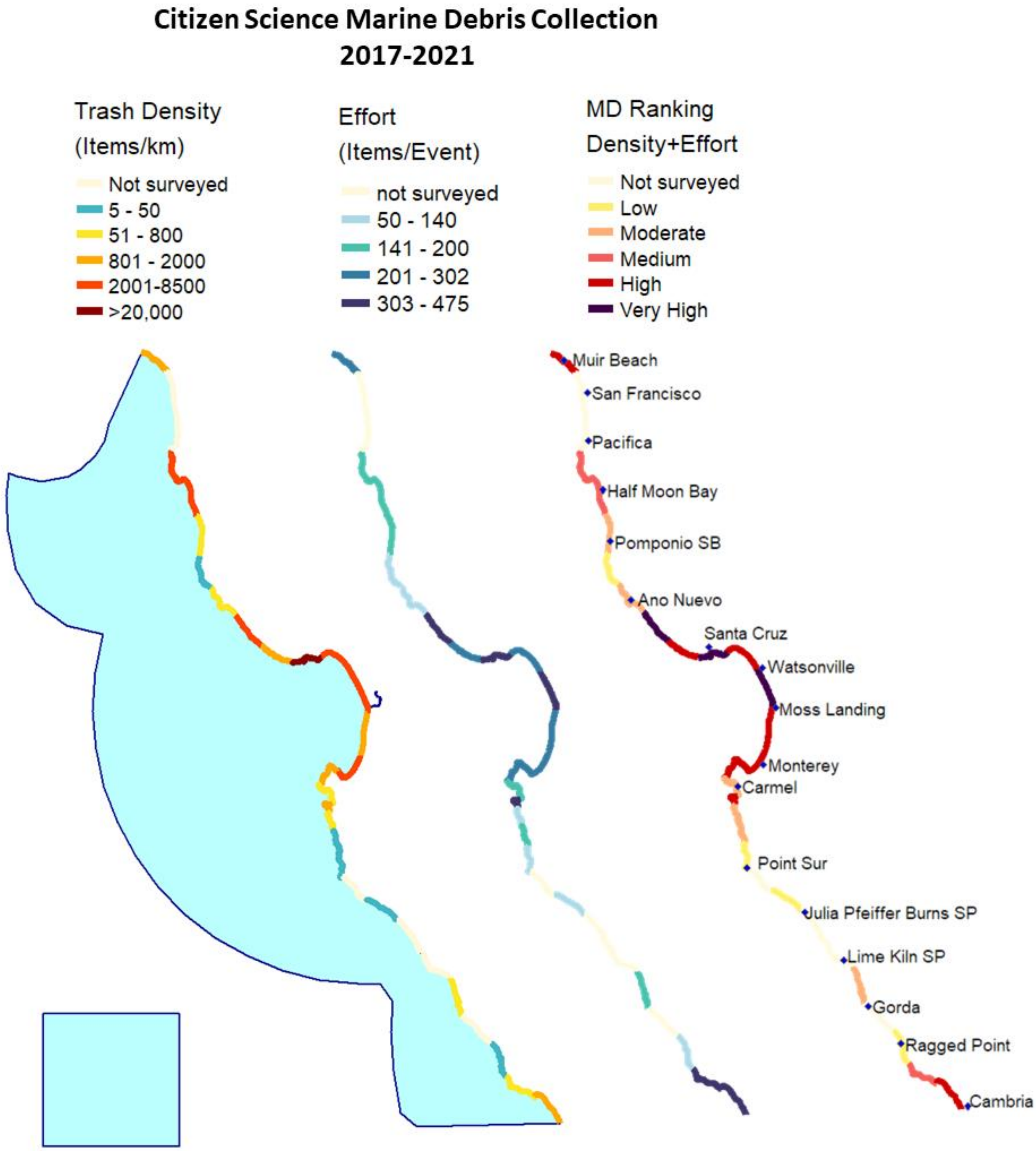

Figure 16: Trash items collected and tabulated for the five data sets from 2017-2021 on 28 shoreline segments (S1-S28) of 14.5 km length each along Monterey Bay National Marine Sanctuary. By segment, the left map displays items per km of shoreline, the center map shows items collected per cleanup event, and the right map shows a ranking based on both effort and marine debris density.

Table 4: Trash recovered for 28 segments of equal shoreline length along MBNMS shoreline, collected from five citizen science datasets over a five-year period from 2017-2021. Segment IDs are highlighted with a color scale depicting their position as hotspots for both number of trash items collected and items collected per event. The counties for each segment are identified: Marin, San Mateo (SM), Santa Cruz (SC), Monterey (Mo), San Luis Obispo (SLO).

ID	Description	Number of Events	Total Items Recorded (2017-2021)	Items/km	Trash Density Rank	Items/ event	Effort Rank
S1	Marin - Mount Tam. to Point Bonita	81	23348	1611	Medium High	255	Medium High
S2	SM - San Pedro Rock to El Granada Beach	271	38252	2640	High	111	Medium Low
S3	SM- El Granada Beach to Seal Rock	321	51810	3576	High	105	Medium Low
S4	SM - Seal Rock to Pescadero SB	64	10284	710	Medium Low	74	Medium Low
S5	SM - Pescadero SB beyond Pigeon Pt	8	446	31	Low	15	Low
S6	SM/SC - Gazos Creek to Waddell Creek	50	5416	374	Medium Low	106	Low
S7	SC - Wadell Creek to Bonny Doon Beach	126	54354	3751	High	431	High
S8	SC - Yellow Bank to Wilder Beach	49	14777	1020	Medium High	302	Medium High
S9	SC -Natural Bridges to Opal Beach	775	310837	21452	Very High	401	High
S10	SC - Hooper Beach to Manresa Uplands	310	87490	6038	High	282	Medium High
S11	SC/Mo - Manresa SB to Moss Landing	207	65738	4537	High	318	High
S12	Mo - Salinas River SB to Indian Head Beach	69	19019	1313	Medium High	276	Medium High
S13	Mo - Stillwell Hall to PG Shoreline Park	466	121608	8393	High	261	Medium High
S14	Mo - Lovers Point to Cypress Point	77	15633	1079	Medium High	203	Medium High
S15	Mo - Cypress Point to Monastery Beach	51	7524	519	Medium Low	148	Medium Low
S16	Mo - Point Lobos SP	52	24617	1699	Medium High	473	High
S17	Mo - Yankee Point to Soberanes Point	7	986	68	Medium Low	141	Low
S18	Mo- Kasler Point and Rocky Point	2	315	22	Low	158	Medium Low

S19	Mo - Bixby Landing to Point Sur	1	116	8	Low	116	Low
S20	Mo - False Sur beach to Pfeiffer Rock	0	NR	NR	unknown	NR	unknown
S21	Mo - Wreck Beach to Partington Creek	2	105	7	Low	53	Low
S22	Mo - McWay Rocks to Devils Canyon	0	NR	NR	unknown	NR	unknown
S23	Mo - Devisl Canyon to Limekiln SB	0	NR	NR	unknown	NR	unknown
S24	Mo - Kirk Creek to Cape San Martin	5	782	54	Medium Low	156	Medium Low
S25	Mo - Spruce Creek to Salmon Creek	0	NR	NR	unknown	NR	unknown
S26	SLO - Ragged Point to San Simeon Point	1	70	5	Low	70	Low
S27	SLO - Ragged Point to San Simeon Point	5	1943	134	Medium Low	389	High
S28	SLO - San Simeon Bay to Abalone Cove	41	17382	1200	Medium High	424	High

Of the 24 segments surveyed, 21 were within the same rank or the next higher or lower rank comparatively between trash density and effort. Two segments along the San Mateo coast (S2 & S3) scored high for trash density and medium low for effort, indicating that despite high amounts of marine debris on the shoreline, cleanups are keeping pace with trash deposition in these segments. One segment in San Luis Obispo county (S27) scored medium low for trash density and high for effort, indicating that each cleanup event recovered a high amount of trash. More cleanups could be useful in this segment to keep pace with trash deposition. Trash segments with few cleanups and sparse data could benefit from additional future surveys so that more information is available for comparative ranking.

Results from mapping using only the TIDES dataset in order to include measured length of cleanups portrays hotspots differently (Figure 17). The top three hotspots for linear debris density are the Big Sur coast between Limekiln State Park and Gorda (S24), Point Lobos State Reserve (S16), and south of Moss Landing along the Salinas River State Beach (S12). The number of surveys in all 28 segments surveyed varied from 1 to 269. The three segments with the highest count of items per km had few surveys (n=5–21), so it is possible higher linear trash densities resulted from the accumulation of trash over a longer period compared with segments with more surveys (n=210–269), such as south of Pacifica (S2), Half Moon Bay (S3), and Monterey (S13). Using the TIDES dataset, the Big Sur coast segment exhibited the highest linear trash density, averaging 7,687 items per kilometer over the five cleanup events, with a wide range from 40 to 26,233 items per kilometer. The survey reporting the highest trash density covered a very short distance of 0.01 miles, and cannot be presumed to represent trash density along the entire segment.

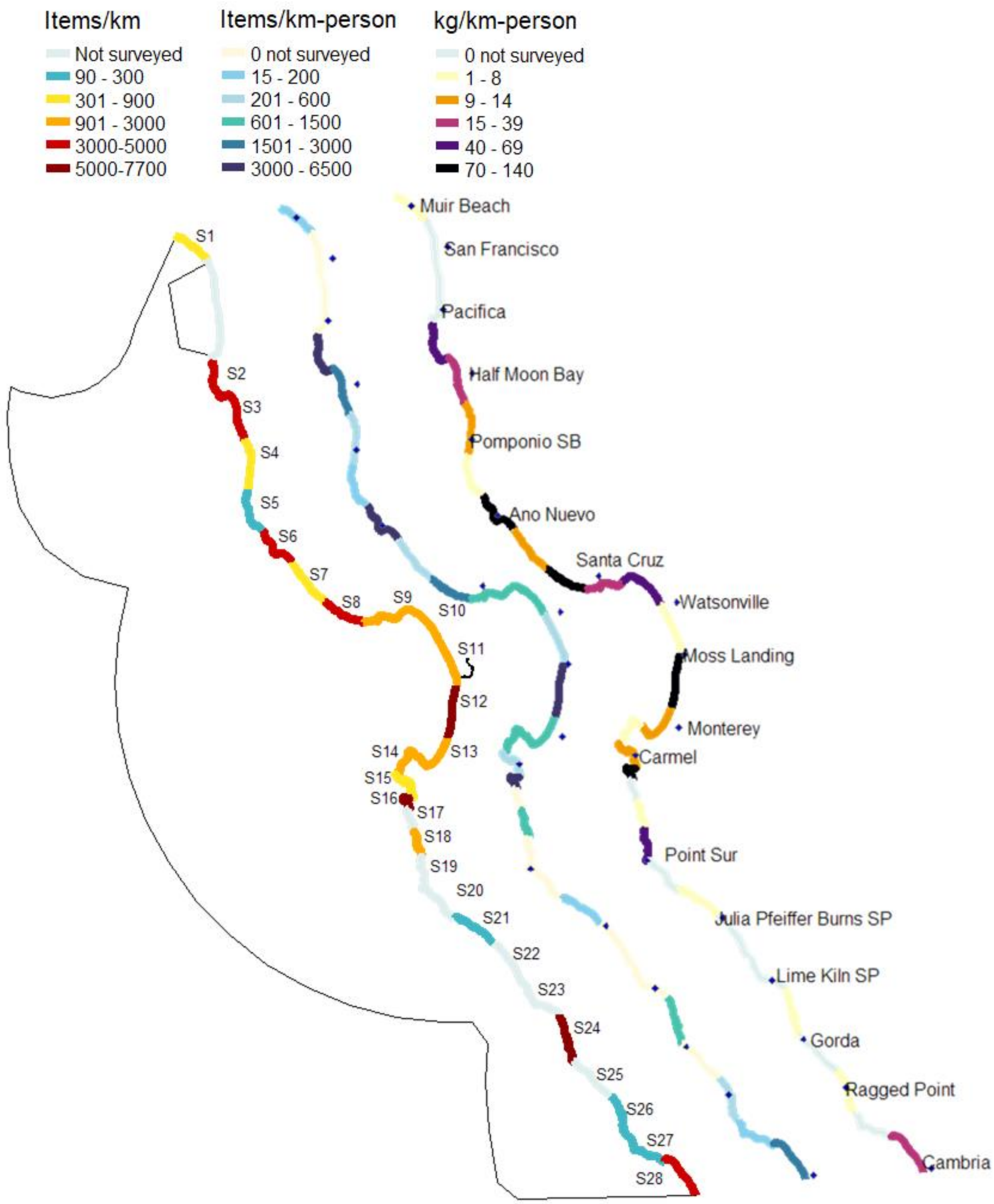

Figure 17: Marine debris hotspots along MBNMS shoreline using only the TIDES dataset portrays different segments with the highest trash density, compared with the map depicting all five datasets. Disparities are likely due to differences in methodology, temporal and geographic distribution, and sparser data.

6.3 Discussion

Our study of hotspots for marine debris along MBNMS shoreline showed more trash items were collected along some segments of the shoreline over the five-year period than others, ranging from 70 to 310,837 items per segment (Figure 17). However, the number of collection events in a segment also influenced the amount of trash recovered, with more events resulting in higher trash recovery, although not at a uniform rate across all segments. We attempted to account for distance covered by reviewing the TIDES dataset, which includes this parameter, and found that a single outlier data point, a short distance surveyed, and infrequent cleanups may greatly influence the outcome of the analysis and create a very different hotspot map. Furthermore, other unaccounted effort variables influence the amount of marine debris collected include numbers of people participating in cleanup events, event duration, and location choice. One would expect that having more people involved in an event for a longer period would result in more trash items being collected, information that is not uniformly available across the five datasets. The importance of people and events is analyzed in more detail in Section 7.

To add to the complexity, the time period since the last cleanup also influences how much trash has accumulated at a location. Furthermore, individuals and organizations collect marine debris without reporting it. Considering these complexities, unknowns, and uncertainties, determining how to define hotspots is a challenge.

1) We believe using all five datasets resulted in more comprehensive findings regarding the total amount of marine debris recorded in each segment, compared with using a single dataset.
2) Effort parameters influence the amount of trash collected during a cleanup event and may skew hotspot results if not accounted for: distance or area covered, duration of an event, and number of people involved.
3) Unknowns, such as time period between recorded and unrecorded cleanup events, influence the amount of marine debris that accumulates.
4) Unrecorded cleanup events introduce further unknowns regarding how much marine debris is present.
5) Averaging total marine debris items over the entire segment length to estimate linear trash density underestimates debris density, as the entire segment length is not surveyed during an event.
6) Trash density (items/km) may be under or overestimated for a segment using a dataset that includes distance, if a small survey distance is extrapolated to represent the entire segment.
7) Choice of where sampling occurs is not random, as citizen scientists choose based primarily on ease of access or where they see trash.
8) Distance is estimated in some cases, and may not be accurate, when it is recorded.
9) Few events in a segment and large variations in trash recovered among events can result in larger uncertainty in making comparisons between segments.
10) The method for data collection varies between datasets, in terms of size of items recorded. These differences introduce inconsistencies between data sets and uncertainties regarding comparisons, depending on which data set is more prevalent in a geography.

Our first methodology for calculating marine debris density differed from other studies because we summed all trash items collected within a segment over a five-year period and divided by the length of the entire segment. Using this method, linear marine debris density ranged from 3.5 to 32.7 items/km-event in the 28-segment assessment with the highest density in Point Lobos State Reserve (S16) and the lowest in Big Sur south of Wreck Beach (S21). The average linear marine debris density along the entire MBNMS shoreline of 15.8 items/km-event; however, this method underestimates the debris density because collectors did not cover the entire segment. Using the more conventional method of determining linear marine debris density using a distance travelled for each event was accomplished using TIDES data that includes this measure. Using the conventional method, we calculated a linear debris density range between 98 and 7,687 items/km with an average of 2,150 items/km across the entire MBNMS shoreline. These numbers are more comparable to other debris density studies because they are calculated using a similar methodology. Hardesty et al., 2017 reported baseline estimates of average marine debris densities on U.S. beaches of 16.5, 1.21, and 12.1 items/km depending on the dataset used for assessment, with differences due to survey methods and geographic coverage. Because the Hardesty report accounted for effort (time, people, and interval between surveys) in computing these densities, their numbers are not comparable with our results; however, their findings demonstrate that dataset methods influence outcomes. Using only the NOAA MDMAP Accumulation data, they reported the California central coast as having relatively high marine debris density, but noted that absence of data and interpolation of a single southern data point skewed this finding. Our efforts also resulted in sparse data along the Big Sur coast, however, did include multiple points. Studies across the globe reported linear debris density ranges from 9 to 250 items/km in north-central Chile (Thiel et al., 2013), 770 to 1,900 items/km on Corfu Island in Greece (Prevenios et al., 2018), 4,700 items/km in the Seychelles (Duhec et al., 2015), and 5,300 to 10,700 items/km in Cassina, Brazil (Tourinho and Fillmann, 2011). A review of global debris monitoring found that many beaches (n=177) across the globe reported low densities ranging from 0–5,000 items/km; with higher densities in the range between 125,000–250,000 items/km in New Zealand, Belgium, Curacao, and Israel (Serra-Goncalves, 2019). Compared with studies of other regions, linear marine debris density on the California central coast would be characterized as low. More comparisons would have been possible if we had been able to calculate items based on area density, as used in most current studies (Serra-Goncalves, 2019), however, area was not reported in 43% of the combined data.

6.4 Geographic Analysis: What activities contribute the most marine debris in each geographic segment?

Methods

Using the same 28 segments and bounding box as for the hotspots, we codified the trash collected and reported for each segment into the seven activities associated with each item (see Section 3). For each segment we compared the number of trash items associated with the two distinctive activities that resulted in the most trash: (1) Eating and Drinking and (2) Smoking. We did not include Various because we wanted to spotlight specific activities that could be targeted for improvement. We also compared the activities Dumping and Disasters, Personal Hygiene, Fishing, and Recreation for each segment.

Results

The amount of litter (# items) from the activities Eating and Drinking, Smoking, and Various surpassed litter from all other activities for all 28 shoreline segments. For the majority of segments (n=19, 83%) where surveys occurred over the five-year period, Eating and Drinking contributed more debris than Smoking (Figure 18). Trash on the beach from Smoking contributed more debris than did Eating and Drinking in four segments (17%). Smoking contributed more debris items along the Big Sur coast from just south of Soberanes Point to Point Sur (S18 and S19), from Wreck Beach to Partington Creek (S24) and in the southernmost segment near Cambria from San Simeon Point to Abalone Cove (S28). Five segments were not surveyed.

The second-tier activities contributing to marine debris in the 28 segments were Fishing (n=9), Personal Hygiene (n=8), Recreation (n=2), and Dumping and Disaster (n=2). Compared with the other second-tier activities, fishing contributed more trash items along much of the coastline: from Año Nuevo to Moss Landing (S7-S11), San Gregorio and Pomponio State Beaches (S4), Monterey beaches (S13), Carmel beaches and Point Lobos (S15 and S16), Wreck Beach to Partington Creek (S24), and Point Piedras Blancas and San Simeon Point (S27). Personal Hygiene contributed more trash from Point San Pedro to Seal Rock (S2 and S3), along the San Mateo coast from Seal Rock to Pescadero Creek (S5), from Bonny Doon to Wilder Beach (S12), Capitola and Aptos beaches (S14), and from Yankee Point to Point Sur (S17-S19). Recreation produced more abandoned trash items from Wreck Beach to Partington Creek (S21) and near Cambria from San Simeon Point to Abalone Cove (S28). Dumping and Disasters produced more trash items along the southern Marin County shoreline (S1) and Pescadero Creek to south of Pigeon Point Lighthouse (S6).

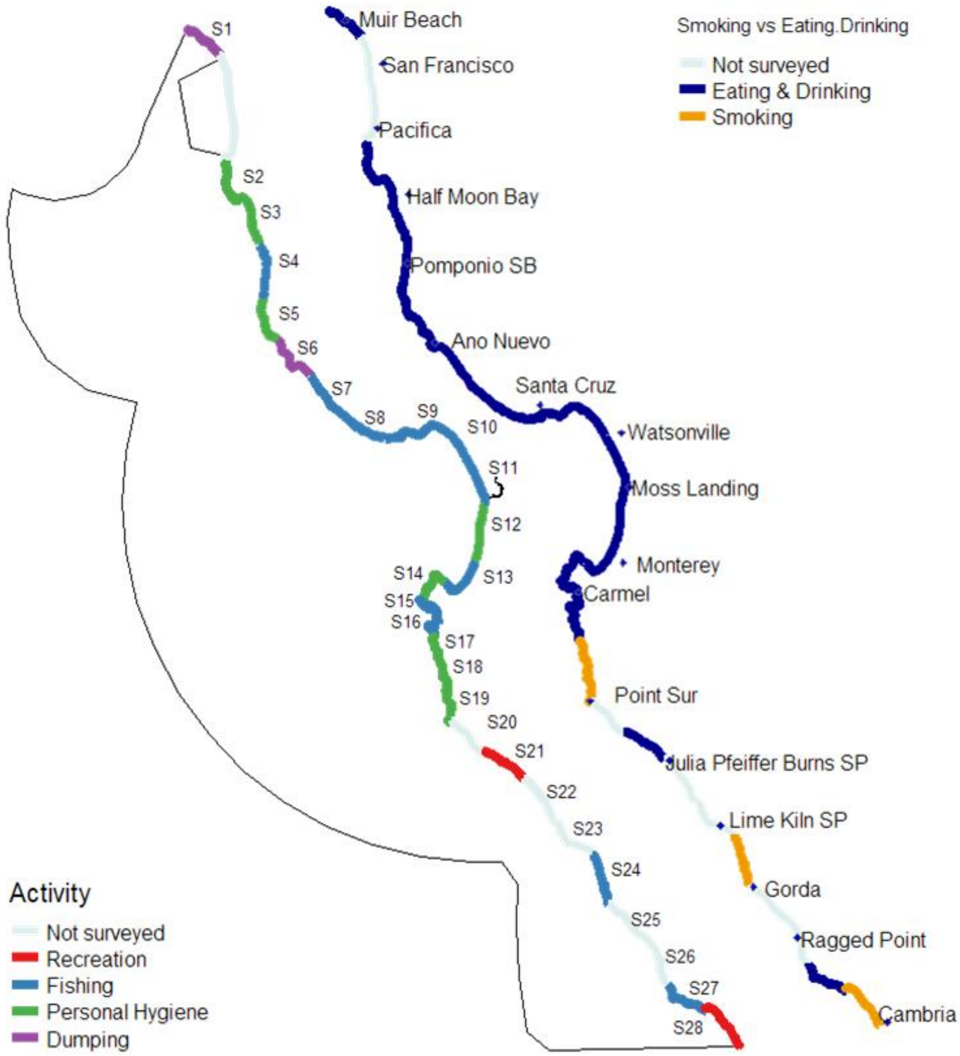

Figure 18: Smoking and Eating and Drinking activities contributed the most trash items for each of the 28 segments of MBNMS shoreline (right shoreline map). Secondary activities (Recreation, Fishing, Personal Hygiene, and Dumping and Disaster) each contributed more items of debris in some segments (left shoreline map).

Section 7: What are the predictors of marine debris on MBNMS shoreline?

7.1 Methods

A generalized linear mixed model (GLMM) using a negative binomial distribution (log link function) was used to evaluate the relative strength of various predictors on the number of debris items collected, including all five datasets over the five-year period from 2017 to 2021. R statistical software was used for statistical analysis with the TMB package for GLMM. Negative binomial regressions are appropriate for count data when the mean of the count is less than the variance and high dispersion is suspected (Logan, 2010). Akaike Information Criterion (AIC) model selection was used to choose the best model, defined as the model with the highest likelihood that did not differ more than two AIC points from the top model (Burnham and Anderson, 2002). We used the set of fixed effect predictor variables listed below with number of items as the dependent variable in the model. The two random effects were shoreline segment and dataset. After removing cleanup events where the number of trash collectors in the survey event was not recorded from the dataset, there were 2,706 events remaining. To measure the other predictor variables, we divided MBNMS shoreline into 84 segments of equal length (4.8 km/3 mi), and determined the value of each variable for that segment. Using GIS techniques to develop non-overlapping bounding boxes surrounding each segment, we associated each cleanup event with a segment. We standardized the predictor variables to facilitate comparing their relative effects on the amount of debris recovered.

We used a similar GLMM model with pieces of plastic as the dependent variable to discover whether plastic fragments might be associated with different predictor variables and have a different set of drivers bringing them to beaches in our area.

Predictor Variables

Collectors: Number of people collecting trash and data for a cleanup event. When number of collectors was not recorded, these events were removed from the data set (n=346, 11%).

Events: Number of cleanup events within a segment including all five datasets.

Distance to Nearest River Mouth or Bay: We identified the major rivers and bays along MBNMS shoreline, using the US Geological Survey National Hydrology Dataset. Because the coastal mountains have many small streams draining through pristine areas to the ocean, we eliminated smaller water courses that were characterized as arroyos or creeks rather than rivers. For each of the 84 shoreline segments, we calculated distance to the nearest river mouth or bay from the midpoint of the segment.

Current Direction and Speed: Central California Ocean Observing Systems (CenCOOS) data was used to calculate the average speed and direction of the nearshore current over the five-year period of interest. Using the midpoint of each of the segments, the CenCOOS model grid index closest to this point was averaged over the five years to compute current speed and direction.

Beach Current Angle: Nearshore currents could be driving marine debris onto the beach. We connected the beginning and ending points for each segment to determine the beach angle for that segment. Then we calculated the angle of intersection between the nearshore current direction and beach angle to compute the angle at which the current was inclined toward or away from the coast segment. Because angles are measured in a circular scale, we transformed the number to an index of values between -1 and +1 with negative values indicating the current is away from the shoreline and positive toward the shoreline: Index = sin (π*angle of intersection/180).

Population Density: Utilizing the Environmental Systems Research Institute population density map based on the 2020 Census Demography for each census tract, we calculated the population density (persons/square mile) for each shoreline segment.

Beach Visitors: We would have liked to use beach visitation data; however, we could not find a dataset with number of visitors along MBNMS coastlines. We know, for example, that Point Lobos State Reserve has more than one million visitors annually from around the world, and people from San Jose visit Santa Cruz beaches on the weekend. Despite considerable searching, no source of this likely critical data could be found.

State Park Fraction: We determined the percent of shoreline along each segment within a state park. This variable was included with the thought that California State Parks could both attract visitors and their debris and support employees responsible for beach cleanups.

Percent Sandy Shoreline Substrate: Using the Environmental Sensitivity Index shoreline classification spatial data for each of the shoreline segments, we computed the length of simple shoreline types (sandy, rocky, and mixed sandy and rocky) to calculate the percent sandy shoreline coverage.

Pelagic Bird Carcass: As a proxy for offshore currents and winds that might influence transport of debris to beaches, we used counts of bird carcasses found on the beach from the NOAA ERDDAP "Beach COMBERS effort-based marine mammal and seabird beach cast surveys" and from NOAA's Greater Farallones National Marine Sanctuary "Beach Watch" program. Assuming that dead pelagic birds were predominantly carried from further out in the ocean to the shore by currents, we restricted as pelagic birds those in the following families: Alcidae, Procellariidae, Diomedeidae, Hydrobatidae, and Scolopacidae (phalaropes only). We used the shoreline bounding boxes around each MBNMS segment to count carcasses found within each segment between January 1, 2017 to January 6, 2021 (the last available date online).

7.2 Results

The GLMM model allowed us to evaluate the effects of 10 predictor variables on marine debris along MBNMS shoreline. By using coastline segments and dataset as random effects, we were able to remove sources of non-independence introduced by these two variables. There was low correlation between the 10 different predictors, so all could be included in the model, if relevant. Using AIC model comparison, we removed only population density (p-value=0.56 and delta AIC >2) as an important predictor. The remaining predictors included both effort variables (number of collectors on the survey team and number of events in a segment) and environmental variables (distance from nearest river mouth, beach-current angle, pelagic bird carcass count, fraction of sandy shoreline, fraction in a state park, and near shore current speed, see Table 6). Although standardized residuals increased with increasing debris items, we believe this scatter is primarily due to missing model variables rather than to the modelling approach taken; however, it is possible that some variables cannot be well modeled with a linear approach. About 45% of the variance was explained by combined fixed and random effects in the model and 25% by the fixed effects.

Variable	Estimate	Standard Error	z-Value	P-value	
Intercept	4.905	0.292	16.827	<0.001	***
Collectors	5.136	0.281	18.293	<0.001	***
Distance from river mouth	0.676	0.263	2.568	0.010	*
Beach-current angle	0.273	0.107	2.564	0.010	*
Number of surveys in segment	0.627	0.303	2.065	0.039	*
Fraction of sandy beach	-0.412	0.219	-1.880	0.060	.
Pelagic bird carcasses	0.483	0.398	1.214	0.225	
Current speed	0.190	0.189	1.004	0.316	
Fraction in State Park	0.413	0.454	0.910	0.363	

Table 6: Fixed effects results from the GLMM model shows variables with the strongest impact on marine debris count. The GLMM model random effects were the 84 segments of shoreline and the five datasets for 2,706 cleanup events. The model had a marginal and conditional R^2 values of 0.25 and 0.45, respectively.

Based on model estimates shown in Table 6, the variable with the strongest impact on number of marine debris items was number of collectors involved in the cleanup event, such that more people on a cleanup event meant more marine debris collected. The estimate of 5.14 for collectors compared with 0.68 for distance to river mouth shows the influence was 7.5 times stronger. Distance from the nearest river mouth and the number of surveys held in that segment had the second and third strongest effect, respectively, with estimates of influence greater than 0.6. These were followed by pelagic bird carcasses (our proxy for far offshore wind and currents), and fraction of sandy beach within the segment with estimates of influence greater than 0.4. The remaining two variables, current speed and angle of intersection of the current direction with the beach, had a lesser effect.

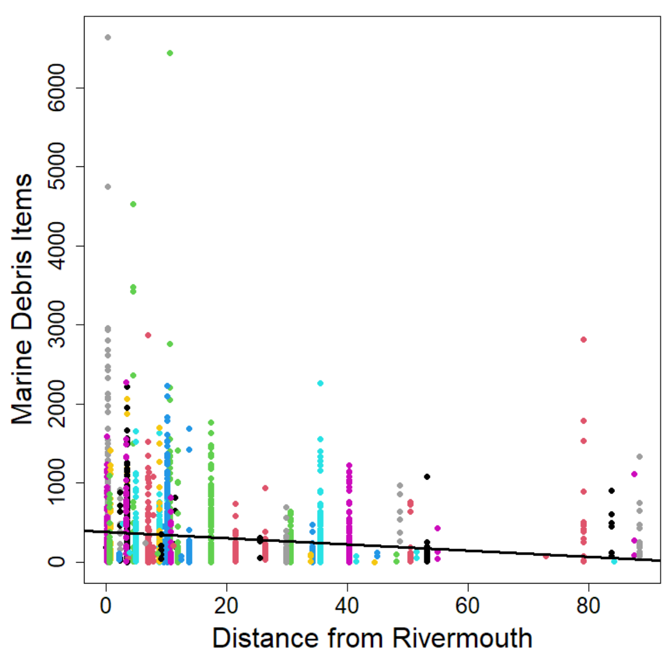

Figure 19. Increasing distance from river mouth is associated with less marine debris.

It is not too surprising that distance to river mouth would be the environmental predictor with the largest impact on number of marine debris items. However, the positive sign of this coefficient seems counterintuitive (Table 6). The positive estimate for this coefficient derives from type 3 sums of squares, a method of estimation that measures the effect of distance to river mouth while adjusting for the effect of all other predictors in the model. Thus, though this adjusted effect of distance to river mouth is positive, this is only because the other predictors are distributed unevenly relative to distance to river mouth. That the unadjusted effect of distance to river mouth has the negative effect on number of marine debris items that what one would expect is revealed by direct scatterplot (Figure 19). The overall distribution of marine debris also reveals the key role of rivers in bringing marine debris to the coast. Locations closer to river mouths had more trash: only 6% of cleanups had more than 1,000 trash items collected, but almost half of these (47%) were in segments with river mouths, even though only 13% of segments are intersected by a river mouth.

The other environmental predictors of marine debris had much smaller, but more directly interpretable, effects. There was more marine debris on beaches that had more pelagic bird carcasses (our proxy for far offshore wind and currents), and faster currents inclining toward the beaches. Interestingly, the results also suggest that, all other factors controlled for, there is more marine debris in stretches of coast with a lower percentage of sandy substrate. Perhaps debris is caught or trapped by rocks and therefore is more likely to be removed during cleanups. The key variable we could not assess was the number of beach visitors, the effect of which appears not to have been well approximated by local population density (p-value=0.54). To check this hypothesis, we subtracted model predictions from observed number of items within each of the 84 segments along MBNMS shorelines to explore whether the absence of an accurate count of beach visitors could have hampered the predictive ability of our model. A map of the result of this difference indicates that the most exaggerated over predictions of the model occurred predominantly along segments with the most collectors involved in cleanups (Figure 20). When >1,000 collectors were involved, the model over predicted by >5,000 items in many cases (6 out of 9): Main and Cowell beaches in Santa Cruz, Sand City beach, Half Moon Bay beaches, Pajaro Dunes and Pajaro River State beaches, Sunset and Manresa Beach, and Davenport and Bonny Doon. This suggests that the actual relationship between the number of collectors and items of marine debris may be non-linear and that over some threshold higher number of collectors are exceeding the rate of addition of marine debris to the beach and end up effectively cleaning the beach and freeing it of debris while sampling it. Model underpredictions, when more marine debris was collected than the model predicted, occurred in three segments near Santa Cruz (Aptos and Rio Del Mar, Capitola, and New Brighton State Beach, near Pleasure Point), Point Lobos State Reserve, and San Simeon State Beach. It seems very likely that these excessive counts of marine debris are the result of the high popularity of these shore segments, but an accurate test of this hypotheses must await the availability of accurate numbers of beach visitors. The most important lesson from this modeling exercise is that getting people involved in beach collection efforts makes a big difference in the amount of marine debris collected, and more people collecting means cleaner beaches.

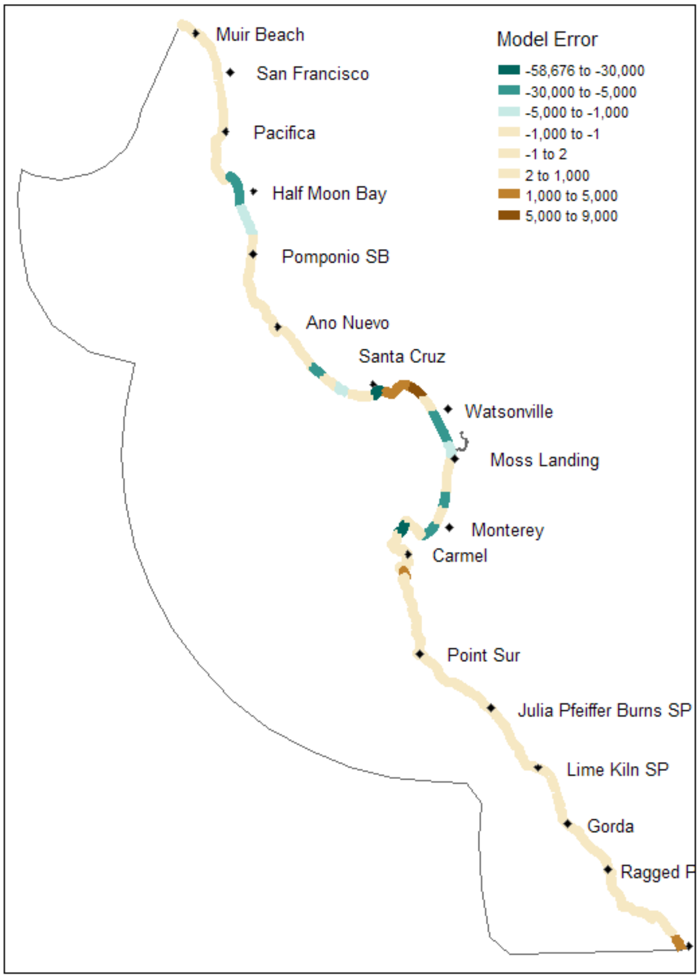

Figure 20. Segments along MBNMS shoreline showing where the model over predicted in segments with high numbers of collectors and under predicted in some segments with high visitation rates.

We used the same modeling approach for plastic fragments as for total items, finding effort variables to be equally important; however, fewer environmental predictors appeared relevant. The environmental predictors remaining after AIC model simplification, in order of influence, were current speed and fraction in a state park. The conditional R^2=0.79 and marginal R^2=0.08 indicates that the model was more accurate overall; however, the fixed effects variables played a smaller role in predictions. It is puzzling that neither nearshore currents intersecting with the beach nor offshore wind and current were relevant in this model, nor was distance to river mouth. Transport mechanisms for these fragments remains unclear. Current speed was an important variable, making it plausible that fragments (or whole objects that became fragmentized in the ocean) were carried off the beach by wind, waves, and tides, moved a short distance and redeposited onto the shoreline. Current strength could play a role in redeposition rates. The effect of a state park fraction could be influenced by park employees, who may recover larger items of trash but not fragments, possibly leaving these behind to be recovered by collectors. The number of collectors was more important for number of plastic fragments than for total items, with the estimated effect increasing by one point to 6.2. As more collectors are present, they may begin to pay attention to smaller items and retrieve more plastic fragments.

7.3 Discussion

Sources of marine debris entering the ocean are diverse, and tracking pathways and processes driving marine debris to the beach is crucial for source identification and determining where to target management measures (Ribic et al., 2012; Falk-Andersson, 2021). Surveys of marine debris on beaches are useful not only for evaluating the status of the beach, but also are respected as an index of conditions in surrounding water (Ribic eat al., 2012). Primary marine debris pathways to the beach include direct deposit of litter on the beach by visitors, transport from the ocean to the beach by wind and currents, and inland based litter carried by water down rivers or through storm drains (Willis et al., 2017). Environmental process variables used to understand these pathways vary across studies; however, many studies have included distance to river mouth, local population metrics, and shoreline substrate (Ribic et al., 2012; Willis et al., 2017). Our model did not find local population metrics from adjacent census blocks to be relevant. A study of marine debris on the U.S. Atlantic coast found that distance to a city with population greater than 250,000 people was significantly related to marine debris, however in a non-linear way (Ribic et al., 2010). Perhaps a better population metric for our study would have been distance from a large city; however, the barrier of the Santa Cruz mountains would have made computing travel versus closest distance necessary, and we lacked the resources for this evaluation. We would have preferred a direct measure of beach visitors but could not find a source, and we did not find a good substitute parameter.

Rather than using beach aspect, a more commonly included predictor (Hardesty et al., 2017), we calculated the angle of intersection of the direction of nearshore current to the beach aspect. This novel approach, made possible through Central California Ocean Observing Systems (CenCOOS) stations and modeling expertise on the Central California coast, considers the angle of the driving force of nearshore currents in regard to the ocean-facing beach direction. The angle of intersection variable was significant (p-value≤0.01) for predicting debris counts. The point of origination of these items as trash cannot be determined from this evidence alone, as it is possible, they came from offshore ocean activities (dumping, fishing, or recreational boating), originated on the beach and were taken out to sea and washed back onto the shore, or came down a river or storm drain. Studies have also found that tidal activity and ocean upwelling can influence marine debris and could be a way that it is transported onto and off beaches with the assistance of currents (NASEM, 2022).

To estimate whether offshore wind and currents carry debris to the beach from the open ocean, we used pelagic bird carcasses as a proxy. Pelagic birds spend a large portion of their lives over the open ocean and are likely to die at sea. Some of these open ocean species range hundreds of miles from shore. Their carcasses drift on the surface and are transported by wind and currents to the shoreline (Flint and Fowler, 1998; Wiese, 2003). Anomalous events, especially reduced upwelling that decreases food resources and storm events causing stress from exertion, cause increased episodic mortality (Parrish et al., 2007). Data used for this study was collected over a four-year period and may include some of these episodes; however, these events would not likely impact the distribution of birds along the shoreline over that timeframe. Though colonies of common murres (*Uria aalge*) and rhinoceros auklets (*Cerorhinca monocerata*) occur in or adjacent to MBNMS, their distribution in offshore waters for most of the year is not likely to be dramatically biased by local concentrations of birds. The influence of offshore winds and currents, based on pelagic bird carcass data, should also be interpreted with some caution because bird carcass counts were not available in all the locations where marine debris was collected and more collections may have yielded a more robust understanding of influence (Figure 21). Because offshore wind and currents carry marine debris from a greater distance than near shore currents, debris carried by these forces could come from sources beyond the rivers and beaches of MBNMS, perhaps brought to MBNMS shoreline by deep ocean currents.

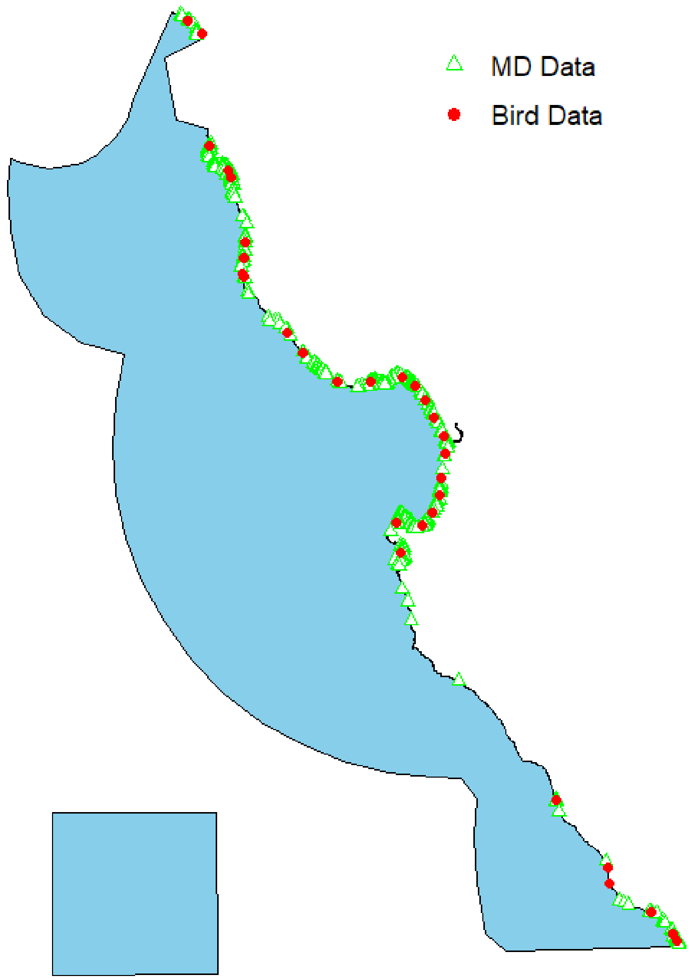

Figure 21: Locations for marine debris collection and pelagic bird carcass surveys along shorelines of MBNMS.

Many studies have shown that marine debris transported by rivers accumulates on nearby beaches, and proximity to a river mouth is an indicator of this source (Wessel et al., 2019; NASEM, 2022). Global estimates predict rivers and streams represent a major pathway for marine debris, with estimates of up to 80% of marine debris entering oceans (Meijer et al., 2021). Along MBNMS shoreline, numerous streams originate in pristine areas in the Coast Ranges that span two-thirds of the California coastline. Because of the high number of streams typically sourced in low population forested areas, we elected to include only rivers in this study. The majority of marine debris traveling to the ocean from rivers occurs during high flow, storm conditions. Storm waters can carry marine debris from urban areas through storm drains into tributaries and channels that reach the ocean. River banks are a common place where marine debris collects and is transported seaward as waters rise during high flow. Presumably, California's rainy season is when most marine debris enter the ocean from rivers as this season has periods of higher flow, and because many of the rivers entering MBNMS form sand bars in the dry season. These sand bars would prevent the passage of marine debris to the ocean seasonally. Investigating the seasonality of beach debris and relating it to times when the rivers are flowing is a topic for a future study that could add additional insight into the quantity and type of debris entering MBNMS from rivers compared with other sources.

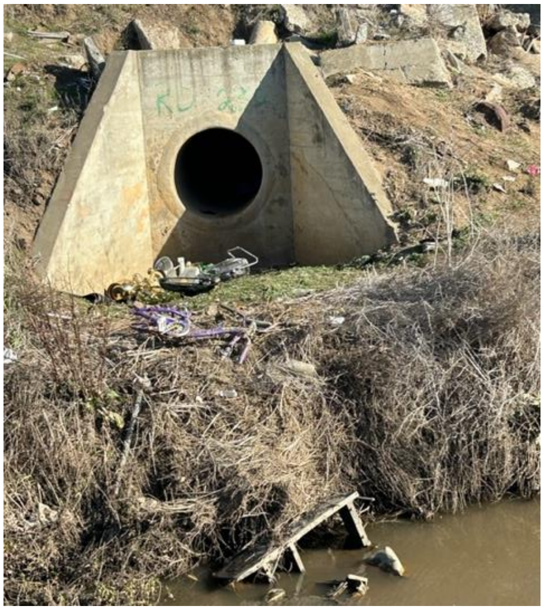

Figure 22: Marine debris can be carried from city streets through storm drains entering tributaries that travel to rivers and the ocean. Photo: Pam Krone/NOAA

Figure 23: The Carmel River breaks through the sandbar to reach the sea, during early winter storms. Photo: Pam Krone/NOAA

We included a variable for fraction of shoreline in a state park, state reserve, or state beach as these may represent a special case that is different from other areas for several reasons: many have workers periodically removing marine debris from the shoreline, these areas may attract more visitors, and

California State Parks imposed a smoking ban on most state beaches in 2019. The best AIC model included this variable for both total items and plastic fragments. However, the considerable span in the 5% confidence interval from 0.18 to 0.56 for total marine debris indicate that state beaches were sometimes a positive influence in reducing marine debris and other times a negative influence. This is understandable as more visitors mean more trash, even if state beach employees are aiding with cleanups, plus there is considerable variability in both factors among state beaches.

Other variables not included in the model that could be relevant to amount of marine debris include unreported cleanup events, distance from roads and parking, accessibility, wind direction, distance from take-out food or convenience stores, convenience of garbage cans or cigarette butt receptacles, storm events, signage, offshore and onshore fishing activity, and bans or fines related to specific activities.

These complex interactive processes and geographic differences in their importance across regions of the globe are suggestive of the challenges of assessing the amounts, sources, and transport of marine debris in the marine environment (NASEM, 2022). Many of these influences may vary seasonally in MBNMS, including fishing activities, current direction, ocean upwelling, and river flow to the ocean. Finer temporal scale analysis could build better understanding of transport mechanisms for marine debris and may contribute to source understanding that could lead to better solutions. Three oceanographic seasons are recognized for MBNMS and each may have different transport mechanisms: the upwelling period from early spring to late summer (February to July), the California Current periods for late summer to early fall (August to October), and the Davidson Current period from late fall to late winter (November to January) characterized by winter storms. Further study of seasonal current differences coupled with river outflow in the absence of sand barriers and factoring in seasonal beach tourism would provide better understanding of source and transport mechanisms of marine debris in MBNMS.

Section 8: Recommendations for Reducing Marine Debris in MBNMS

This report focused on plastics as it was the most predominant material found during beach cleanups and is also the most concerning due to the harm caused to marine environments across the globe and in MBNMS. Plastic is a synthetic compound that is manufactured primarily from petroleum into a variety of products with many different characteristics and functions. Because it is lightweight, inexpensive, and flexible, many single-use disposable products are made of plastic and are prevalent in MBNMS beach cleanups: wrappers, bottles, bags, straws, stirrers, and foodware. It is also used in durable goods that are designed to last for a longer time, such as seatbelts, clothing, medical supplies, household goods, and fishing gear. There are 14 different plastic polymer chemistries, each with specialized properties designed for different functions and to perform in different user environments. Plastic is used in almost every segment of our economy, including agriculture, transportation, medicine, information technology, and construction. For this reason, the marine debris composed of plastic does not apply to just one activity or object that can be managed or controlled.

Figure 24. The chemistry of microplastic particles in Monterey Bay were analyzed and about 40% were PET (Choy et al., 2018). Many different products are made from each plastic type, including these examples.

Exponential increases in plastic production have resulted in exponential increases of marine debris entering the ocean, due to improper disposal and accidental escape to the environment, demonstrating a need for adequate policy and stewardship for managing plastic products through their entire life cycle (OECD, 2022). Because plastic does not degrade in the ocean, unless we can halt or greatly reduce the rate of transport to the ocean, the addition of more plastic on top of the current amounts will further exacerbate problems and harms caused by marine debris. It is the responsibility of all of us, including consumers, producers, businesses, legislators, waste management, and organizations who manage cleanups, to pursue solutions. We must play an active role in reversing the amount of marine debris that is entering our diverse marine ecosystems.

8.1 Actions for Reducing Marine Debris

The phrase "Reduce, Refuse, Reuse, Recycle, Replace" is the coined slogan for the five R's for reducing plastic waste and thereby diminishing export into the environment. Each word of this phrase provides guidance to actions, decisions, and policies that can be determined at any scale from the individual to business and municipality.

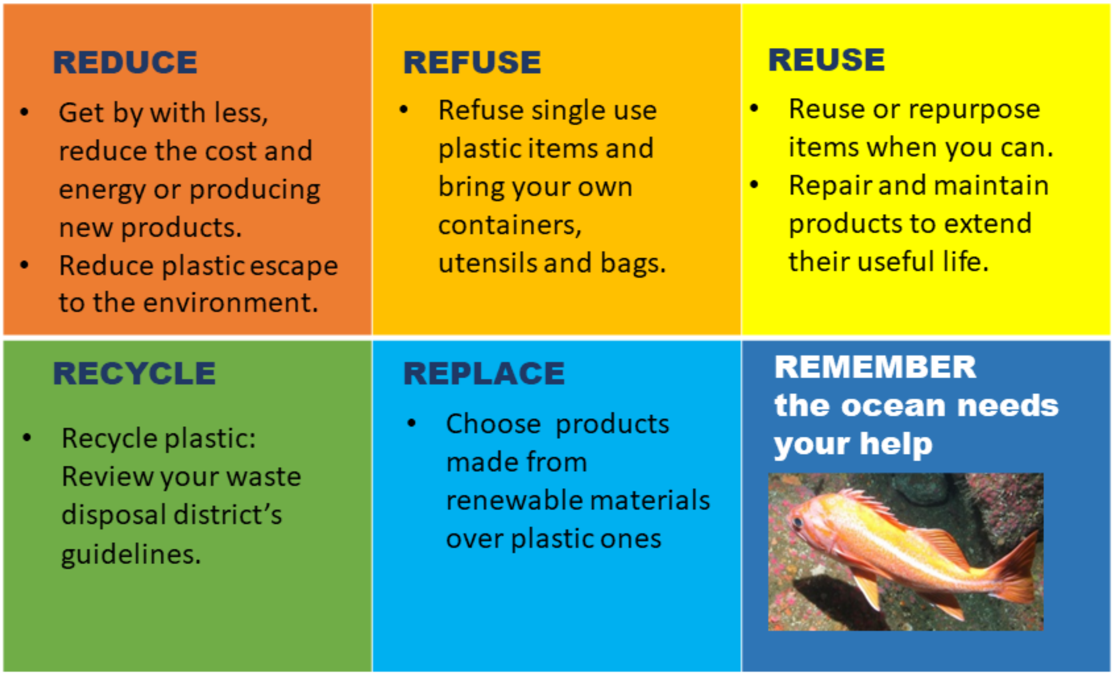

Figure 25: The five R's for reducing plastic waste and guidance to actions, decisions, and policies that can be determined at any scale from the individual to business and municipality.

The organization ReThink Disposable works with businesses, communities, and governments to find ways to diminish disposable plastic use and the website has many suggestions for the five R's. In addition to the five R's, there are recommended policies to lower rates of plastic disposal to landfills. The organization Upstream Solutions has created policy recommendations through their "Policy Ladder to the Circular Economy" best practices (Figure 27). The Plastic Pollution Coalition is another organization providing information, guidance, and solutions to plastic pollution.

Consumer Actions (all of us)

NOAA's Marine Debris Program provides guidance regarding actions that all of us can take to reduce the amount of plastic that is used and to use plastic responsibly, recycling or replacing it when we can. We can enjoy the benefits of plastic while using it conscientiously and protecting the environment through thoughtful consideration and stewardship to replace plastic with other materials when we can and to prevent it from getting into marine systems when we cannot. By reusing durable utensils, cups, and other items rather than purchasing single-use plastic products, we can diminish the trash we produce and prevent it from becoming marine debris.

When on the beach, take care of your own trash. If there is insufficient space in a waste can, pack it out rather than leaving it by the can. When left on the sides of cans, it can easily blow into the ocean.

Figure 26: If there is insufficient space, don’t leave your waste. Photo: Pam Krone/NOAA

Legislative Actions

Legislative actions can reduce the severity of the plastic problem to ocean ecosystem health. The exponential growth rate of plastic production and pollution internationally, the globality of points-of-entry from all continents and countries with shorelines, and the shared ocean space as a common resource makes the problem something all government entities can work to control on the appropriate scale. The issue can be managed and regulated at a local level, reinforced at the national level, and perhaps evolved through international agreements (Dauvegne, 2018). The Organization for Economic Cooperation and Development (OECD) reports that dramatically different outcomes can be accomplished depending on the world’s ability to combine policies that target different lifecycle stages of plastic and reduce leakage. OECD predicts that continued business as usual will result in leakage of about 45 million tonnes of plastic annually by 2060, whereas regional actions could reduce this to 20 million tonnes and global agreements could reduce leakage to eight million tonnes a year (OECD, 2022b). Another example includes California’s Senate Bill 54 (CA SB-54), which was signed into law in 2022, requiring that material offered for sale or distributed in the state is recyclable or compostable by 2032, and requiring producers of single-use packaging or foodware to join a producer responsibility organization by January 1, 2024. The city of Santa Cruz provides an example of municipal scale initiatives and policies to reduce trash entering the ocean. One initiative is the recently adopted Environmentally Acceptable Packaging and Products Ordinance that encourages reusable or compostable dishware and imposes fees on disposable cups sold containing a beverage. In the ordinance, the city of Santa Cruz specifically mentions the need to protect species in Monterey Bay National Marine Sanctuary as justification for the measure. The organization, Upstream Solutions, has several policy recommendations for governments:

Policy Ladder to the Circular Economy

Policymakers have a variety of policy tools to help build the circular economy. Unfortunately, these tools are sometimes presented as "either/or" propositions. But to reach our goal of a truly sustainable economy, we need all these policies and likely more. And we need to understand that they compound upon each other. In order of most beneficial for the environment (from the top down), we've developed a ladder to envision the tools. Policy makers can start at any point on the ladder, but the goal should be to eventually enact all of them.

Reuse / Refill Targets & Funding

- Require consumer brands to use a minimum threshold of reusable packaging and products, and increase this share over time.
- Create a mechanism to pool producer funding for shared infrastructure to enable reuse at scale.

Reuse in Deposit Return Systems (DRS or Bottle Bills)

- Incentives and requirements for beverage producers to choose refillable containers.
- Funding for reuse infrastructure and systems (reverse logistics, washing).
- Complementary/running in parallel to EPR.

Reuse in Extended Producer Responsibility (EPR)

- Incentives and requirements for producers to choose reusable packaging.
- Funding for reuse infrastructure and systems (reverse logistics, washing).
- Should be enacted as complementary to DRS.

Reusable Foodware Policy

- Require reusables only for on-site dining.
- No unwanted accessories for take-out and delivery ("Skip the Stuff").
- Charges on single-use cups & containers to fund investment in reuse service infrastructure.

Single-use Packaging Bans

- Single-use bags
- Polystyrene foam
- Straws, stirrers and other accessories
- Individual hotel toiletries, etc.

Good Solid Waste / Recycling Policy

- Universal cart-based curbside recycling.
- Statewide Pay-As-You-Throw.
- Landfill bans on recyclable materials and organic waste.
- Modernized Material Recovery Facilities.
- Away-from-home collection/recycling.
- Outreach and education on reuse and recycling.

www.upstreamsolutions.org

Upstream

Figure 27: Suggested best practices and tools for policy makers to help build a circular economy around waste products that can benefit the environment by Upstream. Image courtesy of Upstream.

Producer Actions

The production of plastic spans hundreds of transnational corporations, all of whom can help by accepting responsibility for plastic use, recycling, and reuse, and in designing the management of the entire process from cradle to cradle (Dauvegne, 2018). United Nations Environment Programme suggests producers could consider stages in the life cycle of a product and has developed concepts for reducing plastic during each stage:

- Source renewable raw materials from sustainable managed sources.

- Increase the use of recycled plastics as raw materials, provided they do not contain hazardous substances.
- Design durable and repairable plastic products to maximize their life span.
- Design plastic products to be easy to recycle.
- Apply standards to plastic production (e.g., ISO 83.080.01).
- Avoid hazardous substances in plastic products by finding non-hazardous substitutes.

- Inform consumers through labelling plastic products: include recycled content.
- Use superior products to build awareness of plastic conscientious design through campaigns or programs.
- Introduce infrastructure and services to enhance the repair and reuse of products.
- Avoid manufacturing single use plastic products.

- Follow practices for developing sustainable end of life practices (e.g., ISO 18604)
- Ensure the necessary infrastructure and services are available for recycling that will allow extended producer responsibility.

8.2 Monterey Bay National Marine Sanctuary Marine Debris Action Plan

As referenced in the MBNMS 2021 Management Plan, the Marine Debris Action Plan contains three primary strategies and several activities under each for reducing marine debris:

MBNMS staff and partners will evaluate the types of marine debris impacting sanctuary resources with concentration on identifying the level of persistence of plastic pollution, how plastic pollution enters the sanctuary, and the distribution of plastic pollution in the sanctuary. The assessments will focus on pelagic and coastal environments and will also specifically consider plastic inputs from agricultural activity within sanctuary watersheds. Results will be publicly available on the MBNMS website and will be used to inform future policy development.

Complete an assessment of ongoing current marine debris data collection efforts within MBNMS. Determine if data collected by the numerous groups in the sanctuary region and the state of California can be standardized for data collection and reporting, and if historic or existing data can be integrated with new data.

Support monthly citizen science led surveys of marine debris on shorelines. Work with partners to explore potential modification of Beach COMBERS program or other existing citizen science programs to include monthly assessments of marine debris at each assigned beach segment, using protocols from the NOAA Marine Debris Monitoring and Assessment Project. Ensure coordination and post-survey analytical resources are available before implementing such program modifications.

Conduct monitoring of microplastics debris in offshore waters and rivers within MBNMS watersheds. Systematically collect microplastic samples at sea to determine the spatial extent of the occurrence of microplastics. Collect microplastic samples in streams to assess the influx of plastic pollution from agricultural activities within watersheds that flowing to MBNMS.

Incorporate plastic pollution information including impacts on sanctuary into existing education and outreach programs and work with business and tourism partners to reduce plastic pollution, focusing on single-use plastics such as straws and drink containers. Work in tandem with communities' efforts to comply with storm drain runoff regulations and structural controls.

Develop and conduct general and targeted outreach programs about reducing plastic marine debris, in concert with partners and stakeholders. Some potential outreach tools include: beach and waterway cleanup events, event booths, signage, media stories, social media, videos, brochures, public presentations, visitor center displays, and interpretative programs. MBNMS will lead by example by reducing single-use plastic items, e.g., straws and water bottles, at MBNMS hosted events and will aim for zero waste events.

Support existing school programs to educate about the impacts of marine debris, and work to monitor and reduce the amount of plastic debris entering the sanctuary. Engage with local K–12 students through education programs to conduct shoreline monitoring using the NOAA Marine Debris Monitoring and Assessment Project protocols. This activity will lead to increasing awareness of the negative impacts of marine debris while generating solutions that help communities become more sustainable.

Collaborate with partners to reduce plastic pollution from on-the-water businesses. Focus outreach efforts on reducing plastic pollution from on-the-water businesses who can in turn share strategies with their customers through orientations or incorporation into rental guidelines. Support partner efforts to develop outreach products on reducing plastic pollution to coastal businesses, such as hotels and tourist services. Work with partners to develop best practices for reducing marine pollution, focusing on plastics. Work with Sanctuary Advisory Council to write letters of support for local advocacy efforts.

MBNMS staff will focus on reducing marine debris inputs as noted in Strategy MD-1 and MD-2, but have identified activities to remove debris from within the sanctuary known to have adverse effects on marine life.

Respond to marine vessel incidents and other discharge incidents. Utilize regulatory and other authorities to effect removal of debris from discharge incidents, including from cargo ships and other vessels, aircrafts, vehicles, and incidental shoreline discharges.

Continue inland watershed protection efforts. Collaborate with partners to prevent or reduce discharge of marine debris into waterways leading to MBNMS.

Work with entities and individuals who work and live on the ocean to reduce debris released while at sea. Aim to discourage the repetition or duplication of specific unlawful discharge activities such as shipping containers lost at sea.

Coordinate with state and local partners on lost fishing gear removal program, on an as needed basis. Determine if MBNMS can provide any support that would materially increase recovery of lost fishing gear within the sanctuary. Lost gear can change the physical structure of the benthos, entangle wildlife, and pose a threat to personnel and equipment, such as autonomous underwater vehicles (AUVs) and remotely operated vehicles (ROVs).

Use MBNMS permit authority to prevent or reduce potential marine debris. Identify any debris that could be released into the sanctuary as a result of planned human activities and require removal within permit terms and conditions. Work with discharge permit holders. Research MBNMS policy barriers to lost fishing gear removal and ocean-based marine debris cleanup and share results with agencies working on California's Ocean Litter Strategy.

8.3 Top Items: Impacts and Recommendations

Plastic Fragments (# items=260,613, 25.9%)

Plastic fragments were the single largest item by count contributing to shoreline trash with a total of 260,613 pieces counted, composed of 21% foam pieces and 79% plastic pieces (hard, soft, or film plastics). Plastic fragments counted during beach surveys were visible fragments, on the disintegration path between a useful object that was improperly disposed of to a potentially harmful macroplastic to becoming a microplastic. Both macro and microplastics pose harm to ocean ecosystems and marine biota, as well as to human health (Li et al., 2016). Plastic entanglement in macroplastics can reduce movement, increase the energetic cost of food consumption, and reduce marine organisms' abilities to compete for resources (Laist, 1997; Moore et al., 2009). Plastic can be ingested by marine biota at all scales, from whales to seabirds, turtles, fish, invertebrates, and plankton (Cole et al., 2011; Savoca et al., 2018; Savoca et al., 2021).

Approaches to Reducing Plastic Fragments on Beaches

To control plastic fragments, we need to manage our overall plastic use and disposal processes as described above. In addition to earlier ideas, we can do much to help while on the beach or at home by taking extra time and effort to manage our own plastic use and purchasing decisions through following the five R's. Be responsible for your own plastic items and be sure they are properly contained, recycled, or placed into proper waste disposal. If a beach garbage can is full, avoid leaving bags or items where they might overflow, and don't put them outside the garbage can where they might blow away. Instead, take them home and properly dispose of them through your home waste disposal service. Be a steward of the beach and outdoor environment and pick up plastic when you see it. Try not to leave it where it could end up in the ocean. Join beach cleanups that keep beaches clean through collective efforts. The more we can do to keep fragments from getting so small we cannot see and gather them, the easier it will be for us to get the plastic to the right place for disposal or recycling.

Cigarette Butts (# items=231,735, 23.1%)

Cigarette butts were the single largest trash item counted during beach cleanups, with a total of 231,735 tabulated making up 23.1% of trash items. Butts are made from cellulose acetate fibers that were added to cigarettes in the 1950s and are present on 97% of current cigarettes manufactured (Puls et al., 2011). Because cigarette butts contain more than 4000 toxic chemicals, they pose a health risk to humans and marine life (Kumus and Mohejerani, 2020). Unfortunately, smokers often do not see these plastic filters as a trash hazard, believing they are biodegradable, and casually dispose of them into the environment at an alarming rate (Araujo and Costa, 2019). Estimates between one-third to two-thirds of the total six trillion cigarette butts produced globally are discarded to the environment (Novotny and Slaughter, 2014), potentially releasing 300,000 tons of microplastics into the environment annually (Shen et al., 2021).

The National Cancer Institute has found that no identifiable health benefit has come from including the acetate filter in the cigarette design (USNCI 2001). In addition to cigarette redesign, other avenues to reducing cigarette butt waste include portable beach ashtrays, campaigns targeting beach users, public education, producer responsibility, and legislative action (Araujo and Costa, 2019).

Figure 28: Cigarette butts collected during a Monterey State Beach cleanup in 2021. Photo: Surfrider Foundation

Approaches to Reducing Cigarette Butts on Beaches

Communities, governments, organizations, and manufacturers can play a role in reducing exposure of marine life to cigarette butts by taking action to bring about change. Examples include:

Education and Public Awareness: Increase everyone's awareness of the toxicity and negative environmental impacts of cigarette butts. This could mobilize environmental advocate groups and others to target this issue, as well as informing smokers so they can act responsibly.

Extended Producer Responsibility: Apply total life cycle responsibility to the manufacturer of the waste product so they have liability as well as responsibility for the economic, physical, and educational aspects of reducing cigarette butt waste.

Product Stewardship: Involve the distribution chain in post-consumer take back and final disposal of cigarette butts.

Package Labeling: Include information about the toxicity of discarded butts and instructions for safe disposal of the toxic waste product.

Banning Cigarettes: Cigarette butts pose a toxicity risk to ocean creatures, pets, and humans, so imposing a ban on their use on beaches should be considered by counties and municipalities. Current cigarette bans exist in California State Parks.

Individual Cigarette Receptacles: Individual receptacles (small metal boxes, like those used for breath mints) could be made available for loan at the entrance to beaches with the heaviest cigarette butt issues, along with bi-lingual signage regarding the toxicity of butts.

Helping People Quit: Smoking is the leading preventable cause of death and disease in the U.S. and most smokers want to quit (CDC, 2021). Programs to help people quit can help reduce addiction to cigarettes.

Wrappers (# items=96,954, 9.6%)

Wrappers were the third most counted litter items on MBNMS shoreline, with a total of 96,954 pieces collected over the five-year period representing 9.6% of items. Most wrappers were related to Eating and Drinking (99.5%); however, a small percent related to Various activities that were tabulated as "wrappers – non-food or unknown." Cigarette packaging and wrappers were considered as a separate category, however if combined would have increased the count to 100,222 pieces collected and counted. Most wrappers were composed of plastic (99.9%).

Wrappers are used to protect food or other consumer goods from contamination, to provide an identity and information related to the product contained, and to prolong shelf life. Wrappers are made of different plastic chemistries, with the most common being polypropylene (used for chip bags and candy wrappers) and polyvinyl chloride (used for cling wrap and food foils). Some are composed of multiple layers to provide the desired properties, which may include plastic, aluminum, and paper. Wrappers generally cannot be recycled, however there are replacement options available on the horizon.

Approaches to Reducing Wrappers on Beaches

Consumers can make a difference through purchasing products with a minimal amount of packaging and by making sure their wrappers are correctly disposed. These light weight food sleeves are easily blown by the wind so containment is key. Consider purchasing larger bags of desired products and then parceling a smaller quantity into a reusable container that is heavier and less likely to escape when going to the beach or other outdoor activity. As packaging design advances, consider looking for biodegradable or reusable food wrap alternatives.

Figure 29: Stewardship activities that humans can practice to help protect wildlife from marine debris. Photos: Karen Grimmer/NOAA, Josh Pederson/NOAA

Conclusion

Marine debris, especially plastic, is harming our ocean ecosystems. If we are to prevent increasing threats to marine organisms from entanglement and ingestion, we must reduce the amount of plastic leaking into the marine environment from human activities. Plastic in the ocean is nearly impossible to remove, and it does not biodegrade but only breaks apart. Thus, as more plastic is created each year, the problem will continue to worsen until we take measures to reduce debris at its source and prevent transport from land to sea. The most concerning marine debris items found in MBNMS, due to high quantities collected, are similar to those found around the globe: plastic fragments, cigarette butts, and wrappers. Collective action taken on the part of individuals, plastic producers, governments, and non-profit organizations are needed to reduce the amounts of these in an expedient and coordinated way.

Transport pathways for marine debris to the beach in MBNMS include rivers, storm drains, currents, offshore winds, and beachgoers. Until a robust dataset is available for numbers of beachgoers along the shoreline, it is not possible to accurately calculate the relative importance of each of these transport mechanisms. Once on the beach, marine debris can be prevented from entering or reentering the ocean if it is cleaned up prior to being transported from the beach to the ocean. We found that numbers of collectors involved in beach cleanups had a significant and consequential influence in this prevention effort. We encourage organizations and individuals to participate in shoreline cleanups and to simultaneously provide data on items collected using phone apps so that data is available for continued research and analysis to better understand source contributions and transport processes.

Involving citizen scientists in data collection not only provides a larger and more geographically distributed dataset for scientific analysis, more importantly, it develops a sense of stewardship and agency on the part of volunteers. The utility of these datasets could be greatly improved through standardized information related to effort: accurate date, accurate numbers of volunteers, time spent, and precise geographical coverage. The MBNMS Marine Debris Action Plan includes efforts to standardize data collection and reporting, which can now be carried forward as recommendations and in interactions with organizations collecting citizen science data. More information on this topic is included in Appendix A with additional recommendations for data that should be included for cleanups, considerations in regard to data categories and harmonization, and data integrity. Harmonization of different datasets could be facilitated through coordinated planning between organizations collecting citizen science data and the users of that data in order to determine a common framework for item classification.

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Appendix A: Data sources, cleanup, harmonization, and recommendations

Data Set Descriptions

We identified data sources collected by various organizations that both engaged in beach cleanups and simultaneously recorded trash items found along the shoreline of MBNMS. Our goal was to use multiple data sets in our analysis in order to be as complete and spatially comprehensive as possible. Even so, our data and subsequent analysis is incomplete. Many groups, individuals, state parks, and city services collect debris on the beaches without recording the items. Due to many cleanups where no records are kept, our analysis underrepresents the beach trash problem; however, we do not have a way of estimating how many such cleanups happened and how much debris removal went undocumented.

We were able to gain access to eight major data sets (n>100 cleanup events) that contained trash data for MBNMS shoreline. Each data set is described below.

NOAA Marine Debris Monitoring and Assessment Project (MDMAP)

MDMAP is a monitoring program of NOAA's Marine Debris Program. The MDMAP data portal is available on the web for data entry and download for the study of marine debris across the globe, with more data available for the U.S. than other nations. MDMAP prioritizes data quality and consistency. Data are collected following specific protocols and reviewed by NOAA staff before being published. The data portal is available to organizations who collect data following the protocol, and wish to use it for data management and display. Because registration is required and no downloadable app is available, the extent of usage is limited compared with datasets oriented toward opportunistic data collection; however, the rigor of including specific data (such as amount of time spent, cleanup area, and weather conditions) is increased. The MDMAP website maps international beach locations and provides a means to query marine debris data collected within countries, states, data collection organizations, or named beaches. Counts of marine debris are entered for surveys for seven materials of debris: cloth, glass, metal, plastic, rubber, processed lumber, and other. Each of these types of debris are broken into more categories. Organizations can optionally adopt sub-categories for more detailed information. Data can be explored and downloaded on MDMAP website. Visit for more information: https://mdmap.orr.noaa.gov

From 2011 to 2021, two different survey protocols were possible: Standing Stock and Accumulation. These were retired in 2021 and replaced with a single protocol that combines the two methods. MDMAP is segregated so that the mode of the survey is clear:

> During standing stock surveys the debris is not removed from the beach and remains in place. Normally this survey method is used by organizations for projects investigating the long-term balance between debris input and removal on specific beaches. Detailed data is collected on debris type, load, and density. The organizations using this method of data collection along MBNMS coastline include NOAA's Marine Debris Program, Long Marine Lab Stranding Network, and Greater Farallones National Marine Sanctuary.

> During accumulation surveys, the debris is collected and removed from the beach. This survey method is used by organizations wanting to help with beach or inland cleanups as well as to collect data that can be used to understand the rate of debris deposition, debris material types, and debris weight. The organizations who have

contributed data along MBNMS coastline to MDMAP include NOAA's Marine Debris Program, Long Marine Lab Stranding Network, California Coast National Monument Task Force, Save Our Shores, Scott's Valley High School, Sonoma Coast Surfrider, Surfrider Foundation Monterey Bay, and The Clean Oceans Project.

This data set has specific information on large pieces of debris found on beaches. The type and subtype of the debris are recorded using the same categories as the accumulation data. Examples of the specific debris subtype includes items such as shoes, cardboard, building materials, ropes, tires, etc. In addition, measurements of the size of the debris are included. The data can be used in the same way as other accumulation data, to understand the debris type and deposition rate of large debris. Although the subcategories are the same for the type of debris collected, the data format is different from the other two data sets from MDMAP, as this data set has each marine debris item listed on a separate row.

Debris Tracker

Debris Tracker is an app designed to help citizen scientists contribute data on debris while doing cleanups at any location globally: inland, beaches, and ocean based. Debris Tracker is powered by Morgan Stanley in partnership with National Geographic Society and the University of Georgia, developed with startup funding and assistance from NOAA's Marine Debris Program. It is an easy-to-use app that transmits data to an open data platform that is available for data download by individuals or organizations. Data can be downloaded relevant to collection efforts of specific organizations or for all data contributors within a date range. Debris Tracker allows data to be filtered geographically and is organized by type and subtype in a similar way to MDMAP, however the data categories are somewhat different. The major debris categories are fishing gear, plastic, metal, paper, lumber, boat parts, glass, rubber, cloth, and other items. There are 80 subcategories within these categories. The data download has separate rows for each item collected and identified. Debris Tracker can be customized to include area, number of people, land use, and duration by "opting in" to these options. As of February 2023, over six million debris items had been collected and recorded on the app. Visit for more information: https://debristracker.org

Trash Information and Data for Education and Solutions (TIDES)

TIDES is an online, open-access database hosted by Ocean Conservancy, containing the world's largest ocean trash dataset collected by volunteer cleanups. These data are collected during the annual International Coastal Cleanup (ICC) season, as well as year-round. Data can be submitted in several ways including submission via Ocean Conservancy's mobile data collection app, Clean Swell. Paper data cards can also be submitted manually on their website by making a free account, or data in other formats can be emailed directly to Ocean Conservancy for inclusion. The home page of the website features the running totals of the global impact volunteers have made over the 36-year history of the ICC, totaling more than 17,350,000 volunteers who have cleaned >125,000 locations and removed more than 349 million lbs. of trash across all continents (site accessed 05/20/22). In addition to collecting the number of participants at a cleanup and the total weight of debris removed, TIDES entries also may include itemized data spanning approximately 50 trash item categories. Summaries and other reports can be downloaded for any geographic area and timeframe. Note that most TIDES data contain categorized items however in some cases only includes weight. Visit for more information: https://www.coastalcleanupdata.org

Save Our Shores

For over 45 years, Save Our Shores (SOS) has been engaging community members in beach, inland, and river cleanups to remove harmful debris from the Monterey Bay Region in California. SOS hosts hundreds of events throughout the year and is also a regional coordinator for the Ocean Conservancy's International Coastal Cleanup Day (coordinated in California by the California Coastal Commission). During this event, they host between 60–80 cleanup events in Monterey and Santa Cruz Counties on the third Saturday in September each year. In 2008, SOS began training volunteers how to collect community science marine debris data that includes recording the types and quantities of debris collected during cleanup events. SOS continues to engage thousands of volunteers in litter removal and data collection at hundreds of cleanups a year, removing several tons of trash from the environment annually. The geographic extent of SOS beach cleanup along the Central California shoreline is from Ocean Beach in San Francisco to Soberanes Point in Garrapata State Park, Monterey County. Data are collected via a combination of paper data cards and mobile applications. Save Our Shores utilizes their internally generated paper data cards and mobile application (Save Our Shores Marine Tally app) for cleanups throughout the year. Additional information is also collected by the cleanup leader including the number of adult and youth participants, the weight (pounds) of debris collected (landfill and recycling), the cleanup site name, and the event duration (hours). Recently in 2021, a “Percent Area Cleaned” category was added to the SOS Marine Tally app to help estimate cleanup area and standardize the dataset. During International Coastal Cleanup Day, SOS utilizes the Ocean Conservancy’s Clean Swell mobile application and paper data cards, all of which populate a global online database for debris, Trash Information and Data for Education and Solutions (TIDES). The Clean Swell app collects similar data to the SOS mobile app; however, the categories differ slightly. Volunteers are given an orientation for how to properly record debris data at all SOS cleanups. The SOS Program Manager increases data integrity by downloading and merging each dataset (SOS and TIDES), combining overlapping categories, removing redundancies, and ensuring all event details are entered correctly. Visit for more information: https://saveourshores.org

Surfrider Foundation

Surfrider organizes chapters that convene beach cleanups in U.S. coastal states and engages in other activities to preserve beach access and protect the ocean. Surfrider uses a combination of data sheets and the Debris Tracker app to track marine debris in coastal cleanup events. When a chapter sees the need for data collection, they put more effort into trash surveys; however, often their primary purpose is beach cleanup, which is more effectively accomplished if data is not tracked and volunteers can focus on picking up litter. If a city or county is concerned with a particular litter item, such as plastic bags, they can initiate debris tracking to build a case for a ban or other community action. The marine debris data is organized in the same categories as Debris Tracker app. Visit for more information: https://www.surfrider.org

Downtown Streets Team Santa Cruz

Downtown Streets Team (DST) is a volunteer, work-experience program for those who are experiencing homelessness or are on the brink of becoming homeless. While volunteering their time, DST members participate in beautification projects throughout Santa Cruz including the beaches in town and in the northern part of Santa Cruz County. These beautification projects include beach cleanups and are a way for our unhoused community members to change the perceptions of homelessness, as well as engaging in dignified work that benefits the whole community. The data is not categorized by type of debris. Data includes total amounts of trash or recycling collected, measured as number of bags at each beach for each date. Visit for more information: https://www.streetsteam.org/santacruz

Data Set Assumptions

Data sources varied widely in terms of number of beach cleanups, geographic distribution, trash categories, purpose, methodology of data collection, and other information collected at the time of the survey (e.g., time spent, number of people involved, area covered, relevant conditions). In order to use as much of the data as possible in our analysis, we had to make assumptions and develop comparisons to overcome data differences. The Downtown Street's Team dataset did not contain sufficient detail to use in the analysis as it did not contain an item count or weight and the only data category was syringes, so it was omitted. The NOAA Marine Debris Map standing stock collection method did not involve beach cleanup, and trash items were left in place in order to provide data for a continuous study. For this reason, we elected not to include this data set in our analysis. The NOAA Marine Debris Large item dataset was in a vertical format at the time we received the data, however has since been reformatted to match the typical horizontal format. Due to the original data structure and few data points (513 total items), we did not include it. Five datasets included for analysis are the NOAA Marine Debris (MD) Map: 2.5–30cm, SOS, Debris Tracker, Surfrider, and TIDES.

Data Set	Start Date (all include 2021)	Number of Categories	Trash Weight	# People	Dimensions	Duration	Beach Name	lat & long
MDMAP: 2.5-30 cm	6/12/2012	48	NI	100%	length and width	100%	yes	yes
Save Our Shores	2/2/2008	75	77%	85%	31% (est. length)	79%	yes	NI
Debris Tracker	10/1/2014	53	NI	NI	0%	0%	0%	yes
TIDES	6/26/2015	50	100%	100%	distance	NI	NI	yes
Surfrider	1/9/2016	81	96%	96%	24%	45%	yes	yes

Table A1: Differences across the data sources for the five-year period 2017–2021. Percentages denote missing data from some entries and represent the percent of beach cleanup data that contains this information. Note that for TIDES data, for some beach cleanup events items are not tabulated and only total trash weight is reported.

General Data Clean Up Steps Taken

1. Removed data outside MBNMS boundaries and excluded inland or ocean data, not on the shoreline.
2. Removed data that did not contain basic information: date, location.
3. For location data with only a beach name, we identified the latitude and longitude for the beach.
4. Reviewed data sets for redundancy and removed repeated items. When two data sets contained the same data (same date, same beach, same trash), we removed the data from the smaller of the two data sets. For example, SOS uses the TIDES app for the Ocean Conservancy's Coastal Cleanup Day, so this data was removed from the SOS data to prevent double counting. We also removed repeated data from the same data set. In the case of TIDES, this resulted in removing 137 duplicated events.
5. Removed incongruent data. For example, one TIDES data point was 1,155 people collected one item of debris and weight was not given. Another removed point was one person collecting >3000 lbs. of trash in one day.

6. When weight was provided but not trash item count, we used a linear regression with the completed dataset that included both weight and count to estimate missing total number of items. We did this estimation separately for different weight intervals: 0 to 1 lb., 1 to 10 lbs., 10 to 100 lbs., and >100 lbs. of trash. (Note that estimation was not extended to activities or categories, just to total count.)
7. Removed data that had zeros for all items and <=0.01 lbs. for weight.
8. When the number of people involved distinguished adult volunteers from youth volunteers, we counted the youth volunteers as half an adult volunteer.

Data Harmonization Methods

The five data sets that were used for analysis (NOAA MD Map 2.5–30 cm accumulation data, Debris Tracker, TIDES, SOS, and Surfrider) required "harmonization" in order to create comparable data. We harmonized data sets by assigning beach activities, item categories, and the material composition of items so that these would be the same across all datasets.

1. We identified activities as a basis for the beach activities that result in trash found on beaches: eating and drinking, smoking, recreation, personal hygiene, fishing, and dumping and disaster. We added "various" activities because the trash item could have come from more than one of the other six identified activities.
2. We assigned categories to each trash item reported, working to find commonality between the datasets. Our goal was to retain as much of the original detailed identity of items as possible, however to use common categories across data sets.
3. Materials were included for each trash item, originating from the data set, or assigned based on knowledge of the item. "Rubber" was included as a "plastic," as objects identified as rubber (tires, flip flops, balloons) are normally manufactured from petroleum products rather than the sap of rubber trees.

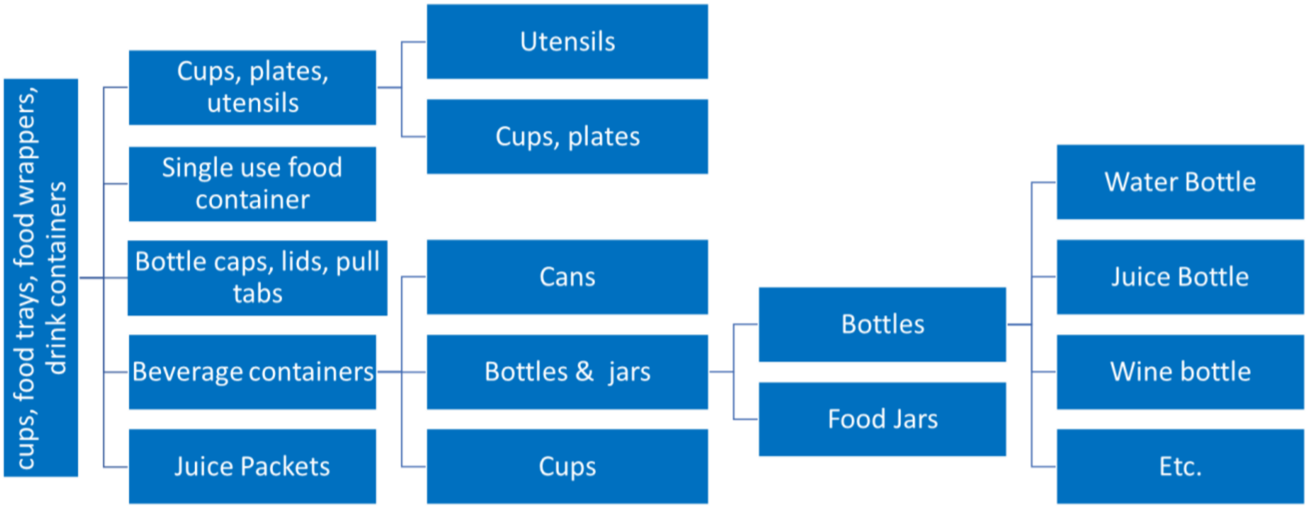
Assignment of Categories

We utilized the trash taxonomy tool (TTT) to assist us in harmonizing the counted items into similar categories across the different data sets. The trash taxonomy tool consists of hierarchical levels, starting with Level 1 that includes very general categories and moves toward more specificity as it progresses through levels, up to Level 6 (Hapich et al., 2022). Figure A1 is a simplified version of TTT levels expanding on the theme of food and beverage containers and carrying only one of the subthemes forward to more detailed levels. The complete TTT can be found online at: https://openanalysis.org/trashtaxonomy

Some of the datasets we used collect general TTT Level 1 or 2 specificity in their cleanup checklist while other datasets contain more specific categories (Levels 2–6). It is these differences that make the harmonization necessary. The issue is choosing which level of specificity to use in the analysis, which may include mixing and matching different levels. Harmonizing all data sets to the most generic common category, entails the risk of losing much of the information that is potentially interesting and relevant to determining what actions could be taken to mitigate that category of beach trash. For example, a municipality could determine to prohibit alcoholic beverages on the beach if a large number of beer, wine, or liquor bottles (Level 5) were found during cleanups; however, if this level of specificity is lost due to harmonizing to a broader more generic category such as beverage containers (Level 2), then the assessment of such a regulatory action might not be brought under consideration. For this reason, we chose the following approach to determining the level of specificity:

- Keep as much specificity as possible, so long as at least three out of the five data sets contain that level of specificity, recognizing that these specific items would be underrepresented in our findings however would not be completely lost in a more general category. We made a few exceptions to include categories of special interest, including take-out food containers, dog poop bags, shotgun wads, toys, and appliances.
- If the item represents at least 5% of the trash in the data sets where that item was tabulated, we decided to redistribute the items from the more general category in the datasets where the item was not represented in accord with the percent distribution in the representative datasets. However, this decision was not enacted, as in all cases the item was less than 5%.
- We chose names for categories where items were listed. For example, we changed the list "bottle caps, lids, and pull tabs" to the name "container.closures" (Figure A1).
- In some cases, we combined categories within the same level of the hierarchy and renamed them to fit the items included in the data set. For example, we combined "juice packets" with "beverage containers."

Harmonization between the five data sets following these guidelines resulted in a total of 41 trash categories.



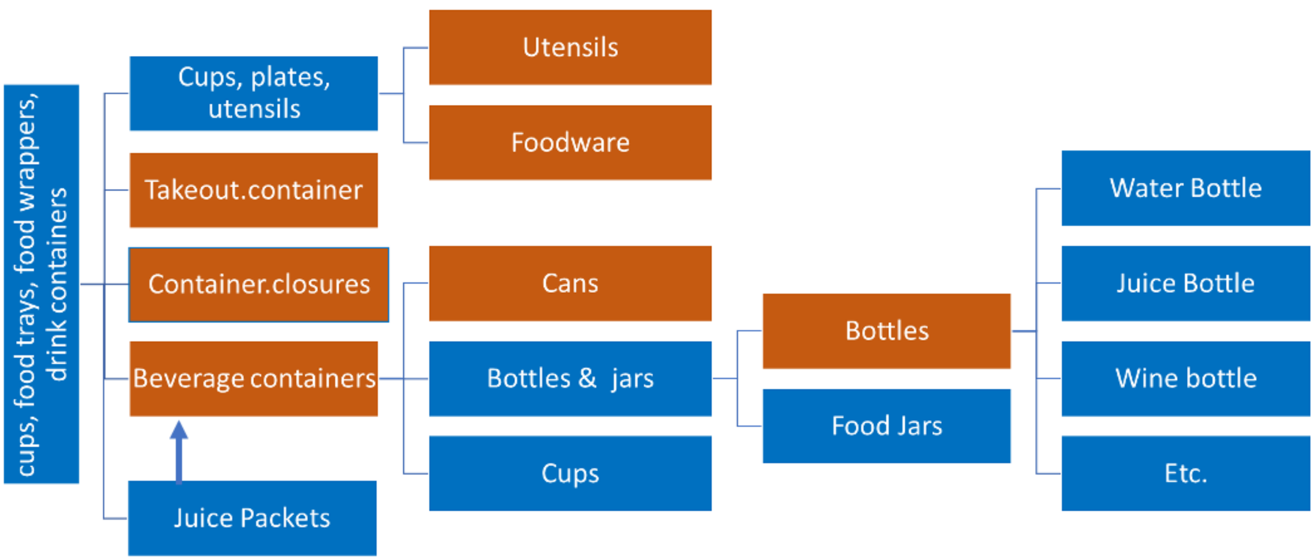


Figure A1: The Trash Taxonomy Tool (TTT) was used for harmonizing the five datasets. We determined TTT categories for beach debris items related to each beach activity. The top figure shows a subset of the TTT hierarchy applied to "eating" and original TTT categories and relationships. The bottom figure shows in orange highlights the categories used for our analysis, including name changes. Note that "Beverage containers" includes jars, juice packets, jugs, and juice sachets. We maintained a separate identity for bottles and cans since these are more prevalent and because regions may develop bottle and can return policies to encourage retaining and recycling these items.

Table A2: Each data set and the totals for the categories within that data set. "NA" represents that no items fit into that category for that data set.

Category	TIDES	SOS	MDMAP	Surfrider	Debris Tracker	Total	Percent
six-packholders	50	87	9	38	NA	184	0.02
appliances	73	23	NA	NA	NA	96	0.01
bags	12,142	4,981	797	2,519	42	20,481	1.97
balloons	1,235	1,153	216	152	NA	2,756	0.26
beverage.containers	987	89	660	96	31	1,863	0.18
bottlecap	23,619	19,850	NA	3,884	23	47,376	4.55
bottles	15,875	11,675	1,605	3,257	107	32,519	3.12
buoys.pots.traps	117	70	22	28	2	239	0.02
cans	7,671	8,231	1,039	2,036	247	19,224	1.85
cig.packaging	2,944	282	NA	186	12	3,424	0.33
cigarettebutts	148,880	NA	NA	85,587	281	234,748	22.53
cigartip	1,031	284	622	446	NA	2,383	0.23
clothing.fabric	NA	2,190	2,879	NA	31	5,100	0.49
construction	3,729	2,484	2,632	NA	5	8,850	0.85
container.closures	6,968	858	4,408	478	61	12,773	1.23
diapers	117	166	NA	14	1	298	0.03
dogpoopbags	NA	224	NA	82	NA	306	0.03
ecigarette	1,205	126	NA	12	NA	1,343	0.13
fireworks	520	178	NA	200	NA	898	0.09
fishing.line	452	657	354	153	1	1,617	0.16
fishing.net	268	206	1,658	282	20	2,434	0.23
fishinggear	2,638	1,427	NA	165	NA	4,230	0.41
foodware	7,206	8,920	733	1,792	61	18,712	1.80
glassfragments	7,860	21,157	3,670	2,415	NA	35,102	3.37
lighter	251	552	195	55	NA	1,053	0.10
metalfragment	NA	NA	2,826	626	2	3,454	0.33
misc	50,250	4,884	9,138	312	131	64,715	6.21
packaging	11,560	NA	136	NA	1	11,697	1.12
paper.wood	0	54,139	8,281	1,107	NA	63,527	6.10
personal.careproducts	160	2,256	686	428	NA	3,530	0.34
plasticfragments	94,528	135,196	26,997	19,586	299	276,606	26.55
PPE	10,828	804	53	919	292	12,896	1.24
shotgunwads	NA	NA	NA	31	NA	31	0.00
straws.stirrers	8,647	5,787	1,293	1,265	45	17,037	1.64
syringes	92	414	NA	21	NA	527	0.05
Take-outfood.container	9,123	7,292	NA	430	14	16,859	1.62
tampons.applicators	131	469	NA	21	NA	621	0.06
tires	170	45	32	7	1	255	0.02
toys	2,489	2,656	NA	NA	NA	5,145	0.49
utensils	5,164	620	550	332	13	6,679	0.64
wrappers	46,037	44,314	5,652	4,051	150	100,204	9.62

Recommendations for Organizations Developing Apps and Providing Data Sets

First and foremost, collect data on a regular basis at all events, even though it may take longer. Without data, it is impossible to understand worst debris problems, where debris is sourced, how it is transported, and importantly to strategize preventative measures. Organizations managing datasets could benefit research attempts to understand trash density and types of trash by including common basic information: date, number of people, starting and ending GPS coordinates, area, and location definition (such as beach, roadway, parking lot, and dune), without which comparisons across data sets are not feasible (Serra-Goncalves, 2019). Additionally, agreement is needed about categories that should be included in all datasets due to the need to make strategic decisions regarding social change and to inform legislative efforts. Based on our efforts to develop understanding of beach trash cleanup data for MBNMS shoreline, we provide the following suggestions for data sets that could be used to derive more informative statistics and be more easily harmonized:

Include in Data Collected

1) Include basic information: date, general site information, specific location (beach name or latitude and longitude), area covered, number of people, and time spent. Be precise in this information and don't estimate. Number of people involved in cleanups turned out to be the most important predictor variable for shoreline debris.
2) Include categories for the general site information: shoreline, beach, roadways, parking lots, river banks, inland developed area, or ocean.
3) Avoid collecting large cleanups in one compiled event. Better information is collected when individuals use an app and track data for a smaller group.
4) Allow individuals to edit their data later, if possible.

Data Available for Download

1) Remove duplicate values from the data set prior to putting it online or distributing it. Although it is possible for the analyst to remove duplicate events when all values are the same, especially be sure that if an organization is summing information for an event, that results are not also reported separately by individuals.
2) Make sure the data download from a website is organized properly with data in the correct columns.
3) Make downloads possible within a geographic region.

Categories to Include

1. Include categories of concern where legislative or other corrective action could be taken and be sure to list these as categories. For example, do not combine cigarette butts and cigar tips as these each have distinctive legislative, producer responsibility, or end of life solutions.
2. Convene with other apps and organizations to identify the categories that should be common across all data sets and develop a common framework so that datasets can be more easily harmonized for items that are not in common.
3. For recording fragments, consider including counts for different sizes and materials. For example, include foam, film, and hard plastic in three sizes each: SMALL: the size of a fingernail

(2.5 cm), MEDIUM: smaller than an outstretched hand (2.5-15 cm), and LARGE: larger than a hand (>15 cm).

Meetings and Collaborations

- Consider having annual meetings with others collecting marine debris data and discussing what categories and additional information to include on data sheets.
- Discuss the use of the data with researchers who have analyzed the data or who use the apps for collecting data to find out what issues they encountered and what additional information would help them.
- Meet with local organizations who are focused on eliminating debris from activities, such as smoking and cigarette butts or preventing certain types of plastic use. Find out what type of data would help their mission.
- Ensure that individual organizations spearheading volunteer efforts, as well as volunteers themselves, are recognized within larger datasets in order to foster sustainable relationships.
- Find ways to include data collection training without discouraging volunteers. Having more accurate and inclusive training would help with data analysis and volunteer training is important toward this end.

NATIONAL MARINE
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