Urban Creek Plastic Pollution in the Bay Area, California: Protections, Litter Compositions and Sources

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ABSTRACT

Urban streams serve both as corridors of plastic pollution to the ocean and as a sink of plastic waste. Freshwater wildlife organisms interact with this plastic waste in many ways which can negatively disrupt the freshwater ecosystem. To investigate how plastic waste enters streams and who is responsible for cleaning up and preventing sources of litter, I researched the effectiveness of creek protections on plastic litter control. I chose three sites at three creeks in Contra Costa County, California, and searched for government regulations and volunteer activities by non-profit organizations. Through creek litter sample collection, I studied the litter components and drew relationships between creek litter and the nearby structures. I found an average of 76.3% of the total litter to be plastics that were in diverse types. Among the plastic litter, the top 3 components were packages (28.2%), films (21.1%) and Styrofoam (20.2%). Nearby structures, the creek visitor diversity and the parties involved affected the creek litter quantity, but were not conclusive on the types of litter. Parties involved should be taking more effective actions on reducing future plastic litter and cleaning existing ones, especially planning on restarting the activities after the Covid-19 pandemic. Further studies on looking at more creeks for a more comprehensive analysis and looking at plastic litter in a micro-way are also needed.

KEYWORDS

neighborhood litter source, stream litter, volunteer clean-ups, regulations, sorting methodology

INTRODUCTION

Plastic pollution is a pervasive environmental problem (Carpenter and Wolveton 2017). With the increased use of plastics in industries and our life, the pollution from plastic that appears in open water and beaches has increased along with ecological impacts. Annual plastic production has increased 200-fold from 1950 to 2015 (Geyer et al. 2017). Over the past 60-years, plastic pollution in the open ocean plastics has significantly increased (Ostle et al. 2019). Certain plastics occur more in urban beaches than in remote beaches and open oceans (Hirai et al. 2011). Increasing pollution is not limited to open water. Although current research focuses on plastic pollution in oceans or beaches, scientists also found and studied plastic litter in streams as a source of ocean plastic pollution (Lechner et al. 2014). Rivers and creeks usually run from the mountains or parks and eventually act as corridors for plastics to enter the ocean environment. By researching plastic litter in rivers and creeks, we can know more about reducing sources of ocean plastic.

Plastic litter in streams can come from cultural and non-cultural sources (Carpenter and Wolveton 2017). The cultural sources include plastic bottles and bags on the bank by litterers and the non-cultural sources include plastic pollution brought by wind, rain and urban runoff (Carpenter and Wolveton 2017). Wind and rain can bring the potential plastic litter from nearby neighborhoods to the bank or into the streams. Moreover, the composition of plastic litter can vary depending on the locations of the streams. Previous studies show a lack of study in freshwater plastic pollution compared to marine plastic litter: 87% of the literature reviewed are related to the marine environments and only 13% of them are related to freshwater systems (Blettler et al. 2018, & Winton et al. 2017). The ratio of marine plastic pollution studies and freshwater ones is 41:7 (Blettler et al., 2018). In order to understand the effective ways to reduce and control the plastic pollution in the streams, we need to look at the protections on these natural areas and determine where these litter come from.

To protect these streams from increased plastic pollution, reducing, removing and controlling the entry of litter are the critical solutions. One factor that affects the compositions and concentrations are urban runoff and the discharge from water treatment plants. The Federal Clean Water Act has mandated a municipal stormwater National Pollutant Discharge Elimination System (NPDES) permit (Contra Costa County Watershed Program). Whoever discharges water into streams in Contra Costa County needs to obtain this permit. Another type of protection in these natural areas is active cleanup programs. There are formal and informal cleanups by different groups of people and only certain groups have information recorded. For example, Contra Costa County has volunteer creek groups, such as Friends of the Creeks (http://www.friendsofthecreeks.org/), that perform regular cleanups and other programs to protect the creeks. However, the effectiveness of these programs and protections has yet been investigated by comparing the open water and beaches in the percentages of plastics over total pollution. By addressing that, the related authorities and organizations are able to further design and improve on water protections and be inspired more on wildlife protections from plastic pollution.

In this study I ask, how effective are the protections on Grayson Creek, Walnut Creek and Pine Creek in Contra Costa County to control plastic pollution. I ask four sub-questions to help answer the central research question: (1) What are the protections for these streams? (2) What are the components of plastic litter and total litter in these streams? (3) What are the sources of plastic litter? (4) And is there a relationship between the neighborhoods and plastic litter? I predict that: (1) protections include government regulations and cleanup programs. The government regulations control the litter from discharge pipes and the cleanup programs pick up litter regularly and educate the public on plastic pollution. (2) Grayson Creek and Alamo Creek have different components of pollution than Ygnacio Canal as both of them are near college which is a different source of litter. (3) The sources of litter include cultural and non-cultural inputs. (4) And there is a relationship between neighborhoods and the plastic litter.

METHODS

Study Site

Grayson Creek flows from Briones Regional Park, merges with Pacheco Creek, and eventually connects to the Suisun Bay in California (Figure 1a). The study section of the creek is characterized by dense grass and trees on both sides of the bank (Figure 1d). Some parts of the creek are in concrete structures which are used for flood control.

The Walnut Creek is merged by 3 small creeks: San Ramon Creek, Tice Creek and Las Trampas Creek. Some of these small creeks are further merged by smaller creeks that flow from the cities of Lafayette, Moraga, Walnut Creek and San Ramon. The Walnut Creek merges with Pacheco Creek which connects with the Suisun Bay in California (Figure 1b). The study section of the creek is low in water level and has various widths in different parts. It has a wider bank and is located in a more urbanized area compared to Grayson Creek (Figure 1e). It is a big trapezoidal channel and there is also a small dam both for the purpose of flood control in the study section where waterbirds are observed there.

Pine Creek flows from Mount Diablo in Contra Costa County and then merges with Walnut Creek which then merges to Pacheco Creek and eventually connects to the Suisun Bay in California (Figure 1c). It is parallel to the Contra Costa Canal and the nearby canal trail which are both near the South-West part of Lime Ridge Open Space in the city of Walnut Creek (Figure 1f). It is covered by grass and little water flow is seen during the spring. Some parts of the creek are in concrete structures which are used for flood control.

Protections

To collect the protection information in my three study sites, I searched the Contra Costa Clean Water Program (CCCWP) website (https://www.cccleanwater.org/) and Walnut Creek Water Council to look up what the volunteer creek groups had done to protect the creeks. I found out that one of the groups, Friends of the Creeks (http://www.friendsofthecreeks.org/) and Friends of Pleasant Hill Creeks http://www.pleasanthillcreeks.org/), had done creek cleanups and reported the assessments of trash in 2018. The Last Plastic Straw Campaign in Contra Costa County used the assessment data to promote a policy on reducing disposable foodware. FOTC and FPHC also performed water quality monitoring and public education.

I have also searched the Contra Costa County website specifically on the Watershed Program (https://www.contracosta.ca.gov/344/County-Watershed-Program). The program was to ensure the county compiled with the municipal stormwater National Pollutant Discharge Elimination System (NPDES) permits. These permits were mandated by the Federal Clean Water Act and the law was administered by the State Water Resources Control Board and the Regional Water Quality Control Boards representing the U.S. Environmental Protection Agency (EPA).

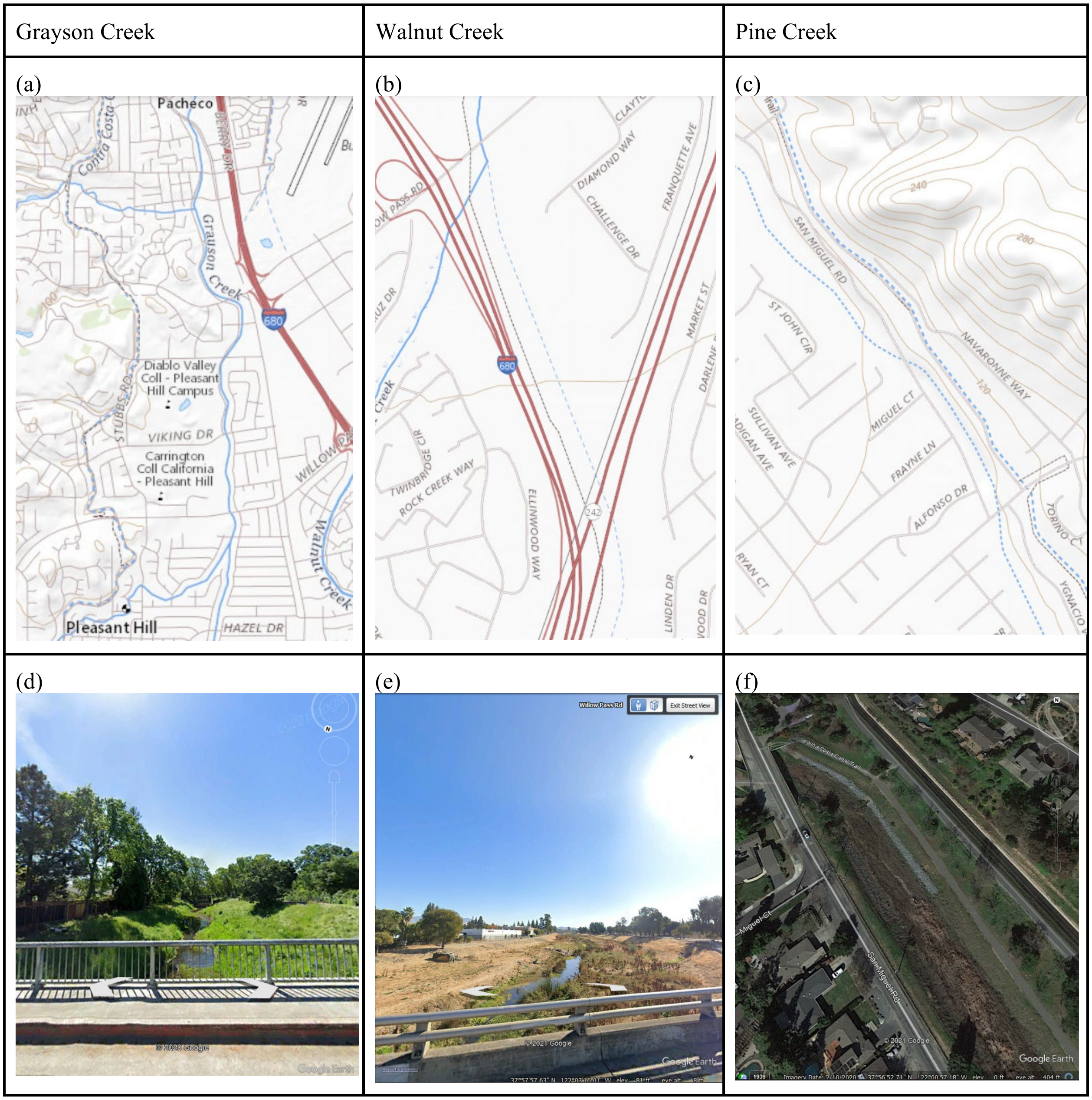

Figure 1. The maps or photos extracted from the USGS maps and Google Earth Pro of the study site at each creek. (a) The map extracted from the USGS website (https://viewer.nationalmap.gov/advanced-viewer/) showing the study section of Grayson Creek in a solid line with the Diablo Valley College Pleasant Hill campus nearby; (b) The map extracted from the USGS website showing the study section of the Walnut Creek in a dotted line as it is a branch of the main creek; (c)The map extracted from the USGS website showing the study section at Pine Creek in a line with shorter dots (the one on the left); (d) The photo extracted from Google Earth Pro in a street view showing the study section at Grayson Creek on Viking Dr.; (e) The photo extracted from Google Earth Pro in a street view showing the study section at Walnut Creek on Willow Pass Rd; (f) The photo extracted from Google Earth Pro in a ground view showing the study section at Pine Creek as a grey and muddy channel in between the San Miguel Rd and the Contra Costa Canal Trail.

Plastic Litter Collections

To establish the sample collection sites, I selected a section at Grayson Creek and Walnut Creek and my selection was based on my observation of where the most litter were seen. I collected 3 sets of litter samples every time. I went to Grayson Creek on January 21, 2021 and March 10, 2021 and Walnut Creek on February 19, 2021. For the collection, I used a land measuring surveyor tape to establish a 50-meter line transect along the bank in each section. For each transect of the litter sample, I collected litter including plastics and non-plastics from 1 meter left and right along the line. I repeated the process with a region that I had not already been collected from at the same study section. I used a plastic bag to collect all the litter and brought it home to sort. I sorted based on the types such as plastic and non-plastic litter. I further sorted the plastic litter based on their physical characteristics such as plastic bottles and plastic packages and categorized them by recyclability (Figure 2). I recorded the numbers of items in each type and tabulated them into an Excel sheet. I counted each plastic piece as one and I sorted the plastic litter using my best judgement based on their similarities.

I then put the data into a spreadsheet and produced graphs to compare the litter at each site. I made three graphs to compare the data at each stream. First, I compared the average of the total litter for each time I collected samples. In the same graph, I also compared the average plastic litter. For the second graph, I compared the average percentage of plastic litter in each category by averaging the counts at each date. I compared the average percentage of both plastic and non-plastic litter in each category by averaging the counts at each date.

Besides data collection, I also performed observations at each site to describe what plastic litter I could see and recorded on paper. As I could only observe very little litter at Pine Creek, I only performed observation surveys at this creek and compared the litter samples at Grayson Creek and Walnut Creek. At each creek, I observed what plastic litter and non-plastic litter could be seen at the bank and in the water and observed if there were any illegal dumping sites. I also observed who the visitors were and whether the creek was being used frequently by humans.

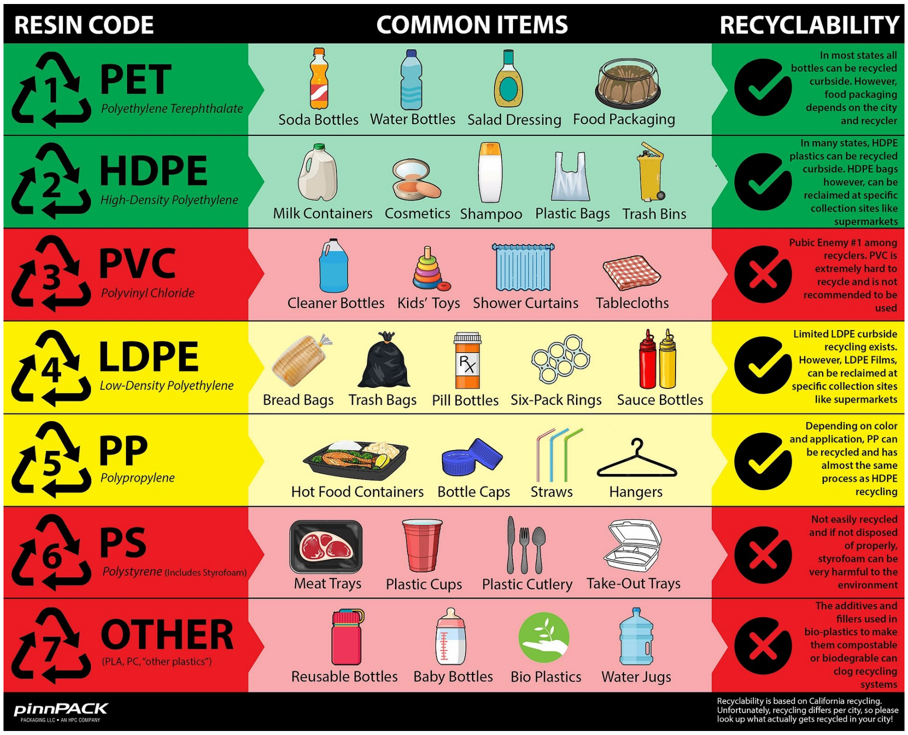

Figure. 2. Types of plastics based on the chemical structures and the resin codes. Source: https://www.pinnpack.com/rpetplastic

Sources of Litter

To determine the sources of litter, I looked at the types of plastic litter collected and observed during sample collections at Grayson Creek and Walnut Creek and compared the types and quantities of litter with the neighborhoods and nearby structures. Referring to and modifying from the method in Carpenter and Wolverton (2017), I sorted the plastic litter based on their prevalence at the site (Table 1).

Neighborhoods at the Creeks

To understand the neighborhoods near each site, I conducted a neighborhood analysis using Google Maps. I searched the study section at each creek and looked at the neighborhood approximately within 100 meters of the creek area. I then analyzed the relationship between the neighborhood and the creek litter quantity and types. I also analyzed the relationship between the traffic nearby each creek and the creek litter characteristics.

Table 1. The plastic litter sorting methods from Carpenter and Wolverton (2017) (a) and my modified sorting method (b). The literature sorted the plastic litter based on the broad use type, while my sorting method is based on the prevalence of each type.

(a)

Plastic Use Type	Examples
Beverage	Polystyrene cup, water bottle, soda bottle
Packaging	Candy wrapper, cigarette package wrapper, chip bag
Food & drink accessory	Straw, fountain drink lid, plastic cutlery
Bag	Grocery bag, garbage bag
"Other"	Surveyor's tape, bulky items, plastic fishing floats

(b)

Plastic Categories
1. Bottles (#1 PET)
2. Packages
3. Labels
4. Films
5. Beverage & lid & straw
6. Food containers & utensils
7. Styrofoam (#7 Polystyrene)
8. Tape
9. Miscellaneous

RESULTS

Site observations

All study sites are located at Contra Costa County in California and they are accessible by foot for litter collection. The study section at Grayson Creek in Pleasant Hill, CA, is 5 to 6 meters in width, crossing Viking Dr. and is parallel to Ruth Dr.. The traffic on these roads is usually light.

One side of the creek section is surrounded by a middle school, a high school and a college. The college has two sports fields which are located beside the creek. The other half of the creek section is surrounded by residential areas. From a site visit, I observed that there was some litter floating on the water especially under the bridge of Viking Dr., or in the sediment. There was also some litter at the bank, in where wild grass and plants grow. During the two visits from January to March, the grass and plants at the bank grew so much that some litter was covered by the grass, making it hard to collect. Moreover, there are two stormwater discharge pipes, opposite to each other on each side of the creek (Figure 3).

The study section at Walnut Creek in Concord, CA, has an estimated width from 2.5 to 10 meters. There is an Iron Horse Regional Trail parallel to it, as well as a major freeway, I-680. People who use the trail are usually trail visitors and homeless, who take temporary shelter at the bank of the creek or under the bridge of another freeway I-242, crossing the creek. These two freeways have metal fences on the side, preventing large amounts of traffic litter, which I observed at the fences during my site visit, from entering the creek or the trail. However, due to the high speed traffic on the freeways, some light-weight plastics can be brought into the creek area by wind and some small pieces of plastics, such as styrofoam, can pass through the fence and enter the creek area during raining days. Besides that, the creek section is also surrounded by commercial areas on one side of it, including automobile shops, furniture stores and large parking lots. Through my site visit, I observed that the creek area had a lot of litter in the water, the sediment and the bank. These include cloth, metal cans, plastic bag debris and candy wrappers. It was not easily accessible compared to Grayson Creek, as it was rainy during the litter collection date on February 19, 2021, and the bank was muddy with wildlife animal defecates distributed unevenly.

The study section at Pine Creek in the city of Concord, CA, serves as a control and comparison to the other two creeks. It is under the jurisdiction of the East Bay Regional Park District because it is parallel to the Contra Costa Canal and the canal trail. Besides the canal and the trail, the creek section is also surrounded by San Miguel Rd. and many residential areas. The traffic on the road is light, but slightly faster than that on Viking Dr.. From my site visit, I did not observe a lot of litter on this creek section except a shopping cart laying beside the road with some cloth and litter scattered on the ground.

Figure 3. Photos showing the water discharge pipes on each side of the bank of Grayson Creek.

Figure 4. Photos shot of the Penal Code print at Grayson Creek at the bridge of Viking Dr. This was printed on the surface of the bridge warning people not to trespass to the creek region.

Regulations and environmental stewardship

Through online research on websites including EPA, CCCWP, Contra Costa Flood Control and Water Conservation District, I found the legislations, regulations and permits related to creek protections (Table 2). However, they were not specific for plastic litter control and prevention. The Clean Water Act is the federal law that governs water pollution by making it illegal to discharge pollutants into water bodies unless a permit is obtained from the EPA's National Pollutant Discharge Elimination System (NPDES) permit program (Table 2). Moreover, a penal code of California, had a trespassing regulation on the creeks and the enforcement and the prosecution of violation was ensured and conducted by the city agencies (Figure 4). In this study, the agencies involved in the three creeks were the city of Pleasant Hill, Concord and Walnut Creek for each of the study sections at Grayson Creek, Walnut Creek and Pine Creek respectively (Table 2). Additionally, besides the regulations above, Pine Creek was also under the jurisdiction of the East Bay Regional Park District (Table 2). There are no related regulations that are specifically established for creek plastic litter control.

Moreover, through online research on non-profit organizations which were dedicated to local creek protections, I found that volunteer creek clean-ups existed in all three creeks where my study sites were. Walnut Creek Watershed Council (https://www.wcwatershed.org) was the one that included information about each stakeholder involved in creek protection, including non-profit organizations, cities and towns, government agencies and corporations (Table 2). Friends of the Creek, one of the non-profits, had gathered citizen volunteers from the Contra Costa County local community and provided creek clean-up and restoration opportunities. Its purpose is to promote creek protections for wildlife and human recreational use. They performed regular creek clean-up for trash and invasive species removal and they had produced trash assessments every year (Table 2). However, due to the Covid-19 pandemic situation, the organizations paused the large group clean-ups for 2020 and 2021. It was unsafe and risky to have large group gatherings as the coronavirus could be easily spread and cause detrimental impacts. Due to their own hardships such as adapting to the Covid-19 situation, the organizations reduced their in-person activities but remained active online to promote virtual education programs and provide announcements and information.

Litter collections

I found that litter collections from all three sampling dates consisted of similar types of litter such as plastics, metal, cloth and paper, but they varied slightly in the percentages of each type and the percentage of plastics over total litter. In all sites, plastics were the most component of creek litter, with an average of 76.3% over the total average litter count, calculated by dividing the average

Table. 2. Information on litter enforcements and organizations at each creek. I searched up the laws and clean-up groups for each creek to determine the extent of protection and enforcements.

Creeks	Volunteer creek clean-ups	Frequency of clean-ups	Enforced laws & regulations
Grayson Creek at Viking Dr.	• Friends of the Creeks • Friends of Pleasant Hill Creeks	Used to be annual, but paused in 2020 and 2021	• Penal Code CA, section 602 • Discharge Permit by NPDES
Walnut Creek at Iron Horse Trail	• Friends of the Concord Creeks		• Metal fences along the freeway sides • Penal Code CA, section 602 • Discharge Permit by NPDES
Pine Creek at San Miguel Rd	• Friends of the Creeks		• Trash bins • Penal Code CA, section 602 • Discharge Permit by NPDES

total litter by the average total litter (Figure 5). The site at Walnut Creek contained an average of 35.7 pieces of total litter and that was 2.7 to 11.4 more pieces than Grayson Creek, which had an average of 24.3 to 33.0 pieces of total litter during two collections (Figure 5). This increase in Walnut Creek was also proved by observations: there were some holes at the bank, dug by presumably homeless people who might have temporarily stayed there and left litter in the holes. Moreover, I observed that a lot of litter stayed in the sediment of the Walnut Creek, including ceramics, colored plastic bags in whole or debris, batteries, plastic bottles and many other types of litter. The study section in Walnut Creek also had more plastic litter, by 4.3 to 9.6 counts, than the sections in Grayson Creek (Figure 5).

During the two data collections at Grayson Creek, the average amount of total litter and plastic litter both decreased throughout the time by 8.7 counts and 5.3 counts respectively (Figure 5). From January 21, 2021 to March 10, 2021, the grass and the wild plants at the bank had grown up so much that they covered most of the soils during my second visit. The grass covered some of the litter which were stuck into the mud and difficult to collect.

For the plastic litter, the major types were packages (28.2%), films (21.1%) and Styrofoam (20.2%) (Figure 6). There were very few complete plastic bags collected, nor plastic bag debris. In my categorization of plastic litter, the difference between packages and films was that packages were thicker and harder to tear into pieces while films could easily break into many smaller pieces.

Examples of packages were candy wrappers, Ziplock bags and packaging stuff while films referred to plastic bag debris and straw wrappers. Another type of plastics that could also break into pieces were Styrofoam, which was number 7 in resin codes and made of polystyrene. Additionally, many of the plastics were difficult to identify and for some types I only collected very few counts, therefore I grouped them into "miscellaneous" and that was why this category made up a big percentage along with packages, films and Styrofoam.

By calculating the average percentages of litter in each category, including each type of plastic litter, showed that plastics ranked the top 4 types of litter in percentages: packages (21.51%), films (16.13%), Styrofoam (15.41%) and other plastics (12.54%) (Figure 7). Among the non-plastic litter, paper had the highest percentage (10.04%) while there was no glass collected during all three visits (Figure 7). There were not many beverage related plastics (3.58%), tape (2.87%), plastic bottles (2.87%), labels (1.08%) and food containers and utensils (0.36%) collected (Figure 7).

Sources of litter

I analyzed the sources of litter through two aspects: locations and types. From the location perspective, I found that the potential sources of litter are residential, commercial, traffic and school litter, litter left by visitors and creek users, and urban runoff, along with a major impact by the environmental factors such as wind and rain (Table 3).

By considering where the litter could come from, I searched the neighborhood map for each study site along the creek section. One side of the study site at Grayson Creek was surrounded by two light-traffic roads, 3 school campuses and some of their sports fields, while residential areas surrounded the other side of the creek completely. The potential sources of human input litter were residential litter, which were left accidentally by the residents or litter trucks, traffic littering, sports accessories, littering by people who took temporary shelters at the creek bank or under the bridge of the creek and left items there. Grayson Creek was less frequently occupied by homeless people compared to Walnut Creek, so the litter quantity was relatively less. The environmental inputs here were wind, rain, water discharge and urban runoff.

The site at Walnut Creek was surrounded by 2 major freeways and I observed that there were metal fences at the side of the freeways which prevented litter on the freeways from blowing

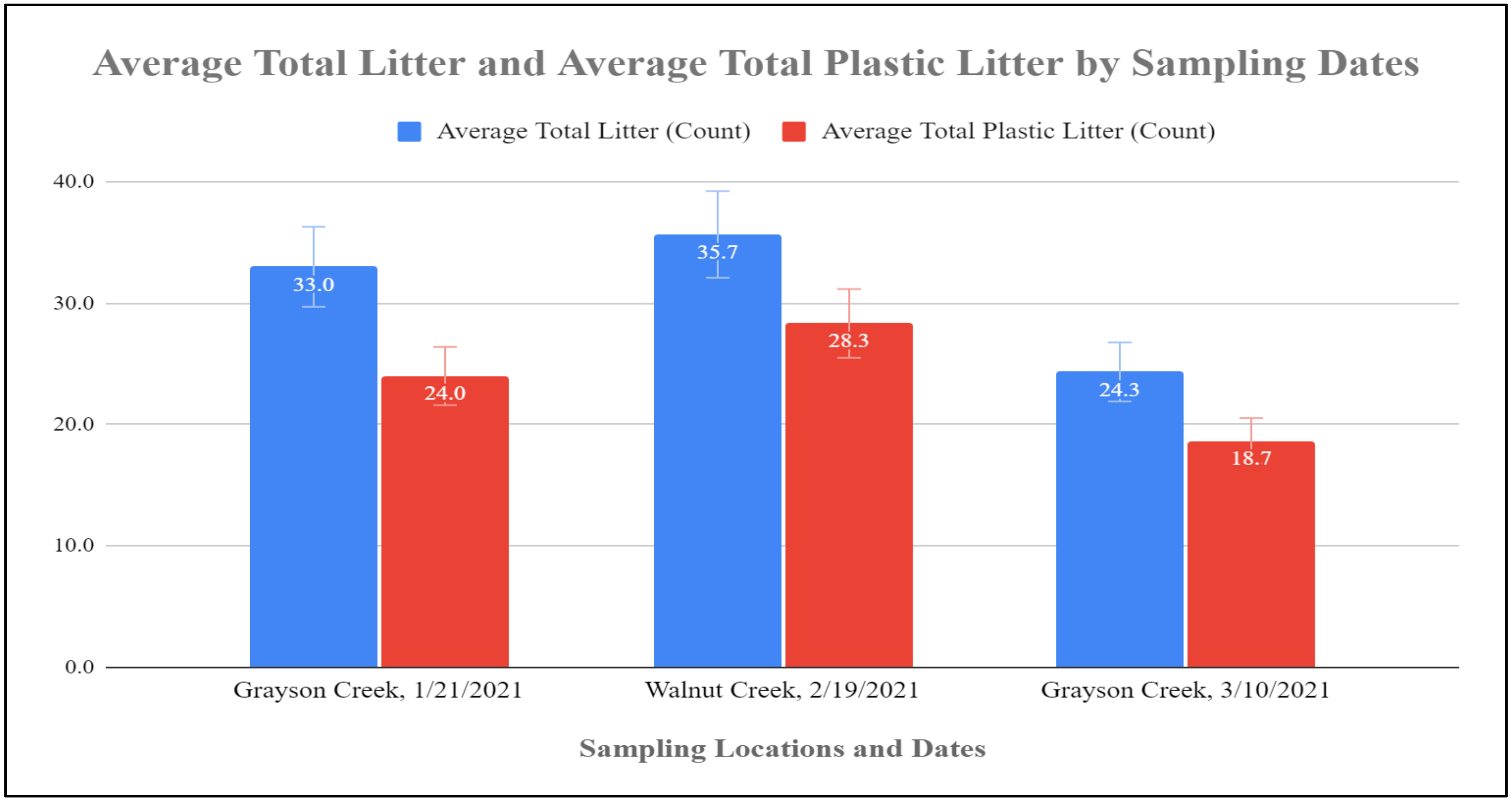

Figure 5. Average total counts of litter and plastic litter on each sampling date. I calculated the average total counts of litter and plastic litter collected at Grayson Creek and Walnut Creek for each visit.

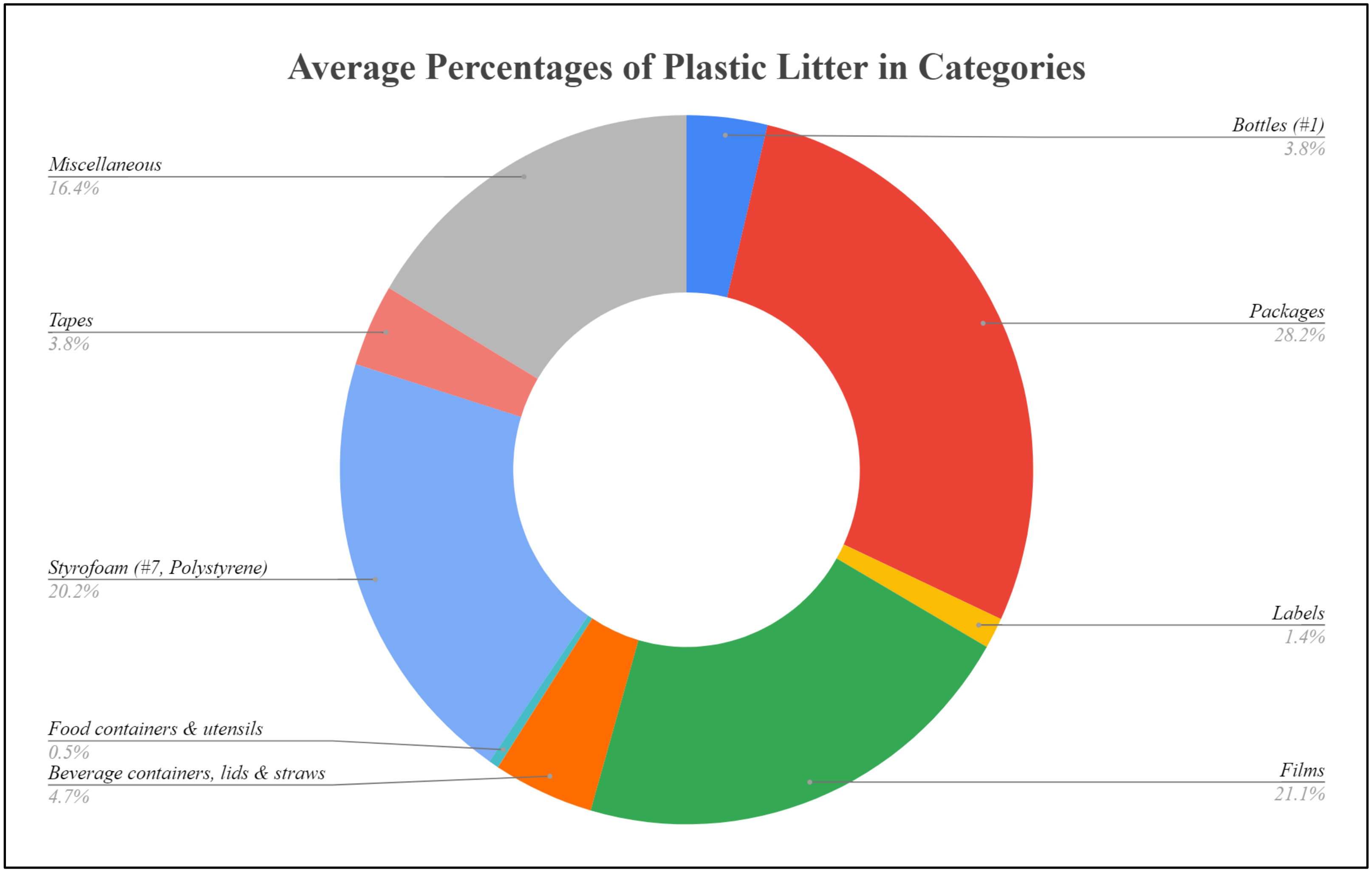

Figure 6. The average percentages of each type of plastic litter collected. I summed up and averaged each type of plastic litter in counts and divided the total counts of plastic litter to obtain the average percentage of each type of plastic litter. The major types of plastic litter were packages, films and Styrofoam.

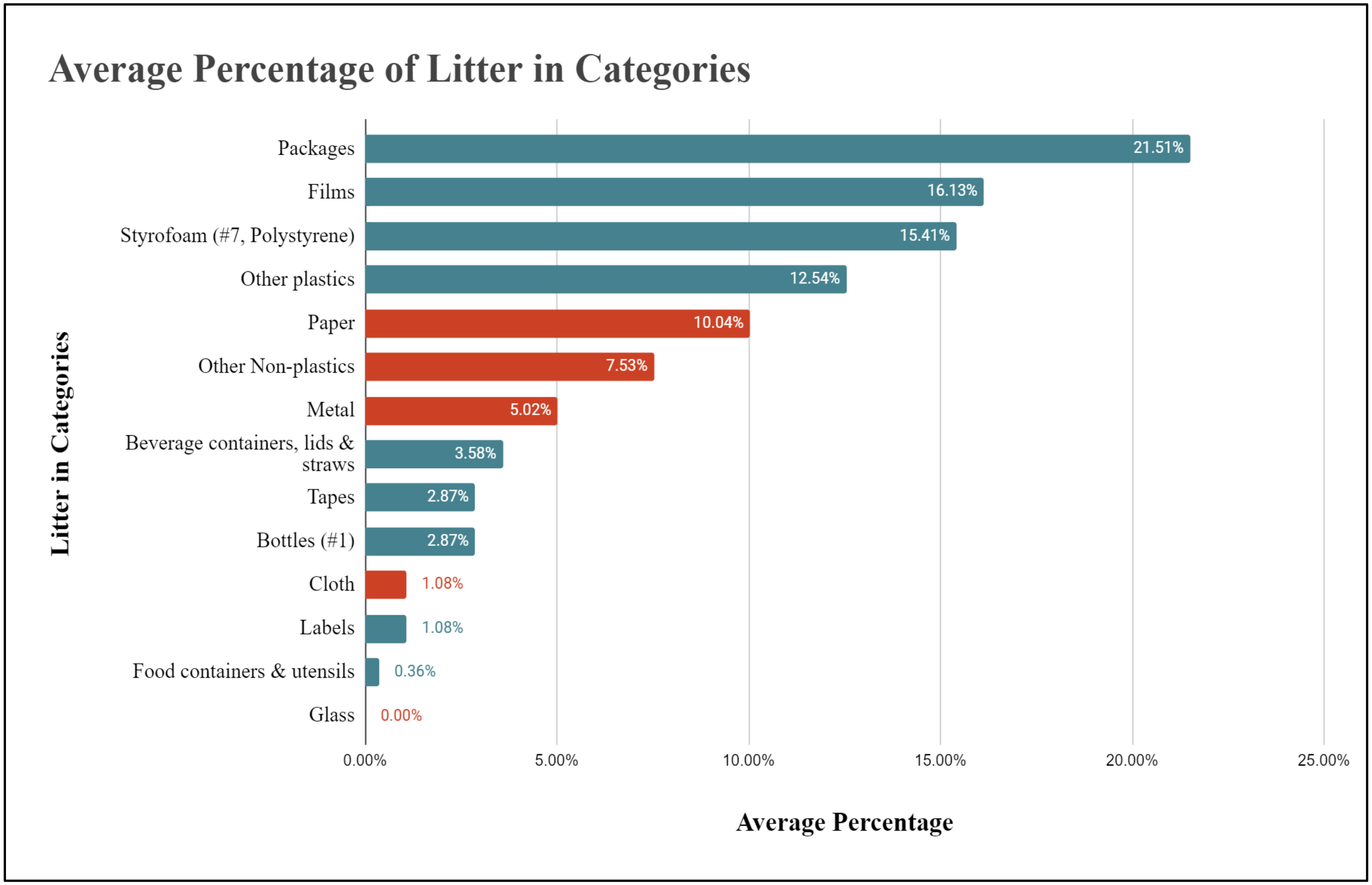

Figure 7. The average percentages of each type of litter, including each type of plastics. I ranked the types of non-plastic litter (in red bars) and plastic litter (in blue bars) in their percentages in the total litter in an ascending order. The top 4 were all plastics while paper being the top in non-plastic litter.

Table 3. Environmental inputs and human inputs of litter. I categorized the litter by my best judgement identifying if they were human or environmental inputs. Human inputs were sourced from human activities while environment inputs were brought by weather factors or water flow.

Human Inputs	Environmental Inputs
Littering by visitors	Wind
Littering from temporary shelters by the creek	Rain: urban runoff from residential/commercial areas
Illegal dumping	Stormwater discharge
School: sports field, campus	Water flow: litter from the upper stream

into the creek area. There was also a trail along the creek section, and I observed the users were runners, visitors with or without walking dogs and homeless people riding bikes. Another observation was that under the bridge of freeway I-242, there was an encampment with lots of litter scattered on the muddy ground. There were also loose camps and some holes at the creek bank; there were clothes and litter inside the holes and that showed that people had been taking stops inside. This section was heavily occupied by homeless people and even the litter in the creek was more in quantities than the other two creeks. The creek litter here included metal cans, clothing, shoes, food and beverage containers and accessories and bike tire debris, according to my data collection. Besides these human inputs, I also observed that there were two big pipes at the concrete part of the creek bank, discharging water from it, creating bubbles in the creek and therefore suggesting a potential litter source from the discharged water. The environmental input was wind: Walnut Creek had a stronger wind than the other two creeks as the freeway traffic was fast and created strong wind, rain and urban runoff.

The section at Pine Creek was surrounded mostly by residential areas and parallel with the Contra Costa Canal Trail. The creek was at a lower altitude while the trail was higher by around 2 meters. I observed that this creek was relatively clean and some of the parts were dried at the time I visited in March. The traffic on San Miguel Rd was light. The most common creek users are the trail visitors and residents living there. The possible human litter input was from residents, trail visitors and traffic litter. There was a shopping cart abandoned on the bank with some clothing, food and drink containers and accessories and other daily use items left on the ground. In the creek under the bridge, there was an abandoned sofa and illegal dumping was also present here. The environmental input was wind and rain. I did not observe any discharge pipes there.

To look at the sources of plastic litter from their types, there were plastic bottles, packages, labels, films, bags, food containers and utensils, beverage related litter, Styrofoam, tape and other miscellaneous ones (Table 4). The miscellaneous ones did not belong to any of the main types and some of them were unable to recognize which type they were in. The non-plastic litter types included glass, metal, paper, cloth and others (Table 4). The others in non-plastic litter were too few in quantities and therefore I grouped as miscellaneous.

Table 4. Creek litter types based on three sample collections. I separated the creek litter into plastic and non-plastics, and further categorized them based on the types, materials, use and structures.

Types of Plastic Litter	Types of Non-plastic Litter
Bottles, #1	Glass
Packages, labels, films, bags	Metal
Food containers & utensils	Paper
Beverage, straws & lids	Cloth
Styrofoam, #7	Miscellaneous (Ceramics, batteries, etc.)
Tape	
Miscellaneous (hard plastic debris, party decor, etc.)	

Relationship between neighborhoods and buildings nearby

There is a relationship between the structures or buildings near a creek and the types and quantities of litter in the creek. There was more litter in the creek if it was near major freeways, schools, commercial areas and heavy-traffic roads. In the opposite, there was less litter if the creek was near residential areas, open green spaces or did not have many nearby structures which were usually occupied by human activities. Besides the quantity of litter, the locations of a creek also affected the types of litter.

The part of Grayson Creek where my site was located was surrounded by schools, residential areas and a road which usually had light traffic (Figure 8a). The road was less used during the pandemic than the normal time as Diablo Valley College and Valley View Middle School campuses were closed. Moreover, as I observed at the creek, the litter at this section of the creek was often small pieces and the most common ones seen were plastic bottles, paper, plastic packages and other small plastics. Some litter seen were at the bank while some were in the water. Wildlife animals, such as egrets, ducks, Turkey Vultures and Canadian geese, often come to the water and feed themselves the micro-organisms, shrimps or fish from the creek and drink the water. These organisms would possibly encounter litter including plastic ones when they interact with the environment. An additional finding was that after raining, the litter at the bank got trapped in the soil and the growing grass gradually covered the litter during the wet winter season. I went to the site on January 12, 2021 and March 10, 2021 and I observed that the grass on the bank grew so much that litter was not obviously seen during the second sample collection.

There is no public trail on study section of Grayson creek, and therefore there were few visitors at this creek except some people who illegally take temporary shelters for hours or days at the bank or under the bridge at Viking Dr. Interestingly, litter also came from the nearby sports fields which belong to Diablo Valley College, as reflected in my litter collections.

At the site on Walnut Creek, I observed that there were a lot of temporary shelters and an encampment along the creek, especially the part under the bridge which belonged to the SR-242 freeway (Figure 8b). Litter from the daily supplies that the shelter people produced could be seen scattered on the ground that could potentially enter or stay in the creek, or flow into the down streams. Comparing among the three creeks, this site was relatively the most polluted one, both at the bank and in the creek, as it served as a station for homelesses and the little samples revealed a higher quantity and variety in categories.

The study site at Pine Creek was located parallel to the Contra Costa Canal and its trail (Figure 8c). The canal and the trail were approximately 2 meters higher than the creek as there was a staircase in between, and therefore the litter from the canal trail was not likely to travel into the creek. The common visitors were park users, runners, and walkers. The traffic at San Miguel Rd was light, so less litter was blown by wind from traffic. Illegal dumping was seen here as a sofa dumped under the bridge. Besides that, I observed that almost every household near the creek had fences that could prevent litter from entering the creek area. The litter condition was much better than the other two above and I think one reason was that the visitors were usually residents and the creek area serves as a short time stop, unlike the section at Walnut Creek which serves as a long-term station for homelesses.

DISCUSSION

Introduction

While improvements need to be implemented in the regulations which are not focused on creek plastic litter control, public education, environmental stewardship and corporation efforts also play an important role in preventing and reducing creek plastic litter. Most of the creek litter from the litter samples was plastics which varied in types, quantities and recyclability. The differences of methodology in sorting plastic litter made the comparisons among literature more difficult. Furthermore, the source of litter is related to the local environments and occupying frequency of the creek.

Protections: regulations, environmental stewardship and corporations

There were many authorities that were responsible for the creek protection and a few legislations targeting creek pollution. However, few of the government agencies were set up for litter control, especially for plastic litter which made up the major portion of creek litter. The Federal Clean Water Act covered many perspectives regarding water pollution and the one section, sec. 1313(d), covered that each state needed to report the total maximum daily load (TMDLs) in the water quality management plans to control point-source and nonpoint-source pollution. The focus of the act was targeting chemicals such as pesticides and other toxic substances from home use, not on macroplastics. The EPA's NPDES discharge permit, under the act, also only focused on chemical discharge and targeted only point-source pollutants. The main purpose of the permit is to protect the water that enters the bay. It does not regulate the macroplastics in the creek, therefore the recycling programs are crucial in controlling plastic input. A way to increase the incentives of the residents to recycle plastics other than bottles is to give rewards for collecting other plastics. Given that a majority of creek litter was plastics, a regulation targeting creek plastic pollution should be established and implemented. Moreover, waste management such as for households and commercial areas, should also be responsible for the land-based, nonpoint-source plastic pollution. My findings align with Lahens et al. (2018) that land-based macroplastics in the river might be related to local habits and waste management.

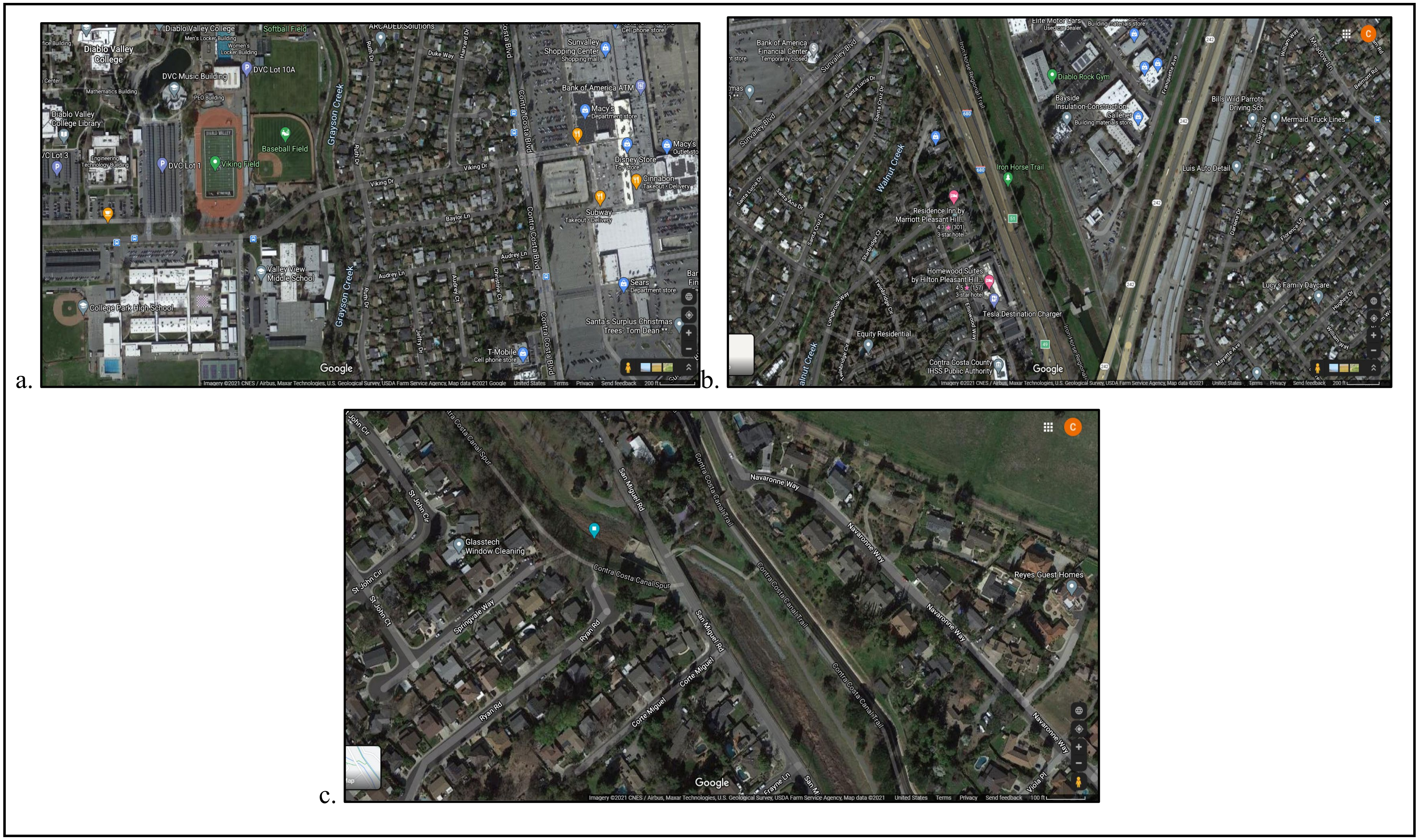

Figure 8. Three neighborhood maps extracted from Google Map, showing the surrounding structures at the study sections for each creek. (a) A neighborhood map extracted from Google Map, of the study section at Grayson Creek: Viking Dr. to Ruth Dr. (b) Walnut Creek: surrounded by Sun Valley Rd, Interstate Highway I-680 and California State Highway 242. (3) Pine Creek: San Miguel Rd to Contra Costa Canal Spur.

Stewardship by the community plays an important role in managing creek litter pollution. The volunteer clean-ups by FOTC are effective in reducing existing creek litter in a short time, but they are not preventing future litter from entering and they do not reduce the sources of litter. Since the Covid-19 pandemic, these activities were even paused and only the small-sized, family based and informal creek litter clean-ups continued. Lack of data regarding clean-ups is a limitation to my study as it is hard to gather all the formal and informal clean-up information at each creek because some of them are not recorded. Moreover, these organizations can continue promoting public education on household recycling programs and topics on plastic pollution in creeks and littering, as they can increase the incentives of residents to recycle plastics.

Corporations also play a role in managing creek plastic litter in many ways. For example, the companies can research and improve the product sustainability and biodegradability, reduce the package use of a product and they also have a great impact on consumer behavior towards a more sustainable product. An example is that sanitary products which were found in the river should be improved in biodegradability by the manufacturers (Morritt et al. 2014). These corporations can collaborate with local communities and city or county agencies to promote public awareness.

Creek litter and plastic litter

Plastic litter is the major component of creek litter (Morritt et al. 2014) and it varies in types and the recyclability, resulting in a difficulty to sort them and properly recycle or dispose them. My finding in the diversity of plastic creek litter supports the trend of global plastic production: multi-functional products with diverse properties and chemical structures (PlasticEurope, 2018 and Lahens et al. 2018). Because of its light-weight properties, a reasonable amount of plastic creek litter eventually enters the ocean. Unlike non-plastic litter which are mostly single-materialed, recyclable, compostable or having convenient access to proper disposal, many of the plastic litter are not recyclable, such as styrofoam, or in a recyclable state, such as being polluted and uncleaned. Interestingly, my results did not find a lot of plastic bags, similar to the findings of Morritt et al. (2014), which observed plastic bags of less than 2% in the total litter. However, due to the limitations of my study site numbers, my data may be subjective and not comprehensive. One possible alternative hypothesis is that the litter in the water of the creek has a different component from that at the bank, as the medium for the litter is different. Data from more sites would have a more comparable and averaged result that could better align with previous studies.

In the plastic litter composition of my study, I found that packages, films and styrofoam made up the majority of the litter (Figure 6). Previous studies have used different categories for plastic litter and these may affect the comparisons among studies (Guerrantti et al. 2017, Morritt et al. 2014, Carpenter & Wolveton, 2017, and Lahens et al. 2017). A standardization of plastic litter categories for research is needed urgently so that scientists can use the information gathered from different regions more accurately and develop solutions more effectively. Moreover, my study did not cover microplastic litter in the creek which may be the result from the decomposition of macroplastics. This type of plastic litter may be more in quantities than macroplastics (Blettler et al. 2018) and targeting the reduction of macroplastics may help reduce the microplastic quantities. Additionally, shifting the focus of current studies from microplastics to macroplastic litter in the creek can contribute to reducing microplastic litter, as the field is focusing on microplastic studies (Blettler et al. 2018).

Sources of Litter

Based on the litter types and quantities from the site collections, I determined that creek litter may come from two types of sources: environmental and human inputs. Environmental inputs include litter brought by the impact of weather or from the water discharge pipes. Human inputs include littering by visitors and homelesses, illegal dumping and sports items accidentally flown out from sports fields. This aligned with the previous studies that analyzed creek litter using these two categories (Carpenter and Wolveton, 2017) and my findings agree with the previous studies that litter could reflect the possible sources of litter from the structures or buildings nearby.

The different types of creek litter can also reflect on how they enter the creek area. For example, littering by visitors or from residential households nearby is one source of litter. My findings on the relationship between the creek litter type and the way litter enters the creek supports a previous study which found that the land-based macroplastic stream litter may be related to local habits and waste management (Lahens et al. 2018). This is also shown my results that compare the sources of litter at Walnut Creek and Pine Creek. At Walnut Creek, litter is more easily left in the creek environment as homelesses lack of proper litter disposal facilities. Comparingly, at Pine Creek, the major sources of litter are illegal dumping without witnesses and littering by walkers. The differences between sources of litter at two creeks reflect the relationship of creek litter with local environments. Additionally, the environmental and human inputs could intertwine as some litter could be from either one or both sources. For example, a person drops a styrofoam cup at the roadside and the cup may be brought to the creek through rain or wind. Moreover, from my litter collection and observation, I suspect that human activity has a great impact on the litter quantity in creeks: the study section at Walnut Creek had more litter than Grayson Creek and at Walnut Creek there were many homelesses taking temporary shelters while at Grayson Creek, lesser human activity was observed. This finding supports the previous studies that a central factor of macroplastic accumulation in urban shorelines is human activity with the influence of environmental factors (Dalu et al., 2019). A reason why my results agree with these literatures was because we all studied in similar urban creek environments.

A difference of my study from some other previous studies was that I observed that the creek encampment was a major source of litter in many of the urban creeks. Many homelesses are common in California and other major cities in the United States. The homelessness issue is another study direction on litter by encampment and it is a multidisciplinary problem that we must address in order to prevent or reduce creek litter. The people living in such a harsh environment have something more important and critical to deal with in life than daily garbage. I feel like solving homelessness issues should be starting from the roots and all parts in the process, but my study has a limitation on discussing this further.

My study did not discuss in detail the impacts of creek litter on wildlife which use or habitat in the creek environment, but through observations. I observed ducks, waterbirds and geese feed by catching organisms from the creek. During feeding they could possibly ingest litter including micro-plastics which could be in the sediment and they may ingest it when they dig into the water and catch something which looks like fish or shrimp. Birds may also be entangled in plastic films or bags. Some plastics may be excreted from their bodies through feces, but some could be passed along the food chain through bioaccumulation. It is a necessity to take action and needs immediate attention from the public, related authorities and parties. Another unexpected view and alternative hypothesis would be that one more source of the litter may be the ones that are flown from the upper streams.

Relationships between neighborhood and creek litter

There is a relationship between the neighborhood, the structures nearby and the creek litter. It affects the quantity and types of litter. This relationship is less frequently discussed in previous studies and no significant influence has been found between household density and macroplastic abundance (Dalu et al., 2019), making this issue a future direction to manage creek litter and a way to improve effective regulations based on what structures are nearby. My results did not reflect on the impact of household density on macroplastic quantity, but there remains a possible relationship for the creek litter with the influence from commercial areas, schools and creek users. An alternative hypothesis would be that there is no relationship between the neighborhood and the creek litter; instead, the environmental input has a major impact on creek litter such as litter brought by rain, which causes urban runoff to the creek. Furthermore, another alternative hypothesis is that the distance between the households or any structures nearby and the creek inversely affects the creek litter quantity (Lee et al., 2015).

Limitations

Due to the scope of an individual field survey and impacts by Covid-19 restrictions, there are a few limitations in this study. For example, the study did not cover the litter comparison during different seasons and temperatures as the weather and water level of the creek may play an important role in creek litter characteristics. A previous study compares the litter quantity during cool-dry and warm-dry seasons and finds a slightly different difference in between (Dalu et al. 2019). Other studies argue that temperature is a critical factor which determines the period in which an area is utilized for recreational purposes and therefore more litter may appear in this time (Brandenburg and Arnberger, 2001 and Dalu et al., 2019). Further studies on urban creek litter in California may also consider these factors to make a more comprehensive analysis.

Moreover, my study does not discuss the macroplastics based on the materials that they are made of, such as polyethylene, polypropylene and polystyrene. Tracing back the manufacturing of what lately becomes litter is a way to solve the problem at the root. Furthermore, the study does not cover microplastics or creek litter in the water body. Instead, I focused on the macroplastics at the bank of the creek, and the other two aspects should also be studied in further research.

Additionally, this study has a short litter collection period and does not cover all the creeks in the Bay Area in California, resulting in my study being possibly biased and subjective due to the limited numbers of study sections and collection times. Further studies on looking at more than three local creeks in the Bay Area and having a longer collection period may have collected more data to perform testing, such as Kruskal-Wallis analysis, to identify the significance of the data which could make a more comprehensive analysis on the results. Furthermore, due to the Covid influences, this individual research was less likely to join the volunteer efforts to deeply study what is really inside the creek.

Further Directions

Based on the findings of my study, I suggest a few approaches for further research. One direction would be to calculate the rate of land-based plastic debris entering the creek by the number of residents (Lahens et al. 2018). Through comparing the daily rate of plastic debris entering the creek per resident at each creek, regulations regarding the land-based litter could be improved on this focus and public education programs could establish a focus on the residential area litter and local environmental stewardship. Furthermore, a standardization of methodology on plastic litter categorization should be developed, structured and applied by future researchers. Comparing the previous studies on urban creek litter, different methods were used with different focuses and therefore it is difficult to make a comparison with accuracy and the right focus. They do not give a consistent method which could be referred to during my field study. Here I suggest that a standardization of methodology should be developed for each way of sorting plastic litter, such as according to the recyclability (the resin code of each type of plastics) and the use of plastics.

Another way to further study urban creek plastic litter is to investigate the impact of macroplastic content on microplastic contamination through the assumed fragmentation and degradation (Lahens et al., 2018) and the freshwater environment as a medium for plastics to enter the marine environment. Previous studies clearly show a dominance of marine studies on plastic interactions with wildlife compared to freshwater and a dominance of microplastic studies over macroplastics in the freshwater environment (Blettler and Wantzen, 2019), resulting in lack of attention on macroplastic litter which could be reduced in the first place to minimize fragmentation and degradation. Furthermore, if macroplastic litter is controlled from entering the river, there will be less microplastics and this will reduce the cost of cleaning and researching the microplastic litter, which are shown in previous studies to be highly concentrated in the freshwater environment (Lahens et al., 2018). The gradual fragmentation of macroplastics generates microplastics which ultimately find their way into the bodies of wildlife organisms (Morritt et al., 2014, Browne et al., 2008, Murray and Cowie, 2011, Lusher et al., 2013). One more direction of future study is to look at the impact of water flow at different times on the plastic contamination levels (Guerrantti et al., 2017). The impact of water flow was discussed by previous studies and further discussions could be made when researching urban creeks in the Bay Area, California. Furthermore, future research can include more sections of the same creek to make a comparison within the creek and understand more deeply the sources of litter.

Conclusion

In the freshwater studies, there remains a lack of enough macroplastic studies and field-data on plastic contamination especially macroplastics (Blettler and Wantzen, 2019). Therefore, a need to deep dive on this topic is urgent and this could largely reduce one source of marine plastic litter and reduce the impact of plastic contamination on freshwater wildlife animals. Protecting the creek environment does not rely on legislations and regulations, and the environmental stewardship from the community and the corporate efforts also can make a huge impact on raising the awareness and taking actions on reducing plastic contamination. Through cooperating among each stakeholder and conducting further research on plastic litter, a more effective way of reducing plastic contamination in creeks could be achieved and this would encourage more parties to get involved in creek protection.

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APPENDIX: Raw Data Sheet

	January 21, 2021, Thursday		Site: Grayson Creek		
	Total Counts	Sub-division 1	Sub-division 2	Sub-division 3	
Plastics					
bottles (#1)	3	3	NA	NA	
packages	17	4	11	2	
labels	0	NA	NA	NA	
films	14	5	6	3	
beverage & lid & straw	3	NA	3	NA	
food containers & utensils	0	NA	NA	NA	
Styrofoam (#7, Polystyrene)	19	NA	19	NA	
tape	1	NA	1	NA	
miscellenous (hard debris, button)	15	4	11	NA	
Non-plastics					
Glass	NA	NA	NA	NA	
Metal	5	3	2	NA	
Paper	7	5	2	NA	
Cloth	3	2	NA	1	
Others (battery, ceramics, tire debris)	12	3	7	2	
	Total Counts	Sub-division 1	Sub-division 2	Sub-division 3	Mean counts
Total Plastics	72	16	51	5	24
Total Non-plastics	27	13	11	3	9
Total counts	99	29	62	8	33

	February 19, 2021, Friday		Site: Walnut Creek		
	Total Counts	Sub-division 1	Sub-division 2	Sub-division 3	
Plastics					
bottles (#1)	3	1	1	1	
packages	26	17	9	NA	
labels	1	NA	NA	1	
films	27	9	18	NA	
beverage & lid & straw	3	NA	NA	3	
food containers & utensils	1	NA	NA	1	
Styrofoam (#7, Polystyrene)	11	1	8	2	
tape	6	NA	6	NA	
miscellenous (hard debris, button)	7	3	3	1	
Non-plastics					
Glass	NA	NA	NA	NA	
Metal	6	2	4	NA	
Paper	10	3	3	4	
Cloth	NA	NA	NA	NA	
Others (battery, ceramics, tire debris)	6	4	1	1	
	Total Counts	Sub-division 1	Sub-division 2	Sub-division 3	Mean counts
Total Plastics	85	31	45	9	28.3
Total Non-plastics	22	9	8	5	7.3
Total counts	107	40	53	14	35.7

	March 10, 2021, Wednesday		Grayson Creek		
	Total Counts	Sub-division 1	Sub-division 2	Sub-division 3	
Plastics					
bottles (#1)	2	1	1	NA	
packages	17	7	9	1	
labels	2	NA	2	NA	
films	4	3	1	NA	
beverage & lid & straw	4	1	2	1	
food containers & utensils	0	NA	NA	NA	
Styrofoam (#7, Polystyrene)	13	2	9	2	
tape	1	1	NA	NA	
miscellenous (hard debris, button)	13	6	4	3	
Non-plastics					
Glass	NA	NA	NA	NA	
Metal	3	1	1	1	
Paper	11	5	4	2	
Cloth	NA	NA	NA	NA	
Others (battery, ceramics, tire debris)	3	1	2	NA	
	Total Counts	Sub-division 1	Sub-division 2	Sub-division 3	Mean counts
Total Plastics	56	21	28	7	18.7
Total Non-plastics	17	7	7	3	5.7
Total counts	73	28	35	10	24.3

Sampling Dates	Average Total Litter (Count)	Average Total Plastic Litter (Count)	
Grayson Creek, 1/21/2021	33	24	
Walnut Creek, 2/19/2021	35.7	28.3	
Grayson Creek, 3/10/2021	24.3	18.7	
	31.0	23.7	76.34%
	Average Total in counts	Average Total in counts	Percentage of plastic litter over total litter

Figure 9. The raw data sheet with calculations on total counts and percentages on Excel. I sorted the litter into plastic litter and non-plastic litter and calculated the total counts for each sub-division at each collection. I then calculated the average of total litter and plastic litter among the three subdivisions. In the table at the bottom, I calculated the percentage of plastic litter over the average total litter from the three sample collections.