Special Study Proposal: Convening an Expert Workshop on the Ecotoxicological and Human Health Impacts of Microplastics

Summary: SFEI and SCCWRP will work together to convene world experts on microplastic environmental and human health toxicology for a three-day workshop aimed at summarizing the current state of scientific knowledge on the potential risks of microplastics to aquatic life and humans. Through this project, we will identify environmentally relevant exposure information for different particle types, identify data gaps, and develop a roadmap describing what additional research should be prioritized to give managers the relevant insights they need to develop a comprehensive risk management plan. This project would fund SFEI staff time to attend the workshop and make writing contributions to reports summarizing results of the workshop. This project leverages significant contributions from SCCWRP in planning and hosting the workshop.

Estimated Cost: $18,000 (with $56,000 matching funds from SCCWRP)

Oversight Group: Microplastic Workgroup

Proposed by: Ezra Miller, Diana Lin, SCCWRP staff

PROPOSED DELIVERABLES AND TIMELINE

Deliverable	***Due Date***
Task 1. Facilitate workshop	October 2020*
Task 2. Draft summary reports	January 2021
Task 3. Final summary reports	February 2021

*Note: May be potentially delayed due to Covid-19 events.

Background

Microplastics, tiny pieces of plastic smaller than 5 millimeters, are recognized as a pervasive and preventable global threat to the health of aquatic ecosystems. There are a myriad of sources of microplastics, including the breakdown of plastic debris, plastic products such as tire wear and artificial turf, and fibers from textiles. These tiny particles can be transported long distances, and are ubiquitous and persistent pollutants in the ocean. As a result, aquatic organisms at every trophic level, as well as the terrestrial animals and humans that consume them, are exposed to microplastics.

A growing body of research indicates that microplastics have the potential to threaten the health of a wide range of organisms, from zooplankton to humans. However, the health risks from microplastic exposure remain uncertain. Ingested microplastics can potentially impact the biochemical and physiological processes of many different types of animals. Their toxicity likely varies based not only on species, but also on the particle's chemistry, shape, size, and concentration. Potential modes of action include creating a false sense of satiation upon ingestion, blocking gastrointestinal tracts, and triggering cellular-level toxic response. Microplastics can also expose organisms to potentially harmful chemicals, especially plastic additives such as flame retardants, plasticizers, or dyes.

While some progress has been made toward characterizing the extent, transport, and fate of microplastics in aquatic environments, research to understand the toxicological effects of microplastics on wildlife and humans is still in its infancy. In particular, microplastics researchers have not yet reached consensus on how to correlate exposure to health risk, especially the nuances of how different particle materials, sizes, and shapes influence exposure risk for different types of organisms. Furthermore, many toxicological investigations are not yet focused on environmentally relevant exposure scenarios.

In 2018, the California State Legislature enacted Senate Bill 1263 requiring the California Ocean Protection Council (OPC) to adopt and implement a statewide strategy to evaluate the ecological risks of microplastics in marine environments by 2025. California also enacted Senate Bill 1422 (Portantino, 2018), requiring the testing and reporting of microplastics in drinking water. In order to understand the scale of the microplastic problem in California, it is crucial to develop a better understanding of the risks posed by microplastic exposure. There is, therefore, a need for microplastics researchers to come together to develop consensus around the state of the science and agree on what additional research should be prioritized to support development of a comprehensive risk evaluation strategy.

Although researchers are studying microplastics exposure risk from a variety of perspectives, the proposed workshop will have a focus on reaching consensus on environmentally relevant exposure scenarios, including different microplastic particle types (i.e., size, shape, and chemical composition) and exposure routes (i.e., ingestion, passive uptake through gills and skin) that represent potential threats to aquatic life and human health. Workshop participants will also synthesize knowledge about which factors may affect these thresholds (e.g., how sensitive certain biota may be, and in particular which toxicity endpoints appear to be the most important). From this synthesis, we will gain insights into the current state of knowledge on the toxicological relevance of occurrence – that is, whether a given level and type of particles at a specific site can be expected to impact biota and, if so, how. Because research on microplastic environmental and human health impacts is still in its infancy, the workshop will also help develop clarity and consensus around data gaps and which future studies will give managers relevant, actionable insights to enhance understanding of the effects of microplastics on biota. This will in turn inform OPC's microplastics strategy development and implementation.

Study Objectives and Applicable RMP Management Questions

The proposed workshop will bring together leading global experts on microplastic ecotoxicology and human health to discuss and develop consensus on how to approach and develop a microplastic ecotoxicological and human health risk evaluation strategy. The three-day workshop, which will be co-facilitated by SFEI and SCCWRP and hosted at SCCWRP, will begin with a day of public presentations by leading international experts in the toxicology of microplastics. The remaining two days will consist of invitation-only working groups charged with 1) outlining review documents summarizing the current state of knowledge in the field (one for wildlife, one for human health); and 2) developing a list of research priorities necessary to fill the knowledge gaps they have identified to direct future research.

Table 1. Study objectives and questions relevant to RMP Microplastic Strategy management questions (Sutton and Sedlak 2017).

Management Question	**Study Objective**	**Example Information Application**
1) How much microplastic pollution is there in the Bay?		
2) What are the health risks?	Summarize current knowledge of microplastic effects on wildlife and human health	Identify research needs; Develop risk assessment framework for microplastics
3) What are the sources, pathways, loadings, & processes leading to microplastic pollution in the Bay?		
4) Have the concentrations of microplastic in the Bay increased or decreased?		
5) Which management actions may be effective in reducing microplastic pollution?	Identify research needs	Inform OPC's statewide microplastics strategy and the State's microplastics drinking water requirements

Approach

SFEI and SCCWRP will work with representatives from OPC and the State Water Board to develop a list of workshop participants and invitees. The first day of the workshop (expert presentations) will be open to the public, while the second and third days (working groups) will be limited to the invited experts, along with selected participants from State agencies that will provide perspective on management needs and priorities.

During the workshop, participants will develop a list of research priorities necessary to fill the knowledge gaps they identify. After the workshop, SFEI and SCCWRP staff will work with workshop participants to prepare review documents summarizing the workshop outcomes and the current literature. The OPC and State Water Board will be able to use these review documents as the basis for developing their strategic plans.

This project leverages significant contributions from SCCWRP. SFEI and SCCWRP staff will co-facilitate the workshop and work together to write the follow-up documents.

SCCWRP will provide the meeting facilities and support the travel expenses of the workshop's invited experts. The SCCWRP portion of the total workshop budget (approximately $56,000) is therefore not included in the estimated project budget below, which is just for SFEI staff time.

Budget

The following budget represents estimated costs for this proposed special study (Table 2).

Table 2. Proposed Budget.

Budget Item	Hours	Budget
Workshop Attendance by two SFEI Staff	64	$9,000
Report Writing	55	$7,000
Direct Expense - Travel		$2,000
Total		$18,000

Budget Justification

Workshop Attendance
Workshop attendance budget is based on labor hours for two SFEI personnel to attend three days at the workshop including travel time. Because the workshop is being planned for October 2020, funds would need to be released prior to 2021. Direct travel costs are estimated separately below. The workshop will be held at SCCWRP, which will eliminate the need for facility rental charges. SCCWRP offers state-of-the-art meeting facilities, including the ability to live-stream the public presentations on the web.

Report Writing and Manuscript Writing
The report writing budget is based on labor hours for SFEI staff to collaborate with SCCWRP staff to write a report for OPC summarizing the results from the workshop.

Direct Expense
Direct expense travel costs include round-trip flights, lodging, and per diem for two SFEI staff to attend the workshop.

Leveraged Value
SCCWRP is contributing significantly to the cost of running the workshop, including travel expenses (airfare, accommodations, local transport, etc.) for 20 invited experts ($24,000), SCCWRP staff time to organize and facilitate the workshop and draft follow-up reports ($32,000), and in-kind facilities support.

Reporting

The first day of the workshop will be recorded and made available to the public. The results will be documented in reports to OPC and the State Water Board.

References

Sutton, R and M Sedlak. 2017. Microplastic Monitoring and Science Strategy for San Francisco Bay. Contribution 798. San Francisco Estuary Institute. Richmond, CA.

Sedlak, M, Sutton, R, Miller, L, and D Lin. 2019. Microplastic Strategy Update. Contribution 951. San Francisco Estuary Institute. Richmond, CA

Special Study Proposal: Microplastics in San Francisco Bay Sport Fish

Summary: In summer 2019, as part of RMP Status and Trends monitoring, sport fish were collected and analyzed for a suite of contaminants. The digestive tracts of some of these fish were archived specifically for future microplastic analysis. This project proposes to make use of archived fish digestive tracts from striped bass, largemouth bass, and shiner surfperch to assess the level of exposure in the Bay food web to microplastics and associated pollutants. Striped bass and shiner surfperch are popular for human consumption and are important to analyze to assess potential human exposure routes to microplastics.

Estimated Cost: $50,500

Oversight Group: Microplastic Workgroup

Proposed by: Diana Lin and Nina Buzby (SFEI); Chelsea Rochman (University of Toronto)

PROPOSED DELIVERABLES AND TIMELINE

Deliverable	***Due Date***
Task 1. Laboratory analysis	January - October 2021
Task 2. Draft manuscript	April 2022
Task 3. Microplastic Workgroup presentation.	May 2022

Background

Microplastics have been found in the tissues of seafood, including tiger prawns (Abbasi et al., 2018), shellfish (Cho et al., 2019; Naji et al., 2018) and fish (Rochman et al., 2015). The literature shows a variety of adverse effects associated with microplastic exposure, including inflammation and oxidative stress, microbiome changes, altered swimming and feeding behavior, altered reproductive success, and decreased growth and body condition (Foley et al., 2018). Although the ingestion of microplastics by fish and shellfish is unlikely to cause acute toxicity or mortality, the effects of chronic exposure require further research (Rist et al., 2018). The minimal availability of data on this topic is a cause for concern for public health (Hantoro et al., 2019).

Currently, there is no information regarding the fate of microplastics in the human body upon ingestion (Rist et al., 2018). However, interactions between microplastics and the immune system have been postulated to cause immunotoxicity and trigger adverse effects (Wright and Kelly, 2017). Microplastics contain chemical additives that are intentionally added to achieve desired properties, many of which can be toxic to humans and wildlife, such as carcinogens, endocrine disruptors, and neurotoxins (Talsness et al., 2009; Thompson et al., 2009). In laboratory studies, microplastics or chemicals associated with microplastics have been shown to transfer out of the gut and accumulate in tissues (Carbery et al., 2018). A recent study found that wild fish that had ingested microplastics had higher concentrations of bisphenols (a common class of plastic additives) in their liver and muscle tissue (Barboza et al., 2020). Additionally, the hazard index calculated from ingestion of fish tissue containing the levels of bisphenols measured suggested a health risk to human consumers. The potential of plastic debris to sorb and desorb chemicals in aquatic organisms may pose another potential threat to humans and wildlife.

SFEI recently completed a comprehensive regional investigation of microplastics in San Francisco Bay (Sutton et al., 2019). Microplastic contamination was found throughout the Bay, and concentrations measured in Bay water and sediment were among the highest reported in the literature to date. Microplastics were present in two species of prey fish analyzed, anchovies (*Engraulis mordax*) and topsmelt (*Atherinops affinis*). Concentrations of microparticles in prey fish ranged between 0 – 57 microparticles per fish. A separately funded RMP study also found microplastics to be present in California mussels (*Mytilus californianus*) and Asian clams (*Corbicula fluminea*) (Miller et al., 2020). The high levels of microplastics in the Bay and the presence of microplastics in prey fish indicate the potential for microplastic and associated chemical exposure at higher trophic levels, including sport fish and, ultimately, humans. However, sport fish that are consumed by humans have not been monitored for microplastics; this is a major data gap for the Bay.

Sport fish may have very different exposure compared to prey fish due to their larger size, feeding patterns, feeding range, and generally longer lifespan. Sport fish are potentially exposed to microplastics directly through mistaking them for a food source, and indirectly through consuming smaller prey species contaminated with microplastics.

Bay sport fish microplastic levels can be compared to a limited number of other studies elsewhere in California. One regional study of pelagic fish (> 30 species) off the coast of southern California found less than 1% of the fish had ingested microplastics in the 1-5 mm size range (Moore et al., 2016). However, another study in San Diego Bay (Salas et al., 2016), found three out of four fish species had consumed microplastics (1-5 mm), with about 18% of stingrays and 12% of spotted sea bass ingesting microplastics. Study of sport fish in the Bay is critical to understanding the fate of microplastics in the Bay food web, determining risks to human and ecological health, and evaluating sport fish monitoring as a potential index of microplastic contamination in the Bay.

Gastrointestinal tracts from fish collected during 2019 RMP Status and Trends sport fish monitoring have already been archived for the purpose of future microplastic analysis, should funding be appropriated. Evaluating levels of microplastics in sport fish is important for understanding potential impacts to Bay fish, and for understanding whether people may be exposed to microplastics through ingestion of sport fish. While people generally do not eat the gastrointestinal tracts of fish, it is possible for microplastics smaller than 150 μm (Lusher et al., 2017) to translocate out of the gut to other organs and for chemical additives from plastics to accumulate in fish tissue.

Study Objectives and Applicable RMP Management Questions

The purpose of this study is to determine the amounts and types of microplastics in sport fish in the Bay.

Table 1. Study objectives and questions relevant to RMP Microplastic Strategy management questions (Sutton and Sedlak 2017).

Management Question	Study Objective	Example Information Application
1) How much microplastic pollution is there in the Bay?	Assess concentration in an important upper trophic organism.	Assess the potential for uptake of microplastics into Bay food webs, and add to the conceptual model for microplastics in the Bay.
2) What are the health risks?	Compare concentrations in Bay sport fish to literature studies and previous prey fish results.	Assess magnitude of exposure to fish and potential human exposures.
3) What are the sources, pathways, loadings, & processes leading to microplastic pollution in the Bay?	Assess variation among species and sites to gain insight into the importance of local inputs.	
4) Have the concentrations of microplastic in the Bay increased or decreased?	Establish a baseline for future trend analyses.	Assess if concentrations and composition of microplastics change over time.
5) Which management actions may be effective in reducing microplastic pollution?	Characterize types of microplastics present in sport fish.	Understanding the type and composition of microplastics accumulating in biota will be important for prioritizing appropriate management actions.

Approach

Three following sport fish species are currently archived for microplastic analysis: shiner surfperch (*Cymatogaster aggregata*), striped bass (*Morone saxatilis),* and largemouth bass (*Micropterus salmoides*). Striped bass are a popular sport fish species that is higher in the food chain and provides an integrated signal for the Bay as a whole because of its wide foraging behavior and opportunistic consumption of lower trophic level fish. Striped bass are also the most popular sportfish for consumption in the Bay (SFEI and CDHS, 2000). Largemouth bass collections were substituted for striped bass in Artesian Slough, where striped bass were not collected in sufficient numbers. These two bass species have similar feeding strategies. Shiner surfperch are an abundant and popular sport fish species that feeds on invertebrates in the benthic zone and exhibits high site fidelity, making them useful for assessing regional differences in contaminants. In total, 66 fish were collected and archived for microplastic analysis from sites within the Central Bay and South Bay (Table 2).

Table 2. Sport fish samples available for microplastic analysis. Highlighted bold samples are those prioritized for analysis.

	Shiner Surfperch	Striped Bass	Largemouth Bass
Central Bay		7	
San Francisco	10		
Berkeley	10		
South Bay	**10***	**12**	
San Leandro Bay	10		
Artesian Slough			**7***
Totals	**40**	**19**	**7**

*Composite tissue archives of these fish will be analyzed for Bisphenols as part of a 2020 ECWG special study effort.

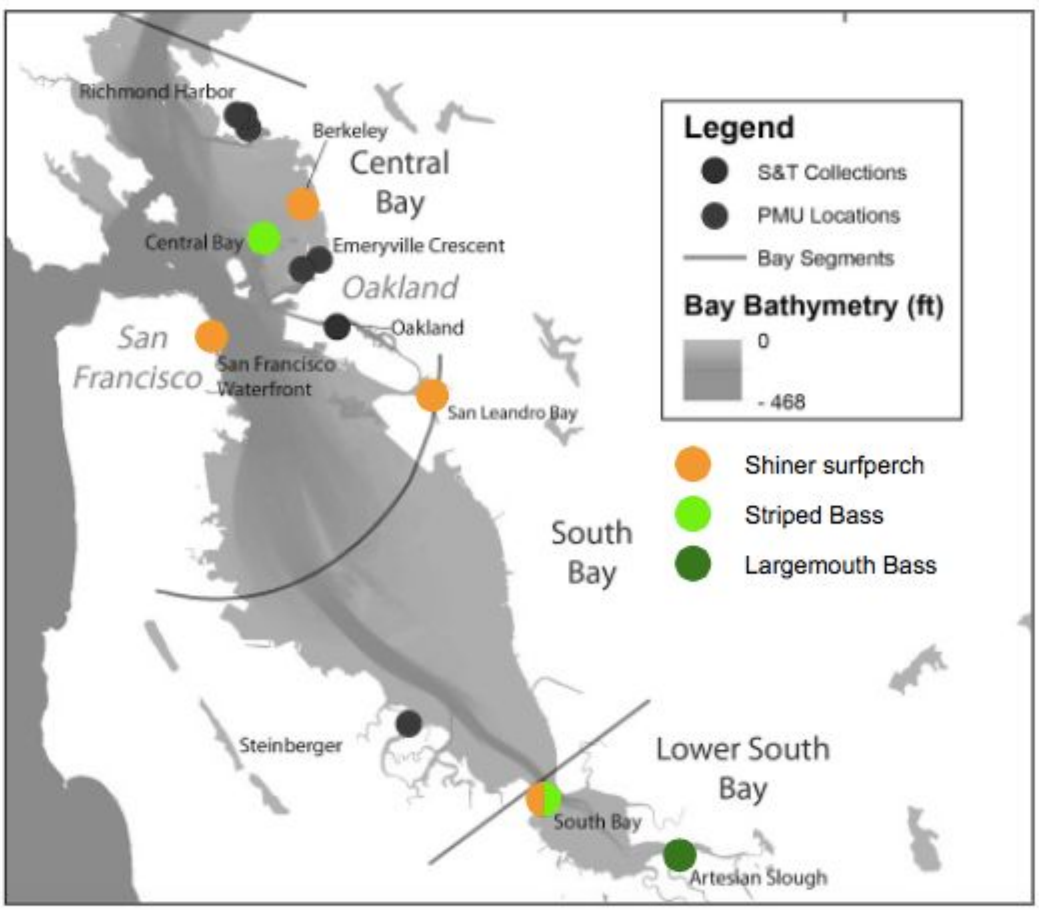

Figure 1: Sport fish sampling sites.

The fish sampling locations include sites that are dominated by stormwater and wastewater pathways. For example, Artesian Slough receives water from the San Jose-Santa Clara

Regional Wastewater facility. Fish collected in the area in 2014 and 2015 showed relatively high PBDE concentrations that suggests wastewater-influence (Sun et al., 2017). Striped bass that were captured at the South Bay site were mostly captured downstream of Artesian Slough, while shiner surfperch that were captured at the South Bay site were captured in Redwood City Harbor. This area is part of a priority margin unit being investigated by the RMP due to high PCB concentrations and is a stormwater-influenced site. San Leandro Bay is a nearshore area located next to the Oakland Airport with previous fish gut analysis also confirmed the presence of plastic fibers (Jahn, 2018). Approximately 10% of the area is industrial, and 85% of that area is either older industrial or source areas that are conceptually associated with higher concentrations of PCBs (Yee et al. 2019).

We propose to investigate the influence of species and relevant foraging habits on microplastic ingestion levels by analyzing all three species from the same general location. Specifically, based on the available samples, we propose to analyze samples from South Bay and Artesian Slough. An alternative approach, should regional differences be of stronger interest, is to analyze one species (shiner surfperch) from three different sites.

As an initial screening study, we propose to analyze a limited set of 24 samples with a greater emphasis on striped bass due to their popularity for human consumption. Based on the available samples, we propose to analyze 12 striped bass, 6 shiner surfperch, and 6 largemouth bass.Blank samples are clean un-opened sample containers that were stored with the fish samples after processing. Sample containers were only opened while inserting the digestive tract. The samples will be shipped to the University of Toronto where they will be processed using previously published protocols (Corcoran, 2015; Dehaut et al., 2016; Foekema et al., 2013). Briefly, samples will be digested in a 20% KOH solution at 55ºC overnight. Microparticles > 45μm will be extracted from the samples and a subsample will be chemically identified using Raman and/or FTIR spectroscopy. Additionally, the morphology, color, and size of each particle will be recorded. Microparticles down to 45 μm in size will be analyzed.

The data collected from this study will characterize the abundance and composition of microplastics consumed by sport fish to evaluate the level of exposure and uptake to the Bay food web.

We plan to compare microplastic abundance levels in sport fish with levels previously measured in prey fish and with fish in other published studies.

Results will be shared in a presentation to the Microplastic Workgroup. The final deliverable will be a manuscript prepared by the University of Toronto with assistance from SFEI.

Budget

The following budget represents estimated costs for this proposed special study (Table 3).

Table 3. Proposed Budget.

Budget Item	Hours	Budget
Data Management		$5,300
Data Analysis and Reporting	165	$19,200
Subcontract - laboratory analysis (minimum 24, up to 66 samples) - $1000 per sample		$24,000
Direct cost - shipping		$2,000
Total		$50,500

Budget Justification

Data Management
Data management will be conducted by RMP staff. Microplastic data management has been streamlined based on previous SFEI microplastic project experience. Results will be uploaded to CEDEN.

Data Analysis and Reporting
Budget is based on SFEI labor hours to analyze data, conduct literature review to evaluate results in context of the literature, and summarize results in a presentation to the MPWG and a short summary report. The contracting laboratory will prepare a manuscript summarizing the findings of this work, which will reduce reporting costs. RMP staff will assist in manuscript completion.

Subcontract - Laboratory Analysis
SFEI has previously worked with the University of Toronto on multiple microplastics projects. The Rochman laboratory uses state of the art instrumentation to conduct microplastic analyses and is a recognized pioneer and leader in the field of microplastic research. The analysis of microplastics is a labor-intensive process and each sample costs $1,000 to extract and identify, count, and analyze particles via spectroscopy. Laboratory blanks will be included in the analyses (approximately 10 percent of the samples). Clean unopened sample containers were archived along with the fish samples for analysis as field blanks. The analysis of multiple fish of each species from each site will provide information on the variation in field samples. The budget is based on analyzing 24 samples, which is considered the minimum number of samples for the study. The budget can be scaled up based on the number of samples.

Direct Costs
Direct costs are for shipping frozen samples from SFEI to the University of Toronto. The overnight courier costs are more expensive because the samples are being shipped to Canada and need to clear customs in an expedited manner.

Reporting

Findings will be shared in a presentation during the MPWG spring meetings in 2022. The results of the project will be summarized in a draft manuscript prepared by University of Toronto with assistance from SFEI.

References

Abbasi, S., Soltani, N., Keshavarzi, B., Moore, F., Turner, A., Hassanaghaei, M., 2018. Microplastics in different tissues of fish and prawn from the Musa Estuary, Persian Gulf. Chemosphere 205, 80–87. https://doi.org/10.1016/j.chemosphere.2018.04.076

Barboza, L.G.A., Cunha, S.C., Monteiro, C., Fernandes, J.O., Guilhermino, L., 2020. Bisphenol A and its analogs in muscle and liver of fish from the North East Atlantic Ocean in relation to microplastic contamination. Exposure and risk to human consumers. J. Hazard. Mater. 393, 122419. https://doi.org/10.1016/j.jhazmat.2020.122419

Carbery, M., O'Connor, W., Palanisami, T., 2018. Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health. Environ. Int. 115, 400–409. https://doi.org/10.1016/j.envint.2018.03.007

Cho, Y., Shim, W.J., Jang, M., Han, G.M., Hong, S.H., 2019. Abundance and characteristics of microplastics in market bivalves from South Korea. Environ. Pollut. 245, 1107–1116. https://doi.org/10.1016/j.envpol.2018.11.091

Corcoran, P.L., 2015. Benthic plastic debris in marine and freshwater environments. Environ. Sci. Process. Impacts 17, 1363–1369. https://doi.org/10.1039/C5EM00188A

Dehaut, A., Cassone, A.-L., Frère, L., Hermabessiere, L., Himber, C., Rinnert, E., Rivière, G., Lambert, C., Soudant, P., Huvet, A., Duflos, G., Paul-Pont, I., 2016. Microplastics in seafood: Benchmark protocol for their extraction and characterization. Environ. Pollut. 215, 223–233. https://doi.org/10.1016/j.envpol.2016.05.018

Foekema, E.M., De Gruijter, C., Mergia, M.T., van Franeker, J.A., Murk, A.J., Koelmans, A.A., 2013. Plastic in North Sea fish. Environ. Sci. Technol. 47, 8818–8824. https://doi.org/10.1021/es400931b

Foley, C.J., Feiner, Z.S., Malinich, T.D., Höök, T.O., 2018. A meta-analysis of the effects of exposure to microplastics on fish and aquatic invertebrates. Sci. Total Environ. 631–632, 550–559. https://doi.org/10.1016/j.scitotenv.2018.03.046

Hantoro, I., Löhr, A.J., Belleghem, F.G.A.J.V., Widianarko, B., Ragas, A.M.J., 2019. Microplastics in coastal areas and seafood: implications for food safety. Food Addit. Contam. Part A 36, 674–711. https://doi.org/10.1080/19440049.2019.1585581

Jahn, A., 2018. Jahn 2018 Gut contents of four fish species in San Leandro Bay 2016.pdf (No. 900). San Francisco Estuary Institute – Aquatic Science Center.

Lusher, A., Hollman, P.C.H., Mendoza-Hill, J., 2017. Microplastics in fisheries and aquaculture: status of knowledge on their occurrence and implications for aquatic organisms and food safety, FAO fisheries and aquaculture technical paper. Food and Agriculture Organization of the United Nations, Rome.

Miller, L., Klasios, N., Rochman, C., Lin, D., Sedlak, M., Sutton, R., 2020. Microparticles, Microplastics, and PAHs in Bivalves in San Francisco Bay (No. Contribution No. ##). San Francisco Estuary Institute.

Moore, S., Sutula, M., Von Bitner, T., Lattin, G., Schiff, K., 2016. Southern California Bight 2013 Regional Monitoring Program: Volume III. Trash and Marine Debris (SCCRWP Technical Report No. 928). Southern California Coastal Water Research Project, Costa Mesa, CA. https://doi.org/10.13140/RG.2.2.32214.04163

Naji, A., Nuri, M., Vethaak, A.D., 2018. Microplastics contamination in molluscs from the northern part of the Persian Gulf. Environ. Pollut. 235, 113–120.

Rist, S., Carney Almroth, B., Hartmann, N.B., Karlsson, T.M., 2018. A critical perspective on early communications concerning human health aspects of microplastics. Sci. Total Environ. 626, 720–726. https://doi.org/10.1016/j.scitotenv.2018.01.092

Rochman, C.M., Tahir, A., Williams, S.L., Baxa, D.V., Lam, R., Miller, J.T., Teh, F.-C., Werorilangi, S., Teh, S.J., 2015. Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Sci. Rep. 5, 14340. https://doi.org/10.1038/srep14340

Salas, N., Talley, T., Miller-Casman, T., Von Bitner, T., Busse, L., Loflen, C., Woodward, D., Venuti, N., 2016. San Diego Bay Debris Study Special Study Plastic Debris Monitoring Report, San Diego Bay Debris Study Workgroup. Surface Water Ambient Monitoring Program of the State Water Resources Control Board and Southern California Bight 2013 Regional Marine Monitoring Survey Bight '13 Debris Planning Committee.

SFEI, CDHS, 2000. The San Francisco Bay Seafood Consumption Study Report. San Francisco Estuary Institute, Richmond, CA.

Sun, J., Davis, J., Shira, B., Ross, J., Wong, A., Yee, D., Fairey, R., Bonnema, A., Crane, D., Grace, R., Mayfield, R., Hobbs, J., 2017. Contaminant Concentrations in Sport Fish from San Francisco Bay: 2014 (No. 806). San Francisco Estuary Institute, Richmond, CA.

Sutton, R., Lin, D., Sedlak, M., Box, C., Gilbreath, A., Holleman, R., Miller, L., Wong, A., Munno, K., Zhu, X., Rochman, C., 2019. Understanding Microplastic Levels, Pathways, and Transport in the San Francisco Bay Region. (No. SFEI Contribution No. 950.). San Francisco Estuary Institute, Richmond, CA.

Talsness, C.E., Andrade, A.J.M., Kuriyama, S.N., Taylor, J.A., vom Saal, F.S., 2009. Components of plastic: experimental studies in animals and relevance for human health. Philos. Trans. R. Soc. B Biol. Sci. 364, 2079–2096. https://doi.org/10.1098/rstb.2008.0281

Thompson, R.C., Moore, C.J., vom Saal, F.S., Swan, S.H., 2009. Plastics, the environment and human health: Current consensus and future trends. Philos. Trans. R. Soc. B Biol. Sci. 364, 2153–2166. https://doi.org/10.1098/rstb.2009.0053

Wright, S.L., Kelly, F.J., 2017. Plastic and human health: A micro issue? Environ. Sci. Technol. 51, 6634–6647. https://doi.org/10.1021/acs.est.7b00423

Special Study Proposal: Development of a Stormwater Conceptual Model for Microplastics (Year 2)

Summary: The recently completed study of microplastics in San Francisco Bay identified stormwater to be a major pathway. Given this finding, the Microplastics Workgroup has prioritized the development of a stormwater conceptual model for microplastics. A first year of work focused on black rubbery fragments that were the most abundant type of microplastic in stormwater. This proposal is for a second year of funds to further develop the conceptual model by focusing on other prioritized microplastics, such as fibers, which were the second most abundant type of microplastic in stormwater. Development of the conceptual model for microplastics in stormwater will help inform available management actions to address microplastic pollution and identify data gaps and monitoring data needs to address Workgroup management questions, and to inform the Ocean Protection Council's state-wide microplastic strategy.

Estimated Cost: $30,000

Oversight Groups: Microplastic Workgroup (MPWG) and Sources Pathways and Loadings Workgroup (SPLWG)

Proposed by: Diana Lin, Alicia Gilbreath, and Rebecca Sutton (SFEI); Kelly Moran, TDC Environmental

PROPOSED DELIVERABLES AND TIMELINE

Deliverable	***Due Date***
Task 1. Literature review and discussion with experts	November 2020 - March 2021
Task 2. Present update on findings at MPWG and SPLWG	May 2021
Task 3. Draft Conceptual Model Report to MPWG and SPLWG	July 2021
Task 4. Final Conceptual Model Report completion	September 2021

Background

Plastic is ubiquitous in modern life. Global plastic production was estimated to be 299 million tons in 2013 (Gourmelon, 2015). For the last two decades, society has focused on macroplastic in the ocean, such as the Pacific Ocean Garbage Patch, but recently attention has turned to the plastic particles < 5 mm in diameter, referred to as microplastics. In 2018, the California State Legislature enacted Senate Bill 1263 requiring the California Ocean Protection Council (OPC) to adopt and implement a statewide strategy to evaluate the ecological risks of microplastics in marine environments.

The recently completed San Francisco Bay Microplastics Project identified stormwater as a major pathway for microplastics to enter the Bay (Sutton et al., 2019). Based on the first regional measurements of microplastics in stormwater, a load of 10.9 trillion microparticles to the Bay per year from small tributaries was estimated using a previously developed Regional Watershed Spreadsheet Model (RWSM). Approximately two-thirds of those particles were estimated to be microplastic (not all microparticles are plastic based on chemical analyses conducted on a subset of microparticles). The stormwater microplastics estimate is over 300 times greater than the microplastics load estimated from wastewater. Based on these results, the Microplastic Workgroup has identified stormwater as a priority for additional investigations based on recent findings (Sedlak et al., 2019).

The most abundant microplastics in stormwater were fragments (59%). Most of the fragments were black and rubbery, and tire wear is a suspected major source of these black rubbery particles. Tire ingredients are also being investigated as a source of toxic contaminants in stormwater, through a major CEC stormwater monitoring effort by the RMP.

Last year, the Microplastic Workgroup partially funded the special study proposal to develop a conceptual model of sources and sub-pathways of microplastics into stormwater, and the patterns that may exist among different landscape factors (e.g., land use, imperviousness). Recent designation of microplastics as an emerging contaminant of Moderate Concern to the Bay (Sedlak et al., 2019), based on the RMP's tiered risk-based framework (Sutton et al., 2017), emphasizes the urgency of developing a robust conceptual model to understand the sources, pathways, loadings, fate and effects of microplastics to the Bay. To date, the conceptual model has focused on sources of the black rubbery particles present in stormwater samples.

Fibers (39%) were the second most abundant morphology in stormwater samples. The range of concentrations of fibers measured in stormwater were orders of magnitude greater than concentrations measured in wastewater, and the estimated fiber load from stormwater was approximately 300 times greater than the fiber load from wastewater (Sutton et al., 2019). Fibers in stormwater were composed of a variety of polymers; the most abundant polymers identified were polyester, cellulose acetate, and polypropylene. In all other Bay matrices monitored (Bay surface water, sediment, prey fish, bivalves, and wastewater effluent), fibers were the most abundant shape of microplastics. Fibers made up the vast majority of microplastics ingested by prey fish (86%) and bivalves (98%). Polyester, acrylic, and cellulose acetate were the most abundant fiber polymer in Bay tissue samples. Identifying the sources and pathways of fibers in stormwater is particularly important because concentrations and loads were significantly higher than that in wastewater.

Abraded fibers from textiles and clothing are expected to be major sources of microfibers. A recent study suggested that direct release of microfibers from clothing to the air during wear is similar to releases to water (De Falco et al., 2020). There are a number of other potential sources of fibers to stormwater, including degradation of cigarette filters (made of cellulose acetate), geotextiles in engineering, industrial laundromats and residential dryers expelling fibers into the air, abrasion of fibers from textiles and clothing in the outdoor environment, atmospheric fallout, food packaging, and food containers. Fibers are often embedded with chemicals with known or potential toxic effects, including dyes, flame retardants, and perfluorinated and polyfluorinated alkyl substances (PFAS); ingested microfibers may be a source of these contaminants to Bay wildlife.

We propose to further develop the conceptual model by focusing on sources and pathways of fibers.

Study Objectives and Applicable RMP Management Questions

The purpose of the conceptual model is to identify priority sources and sub-pathways for potential management action, assess data gaps, and prioritize monitoring data needs. It is expected that a microplastic stormwater monitoring study would be developed to evaluate prioritized data needs following completion of the conceptual model development.

Table 1. Study objectives and questions relevant to RMP Microplastic Strategy management questions (Sutton and Sedlak 2017).

Management Question	Study Objective	Example Information Application
1) How much microplastic pollution is there in the Bay?		
2) What are the health risks?		
3) What are the sources, pathways, loadings, & processes leading to microplastic pollution in the Bay?	Assess potential sources of microplastics to stormwater, and potential landscape attributes that may be related to higher levels of discharge.	Inform future monitoring efforts and gain insights into potential management actions.
4) Have the concentrations of microplastic in the Bay increased or decreased?		
5) Which management actions may be effective in reducing microplastic pollution?	Assess potential sources of microplastics to stormwater, and potential landscape attributes that may be related to higher levels of discharge.	Understanding the high leverage areas of microplastic pollution and point source discharges will be important for prioritizing appropriate management actions.

Approach

Through the second phase of this project, we propose to develop a conceptual model that describes additional prioritized sources of microplastics to stormwater. Sources of fibers to stormwater and the Bay are a priority because they were the second most abundant morphology in stormwater samples and composed nearly all of the microparticles in bivalve and prey fish samples.

The model will include a diagram depicting the sources and sub-pathways. An example of a conceptual model diagram is depicted in Figure 2. The conceptual model diagram will be accompanied by a report detailing the research behind each compartment of the model.

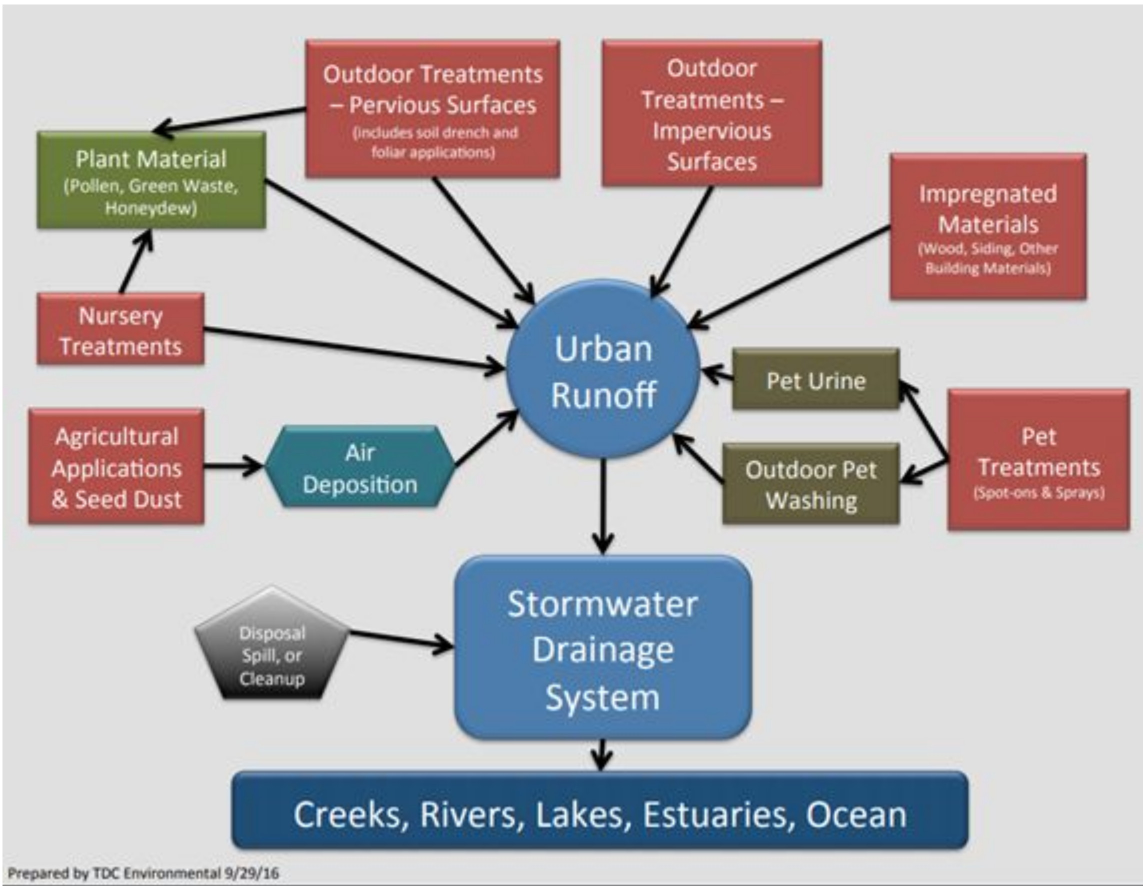

Figure 2. Conceptual model of imidacloprid in stormwater. Prepared by Kelly Moran, TDC Environmental (2016).

The model will be based on an in-depth review of the scientific literature on potential sources and landscape attributes linked to microplastics. Given that microplastics are a relatively new pollutant of concern across the globe and, therefore, appropriate literature may be limited, additional efforts will be made to draw inferences from contaminants with similar sources and/or transport-related properties, as well as to interview experts in the relevant fields. The main sources of information are likely to come from:

- Scientific peer-reviewed journal articles,
- Grey literature technical reports,
- Internet searches and industry publications, and
- Interviews with experts in the relevant industry and scientific fields.

This project will benefit from additional oversight and technical expertise from a local consultant (Kelly Moran, TDC Environmental) who is well-versed in the development of conceptual models to explain sources and pathways of pollutants to the Bay.

The literature review and interviews may suggest specific urban activities or landscape attributes that may explain higher levels of discharge.

Evaluating possible factors influencing microparticle and microplastic loads is important; however, controlling microplastics after they enter stormwater runoff is an expensive endeavor. Therefore, additional focus will be placed on identifying true sources and mechanisms of discharge into the environment. Such identification can serve to aid in development of effective management actions aimed at reducing microplastic discharge at the source.

A comprehensive stormwater conceptual model will help the MPWG identify key data gaps and areas of uncertainty that could be central to future monitoring efforts.

The final deliverable will be a detailed report including a conceptual model diagram. A draft of the report will be provided for Microplastic and Sources Pathways and Loading workgroups and TRC review.

Budget

The following budget represents estimated costs for this proposed special study (Table 2).

Table 2. Proposed Budget for Year 2.

Budget Item	Hours	Budget
Literature Review and Model Development	144	$21,000
MPWG update presentation	40	$5,000
Subcontract - Kelly Moran, TDC Environmental		$4,000
Total		$30,000

Budget Justification

Labor Costs (Literature Review and Model Development and Reporting)
Labor will primarily be spent on reviewing the literature and talking with experts in the field. Up-to-date drafts of the conceptual model will be presented at the MPWG and SPLWG meetings in the spring of 2021.

Subcontract Costs

Dr. Kelly Moran (TDC Environmental) will collaborate on development of the conceptual model. Dr. Moran has been involved in developing numerous such conceptual models on emerging contaminants, copper, and pesticides in stormwater.

Reporting

Findings will be shared in a presentation during the MPWG and SPLWG spring meetings in 2021. The results of this project will be summarized in a detailed report including a conceptual model diagram.

References

De Falco, F., Cocca, M., Avella, M., Thompson, R.C., 2020. Microfiber Release to Water, Via Laundering, and to Air, via Everyday Use: A Comparison between Polyester Clothing with Differing Textile Parameters. Environ. Sci. Technol. https://doi.org/10.1021/acs.est.9b06892

Gourmelon, G., 2015. Global Plastic Production Rises, Recycling Lags. Vital Signs: Global Trends that Shape Our Future 7.

Sedlak, M., Sutton, R., Miller, L., Lin, D., 2019. Microplastic Strategy Update (No. Contribution No. 951). San Francisco Estuary Institute.

Sutton, R., Lin, D., Sedlak, M., Box, C., Gilbreath, A., Holleman, R., Miller, L., Wong, A., Munno, K., Zhu, X., Rochman, C., 2019. Understanding Microplastic Levels, Pathways, and Transport in the San Francisco Bay Region. (No. SFEI Contribution No. 950.). San Francisco Estuary Institute, Richmond, CA.

Special Study Proposal: Microplastics in South Bay Sediment Cores

Summary: Following findings of abundant levels of microplastics in San Francisco Bay, the RMP has elevated microplastics to the Moderate Concern category within the RMP's emerging contaminants tiered risk-based framework. The RMP's recommended strategy for Moderate Concern contaminants includes determining whether Bay concentrations are increasing or decreasing in the Bay. We propose to evaluate sediment as a suitable matrix for monitoring microplastic concentration trends by measuring microplastics in sediment cores. In the summer of 2020, there are two RMP studies collecting and analyzing sediment cores, providing the opportunity to collect samples with minimal additional costs. Additionally, microplastic concentration trends in the sediment core from one of the sites will be compared to trends in PCB sediment concentrations. Radioisotope dating of sediment cores can be added in order to correlate microplastic concentrations with changes in plastic use patterns in the region.

Estimated Cost: $50,500 (optional $7,300 add-on for radioisotope dating)

Oversight Group: Microplastic Workgroup

Proposed by: Diana Lin, Miguel Mendez (SFEI), SCCWRP staff

PROPOSED DELIVERABLES AND TIMELINE

Deliverable	***Due Date***
Task 1. Field collection	October 2020
Task 2. Laboratory analysis	January - October 2021
Task 4. Draft Summary Report	March 2022
Task 5. Presentation to MPWG	May 2022
Task 5. Final Summary Report	June 2022

Background

SFEI recently completed a comprehensive regional investigation of microplastics in the San Francisco Bay (Sutton et al. 2019). Microplastic contamination was found throughout the Bay, and concentrations measured in the Bay water and sediment were among the highest reported in the literature to date. Stormwater was identified as a dominant pathway for microplastics to enter the Bay, and a significant portion of the microplastics in stormwater was suspected to come from tire wear. These black rubbery fragments were also frequently detected in sediment samples, particularly in sites in the Bay margins, but were not present in wastewater, surface water, and fish digestive tracts.

Following the results of this study, the RMP has elevated microplastics to the Moderate Concern category within the RMP's emerging contaminants tiered risk-based framework

(Sedlak et al. 2019). The RMP's recommended strategy for Moderate Concern contaminants includes monitoring whether Bay concentrations are increasing or decreasing in the Bay, and evaluating sources, pathways, and loadings to inform management actions. We propose to evaluate sediment as a suitable matrix for monitoring microplastic concentration trends.

Sediment is expected to be a suitable matrix because it is a likely sink for all microplastics in the Bay, regardless of the pathway to the Bay. Even microplastics that are initially buoyant will eventually sink over time due to accumulation of organic and inorganic material. Sediment is currently monitored for a variety of contaminants, including PCBs, PAHs, PBDEs, methylmercury, and fipronil as part of the RMP Status and Trends Monitoring program.

Bay sediment is also an important matrix for monitoring because sediment may be a source of microplastics to the Bay food web. Bay topsmelt had higher concentrations of non-fiber microplastics compared to anchovies, and the difference is suspected to be because topsmelt depend more on benthic prey than anchovies, which feed primarily in the water column (Sutton et al. 2019).

Results from the San Francisco Bay Microplastic Study (Sutton et al. 2019) suggest sediment may be a suitable matrix for monitoring baseline concentrations and tracking trends. Bay sediment concentrations were higher than concentrations in the reference area (Tomales Bay), and while sample collection was not designed to statistically compare regional differences in the Bay, sediment samples from the Lower South Bay (LSB) had high microplastic concentrations compared to the rest of the Bay. Two of the LSB sites that were near wastewater and urban creek discharge locations were more than four times higher than average concentrations in the Bay, and represent some of the highest reported concentrations of microplastics in the literature to date. After fibers, fragments were the most abundant morphology identified in Bay sediment. Black rubbery fragments that were suspected to be tire wear were the most abundant type of fragment, followed by polypropylene and polystyrene, which may be linked to single-use items such as packaging and foodware, as well as many other items that may end up as trash. Additionally, two sets of field duplicates collected from surface sediment indicated acceptable reproducibility in microplastic sediment concentrations (relative percent difference of 36% and 1%).

Microplastics have been analyzed in sediment cores internationally, though to our knowledge no studies have been conducted in the United States. For example, the temporal distribution of microplastics in sediment cores from Derwent Estuary in Australia, a similar urban watershed to San Francisco Bay, showed a strong correlation between the expected change in plastics production in the region and the rate of plastics deposited in sediment (Willis et al. 2017). Like San Francisco Bay, the Derwent Estuary has been heavily impacted by the surrounding urban environment, providing an opportunity to analyze microplastic concentrations correlated with population growth and proximity to wastewater discharges. Two sediment cores were collected and analyzed for microplastics as well as lead isotopes for aging analysis. The smallest size class (63–100 µm) was found to be the highest in all samples except one. Sediment cores have also been evaluated in China, and concentration changes could be explained by increasing use of plastic products and availability of municipal waste infrastructure (Zheng et al. 2020).

One of the key challenges for microplastic monitoring is the lack of standardized methods for measuring microplastics in water, sediment, and tissue. This is especially a challenge because we are interested in monitoring microplastic trends over time, as well as comparing microplastic concentrations measured in various regions. However, there are currently significant efforts being made to standardize methods for analyzing microplastics. For example, the Southern California Coastal Water Research Project (SCCWRP) is currently conducting an inter-laboratory comparison study to help support the development of standardized analytical methods for analyzing microplastics. The results of the SCCWRP study are expected to inform the accuracy, precision, and reproducibility of microplastic analysis across laboratories and support the development of standardized methods.

Study Objectives and Applicable RMP Management Questions

The purpose of this study is to examine microplastic concentrations and explore temporal trends in sediment cores from San Francisco Bay. This study will also determine the viability of sediment as a matrix for monitoring trends in microplastic concentrations and add to baseline data for future evaluations. Additionally, historic concentrations from sediment deposited before and since the production of plastic (1950s) may provide a useful reference to compare current and future concentrations.

Table 1. Study objectives and questions relevant to RMP Microplastic Strategy management questions (Sutton and Sedlak 2017).

Management Question	**Study Objective**	**Example Information Application**
1) How much microplastic pollution is there in the Bay?		
2) What are the health risks?		
3) What are the sources, pathways, loadings, & processes leading to microplastic pollution in the Bay?		
4) Have the concentrations of microplastic in the Bay increased or decreased?	Evaluate changes in sediment concentrations over time.	Compare the rate of changes in concentration with changes in plastic use. Assess utility of sediment as a tool for monitoring changes in microplastics in the Bay.
5) Which management actions may be effective in reducing microplastic pollution?	Characterize chemical composition and particle type of microplastics present in sediment cores.	Morphology and chemical composition can inform our understanding of sources of microplastics.

Approach

Sediment core collection efforts from two other planned RMP studies provide the opportunity to collect sediment cores from two different locations in the Bay with minimal field costs, in addition to providing information about the site without additional analyses and costs. The RMP has funded a special study to collect sediment cores in Steinberger Slough to evaluate the changes in historical loads of PCBs from upstream watersheds. SFEI's Nutrients team is collecting several box sediment cores from South and Lower South Bay (LSB) for the purpose of conducting microcosm studies to evaluate the biogeochemical processes occurring in Bay sediment. Both sediment core sampling efforts are expected to occur in the summer of 2020.

We propose leveraging both of these efforts: collecting one sediment core from Steinberger Slough and one sediment core in more ambient conditions in LSB. The Steinberger Slough site will represent a site heavily influenced by stormwater, and the LSB site will represent ambient conditions further away from direct stormwater influence. The ambient LSB site has not been selected, but we expect to have several site options when the Nutrients team collects their samples. A site will be selected that is generally depositional, closer to the spine of the Bay, and further from direct stormwater and wastewater outfalls.

The sediment core samples will be sent to SCCWRP for extraction and analysis. To reduce contamination, sediment core sections will be sliced in the SCCWRP laboratory. Two field blanks will be collected during each sampling event to measure procedural and background contamination during sampling. Each of the sediment cores will be analyzed in six sections.

Raman and FTIR spectroscopy will be used to identify the chemical composition of the particles. Additionally, the morphology, color, and size of each particle will be recorded. Of particular interest are tire and road wear particles, as tire rubber has been identified as a potential major source of microplastics to the Bay. While only 9% of total microparticles counted in sediment samples from the San Francisco Bay Microplastic Study were black fragments (Sutton et al. 2019), this proportion is expected to have been larger if we had analyzed a smaller size fraction of particles. Based on a literature review indicating that the most abundant size range of tire and road wear particles may be in the 50-100 µm range (Kreider et al. 2010), analysis of microplastic samples will include microparticles 50 µm in size and greater (our previous study size limit was 125 µm). Additionally, microplastic concentration trends in the sediment core from Steinberger Slough will be correlated with PCB sediment concentrations that will be analyzed as part of the funded PCB passive sampler special study.

The data will be subjected to rigorous quality assurance-quality control review, presented to the Microplastic Workgroup and TRC, and summarized in a technical report. Data will be uploaded to CEDEN.

Sediment cores may also be analyzed for Pb-210 radioisotopes in order to estimate the age of sediment core layers. This is particularly important to correspond microplastic sediment concentrations with changes in use of plastics in the region. Dating sediment cores is also important to evaluate whether management actions, such as the 2015 state and federal ban of microbeads in personal care products, resulted in measurable changes in the environment.

Budget

The following budget represents estimated costs for this proposed special study (Table 2).

Table 2. Proposed Budget.

Budget Item	Hours	Budget
Field Planning and Sampling	25	$2,800
Data Management Services		$6,500
Data Analysis	80	$9,650
Reporting	87	$10,650
Subcontract - Laboratory Analysis		$20,400
Direct cost		$500
Optional radioisotope dating add-on		*$7,300*
Total		**$50,500 - $57,800**

Budget Justification

Field Planning and Sampling
Field costs are reduced by leveraging other RMP sample collection efforts at Steinberger Slough and Lower South Bay. The budget is based on additional SFEI labor hours needed to develop a sampling plan and join existing sediment core collection efforts to collect sediment cores for microplastic analysis. The other projects will cover the cost of operating the boat and collecting sediment cores.

Data Management
Data management will be conducted by RMP staff. Microplastic data management has been streamlined based on previous SFEI microplastic project experience. Results will be uploaded to CEDEN.

Data Analysis and Reporting
Budget is based on SFEI labor hours to analyze data, conduct a literature review to evaluate results in context of the literature, and summarize results in a presentation and final report.

Subcontract - Laboratory Analysis
SCCWRP has recently acquired a state-of-the-art clean room and instruments for microplastic analysis. The cost to analyze each sample is estimated to be $1,700 due to the labor intensive nature of the extraction process, identification, enumeration, and analysis associated with spectroscopy. Two field blanks will be collected during each sampling effort, and at least two laboratory blanks will be included as part of the analysis. Analysis of QA samples is incorporated in the analytical budget.

Direct Costs
The budget will cover the cost to purchase sample containers and equipment and to ship the samples to SCCWRP.

Add-on Radioisotope Dating Analysis
The estimated budget to add radioisotope dating analysis for two cores is $7,300. The subcontract laboratory analysis estimate is $3,100 per sediment core. This estimate includes analyzing sediment cores using Pb-210, Ra-226, and Cs-137; Ra-226 and Cs-137 analysis is recommended to calibrate Pb-210 models for more accurate dating results. Some additional SFEI labor hours are included to cover labor needed to develop and manage the subcontract, archive and ship sediment samples, and direct costs for shipping.

Reporting

The results of this project will be summarized in a technical report prepared by SFEI, as well as a presentation to the TRC. Reported data will be evaluated by SFEI Data Management and will be uploaded to CEDEN.

References

Kreider, Marisa L., Julie M. Panko, Britt L. McAtee, Leonard I. Sweet, and Brent L. Finley. 2010. "Physical and Chemical Characterization of Tire-Related Particles: Comparison of Particles Generated Using Different Methodologies." *Science of The Total Environment* 408 (3): 652–59. https://doi.org/10.1016/j.scitotenv.2009.10.016.

Miller, Liz, Natasha Klasios, Chelsea Rochman, Diana Lin, Meg Sedlak, and Rebecca Sutton. 2020. "Microparticles, Microplastics, and PAHs in Bivalves in San Francisco Bay." Contribution No. 976. Richmond, CA: San Francisco Estuary Institute.

Sedlak, Meg, Rebecca Sutton, Liz Miller, and Diana Lin. 2019. "Microplastic Strategy Update." Contribution No. 951. Richmond, CA: San Francisco Estuary Institute.

Sutton, Rebecca, Diana Lin, Meg Sedlak, Carolynn Box, Alicia Gilbreath, Rusty Holleman, Liz Miller, et al. 2019. "Understanding Microplastic Levels, Pathways, and Transport in the San Francisco Bay Region." SFEI Contribution No. 950. Richmond, CA: San Francisco Estuary Institute.

Sutton, Rebecca, and Meg Sedlak. 2017. "Microplastic Monitoring and Science Strategy." Contribution No. 798. Richmond, CA: San Francisco Estuary Institute.

Willis, Kathryn A., Ruth Eriksen, Chris Wilcox, and Britta D. Hardesty. 2017. "Microplastic Distribution at Different Sediment Depths in an Urban Estuary." *Frontiers in Marine*

Science 4 (December): 419. https://doi.org/10.3389/fmars.2017.00419.
Zheng, Yifan, Jingxi Li, Wei Cao, Fenghua Jiang, Chang Zhao, Haibing Ding, Menghui Wang, Fenglei Gao, and Chengjun Sun. 2020. "Vertical Distribution of Microplastics in Bay Sediment Reflecting Effects of Sedimentation Dynamics and Anthropogenic Activities." *Marine Pollution Bulletin* 152 (March): 110885. https://doi.org/10.1016/j.marpolbul.2020.110885.