Year 1 Progress Report: Monitoring Microplastic in San Francisco Bay and Adjacent National Marine Sanctuaries

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Highlights

- Sample collection has been successfully completed for all matrices: Bay and Sanctuary surface water, and Bay sediment, fish, wastewater effluent, and stormwater.
- Analytical methods to measure microplastic have been developed for all matrices. Both Raman and Fourier-transform infrared (FTIR) spectroscopy can be used to identify which particles are plastic.
- Reported recovery for evaluated sample types and particles types generally falls within RMP criteria designed for matrix spikes (expected value ±35%).
- Zero to very low levels of particles in laboratory method blanks indicate little procedural contamination is occurring.
- Preliminary analysis indicates field blank samples contain fibers and lower levels of fragments. Spectroscopy will be used to determine which of these particles are plastic and whether they match materials in our field samples.
- Preliminary results indicate Bay surface water samples contain many plastic particles.
- Development of the transport model has shown promising results for in-Bay buoyant tracers, and progress toward describing the underlying hydrodynamics in the coastal ocean.
- An educational microplastic sample collection sail attended by key members of the science, policy, industry, elected officials, municipal, and media communities in the Bay Area provided an opportunity for early engagement in the process of developing policy and action recommendations for the region.
- The project has already garnered media coverage, as well as social media engagement through release of a short video.

Executive Summary

Plastic in the ocean, and more specifically microplastic (particles less than 5 mm), has been gaining global attention as a pervasive and preventable threat to the health of marine ecosystems. The field of microplastic research is rapidly evolving in terms of our analytical capabilities to quantify their presence in the environment. There is a great deal of uncertainty regarding the quantity of microplastic in the ocean, the pathways by which it is introduced, the potential for microplastic to accumulate in the food chain, and the effectiveness of proposed policy initiatives that may mitigate the flow of plastic to the sea.

In 2015, a preliminary screening study visually identified microparticles, which include but are not limited to microplastic, in San Francisco Bay surface water, and in effluent discharged to the Bay. The Regional Monitoring Program for Water Quality in the San Francisco Bay (RMP) developed a Microplastic Strategy to prioritize microplastic monitoring and science in the Bay, and a list of management questions to guide this research.

With a generous grant from the Gordon and Betty Moore Foundation and the financial and in-kind support of the RMP and other institutions, the San Francisco Estuary Institute (SFEI) and the 5 Gyres Institute embarked on a two-year project to conduct a comprehensive study of the San Francisco Bay and the adjacent National Marine Sanctuaries to provide scientific information to answer many of the questions articulated in the Microplastic Strategy.

The goal of this project is to improve knowledge about and characterization of microplastic pollution in San Francisco Bay and National Marine Sanctuaries, including the following elements.

- Baseline monitoring of microplastic in San Francisco Bay surface water, sediment, and fish.
- Monitoring of microplastic in ocean waters outside of the Golden Gate, providing information on the transport of Bay microplastic to adjacent National Marine Sanctuaries.
- Characterization of pathways by which microplastic enters the Bay, including wastewater effluent and stormwater.
- Developing an estuarine-marine transport model linking Bay contamination to adjacent Sanctuaries.
- Contributing to standardized sample collection and analysis methodology for microplastic in the environment and in common pollution pathways, including wastewater and stormwater discharges.
- Facilitating evaluation of policy options for San Francisco Bay by leading national and regional experts, with recommendations on source reduction, including potential innovation, design, and household interventions.
- Communicating to regional stakeholders and the general public through meetings and educational materials to assist in the identification of management actions that may be effective in reducing microplastic pollution in the Bay Area.

This Progress Report summarizes the activities that have been completed in the first year of this two-year study, which has largely focused on the collection of samples and analytical method development, with limited laboratory analyses conducted to date. This report is intended to facilitate discussions at the Spring 2018 RMP Microplastic Workgroup meeting.

All of the field sampling for this project, described in detail in the Sampling and Analysis Plan for Microplastic Monitoring in San Francisco Bay and Adjacent National Marine Sanctuaries, has been successfully completed, with a total of 354 samples collected and sent to analytical partners at the University of Toronto for analysis. The analytical team has successfully developed methods for extracting microplastic from a variety of matrices, including surface water, wastewater effluent, stormwater, sediment, and fish, and has refined methods for identifying microplastic using Raman and FTIR spectroscopy.

To date, we have preliminary data for a limited number of samples, which provides an opportunity to discuss methods for categorizing the results (standardized vocabulary and grouping), and an initial review of data quality. Evaluation of laboratory analytical methods based on laboratory blanks and spiked laboratory samples indicates negligible laboratory blank contamination and good extraction and recovery rates for different particle and plastic types. In contrast, field blank samples indicate background contamination, particularly with fibers. In this report, we recommend an approach to qualifying data results to account for the presence of this contamination in field blanks.

Preliminary results suggest that fibers are ubiquitous across all matrices. Based on the data received to date, surface water Manta trawl samples frequently have high particle counts that consist largely of fibers. In samples that underwent spectroscopy, a majority of these fibers were identified as synthetic.

We have developed a Bay transport model that links with oceanic transport models outside the Bay. Once the microplastic monitoring data have been quality assured, they will be used to calibrate and validate the model.

Results will also be used to inform the policy recommendations and outreach elements of the project. To build momentum for data-driven pollution prevention activities, SFEI and 5 Gyres hosted a half-day educational sail attended by influential members of numerous stakeholder groups including scientists, policymakers, journalists, and representatives from environmental groups. We have also taken several steps to educate the general public through articles, films, radio interviews and television reports, with more resources and materials to be generated once the scientific results are completed. A symposium in early 2019 will provide a forum for the larger scientific, policymaker, industry, and stakeholder communities, as well as the general public, to review the findings from this study as well as the recommended actions to reduce microplastic pollution.

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1. Introduction

1.1 Summary of the Issue and Project Components

Plastic in the ocean, and more specifically microplastic (particles <5 mm), has been gaining global attention as a pervasive and preventable threat to the health of marine ecosystems. Microplastic is ingested by marine organisms (Wright et al. 2013), and may impact their physiological processes (von Moos et al. 2012; Cole et al. 2013, 2015; Rochman et al. 2013, 2014b; Wright et al. 2013; Watts et al. 2015; Lu et al. 2016; Sussarellu et al. 2016; Leung and Chan 2017). Microplastic also contains diverse mixtures of chemicals added during the manufacturing process, such as flame retardants, plasticizers, or dyes (Browne et al. 2013; Fries et al. 2013; Rochman et al. 2013, 2014a,b; Jang et al. 2017; Hermabesserie et al. 2017), and may provide a substrate for the adsorption of other harmful chemicals in the ocean, like PCBs and DDT (Teuten et al. 2007), which then may be transferred up the food chain (e.g., Farrell and Nelson 2013; Rochman et al. 2014a; Setala et al. 2014). Many scientific questions remain, however, and there is a need for research on the patterns of distribution and uptake of microplastic by organisms in aquatic ecosystems.

These scientific gaps also exist for San Francisco Bay and adjacent ocean, where basic questions remain unanswered, such as where, when, and how microplastic enters the Bay, and what circulation patterns deliver this contaminant to the ocean. The use of plastic in modern society is ubiquitous; as a result, the pathways by which microplastic reaches the Bay, its transport and distribution throughout the Bay, and the levels to which it is taken up into the food web are complex. A preliminary study of nine surface water sites in Central Bay and South Bay showed greater levels of microplastic than in either the Great Lakes or Chesapeake Bay (Sutton et al. 2016).

In addition, scientific understanding is critical to informing effective policy solutions, interventions, and innovations at the waste treatment, individual behavior, and industrial design level. Current policies are inadequate to address this growing and widespread threat. Data are therefore essential to understanding and minimizing the impacts of microplastic on San Francisco Bay and the adjacent ocean.

To develop critical baseline data and inform solutions, the Gordon and Betty Moore Foundation awarded the San Francisco Estuary Institute and The 5 Gyres Institute a grant for $880,250 to complete a series of studies over two years. This project will support multiple scientific components to develop improved knowledge about and characterization of microplastic pollution in San Francisco Bay and National Marine Sanctuaries, including the following elements.

- Baseline monitoring of microplastic in San Francisco Bay surface water, sediment, and fish.
- Monitoring of microplastic in ocean waters outside of the Golden Gate, providing information on the contribution of Bay microplastic to adjacent National Marine Sanctuaries.
- Characterizing pathways by which microplastic enters the Bay, including wastewater treatment facilities and stormwater.

- Developing an estuarine-marine transport model linking Bay contamination to adjacent Sanctuaries.
- Contributing to standardized sample collection and analyses methodology for microplastic in water and common pollution pathways, including wastewater and stormwater discharges.
- Facilitating evaluation of policy options for San Francisco Bay by leading national and regional experts, with recommendations on source reduction, including potential innovation, design, and household interventions.
- Communicating to regional stakeholders and the general public through meetings and educational materials.

The RMP, Patagonia, and East Bay Municipal Utility District (EBMUD) have allocated matching funds totaling $90,000. In addition, the RMP, San Francisco Baykeeper, and Bay Area stormwater and wastewater agencies are providing expertise as well as in-kind support.

This progress report documents activities that have been completed in the first year of this two-year study, which has focused on the collection of samples and analytical method development, with limited laboratory analyses conducted to date. This report is intended to facilitate discussions at the Spring 2018 RMP Microplastic Workgroup meeting. A final report summarizing the sample collection, laboratory analyses, data review and interpretation will be issued in December 2018.

This report provides a brief overview of the study design, as well as the overall management questions that guide long-term monitoring for microplastic. Additional information on the sampling design for this two-year project can be found in the Sampling and Analysis Plan for Microplastic Monitoring in San Francisco Bay and Adjacent National Marine Sanctuaries (Sedlak et al. 2017).

1.2 Definition of Microplastic

Microplastic is commonly defined as plastic particles smaller than 5 mm (Thompson et al. 2009; Masura et al. 2015). Microplastic is generally defined as 100 nanometers to 5 mm; less than 100 nanometers is generally defined as nanoplastic (Thompson et al. 2015).

Microplastic is a chemically and physically diverse contaminant. The term plastic encompasses a broad range of polymers including polyethylene (PE), polypropylene (PP), polystyrene (PS), polyamide (nylon), polyethylene terephthalate (PET or polyester), polyacrylonitrile (PAN or acrylic), polyvinyl chloride (PVC), and styrene butadiene rubber (e.g., vehicle tires), among others (Hidalgo-Ruiz et al. 2012; Boucher and Friot 2017). Many plastics have chemical additives, including flame retardants, plasticizers, and dyes. The monomers and oligomers that make up the polymers, as well as plastic additives, are the chemical components of microplastic (Fries et al. 2013).

Microplastic particles come in a range of shapes. Particles are commonly classified in five shape or particle type categories, which in some cases provide insights as to the source of individual particles (Free et al. 2014; McCormick et al. 2014):

- Fragment – hard, non-spherical particle
- Fiber – thin or fibrous plastic
- Sphere/Pellet – hard, rounded, or spherical particle
- Film – thin plane of flimsy plastic
- Foam – lightweight, sponge-like plastic

Preliminary work characterizing samples collected for this project has led to the identification of an additional particle type category, fiber bundle, consisting of a number of fibers that cannot be disentangled. Individual fibers within a bundle may be of similar or differing chemical composition.

As shown in Table 1.1, this study will evaluate a variety of microplastic size fractions, depending on the matrix under study and sample collection method employed. Surface water samples from the Bay and Sanctuaries were collected using three methods: Manta trawls, which capture particles > 355 micron size; a pump, which can capture the 5 mm to 20 micron range; and grab samples, which will be used in exploratory research to characterize the particles < 1 micron in size. Sediment and fish will be analyzed for particles > 45 micron. Wastewater and stormwater were collected using stacked sieves with mesh sizes of 355 microns (consistent with the Manta trawl) and 125 microns. Comparisons among matrices will only be possible for identical operational size fractions, determined by the collection method.

To date, researchers leading the investigation on nanoplastic have not identified nano material in Bay water and are continuing to hone their analytical methods. The quantification of nanoplastic in environmental samples remains a major research gap. Because these methods are under development, this element of the project is not discussed in the Progress Report.

Table 1.1 Microplastic and Nanoplastic Analyses for Each Matrix.

Matrix	Field Collection Method	Microplastic size fraction analysis					Nanoplastic
		> 5 mm	5 mm - 355 µm	355 µm - 125 µm	125 µm - 20 µm	20 µm - 10 µm	
Surface Water in Bay + Sanctuary	Manta Trawl	Y	Y				
	Pump, with attached screen and filter		Y	Y	Y		Y
Wastewater	Pump, water flow through two sieves			Y			
Stormwater	Pump, water flow through two sieves			Y			
Sediment	Grab sample	Y	Y	Y	Y	Y	Y
Fish	Seines		Y	Y	Y	Y	Y

2. Microplastic Management Questions and Project Goals

2.1 Overview of Science Strategy

In 2016, the RMP authorized a special study to develop a strategy for continued study of microplastic in San Francisco Bay. To create this strategy, the RMP convened stakeholders to articulate management questions specific to microplastic pollution, and then conducted a one-day workshop that brought together stakeholders and technical experts to develop an understanding of the state of the science on this emerging contaminant, and determine consensus priorities for future work.

The resulting Microplastic Monitoring and Science Strategy (Sutton and Sedlak 2017) provides a multi-year plan that outlines studies in several categories:

- Method development (high priority): On-going USEPA method development followed by laboratory inter-comparison; on-going NOAA laboratory inter-comparison; and additional method development or pilot testing.
- Monitoring biota: Prey fish (high priority); bivalves; sport fish (high priority); benthic organisms.
- Monitoring water and sediment: Ambient and margin sediment (high priority); surface water of Bay and adjacent ocean.
- Characterizing sources, pathways, loadings, and processes: Stormwater and effluent monitoring; transport modeling; refinement of conceptual model.
- Evaluating control options: Evaluating policy options; investigating options for fiber control; characterizing microplastic composition to identify targeted management actions.
- Synthesis: Synthesizing findings, to be presented at a symposium.

2.2 Conceptual Model and Management Questions

Based on discussions with the Microplastic Workgroup and a review of the literature, a conceptual model of the sources, pathways, processes, and fate of microplastic in and around San Francisco Bay has been developed (Figure 2.1). This model aids in the identification of critical data gaps, many of which will be at least partially filled by this project.

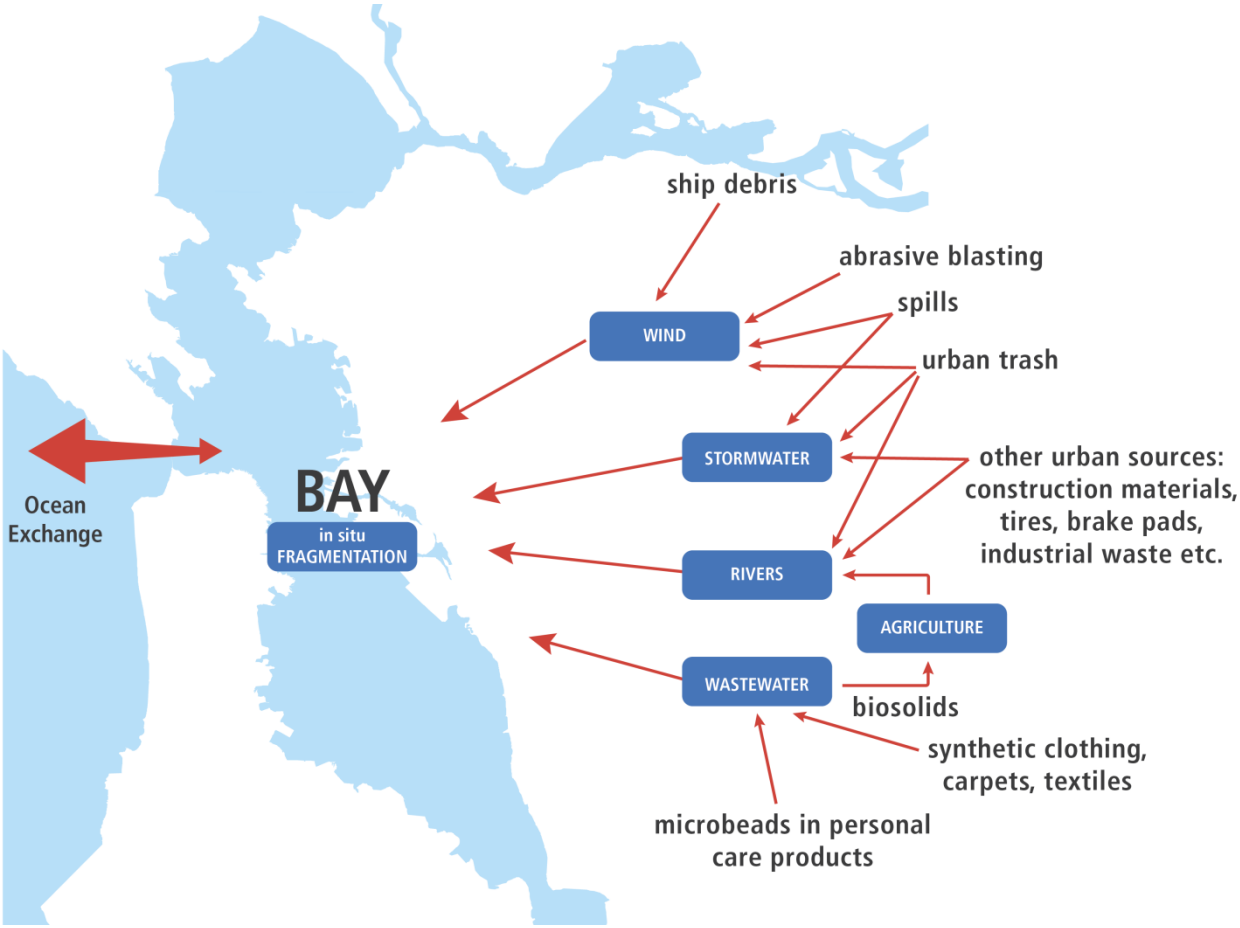

Figure 2.1 Conceptual model of the sources, pathways, processes, and fate of microplastic in and around San Francisco Bay.

The conceptual model identifies four major pathways for microplastic to enter the Bay: stormwater discharges; wastewater effluent; wind or airborne particles; and riverine inputs, which may aggregate stormwater, wastewater, agricultural, and airborne pathways. Lastly, exchange with the Pacific Ocean may introduce some plastic particles to the Bay, though preliminary data from this project suggests that the ocean is likely a sink. The conceptual model and its relevance to the project are described in more detail in the RMP Microplastic Strategy (Sutton and Sedlak 2017) and the Sampling and Analysis Plan (Sedlak et al. 2017).

Informed by the conceptual model, microplastic management questions specific to San Francisco Bay were developed with RMP stakeholders and external science advisors (Sutton and Sedlak 2017). These management questions guided study design for this project, and are presented to show the overarching goals of the microplastic focus area and how this project begins to fill prioritized data gaps.

MQ1) How much microplastic pollution is there in the Bay and in the surrounding ocean?

This question encompasses two issues: a) selection or development of appropriate methods for characterizing microplastic pollution, and b) presence and abundance of microplastic within the abiotic and biotic Bay and ocean environments. This project is addressing both aspects.

First, the researchers at University of Toronto are pioneering new methods for extraction and analysis of microplastic from a myriad of Bay matrices. These methods are described in more detail in Section 4.

Second, this project has taken a comprehensive approach to sampling oceanic and Bay waters, Bay sediment and fish, as well as major pathways by which microplastic enters the Bay, stormwater and wastewater effluent. The collection of samples is presented in Section 3 and a preliminary review of provisional data is presented in Section 5.

MQ2) What are the health risks?

This question addresses risks to humans and wildlife from microplastic. Risks to wildlife include physical impacts such as blockages in the digestive tract, as well as impacts associated with chemical exposures from the constituents of plastic or from contaminants sorbed to the plastic. Risks will vary among species, and will also vary with plastic particle shape, size, and composition. Very little information is available regarding toxicity thresholds for microplastic.

This project will assess concentrations of microplastic in sediment, water, and prey fish. These concentrations can be compared to toxicity thresholds, as they become available, and may inform future toxicological studies. Inferences may be drawn as to the potential for bioaccumulation in the food web.

MQ3) What are the sources, pathways, loadings, and processes leading to microplastic pollution in the Bay?

This project will quantify the concentrations of microplastic in two major pathways to the Bay: wastewater effluent and stormwater discharges. Preliminary estimates of loadings of microplastic via these pathways needs to be evaluated alongside other identified pathways, including spills and illegal dumping as well as wind transport, and with the *in situ* process of fragmentation of larger plastic debris to form microplastic.

In addition, characterization of microplastic particles in surface water, fish and sediment may identify potential sources or pathways. Different sources of plastic can produce microplastic particles of characteristic composition and shape or type. Evaluation of potential sources of microplastic may aid in identifying management actions.

It is also important to understand the fate of microplastic in the Bay, including assessing whether the ocean is a sink or source of microplastic (MQ1). Data obtained from this project will be used to calibrate and validate a transport model for microplastic that is currently under development (Section 6).

MQ4) Have the concentrations of microplastic in the Bay increased or decreased?

This question addresses long-term temporal trends, with the specific goal of understanding the forces that lead to any identified trends, including changes in sources (e.g., urban/consumer use) and management actions. Trends may vary with particle type, reflecting different sources or pathways. This project will establish baseline levels that can be used to track the status of microplastic concentrations in the Bay and assess the efficacy of management actions.

MQ5) Which management actions may be effective in reducing microplastic pollution?

This question explores alternatives for reducing contamination. Source control is typically found to be the most effective and least expensive pollution prevention option, and may be the primary tool applied to reduce microplastic pollution. The federal ban on plastic microbeads in rinse-off personal care products that will take effect in 2018 is one example of microplastic-specific source control. However, the sources of microplastic to the environment are diverse, and different sources or particle types may be more amenable to source control than others.

This study will help to inform identification of which management actions may be effective in reducing microplastic pollution in the Bay Area based on the concentrations and types of microplastic in the region. However, it is likely for a large portion of microplastic, there will be insufficient information to link individual particles directly to the original sources. A discussion of policy outreach and educational materials is presented in Section 7.

3. Field Sites and Collection Methods

This section describes the sample locations for each matrix and the field collection methods. Additional details are presented in the Sampling and Analysis Plan (Sedlak et al. 2017).

3.1 Surface Water (Manta, Pump)

Sample sites

Microparticles, which likely include some microplastic, have previously been identified in the San Francisco Bay (Sutton et al. 2016). This study improves upon previous measurements through more representative sampling and use of spectroscopic analysis to identify plastic polymers.

Sixteen monitoring sites throughout San Francisco Bay and 11 monitoring sites within the Monterey Bay, Cordell Bank, and Greater Farallones National Marine Sanctuaries were selected to provide spatial coverage of the Bay and adjacent sanctuaries. The sample sites were generally distributed throughout the entire project area; however, additional samples were collected in the Central Bay because the geographic area is larger than the rest of the Bay and it is an area of convergence for other sections of the Bay. Within each section of the Bay, sample locations were distributed to characterize ambient conditions as well as the influence of possible pathways such as wastewater or stormwater. Additional samples were collected at the Golden Gate Bridge monitoring site (MBNMS29), when possible, to provide additional data of individual rain events for modeling purposes.

Four monitoring sites within each of the National Marine Sanctuaries were selected. Due to the long transit time to the Cordell Bank National Marine Sanctuary, only three sites were sampled (CBNMS21, proposed in the SAP [Sedlak et al. 2017], was not sampled).

Vessels

The Derek M. Baylis, a 65-foot auxiliary-powered sailing vessel, was used to carry out most of the monitoring. The Derek M. Baylis was designed as a research vessel with a large open deck where equipment and samples were stored.

All of the sites in the Lower South Bay and several in the South Bay were too shallow to be accessed by the Derek M. Baylis. Instead, these sites were sampled using the San Francisco Baykeeper's patrol boat, a small, 26-foot C-dory Tomcat motor boat. Field staff were able to collect samples in depths less than 5 feet using this vessel.

Surface Water Manta Trawl Sample Collection (355 micron and above)

The Manta trawl, a modified Neuston net with a rectangular opening 16 cm high by 61 cm wide, an aluminum frame, and a 3 m long, 335 micron net with a 30 x 10 square cm collecting bag, was used to collect microplastic samples (355 micron and larger) from surface waters (Eriksen et al. 2013; Free et al. 2014; Masura et al. 2015). The trawl was towed behind a vessel (outside of the boat's wake) for 30 minutes at each site, with tow speeds below 3 knots, while the vessel maintained a consistent heading.

A flow meter was attached to the trawl to record how much water passed through, allowing for calculation of standardized values per square kilometer or per volume.

Surface Water Pump Sample Collection (20 micron to 5 mm)

A pump system with a 20-micron filter was designed for this project and used to capture particles from approximately 10 liters of surface water (Lusher et al. 2015; Talvitie et al. 2017; USEPA 2013). The pump system pumped 6 to 10 liters of surface water (top 12 inches of water column) through a 20-micron filter. Surface water was collected from the vessel using a stainless steel bucket. The amount of water passing through the filter was recorded, allowing for calculation of standardized values per liter.

For pump samples collected onboard the Baykeeper vessel, 5-gallon pre-rinsed plastic containers were filled with Bay water and filtered at SFEI. The dry weather pump samples collected at LSB14 and LSB16 in the Lower South Bay contained high levels of sediment that clogged the pump system. Therefore, these samples were first sieved through a 45-micron sieve before pumping the water through the 20-micron filter in the pump system. Particles captured in the sieve were put in a sample jar.

Quality Assurance / Quality Control

To assure that sampling tools were clean, field equipment was rinsed with filtered, deionized (DI) water three times. Additionally, to minimized procedural contamination, field staff avoided wearing synthetic clothing (although synthetic materials in safety equipment such as life vests, or ropes on the boat, could not be entirely avoided) and covered samples with aluminum foil. Field blanks were collected by filtering DI water through the Manta trawl and pumping MilliQ water through the 20-micron filter. Blanks were grouped with the field samples and processed using the same field methods. Manta trawl blanks (8 total) and pump blanks (4 total) were collected in the Bay and sanctuaries during the wet and dry season. Field duplicates for both the Manta trawl (7 total) and 20-micron pump (4 total) were collected in the Bay and the Sanctuary by repeating the transit of the primary sample (at the same location).

A summary of the locations and numbers of samples collected is presented in Tables A-1.1 and A-1.2, as well as Figures B.1, B.8, and B.9.

3.2 Sediment

Margin, Ambient Bay and Reference Sites

Sediment sites were selected to characterize microplastic concentrations near possible pathways in the nearshore “margins” of the Bay, in open or “ambient” portions of the Bay, and in a reference area (Tomales Bay). Most of the sites were located in the margins, locations ranging from depths less than 1 foot below mean lower low water to the unvegetated shoreline (roughly mean high water), because these areas are nearest and likely most affected by potential pathways for microplastic such as stormwater runoff from urban creeks and shallow wastewater discharges.

Margin sediment sampling was conducted at 34 sites including Central Bay (2015), Lower South Bay (2017), South Bay (2017), San Pablo Bay (2017), and North Bay (2017). Margin sediment samples were

also collected from three locations in the reference area, Tomales Bay. Additional information regarding these collection efforts can be found in the 2015 Annual Monitoring Results report (SFEI 2016) and the 2017 Field Sampling report (Shimabuku et al. 2017).

In addition to the margin sites, ten samples were collected for microplastic analyses in deeper ambient portions of the Bay in 2014 (Applied Marine Sciences 2014). A summary of the locations and numbers of samples collected is presented in Table A-2 and Figures B.1 through B.7.

Sample Collection

Sediment samples were collected using 0.1 m^2 modified Van Veen sediment grab deployed using an A frame and hydraulics off an 18' Boston Whaler boat (Figure 3.1 and 3.2). The grab is constructed entirely of stainless steel and the jaws and doors are coated with Kynar™ to improve chemical inertness. Samples were collected from the center of the grab (away from the sides) by directly scooping the sediment into sampling containers using a clean stainless steel spoon. Field measurements such as salinity and depth to bottom sediments were noted on the field collection sheets. Sediment samples were placed on wet ice and shipped to University of Toronto for analyses.

Figure 3.1 Deploying a Van Veen grab for sediment sample collection.

Figure 3.2 Sediment sample collection from a Van Veen sediment grab.

Quality Assurance / Quality Control

To assure that sampling tools are clean, field equipment were rinsed with filtered DI water three times. A blank was collected by rinsing the sampling tools in the field with filtered DI water, with the resulting rinseate collected into a pre-cleaned glass sample bottle. Field blanks were collected prior to collecting the field sample at three sites. Field duplicates will be analyzed by characterizing samples from separate sample jars collected from the same site. If field duplicates are significantly different, then two lab duplicate samples will be analyzed from a composite of the remaining sediment from both jars.

3.3 Fish

Sample Sites

Eight sites were selected to monitor prey fish; two of the sites were located in the reference area, Tomales Bay. Twenty individual prey fish were collected from each site; ten anchovies and ten topsmelt. All sites were co-located with sediment sampling sites, and many were in close proximity to urban creeks or wastewater effluent outfalls. As shown in Table A-3 and Figures B.1 through B.7, at several of these sites, stormwater, wastewater, and Bay water samples were also collected.

The original sample design targeted fish at six sites dispersed within San Francisco Bay (Sedlak et al. 2017); however, despite repeated attempts, no fish were collected in the two San Pablo Bay sites in the northern portion of the Bay (SPB15 and SPB104), nor at the Central Bay Emeryville site (CB105). Based on the dearth of fish at these sites, the decision was made to sample fish in the Central Bay sites (CB010

and CB037) and in the South Bay (SB074). Sediment samples were co-located at these sites. Fish were successfully collected at the two Tomales Bay sites.

Sample Collection

Prey fish (50 to 120 mm) were collected using an otter trawl or cast net, depending on the location and target species. Fish were collected shipboard using the same 18-foot Boston Whaler that was used to collect the sediment samples. All fish samples were individually wrapped in foil and placed immediately on wet ice on the boat and then on dry ice at the end of each day, before being placed in a -20 degrees C freezer at the laboratory. Additional fish caught above project targets were archived for potential future analyses.

The fish samples were couriered to the University of Toronto laboratory to avoid delays at customs. Nonetheless, the fish cooler was inspected by TSA, and a small bag of fish was lost during the inspection (seven anchovies from LSB06). A second bag containing four anchovies from this site was included in the shipment; however, for this site, we do not have the complete set of 10 anchovies. For all other sites, we have the complete set of fish, 10 anchovies and 10 topsmelt.

Quality Assurance / Quality Control

To date, a standardized method for collecting field blanks has not been developed for fish. Therefore, no field blank was collected. Because 10 fish of each species were collected at each site, we have information on the variation among fish; as a result, separate field duplicates were not collected.

3.4 Wastewater Effluent

Sample Sites

Microparticles were previously identified in wastewater effluent discharged to the San Francisco Bay (Sutton et al., 2016); particles were not subjected to spectroscopic polymer identification, and some portion of them were likely not plastic. This study will improve upon previous measurements through more rigorous sampling and use of spectroscopic analysis to identify plastic polymers.

Eight facilities voluntarily participated in the wastewater study (Table A-4). These facilities are geographically distributed, vary in effluent treatment capacity from 30 - 300 million gallons per day, and employ a range of secondary and tertiary treatments.

Sample Collection

Effluent from eight wastewater treatment facilities were collected during the dry season as 24-hour composites, on two weekdays (Tuesday through Friday) to avoid potentially different consumer behaviors on the weekend. These 24-hour samples are thought to be more representative of daily effluent microplastic levels relative to the 2015 RMP study, which sampled over two hours during peak flow (Sutton et al. 2016). At one site, a 12-hour composite sample was collected because the sieves became clogged overnight.

Treated effluent was collected from a sampling port prior to the effluent being discharged. At half the sites, samples were collected before the dechlorination step because of logistical challenges and limited access to final effluent after dechlorination. We do not expect the dechlorination step to contribute significantly to the microplastic concentration or characteristics in the treated effluent.

The effluent was passed through 20.3-cm (standard 8-in.) diameter stacked Tyler sieves with 355 micron and 125 micron stainless steel mesh. At one of the sites, an additional 1 mm sieve was placed on top of the 355 micron sieve to prevent the finer sieves from clogging. During the sampling period, the sieves were placed under an upside down bucket with a hole on top for the effluent flow, to protect the samples from air deposition of particles (Figure 3.3).

Sieves were processed at SFEI. Microparticles collected in the sieves were gently washed using distilled water into glass sample bottles prior to shipping to University of Toronto for analyses.

At most facilities, the sample volume was measured using a Recordall® Disc Meter, with the sampling port effluent passing through the meter, then through the stacked sieves. The total number of gallons that flowed through the meter was shown on the dial, and the meter reading at the beginning and end of the sampling period was recorded. At two facilities, the flow was measured by measuring the amount of time it took to fill a specific volume of water in a bucket, because the sampling port could not be easily connected to the flow meter. At another site, an ISCO sampler was used to continuously pump water from the final effluent channel to the sieves because there was no easily accessible sampling port. The sampled flow rate used at each facility was refined based on trial and error after finding that the sieves often became clogged before the end of the 24-hour sampling period due to presence of solids in the final effluent. The range of sampling flow rates used was between 0.3 - 2.3 gallons per minute, with higher flow rates used at sites known to have lower suspended solids in final effluent.

Figure 3.3 Wastewater effluent sample collection setup. Microplastic wastewater effluent samples were collected by connecting a flowmeter to the effluent sampling valve, and collecting particulates from effluent flow in two sieves that were placed under an upside down bucket. Duplicate samples were collected at one wastewater treatment facility. **Sampling train designed by City of Palo employees.**

Quality Assurance / Quality Control

A field blank was collected at one site by setting up a sieve set in the vicinity of the field sampling sieve set. The field blank sieves were placed under an upside down bucket similar to the field samples for the duration of the 24-hour sampling event, and processed the same way as the field samples to assess procedural contamination. A field duplicate was collected at one site by using a Y splitter on the sampling port to divert effluent to two sieve sets (Figure 3.3).

3.5 Stormwater

Sample Sites

Stormwater samples were collected at 12 sites distributed around San Francisco Bay (Table A-5 and Figures B.1 through B.7). Sites were selected based on drainage area, geographical distribution throughout the Bay, and proximity to known trash hotspots. Sites that correlate with Bay fish and sediment sampling (e.g., San Leandro Bay sites near the Coliseum and the Lower South Bay Guadalupe site) were a high priority for sampling. Similarly, two sites, Coyote Creek and San Mateo Creek were selected because they were the focus of a previous trash (debris > 5 mm) study in 2015 and 2016 (BASMAA 2016; BASMAA 2014b).

Sample Collection

At most sites, samples were collected using an ISCO sampler pump, with the field staff member moving the sampling pole up and down the water column to get a snapshot of the vertical distribution of microplastic in the water column. At the Guadalupe site, the drop from the height of the bridge to the river was too great to use an ISCO pump; instead a water sample was collected using a stainless steel 3-gallon pail. At most sites, the field team pumped a total of approximately 114 liters (30 gallons) of stormwater through stacked 125 micron and 355 micron sieves, by collecting 10 to 20-liter (3-5 gallon) "sips" multiple times throughout a storm, focusing on the rising hydrograph. The number of sips was a function of the duration of the storm; in most instances, the field team was able to collect 114 liters.

Quality Assurance / Quality Control

A field blank was collected at one site by placing a set of sieves near the field sample for the duration of the sampling period. When the foil lid was taken off the field sample, the foil lid was also taken off the field blank to maintain the same level of air exposure. Microplastics collected in the sieves were gently washed using DI water into glass sample bottles at SFEI, prior to shipping to University of Toronto for analyses. A field duplicate was not collected; additional monitoring to collect this sample is recommended. In the Sampling and Analysis Plan, collection of the duplicate sample was proposed by collecting the primary and duplicate sample across serial sips of the hydrograph.

4. Laboratory Methods: Discussion of Progress, Challenges and Opportunities

Samples were sent to Dr. Chelsea Rochman's Laboratory at the University of Toronto for microplastic analysis. The researchers in the laboratory developed and validated microplastic extraction methods for each matrix examined in this study. These methods have been reviewed by the RMP Microplastic Workgroup, and are being used to extract particles from all field samples. Additional matrix spike analysis is planned to more thoroughly evaluate particle recovery from sample digestion and processing procedures.

Each sample matrix (i.e., stormwater, wastewater, surface water [Manta and pump], sediment, and fish) has a different method for sample preparation and extraction. Details of the methods for each matrix are discussed below. All methods extract microparticles from the sample matrix, quantify their counts under a dissecting microscope, analyze individual microparticles for polymer/material type by Raman and/or FTIR spectroscopy, and measure the size of each particle using ImageJ software. See Section 5 for preliminary microplastic recoveries calculated for each method based on initial laboratory spikes.

Quality assurance and quality control samples consisted of laboratory or matrix spikes (see Section 5) and blanks. One laboratory blank is run for every ten samples processed. All laboratory blanks are run using reverse osmosis-treated (RO) water processed by the same methods for each sample type. To prevent contamination in the laboratory, dust is cleaned from the laboratory each day, all glassware and metal tools are rinsed with RO water three times between each sample, and researchers wear cotton laboratory coats, and work in a clean cabinet when possible to prevent the inadvertent introduction of microplastic into the sample.

In addition to using these methods to analyze the samples from the Bay, the researchers at University of Toronto have been using lessons learned to develop advanced techniques. These include methods for identifying microfiber polymer type – a task that is often challenging due to the various dyes used to manufacture textiles. It also includes methods to better extract microplastic from samples – such as by magnetizing plastic particles and then extracting with magnets. Method development has also benefited greatly from the collaboration with the research chemists at HORIBA, the manufacturer of the Raman instrument. The goal is to automate methods for counting, measuring and analyzing to material type. Novel methods that arise from this work will be published in a peer-reviewed scientific journal.

4.1 Sample Extraction and Preparation for Analysis by Matrix Type

Manta Samples

Surface water samples that were collected using the Manta trawl are sorted manually without any sample digestion step. Samples are sieved through a 212 micron sieve to remove excess water and isopropyl alcohol. The 212 micron sieve is used so that all samples collected with the 335 micron net are captured during sieving. They are then sorted under a dissection microscope using the same methods as

5 Gyres (e.g., Eriksen et al., 2013) and SEA (Law et al., 2014), research institutions that have been analyzing surface water for microplastic for many years. Each particle that resembles microplastic or larger plastic debris is removed from the sample with clean metal tweezers and placed in a clean Petri dish on double-sided sticky tape. Individual particles are arranged in rows on a dish and labeled by particle number (see Figure 4.1).

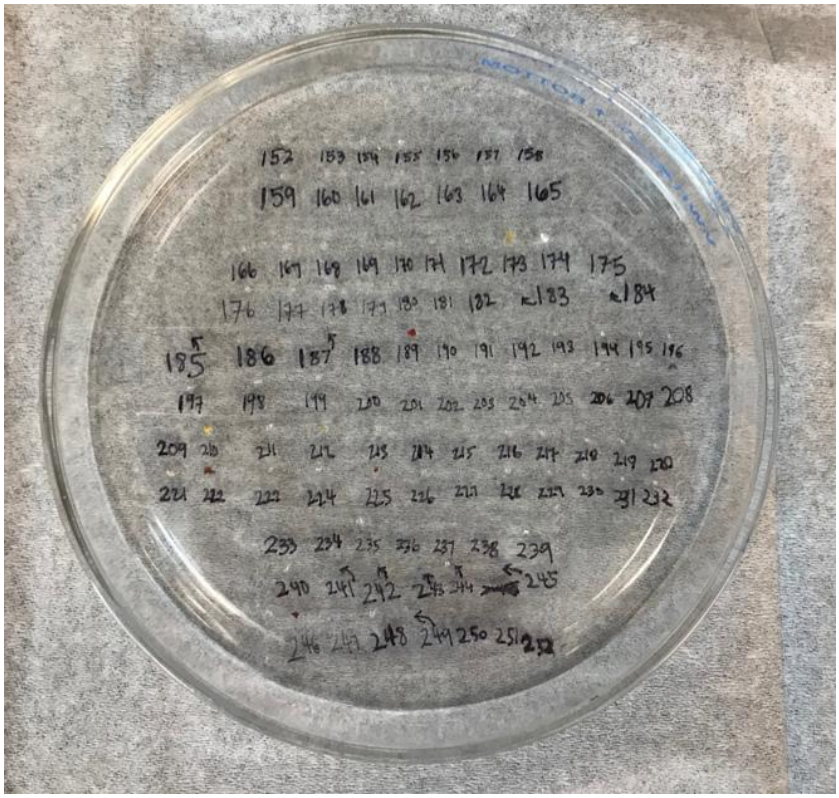

Figure 4.1. An image of a sample prepared for Raman or FTIR spectroscopy. Each number represents an individual particle that was manually extracted from the sample.

Pump Samples

Surface water samples that were collected with the pump will be analyzed during Summer of 2018. To analyze these samples, filters from each sample will be sonicated to remove the particles from the filters. All particles from the filters from the same sample will be combined and sieved through a 20 micron sieve. The contents on the sieve are then rinsed into a clean glass separatory funnel with a saturated calcium chloride ($CaCl_2$) solution with a density of 1.4 g/mL. Because this solution is more dense than the polymers of interest, this density separation method (Stolte et al., 2015) will separate the plastics from the sediments in the sample. After two rounds of density separation, the samples are filtered onto a 20 micron polycarbonate filter. All filters are examined under a dissection microscope for particles greater than 100 micron. These larger particles are removed from the filter with tweezers and prepared and analyzed as the Manta samples above. All smaller particles remaining on the filter that resemble microplastic are directly analyzed via Raman spectroscopy.

Stormwater Samples

Stormwater samples will also be analyzed in the Summer of 2018. To extract microplastic from these samples, density separation as described above is used. Samples are first sieved through a 500 micron and 110 micron sieve. Contents on the 500 micron sieve are rinsed into a clean jar for extraction via microscopy. The fraction of the sample remaining on the 110 micron sieve is rinsed with $CaCl_2$ solution into a separatory funnel. After two rounds of density separation, the sample is rinsed through the 110 micron sieve again, rinsed with RO water and rinsed into a clean jar for sorting via microscopy. Each fraction is analyzed separately under a dissecting microscope and all particles that resemble microplastic are removed with clean metal tweezers and placed in a clean Petri dish on double-sided sticky tape as described above.

Wastewater Samples

Wastewater samples are processed using a digestion step to remove some of the organic material. As suggested by several studies (e.g., Dehaut et al., 2016; Lusher et al., 2017), a potassium hydroxide (KOH) solution is used. First, samples are sieved through a 110 micron sieve to remove water. They are then reconstituted in a 20% KOH solution, as recommended by Munno et al. (2018), at room temperature for a one-week period. At the end of the one-week period, samples are sieved again through the 110 micron sieve and rinsed with RO water. Samples are then rinsed into a clean jar for later plastic extraction manually under the dissecting microscope and analysis by Raman and/ or FTIR.

Sediment Samples

Sediment samples are first sieved using a 45 micron sieve and then dried at 60ºC in a drying oven. Once dry, 150 grams are wet sieved through a 500 micron and 45 micron sieve to separate out the larger size fraction. Both size fractions are then rinsed with $CaCl_2$ solution into a separatory funnel for density separation. After two rounds of density separation, the floating fraction is sieved through their respective sieves and rinsed into clean glass jars. Samples are then ready for plastic extraction and analysis as described above.

Prey Fish Samples

Fish are thawed, weighed and measured. They are then dissected to remove gut and gut contents for digestion, consistent with previously published protocols (Dehaut et al. 2016; Foekema et al. 2013; Corcoran 2015). Tissue samples will not be analyzed for microparticles. The guts are individually weighed and the contents are placed in a jar filled with a 20% KOH solution. The amount of KOH added is typically three times the volume of biological tissue. The material is left at room temperature for up to 14 days to facilitate the digestion. The jars are not stirred to avoid damage to plastic from hard materials such as rocks, shells, etc. After digestion, the sample are filtered through a 10 micron polycarbonate filter. Samples are then analyzed under a microscope and particles are picked out of the samples for analysis as described above for other sample types.

4.2 Spectroscopic Analyses to Identify Particles by Material Type

As noted previously, the RMP conducted a preliminary screening study of San Francisco Bay water and effluent in 2015 and visually identified putative microplastic particles (Sutton et al. 2016). The limitation of visual identification is that some materials, such as cotton fibers, may be characterized as synthetic fibers (e.g., Dyachenko et al. 2017). This study builds upon this prior work to further characterize microplastic in the San Francisco Bay area, using spectroscopy to chemically identify the composition of particles present in the samples. Aside from confirming that particles are indeed microplastic, information is helpful to identify potential sources and to inform policy.

The University of Toronto is using two different methods to chemically identify materials: Raman and FTIR spectroscopy. Larger particles are analyzed by FTIR (Bruker Alpha II) with ATR, and confirmed via Raman spectroscopy (HORIBA Xplora) when necessary. Smaller particles, <100 micron in size, are analyzed via Raman spectroscopy. Spectroscopy is used to chemically confirm the polymer identity of the material using a reference spectra library. Both techniques are powerful for particle identification, but do come with their challenges. As such, the lab is working to improve techniques and develop better methods for analyzing microplastic particles.

Prior to spectroscopy, images are taken of each particle. The images are measured to record their size using ImageJ software. Particles are grouped by category (i.e., fiber, fragment, sphere/pellet, foam, film) and color. Because hundreds of particles may be found in each individual sample, a specific protocol for analyzing each particle by FTIR or Raman is followed. When there are less than ten of a particular group, for example nine blue fibers, all particles are analyzed to material-type. When there are more than ten but less than 100, 10 particles are analyzed. When there are more than 100, 10% of the particles in that group are analyzed. Information on particle size, chemical composition, and particle type is reported and photographs of the particles are included in reported data packages.

For most particles, distinct spectra can be obtained using one or both of the instruments. In some cases, identifiable spectra are difficult to achieve and in many cases it is difficult to confirm polymer or material type because the spectra matches the chemical dyes. This is especially true for microfibers from textiles. Because of this, we have created categories to label such particles. We call a particle or fiber “anthropogenic (unknown base)” if it is chemically dyed but we cannot confirm the underlying material type. We call a particle or fiber “cellulosic (natural based)” if it is chemically dyed and the particle is made of a cellulosic polymer such as cotton, Rayon, or Modal. We call a particle "protein (natural-based)" if the fiber is chemically dyed and is silk, wool, or animal hair. Likewise, a category of “anthropogenic (synthetic)” is used for particles where signals specific to plastic materials are observed, but the specific polymer cannot be identified. At the same time, we are working to improve our methods to better distinguish synthetic and natural materials when dyes are present and the dominant match in our libraries (see below for more detail).

Challenges and Opportunities

In general, there have been three major challenges associated with the analyses of microplastic samples. First, the spectroscopic analysis is very labor intensive. A goal of the laboratory was to automate counting and analysis with particle finding software, but that has not proven easy. To do this, we need to optimize the spectroscopic parameters that are best suited for microplastic. Parameters are often adjusted for nearly all particles individually to avoid fluorescence and get a strong signal. Moreover, the particle finding software cannot find and isolate microplastic easily in a sample with numerous particles. The operator often has to manually identify particles one-by-one. Finally, an application-based library for microplastic is needed to aid in quicker identification of microplastics. HORIBA, the company that manufactures the Raman instrument used in this project, is helping with these challenges to better develop methods for this emerging field. As such, we see these challenges as opportunities to inform and develop new methods.

Another challenge has been the sheer number of particles that are present in samples. For example, one Manta sample from the South Bay had more than 700 particles that were identified under the microscope as potentially being microplastic. Samples with more than 200 particles are common. We have been discussing ways to split samples and subsample particle types in order to meet our timelines for this project. To split samples, the lab purchased a Folsom splitter to divide the samples in half. We have now tried this for two wastewater samples. To subsample particles by type, we follow the protocol described above, which leads to 10 – 100% of the particles in a sample being analyzed chemically to identify material type.

Finally, and as described above, the identification of fiber composition has been difficult due to the presence of dyes. The spectra that we achieve from spectroscopy often match dyes rather than the underlying the material itself. To solve this issue, we have been discussing manufacturing practices with textile industries and examining the literature to determine which dyes are used for certain material-types. Some dyes are only used for certain materials, which is useful for particle identification. Based on what we have learned, we have developed the following flow chart to match dyes with certain plastic polymers or natural-based materials (Figure 4.2). For dyes that can be used for multiple types of materials (plastic and natural-based), we are using specific stains and density separations to further distinguish the materials.

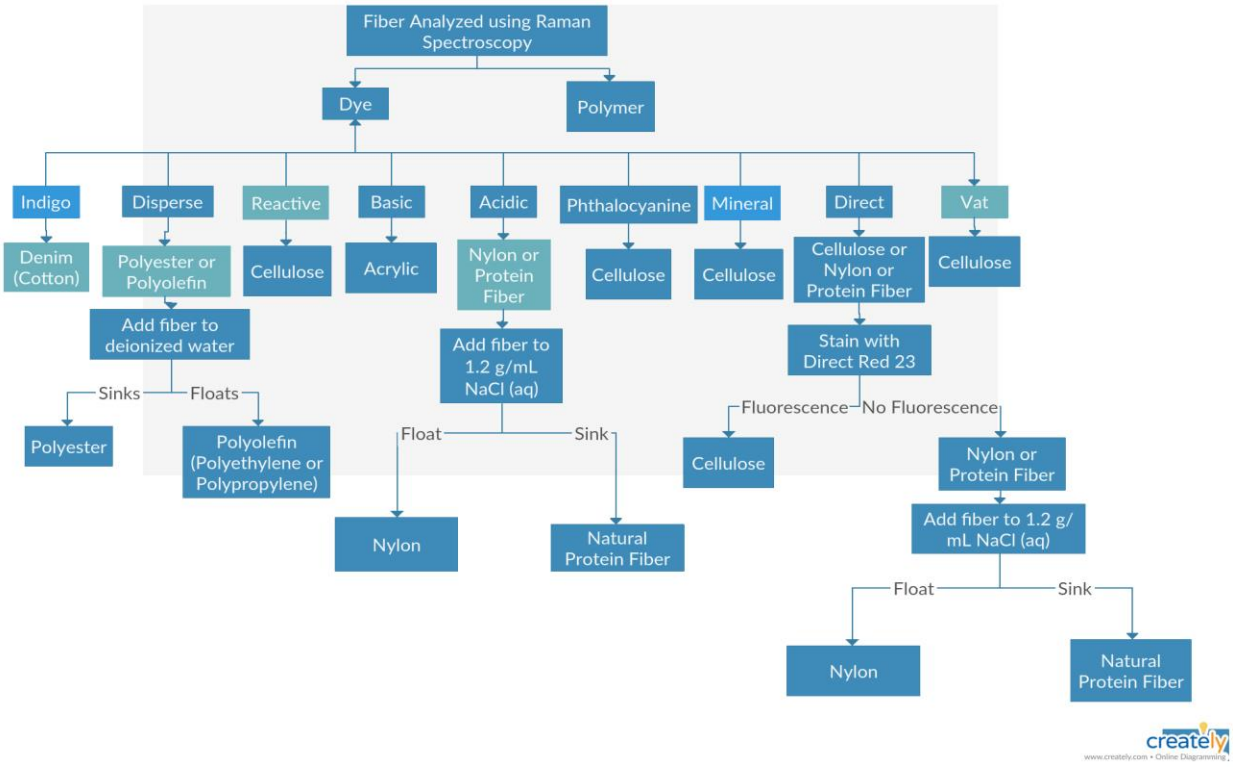

Figure 4.2 Flow chart indicating methods to identify fiber composition (Do not cite, quote or distribute – scientific development in progress.) This flow chart is used when the Raman spectrum matches the dye instead of the underlying polymer. Some dyes can be directly matched to a single plastic polymer or natural-based material (single arrow). In other cases, the dye can be matched to more than one material, and a subsequent test, using density separation or staining is used to confirm the plastic type.

Once we improve and validate our new methods, we will publish them in a peer-reviewed journal. Until then, we are using the particle classification conventions, as described above (e.g., “anthropogenic [synthetic]”), for microfibers and other particles that are identified by their chemical dyes rather than material type.

Overall, the laboratory methods that are currently being applied are working well to extract and analyze microplastics from the San Francisco Bay samples. As described in Section 5.3, laboratory control

procedures are implemented to support analytical precision and accuracy, and laboratory blanks and spiked samples indicate negligible laboratory contamination and good recovery from sample extraction and processing procedures. Due to some challenges, our pace is slower than we anticipated; however, we are developing new methods and pioneering new techniques that can be published and applied broadly in the field.

5. Data Review

This section provides information on the current status of sample collection and analysis, a discussion of data quality assessment, and example data from a Manta trawl sample. A major focus of this project has been application of more rigorous approaches relating to quality assurance and quality control in this rapidly evolving field of study.

5.1 Status of Sample Collection and Analysis

All samples have been collected. A subset of the samples has been extracted, subjected to preliminary counting of particles, and examined via Raman spectroscopy (Table 5.1). Not all counted particles are expected to be plastic.

We expect significant progress in laboratory analysis over the summer, with final data delivered in October.

Table 5.1 Status of microplastic laboratory analysis of samples (April 6, 2018). All planned sampling has been collected. An additional duplicate stormwater sample is planned for collection during the next precipitation event in 2018 to fill a data gap (Section 5.3).

Samples	Collected	Extracted	Counted (Preliminary)	Spectroscopy (Raman/FTIR)
Bay and Sanctuary Surface Water Samples (Manta)	67	20	20	1
Bay and Sanctuary Surface Water Samples (Pump)	28	0	0	0
Fish	152	37	27	0
Sediment	55	5	0	0
Wastewater Effluent*	38	25	17	5
Stormwater*	28	2	0	0

* Each effluent sample is counted as two separate samples, one from 355 micron sieve and one from 125 micron sieve. At one site, a 24-hour sample was collected in two parts. Similarly, stormwater samples are counted as two separate samples.

5.2 Data Reporting: Categorization of Microplastic and Related Particles

As noted previously, microplastic is a chemically and physically diverse contaminant class. Raw data for individual particles will include the particle size, particle type or morphology (e.g., fiber, film,

sphere/pellet, fragment, foam), color, and polymer or substance identification (e.g., polyester, polyethylene, polyurethane). Particles that are not plastic (e.g., cotton, organic natural materials) are also being quantified and categorized as part of this project, to gain an understanding of relative abundance. Particles that are clearly anthropogenic, but cannot be readily identified as either plastic or nonplastic due to spectroscopic interference caused by dyes or other chemicals, are quantified and categorized as "anthropogenic," as noted in Section 4.

The grouping of these individual particles into different categories is essential for data interpretation. Two major drivers for interpretation are: 1) to provide data that can be compared to data collected from other regions using similar methods, and; 2) to provide information that can be used to identify and prioritize different sources of microplastic particles to the environment. These two drivers dictate use of somewhat different frameworks for categorization.

Particle Categorization Designed for Regional Comparisons (CEDEN)

Data generated by this project will be made publicly available in accordance with the Data Sharing Plan established with the Gordon and Betty Moore Foundation. In particular, categorized particle data will be uploaded to the California Environmental Data Exchange Network (CEDEN) (ceden.org) and displayed on SFEI's Contaminant Data and Download Display (CD3) site (cd3.sfei.org). SFEI is a Regional Data Center for the State of California and uses templates, standardized vocabulary and business rules developed and maintained by CEDEN to manage data for field collection, chemistry, taxonomy, tissue, toxicity, and bioassessment sampling.

Because CEDEN and CD3 provide public access to data, the particle categories used for grouping particle data will reflect the goal of making our information readily comparable to data collected in other regions using similar methods. SFEI has provided initial recommendations to the CEDEN community regarding standardized vocabulary specific to microplastic characterization, as this contaminant is not currently represented in the CEDEN database in a format sufficient for reporting data for this project. Vocabulary must at least describe microplastic in terms of size range, particle shape or type, and polymer or material.

Our current CEDEN recommendations include:

- <u>Operational size categories based on sample collection method.</u> Samples of microplastic in surface waters, wastewater effluent, and stormwater were captured by passing contaminated waters through nets or sieves with standardized mesh sizes. To provide a ready means of comparing data collected in other regions using the same types of nets or sieves, categorizing particles relative to the sample collection method is preferred.

  An alternate means of size categorization would be to use the actual sizes measured for each particle. This is not ideal for comparability among studies, as a subset of particles captured by a net or sieve may actually be smaller than the mesh size. Such small particles may be enmeshed with larger biological material such as seaweed, for example. Likewise, fibers that are longer

lengthwise than a specified mesh size may still be able to escape a net or sieve because of their narrower width.

- Particle categories that combine polymer/material type and particle morphology. Examples include polyester fiber, polyethylene pellet, polyurethane fragment, and polystyrene foam. These categories allow independent users accessing the data the flexibility to group compounds by polymer and/or morphology.

SFEI has submitted an initial, microplastic-related vocabulary request to CEDEN that includes both the operational size and particle categories. CEDEN staff may choose to approve the new vocabulary, request more information, or request changes. Once codes have been approved, both SFEI and CEDEN will add them to the appropriate vocabulary lookup list table for general use.

Raw study data will be available upon request for members of the scientific community and the public who are interested in using customized categorizations specific to other goals, such as gaining insights regarding likely sources of microplastic, or comparison to published work using different operational procedures.

Particle Categorization to Investigate Sources of Microplastic

An overarching goal of this microplastic project is to better understand the relative contributions of different sources of plastic pollution, as a means of prioritizing pollution prevention policies designed specifically for the San Francisco Bay Area. Particle categories suggested as CEDEN vocabulary can provide useful information regarding the relative occurrence of particles likely to be derived from specific sources. For example, larger (>355 micron, actual particle size) “polyethylene pellets” are often derived from spills of pre-production plastic pellets, whereas smaller (<300 micron, actual particle size; [Conkle et al. 2018]) ones may be derived from down-the-drain disposal of personal care products with microbeads.

However, to determine the relative contributions of other sources, it may be more appropriate to combine CEDEN categories. For example, tire-derived rubber particles can have fibrous or fragmented morphology (“rubber fiber” vs. “rubber fragment”), a distinction that is not necessary to determine the overall significance of tires as a source of microplastic particles.

There may also be value in distinctions regarding color, a quality recorded in the raw data but not distinguished in recommended CEDEN categories. For example, contamination from thick, curly black fibers from a mat used onboard the boat during Manta trawl sample collection was discovered and the mat subsequently removed. Therefore, color distinctions may be particularly useful for identifying sources of procedural contamination.

Given the goal of investigating the potential relative contributions of different sources to the microplastic burden in different matrices, categories used to group individual particles for this type of

analysis are likely to deviate from the CEDEN categories in some respects. These source-specific categories will be specified in the final report for this project, to be completed at the end of 2018.

5.3 Data Quality Assessment

Methods for characterizing microplastic contamination are rapidly evolving. One of the goals of this project is to further the work in the field by developing sample collection protocols and analytical methods that can be used globally. Informed by extensive RMP experience in data quality assurance (e.g., Yee et al. 2017), we will be using robust techniques to assure we accurately identify microplastic particles, and identify and account for procedural contamination and other factors affecting measurement uncertainty. Rigorous and standardized quality assurance measures specific to microplastic sample collection and analysis are highlighted as an important gap in this field of research.

In the Sampling and Analysis Plan associated with this study (Sedlak et al. 2017), we indicated a number of steps designed to assess the quality of the data produced. Here we provide a preliminary report on data quality assessment, and note refinements planned for the future.

Laboratory Quality Control Procedures

Analytical Precision of Spectroscopic Polymer Identification

To evaluate the precision of the spectroscopic polymer identification, repeat measurements with the laser (Raman or FTIR) are obtained for each particle. One of the challenges of using a laser to identify particles is that occasionally a particle will be compromised due to the heat generated by the laser beam.

Polymer Identification Intercomparison: Raman vs. FTIR Spectroscopy

Approximately 10% of the particles assessed using Raman spectroscopy will be subjected to FTIR spectroscopy as well, to provide an intercomparison of polymer identification obtained using the two techniques. This intercomparison will be conducted at University of Toronto using a newly purchased FTIR instrument. Available studies in the scientific literature typically use a single spectroscopic method for polymer identification. A recent study that compared polymer identification of microplastic particles from environmental samples using each type of spectroscopy found general agreement (Kappler et al. 2016). As noted previously, for some dyed particles, a combination of both spectroscopic methods aids identification (Section 4).

Sample Extraction Particle Recovery

As part of method development, spiked samples were created to assess particle recovery associated with the extraction methods. Microplastic spikes consisted of particles with a range of sizes, morphologies, and polymers, and were designed to provide information on the varying levels of recovery that might be associated with diverse particles.

Recovery of spiked particles in lab-prepared model matrices (matrix spikes) designed to simulate wastewater, stormwater, and San Francisco Bay sediment, are described below (Tables 5.2-5.4).

Reported recovery for evaluated sample types and particles types generally falls within RMP criteria designed for organic chemical matrix spikes (expected value ±35%; Yee et al. 2017), with the exception of polystyrene fragments and polyester fibers in model stormwater (average recoveries of 55% and 40%, respectively, which would receive qualifying data flags according to RMP protocols [Yee et al. 2017]).

It is possible that the wastewater method, which relies on chemical digestion using potassium hydroxide, may increase the risk of fragmentation. A separate study tested six commonly used techniques for removing organic matter and examined their impact on 15 polymers; results indicated treatment with 10% potassium hydroxide and heating to 60 degrees Celsius for 24 hours was the least harmful to plastic integrity (Dehaut et al. 2016). These findings have been confirmed by University of Toronto scientists (e.g., Munno et al. 2018). The potassium hydroxide extraction method suggested by these previous studies was chosen for digesting wastewater samples.

Results from spiked laboratory wastewater samples indicated some possibility for sample extraction procedures to result in fragmentation of some particles, which could lead to recoveries greater than 100%, if each fragment is enumerated. Specifically, one of the 30 spiked polyethylene terephthalate particles fragmented. In addition, all nine cellulose acetate particles had visible cracks, suggesting the potential for fragmentation. Results to date suggest the risk of fragmentation is limited.

Method development spikes may not adequately represent the sizes, morphologies, and polymers commonly seen in samples associated with this project. Once we have identified the typical range of these variables in samples of different matrices, we will create microplastic spikes that mimic a "typical" sample from the central portion of the range of results seen. These customized laboratory spikes will be used to more thoroughly evaluate particle recovery.

Table 5.2. Recovery of spiked microplastic particles in model wastewater effluent sample. To mimic the algae seen in the wastewater samples, seaweed was blended down to a fine size to create the model sample matrix.

Particle and Plastic Type	Particle Size	Replicate 1 Recovery	Replicate 2 Recovery	Replicate 3 Recovery	Notes
Polyethylene terephthalate fragment (clear/white)	1 mm	10 (100%)	10 (100%)	10 (100%)	A particle in Replicate 3 broke into pieces, but was counted as a single fragment
Polystyrene bead (white)	1 mm	10 (100%)	10 (100%)	10 (100%)	
Cellulose acetate bead (red)	1 mm	3 (100%)	3 (100%)	3 (100%)	Cracks evident
Polyethylene bead (green)	250-300 micron	7 (70%)	8 (80%)	8 (80%)	
Polypropylene fiber (blue)	3 mm in length	9 (90%)	9 (90%)	0 (0%)	Replicate 3 was likely not spiked with fibers due to lab error.

Table 5.3 Recovery of spiked microplastic particles in model stormwater sample. The model stormwater matrix consisted of water treated with reverse osmosis, to which was added soil and leaf fragments. Replicates 1 and 2 were sieved first using a 500 µm, then subjected to density separation, while Replicates 3 and 4 were subjected to density separation without pre-sieving (see Section 3).

Particle and Plastic Type	Particle Size	Replicate 1 Recovery	Replicate 2 Recovery	Replicate 3 Recovery	Replicate 4 Recovery
Polyethylene terephthalate fragment (clear/white)	1 mm	4 (40%)	8 (80%)	9 (90%)	10 (100%)
Polystyrene fragment (brown)	2 mm	5 (50%)	7 (70%)	4 (40%)	6 (60%)
Cellulose acetate bead (red)	1 mm	3 (100%)	3 (100%)	3 (100%)	3 (100%)
Polyethylene bead (green)	250-300 micron	10 (100%)	10 (100%)	5 (50%)	9 (90%)
Polyester fiber (red)	3 mm in length	6 (60%)	6 (60%)	1 (10%)	3 (30%)

Table 5.4 Recovery of spiked microplastic particles in San Francisco Bay sediment samples (matrix spikes). Color was used to identify spiked materials relative to background particles in the matrix.

Particle and Plastic Type	Particle Size	Replicate 1 Recovery	Replicate 2 Recovery
Polyethylene terephthalate fragment (clear/white)	1 mm	8 (80%)	8 (80%)
Polystyrene fragment (brown)	2 mm	9 (90%)	10 (100%)
Cellulose acetate bead (red)	1 mm	3 (100%)	3 (100%)
Polyethylene bead (green)	250-300 micron	10 (100%)	9 (90%)
Polyester fiber (red)	3 mm in length	9 (90%)	10 (100%)

Laboratory Method Blanks

Procedural contamination, particularly by fibers, is a serious concern in studies of microplastic (Law 2017). One laboratory or method blank sample is collected for every ten samples extracted and analyzed for each matrix. The following lab method blanks have been enumerated, but not yet subjected to spectroscopy: two Manta trawl blanks contained one and two clear fibers, respectively; one stormwater blank collected during method development contained no particles. For context, field samples may contain hundreds of particles.

Zero to very low levels of particles in lab method blanks indicate little procedural contamination is occurring during laboratory analysis. Numerous measures to reduce the risk of sample contamination are employed, including; rigorous rinsing of all apparatus with ultrapure water; use of fume hood vents to blow-dry key instruments; and use of glassware, cotton (non-synthetic) lab coats, as well as natural (non-synthetic) sponges for cleaning.

Field Performance Measurements

While steps to evaluate and address data quality in the laboratory setting are now frequently reported in microplastic studies, such steps are infrequently applied to field work or are undocumented (e.g., Barrows et al. 2017). With this study, we have emphasized collection of field blanks and field duplicates, applying a more rigorous data quality approach than typically observed in the scientific literature for this emerging field.

Field Blanks

Field procedural contamination during sample collection is of particular concern given the range of synthetic materials that may be in use in the field and could become sources of secondary particles in samples. Potential sources of field contamination include: clothing, wet weather gear, and personal flotation devices (PFDs); ropes, mats, and other vessel materials; plastic tubing and other components of sampling apparatus; more generalized air deposition; and cross-contamination caused by incomplete rinsing and removal of samples from collection equipment.

Methods for collection of field blanks and duplicates for different matrices are described in Section 3. Field blank collection frequency is described in Table 5.5; the frequency for each method and matrix exceeds the minimum specified by the RMP for chemical contaminants of one per 20 sites (or 5%; Yee et al. 2017).

Table 5.5 Field Blank and Duplicate Sample Collection Frequency per Matrix.

Matrix & Method	No. Field Samples*	No. Blanks	Frequency (%)	No. Field Duplicates	Frequency (%)
Bay Surface Water, Manta Trawl	34	4	12%	5	15%
Bay Surface Water, Pump	16	1	6%	2	13%
Sanctuary Surface Water, Manta Trawl	24	4	17%	2	8%
Sanctuary Surface Water, Pump	12	3	25%	2	17%
Wastewater Effluent	16	1	6%	1	6%
Stormwater	12	1	8%	0**	0%
Sediment	47	4	9%	3	6%

*Counts are provided for wet and dry season sampling in the Bay and Sanctuary Waters. Fish samples not included because field blanks were not collected. Each set of stormwater and wastewater samples collected on 355 and 125 micron sieves is counted as a single sample.
**Additional monitoring is recommended to fill this data gap.

Some level of procedural contamination during field sample collection is likely unavoidable, given the ubiquity of plastic. At this time, three Manta trawl field blanks and one pair of wastewater effluent field

blanks (>355 micron and >125 micron operational size fractions) have undergone preliminary counting; no spectroscopy is available.

As expected, these field blanks contain particles, particularly fibers. Not all of these particles are expected to be plastic. Inspection of Manta trawl blanks and samples suggested intermittent contamination with two identified sources of particles onboard the vessels (PFDs and a non-slip mat); as described further below, all particles readily associated with known contamination sources will be excluded from counts in both blanks and samples. Records of these particles will be retained in raw data.

Field blank particle counts can be compared to those of field samples in different ways. In the Sampling and Analysis Plan, subtraction of field blank microplastic levels from sample levels was initially suggested (Sedlak et al. 2017). As we review actual blank data for this diverse contaminant class, two approaches to using field blank information become apparent:

- Option 1: Refined blank subtraction by combined polymer (e.g., polyester, polystyrene), particle morphology (e.g., fiber, fragment), and operational sample size (e.g., >355 micron and >125 micron) categories.
- Option 2: Qualifying flag applied to different types of particles within individual sample results that are not substantially different from those of the field blanks; field blank values are reported, but not subtracted from sample values.

At present, Option 2 is now considered the preferred approach. Given the anticipated variability in field blanks due to the intermittent nature of procedural contamination, subtraction of the average value of blanks may not be a robust or meaningful means of correcting for background levels. As further data become available, particularly regarding the polymer identification of individual particles, adjustments to this approach may be deemed appropriate. Field blank information for matrices evaluated to date is discussed in detail below.

Surface Water Manta Trawl Field Blanks

Three Manta trawl field blanks have been counted, and none have been subjected to spectroscopy. Therefore, the following discussion represents information drawn from preliminary particle counts only; not all particles are expected to be plastic.

In Table 5.6, summary data of particle counts for samples and field blanks analyzed to-date are provided for each particle type, without blank subtraction. In general, the main source of blank contamination detected based on current sample counts was from fibers, with lesser amounts of fragments. The number of fiber and fragments counted in the blank samples was in the range of some of the less-contaminated field samples. Fibers and fragments are not all expected to be plastic.

As noted above, a close examination of particles in blanks and samples has led to identification of intermittent procedural contamination from materials onboard research vessels. One of the field blanks collected in San Pablo Bay during the first day of sampling had a particularly high fiber count, and 36% of the fibers were orange; a similar observation was noted in a field sample collected on a different day. A likely source of this intermittent contamination was from orange PFDs worn on the boat during sample collection. Additionally, a black mat onboard the vessel was identified as the source of thick, curly black fibers that were observed in some field blanks and samples. The black mat was onboard during the first three days of field sampling (August 21-23, 2017), and was subsequently removed.

Identification of these contamination sources, along with observations of the intermittent nature of this contamination, has led to the recommendation that fibers likely associated with PFDs or the black mat present on the first few days of sampling be excluded from reporting. In Table 5.6, reported counts exclude from all counts these two specific particle types.

Table 5.6 Preliminary Manta Trawl sample counts to-date. Plastic polymer identification using spectroscopy analysis is not yet complete; not all particles are expected to be plastic. Median (minimum - maximum) values. Fibers associated with identified local sources of contamination (orange fibers from PFDs, and black mat) were removed from all sample and blank particle counts.

Sample	Fiber	Fiber Bundle	Fragment	Film	Foam	Sphere/ Pellet	Total
Bay (n=14)	88 (18 - 214)	0 (0 - 8)	13 (0 - 461)	1 (0 - 24)	2 (0 - 97)	1 (0 - 47)	114 (17 - 786)
Sanctuary (n=5)	38 (19 - 259)	0 (0 - 1)	2 (0 - 4)	0 (0 - 1)	0 (0 - 1)	0 (0 - 1)	43 (23 - 262)
Field Blanks (n=3)	46 (43 - 66)	5(3 - 8)	2 (0 - 5)	0	0 (0 - 1)	0	57 (53 - 69)

Wastewater Effluent Field Blanks

A single pair of wastewater effluent field blanks (>355 micron and >125 micron) have been counted. Particles have not been subjected to spectroscopy, and may not be all plastics. Spectroscopy analysis is in progress to identify plastic polymers. In Table 5.7, preliminary, uncorrected particle counts for samples and field blanks analyzed to-date are provided for each particle type and operational size fraction. The main source of blank contamination detected based on current sample counts was from fibers. The number of fiber and fragments counted in the blank samples was in the range of some the less-contaminated effluent samples.

As with the Manta trawl samples, it is recommended that results near the blank values be flagged and noted as such. After all samples have been counted and analyzed with spectroscopy, further data review may suggest additional refinements to the method used to account for blank contamination.

Table 5.7 Preliminary median (minimum - maximum) wastewater effluent sample counts to-date. Spectroscopy is not yet complete, and therefore reported particles may not all be plastic.

Sample	Fiber	Fragment	Film	Foam	Sphere/Pellet	Total
Effluent 355 micron sieve (n=7)	30 (3 - 221)	3 (0 - 64)	2 (0 - 27)	0 (0 - 1)	0 (0 - 3)	35 (7 - 230)
Blank 355 micron sieve (n=1)	17	5	0	0	0	22
Effluent 125 micron sieve (n=8)	34 (13 - 48)	7 (0 - 43)	0	0 (0 - 5)	0 (0 - 7)	45 (20 - 69)
Blank 125 micron sieve (n=1)	14	2	0	0	0	16

Field Duplicates

Levels of microplastic are expected to be highly variable in the environment. Collection of field duplicates, as described in Section 3 for each method and matrix, was emphasized to assess spatial and temporal variability in sampling. Field duplicate collection frequency is described in Table 5.5; the frequency for each method and matrix exceeds the minimum specified by the RMP for chemical contaminants of one per 20 sites (or 5%; Yee et al. 2017), with the exception of the stormwater matrix. Collection of a field duplicate was overlooked; SFEI staff will collect a primary sample and duplicate at the next possible precipitation event. It is likely that this will be in October. It is important to collect a duplicate sample to characterize the variability in this matrix.

Currently, laboratory analysis of a set of field duplicates has not been completed, which prevents discussion of environmental variability in microplastic levels in this progress report.

5.4 Spectroscopic Particle Identification: Example Sample Results

An example of the types of data obtained for each sample is provided in this section. The sample described in detail is a surface water Manta trawl field sample collected from the Central Bay (dry season). Manta trawl samples are considered part of the >355 micron operational size class, due to the mesh size of the net used to collect samples (Section 3). Micro particles in this sample were determined using Raman spectroscopy.

In this sample, laboratory analysis identified a total of 63 particles, 33 of which were fibers (52%) and 26 of which were fragments (41%; Figure 5.1). This number of particles is similar to those observed in field blanks. Completion of field blank laboratory and spectroscopic data analyses is required to qualify particle types for which procedural contamination is suspected to be a significant component of observed levels in samples.

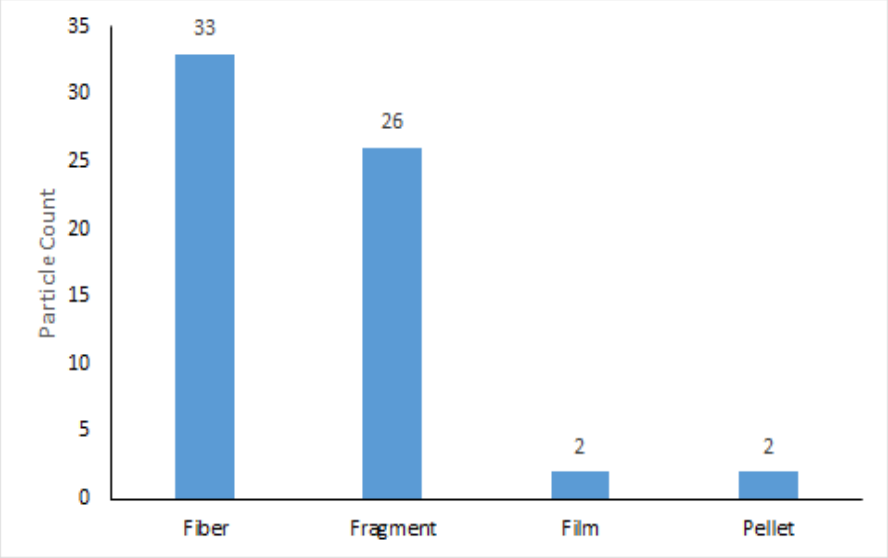

Figure 5.1. Preliminary particle counts in one Manta Trawl sample from Central Bay.

Among the enumerated fibers in the sample, Raman spectroscopic examination revealed seven fibers (22%) that are anthropogenic (e.g., dyed) and can be identified as synthetic (plastic), and seven more that are anthropogenic but cannot be identified further (may be plastic or natural-based; Figure 5.2). The dominant polymers among readily identifiable fiber plastic types are polyester (six fibers, 18%) and polyamide (four fibers, 12%). In total, 23 of 33 fibers (70%) are clearly plastic. A study that applied Raman spectroscopy to visually identified fibers in marine samples found 75% of the fibers were plastic (Lenz et al. 2015).

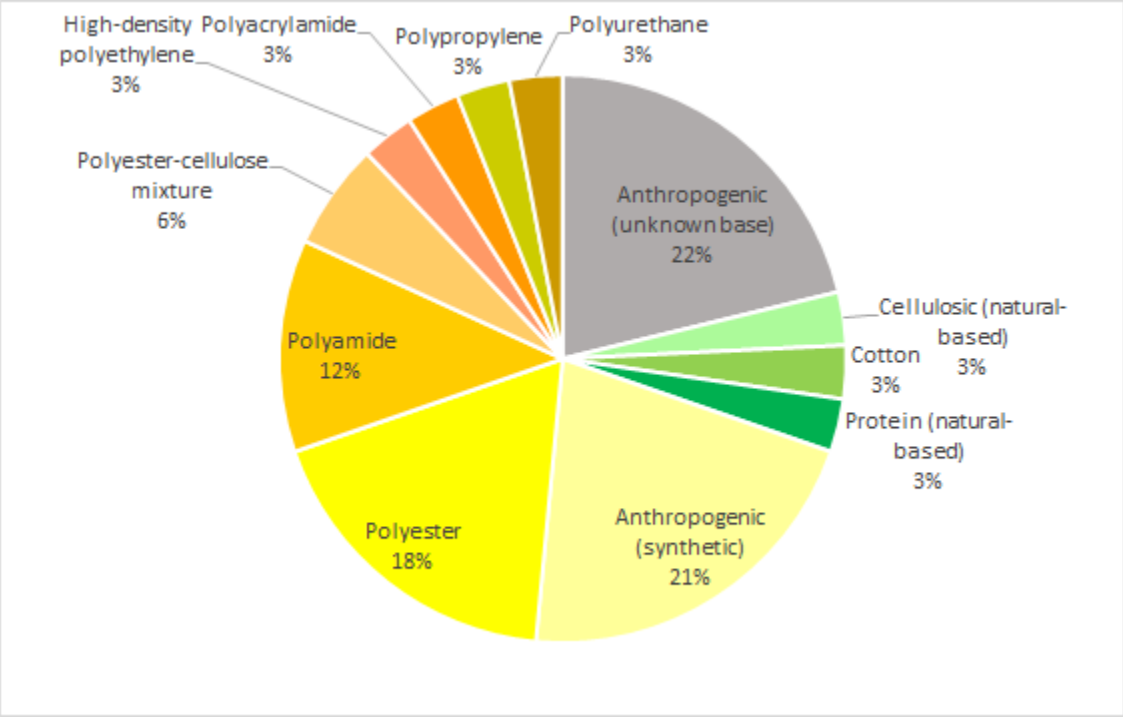

Figure 5.2. Preliminary polymer identification of fibers in one Manta Trawl sample collected in Central Bay in August 2017. Further research may refine the identification of fibers currently categorized in the anthropogenic categories.

Among the enumerated fragments in the sample, Raman spectroscopic examination revealed polyethylene (10 fragments, 38%) as the dominant fragment plastic type, followed by polypropylene (7 fragments, 27%), and anthropogenic particles of unknown material (3 fragments, 11%; Figure 5.3). In total, 20 of 26 fragments (77%) are clearly plastic. In addition to fibers and fragments, two film particles (propyl propionate and polyvinyl alcohol; both likely plastic) and two spheres (paraffin wax and polyethylene) were observed in the sample.

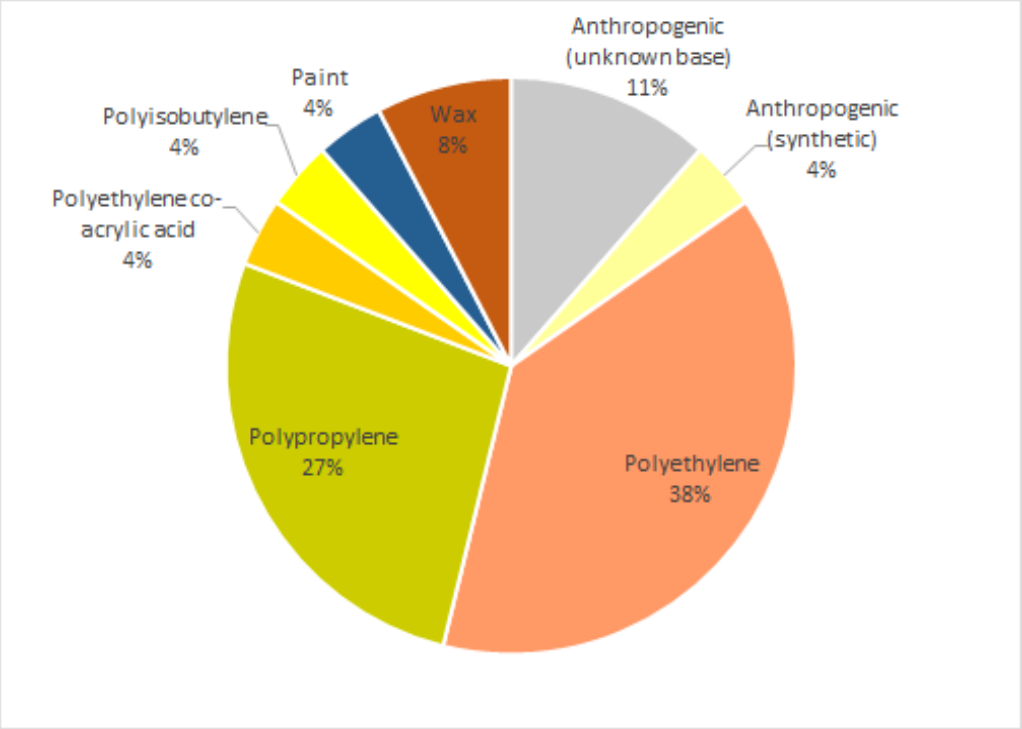

Figure 5.3. Preliminary polymer identification of fragments identified in one Manta trawl sample collected in Central Bay in August of 2017.

6. Update on Modeling Work

The goal of the modeling component of the project is to evaluate how pathways (such as stormwater and wastewater) are linked to ambient microplastic concentrations and potential microplastic fate. These linkages are resolved via physically-based numerical models which account for the effects of tides, winds, stormwater flows, wastewater flows, and particle sinking/floating behaviors.

Work to date has focused on two fronts:

- application of existing hydrodynamic models of San Francisco Bay to the transport of microplastic within the Bay, and
- development of a new hydrodynamic model coupling San Francisco Bay with the coastal ocean and National Marine Sanctuaries.

6.1 Application of San Francisco Bay Hydrodynamic Model to Microplastic Transport

A three-dimensional, unstructured hydrodynamic model of San Francisco Bay has been collaboratively developed over the past several years. This model was originally developed by the US Geological Survey (USGS) and Deltares, with support from SFEI, for the USGS CASCaDE project. Further work has included refinement and broader validation in the Bay as part of work carried out SFEI and Deltares, summarized in the San Francisco Bay Interim Model Validation Report (Holleman et al. 2017).

The spatial extent of the Bay model is shown in Figure 6.1. The numerical core of this model utilizes the Deltares D-Flow FM hydrodynamic model, chosen for its widespread use, adaptability to estuarine and coastal flows, and integration with other Deltares modeling tools. This model application includes the effects of wind, tides, stormwater, Delta inflows and wastewater/refinery discharges. The model accurately captures water surface elevations, velocities, and salinity, validated for water year 2013. An example of the salinity validation is shown in Figure 6.2, in which USGS observations along the spine of the Bay are compared to model data.

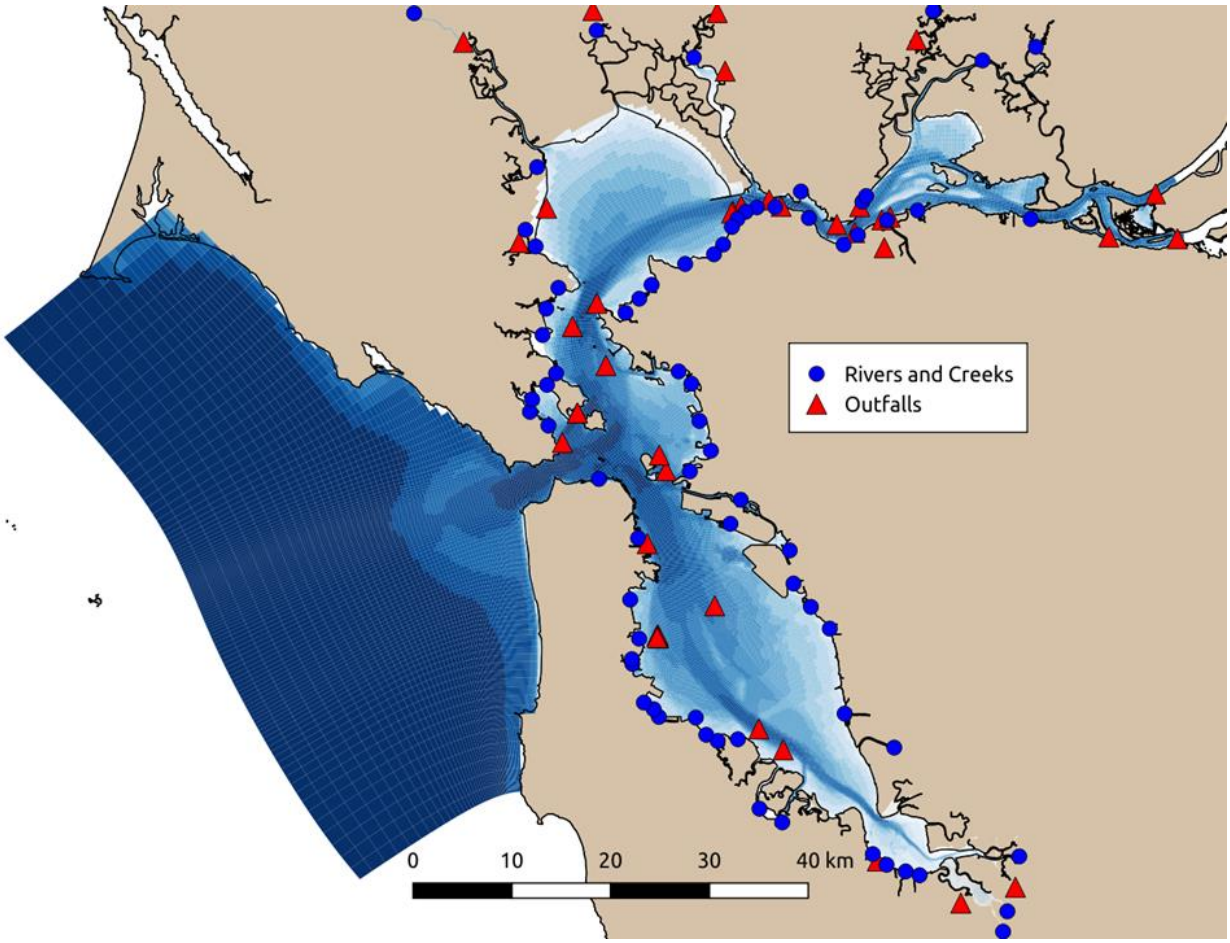

Figure 6.1 San Francisco Bay hydrodynamic model grid. Bathymetry data from the model grid is displayed in shades of blue, with the locations of stormwater and wastewater inputs denoted by the markers.

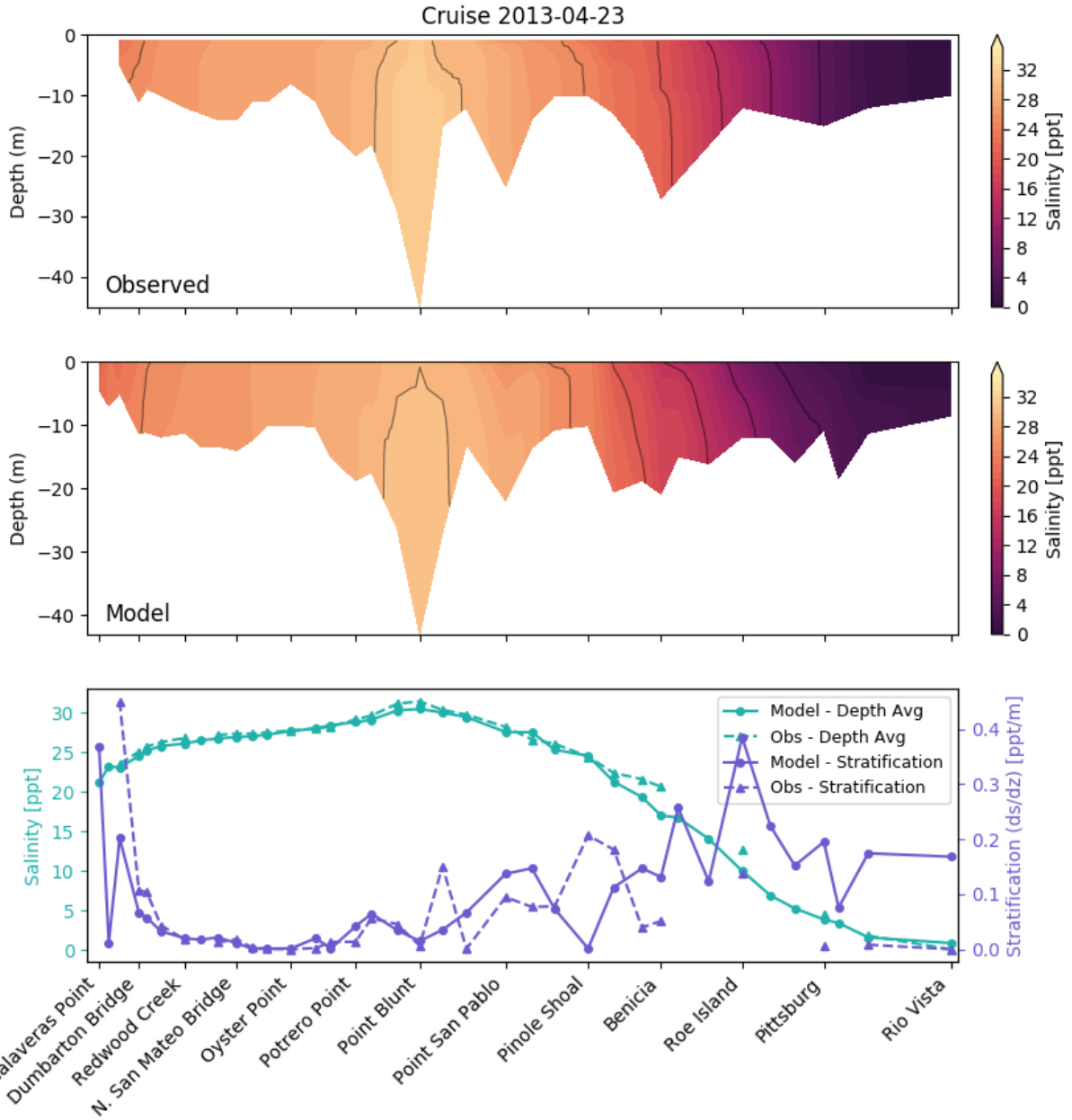

Figure 6.2 Sample model validation plot. The horizontal axis corresponds to locations in the Bay along the thalweg from Lower South Bay (left) to the California Delta (right). The upper two panels depict the full vertical salinity structure, summarized as the depth-averaged salinity and bulk salt stratification[1] in the third panel.

This existing hydrodynamic model provides baseline transport data, which we have adapted to the needs of modeling microplastic transport. There are two fundamental approaches to simulating transport processes in hydrodynamic models: *scalar transport* and *particle tracking*. Scalar transport

[1] Bulk salt stratification is calculated as ([bottom salinity] – [surface salinity])/[depth], with units of ppt/m.

refers to approximating microplastic as a concentration (akin to a dye), whereas particle tracking treats microplastic as a collection of individual particles. On the surface one might assume that particle tracking is a more natural fit for microplastic transport. Particle tracking does have distinct advantages in allowing a greater range of behaviors to be assigned to particles, and providing a full trajectory of where a particle has been. However, nuanced differences between how transport is calculated in the hydrodynamic model and how particle motion is calculated can lead to insidious errors. The equations governing scalar transport are exactly consistent with how the hydrodynamic model calculates velocities, such that utilizing scalar transport methods avoids potential numerical pitfalls in complicated domains such as San Francisco Bay. For that reason, we are currently focused on scalar transport approaches, though, if needed, we may consider particle-based approaches in later steps.

A key aspect of modeling microplastic transport is accounting for the vertical motion of the particles relative to the vertical motion of a water parcel. While dissolved substances necessarily follow the exact trajectory of water parcels, microplastic particles may preferentially rise or settle relative to a water parcel. This tendency to rise or settle is a direct consequence of the density, size and shape of the microplastic. During this model development stage, rather than explicitly calculate the rising/settling velocities for collected microplastic samples, we have chosen a range of settling velocities which bracket the expected range. The simulations to date have focused on microplastic which either sink at 10 mm/s, rise at 10 mm/s, or are neutrally buoyant. This range of rising/settling velocity is sufficient to overcome most of the turbulent mixing in the Bay, as can be seen in Figure 6.3. This figure shows the distribution of these three scalars of varying rising/settling velocity. Literature values for rising/settling velocities do in some cases extend beyond this range, but given that the rates chosen already cause particles to concentrate near the surface or bed in Figure 6.3, we do not expect more extreme values to significantly alter the model output.

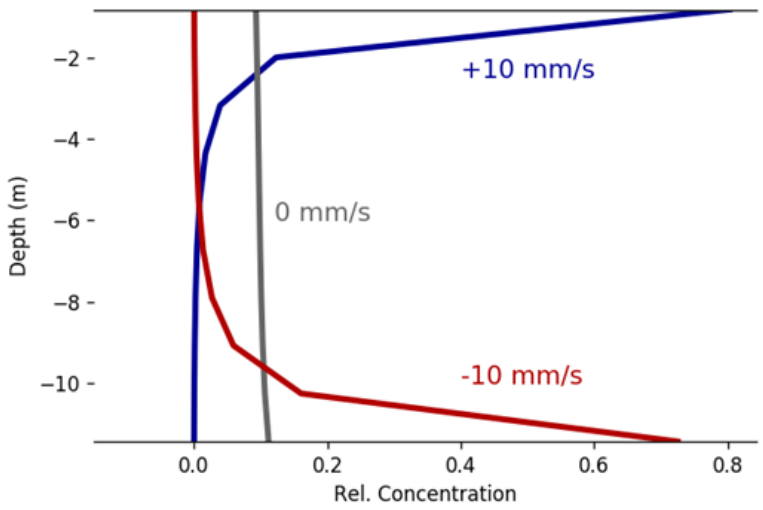

Figure 6.3 Vertical distribution of sinking (red), rising (blue) and neutral (gray) tracers extracted from the transport model in the channel of South San Francisco Bay.

One key process which is still absent from the Bay microplastic transport model is deposition onto the bed. In reality, some dense particles will not only sink to the bottom of the water column but will deposit onto the bed in the same manner as accreting sediment. These particles may reside there permanently, or face resuspension hours, days, or years later. The dynamics of deposition and resuspension are highly complex and poorly constrained, and responsible for a great deal of the uncertainty in sediment transport modeling. For these reasons, we do not plan on modeling resuspension, but will be adding the possibility of microplastic deposition.

Results

Settling Velocity Variability

Figures 6.4 – 6.6 show spatial distributions of modeled microplastic scalars across the aforementioned range of rising/settling velocities. In each panel, concentrations are shown as a dilution percentage on a logarithmic scale, relative to unit concentrations entering at all wastewater discharges in the Bay. These values can be interpreted as the concentration of microplastic in counts/m^3 as a percentage of the concentration in wastewater or stormwater discharges as they enter the Bay. White areas are the most diluted, with predicted ambient concentrations 0.01% (or less) of the potential inflow concentrations. Black areas show the greatest concentration, 10% or more of the inflow concentration.

Note that the model in its current state is only a predictor of dilution, not absolute concentration. Expected ambient concentrations would have to be scaled by the upstream concentrations in respective pathways. As analysis of the field data progresses, we will adapt the model to include more sophisticated treatment of the inflow concentrations and how they vary across sites and time.

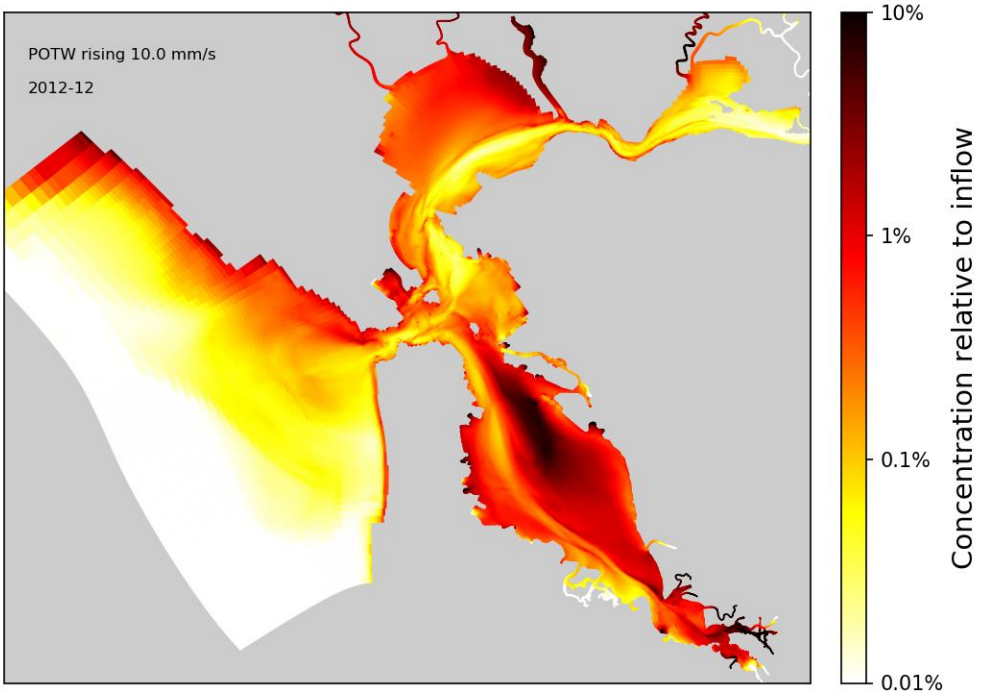

Figure 6.4 Depth averaged distribution of modeled buoyant microplastic scalar during the wet season.

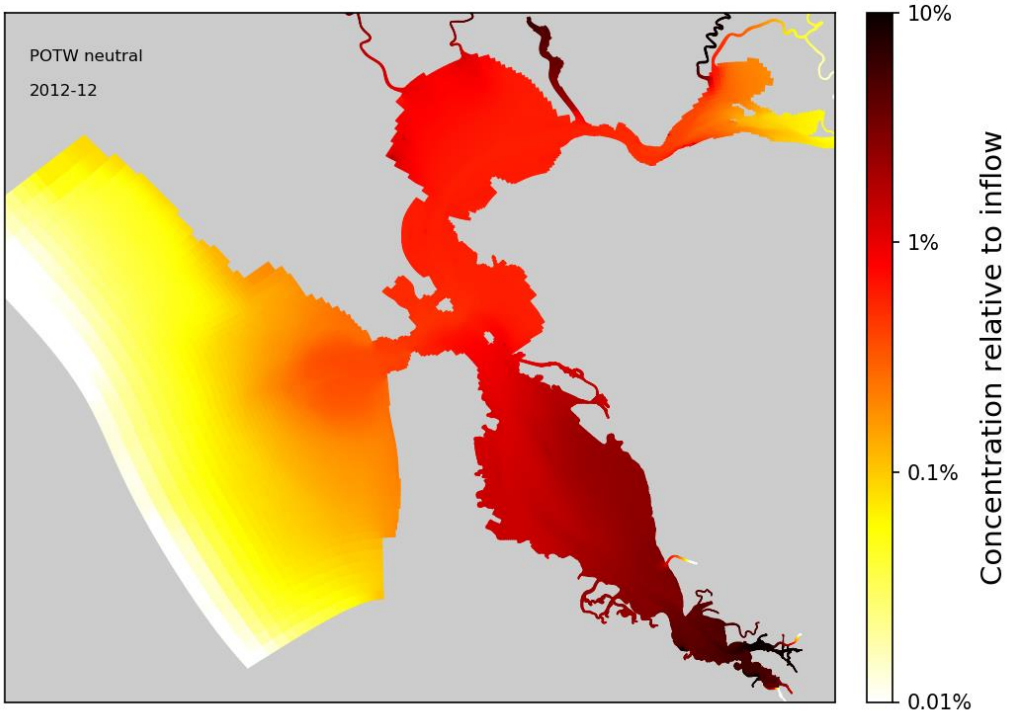

Figure 6.5 Depth-averaged distribution of neutrally buoyant microplastic scalar during the wet season.

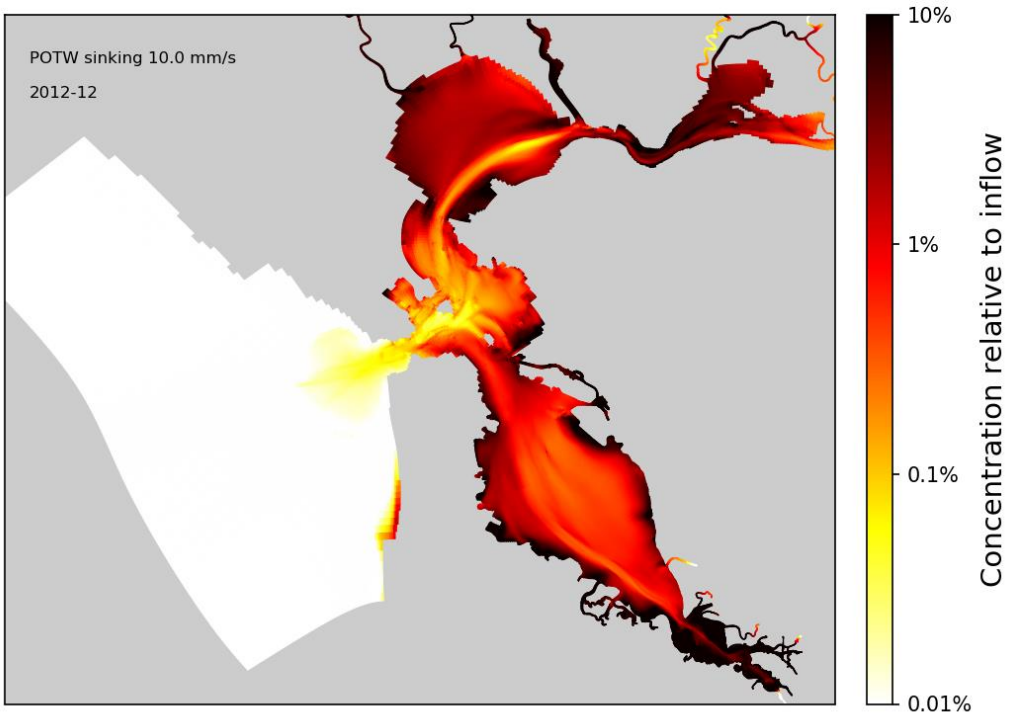

Figure 6.6 Depth-averaged distribution of negatively buoyant (sinking) microplastic scalar during the wet season.

The three panels show remarkably different spatial distribution according to the varying vertical rising/settling rates. In particular, sinking particles are effectively captured within the Bay, as they are perpetually in the landward portion of the estuarine exchange flow. In contrast, buoyant particles are able to ride the surface flows out of the Golden Gate. Within the Bay the interaction between particle buoyancy and density-driven circulation is complex and leads to features such as the hot spots of buoyant particles in South Bay shoals.

Seasonal Variability

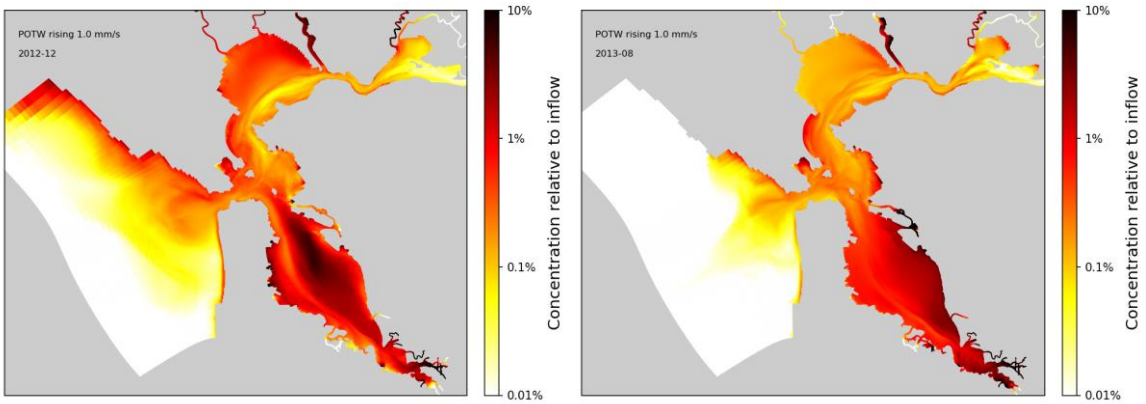

Figure 6.7 Comparison of 1 mm/s buoyant tracers from POTW pathways in (left) the wet season and (right) the dry season.

Figure 6.7 shows spatial distributions of POTW dilution for differing flow conditions. Only the buoyant tracers are shown here. The differences between the two panels reflect both the seasonal variation in POTW inputs (greater discharges in wet weather), and seasonal variations in transport within the Bay driven by density salinity gradients. While there is some difference in the volume of POTW flows between these two periods, the most significant difference is in the spatial shift with wet season conditions showing greater transport into the coastal ocean than the dry season flows. This is a direct consequence of the stronger estuarine exchange flows in winter, driven by the stronger longitudinal salinity gradients.

Pathway Variability

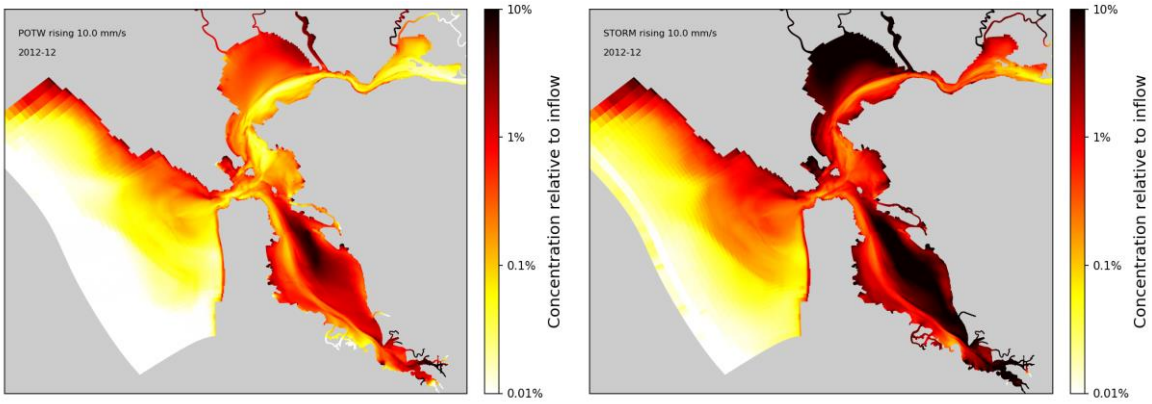

Figure 6.8 Comparison of 10 mm/s buoyant tracers in the wet season between (left) POTW pathways and (right) stormwater pathways.

Figure 6.8 compares the spatial distribution of dilution between POTW and stormwater inputs during the wet season. While the overall magnitude of the stormwater inputs in the wet season is clearly greater than POTW inputs, the general spatial patterns are quite similar. This similarity suggests that the time to flush these concentrations out of the Bay is long compared to the time needed to redistribute them within the Bay, such that the spatial patterns are dominated by in-Bay physics rather than point of discharge. Lower South Bay is possibly an exception to this generalization, where slow flushing rates coincide with POTW discharges that are large relative to the volume of Lower South Bay, and the balance of local POTW versus stormwater contributions is important.

6.2 Coupling Bay and Coastal Ocean Transport

Modeling the exchange of water and microplastic between San Francisco Bay and the adjacent coastal waters is an essential and challenging aspect of the modeling project. After considering multiple approaches and the available modeling tools, we arrived at an approach which involves expanding the existing San Francisco Bay model domain further into the coastal ocean (see Figure 6.9). Approaches which involved merging data from multiple models were deemed too risky in terms of introducing artifacts at the common boundary, and requiring expertise in multiple modeling platforms.

Extending the hydrodynamic model into the coastal ocean requires several steps:

1. *Add additional sections of the numerical grid.* In order to make inter-model comparisons and validation simpler in the future, we have borrowed a portion of the geometry of the CenCOOS (Central California Ocean Observing System) CA-ROMS (California Regional Ocean Modeling System) model grid. This grid was then spliced to the existing DFlow-FM grid at the existing ocean boundary (visible in Figure 6.9).
2. *Include additional forcing data needed for realistic coastal conditions.* Spatial and temporal variability of salinity and temperature have been sourced from a global 3-D ocean model (HYCOM). Spatially variable tidal forcing is derived from Oregon Tidal Prediction Software

(OTPS). Wind forcing, often neglected or poorly resolved at in-Bay scales, is essential in the coastal ocean, and motivated the use of a Navy-developed atmospheric model (COAMPS).

3. *Modify the numerical handling of the model boundaries for stability and consistency with updated forcing.* This step is ongoing, and has proven to be the most challenging. The greater depths and the significance of vertical gradients in flow and density make typical estuarine approaches unstable or inaccurate. We are following the methods of Rayson et al, 2018.

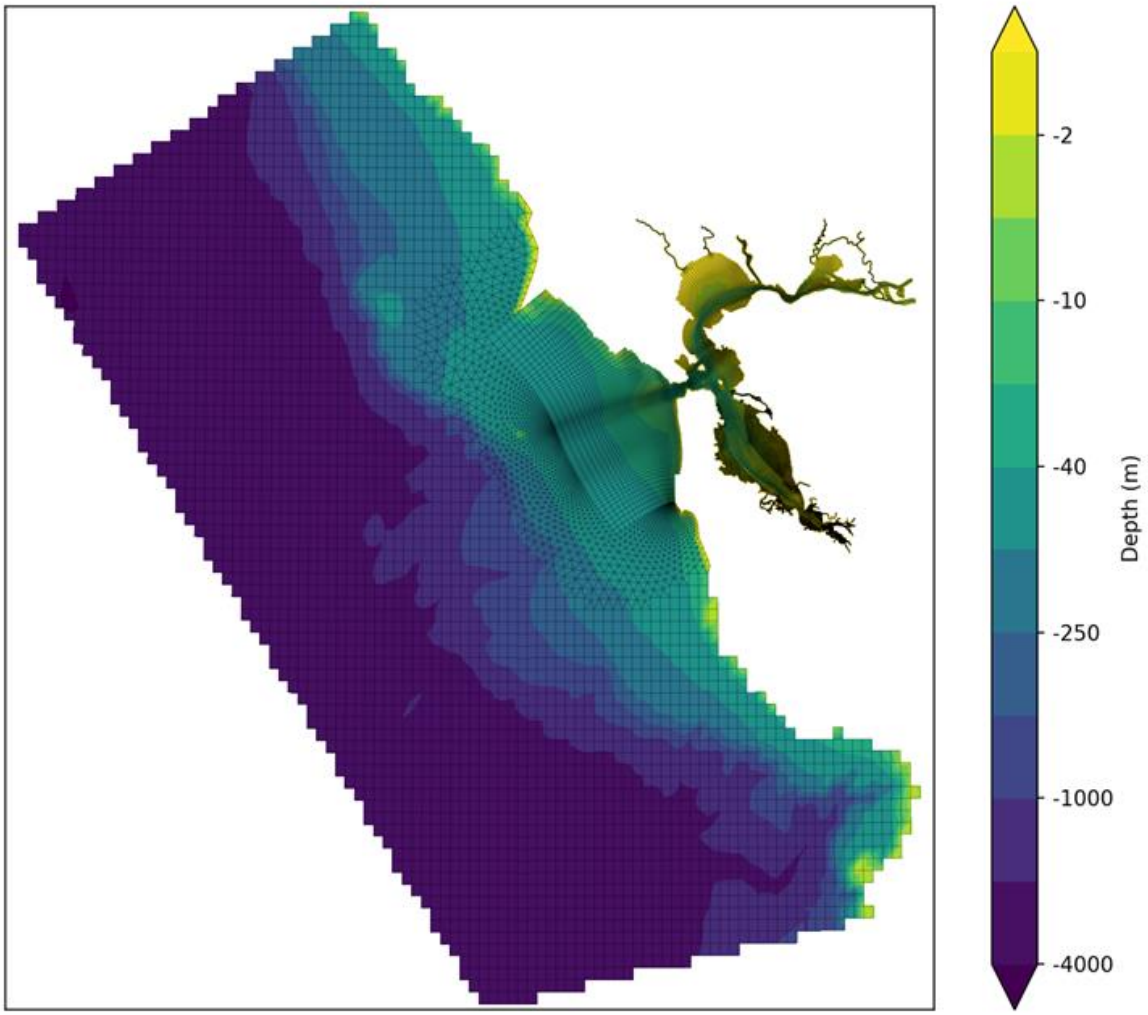

Figure 6.9 Bay-coast model domain grid and bathymetry.

Development of the model boundaries is still underway, with stable runs currently possible when forced by tides, salinity and temperature. These runs compare favorably to observed tides, but capturing the salinity and temperature fields will likely require the further incorporation of flow data from HYCOM (at present only HYCOM temperature and salinity are included). Surface salinity and temperature from a preliminary run are shown in Figure 6.10.

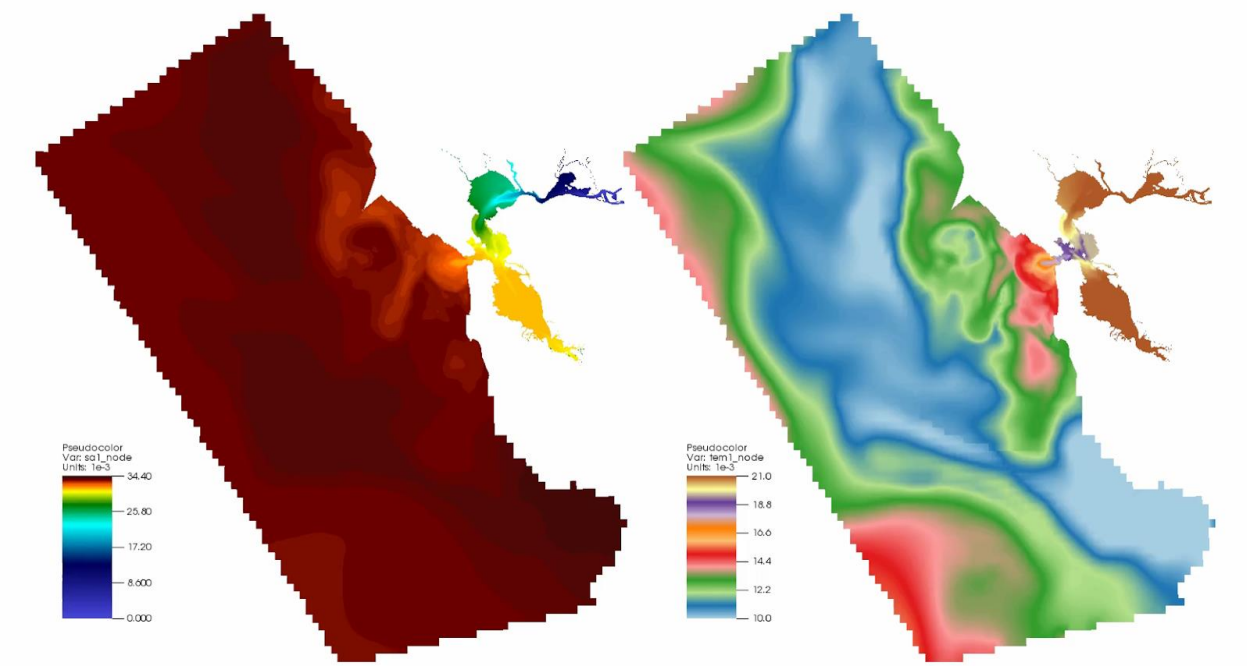

Figure 6.10 Surface salinity (left) and temperature (right) as simulated in the Bay-coast model domain.

7. Policy Recommendations and Outreach

This project was designed to generate resources that will inform and educate our stakeholders and general public. A number of steps have already been taken to begin this outreach, with more resources and materials to be generated upon completion of the scientific aspects of the project.

7.1 Policy Recommendations

Following completion of the analytical and modeling elements of the project, 5 Gyres will facilitate an evaluation of policy options for San Francisco Bay by key experts in the field and the region, providing science-based recommendations on plastic source reduction, including potential innovation, design and/or household interventions. Because the recommended actions and policies to control microplastic release into the Bay and ocean will be directly informed by the comprehensive scientific investigation currently underway, they will carry significant weight. Scientific findings and recommended actions will be shared in a large symposium for policymakers, scientists, and the general public in January 2019.

A small group of engaged stakeholders will be selected by the project team to assist in the development of the draft recommendations, beginning in late Summer 2018. Draft policy recommendations will be distributed to stakeholders for comments in Fall 2018 and will be finalized in early 2019.

7.2 2017 Policy Sail

To build momentum and relationships for the project, SFEI and 5 Gyres hosted a half-day educational sail in September 2017 to kick off the San Francisco Bay Microplastic Project. Influential members of numerous stakeholder groups learned about the project, participated in the sample collection, and explored their shared interests in finding solutions to plastic pollution. The group included experts from the textile industry, local regulators, journalists, additional scientists, city officials, elected government officials (i.e., State assemblymen and staff from a US senator) and representatives from other environmental groups. Some notable outcomes of this event included: 1) invitation to present our preliminary findings at an international conference on marine debris; 2) invitation to provide comments on a draft state strategy to address marine litter; 3) additional funding for policy development elements of the project; 4) invitation to apply for additional funds from a non-profit; 5) a KQED radio and print story on microplastic; and 6) new connections to diverse stakeholders and reporters.

We anticipate hosting an additional half-day policy sail in late 2018 or early 2019, after the study has been completed and the data-driven recommendations have been developed, as an effective means of engaging a broad and influential audience to implement the recommendations. The sail provides an opportunity to train and educate participants, and to network and build support among a broad group of stakeholders.

7.3 Education and Outreach

To educate a broader audience about the scientific findings generated by the project, as well as the data-driven recommendations for pollution prevention policies and actions, educational materials will be developed and distributed to stakeholders and the general public. Outreach materials will clearly explain results and steps that individuals can take to move towards solutions.

To date, a press release was distributed and several local media articles have highlighted the project. Throughout the field sample collection, photographs and short videos were posted on social media outlets, reaching 100,000s of people. The project's hashtag is #SFBayMicroplastics and has reached more than 200,000 people alone. Instagram and Facebook have features that allow real-time interaction during fieldwork with field staff that have, at times, attracted hundreds of people at a time.
5 Gyres and SFEI released a short film about the project in March 2018, and will be releasing additional short films and a professional documentary, anticipated to be completed by Winter 2018. The introductory film is located on the 5 Gyres website (https://www.5gyres.org/science/) and has been viewed more than 1,100 times. All films related to the project are being produced by Plus M Productions.

Moving forward, by early 2019, educational pamphlets and materials will be developed and distributed to stakeholders and the interested public.

8. Next Steps

The goals of this project are ambitious and exciting. Strengths of the project are the comprehensive nature of the study and its close linkage to policy outcomes. Related is the extraordinary level of enthusiasm for the project, the findings, and the potential for developing innovative strategies to mitigate microplastic pollution in San Francisco Bay and beyond.

We have successfully completed first year activities including the collection of all field samples from the Bay, the National Marine Sanctuaries, and the two major pathways, stormwater and wastewater. We have optimized methods for extracting microplastic from a variety of complex matrices and honed the spectroscopic methods that we will use to analyze for a suite of microplastic. Our analytical partner at University of Toronto has developed novel methods for the identification of a variety of synthetic fibers using an array of techniques and knowledge obtained from surveying textile manufacturers. We have also developed a vocabulary for characterizing microplastic that we will share with the State data repository staff.

To address unexpected analytical challenges, our analytical partner is currently evaluating methods to subsample when high particle counts are observed. The team is also working on methods to expedite the identification of polymer type. Despite these challenges, we anticipate that the laboratory will report the remainder of the data in discrete packages in late Summer and early Fall.

As the full data analysis is completed, we will evaluate the data quality to meet project goals. One of the challenges that we face in evaluating the data is the presence of particles, particularly fibers, in some of the field blanks. We have developed a preferred approach for qualifying data potentially influenced by background contamination, which we will discuss at the workgroup meeting. Variability in field duplicates that are still to be completed will be used to assess variability in each sample matrices, which will be important to evaluate data results to test hypotheses about the sources and pathways of microplastics in the Bay.

SFEI and 5 Gyres staff will compile and synthesize the data in the Fall, with a draft report available in December 2018 in accordance with our current contract. We will plan a second workgroup meeting around the release of the report to allow for a preliminary discussion of the findings with scientific experts and interested stakeholders.

Concurrently with the preparation of the report, we will be convening policy experts to review the findings to make recommendations for policy recommendations. Lastly, we will use the field data to calibrate and validate the models of microplastic transport through the Bay and the adjacent ocean.

After the release of our final report, in January 2019, we will convene a symposium with a broad audience to disseminate the key findings of the study, new tools developed, and policy and innovation implications of this work.

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Appendix A
Tables

Table A-1.1 Surface Water Samples Collected in the San Francisco Bay

Site ID	Location	Subregion	Start – Lat[1]	Start – Long[1]	End – Lat[1]	End - Long[1]	Rationale for site selection	Dry Date Sampled	Wet Date Sampled
LSB16	Lower South Bay	Near Guadalupe River	37.464	-122.027	37.463	-122.052	Receiving water for tributaries; wastewater	**8/24/17**** (nano dup)	**3/6/18*** 3/6/18 (pump dup)
LSB15	Lower South Bay	Near Palo Alto WWTP	37.461	-122.084	37.470	-122.060	Receiving water near wastewater	8/24/17*	3/6/18* 3/6/18 (dup)
LSB14	Lower South Bay	Main stem of LSB	37.471	-122.064	37.483	-122.084	Ambient conditions in LSB embayment	**8/24/17***	**3/6/18***
SB11	South Bay	Main portion of Bay – Southeast	37.598	-122.250	37.633	-122.253	Ambient conditions in SB embayment	8/23/17*	3/19/18*
SB13	South Bay	Near San Mateo creek	37.570	-122.213	37.548	-122.181	Receiving water for tributaries	**8/23/17***	**3/19/18***
SB10	South Bay	Main portion of South Bay - Northeast	37.650	-122.243	37.671	-122.278	Ambient conditions in SB embayment	8/23/17*	3/19/18*
SB12	South Bay	Main portion of South Bay - Southwest	37.594	-122.283	37.578	-122.243	Ambient conditions in SB embayment	**8/23/17**** (nano dup)	**3/19/18*** **3/19/18 (dup)**
CB9	Central Bay	Main portion of Bay - Near EBDA outfall	37.687	-122.291	37.699	-122.298	Receiving water for WWTP-EBDA	**8/22/17***	**1/11/18***
CB8	Central Bay	San Leandro Creek / Oakland Airport	37.751	-122.226	37.769	-122.231	Receiving waters for tributaries	**8/25/17 *** 8/25/17 (dup)	**1/11/18***
CB6	Central Bay	Emeryville	37.834	-122.320	37.828	-122.337	Receiving waters for tributaries	8/22/17*	11/16/17*
CB7	Central Bay	South of Bay bridge	37.778	-122.355	37.804	-122.381	Ambient conditions	8/22/17*	11/16/17* 11/16/17 (dup)
CB5	Central Bay	Main Channel in Central Bay, Southeast of Angel Island	37.843	-122.415	37.852	-122.454	Ambient conditions	8/22/17* 11/5/17 11/5/17 (dup)	11/16/17*
CB4	Central Bay	South of Richmond / San Rafael bridge	37.916	-122.441	37.942	-122.420	Ambient conditions	8/21/17*	11/16/17*
SFBay	Central Bay	Southeast of Treasure Island / North of Bay Bridge	37.820	-122.357	37.833	-122.362	Ambient conditions	9/18/17	N/A
SPB3	North Bay	Point Pinole	38.024	-122.371	38.042	-122.322	Receiving water for tributaries	**8/21/17***	**11/17/17***
SUB1	North Bay	Suisun Bay main	38.107	-122.056	38.097	-122.065	Ambient conditions	8/21/17*	11/17/17*
SPB2	North Bay	San Pablo Bay main	38.051	-122.422	38.023	-122.428	Ambient conditions	**8/21/17***	**11/16/17***

Table A-1.2 Surface Water Samples Collected in National Marine Sanctuaries adjacent to San Francisco Bay									
Monitoring Site	**Location**	**Subregion**	**Start – Latitude[1]**	**Start – Longitude[1]**	**End – Latitude[1]**	**End – Longitude[1]**	**Rationale for site selection**	**Dry Date Sampled**	**Wet Date Sampled**
CBNMS23	Cordell Banks	Central region	38.035	-123.313	38.043	-123.285	Ambient conditions	**9/12/17***	**3/29/18**
CBNMS22	Cordell Banks	East side	38.107	-123.114	38.097	-123.098	Ambient conditions	9/12/17*	3/30/18
CBNMS24	Cordell Banks	West side	37.985	-123.497	37.980	-123.466	Ambient conditions	9/13/17*	3/29/18
GFNMS26	Greater Farallones	Farallon Islands	37.821	-123.007	37.819	-122.980	Ambient	**9/12/17*** 9/12/17 (dup)	**3/29/18***
GFNMS28	Greater Farallones	At discharge of GG; SF Plume	37.806	-122.756	37.804	-122.729	Modeling; Load Calculations	**9/13/17***	**3/30/18*** 3/30/18* (pump dup)
GFNMS25	Greater Farallones	Off of Point Reyes	37.967	-122.927	37.957	-122.904	Convergence zone off of Pt Reyes	9/11/17*	3/30/18*
GFNMS27	Greater Farallones	West side	37.733	-123.263	37.725	-123.251	Remote part of Greater Farallons - reference comparison	9/13/17*	3/29/18
GFNMS29	Monterey Bay	At discharge of GG; SF Plume	37.805	-122.508	37.815	-122.471	Modeling; load calculations; outgoing tide	**9/13/17***	**11/17/17*** 1/11/17* **3/30/18** 3/31/18* (nano only)
MBNMS30	Monterey Bay	At discharge of GG; SF Plume	37.672	-122.611	37.662	-122.585	Modeling; load calculations	**9/27/17***	**3/31/18*** 3/31/18* (pump dup)
MBNMS31	Monterey Bay	Off the coast of Ano Nuevo	37.507	-122.580	37.524	-122.580	Upwelling areas around Pt Ano Nuevo	9/27/17*	3/31/18*
MBNMS32	Monterey Bay	West side	37.450	-122.932	37.461	-122.905	Remote part of Monterey Bay - reference for comparison	9/27/17*	**3/31/18***

1 – Latitude & longitude values recorded in this table represent the actual location where the first dry season Manta Trawl sample collected at each site. Latitudes and longitudes for other water samples collected at each site are displayed in the maps in Appendix B, and will be available for download from CEDEN.
2 – Dates shown in bold and purple text represent sampling events at which pump samples were also collected. Dates that are starred represent events at which nanoplastic samples were also collected.

Table A-2 Sediment Sites Sampled in the Ambient Bay and Bay Margins

Embayment	Sediment Type	Site ID	Site Location Description	Latitude	Longitude	Sampling Date	Rationale	Co-located site		
								Small fish site	Stormwater site	Effluent site
Central Bay	Ambient	CB001S	Central Bay	37.876	-122.362	8/7/14	Background characterization			
Central Bay	Ambient	CB073S	Central Bay	37.843	-122.398	8/7/14	Background characterization			
Central Bay	Ambient	CB100S	Central Bay	37.776	-122.330	8/6/14	Background characterization			
Central Bay	Ambient	CB133S	Central Bay	37.839	-122.316	8/7/14	Background characterization			
Central Bay	Margins	CB04	Crab cove off of Alameda	37.768	-122.278	9/2/15	Background characterization			
Central Bay	Margins	CB10	Richmond Marina Bay - just off of Vincent Park	37.907	-122.347	7/28/15	Background characterization	Near CB10	Meeker Slough	
Central Bay	Margins	CB15	Just slightly northwest of Bay Bridge/IKEA	37.828	-122.303	9/1/15	Urban creek - Temescal		Line12A	
Central Bay	Margins	CB24	East of Coast Guard island	37.786	-122.247	9/2/15	Background characterization			
Central Bay	Margins	CB30	Albany Mudflat State Marine Park	37.893	-122.312	9/14/15	Background characterization			
Central Bay	Margins	CB32	San Leandro Bay - NE near East Creek Slough	37.757	-122.220	9/1/15	Urban Creek - East Creek Slough	CB101	Line12F & H	
Central Bay	Margins	CB48	San Leandro Bay - SW near Doolittle Dr	37.743	-122.216	9/1/15	Background characterization		Line12K & Line12J	
Central Bay	Margins	CB37	South of Oyster Point; very close to Colma Creek	37.641	-122.395	8/31/15	Urban Creek - Colma Creek		Colma Creek	
Central Bay	Margins	CB39	Richardson Bay, north of Sausalito	37.876	-122.507	7/27/15	Background characterization			
Central Bay	Margins	CB49	San Francisco - McCovey Cove	37.777	-122.389	8/21/15	Urban Creek – Mission Creek			
South Bay	Ambient	SB002S	South Bay	37.610	-122.167	8/6/14	Background characterization			

Table A-2 Sediment Sites Sampled in the Ambient Bay and Bay Margins										
South Bay	Ambient	SB004S	South Bay	37.601	-122.219	8/6/14	Background characterization			
South Bay	Ambient	SB110S	South Bay	37.547	-122.173	8/5/14	Background characterization			
South Bay	Ambient	SB111S	South Bay	37.695	-122.228	8/6/14	Background characterization			
South Bay	Margins	SB051	Westside - South of SFO runway	37.602	-122.362	7/6/17	Background characterization			
South Bay	Margins	SB062	Westside - Near Seal Slough	37.576	-122.265	7/19/17	Urban Creek (and golf course)		San Mateo Creek	
South Bay	Margins	SB077	Westside - Bair Island	37.545	-122.222	7/19/17	Wastewater (South Bay Systems Authority)	Near SB074		
South Bay	Margins	SB074	Westside - South of Bair Island – Redwood Creek	37.528	-122.184	7/17/17	Urban Creek	Near SB074		
South Bay	Margins	SB058	Westside - north of 84 - Ravenswood Slough	37.498	-122.161	7/17/17	Background characterization			
South Bay	Margins	SB069	Eastside – near Oro Loma	37.663	-122.176	7/18/17	Urban Creek - San Lorenzo			
South Bay	Margins	SB075	Eastside – Eden Landing	37.610	-122.158	7/19/17	Background characterization			
South Bay	Margins	SB056	Eastside – Alameda Creek	37.561	-122.131	7/17/17	Stormwater			
Lower South Bay	Ambient	LSB002S	Lower South Bay	37.479	-122.078	8/5/14	Background characterization			
Lower South Bay	Ambient	LSB004S	Lower South Bay	37.494	-122.085	8/5/14	Background characterization			
Lower South Bay	Margins	LSB11	Westside – north of San Francisquito	37.472	-122.119	6/5/17	Background characterization			
Lower South Bay	Margins	LSB02	Westside – near Palo Alto WWTP	37.463	-122.105	6/5/17	Wastewater	Near LSB06		Palo Alto WWTP
Lower South Bay	Margins	LSB06	Westside – Hooks Point	37.458	-122.092	6/8/17	Urban Creek / Background characterization	Near LSB06		
Lower South Bay	Margins	SOSL15	Westside – Moffett Field	37.452	-122.062	6/7/17	Urban Creek – Stevens Creek			Near Sunnyvale WWTP

Table A-2 Sediment Sites Sampled in the Ambient Bay and Bay Margins										
Lower South Bay	Margins	SOSL16	North of Guadalupe	37.458	-122.040	6/7/17	Urban Creek		Guadalupe Slough	Near Sunnyvale WWTP
Lower South Bay	Margins	SOSL40	Coyote Creek	37.462	-122.022	6/6/17	Wastewater and urban creek	SOSL40	Coyote Creek	San Jose WWTP
Lower South Bay	Margins	LSB04	Eastside near Mowry	37.486	-122.069	6/6/17	Background characterization			
Lower South Bay	Margins	LSB01	Don Edwards	37.499	-122.082	6/6/17	Background characterization			
San Pablo Bay	Margins	SPB126	China Camp	38.020	-122.493	6/20/17	Wastewater			
San Pablo Bay	Margins	SPB15	Petaluma River	38.108	-122.488	6/20/17	Urban river			
San Pablo Bay	Margins	SPB50	Sonoma Creek	38.141	-122.390	6/21/17	Background characterization			
San Pablo Bay	Margins	CAR42	Napa river	38.074	-122.250	6/21/17	Urban river			
San Pablo Bay	Margins	SPB128	Hercules	38.016	-122.300	6/21/17	Background characterization		Refugio Creek	
Suisun Bay	Margins	SUB53	Contra Costa WWTP	38.044	-122.097	6/21/17	Wastewater / Urban creek – Pacheco Creek			CCCSD
Suisun Bay	Margins	SUB52	Montezuma Slough	38.136	-122.035	6/21/17	Baseline characterization			
Suisun Bay	Margins	SUB16	Point Edith Wildlife	38.050	-122.077	6/21/17	Background characterization			
Tomales Bay	Margins	TB109	Near Long Cove Beach	38.161	-122.899	6/22/17	Reference	Near TB102		
Tomales Bay	Margins	TB102	South End of Bay	38.098	-122.846	6/22/17	Reference	Near TB102		
Tomales Bay	Margins	TB101	Near Walker Creek	38.206	-122.929	6/22/17	Reference	Near TB101		

Table A-3 Prey fish sites sampled in San Francisco Bay and Tomales Bay

Site[1]	Location	Site ID	Sampling Dates	Latitude	Longitude	Co-Located Sites			
						Sediment site	Stormwater site	Wastewater site	Adjacent surface water site
Tomales Bay (Reference)	Tomales South	TB102	6/22-6/23/17	38.0908	-122.836	Between TB102 and TB109			
Tomales Bay (Reference)	Tomales North - near Walker Creek	TB101	6/22-6/23/17	38.2093	-122.9292	Near TB101			
Central Bay	Marina Bay	CB10	7/5/17	37.9137	-122.3538	Near CB10	Meeker Slough		
Central Bay	Oyster Point	CB37	7/6/17	37.671217	-122.3790		Colma Creek		
Central Bay	San Leandro Bay - NE near East Creek Slough (CB32)	CB106	6/19/17	37.7579	-122.219	CB32	Line12F; Line12H		CB8
South Bay	Redwood Creek	SB074	7/6 – 7/7/17	37.518152	-122.2072	Between SB074 & SB077			
Lower South Bay	Near Hooks Point	LSB06[2]	6/8 – 6/9/17	37.4576	-122.0921	Between LSB06 & LSB02		Palo Alto	Near LSB15
Southern Sloughs	Alviso Slough – near confluence with Coyote Creek	SOSL40	7/7 – 7/8/17	37.4621	-122.0217	SOSL40	Coyote Creek; Guadalupe River (upstream)	San Jose	Near LSB16

1 -- At each site, at least 10 anchovy and 10 topsmelt were collected (20 individual fish). Bycatch and excess fish were wrapped in foil and archived. At the Lower South Bay (Alviso Slough) and the Tomales Bay (Southern portion of the Bay), additional topsmelt were collected for preliminary nanoplastic analyses.

2 – Approximately half of the samples collected were lost during transit.

Table A-4 Wastewater Treatment Facilities Sampled

Site	Location[1]	Treatment	Design Flow (MGD)	Sampling Dates	Sediment site[2]	Fish	Adjacent surface water site[2]
North Bay	Central Contra Costa Sanitation District	Secondary	~50	9/7/17; 12/6/17	SUB53		
Central Bay	San Francisco Public Utilities Commission- Southeast	Secondary	86	11/6/17; 11/7/17			
Central Bay	EBMUD	Secondary	~120	8/21/7; 9/26/17; 10/20/17			SFBay
South Bay	East Bay Dischargers Authority	Secondary	77	8/31/17; 9/26/17			CB9
South Bay	Fairfield Suisun	Advanced		8/23/17; 9/7/17			Near SUB1
Lower South Bay	Sunnyvale	Advanced	~30	9/19/17; 10/17/17	SOSL15 / SOSL16		
Lower South Bay	Palo Alto	Advanced	39	7/20/17; 8/1/17	LSB02	LSB06	LSB15
Lower South Bay	San Jose Santa Clara	Advanced	167	8/10/17; 9/19/17	SOSL40	SOSL40	LSB16

1 – Field blanks were collected at the SFPUC treatment plant. Field duplicates were collected at the Palo Alto wastewater treatment plant.

Table A-5 Stormwater Samples Collected in San Francisco Bay

Monitoring Sites	RMP Site Name	Location	Sampling Date	Latitude	Longitude	Size of Watershed (km^2)	Rationale for site selection
MMP-Storm-CB-Line12A	Line12AatShellmoundStPedestrianBr	Central Bay	1/8/18	37.83429	-122.29349	10.48	RMP site, Urban (Commercial / Residential)
MMP-Storm-CB-Line12F	Line12FbelowPGEstation	Central Bay	12/15/16	37.762	-122.214	10.18	RMP site, Urban (Commercial / Residential)
MMP-Storm-CB-Col12H	Line12HatColiseumWay	Central Bay	12/15/16	37.762	-122.212	0.97	RMP site, only use if Coliseum 12K is not available. Low priority because of small drainage area
MMP-Storm-CB-Col12J	Line12Jatmouthto12K	Central Bay	12/15/16	37.755	-122.201	8.81	RMP site, Only use if Coliseum 12K is not available
MMP-Storm-CB-Col12K	Line12KatColiseumEntrance	Central Bay	2/9/17	37.754	-122.204	16.4	RMP site, Site is near bay and includes commercial, residential and industrial
MMP-Storm-CB-Meek	MeekerSloughatRegattaBlvd	Central Bay	1/8/18	37.917861	-122.33838	7.34	RMP site, Mixed residential, Drains into inner harbor in Oakland
MMP-Storm-SB-Colma1	Colma Ck at Linden	South Bay	2/7/17	37.65	-122.412	27.5	RMP site, 303d listed for trash, Part of Tracking CA Trash Project, Major Tributary
MMP-Storm-SB-SM	San Mateo Creek	South Bay	1/8/18	37.572638	-122.310769	11.4	303(d) listed for trash, Part of Tracking Trash Project, major tributary
MMP-Storm-LSB-Guad	Guadalupe River	Lower SB	1/8/18	37.37356	-121.93283	233	RMP site near Highway 101
MMP-Storm-LSB-CC	Coyote Creek	South Bay	3/21/18[1] 4/6/18	37.385832	-121.909581	322.8	Major stormwater and wastewater influenced tributary to Lower South Bay, Part of Tracking CA Trash Project
MMP-Storm-NB-Refugio	RefugioCkatTsushimaSt	San Pablo Bay	1/18/17	38.018	-122.277	10.73	RMP site, Open space
MMP-Storm-NB-Rodeo	RodeoCreekatSeacliffCtPedestrianBr	San Pablo Bay	1/18/17	38.016	-122.254	23.41	RMP site, Open space

1 – Coyote Creek was sampled twice in 2018. The sample collected on 3/21/18 is considered to primarily characterize baseflow, while the 4/6/18 sample characterizes significant stormwater runoff. The sampling location is upstream of the wastewater treatment facility.

Table A-6 Field blanks and duplicates				
Matrix	**Collection Method**	**Field Blanks**	**Field Duplicates**	**Comments**
Bay water	Manta	5	5	2 field blanks in Bay (16 sites) for each season (wet and dry). Two duplicate Manta trawls will be taken serially (1 Bay – wet and dry).
	Pump	2	2	
	Nano	2	2	
Sanctuary	Manta	3	2	1 blank will be taken in the Sanctuaries (12 sites) per season (wet and dry). Duplicate Manta trawl will be taken serially (1 sanctuary).
	Pump	2	2	
	Nano	2	2	
Sediment	Grab	4	3	Field blank - DI water will be poured over sampling equipment into pre-cleaned bottle. At 3 sites, fill a second bottle for field duplicate; no archive samples at duplicate sites
	Nano	4	3	
Fish	Net	None	None	
Stormwater	Grab across hydrograph	1	0	Field blank – field blank sieves will remain uncovered as the stormwater sample is being collected. Duplicate - serial sips across the storm, alternating between two different sieve sets.
Wastewater	24-hr composite	1	1	Field blank - sieve uncovered for 24-hour composite period. Field duplicate will be collect using Y splitter off of sampling port to two different sieve sets.

1 – Highlighted cells indicate QA/QC sample types that have not yet been sampled

Appendix B
Figures

Figure B.1 Microplastic Sites Sampled in the Bay

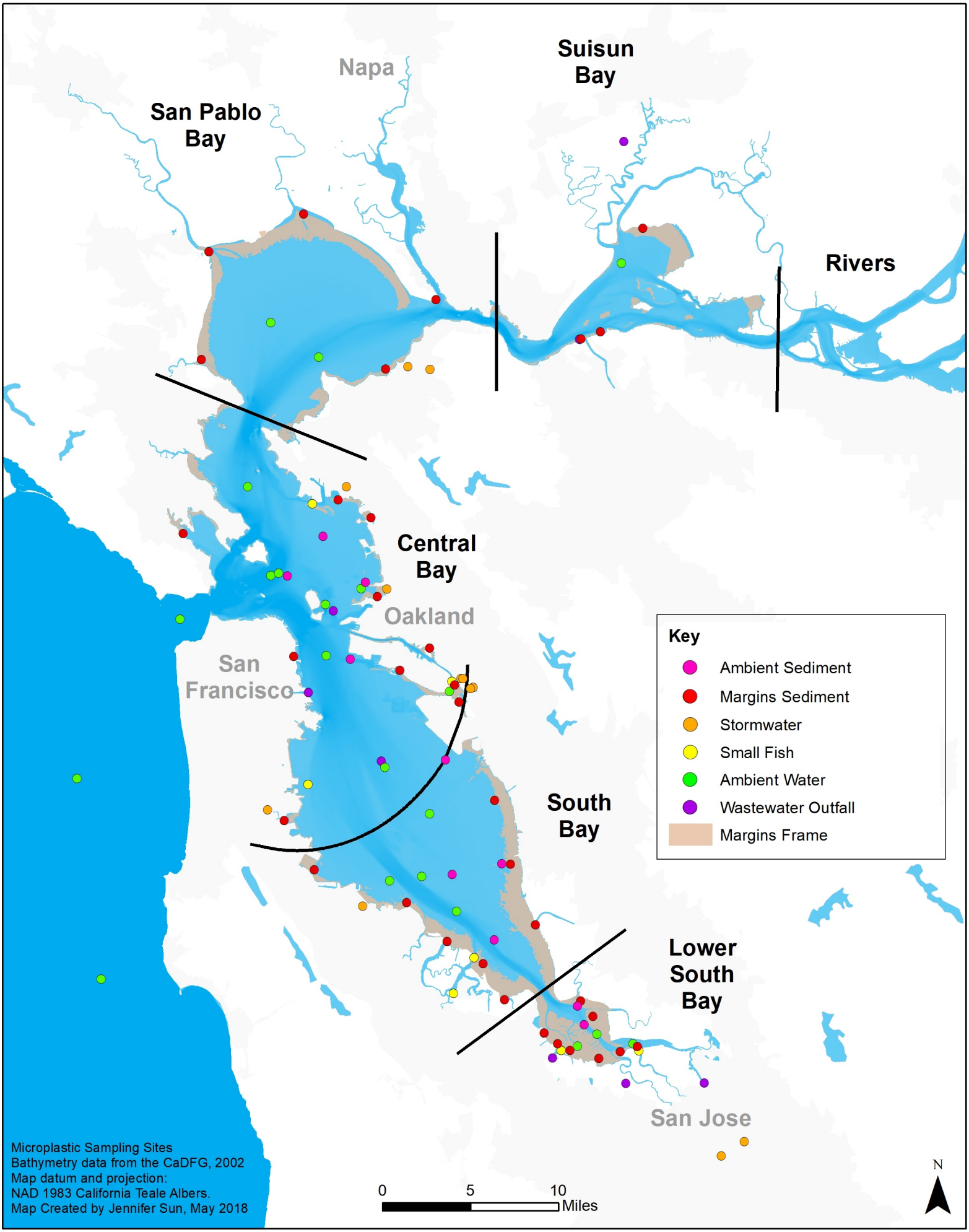

Figure B.2 Microplastic Sites Sampled in the Sanctuaries and Tomales Bay

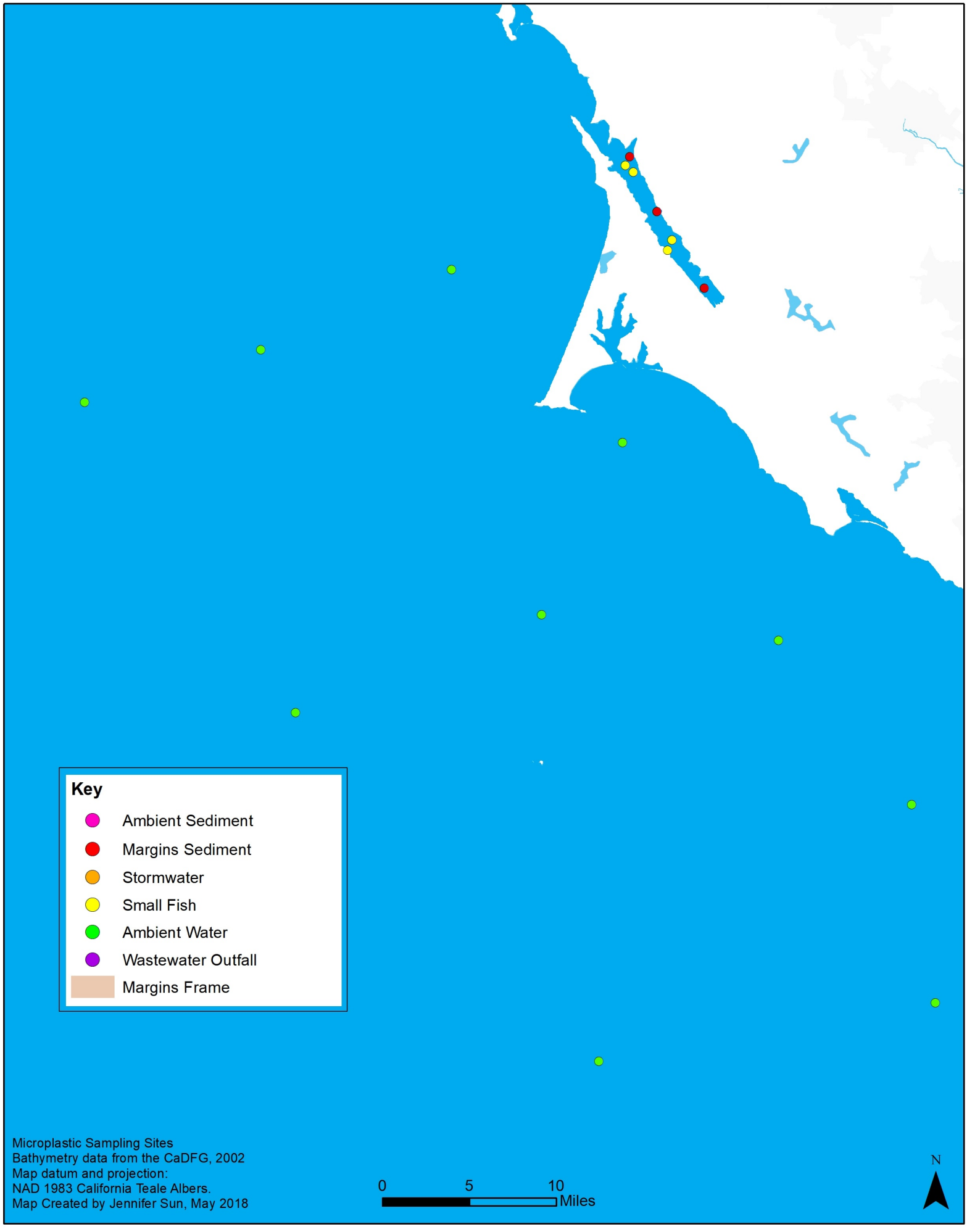

Figure B.3 Microplastic Sites Sampled in Suisun Bay

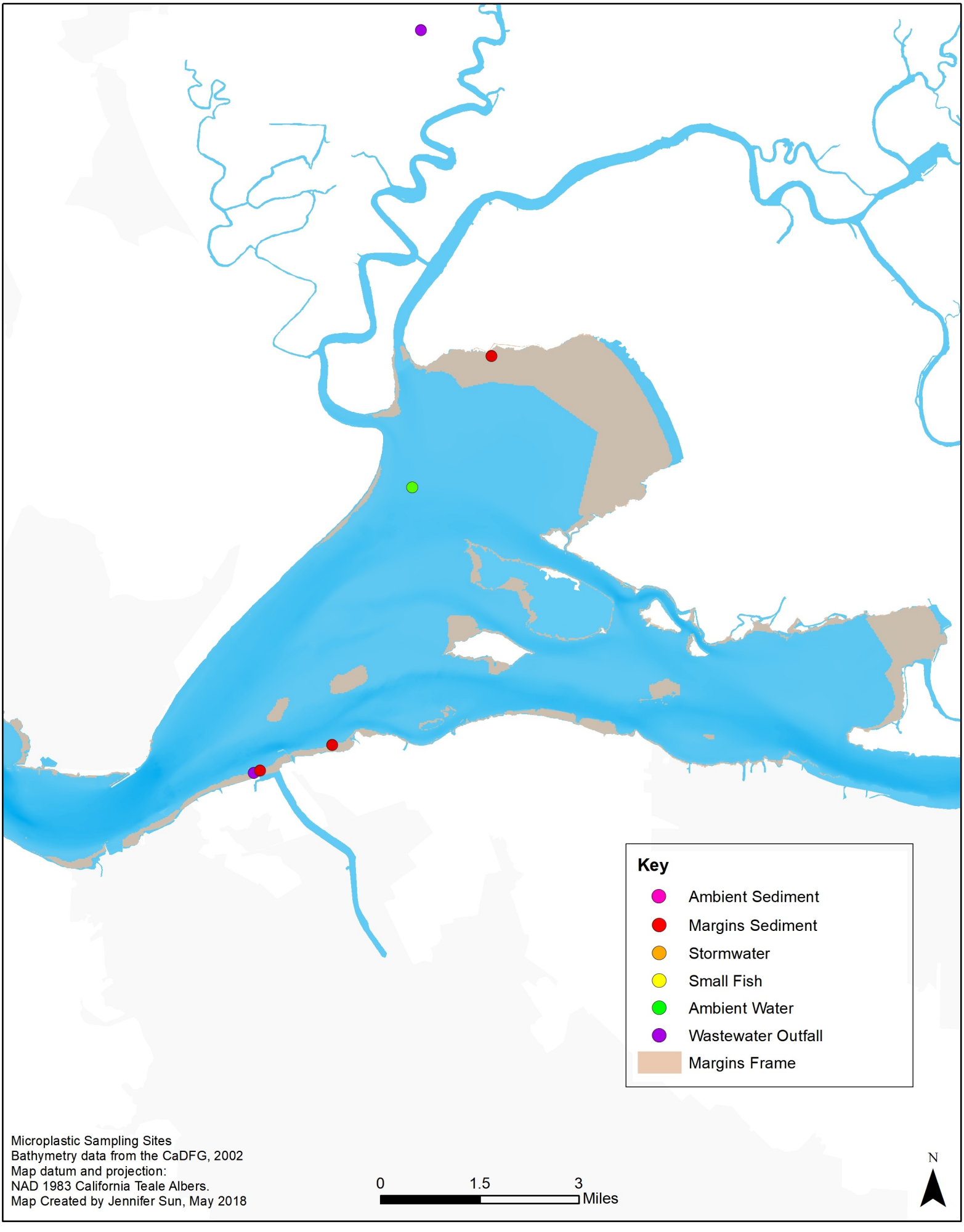

Figure B.4 Microplastic Sites Sampled in San Pablo Bay

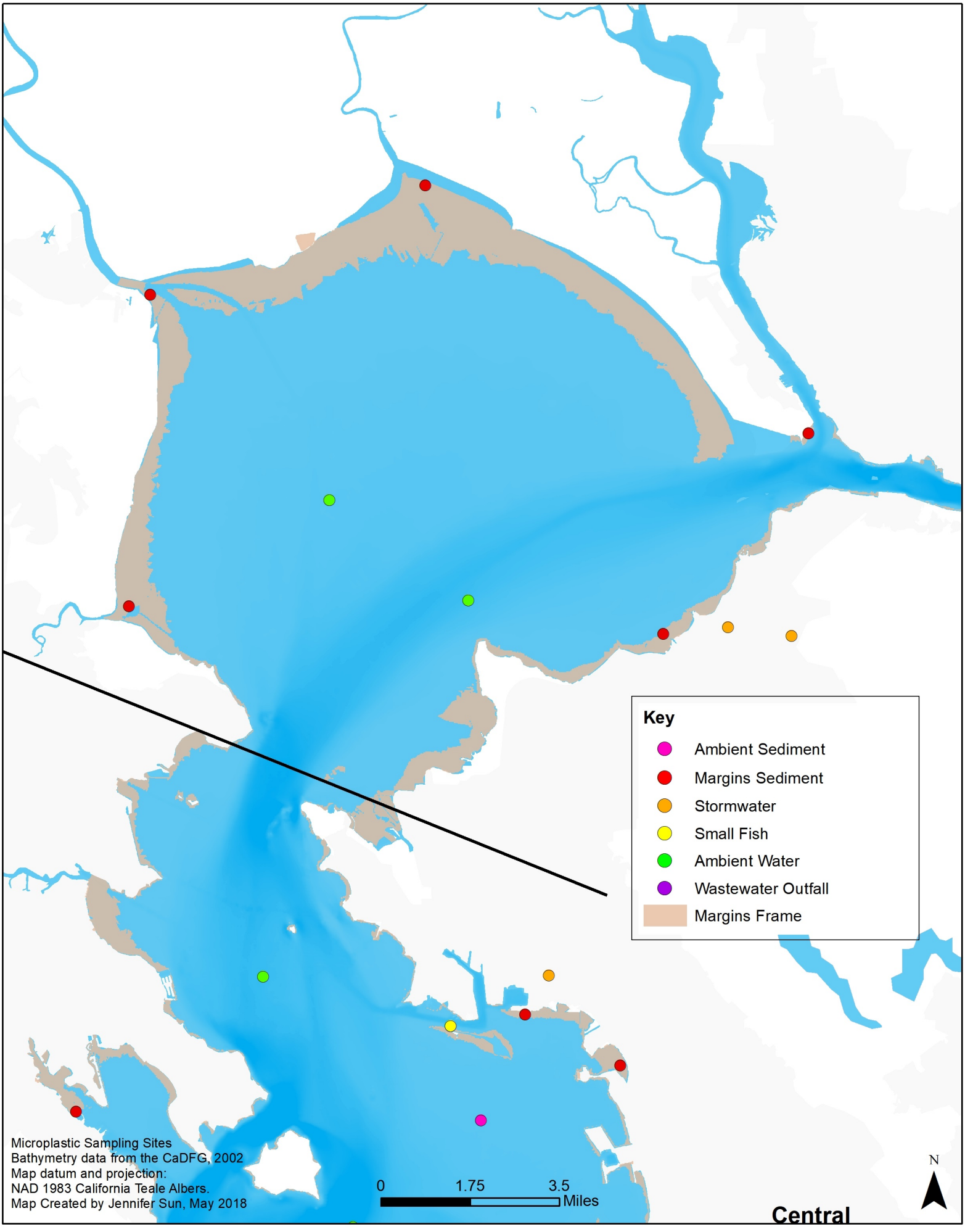

Figure B.5 Microplastic Sites Sampled in Central Bay

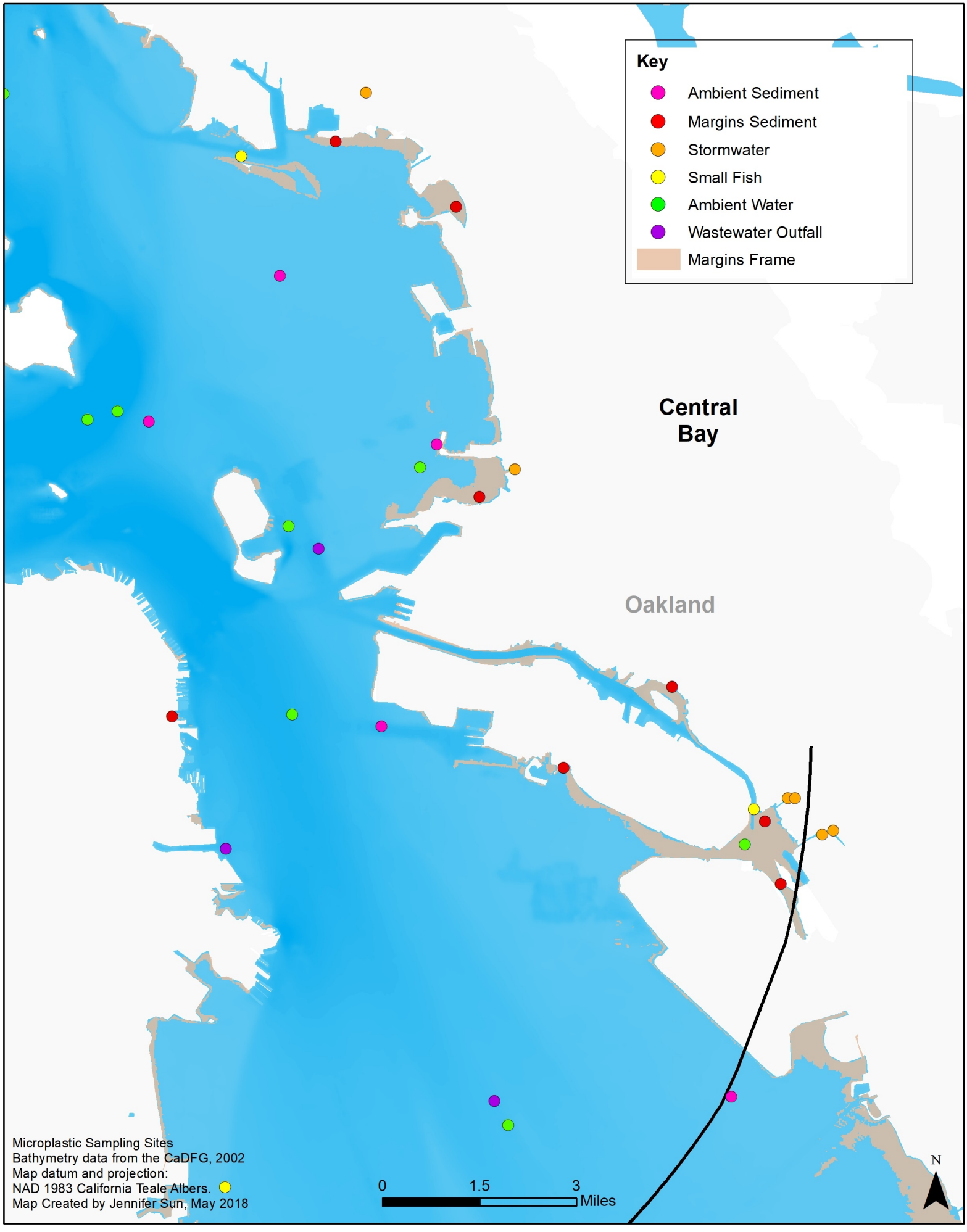

Figure B.6 Microplastic Sites Sampled in South Bay

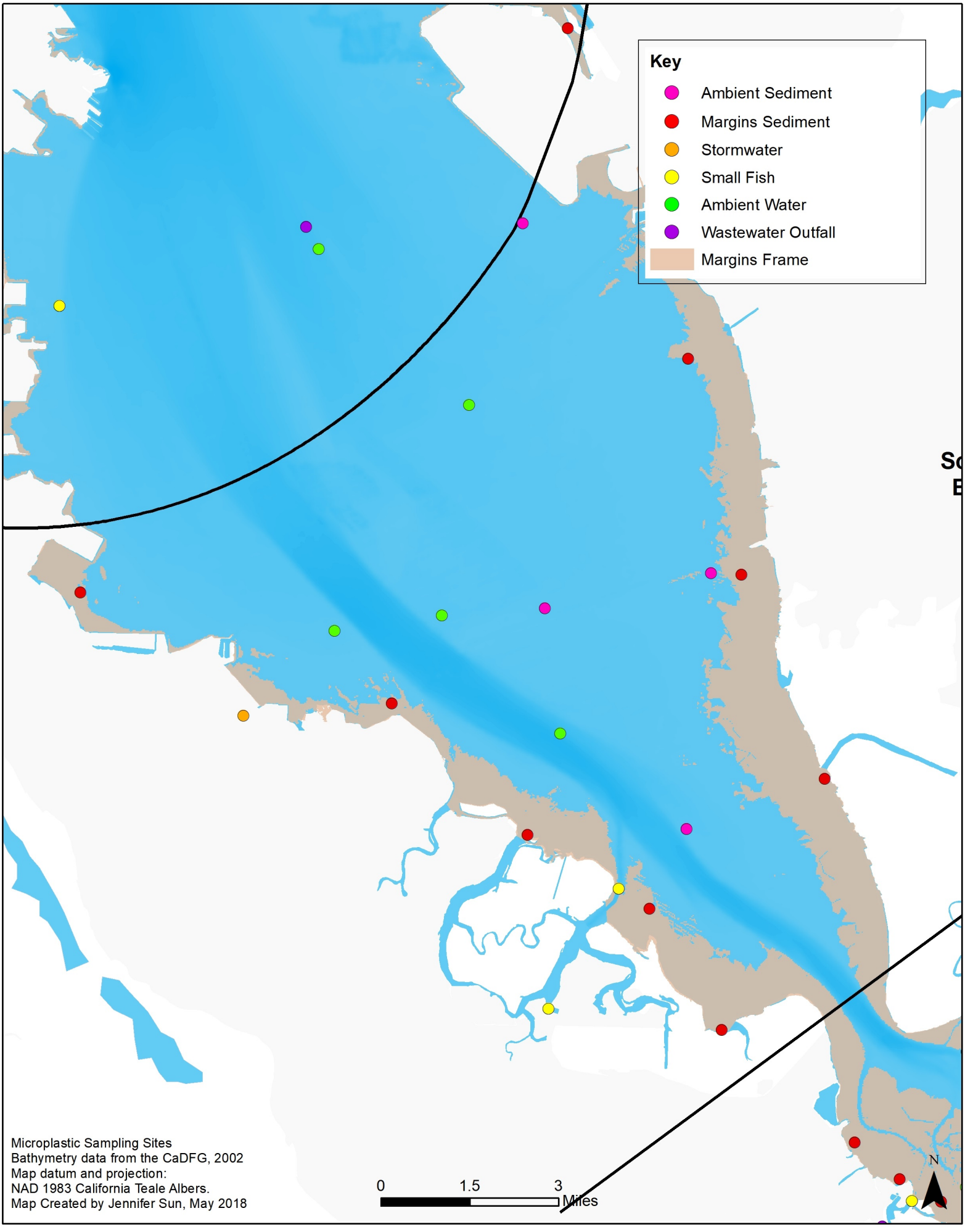

Figure B.7 Microplastic Sites Sampled in Lower South Bay

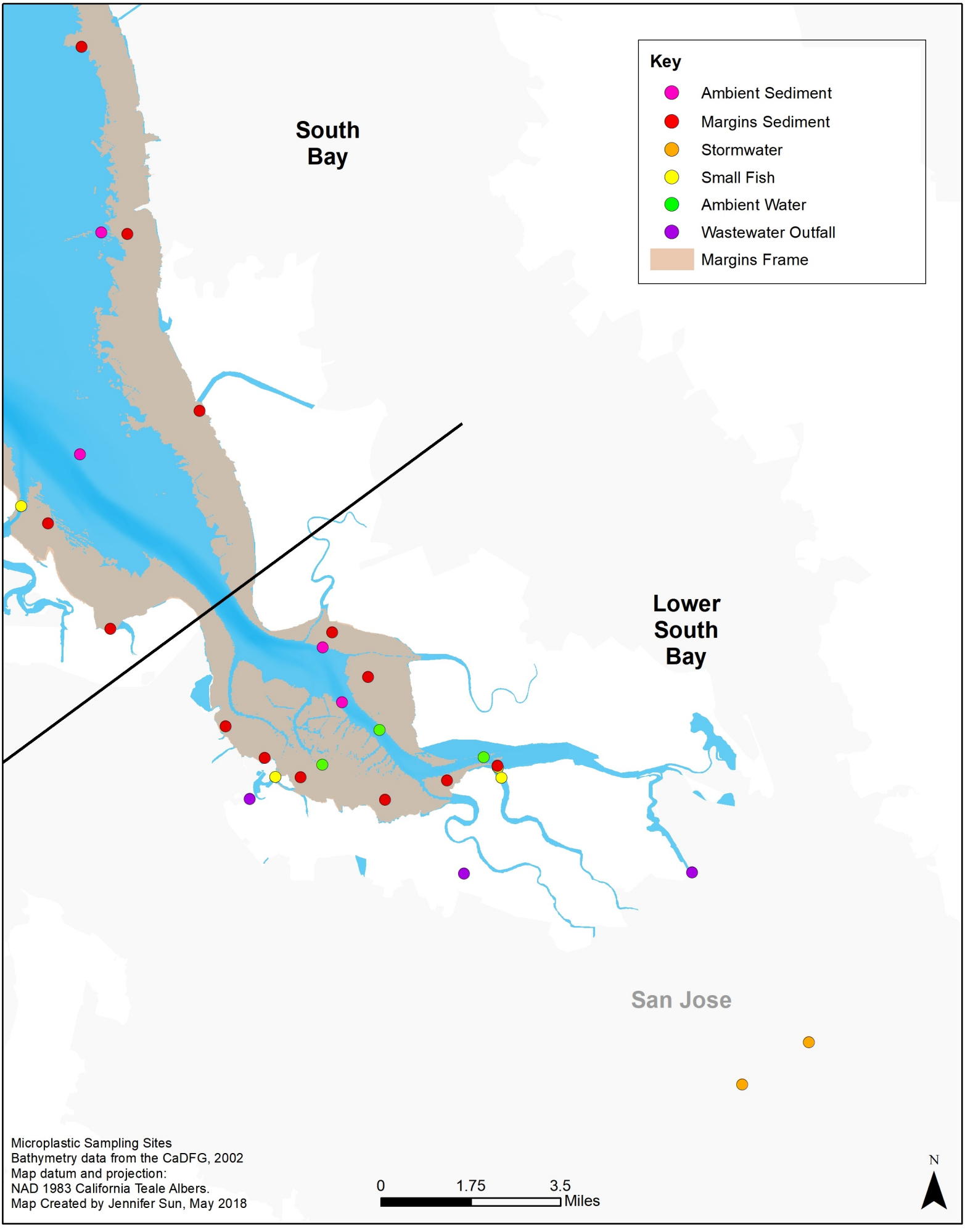

Figure B.8 Surface Water Trawl and Pump Samples Collected in San Francisco Bay

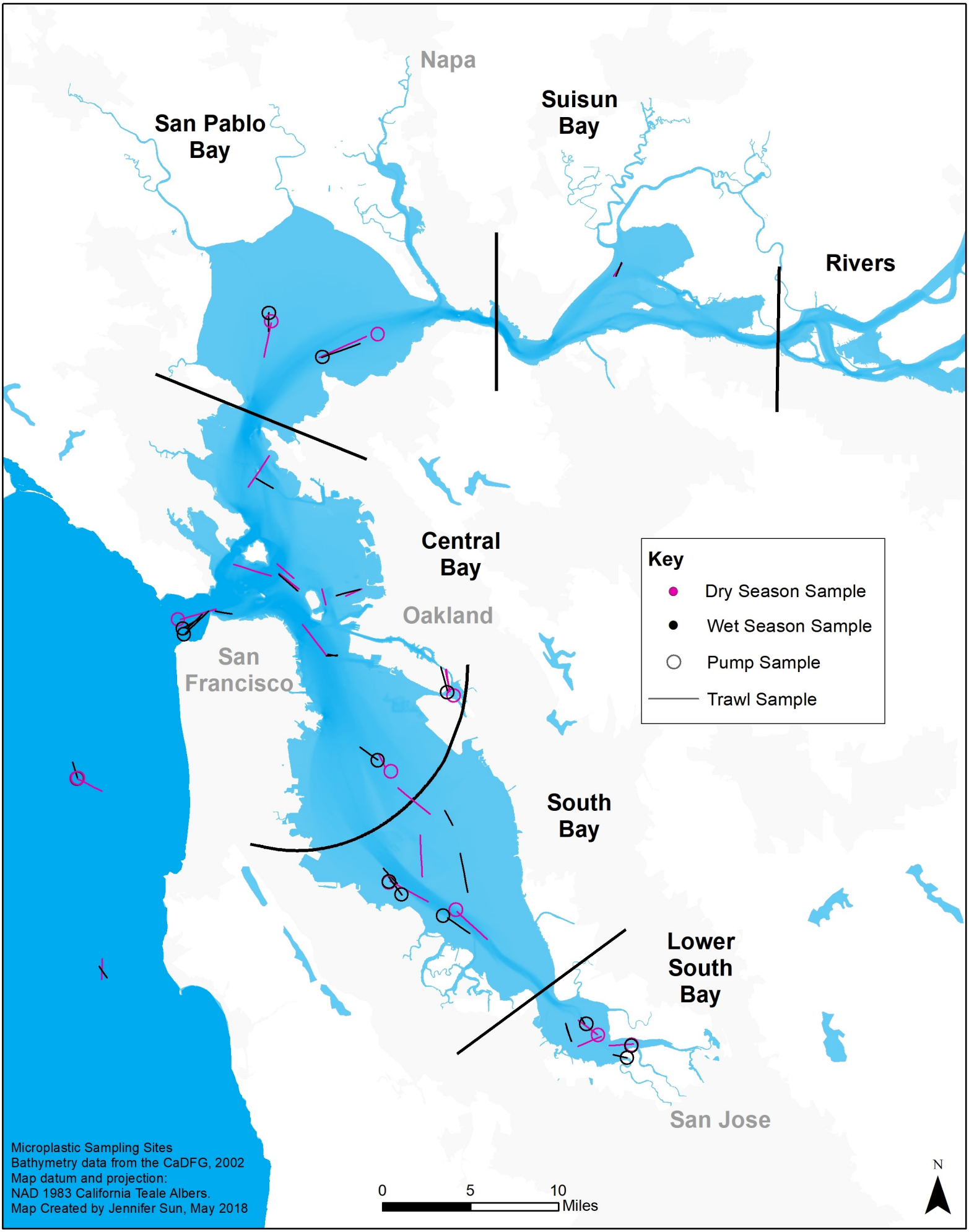

Figure B.9 Surface Water Trawl and Pump Samples Collected in the Sanctuaries

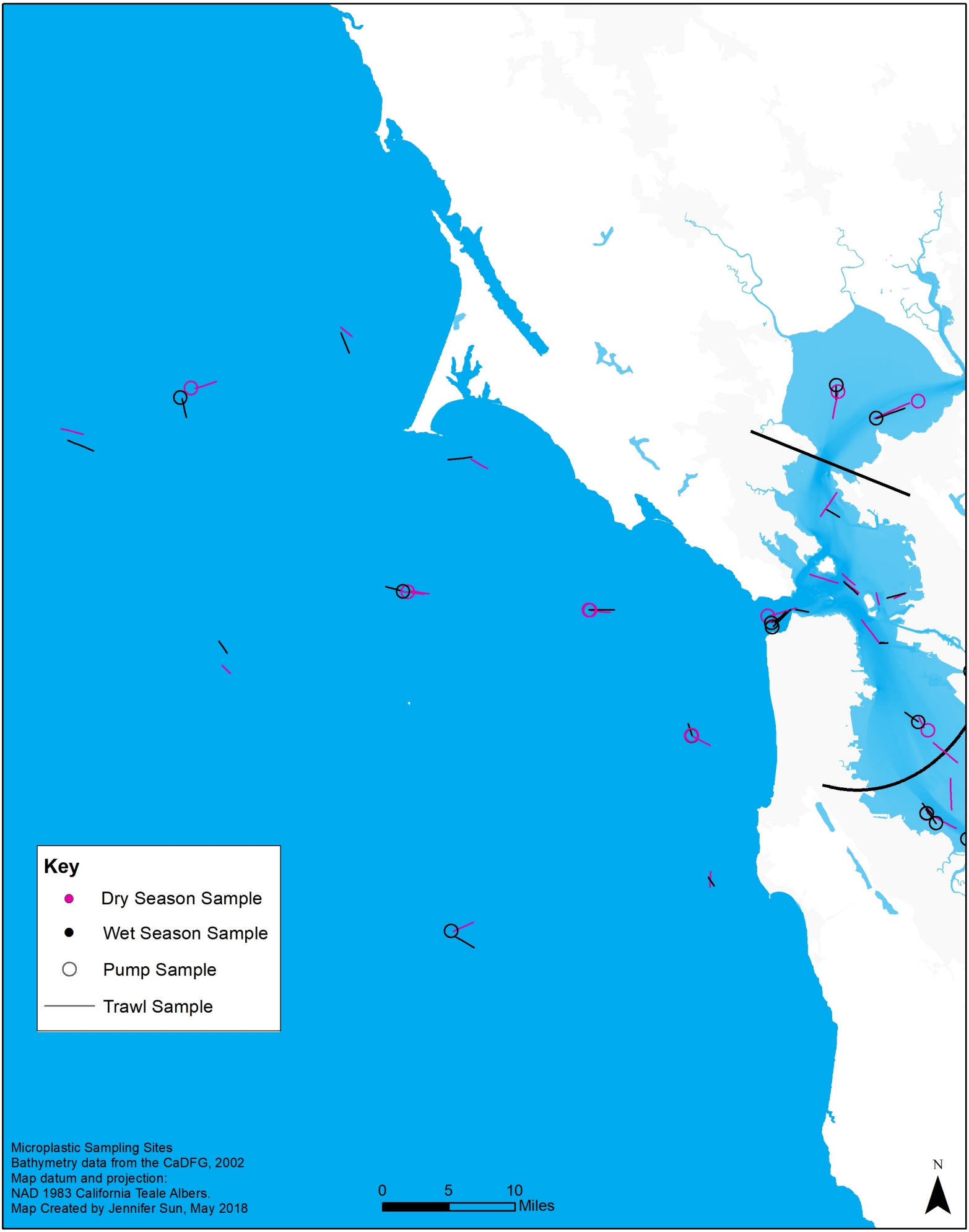

Figure B.10 Nanoplastic Samples Collected in the San Francisco Bay and Sanctuaries