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Plastic Litter in National Marine Sanctuaries in the West Coast Region and Monitoring Solutions

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Cover photo: Plastic litter on a beach. Photo: NOAA

About the National Marine Sanctuaries Conservation Series

The Office of National Marine Sanctuaries, part of the National Oceanic and Atmospheric Administration, serves as the trustee for a system of underwater areas encompassing more than 620,000 square miles of ocean and Great Lakes waters. The 16 national marine sanctuaries and two marine national monuments within the National Marine Sanctuary System represent areas of America's ocean and Great Lakes environment that are of special national significance. Within their waters, giant humpback whales breed and calve their young, coral colonies flourish, and shipwrecks tell stories of our nation's maritime history. Habitats include beautiful coral reefs, lush kelp forests, whale migration corridors, spectacular deep-sea canyons, and underwater archaeological sites. These special places also provide homes to thousands of unique species, some of which are endangered, and are important to America's cultural heritage. Sites range in size from less than one square mile to almost 583,000 square miles. They serve as natural classrooms and cherished recreational spots, and are home to valuable commercial industries.

Because of considerable differences in settings, resources, and threats, each national marine sanctuary has a tailored management plan. Conservation, education, research, monitoring, and enforcement programs vary accordingly. The integration of these programs is fundamental to marine protected area management. The National Marine Sanctuaries Conservation Series reflects and supports this integration by providing a forum for publication and discussion of the complex issues currently facing the National Marine Sanctuary System. Topics of published reports vary substantially and may include descriptions of educational programs, discussions on resource management issues, and results of scientific or historical research and monitoring projects. The series facilitates integration of natural sciences, socioeconomic and social sciences, education, and policy development to accomplish the diverse needs of NOAA's resource protection mandate. All publications are available on the Office of National Marine Sanctuaries website.

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Report Availability

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Abstract

Plastic pollution is ubiquitous in the environment, threatening marine ecosystems. The influx of plastic pollution in national marine sanctuaries poses a threat to marine life, but also challenges the balance of the rich cultural, ecological, and economic history of sanctuaries. The purpose of this report is to synthesize resources pertaining to plastic debris in national marine sanctuaries in the U.S. West Coast region at the time of publication and potential monitoring approaches. This report will discuss (1) the status of marine debris in each national marine sanctuary in the West Coast region, (2) research and monitoring efforts in national marine sanctuaries in the West Coast region, and (3) monitoring gaps and potential solutions. The findings aim to inform and enhance future conservation and monitoring strategies, ensuring the sustained protection and resilience of these vital marine ecosystems.

Key Words

marine debris, microplastics, macroplastics, ocean plastic, monitoring programs, monitoring plan, debris removal, plastics, plastic litter

Chapter 1:
Status of Plastic Debris in Sanctuaries in the West Coast Region

Figure 1.1. Bottle caps removed from beaches during a 2021 beach cleanup. Photo: NOAA

Background

National marine sanctuaries across the United States are intended to protect and preserve marine ecosystems. The West Coast Regional Office of the Office of National Marine Sanctuaries manages 15,333 square miles of marine protected areas, including Channel Islands, Cordell Bank, Greater Farallones, Monterey Bay, and Olympic Coast national marine sanctuaries. Each sanctuary embodies varying characteristics, each with unique habitats, species, and maritime heritage. National marine sanctuaries are crucial for preserving and safeguarding marine ecosystems, fostering biodiversity, and ensuring the sustainable management of our ocean.

Reduction of marine plastic litter is an immense challenge across U.S. coastlines. In California alone, it was estimated that local taxpayers spend over $420,000,000 annually to prevent plastic and other litter from entering waterways (California Ocean Protection Council & NOAA Marine Debris Program, 2018). Sanctuary-specific activity is primarily driven by the National Oceanic and Atmospheric Administration (NOAA) Marine Debris Program, focusing on removal, prevention research, regional coordination, and emergency response related to marine debris (NOAA Marine Debris Program, n.d.). Since 2006, the NOAA Marine Debris Program has supported over 160 marine debris removal projects and removed more than 36,000 metric tons of debris from coasts, the ocean, and the Great Lakes (NOAA Marine Debris Program, n.d.).

Reduction of marine plastic debris is a complex issue that demands a comprehensive approach that encompasses education and outreach, removal efforts, policy development, and scientific investigations. This endeavor necessitates collaboration among governments, communities, and industries to establish effective programs to combat this issue. The goal of this report is to synthesize resources pertaining to plastic debris in national marine sanctuaries along the West Coast at the time of publication. To achieve this, the report is separated into three chapters. Chapter 1: the scope of plastic litter in national marine sanctuaries; Chapter 2: plastic monitoring and research efforts conducted by both federal and nonfederal organizations that contribute to the overall understanding of plastic debris in sanctuaries along the West Coast; and Chapter 3: strategies for monitoring macroplastics and microplastics in national marine sanctuaries along the West Coast.

NOAA categorizes marine debris as any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment (NOAA National Ocean Service, n.d.-a). Marine debris is a broad term and can refer to anything from beachgoer litter to derelict vessels. Despite sanctuary protection efforts, marine debris may be brought into sanctuaries by ocean currents, natural disasters (e.g., tsunamis), storm runoff, recreational and commercial activities, military activities, etc. Marine debris can also be directly deposited into sanctuaries both illegally and through activities that are permitted or exempted.

A significant subset of marine debris is plastic pollution, which is especially problematic because it persists for long periods in the environment. Generally, plastics are categorized into “macroplastics” and “microplastics.” NOAA categorizes microplastics as small pieces of plastic, less than five millimeters long (NOAA National Ocean Service, n.d.-b), while macroplastics are categorized as plastic litter larger than five millimeters long. Macroplastics have the ability to turn into microplastics as they are broken into smaller pieces within the environment. Although plastics may become more and more fragmented, plastics will likely never fully degrade in the marine environment (NOAA Marine Debris Program, 2024a). Microplastics are ubiquitous in the marine environment and have been documented on beaches (Akkajit et al., 2021; Alvarez-Zeferino et al., 2020), among mangroves (Celis-Hernández et al., 2021), in estuaries (Harris, 2020; Pagter et al., 2020), in surface waters (Silvestrova & Stepanova, 2021), in the water column (Defontaine et al., 2020), in sediments (Feitosa Cruz et al., 2019; Pagter et al., 2020), and in the deep ocean (Zhang et al., 2020). Microplastics are also found in most species, as marine organisms at all trophic levels are exposed to microplastics (Besseling et al., 2019; de Sá et al., 2018). They have also been found specifically in the sediments (Steele & Miller, 2022) and surface waters (Sutton et al., 2019) of national marine sanctuaries along the West Coast.

Threats to National Marine Sanctuaries in the West Coast Region

While all sanctuaries experience problems with derelict fishing gear, beachgoer litter, animal entanglements, or debris runoff into sanctuary waters, each sanctuary faces unique concerns regarding marine debris depending on location (Figure 1.2). Marine debris composition and volume varies among sanctuaries due to factors including local current patterns, extreme weather events, public awareness, commercial activity, recreational activity, and input sources. Problems with marine debris have been studied and documented with varying magnitude in each sanctuary, making it difficult to directly compare levels of marine debris among national marine sanctuaries along the West Coast. However, sanctuary condition reports provide insight to specific marine-debris-related issues in each sanctuary.

Major marine debris themes are documented in sanctuary condition reports. It is crucial to emphasize that these challenges extend beyond the confines of any single sanctuary, and this discussion is not intended to provide a comprehensive overview of all relevant aspects. Rather, these are pivotal issues and recurring themes experienced by each national marine sanctuary along the West Coast.

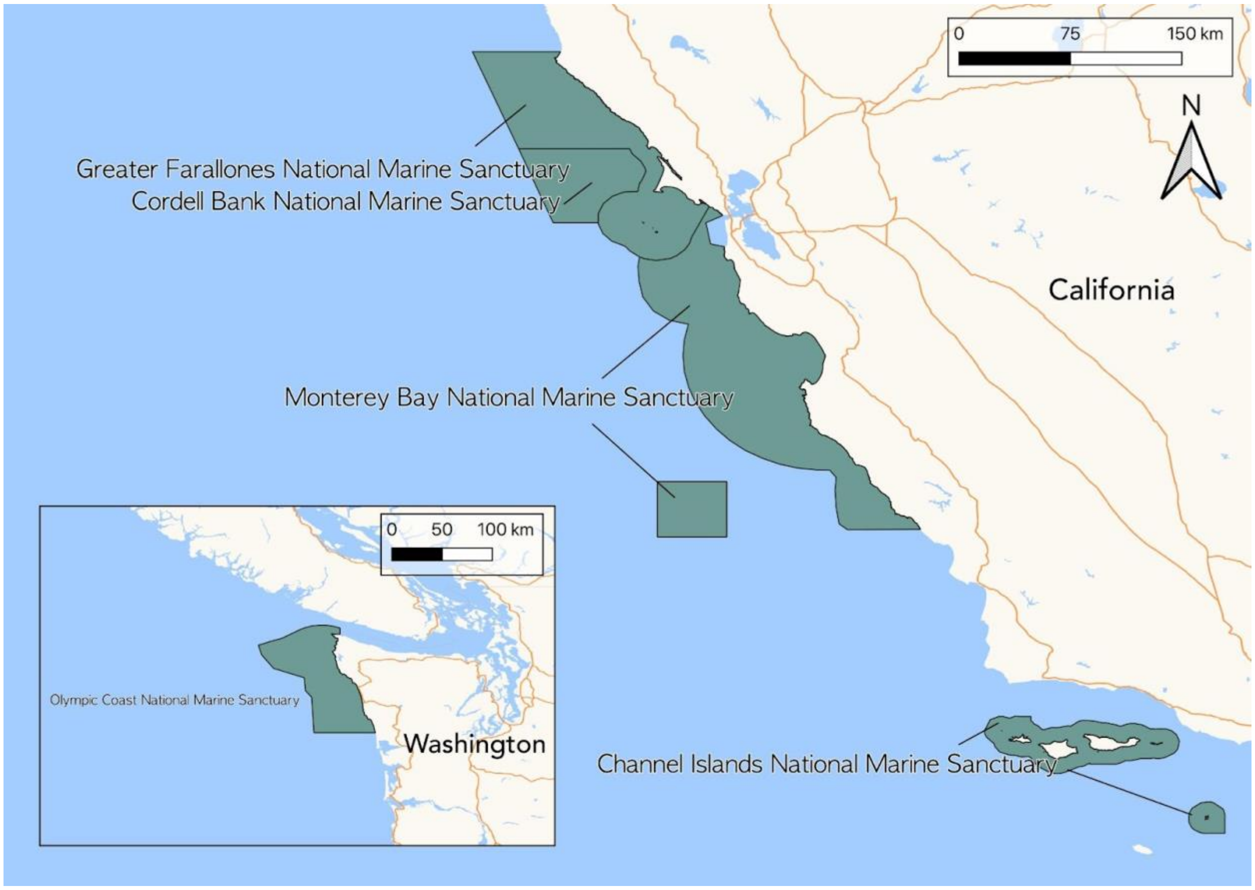

Figure 1.2. Map of national marine sanctuaries in the U.S. West Coast region.

Olympic Coast National Marine Sanctuary

Olympic Coast National Marine Sanctuary (OCNMS) is the only sanctuary in Washington state, encompassing 3,188 square miles of marine waters off the rugged Olympic Peninsula coastline, and is located within the usual and accustomed fishing areas of four coastal tribes with reserved treaty rights: the Hoh Tribe, Makah Tribe, Quileute Tribe, and Quinault Indian Nation. OCNMS represents one of North America’s most productive marine ecosystems and relatively undeveloped coastlines. The prevalence of plastic pollution in OCNMS poses a threat to marine life and also challenges the balance of the rich cultural, ecological, and economic history of this sanctuary. In 2011, a 9.0-magnitude earthquake off the coast of Japan resulted in an unprecedented influx of marine debris, estimated at five million tons, into the Pacific Ocean, bringing significant amounts of debris to OCNMS (Office of National Marine Sanctuaries [ONMS], 2022). This surge in debris created immense challenges for the sanctuary, including entanglement hazards for marine animals, ingestion risks, invasive species risks, and the degradation of habitats crucial for the sanctuary's biodiversity and cultural significance. Recognizing the need to monitor the presence of this anthropogenic debris, the NOAA Marine Debris Monitoring and Assessment Project (MDMAP) was initiated on the coastlines of OCNMS (see Chapter 2 for more information on MDMAP). MDMAP played a crucial role in tracking the impacts of plastic pollution in the aftermath of the influx of marine debris into OCNMS, providing valuable data for informed conservation strategies to ensure the long-term health of the sanctuary.

Marine debris is found on the beaches, surface, and seafloor of OCNMS. Marine debris on beaches includes items that have washed ashore as well as those left by beachgoers. Submerged marine debris includes vessels, fishing gear, research equipment, trash, etc. Crushed cars have fallen off open-deck barges from Canada, and now litter the northern portion of OCNMS. Since 2011, at least four crushed cars have been pulled up in fishing gear of Makah tribal members. In 2015, a survey off Cape Flattery revealed an additional thirteen cars in the sanctuary, and there are no requirements or plans to remove them.

Greater Farallones National Marine Sanctuary

Greater Farallones National Marine Sanctuary is home to the largest concentration of nesting and migratory seabirds in the contiguous United States. These birds rely significantly on the sanctuary’s productive waters for sustenance. The Greater Farallones National Marine Sanctuary (GFNMS) 2024 condition report emphasizes the concern of entanglements in fishing gear and plastic debris, as 1,020 entangled birds and mammals were observed between 2013 and 2021 near Southeast Farallon Island (ONMS, 2024). Moreover, the sanctuary struggles with abandoned or lost crab pots, with approximately 29,200-83,500 commercial Dungeness crab traps are set on the seafloor annually (ONMS, 2024). Additionally, a unique concern within the sanctuary is the presence of plastic shotgun wads, likely originating from waterfowl hunting and shooting activities in the San Francisco Bay Area. In response, GFNMS has initiated a behavior change campaign to address the issue, leveraging signage and outreach efforts to raise awareness and encourage responsible hunting practices (Bimrose et al., 2020). The campaign has had promising results, including increased hunter participation in wad cleanup efforts and heightened awareness of the problem (Bimrose et al., 2020). However, continued efforts and collaborative action are essential to effectively tackle the complex issue of plastic pollution in GFNMS.

Cordell Bank National Marine Sanctuary

Plastic debris presents a challenge within Cordell Bank National Marine Sanctuary (CBNMS), where it is found in both surface waters and benthic habitats across the bank, shelf, and deep canyons. Particularly concerning is the high presence of offshore derelict fishing gear, including longlines, gill nets, and crab gear, observed entangled on benthic structures in remotely operated vehicle (ROV) surveys (ONMS, 2023). While marine debris is recorded during ROV surveys, the lack of standardized collection methods limits comprehensive comparison across spatial and temporal scales. Additionally, despite management efforts to mitigate fishing gear loss, derelict fishing gear and litter persists in deeper slope and canyon habitats, suggesting complexities of local and external sources contributing to marine debris accumulation within benthic environments in the sanctuary.

Monterey Bay National Marine Sanctuary

Monterey Bay National Marine Sanctuary (MBNMS) encompasses approximately a quarter of California's coast and 6,094 square miles of waters: about the size of Connecticut. A comprehensive study conducted within the sanctuary's waters shed light on the distribution of microplastics and microfibers, revealing higher concentrations in nearshore compared to offshore areas (Kashiwabara et al., 2021). Along the sanctuary's remote beaches, fragmented plastics and polystyrene foam emerged as the two most common types of litter, highlighting the pervasive nature of plastics even in seemingly remote locations. Additionally, MBNMS has employed ROV surveys to quantify debris within Monterey Canyon, uncovering over 1,000 human-made items over a 22-year period, with plastic being the most common (Schlining et al., 2013). The ubiquity of plastic debris in remote benthic habitats and coastlines demonstrates the need for efforts to further monitor plastic pollution in sanctuaries.

Channel Islands National Marine Sanctuary

Channel Islands National Marine Sanctuary (CINMS), located approximately 20 miles off the coast of California, is rich in biodiversity and natural beauty, yet the persistent challenges of marine debris remain prominent. Marine debris levels in CINMS have been surveyed by a team at the Santa Rosa Island Research Station, resulting in the removal of over 12,000 pounds from beaches on Santa Rosa and Santa Cruz islands between September 2020 and September 2023 (NOAA Marine Debris Program, 2024b). Additionally, a comprehensive 30-year study revealed significant differences in the composition of debris items between Northern Channel Islands beaches and mainland beaches, with fishing gear constituting a notably higher percentage of debris on island beaches (Miller et al., 2018). Additionally, CINMS experiences strong seasonal upwelling patterns that drive a seasonal influx of marine debris, particularly during the winter months.

Concluding Thoughts

While each sanctuary experiences various levels of plastic debris and microplastic contamination, there is an overarching common need to minimize levels of contaminants in the marine environment, including plastic debris and microplastics. Examining the varying problems facing different national marine sanctuaries allows a more targeted discussion on how plastic pollution differs between sanctuaries, as well as sanctuary-specific discussions for tackling plastic pollution.

Chapter 2: Research and Monitoring Efforts in Sanctuaries in the West Coast Region

Figure 2.1. NOAA Marine Debris program personnel removing coral skeletons caught in a derelict net. Photo: NOAA

Background

Several organizations have provided context to the scope of plastic debris in national marine sanctuaries along the West Coast. Ideally, ecosystem monitoring programs would quantify plastic pollution at periodic intervals across multiple sites with a consistent approach to sample collection and analysis; however, funding issues and lack of support for a systematic monitoring effort are barriers to starting successful long-term monitoring programs. This section of the report will discuss the organizations that have been performing plastic debris monitoring in sanctuaries and their findings, including (1) ongoing debris removal within the boundaries of national marine sanctuaries in the West Coast region, (2) long-term monitoring efforts, and (3) short-term research.

Ongoing Debris Removal

Debris removal events can be an important source of data on plastic debris, providing valuable insights into their sources and distributions in the absence of directed monitoring. These cleanups also have the potential to aid in the tracking of plastic pollution trends over time and understanding what types of pollution are prevalent most locally. Moreover, they raise public awareness about the issue and foster collaboration among stakeholders, including researchers, government agencies, and local communities, as well as Indigenous tribes and nations. Organizations that host beach cleanups with national marine sanctuaries along the West Coast include:

Name of Organization	Geographic Scope	Number of Events
Surfrider – Better Beach Alliance	United States	Organized 685 beach cleanups on the West Coast in 2022 (Surfrider, 2023)
California Coastal Commission – California Coastal Cleanup Day	California	Organized 600 cleanups in California on 38th Annual California Coastal Cleanup Day in 2022 (California Coastal Commission, 2022)
Washington CoastSavers	Washington	Organized 30+ cleanups in Puget Sound and coastal Washington in 2021 (Washington CoastSavers, n.d.)
Save Our Shores	Monterey Bay	Organized 200+ beach cleanups in Monterey Bay (Save Our Shores, n.d.)

This report does not encompass all organizations that organize beach cleanups in national marine sanctuaries along the West Coast. However, these are examples of organizations that have prevented significant amounts of debris from entering the ocean.

Some of these organizations quantify the type and frequency of different debris items, potentially providing insight into marine debris trends on beaches. Their efforts are imperative to reducing litter in the ocean and raising awareness about the impacts of plastic pollution on marine life, habitats, and human health.

Long Term Monitoring Programs

Background

Long-term monitoring programs are important for understanding the scope of marine debris on the West Coast. Three long-term marine debris monitoring programs will be highlighted: the NOAA Marine Debris Program MDMAP, the San Francisco Estuary Institute (SFEI) Regional Monitoring Program, and the Southern California Coastal Water Research Project (SCCWRP) Bights Survey. Long-term monitoring occurs at sites over periodic intervals with a consistent approach to sample collection and analysis.

NOAA Marine Debris Program

The NOAA Marine Debris Program, established in 2006, is a federal organization dedicated to tackling the issue of debris influx into marine environments. The NOAA Marine Debris Program operates under six primary pillars: prevention, removal, research, monitoring and detection, response, and coordination (NOAA Marine Debris Program, n.d.). One of its initiatives, MDMAP, launched in 2012, engages citizen scientists in quantifying plastic debris types and abundance along beaches. MDMAP provides information about the scale, composition, and distribution of debris found on beaches across the United States. By understanding the types and amounts of debris, as well as emerging patterns and trends, targeted mitigation strategies and policies can be implemented to protect marine life, habitats, and biodiversity, ultimately contributing to the overall health of marine environments.

MDMAP relies on community members to inventory marine debris along coastlines and input findings into a centralized database. Volunteers select a 100-meter shoreline survey site and randomly select four 5-meter transects to survey for items 2.5 centimeters or longer (NOAA Marine Debris Program, 2021). All items recorded are categorized based on the material and type of debris (e.g., “plastic, hard fragment” or “plastic, straw”). Volunteers also report information about the transect, including beach width, slope, primary substrate, team size, and photos. This is helpful to determine variability in marine debris among different transects, as well as potential biases. Since the program's initiation in 2012, it has expanded to over 200 transects on the West Coast.

MDMAP reported that 85% of all debris recorded on all surveyed beaches between 2012 and 2023 was plastic (Figure 2.2). The breakdown of plastic debris >5 millimeters was as follows: hard fragments (30%), foam fragments (11%), bottle or container caps (8.5%), rope and nets (7.8%), and film fragments (6.6%; Figure 2.3). A significant number of plastic debris recorded was fragmented, indicating a high potential for plastic breakdown to result in microplastics (<5 mm).

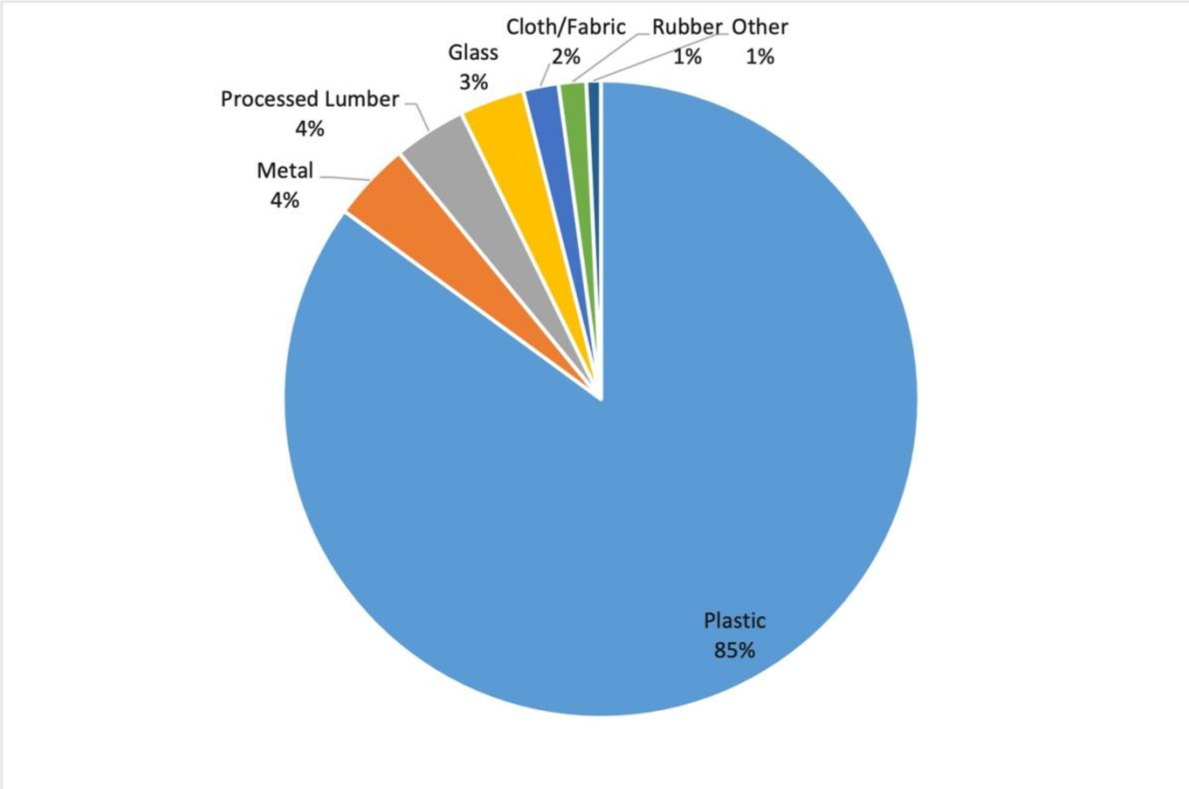

Figure 2.2. Recorded type of all marine debris surveyed between 2012 and 2023. Source: NOAA Marine Debris Program, 2024c

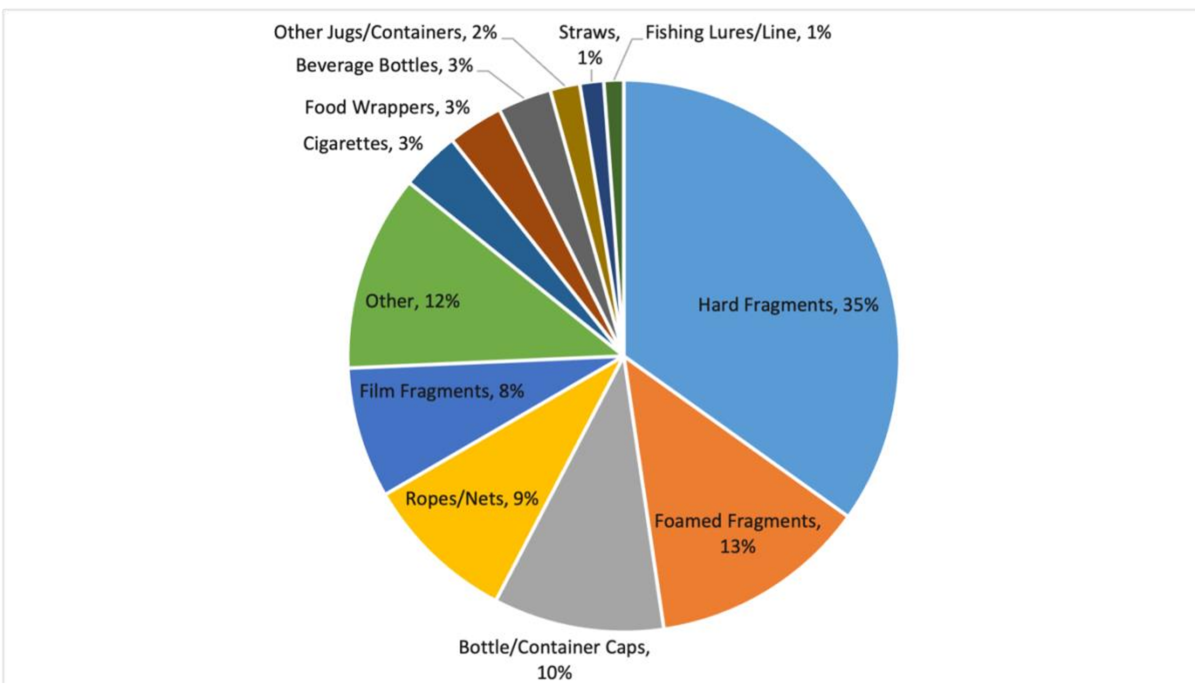

Figure 2.3. Recorded morphology of plastic marine debris surveyed between 2012 and 2023. Source: NOAA Marine Debris Program, 2024c

MDMAP serves as a valuable resource for analysis of marine debris trends in sanctuaries. Utilizing this database in subsequent studies could provide valuable information regarding the variability of debris across various sanctuaries and shed light on the underlying factors contributing to these variations. These data may be utilized by organizations to do rapid analysis of beach-based marine debris trends.

San Francisco Estuary Institute

SFEI has initiated a successful microplastic monitoring program, which includes comprehensive data collection and analysis aimed at understanding and mitigating the impact of microplastic pollution in aquatic ecosystems. SFEI is an non-profit environmental research organization that works to sustain the chemical, physical, and biological health of the San Francisco Bay-Delta Estuary. In 1993, SFEI established the Regional Monitoring Program for Water Quality in San Francisco Bay, providing information on contaminant issues facing the bay, sampling the status of water, sediment, sport fish, bird eggs, prey fish, marine mammals, and hydrographic and suspended sediment. Microplastic sampling was integrated into the Regional Monitoring Program in 2017. Incorporation of microplastics in the Regional Monitoring Program was sparked by a previous study of microplastic pollution in the San Francisco Bay, which found extensive contamination that surpassed that of other U.S. water bodies characterized by significant urban development, including the Great Lakes and Chesapeake Bay (Sutton & Sedlak, 2017).

SFEI and 5 Gyres, an environmental non-profit focused on reducing plastic pollution, published a two-year study of microparticle and microplastic levels in stormwater, treated wastewater, surface water, sediment, and prey fish (Sutton & Sedlak, 2017). These data increased understanding of the extent of plastic pollution in several national marine sanctuaries along the West Coast, as San Francisco Bay flows into MBNMS, GFNMS, and CBNMS (Figure 2.4). Additionally, 11 surface water monitoring sites were established within these sanctuaries. Using manta trawls, it was estimated that sanctuary surface waters have a median microplastic concentration of 82,000 particles per square kilometer and mean of 110,000 particles per square kilometer (including fibers; Sutton et al., 2019). Transport models were also developed to simulate anthropogenic particle movement between the bay and adjacent national marine sanctuaries.

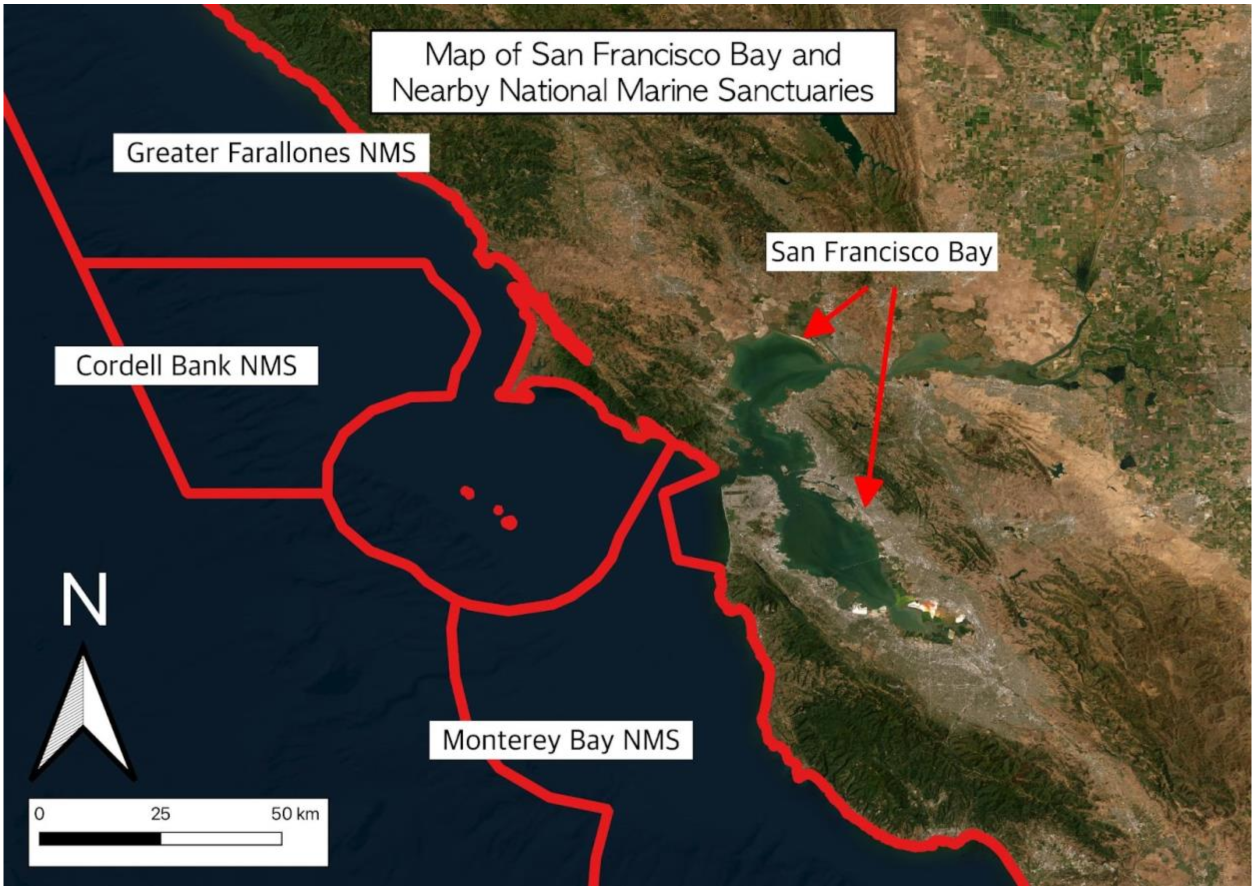

Figure 2.4. Map of San Francisco Bay and nearby national marine sanctuaries.

Additionally, SFEI is currently collaborating with the State Water Resources Control Board on the implementation of a multi-year Statewide Plastics Monitoring Plan and Strategy, which is funded by the California Ocean Protection Council. This monitoring program aims to determine what macroplastics are most pervasive in the environment to support policy and regulatory decisions in California. Objectives from a 2022 report include developing strategies for plastic pollution prevention and monitoring, developing risk thresholds, identifying microplastic sources, and evaluating new solutions (California Ocean Protection Council, 2022). These strategies will be utilized to establish the Statewide Microplastics Strategy aimed to ensure microplastic contamination falls under thresholds for biological health impacts.

Southern California Coastal Water Research Project

SCCWRP is an intergovernmental public agency dedicated to aquatic sciences research, striving to enhance effective management of aquatic systems. SCCWRP publishes the Southern California Bight Regional Monitoring Program every five years, reporting the status of freshwater and marine sediment toxicity, sediment chemistry, benthic infauna, demersal fishes and megabenthic invertebrates, contaminant bioaccumulation in sport fish tissue, sediment quality synthesis, harmful algal blooms, and trash/marine debris. Although the geographic scope of the bight survey is outside of most sanctuary boundaries besides CINMS, it serves as an example of effective implementation of a monitoring program that studies marine litter on the West Coast.

Marine debris and trash were first incorporated in the Southern California Bight Regional Monitoirng Program in 1994 to evaluate the scope and scale of marine debris across Southern California. The most recent 2018 assessment report described results from a total of 138 manta trawls at depths of 5–500 meters (McLaughlin et al., 2022). Over 250,000 trawl-caught pieces of trash were collected offshore, highlighting the substantial quantity of marine debris affecting the surveyed areas (McLaughlin et al., 2022). Plastic trash prevalence increased from 4% to 17% in these offshore areas from 1994 to 2018 (McLaughlin et al., 2022). In 2013, the bight survey incorporated transport and extensive trend analysis of both land and ocean-based trash into the study. While monitoring programs such as the Southern California Bight Regional Monitoring Program serve as foundations for understanding the extent of litter accumulation in aquatic ecosystems, research also has significant implications for developing understanding of the extent of plastic pollution in national marine sanctuaries along the West Coast.

Research

There has been an abundance of research on the West Coast focused on quantifying plastic debris and the impacts of such material on ecosystems. Gathering plastics data over a set period is important for our understanding of the scope of the problem; however, research has limited implications when comparing datasets over time. Academic research plays a role in targeting specific questions and tracking patterns that can be used to enhance the effectiveness of long-term monitoring. The papers included in Appendix A focus primarily on microplastic pervasiveness in selected species and macrodebris along shorelines, reporting high amounts of both macro and microplastics along the West Coast. See Appendix A for information on research projects that have been conducted in and near the boundaries of national marine sanctuaries along the West Coast.

Chapter 3:
Monitoring Gaps and Potential Solutions

Background

Combining various long-term monitoring strategies offers the most effective means of assessing plastic pollution for comparison over temporal and spatial scales. This chapter outlines recommendations for long-term monitoring programs gleaned from the successful programs described previously. We acknowledge that many of these suggestions may have practical challenges considering staffing, funding, and timing limitations.

Microplastic Monitoring

Due to the complexity and vastness of marine environments, multiple methods are necessary to analyze the abundance of marine microplastics. Sampling sediment, surface water, and indicator species helps provide a comprehensive understanding of microplastic distribution and abundance in marine environments. Each sampling technique requires specific field collection and laboratory approaches. Currently, there are varying methods and materials used for field collection and lab analysis. Organizations, including SCCWRP, are working toward standardizing these protocols to ensure accurate comparison of results over time. Standardized protocols are crucial for consistently comparing data across different projects. Most research and monitoring programs involve separating microplastics from in situ samples, followed by the use of microscopy and spectroscopy to determine the morphology and material of each microplastic. However, monitoring does not need to consist of all sampling methods and programs should prioritize selecting one or more methods that are most suitable for the specific research objectives and environmental conditions of the study area.

Sediment Sampling

Sediments act as a major sink for microplastics, with studies showing that is where more than 70% of marine microplastics accumulate (Yang et al., 2021). Additionally, microplastics in sediment have been proven to reduce bacterial community diversity (Li et al., 2022). Typically, sediment samples are extracted from benthic environments and analyzed using laboratory techniques to quantify microplastic contamination levels. Lab analysis typically includes performing a density separation of sediment and microplastics, then separating microplastics from reagents using a vacuum filtration system.

Surface Water Sampling

Surface waters account for approximately 15% of marine microplastic distribution (Yang et al., 2021). The analysis of microplastics in surface waters commonly involves the utilization of a fine-mesh manta trawl. Manta trawl systems, designed specifically for collecting microplastics and macroplastics from surface waters, consist of a winged, rectangular metal box that channels surface water debris into a net equipped with a fine mesh, typically sized at 0.355 millimeters. This mesh size allows for the capture of microplastics larger than 0.355 millimeters. Sampling procedures are conducted under standardized time and speed conditions to determine the frequency of microplastics per kilometer of trawl. Microplastics collected from surface trawls are brought back to the lab and characterized by morphology and material type, ultimately providing a better understanding of the type and abundance of microplastics found in surface waters.

Indicator Species Tissue Sampling

Tissue analysis of marine organisms has been used to quantify microplastics in trophic pyramids (Savoca et al., 2022), as marine organisms at all trophic levels are exposed to microplastics (Besseling et al., 2019; de Sá et al., 2018). Plastics can be ingested by organisms and accumulate in food webs (Gola et al., 2021; Miller et al., 2020). Microplastic consumption in marine animals can cause infertility, retardation of growth, internal or external injuries, and blockage of body tracts (Cole et al., 2015; Ogonowski et al., 2016; Sussarellu et al., 2016).

Utilizing biological tissue samples brings a different understanding to local microplastic concentrations by allowing for direct quantification of microplastic pervasiveness in marine organisms. Additionally, microplastic concentrations in sediment and water samples are more sensitive to periodic fluctuations; trawling, bioturbation, tidal forcing, and weather events are all examples of factors that can influence the distribution of particles, giving biased results of microplastic contamination (Martin et al., 2017). Therefore, biologic samples can provide more accurate assessments of microplastic concentrations that have actually entered the food web, offering a more reliable representation of how these pollutants impact organisms.

An indicator species is a species that is indicative of overall environmental contamination (Bonanno & Orlando-Bonaca, 2018). Common organisms utilized for microplastic indicator species on the West Coast include invertebrate filter feeders and benthic vertebrates. Selection of a good indicator species should consider various criteria, including regional representation, abundance in chosen environment, previous use as an indicator species, cost of routine sampling, ease of laboratory analysis, commercial importance, ecological importance, feeding strategies, and ecological niches (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection [GESAMP], 2019). Criteria for a good indicator species vary from sanctuary to sanctuary due to ecological differences, existing research/programs, and goals of monitoring solutions.

Invertebrate Filter Feeders

Invertebrate filter feeders are commonly used as indicator species for microplastics due to their high abundance and presence in intertidal zones. Moreover, invertebrate filter feeders play a crucial role in filtering water and removing particulate matter, including microplastics (GESAMP, 2019). Filter feeding organisms such as bivalve mollusks, jellyfish, tunicates, and crustaceans inadvertently ingest microplastics along with their food. Consequently, these organisms act as vectors for microplastics, facilitating microplastic transfer into the food web and potentially exposing higher trophic levels to plastic pollution (GESAMP, 2019). By monitoring the presence and accumulation of microplastics in filter feeders, scientists can gauge the extent of plastic pollution in marine ecosystems and assess its impact on both wildlife and human health. For example, invertebrate filter feeders are used as an indicator species in

NOAA's National Mussel Watch Program, which aims to assess coastal water quality and detect pollutants.

Benthic Vertebrates

Benthic vertebrates, including species such as small sharks, rays, and flatfish, are an important link in energy and matter flow between pelagic and benthic parts of marine ecosystems (Drgas & Całkiewicz, 2019). Given that approximately 70% of microplastics are found in sediments (Yang et al., 2021), organisms that frequent benthic environments are likely to experience higher exposure rates compared to species that predominantly inhabit the pelagic zone. As these organisms feed close to or on the seafloor, inadvertent ingestion of microplastics is common, contributing to the potential accumulation of plastic particles in the gastrointestinal tract and tissue (GESAMP, 2019). Moreover, benthic vertebrates can serve as a vector for the transfer of microplastics up the food chain (GESAMP, 2019). Although it may be difficult to obtain tissue and/or gastrointestinal samples from these species, examining benthic vertebrates could be advantageous for understanding the scope of microplastic presence in the benthic ecosystems.

Macroplastic Monitoring

Macroplastics (plastic pieces >5 mm) significantly contribute to oceanic plastic pollution through various pathways. These include deliberate disposal or accidental loss at sea of plastic materials such as fishing gear, packaging, and other marine debris. Macroplastics can be transported into the ocean from terrestrial environments via runoff, carrying particles from land-based sources into marine ecosystems. Additionally, fishing activities contribute significantly to plastic pollution in ocean due to the extensive use of plastic materials, such as nets, lines, buoys, and packaging, which are often lost or deliberately discarded at sea, leading to the introduction of macroplastics into marine environments (Richardson et al., 2018). Once introduced into these environments, macroplastics pose substantial threats to marine life, including entanglement, ingestion, and habitat destruction. Additionally, macroplastics degrade over time, turning into microplastics. These impacts not only harm individual organisms but also disrupt marine ecosystems.

Initiating a comprehensive monitoring program for macroplastics is important to advance our understanding of macroplastic contamination, track its sources, and assess the effectiveness of mitigation strategies. Approaches to macroplastic monitoring include the expansion of citizen science programs, bottom trawling, and ROV video surveys. Each of these approaches provides a different understanding of the distribution, abundance, and types of macroplastics present in marine environments.

Shoreline Citizen Science Monitoring

Citizen science programs have been pivotal in shedding light on the pervasive issue of plastic pollution along coastlines (see Chapter 2). Volunteers have collected data on the presence of macroplastics along hundreds of beaches, contributing to a wealth of information on the distribution and abundance of marine debris. To enhance scientific monitoring and effectively track trends, routine sampling efforts utilizing a consistent methodology should be employed. These methods should encompass longer timescales and span various seasons to capture the dynamic nature of macroplastic distribution on beaches. Citizen science has proven to be a strong monitoring method within national marine sanctuaries, demonstrated by long-standing programs like BeachWatch, which has been actively engaged for over 30 years, and LiMPETS, which has been actively running for 20 years. BeachWatch is a long-term shoreline monitoring project conducted by trained staff and volunteers who regularly survey over 50 beaches along the shores of Greater Farallones and Monterey Bay national marine sanctuaries. LiMPETS monitors the biology in rocky intertidal and sandy beach ecosystems along the California coast to provide publicly available long-term data.

Despite the value of citizen science monitoring programs, they can also be associated with inconsistencies in data. These variations may arise from differences in data collection approaches among participants, potentially impacting the reliability of the data. Another consideration is the likelihood of sampling biases, which could be influenced by the timing of data collection. For example, volunteers may show a preference for sampling during certain seasons, potentially affecting the representativeness of data. Moreover, accessibility to sampling sites might affect sampling frequency, potentially leading to a skewed portrayal of debris distribution, particularly in frequently visited areas. To combat these limitations, formal training for volunteers could be held to ensure good data collection. By implementing systematic and consistent monitoring protocols, researchers can gain deeper insights into the spatial and temporal patterns of macroplastic pollution along beaches.

Bottom Trawling

Bottom trawling techniques, such as demersal/otter or beam/pole trawls, have been considered as an efficient means of evaluating and monitoring seafloor litter in deeper waters (≥10 m) on a large scale (GESAMP, 2019). By controlling the mesh size and opening width of the trawl, plastic densities (items/km^2) can be determined (GESAMP, 2019). However, despite its efficiency for evaluating seafloor litter, bottom trawling poses significant environmental risks by causing habitat destruction, disrupting marine ecosystems, and contributing to bycatch of non-target species. Therefore, bottom trawling should be cautiously weighed when considering its negative environmental impacts alongside the benefits of assessing plastics. A possible option includes completing opportunistic sampling from fisheries monitoring programs dedicated to demersal (bottom-dwelling) fish stocks in tandem with plastics monitoring. These operations are completed on large regional scales and employ standardized protocols, thus offering an opportunity to establish a consistent approach to seafloor litter monitoring (GESAMP, 2019). These trawl surveys conducted as part of routine fish stock assessments present a potential effective and more environmentally sound strategy for determining the extent of plastics in deeper waters (GESAMP, 2019).

Remotely Operated Vehicle Video Surveys

Studies have shown that debris tends to accumulate near rocky ledges, offshore canyons, or channels (GESMAP, 2019; Lippiatt et al., 2013). ROV surveys are recommended to assess continental slopes, uneven terrain, and the deep seafloor (GESMAP, 2019; Lippiatt et al., 2013). A successful regional study used 22 years of ROV footage from a video annotation database to survey marine litter in Monterey Canyon in central California (Schlining et al., 2013). This study quantified marine debris in depths ranging from 25–3971 meters, finding that the highest frequencies of debris occurred below 2000 meters (Schlining et al., 2013). Other studies may underestimate the extent of marine debris on the seafloor because of limitations associated with studying deeper regions (Schlining et al., 2013). However, ROV operations are notoriously costly and are typically conducted in conjunction with other projects. Some national marine sanctuaries have existing footage that can be analyzed to assess marine macroplastics.

Data Integrity

Maintaining data integrity for microplastic and macroplastic monitoring is critical to ensure accurate representations of plastic pollution levels in national marine sanctuaries. Both macroplastic and microplastic monitoring strategies have biases, including seasonal fluctuations, weather variations, human error, and laboratory error. These biases can be minimized by maintaining consistent monitoring strategies, including regular sampling using the same monitoring strategy (e.g., trawling, beach survey, sediment sampling) and methodology during the same time of year. Any relevant conditions should be noted during sampling, including any recent storm events, water temperature(s), etc. to inform findings. For example, ocean upwelling is known to increase deposition of debris on the Pacific coast (Ribic et al., 2012). Similarly, the El Niño-Southern Oscillation is also thought to increase plastic levels on the west coast of the United States (Ribic et al., 2012). Noting physical conditions at the time of sampling is important to understand outcomes of collected data.

Other Considerations

Efforts to monitor plastic pollution play a crucial role in understanding its extent and impact on marine ecosystems, but they’re just one piece of the puzzle. Equally important are proactive measures aimed at intercepting plastic before it reaches the marine environment, such as improved waste management systems and cleanup technologies. Additionally, reducing plastic consumption and promoting sustainable alternatives are essential steps toward mitigating plastic pollution at its source. Moreover, effective policy implementation, including regulations on single-use plastics and incentives for eco-friendly practices, is essential for long-term change.

ONMS strives to protect and conserve the extraordinary scenic beauty, biodiversity, historical connections, and economic productivity of many of our most special ocean places. Monitoring and addressing plastic pollution directly aligns with this mission, as growing amounts of plastic debris pose a threat to marine ecosystems. By addressing plastic pollution comprehensively, we can work toward a cleaner ocean for generations to come.

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Glossary of Acronyms

CBNMS	Cordell Bank National Marine Sanctuary
CINMS	Channel Islands National Marine Sanctuary
GFNMS	Greater Farallones National Marine Sanctuary
MBNMS	Monterey Bay National Marine Sanctuary
MDMAP	Marine Debris Monitoring and Assessment Project
NOAA	National Oceanic and Atmospheric Administration
OCNMS	Olympic Coast National Marine Sanctuary
ONMS	Office of National Marine Sanctuaries
ROV	remotely operated vehicle
SCCWRP	Southern California Coastal Water Research Project
SFEI	San Francisco Estuary Institute

Literature Cited

Akkajit, P., Tipmanee, D., Cherdsukjai, P., Suteerasak, T., & Thongnonghin, S. (2021). Occurrence and distribution of microplastics in beach sediments along Phuket coastline. *Marine Pollution Bulletin*, *169*, 112496. https://doi.org/10.1016/j.marpolbul.2021.112496

Alvarez-Zeferino, J. C., Ojeda-Benítez, S., Cruz-Salas, A. A., Martínez-Salvador, C., & Vázquez Morillas, A. (2020). Dataset of quantification and classification of microplastics in Mexican Sandy Beaches. *Data in Brief*, *33*, 106473. https://doi.org/10.1016/j.dib.2020.106473

Amelia, T. S., Khalik, W. M., Ong, M. C., Shao, Y. T., Pan, H.-J., & Bhubalan, K. (2021). Marine microplastics as vectors of major ocean pollutants and its hazards to the marine ecosystem and humans. *Progress in Earth and Planetary Science*, *8*(1). https://doi.org/10.1186/s40645-020-00405-4

Besseling, E., Redondo-Hasselerharm, P., Foekema, E. M., & Koelmans, A. A. (2018). Quantifying ecological risks of aquatic micro- and nanoplastic. *Critical Reviews in Environmental Science and Technology*, *49*(1), 32–80. https://doi.org/10.1080/10643389.2018.1531688

Bimrose, K., Van Leuvan, N., Highleyman, L., Tsai, C., Lindquist, K., Lippiatt, S., Reyna, K., & Roletto, J. (2020). *A behavior change campaign to reduce plastic shotgun wad debris on the North-Central California coast*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. https://marinedebris.noaa.gov/other-reports/behavior-change-campaign-reduce-plastic-shotgun-wad-debris-north-central-california-coast

Bonanno, G., & Orlando-Bonaca, M. (2018). Perspectives on using marine species as bioindicators of plastic pollution. *Marine Pollution Bulletin*, *137*, 209–221. https://doi.org/10.1016/j.marpolbul.2018.10.018

California Coastal Commission. (2022). *Tens of thousands of volunteers clean California's coast and inland shorelines at the 38th Annual California Coastal Cleanup Day*. State of California, California Natural Resources Agency. https://www.coastal.ca.gov/publiced/ccd/9-17-22_CCD_Prelim_Results_Release.pdf

California Ocean Protection Council. (2022). *Statewide microplastics strategy: Understanding and addressing impacts to protect coastal and ocean health*. https://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20220223/Item_6_Exhibit_A_Statewide_Microplastics_Strategy.pdf

California Ocean Protection Council & NOAA Marine Debris Program. (2018). *California ocean litter prevention strategy: Addressing marine debris from source to sea*. https://opc.ca.gov/wp-content/uploads/2018/06/2018_CA_OceanLitterStrategy.pdf

Celis-Hernández, O., Ávila, E., Ward, R. D., Rodríguez-Santiago, M. A., & Aguirre-Téllez, J. A. (2021). Microplastic distribution in urban vs pristine mangroves: Using marine sponges as bioindicators of environmental pollution. *Environmental Pollution*, *284*, 117391. https://doi.org/10.1016/j.envpol.2021.117391

Cole, M., Lindeque, P., Fileman, E., Halsband, C., & Galloway, T. S. (2015). The impact of polystyrene microplastics on feeding, function and fecundity in the marine copepod *Calanus helgolandicus*. *Environmental Science and Technology*, *49*(2), 1130–1137. https://doi.org/10.1021/es504525u

Defontaine, S., Sous, D., Tesan, J., Monperrus, M., Lenoble, V., & Lanceleur, L. (2020). Microplastics in a salt-wedge estuary: Vertical structure and tidal dynamics. *Marine Pollution Bulletin*, *160*, 111688. https://doi.org/10.1016/j.marpolbul.2020.111688 de Sá, L. C., Oliveira, M., Ribeiro, F., Rocha, T. L., & Futter, M. N. (2018). Studies of the effects of microplastics on aquatic organisms: What do we know and where should we focus our efforts in the future? *Science of The Total Environment*, *645*, 1029–1039. https://doi.org/10.1016/j.scitotenv.2018.07.207

Drgas, A., & Całkiewicz, J. (2019). *Assessing the role of benthic filter feeders in in the food web of the Gulf of Gdansk (Sothern Baltic)—an ecopath with Ecosim exercise* [Poster presentation]. XX Iberian Symposium on Marine Biology Studies (SIEBM XX), Braga, Portugal. https://doi.org/10.3389/conf.fmars.2019.08.00040

Feitosa Cruz, A. C., Gusso-Choueri, P., Seraphim de Araujo, G., Galvão Campos, B., & Moledo de Sousa Abessa, D. (2019). Levels of metals and toxicity in sediments from a Ramsar site influenced by former mining activities. *Ecotoxicology and Environmental Safety*, *171*, 162–172. https://doi.org/10.1016/j.ecoenv.2018.12.088

Gola, D., Kumar Tyagi, P., Arya, A., Chauhan, N., Agarwal, M., Singh, S. K., & Gola, S. (2021). The impact of microplastics on marine environment: A review. *Environmental Nanotechnology, Monitoring and Management*, *16*, 100552. https://doi.org/10.1016/j.enmm.2021.100552

Harris, P. T. (2020). The fate of microplastic in marine sedimentary environments: A review and synthesis. *Marine Pollution Bulletin*, *158*, 111398. https://doi.org/10.1016/j.marpolbul.2020.111398

Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP). (2019). *Guidelines for the monitoring and assessment of plastic litter and microplastics in the ocean*. P. J. Kershaw, A. Turra, & F. Galgani (Eds.). United Nations Environment Programme. http://dx.doi.org/10.25607/OBP-435

Kashiwabara, L. M., Kahane-Rapport, S. R., King, C., DeVogelaere, M., Goldbogen, J. A., & Savoca, M. S. (2021). Microplastics and microfibers in surface waters of Monterey Bay National Marine Sanctuary, California. *Marine Pollution Bulletin*, *165*, 112148. https://doi.org/10.1016/j.marpolbul.2021.112148

Li, W., Wang, Z., Li, W., & Li, Z. (2022). Impacts of microplastics addition on sediment environmental properties, enzymatic activities and bacterial diversity. *Chemosphere*, *307*, 135836. https://doi.org/10.1016/j.chemosphere.2022.135836

Lippiatt, S., Opfer, S., & Arthur, C. (2013). *Marine debris monitoring and assessment: Recommendations for monitoring debris trends in the marine environment*. NOAA Technical Memorandum NOS-OR&R-46. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Marine Debris Program. http://dx.doi.org/10.25607/OBP-727

Martin, J., Lusher, A., Thompson, R. C., & Morley, A. (2017). The deposition and accumulation of microplastics in marine sediments and bottom water from the Irish Continental Shelf. *Scientific Reports*, *7*, 10772. https://doi.org/10.1038/s41598-017-11079-2

McLaughlin, K., Mazor, R., Schiff, K., & Thornton Hampton, L. (2022). *Southern California Bight 2018 Regional Monitoring Program: Volume IX. Trash and marine debris*. Technical Report #1263. Southern California Coastal Water Research Project. https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1263_Bight18Trash.pdf

Miller, M. E., Hamann, M., & Kroon, F. J. (2020). Bioaccumulation and biomagnification of microplastics in marine organisms: A review and meta-analysis of current data. *PLoS ONE*, *15*(10), e0240792. https://doi.org/10.1371/journal.pone.0240792

Miller, M., Steele, C., Horn, D., & Hanna, C. (2018). Marine debris trends: 30 years of change on Ventura County and Channel Island Beaches. *Western North American Naturalist*, *78*(3), 328–340. https://doi.org/10.3398/064.078.0308

NOAA Marine Debris Program. (n.d.). *Who we are*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Response and Restoration. https://marinedebris.noaa.gov/who-we-are

NOAA Marine Debris Program. (2021). *NOAA Marine Debris Monitoring and Assessment Project: Shoreline survey guide*. Technical Memorandum NOS-OR&R-56. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Response and Restoration. https://marinedebris.noaa.gov/protocol/noaa-marine-debris-monitoring-and-assessment-project-shoreline-survey-guide

NOAA Marine Debris Program. (2024a). *Marine debris*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Response and Restoration. https://marine-debris-site-s3fs.s3.us-west-1.amazonaws.com/s3fs-public/publications-files/2017MarineDebris101OnePager.pdf?VersionId=ZFc5RuPx5V5UsQIAGMiqzi3oh5EBl42U

NOAA Marine Debris Program. (2024b). *Performance progress report: Marine debris removal on the California Channel Islands: improving critical habitats*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Response and Restoration. https://clearinghouse.marinedebris.noaa.gov/documents/60819/401541/upload_00002717.pdf

NOAA Marine Debris Program. (2024c). *Marine Debris Monitoring and Assessment Project* [Data set]. Global dataset. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Response and Restoration. https://mdmap.orr.noaa.gov/

NOAA National Ocean Service. (n.d.-a). *What is marine debris?* U.S. Department of Commerce, National Oceanic and Atmospheric Administration. https://oceanservice.noaa.gov/facts/marinedebris.html

NOAA National Ocean Service. (n.d.-b). *What are microplastics?* U.S. Department of Commerce, National Oceanic and Atmospheric Administration. https://oceanservice.noaa.gov/facts/microplastics.html

Office of National Marine Sanctuaries. (2022). *Olympic Coast National Marine Sanctuary condition report: 2008–2019*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2008-2019-ocnms-condition-report.pdf

Office of National Marine Sanctuaries. (2023). *Cordell Bank National Marine Sanctuary condition report: 2009–2021*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2009-2021-cordell-bank-national-marine-sanctuary-condition-report.pdf

Office of National Marine Sanctuaries (2024). *Greater Farallones National Marine Sanctuary condition report: 2010–2022*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service. https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/docs/2010-2022-greater-farallones-national-marine-sanctuary-condition-report.pdf

Ogonowski, M., Schür, C., Jarsén, Å., & Gorokhova, E. (2016). The effects of natural and anthropogenic microparticles on individual fitness in *Daphnia magna*. *PLoS ONE*, *11*(5), e0155063. https://doi.org/10.1371/journal.pone.0155063

Pagter, E., Frias, J., Kavanagh, F., & Nash, R. (2020). Varying levels of microplastics in benthic sediments within a shallow coastal embayment. *Estuarine, Coastal and Shelf Science*, *243*, 106915. https://doi.org/10.1016/j.ecss.2020.106915

Ribic, C. A., Sheavly, S. B., Rugg, D. J., & Erdmann, E. S. (2012). Trends in marine debris along the U.S. Pacific Coast and Hawai'i 1998–2007. *Marine Pollution Bulletin*, *64*(5), 994–1004. https://doi.org/10.1016/j.marpolbul.2012.02.008

Richardson, K., Asmutis-Silvia, R., Drinkwin, J., Gilardi, K. V. K., Giskes, I., Jones, G., O'Brien, K., Pragnell-Raasch, H., Ludwig, L., Antonelis, K., Barco, S., Henry, A., Knowlton, A., Landry, S., Mattila, D., MacDonald, K., Moore, M., Morgan, J., Robbins, J., van der Hoop, J., & Hogan, E. (2018). Building evidence around ghost gear: Global trends and analysis for sustainable solutions at scale. *Marine Pollution Bulletin*, *138*, 222–229. https://doi.org/10.1016/j.marpolbul.2018.11.031

Save Our Shores. (n.d.). *Beach cleanups*. https://saveourshores.org/beachcleanups/

Savoca, M. S., Kühn, S., Sun, C., Avery-Gomm, S., Choy, C. A., Dudas, S., Hong, S. H., Hyrenbach, K. D., Li, T.-H., Ng, C. K., Provencher, J. F., & Lynch, J. M. (2022). Towards a North Pacific Ocean long-term monitoring program for plastic pollution: A review and recommendations for plastic ingestion bioindicators. *Environmental Pollution*, *310*, 119861. https://doi.org/10.1016/j.envpol.2022.119861

Schlining, K., von Thun, S., Kuhnz, L., Schlining, B., Lundsten, L., Jacobsen Stout, N., Chaney, L., & Connor, J. (2013). Debris in the deep: Using a 22-year video annotation database to survey marine litter in Monterey Canyon, Central California, USA. *Deep Sea Research Part I: Oceanographic Research Papers*, *79*, 96–105. https://doi.org/10.1016/j.dsr.2013.05.006

Silvestrova, K., & Stepanova, N. (2021). The distribution of microplastics in the surface layer of the Atlantic Ocean from the subtropics to the equator according to visual analysis. *Marine Pollution Bulletin*, *162*, 111836. https://doi.org/10.1016/j.marpolbul.2020.111836

Steele, C. L. W., & Miller, M. R. (2022). Temporal trends in anthropogenic marine macro-debris and micro-debris accumulation on the California Channel Islands. *Frontiers in Marine Science*, *9*, 905969. https://doi.org/10.3389/fmars.2022.905969

Surfrider. (2023). *2022 beach cleanup annual report*. https://20811975.fs1.hubspotusercontent-na1.net/hubfs/20811975/Beach-Cleanup-Report_062623.pdf

Sussarellu, R., Suquet, M., Thomas, Y., Lambert, C., Fabioux, C., Pernet, M. E., Le Goïc, N., Quillien, V., Mingant, C., Epelboin, Y., Corporeau, C., Guyomarch, J., Robbens, J., Paul-Pont, I., Soudant, P., & Huvet, A. (2016). Oyster reproduction is affected by exposure to polystyrene microplastics. *Proceedings of the National Academy of Sciences*, *113*(9), 2430–2435. https://doi.org/10.1073/pnas.1519019113

Sutton, R., & Sedlak, M. (2017). *Microplastic monitoring and science strategy for San Francisco Bay*. San Francisco Estuary Institute. https://www.sfei.org/sites/default/files/biblio_files/SFEI%20Microplastics_021517%20highres.pdf

Sutton, R., Franz, A., Gilbreath, A., Lin, D., Miller, L., Sedlak, M., Wong, A., Box, C., Holleman, R., Munno, K., Zhu, X., Rochman, C., Askevold, R., & Shimabuku, I. (2019). *Understanding microplastic levels, pathways, and transport in the San Francisco Bay Region*. San Francisco Estuary Institute. https://www.sfei.org/documents/understanding-microplastics

Washington CoastSavers. (n.d.). *Thank you CoastSavers!* https://us12.campaign-archive.com/?u=d11d944c878c12a595f13d2c7&id=f93796742c

Yang, H., Chen, G., & Wang, J. (2021). Microplastics in the marine environment: Sources, fates, impacts and microbial degradation. *Toxics*, *9*(2), 41. https://doi.org/10.3390/toxics9020041

Zhang, D., Liu, X., Huang, W., Li, J., Wang, C., Zhang, D., & Zhang, C. (2020). Microplastic pollution in deep-sea sediments and organisms of the western Pacific Ocean. *Environmental Pollution*, *259*, 113948. https://doi.org/10.1016/j.envpol.2020.113948

Appendix A:
Marine Plastic Projects and Research Around National Marine Sanctuaries in the West Coast Region

Table App.1. Details

Publication or Project Title	Author(s) or Lead(s)	Affiliated Organization(s)	Date Published	Dates of Study	Region of Study	Variables Measured	DOI
Microplastic exposure by razor clam recreational harvester-consumers along a sparsely populated coastline	B. Baechler; E. Granek; S. Mazzone; M. Nielsen-Pincus; S. Brander	Portland State University, Quinault Indian Nation Department of Fisheries, Oregon State University	30 November 2020	April 2018	Olympic Coast region, including OCNMS	Microplastic concentrations in Pacific razor clams	https://doi.org/10.3389/fmars.2020.588481
A growing plastic smog, now estimated to be over 170 trillion plastic particles afloat in the world's oceans—urgent solutions required	M. Eriksen; W. Cowger; L. Erdle; S. Coffin; P. Villarrubia-Gomez; C. Moore; E. Carpenter; R. Day; M. Thiel; C. Wilcox	5 Gyres	8 March 2023	1979–2019	11,777 stations sampled, dataset has specific information on West Coast region	Surface waters	https://doi.org/10.1371/journal.pone.0281596
Assessing marine debris in deep seafloor habitats off California	D. Watters; M. Yoklavich; M. Love; D. Schroeder	National Marine Fisheries Service, University of California Santa Barbara, Minerals Management Service	2010	1993–2007	Central California, MBNMS, Cowcod Conservation Area (Southern California)	Macrodebris on deep seafloor	https://doi.org/10.1016/j.marpolbul.2009.08.019
Trends in marine debris along the U.S. Pacific Coast and Hawai'i 1998–2007	C. Ribic; S. Sheavly; D. Rugg; E. Erdmann	U.S. Geological Survey, Sheavly Consultants, U.S. Forest Service Department of Forest and Wildlife Ecology	May 2012	1998–2007	Monterey Bay, California	Macrodebris (>5 mm) along beaches	https://doi.org/10.1016/j.marpolbul.2012.02.008

Publication or Project Title	Author(s) or Lead(s)	Affiliated Organization(s)	Date Published	Dates of Study	Region of Study	Variables Measured	DOI
Temporal trends in anthropogenic marine macro-debris and micro-debris accumulation on the California Channel Islands	C. Steel; M. Miller	California State University Channel Islands; National Marine Sanctuary Foundation	28 July 2022	2016–2020	Channel Islands National Park, CINMS	Macrodebris (>5mm) and microdebris (<5mm) in sediment	https://doi.org/10.3389/fmars.2022.905969
Microplastics and microfibers in surface waters of Monterey Bay National Marine Sanctuary, California	L. Kashiwabara; S. Kahane-Rapport; C. King; M. DeVogelaere; J. Goldbogen; M. Savoca	California State University Monterey Bay; Hopkins Marine Station; Monterey Bay National Marine Sanctuary; University of Oregon	17 February 2021	2017–2019	MBNMS	Microplastics in surface water using manta trawl	https://doi.org/10.1016/j.marpolbul.2021.112148
Marine debris trends: 30 years of change on Ventura County and Channel Island beaches	M. Miller; C. Steel; D. Horn; C. Hanna	California State University Channel Islands; Portland State University	2 May 2018	Data collected 2015–2016 was compared to 1989–1994	Santa Cruz Island, Santa Rosa Island (Channel Island National Park); Ventura County beaches	Microplastics (<5mm) in sediment were compared to visually observable debris (>25mm)	https://doi.org/10.3398/064.078.0308
Temporal trends and potential drivers of stranded marine debris on beaches within two US national marine sanctuaries using citizen science data	A. Uhrin; S. Lippiatt; C. Herring; K. Dettloff; K. Bimrose; C. Butler-Minor	NOAA	25 November 2020	Data collected July 2012–June 2018	GFNMS	Macrodebris along beaches	https://doi.org/10.3389/fenvs.2020.604927

Publication or Project Title	Author(s) or Lead(s)	Affiliated Organization(s)	Date Published	Dates of Study	Region of Study	Variables Measured	DOI
Marine debris monitoring and assessment program at Greater Farallones National Marine Sanctuary: July 2012–June 2017	K. Bimrose; K. Lindquist; J. Roletto	GFNMS	2 October 2018	Data collected July 2012–June 2017	GFNMS	Macrodebris along beaches	https://clearinghouse.marinedebris.noaa.gov/documents/60819/185732/upload_00004737.pdf
Debris in the deep: Using a 22-year video annotation database to survey marine litter in Monterey Canyon, central California, USA	K. Schlining; S. von Thun; L. Kuhnz; B. Schlining; L. Lundsten;N. Jacobsen Stout; L. Chaney; J. Connor	Monterey Bay Aquarium Research Institute	28 May 2013	Dive footage collected January 1989–January 2011	Monterey Canyon	Macrodebris in a submarine canyon	http://dx.doi.org/10.1016/j.dsr.2013.05.006
Marine debris in central California: Quantifying type and abundance of beach litter in Monterey Bay, CA	C. Rosevelt; M. Los Huertos; C. Garza; H.M. Nevins	California State University Monterey Bay, California Department of Fish and Game	2013	June 2009–June 2010	MBNMS	Beach litter	https://doi.org/10.1016/j.marpolbul.2013.01.015
Quantification of microplastics on national park beaches	S. Whitmire; C. Toline	NOAA Marine Debris Program, National Park Service, Clemson University	N/A	June 2015–May 2017	Nine West Coast national parks, including Channel Islands and Olympic national parks	Microplastics (<5 mm)	https://marinedebris.noaa.gov/sites/default/files/publications-files/Quantification_of_Microplastics_on_National_Park_Beaches.pdf

Publication or Project Title	Author(s) or Lead(s)	Affiliated Organization(s)	Date Published	Dates of Study	Region of Study	Variables Measured	DOI
Microplastics are ubiquitous on California beaches and enter the coastal food web through consumption by Pacific mole crabs	D. Horn; M. Miller; S. Anderson; C. Steele	California State University Channel Islands	4 January 2019	N/A	California Coast: Marin to San Diego counties	Microplastics in Pacific mole crab digestive tracts	https://doi.org/10.1016/j.marpolbul.2018.12.039
Occurrence of plastic micro-debris in the southern California Current system	L. Gilfillan; M. Ohman; M. Doyle; W. Watson	University of Washington, Seattle	December 2009	Samples collected 1984, 1994, and 2007	Offshore of San Diego	Microplastics in plankton	https://www.researchgate.net/publication/263425784_Occurrence_of_plastic_micro-debris_in_the_southern_California_Current_system
Patterns of suspended and salp-ingested microplastic debris in the North Pacific investigated with epifluorescence microscopy	J. Brandon; A. Freibott; L. Sala	Scripps Institution of Oceanography, Pacific Northwest Research Station	15 August 2019	Samples collected 2009–2015	North Pacific Subtropical Gyre, California Current, the transition region, and a nearshore region	Microplastics in salp gut	https://doi.org/10.1002/lol2.10127
Microplastic in northern anchovies (*Engraulis mordax*) and common murres (*Uria aalge*) from the Monterey Bay, California USA—insights into prevalence, composition, and estrogenic activity	S. Michishita; C. Gibble; C. Tubbs; R. Felton; J. Gjeltema; J. Lang; M. Finkelstein	University of California Santa Cruz, California Department of Fish and Wildlife, San Diego Zoo, University of California Davis School of Veterinary Medicine	4 November 2022	Samples collected 2019–2021	Monterey Bay, California	Microplastic concentrations in seawater, anchovies, and murre carcasses	https://doi.org/10.1016/j.envpol.2022.120548

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Microplastic accumulation and biomagnification in a coastal marine reserve situated in a sparsely populated area	A. M. Saley; A. Smart; M. F. Bezerra; T. L. Burnham; L. Capece; L. Lima; A. Carsh; S. Williams; S. Morgan	University of California at Davis; San Diego State University	27 May 2019	Samples collected 22 April 2018	Bodega Marine Reserve in Sonoma County, California	Microplastics in sea water, sediment, macroalgae (*Pelvetiopsis limitata* and *Endocladia muricata*), and herbivorous snail (*Tegula funebralis*)	https://doi.org/10.1016/j.marpolbul.2019.05.065
Marine water and sediment monitoring program	J. Masura; S. Weakland	State of Washington Department of Ecology, University of Washington Tacoma	N/A	Sediment work since 1989	Puget Sound Bay, Washington	Sediment and water column microplastics	N/A
Analyzing microplastics in rhinoceros auklet specimens	L. SanAhmadi	San Francisco State University	N/A	Started fall 2023	GFNMS	Microplastics in rhinoceros auklets	N/A

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