Microplastic Storage Dynamics in Bay Area Streams

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ABSTRACT

Microplastics are largely understudied in stream systems in comparison to larger aquatic systems. This study aimed to understand key concepts pertinent to the storage areas of stream microplastics and the types of microplastics present in these storage areas. I sampled 2 streams and sampled 2 sites within these streams. I sampled 1 upstream and 1 downstream site within these streams. To understand where microplastics are found within streams, I took samples from the surface water as well as samples from the benthic zone and sediment. In order to understand the effects of disturbance on microplastic levels in streams, I sampled the surface water and benthic zone after creating an upstream disturbance. The results from my study displayed a clear indication that microplastics were, on average, more common in the benthic layer of streams. Strawberry Creek contained 2% more microplastics upstream while Wildcat contained 15% more microplastics upstream. However the levels of microplastics differed downstream where I found a greater amount of microplastics in the surface water. The most common microplastic type found was fibrous microplastic followed by fragments, and then pellets. Stream disturbance results were inconclusive as some instances of physical disturbance increased microplastic levels while other disturbance instances decreased or had no effect on microplastic levels. I hypothesize that lighter microplastics such as fibers were likely not able to be deposited upstream and as such, continued downstream in the surface water. I hypothesize that heavier microplastics are deposited farther upstream into the substrate.

KEYWORDS

Benthic Zone, Riffle Zone, Depositional Zone, Pollution, Disturbance

INTRODUCTION

Streams are an incredibly important, and often overlooked, area of ecological research. Streams are biodiversity hotspots harboring thousands of species (Jackson et al. 2014) and freshwater ecosystems include bioindicators and endemic species that are useful in evaluating future threats to streams. Streams are highly responsive systems and will be affected by changing biotic or abiotic factors more rapidly than other bodies of water (Pringle 1997). Therefore, the largely overlooked threats to streams are instrumental to study as they can be spread to larger ecosystems (Sekabira et al. 2010). Sampling streams and the pollutants within them is imperative to evaluating emerging ecological and environmental threats (Stancheva and Sheath 2016).

Microplastics are an emergent threat to streams and can cause a multitude of negative biological effects. Their small size and distribution makes them extremely pervasive (Coffin et al. 2022). Bodies of water in the San Francisco Bay Area contain a large amount of microplastics (Sutton et al. 2016). Industrial pollution in the Bay Area is also a known contributor to microplastic particles within the aquatic system (Sutton et al. 2016). These microplastics are contributed to streams from industries such as textiles and wastewater.Research on microplastics has been conducted in marine systems to a greater extent than smaller, freshwater systems. Microplastics are an issue on a global scale due to the increased industrialization of plastic and its widespread use (Hoellein et al. 2019). As such, it is important to collect data on smaller aquatic systems as they contribute greatly to their surrounding populations by maintaining native biota and facilitating other ecosystem services (Wohl 2017).

These plastics pose a threat to organisms that are responsible for necessary biological processes (Sjollema et al. 2016). Understanding how these plastics are transported in streams and the substrates they are found in can help stream ecologists determine the extent and dynamic of this threat (Rimondi et al. 2022). For example, fragments and fibers of microscopic plastics are found in larger flowing waterbodies; generally in the sediments (Vincent and Hoellein 2021). Fibrous and fragmented microplastics are largely found within the sediments of streams (Rimondi et al. 2022). Identifying what common substrates exist among urban streams in the Bay Area and where microplastics accumulate within these substrates is essential to understand risks to organisms. Despite current literature on microplastics in aquatic systems, further research is required for smaller, urban streams.

To evaluate the extent of microplastic pollution in Bay Area streams I sampled 2 urban streams in the San Francisco Bay Area. I also aimed to understand how physical disturbance affects microplastic levels and area in streams. I selected an upstream and downstream site to understand which site contains more microplastics and how they differ. Microplastics were categorized by their color and type. This study aimed to lay foundational knowledge for microplastic dynamics in Bay Area streams.

METHODS

Study sites

To estimate microplastics in East Bay Streams, I sampled 2 sites: Wildcat Creek (San Pablo, Richmond) and Strawberry Creek (Berkeley). Strawberry Creek is the main watershed in Berkeley and water is contributed by two primary forks. It is a relatively calm creek that is 3 meters wide on average and is 3 miles long. This creek begins in the Berkeley Hills and flows through the UC Berkeley campus into San Francisco Bay. Strawberry Creek runs under the city of Berkeley in culverts. Wildcat Creek is a much larger stream that is 13 mi long beginning in Tilden Park and flowing into San Pablo Bay. Wildcat Creek flows through urban zones such as residential and commercial areas in Richmond.

I sampled microplastics from substrates and the surface water at multiple sites longitudinally within the 2 streams. Within each stream I designated 2 transects for data collection. Site 1 for each stream point of collection was a downstream site and was collected first to prevent upstream disturbances from data collection from interfering with downstream measurements. The second collection point was taken upstream in an area that contained both riffles and depositional pools. SC1 was approximately 812 m from SC2. WC1 was approximately 42 meters from WC2. Table 1 gives exact coordinates as well as general locations for each site that I sampled.

Table 1. Sampling site locations.

Stream	Site	Coordinates
Strawberry Creek At the confluence near the West side of campus	SC1	37°52'16.56"N, 122°15'51.74"W
Strawberry Creek At Faculty Glade/4.0 Hill	SC2	37°52'18.54"N, 122°15'24.74"W
Wildcat Creek At Arlington Rd.	WC1	37°56'36.11"N, 122°18'25.12"W
Wildcat Creek About 30m US of WC Site 1	WC2	37°56'31.58"N, 122°18'20.52"W

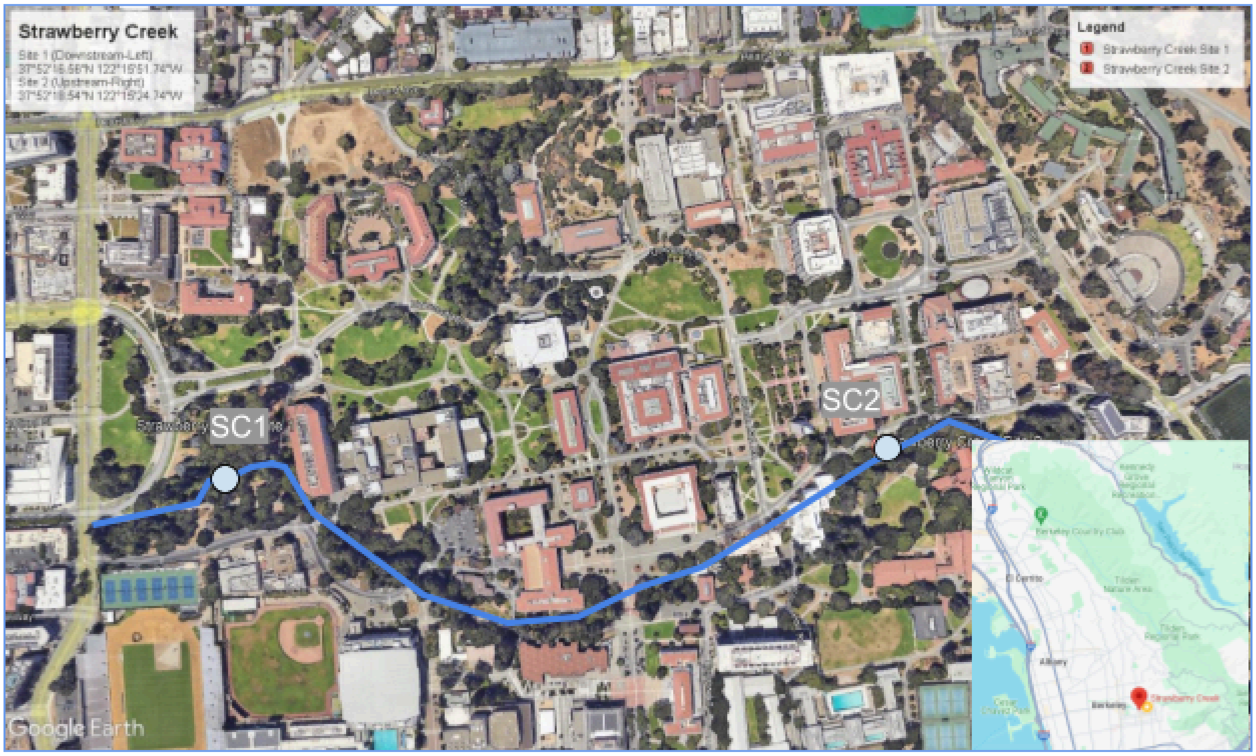


Figure 1. Map of Strawberry Creek. SC1-DS (left) is located downstream. SC2-US (right) is located upstream.

Figure 2. Map of Wildcat Creek. WC1-DS (right) is located downstream. WC2-US (left) is located upstream.

Data collection

Study site characterization

Within each stream I sampled 1 upstream and 1 downstream site. Strawberry Creek was much more urban than Wildcat Creek because I samplied on the UC Berkeley campus and as such, was much closer to buildings and urban influences. SC1-DS (Downstream) at the Strawberry Creek Confluence was characterized by a 5m wide stream channel and a cobble embankment on the left bank. The right bank of the stream included a rich vegetation zone with little sedimentation. SC2-US (Upstream) of Strawberry Creek in Faculty Glade/4.0 Hill was characterized by thick vegetation (Algerian Ivy) on both banks and dense overhead coverage. SC2-US was much narrower than SC1-DS. Wildcat Creek was more natural, flowing through a well-developed riparian area in Wildcat Canyon Regional Park with no buildings around. I took visual habitat assessments of the upstream and downstream sites at Wildcat Creek. WC1-DS contained many riffle zones and large boulders within the stream itself. There were cobble embankments on both sides of WC1-DS. WC2-US of Wildcat Creek contained a sandy right bank and a vegetative left bank. Both sites were of similar width and in-stream characteristics. I noticed slower moving depositional zones within each site of the stream. I sampled benthic sediments in both riffles and these depositional pools.

Water quality measurements

To evaluate conditions of the water quality, I measured in-stream dissolved oxygen with a dissolved oxygen meter from ExTech (DO600 ExStik 2) to quantify dissolved oxygen levels at each site (Newbury and Bates 2017). I also measured TDS, salinity, conductivity, and pH measurements with an ExTech (EC500 ExStik 2) meter at each site. To measure flow and discharge, I created a cross-section for each site using a Pygmy flow meter (Gore and Banning

2017). Flow rate may have played a role in the amount of microplastic collected due to more water moving through the surface water during a given period of time. As such, I collected discharge rates for each site. I attached the flow meter to a wading rod and counted rotations visually using a stopwatch. Measurements were taken at 0.6x of the water depth for 30 seconds to calculate average flow rate. Measurements were taken starting with the left to the right bank measured in 1/10th increments with a measuring taper. I also recorded algal substrates at each site according to SWAMP protocol and were usually found on submerged boulders. I used a gravelometer to record the size of the pebbles present.

Physical habitat measurements and assessment

I measured physical habitat variables related to the surrounding environment and characterized the riparian zone of the stream ("SWAMP - Standard Operating Procedures | California State Water Resources Control Board" 2016.). I recorded urban environment measurements such as proximity to buildings, bridges, parking lots, and other urban areas via visual estimation. I took measurements for total overhead vegetation coverage using visual estimates at each site. Bank measurements were taken according to SWAMP protocols. I observed substrate types in each stream and the most prevalent was finer clay and sand. I scored all criteria on a scale of 0-20 and took an average of total habitat score. The scores of 0-5 is a poor habitat, 6-10 is a marginal habitat, 11-15 is suboptimal, and 16-20 is an optimal habitat.

Surface water sampling

To sample for microplastics in the surface water, which occur at the top layers of water (after Vincent and Hoellein 2021), I used drift nets that I constructed using string reinforced greenhouse tarp (Figure 3). I created a template in the Mendez Lab at UC Berkeley to create the cone shape for the capture net. My team and I used a sewing machine to attach the tarp sides to one another resulting in a sturdy frame collection net. I constructed the nets using 1.5” PVC PVC pipes as a frame to attach the collection net to with an effective opening of 9x23 in. I attached the tarp to the frame using snap fasteners. This PVC frame used rebar to stake it into the substrate during sampling. I deployed two of the net for 5 minutes at each of the sites at about 8 cm deep in the surface water.I collected the samples using a filtered collection bag sewn onto the end of each net with a 35 µm Nytex mesh. I then inverted the filtered bag and rinsed the samples into 16oz wide mouth mason jars.

Figure 3. Completed drift nets.

I measured the depth and discharge rate to determine the total volume of water passing through the drift net. The nets were partially submerged a majority of the time as the streams were not usually deep enough to fully submerge the nets. I washed the outside of the filtered collection net with stream water to rinse off stuck items. These samples were then rinsed directly into clean 16 oz mason jars and capped with the screw lid. I collected samples only once per site and stored them for laboratory analysis. To understand the effects of physical disturbance on microplastic levels, I created small physical disturbances upstream by kicking around sediment upstream with our boots then sampled the surface water and captured the material in drift nets for 5 minutes using the same methods for surface water collection.

Substrate sampling

To determine the levels of microplastics found in the stream bed substrates, I collected benthic samples in the same areas with the drift nets. I collected benthic samples after surface samples to limit possible disturbance in drift net MP collection. I visually estimated the best substrate for collection at each site in order to find a substrate that was viable and not composed of non-collectible boulders. I collected benthic substrate samples using 16oz glass bottles (mason jars). The half-liter jar was dug into the substrate by hand approximately 2 cm deep and held in place for 3 seconds. The sample was extracted and immediately capped to be processed in the lab (Vincent and Hoellein 2021).

Lab processing

Sieving and Filtration. To remove a large amount of debris from the samples, I washed and filtered them. I washed samples out of the glass jars using deionized water onto a 0.45 Whatman micrometer filter paper. I had weighed these filters beforehand as well as the aluminum containers they were to be placed in. I pumped water out of these samples using a homemade hand pump. I used a Buchner funnel to rinse the microplastics down onto the filter. After filtration, I placed the filters back into their respective aluminum foil containers. I then placed these samples into a Quincy Lab Model 10GC Lab Oven set to 3 (65 ˚C). This drying process took 3 days in total to accomplish and I placed them in such a way to ensure proper airflow and drying.

Sediment Samples were processed differently. I initially sieved the samples using 4mm (No.5), 1mm (No.18), and 0.125 mm (No.120) stainless steel sieve to remove larger debris. I rinsed these samples through the sieves using distilled water and discarded larger debris from the 4mm (No.5) and 1mm (No.18) sieves (Masura 2015). I retained material from the 0.125mm (No.120) sieve and proceeded to check for microplastics under the microscope using magnification up to 60x. I preserved any microplastics found using a 70% ethanol solution. I transferred microplastics to this solution using fine, pointed forceps and labeled them accordingly. I transferred material from the 0.125 (No.120) sieve to a 16 oz mason jar and used distilled water to rinse any remaining particles from the sieve, leaving the jars to settle overnight. After settling, I skimmed off top water and filtered this through its respective Whatman filter. I then placed these filters into a labeled aluminum envelope and dried them in a Quincy Lab Model 10GC Lab Oven set to 3 (65 C) for 3 days. I covered the remaining jars with aluminum foil and placed into a large lab oven set to 65 C and dried for 3 days.

Digestion. To separate microplastics from organic matter I oxidized the samples using a solution of H_2O_2 and deionized water (Figure 4). I placed filters that had finished drying into their respective 16 oz wide mouth mason jar. I used 20 ml of water and 20 ml of 30% H_2O_2. Underneath the fume hood, I oxidized each sediment sample in the 16 oz mason jars. I initially added only 10ml of the H_2O_2. If the digestion reaction was not too violent, I would add the remaining 10 ml H_2O_2. I swirled and mixed the contents of the jar using a nonreactive stirrer to speed up the reaction. Once the reaction stopped bubbling, I placed 1 cm bits of red meat to the samples to check for remaining H_2O_2. If the meat continued to bubble, I would then know that there was remaining H_2O_2. I used pointed forceps after the reaction to pull out the test meat and check for microplastics under the microscope at 40x magnification. Any microplastics I found were transferred to their respective ethanol vials using pointed forceps. Once the reactions were complete, I took out the filters using pointed forceps and placed them into vials. I then filtered the remaining topwater from the 16 oz jars using a 35-micrometer mesh sieve. I rinsed the samples through the sieve using distilled water. Once this was complete, I rinsed trapped particles back into their jars using distilled water and checked the mesh sieve for microplastics under the microscope. I then placed the previously removed filters back into their respective jars.

Figure 4. Removal of organic material in sediment samples through a 30% H_2O_2 digestion.

Density Separation. To start density separation, I created a high-density NaCl solution. I dissolved 337g of NaCl in a liter of distilled water. I then mixed this solution for 10 minutes to completely dissolve the NaCl. The resulting density in the NaCl solution was 1.2 g/cm^3. This solution of NaCl allowed me to separate microplastics from the substrate and water by creating a density gradient where microplastics floated to the surface. I poured the solution into the 16 oz jars containing the sediment samples and filters. I poured enough of the solution to submerge everything and I mixed the samples thoroughly via shaking the jars. I left these jars to settle overnight. I returned the next day and filtered the top water through a 300-micrometer mesh filter. I checked the filter for microplastics under the scope and placed them into a labeled ethanol vial using pointed forceps, I then took out the Whatman filter from the 16 oz mason jar and checked it for microplastics underneath the scope as well. Any microplastics found at any point underneath the microscope were placed into their respective ethanol vial. To verify the density separation had been effective, I looked through the remaining sediment sample under the microscope to ensure microplastics had already been removed. The remaining sediment did not contain microplastics indicating that density separation had been successful.

Scanning and Counting. To capture an image of microplastics for data processing, I scanned the microplastic samples using a Epson Perfection E600 scanner using equipment and scanning settings by Mendez et al. (2018). I poured the ethanol vials into a silicon tray within a scanning tray. I scanned the samples at 2400 dpi as JPGs and exported the images to ImageJ for further analysis. After scanning, I placed the samples back into their respective ethanol vials. Once the images were imported to ImageJ (Schneider 2012), I labeled and counted individual microplastics. I also characterized microplastics by their type and color. I recorded all data onto an excel spreadsheet to allow for data visualization and analysis. I took physical size measurements for two of the sites. However, I stopped further size analysis due to the lack of size difference between microplastics.

Data Analysis

To compare types of microplastics, I compared the concentration of microplastics by type for upstream and downstream sites within each stream. To standardize microplastic units for benthic and surface water samples, I calculated microplastics (MP) as MP/cubic meter of water and MP/gram of sediment. For the benthic standardization, I simply divided the total microplastic found by the weight of the sediment to achieve MPs per gram. For surface water samples, I calculated the total volume of water passing through the surface water samples by taking the average flow velocity that was derived from my discharge values and multiplied them by the area of the drift net opening. Once I attained this value I multiplied this by the amount of seconds in 5 minutes. Finally I divided the total number of microplastics by my water volume calculation to achieve a standard value of microplastics per cubic meter. To compare differences in the concentration of microplastics between the surface water and benthic substrate, I used total microplastic counts.

RESULTS

Physical habitat characteristics and water quality

Water quality metrics were fairly consistent across sites. Strawberry Creek was warmer by 1°C at around 13°C (Table 2). Wildcat Creek displayed variable TDS levels with the lowest level being at 315 ppm and the highest being 536 ppm. The TDS of Strawberry Creek was fairly consistent, around 430 ppm. The pH levels across all streams were all approximately at 8.4. Conductivity was stable across all streams but reached a high level at SC2-US in Strawberry Creek reaching a reading of 637 µS/cm.

Table 2. Water quality measurements for Strawberry Creek and Wildcat Creek.

Water Quality Measurements	Strawberry Creek SC1-DS	Strawberry Creek SC2-US	Wildcat Creek WC1-DS	Wildcat Creek WC2-US
Conductivity (µS/cm)	474	637	467	480
pH	8.41	8.38	8.4	8.5
TDS (ppm)	421	443	315	536
Temp (°C)	13.2	13.4	12.5	12.8

Discharge calculations for Wildcat Creek and Strawberry Creek reflected differences in watershed size at the sampling point (Table 3). Wildcat Creek had a greater discharge than Strawberry Creek with the highest discharge of 0.013 m/s^3. In Strawberry Creek, the upstream site had lower discharge than the downstream site.

Table 3. Discharge measurements for Strawberry Creek and Wildcat Creek.

Stream	1-DS (m/s^3)	2-US (m/s^3)
Strawberry Creek	0.004	0.002
Wildcat Creek	0.013	0.012

Habitats did not differ considerably in their total visual habitat assessment health scores between streams, or for most of the individual habitat parameters (Table 4). Wildcat Creek was much more rural in the upper part of the watershed. Therefore, features such as riparian vegetation zone width scored higher than an urbanized stream like Strawberry Creek. Pool variability was also much higher for WC2-US.

Table 4. Stream health assessment metrics for Strawberry Creek and Wildcat Creek.

Habitat Parameter	Strawberry Creek SC1-DS	Strawberry Creek SC2-US	Wildcat Creek WC1-DS	Wildcat Creek WC2-US
Epifaunal Substrate/Available Cover	14	16	16	16
Pool Substrate Characterization	19	18	12	11
Pool Variability	5	1	4	13
Sediment Deposition	16	17	18	16
Channel Flow Status	18	14	13	14
Channel Alteration	16	15	19	17
Channel Sinuosity	4	4	6	3
Bank Stability	17	16	16	14
Vegetative Protection	10	15	6	11
Riparian Vegetation Zone Width	12	9	20	20
Total Score	131	125	120	135

Surface water samples

In total, I counted 671 surface water microplastics across the 4 sampling sites. Total surface water plastics followed a similar trend in both streams. Downstream sites contained more microplastics than upstream sites. The most surface water microplastics were found at SC1-DS. The fewest number of microplastics were found at SC2-US (Figure 5a). I converted the total microplastics to microplastics per cubic meter of water to standardize (Figure 5b); although the graphical results look largely the same as raw counts. Fibers composed 81% of total surface water microplastics found. Fragments comprised 14% while pellets comprised 4% and lines just accounted for 1% of surface water microplastics (Figure 6a).

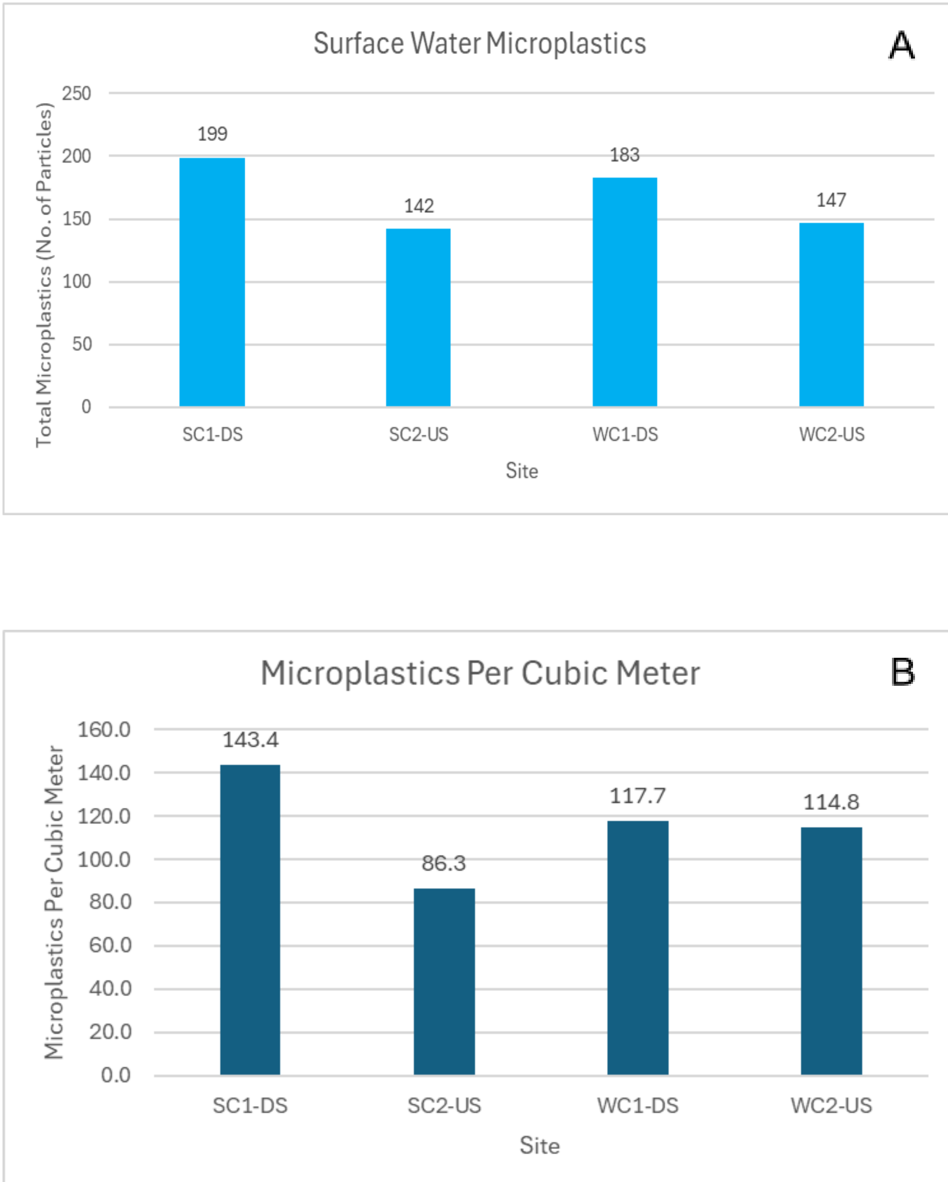


Figure 5. Microplastics in surface water samples for Strawberry Creek and Wildcat Creek. (a) Total number of microplastics found in the surface water. These values are unstandardized and not corrected by differences in flow through the surface water sampler. (b) Microplastics standardized per cubic meter of water based on the flow rate.

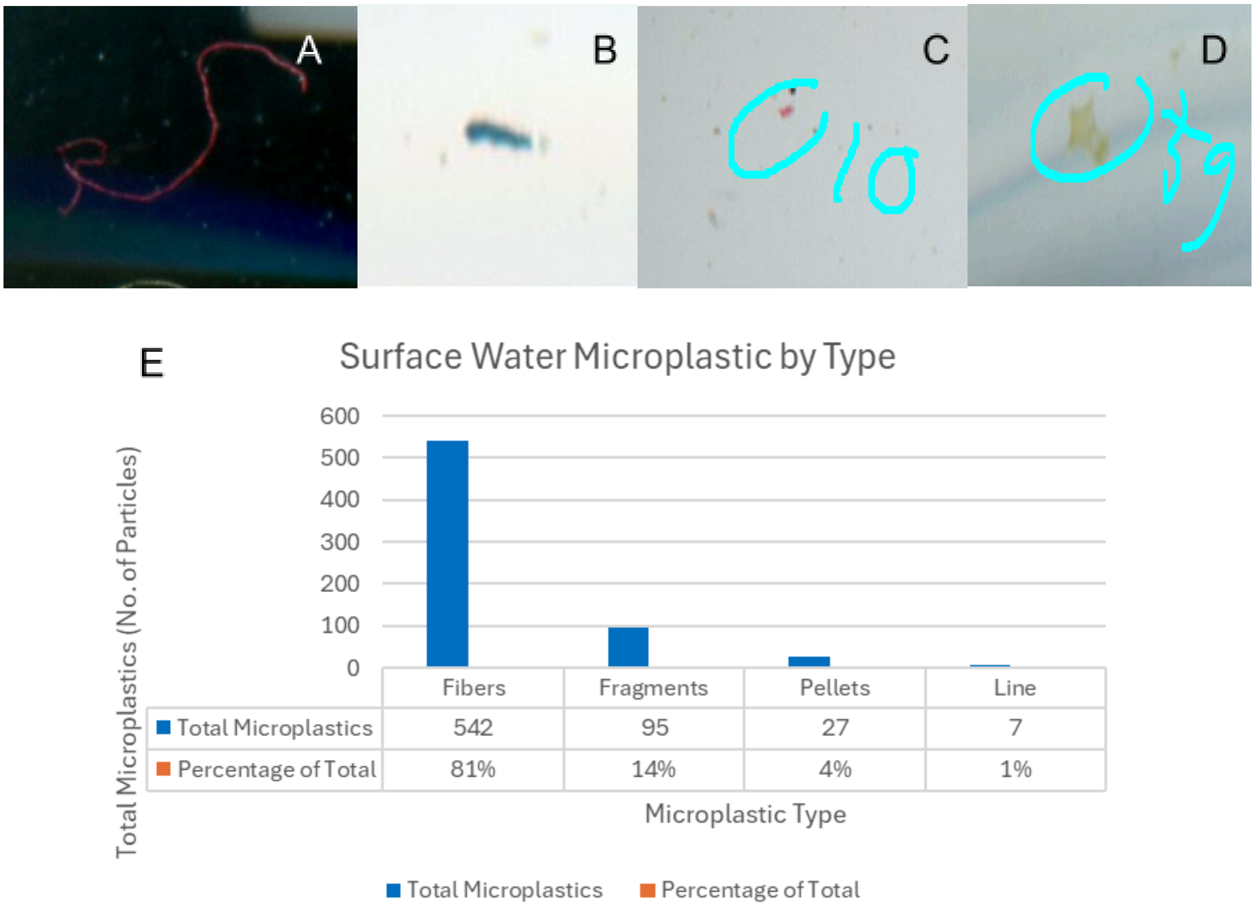
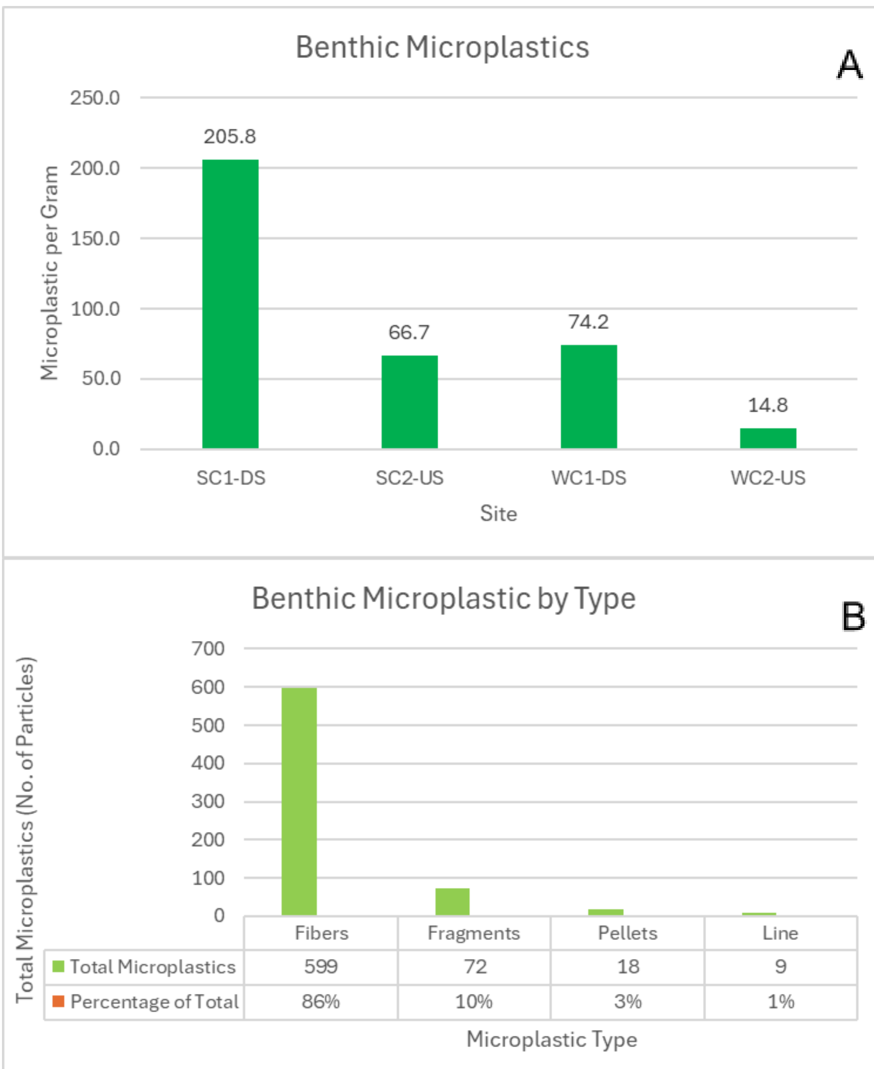


Figure 6. Types of microplastics. Examples of (a) Fiber, (b) Fragment, (c) Pellet, (d) Film. And (e) types of microplastic found in the surface water of Strawberry Creek and Wildcat Creek.

Benthic Zone Microplastics

In terms of total microplastics I found more microplastics in the benthic zone in comparison to the surface water given that there were over 200 MP/g in some sites, and at most, 140/m^3 of water in surface water samples. Each site except for WC1-DS contained more total microplastics in the benthic zone. In total I found 698 microplastics across all streams in the sediment. Benthic microplastics were found most often in the downstream sites. The most common type of microplastic found in the benthic zone was fibrous microplastic. Fibers composed 86% of microplastics in the benthic layer followed by fragments, pellets, and lines at 10%, 3%, and 1% (Figure 7a).



	Fibers	Fragments	Pellets	Line
Total Microplastics	599	72	18	9
Percentage of Total	86%	10%	3%	1%

Figure 7. Microplastics in benthic samples. (a) Microplastic per gram of sediment recovered from the benthic zone of Strawberry Creek. (b) Types of microplastics found in the benthic zone of Strawberry Creek and Wildcat Creek.

Effects of disturbance on microplastic levels

Microplastic levels were affected by physical disturbances upstream of the drift nets. For all sites except SC2-US, microplastic levels were lower in terms of total microplastics following a physical disturbance. SC1-DS reflected only half of the microplastic levels following a disturbance. Before disturbance microplastic levels were at 102 total microplastics and following a physical disturbance, this number fell to 62 total microplastics.

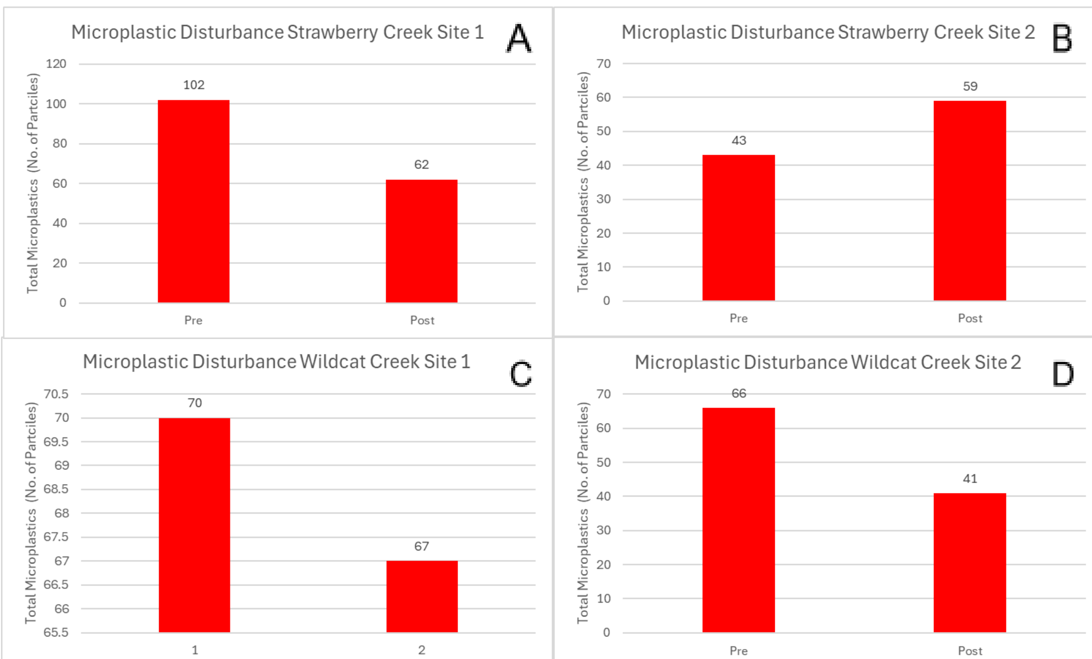


Figure 11. Effects of disturbance on total microplastic levels in Strawberry and Wildcat Creek. (A) SC1-DS, (B) SC2-US, (C) WC1-DS, (D) WC2-US.

Microplastics in riffles and depositional zones

Microplastics were found more in riffle zones of streams in comparison to depositional pools for benthic zones

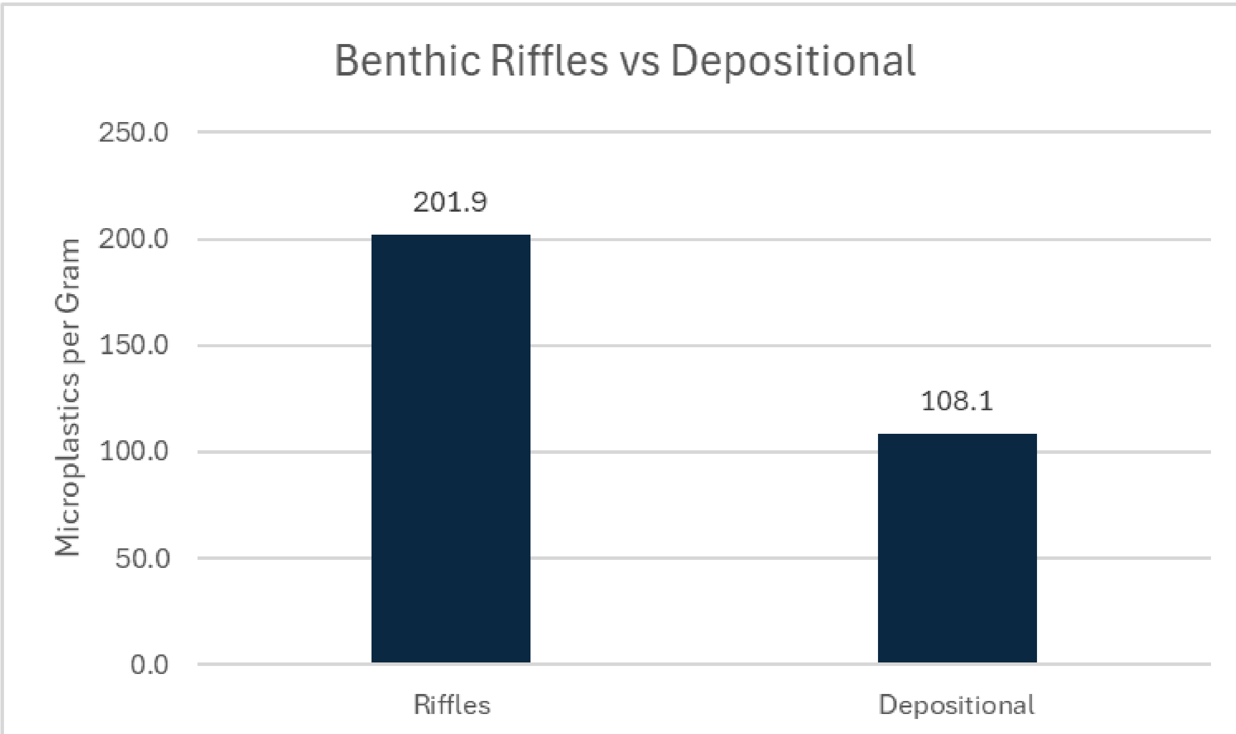


Figure 12. Microplastics in riffles vs depositional pools. Benthic microplastics found in riffles vs depositional pools per gram.

DISCUSSION

This study aimed to understand microplastic storage area, type of microplastic in these storage areas, and effect of disturbance to substrates of microplastics in 2 Bay Area streams. Microplastics found in Bay Area Streams followed a similar distribution among the streams. Benthic sites in Wildcat Creek and Strawberry Creek contained more total microplastics than surface water samples and these amounts could not be directly compared because of differences in units for collection. Fibrous microplastics were the most abundant plastic found in streams; with fragmented plastics being the second most common. Disturbances affected microplastic levels in surface water samples by releasing plastic stored in stream sediments. Microplastic levels decreased compared to the baseline as a result of disturbance. Results found in this study require a higher level of replication and samples taken along the stream continuum. It is important to take into account the context of the study area and climate during sampling.

Physical habitat characteristics and water quality

Both streams received similar stream water quality scores from physical habitat assessments. Within the metrics of stream health I did not expect to find much variability in microplastic levels due to these criteria. However, the two streams differ greatly in their discharge levels, width, and location in proximity to civilization. Strawberry Creek is highly urbanized. The downstream site of Strawberry Creek is especially urban due to flowing through the UC Berkeley Campus. Strawberry Creek likely contained the most microplastics of any site and this can be due to its geographical location.

Wildcat Creek may have had lower levels of microplastics due to the width of the stream and its location in the upper sector of the watershed. When I sampled using drift nets, I may have not captured the area of the stream where microplastics were flowing through. Wildcat Creek had a much larger watershed area and higher discharge levels than Strawberry Creek. However I believe that the geographical factor alone contributed to the lower microplastic levels.

Surface water and benthic samples

Surface water samples contained values much lower than that of other studies. Vincent and Hoellein found numbers ranging from 50-12,000 microplastics per cubic meter. Values for both creeks were about 120 microplastics per cubic meter. This lower value can be due to the smaller aquatic environments I studied. For benthic samples, larger systems than the stream I studied found 9-760 items per kg (Dikareva and Simon 2019). My study identified microplastics in the sediment at much higher levels than other studies. My study found 1000-56000 items per kg. Rivers had much higher surface water microplastics found (Vincent and Hoellein 2021) while my study found higher microplastics in the benthic layer. I believe this to be due to the lower flow levels in streams allowing for microplastics to be deposited in the sediment. Rivers have much greater flow and do not allow for microplastics to settle. Benthic riffles likely contained greater microplatsics that benthic pools due to the path of water. Riffles are where the current occurs and due to their weight, microplastics likely follow the current strictly and are found in riffles more often.

Surface water microplastics levels were consistent with the hypothesis of higher amounts of microplastics found downstream due to the increasing amount of urbanization downstream in Strawberry Creek. For Wildcat Creek, the two sampling sites were not very far apart, and were under similar landscape conditions meaning that differences in microplastics weren't as pronounced. Urbanization plays a factor in the amount of microplastics discovered in both the surface water as well as the benthic layer (Dikareva and Simon 2019). In both streams, microplastic types in the surface water were nearly exclusively fibrous microplastics. Fibrous microplastics are highly abundant in products such as clothing, it makes sense why they are the most abundant microplastic found (de Oliveira et al. 2023). I believe a greater amount of plastics were found downstream due to their physical characteristics as well, microplastics are light and therefore move and accumulate downstream easily.

In larger bodies of water, there is no net suspension or deposition distance from point sources of microplastics (Hoellein et al. 2017). Such that microplastics will remain in the water column and not be sedimented at a certain distance. However, I hypothesize that in smaller streams and bodies of water, the flow is not great enough to suspend the microplastics continuously. Therefore, in both streams microplastics were most often found stored in the benthic substrate than in the surface water. I hypothesize that due to microplastic size, invariability of stream flow and low flow levels, microplastics are found in the substrate more often. I hypothesized that any plastics light enough to continue and not be deposited will likely be found downstream in the surface water. Microplastics in the benthic layer may also serve as a source for surface water microplastics when they are released.

Microplastic types

Net samples from the surface samples contained mostly fibrous microplastics since these are the lightest microplastic and are easily carried along in currents (de Oliveira et al. 2023). Conversely Microplastic fragments which are denser fall more easily to the benthic layer and deposit there due to their very adhesive properties (Hoellein et al. 2019).

Microplastics found in Wildcat Creek included mostly fibrous material across all substrate types. The site sampled was higher up in the watershed and upstream of most urbanization making the source of the microplastics uncertain. Recent studies show that microplastics, especially fibers, are easily carried by wind currents (Bullard et al. 2021). Heavier plastic fragments entering the stream were likely deposited and stored in the sediments near their point sources while lighter fibers were carried farther along with the current. The substrate in Wildcat Creek is also more adhesive allowing for lighter fibers to attach. More urbanized streams tend to contain more microplastics immediately downstream of their sources in the terrestrial environment (Rimondi et al. 2022). I hypothesize that this is why at the downstream sites of both streams, the benthic zones contained the most microplastics and lighter plastics that were too light to be suspended downstream. Strawberry Creek is highly urbanized and as such pellets, fibers, and fragments were frequently found. Fibrous microplastics are likely derived from laundry wastewater, textiles, and clothing while fragments come from plastic bottles and bags (An et al. 2020).

Effects of Disturbance on Microplastic Levels

Disturbances release plastics from the substrate, and in turn these are remobilized in the stream. I therefore expected more plastics to be found in post-disturbance samples. Disturbances that pertain to the benthic layer and affect microplastic levels could be small like human recreational activities in streams or increases in flow from precipitation events, or larger such as channelization and small dredging operations (Wohl 2006). My simulated disturbance aimed to mobilize microplastics stored in the sediments. However, this change in microplastic level was not in the direction I expected as resulting microplastic levels were lower than the baseline levels following the physical disturbance. Not all samples displayed a significant change in microplastic levels after disturbance. Only 1 sample contained more microplastics following a physical disturbance and this was SC2-US suggesting that some material stored in the sediment was captured in the net. Studies exist that allow one to estimate the amount of particulate matter released in proportion to the magnitude of disturbance (Hawley and Vietz 2016).

The results I obtained disturbance levels were not consistent with my hypothesis on immediate effects of disturbances on microplastic levels in streams. Benthic microplastics are expected to be released during a disturbance (Vincent and Hoellein 2021) and resuspend in the surface water, leading to greater amounts found in net samples. This physical tendency for disturbance to release more fine particulate matter is consistent with studies conducted in disturbed streams (Webster et al. 1990). Population size contributes to microplastic input and disturbances as well. Streams in urban areas generally contain more microplastics in proportion to the population present (Mora-Teddy and Matthaei 2020). Disturbance levels in the case of this study could have been due to microplastics in the substrate and surface water dispersing in different directions, or interference from the operator making the disturbance in the streamflow resulting in much of the material missing the net. More replication for baseline levels, and revisions to the design approach for the disturbance would likely provide more insight in future studies.

Limitations and Future Directions

AGiven that California's Mediterranean climate has high variability and generally low-levels of flow-related disturbance during the dry summer months, applicability to streams outside of the Mediterranean climate system and California may be limited. My study sites were in relatively urban areas, mostly making this study difficult to apply to remote streams. The equipment I utilized was also crafted by myself and as such may have had imperfections in its designated purpose, especially if in-flow exceeded the outflow through the end of the surface water net. My nets minimized expensive nytex mesh meaning that most of the net was not permeable and may have slowed down flow. Vincent and Hoellein (2021) had access to precisely crafted neuston nets which allowed for more accurate measurements. Human error also applies major variability to questions such as disturbance affecting microplastics.

Future exploration of stream microplastics should aim to answer the disturbances hypothesis more specifically. This future research may include questions such as "what kind of disturbance affects microplastic levels" or" what does disturbance do specifically to microplastics". I can address these questions through smaller experiments in the lab (such as flume experiments) or with smaller sites in stream. To improve my study for future iterations, equipment such as nets should be of greater quality to eliminate confounding factors and simulated disturbances should have more specific procedures.

Broader Implications

Microplastics are an extremely prevalent form of pollution in aquatic systems and as such, it is important to study their dynamics and where they are present. This study was designed to lay the groundwork for future microplastic research in Urban Streams in the San Francisco East Bay. As a result, there is a general understanding of where microplastics are present in two Bay Area streams to aid future research efforts. Future research may allow for direct identification of sources of these microplastics and how predictable seasonal events such as winter storms result in fluxes of suspended microplastics from their storage in benthic sediments. Identifying microplastics' sources can aid mitigation efforts in terms of stricter legislation. Knowing where microplastics are located in streams allows for policymakers and mitigation efforts to reduce these plastics and hopefully, their sources as well.

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