Chemical and Biological Health Assessment of Urban Streams in the Richmond and San Francisco Bay Area

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ABSTRACT

Urban streams' importance is typically overlooked as they are mostly seen by the average person as a commodity that exists to beautify an urban community. Yet, they are also beneficial in reducing the impacts from flash flooding due to heavy rain storms and reducing contaminants through dilution. I studied three creeks located within very active urban neighborhoods, and all have undergone or are currently undergoing some form of restoration effort. This study examined the water chemistry and benthic macroinvertebrate assemblages of each of the three creeks over a period of two months to assess water quality. Although each creek was visibly different, water chemistry analyses revealed that they did not vary much chemically. ANOVA tests demonstrated insignificant ($p>0.05$) differences in terms of water chemistry and most benthic macroinvertebrate community structure metrics between all three sites. Using Strawberry Creek as a reference site on the UC Berkeley campus, the two off-campus sites exhibited differences such as lower diversity and EPT presence than the reference site, and phosphate levels being near or slightly below the EPA standards for preventing algal blooms in flowing waters. The literature revealed that further studies in chemical analyses and emphasis on community function rather than structure could potentially provide clearer results of urban stream health.

KEYWORDS

Benthic macroinvertebrates, Water chemistry, EPT, rainfall, urban streams

INTRODUCTION

Urban streams are characterized by their proximity to and impacts deriving from urban communities. Due to their proximity to urban environments, these streams are more likely to experience runoff from their surroundings, either directly from washing effects of fertilizer, oil, pesticides, or other pollutants, caused by rain or stormwater runoff, or from sewer systems that introduce organic anthropogenic waste from from homes and other building (Liu et al. 2014, US EPA 2015d). Runoff effects are especially problematic in urban environments due to the coverage of land by impervious materials. These impervious surfaces include roads, parking lots, and different types of compacted soils, all of which trap and release contaminants during the production of these surfaces, with streams acting as conduits for these contaminants (US EPA 2015c). These contaminants are detrimental to wildlife that use streams for both habitats and as a resource, and for those who use them for recreation (Netusil et al. 2014, Bai et al. 2018).

Water chemistry tests can provide a snapshot of water quality and can be conducted on-site or in a laboratory setting if samples are properly stored. Along with this, chemical levels determined from these tests can easily be compared to safety regulations suggested by the EPA for both drinking water and for the health of the ecosystems themselves (US EPA 2015a, 2015b). For example, eutrophication, the excess growth of plant material in aquatic systems, is an increasingly frequent threat to freshwater ecosystems, mainly due to two organic nutrients nitrate and phosphate that fuel this growth of plant material, with phosphate being the key limiting nutrient in these systems (Correll 1998, Hornung 1999, Bernes et al. 2013). Because these nutrients can be found in fertilizers specifically, urbanization has led to a great influx of them in our urban waterways from lawns and other activities where nutrients are added to landscape (Hodgkin and Hamilton 1993). However, these chemicals are not necessarily telling of the whole picture. Variables such as change over seasons, equipment availability/costs, practicality, and fluctuations from rain events all create difficulties in the accuracy of assessing water quality in streams (Walling and Foster 1975, Lowe and Pan 1996, Resources n.d.). Thus, other assessment methods must be used to capture a better understanding of water quality, and this may come in the form of biomonitoring.

Benthic macroinvertebrates have long been used as biomonitoring organisms because taxa have varying sensitivity ties to pollution and relatively long-lived aquatic life stages that can show longer-term responses to pollution. Disturbances in their habitats from human activities are usually reflected in their community structure, specifically in regard to abundance of highly sensitive taxa in the insect Orders of Ephemeroptera, Plecoptera, and Trichoptera (EPT). For instance, a more homogenous community of invertebrates, especially those with higher tolerance for pollution, would indicate poorer water quality, and is actually correlated with urbanized sites (Bourassa et al. 2017). Conversely, low abundance of EPT would also indicate poor water quality due these orders having a low tolerance to pollution in comparison to others (Ab Hamid and Md Rawi 2017). Their simple sampling method also makes them an easy and ideal organism to study the health of their site in the lab.In addition, their limited mobility allows us to study these anthropogenic effects as they impact the invertebrates over time (US EPA 2013).

This study aims to focus on water chemistry and benthic macroinvertebrates to assess water quality of three urban streams in the Bay Area: Wildcat Creek, Codornices Creek, and Strawberry Creek. This study was conducted during a particularly rainy season in the East Bay of the San Francisco Bay Area. To perform this assessment, I asked 1) how the water chemistry differs between the three sites, and are there any significant differences, and 2) how the community structure of benthic macroinvertebrates differs between the three sites according to various community metrics.

METHODS

Study Site

This study examines three sites: Wildcat Creek, Codornices Creek, and Strawberry Creek. These sites were selected because of the presence of continuous stream monitoring from Balance Hydrologics. Below is a map depicting where they are located in relation to each other.

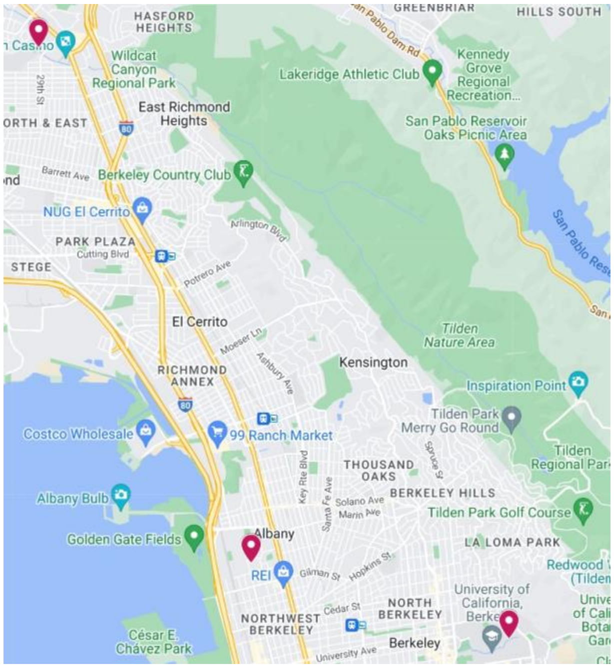

Figure 1 Map depicting the three sites. On the top left corner is Wildcat Creek; on the bottom left corner is Codornices Creek; and on the bottom right corner is Strawberry Creek

The section of Wildcat Creek studied is in Richmond, CA, and it debauches to the San Pablo Strait (SFEI, 2018). This site lies between the Brookside San Pablo Health Center and the Salesian College Preparatory School, at the intersection of Vale Road (37° 57' 13.8708"N, 122° 20' 20.904"W). This section of Wildcat Creek had been abandoned for a long time, but it recently underwent a restoration project in 2021, with the goal of creating refuge for fish, increasing support for larger flow volumes, widening the creek corridor, and planting native species along the bank (Project 2021). Prior to its restoration, the creek's proximity to dense urbanization resulted in heavy pollution, inaccessibility, and increased frequency of flooding (Project 2021). Despite its recent restoration, this site had the heaviest visible anthropogenic influence, with debris such as clothing, trash, metal bars, glass, and pillows present throughout the study period. Along with this, storm drains emptying water into the creek deposited oil-like substances mixed with the water. There is also a bike trail that runs parallel to the creek on which people and pets frequently walk through. There are multiple parking lots and other impervious surfaces in its vicinity, as well as lots of homes surrounding the site. The site contains very scarce amounts of riparian vegetation on the parking lot side of the bank, but canopy cover on the cemetery side was high. The channel was widest in the study (~2-3 meters in most areas) waters appeared murky during each visit, especially after rainfall events, and contained only a few riffles.

The section of Codornices Creek studied was located in Albany, CA. Codornices Creek debauches to the San Francisco Bay (\uc0\u8220{}Codornices Creek, West Albany Hill, and Gilman Street Watersheds | Alameda County Flood Control District\uc0\u8221{}, 2023). This site was located behind the University Village in Albany (37° 52' 56.9598"N, -122° 18' 6.771"W). It is situated between the village and several establishments, ranging from bars, to an auto repair shop, and even a community farm. A bike trail runs parallel to the creek. There is also a small community of unhoused people living approximately one block away from the creek. I was unable to confirm if people from the community interacted with the creek frequently. Codornices Creek has had continual restoration work performed on it beginning in 1999, and has since had its flora replaced with native plants based on the Memorandum of Understanding (“Codornices Creek | City of Albany, CA” n.d., “Codornices Creek, West Albany Hill, and Gilman Street Watersheds | Alameda County Flood Control District” n.d.). Established in 2004, the memorandum had the aim of implementing improvement and maintenance practices along the creek (“Codornices Creek | City of Albany, CA” n.d.). This site had lots of riparian vegetation on both sides of the bank and canopy coverage along the stretch of the creek studied. There were also ducks and a variety of birds present at the site. This channel was the narrowest of the sites examined (~1.5m), was the clearest during each visit and contained many riffles.

The section of Strawberry Creek studied flows through the University of California, Berkeley campus, near Faculty Glade. Strawberry Creek also empties out into the San Francisco Bay (“Strawberry Creek and Schoolhouse Creek Watersheds | Alameda County Flood Control District” n.d.). This site flows adjacent to the Faculty Glade of the UC Berkeley campus (37° 52' 19.1172"N, -122° 15' 23.8134"W). This site contained many boulders along the bank, as well as exposed roots, lots of small bushes, riparian vegetation, and canopy coverage along its banks. The water is clear and the site contains many riffles in addition to a high amount of concrete and structures to constrain the stream. There is also a concrete bridge perpendicularly above it on which people cross very frequently throughout the day, every day. Although there is a heavy presence of people around the creek, there are very few, if any, direct interactions between people and the stream water on a daily basis. Most interactions occur from nearby buildings. Along with the already scarce direct anthropogenic influences, there is also constant reports and maintenance on the creek due to the 1987 Strawberry Creek Management Plan, which improved the overall water quality in the creek, allowing for native fish species to return (Hans et al. 2008). It is for this reason that Strawberry Creek was chosen as the reference site for this study.

Data Collection

Sampling Dates

I collected water and benthic macroinvertebrate samples biweekly between the end of January and the end of March at each of the three sites. I began sampling on January 29, 2023 at Wildcat Creek and Codornices Creek, but sampling at Strawberry Creek began on January 31, 2023. I sampled Strawberry Creek on a separate day due to its further proximity from the other two creeks. From then, I sampled every subsequent two weeks as follows: 02-12-2023, 02-25-2023, and 03-25-2023 for Wildcat Creek and Codornices; 02-16-2023, 03-02-2023, and 03-23-25 for Strawberry Creek. There was an absence of sampling for the two subsequent weeks following the 02-25-2023 to 03-02-2023 sampling week due to harsh weather conditions that made sampling dangerous. This resulted in the final sampling dates being separated from the aforementioned sampling week by three weeks rather than two.

Water Chemistry

One of the most important indicators for the water quality of urban streams is the chemical composition of the water. In this study, I tested the water chemistry for nitrate-N and orthophosphates, alkalinity, copper, zinc, total residual chlorine (TRC), pH, and turbidity. I monitored the levels of each using various techniques.

To perform these measurements, I first collected two 50mL water samples from each sampling site into falcon-style centrifuge tubes at each study site. I collected these water samples prior to any macroinvertebrate sampling. I used a LaMotte Nitrate & Phosphate in Water test kit (3119-01), an Alkalinity test kit (4491-DR-01), a Copper test kit (6616-01), and a Zinc test kit (7391-02) to measure the concentration of these chemicals in the water. The sensitivity for both Nitrate and Phosphate is 0.2, 0.4, 0.6, 0.8, and 1.0 ppm; the alkalinity test used a direct reading titrator with a range of 200 ppm, though it could make larger readings by adding more Alkalinity Titration B; the range for the copper test kit is 0, 0.05, 0.10, 0.15, 0.20, 0.30, 0.40, and 0.50 ppm; and the range for zinc is 0, 1, 2, 3, 4, 6, 8, and 10 ppm. To determine the pH, I placed Hach pH test strips into the samples for two minutes and compared the strip to the reference provided on the container. Finally, I used a Storm Drain Kit (7446-01) to measure the levels of TRC and the turbidity of the sample. The range of readings for TRC is 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, and 3.0 ppm; and turbidity was measured on a scale of Low, Med, High.

Benthic Macroinvertebrates

To measure the water quality in the streams, I studied benthic macroinvertebrates, known biomonitoring organisms that have a range of pollution tolerance depending on their order. Ephemeroptera, Plecoptera, and Trichoptera are the three orders that make up the EPT Index, a biomonitoring tool devised to determine water quality due to their low pollution tolerance, and their presence in the creeks were the main factor in determining water health in my study. I collected macroinvertebrates at two sample sites within each study site (i.e., Wildcat Creek, Codornices Creek, and Strawberry Creek). I collected samples at a downstream location first and then moved approximately 5-10 meters upstream to take the second sample, using the same procedure for all three sites. This order of collection ensured that the first sample taken would not interfere with the second sample due to debris moving downstream, consequently disturbing the invertebrates before sampling commenced. This work was conducted with Dr. Patina Mendez (University of California, Berkeley).

To sample benthic macroinvertebrates, I wore water-proof boots to enter the creek. I used a sample dish to collect water from the creek that I later used to rinse out the sample. I placed a 500-micron mesh net approximately one foot downstream of myself to collect the invertebrates, as well as any debris that flowed into it. I set a timer for one and a half minutes, during which I disturbed the sediment by vigorously kicking around with my feet. After the time passed, I lifted the mesh net out from the creek, making sure to pull it toward myself to avoid anything falling out. The samples usually consisted of sediment, woody debris, plant material, and the invertebrates. I turned the net inside out over the dish containing the creek water, and rinsed it out with that water by hand. After the sediment in the dish settled, I made careful observation of movement or small invertebrates in the dish. I ran the sample through a 500-micron sieve, which I then rinsed with 95% ethanol, using a squirt bottle, into a Ziploc bag for preservation. I later transferred the samples to a container with a solution of 70% ethanol for further preservation. There is the possibility that creek water would dilute the 95% ethanol solution, so draining the bags of this solution and adding an undiluted 70% ethanol solution ensured proper preservation. Once taken to the lab, I sorted the macroinvertebrates from the debris. Once sorted, I identified them based on classifications from *An Introduction to the Aquatic Insects of North America* (Merritt et al. 2009) and sorted them to their family level.

Data Analysis

Water Chemistry

I performed One Way ANOVA tests for each water chemistry metric to determine if there were statistically significant differences ($p < 0.05$) between the water chemistry ppm levels of the three sites. As with the benthic macroinvertebrate analysis, if there was a statistically significant difference, I proceeded with the Bonferroni method to perform a post hoc test to determine the impactful site for these water chemistry metrics. I also analyzed the water chemistry of the sites by graphing each metric across time for all three sites.

Benthic Macroinvertebrates

I performed calculations to determine and record the richness (and EPT richness) and abundance of each family, the % Contribution of the Dominant Taxon, % EPT Abundance, and the Ratio of EPT to EPT + Chironomidae Abundance from each sampling site. I created graphs of these metrics for visualization purposes. I plotted the rain events that occurred throughout my study period on the same graphs to visualize the effect that they had on these metrics.

I performed One Way ANOVA Tests for each of these metrics to determine if there was a statistically significant difference ($p < 0.05$) between the three sites. If there was a statistically significant difference, I proceeded with the Bonferroni method of a two sample t-test assuming equal variances to perform a post hoc test to determine the impactful site. However, even if there was no statistically significant difference between all three creeks, I used the same method to determine if there were any differences between any two creeks.

I performed a non-metric multidimensional scaling (NMDS) to determine if there are any patterns in the distributions between the three sites. This analysis was conducted using the vegan package in RStudio for a 2-axis solution and correlated species scores with the resulting NMDS axes (Oksanen et al. 2022, “Posit” n.d.).

Richness was determined by identifying the total number of taxa in the sample, and EPT richness was determined in this same manner but only considering Ephemeroptera, Plecoptera, and Trichoptera. Abundance was determined by summing the total number of invertebrates in each sample. The % Contribution of the Dominant Taxon, the % EPT Abundance, and the Ratio of EPT to EPT + Chironomidae Abundance were determined using the following equations:

$$\%\ \textit{Contribution Dominant Taxon} = \frac{Total\ \#\ individuals\ in\ the\ dominant\ taxon}{Total\ \#\ individuals\ in\ the\ sample}$$

$$\%\ \textit{EPT Abundance} = \frac{Total\ \#\ EPT\ individuals}{Total\ \#\ of\ individuals\ in\ the\ sample}$$

$$\textit{Ratio EPT \& C} = \frac{Total\ \#\ EPT\ individuals}{Total\ \#\ EPT\ individuals + Total\ \#\ Chironomidae\ individuals}$$

Metric calculations were based on the Disturbance Detectives - Biomonitoring Lab Handout for Students (Mendez et al. 2014).

RESULTS

Data Collection

In Table 1, I recorded and summarized the water sample metrics that I tested for. The majority of the water samples showed very little, if any, presence of the chemicals tested for. Specifically, copper, zinc, and TRC had values of 0 ppm for each site throughout the entire study period, with the exception being one reading of 0.2 ppm for TRC at Wildcat Creek on 02/25/23. Thus, ANOVA tests were not performed on these metrics. In Table 2, I recorded the Benthic macroinvertebrate samples based on taxon identified abundance and tolerance value. Figure 2 shows the rainfall events and quantities for the past three years based on the gauges from Balance Hydrologics.

Table 1. Water chemistry metrics. Note: The values for (a) Alkalinity, (b) Copper, (c) Nitrate-N, (d) Orthophosphates, (e) Zinc, and (f) TRC are all measured and reported in ppm.

(a) Alkalinity

Date	Wildcat	Codornices	Strawberry
1/29/23	232	352	
1/31/23			172
2/12/23	200	288	
2/16/23			276
2/25/23	184	256	
3/02/23			200
3/23/23			184
3/25/23	204	360	

(b) Copper

Date	Wildcat	Codornices	Strawberry
1/29/23	0	0	
1/31/23			0
2/12/23	0	0	
2/16/23			0
2/25/23	0	0	
3/02/23			0
3/23/23			0
3/25/23	0	0	

(c) Nitrate-N

Date	Wildcat	Codornices	Strawberry
1/29/23	0.2	0.2	
1/31/23			0.2
2/12/23	0.2	0.2	
2/16/23			0
2/25/23	0.1	0.2	
3/02/23			0.2
3/23/23			0.2
3/25/23	0.1	0.2	

(d) Orthophosphates

Date	Wildcat	Codornices	Strawberry
1/29/23	0.2	0.2	
1/31/23			0.2
2/12/23	0.2	0.1	
2/16/23			0
2/25/23	0	0.1	
3/02/23			0.1
3/23/23			0
3/25/23	0	0	

(e) Zinc

Date	Wildcat	Codornices	Strawberry
1/29/23	0	0	
1/31/23			0
2/12/23	0	0	
2/16/23			0
2/25/23	0	0	
3/02/23			0
3/23/23			0
3/25/23	0	0	

(f) TRC

Date	Wildcat	Codornices	Strawberry
1/29/23	0	0	
1/31/23			0
2/12/23	0	0	
2/16/23			0
2/25/23	0.2	0	
3/02/23			0
3/23/23			0
3/25/23	0	0	

Table 1 (continued). Water chemistry metrics. Note: The values for (a) Alkalinity, (b) Copper, (c) Nitrate-N, (d) Orthophosphates, (e) Zinc, and (f) TRC are all measured and reported in ppm.

(g) pH

Date	Wildcat	Codornices	Strawberry
1/29/23	7	7	
1/31/23			8
2/12/23	7	7	
2/16/23			7
2/25/23	7	7	
3/02/23			7
3/23/23			7
3/25/23	7	7	

(h) Turbidity

Date	Wildcat	Codornices	Strawberry
1/29/23	Low	Low	
1/31/23			Low
2/12/23	Low	Low	
2/16/23			Low
2/25/23	Low	Low	
3/02/23			Low
3/23/23			Low
3/25/23	Low	Low	

Table 2. Identified benthic macroinvertebrate samples by site and date, including Order and Family. Values indicate macroinvertebrate abundance.

	WC				**CC**				**SC**			
Taxon	1/29/23	2/12/23	2/25/23	3/25/23	1/29/23	2/12/23	2/25/23	3/25/23	1/31/23	2/16/23	03/02/23	3/23/25
Acari					1		1	1	2			
Amphipoda				2	1		2					
Coleoptera Elimidae											1	
Collembola	1		1		3		1		1			
Copepoda					1							
Diptera Simuliidae		1	1		10					1		
Diptera Chironomidae	5	4	6		92	18	24	8	4	4	1	3
Diptera Stratiomyidae				1						1		
Ephemeroptera Baetidae					15	4	1	11	1	5		
Ephemeroptera Leptophlebiidae									1	4		
Hirundinea	2		15			5	2			2		1
Nematoda				1		3			1	1	5	
Nematomorpha			2				1	1				
Odonata Coenagrionidae					1	1	1	1	1			
Odonata Gomphidae										1		
Oligochaeta	15	9	20	2	67	21	69	43	3	4	2	2
Plecoptera Nemouridae					5		4			4		
Plecoptera Perlodidae	1					1						
Plecoptera Taeniopterygidae						2						
Trichoptera Lepidostomtidae										4		

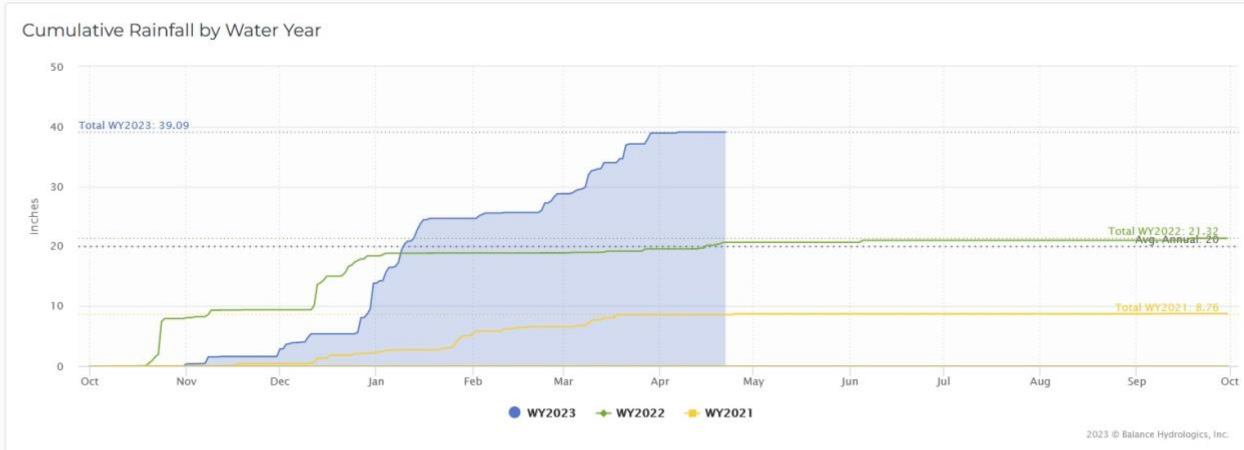

Figure 2. Total rainfall by water year for the Codornices Creek site at 10th Street in Albany for the past three years. During the same time period as the study period, for all three years, 2023 has the most cumulative rainfall.

Rainfall events produced a total of 58.87 cm of rain throughout the study period, including dates not sampled. Prior to the first sampling date, a heavy rain storm produced 26.87 cm of rain by its end date of 1/15/23; another rain event, ending on 2/05/23, produced 2.90 cm of rain prior to the second sampling date; a third rain even, ending on 2/24/23, produced 4.27 cm of rain prior to the third sampling date for Wildcat Creek and Codornices Creek, but another rain even, ending on 2/28/23, prior to the sampling date for Strawberry Creek produced 3.94 cm of rain; and a final rain event, ending on 3/21/23, prior to the final sampling dates, produced 7.39 cm of rain. Data for rainfall events and quantities was retrieved by the Balance Hydrologics gauge at Codornices Creek at 10th Street in Albany.

Water Chemistry Analysis

Nitrate-N and orthophosphate readings were also very low, but more detectable, so ANOVAs were performed, but yielded non-significant results of p=0.5 and p=0.92, respectively. Alkalinity levels, however, varied the most between the three sites, and the ANOVA test yielded a p-value of p=0.007, a statistically significant difference between the three sites. Moreover, the post hoc test showed that the site that was the most different from the other two was Codornices Creek. When compared to Wildcat Creek using the post hoc test, a p-value of p=0.007 was yielded; and when compared to Strawberry Creek, a p-value of p=0.021 was yielded.

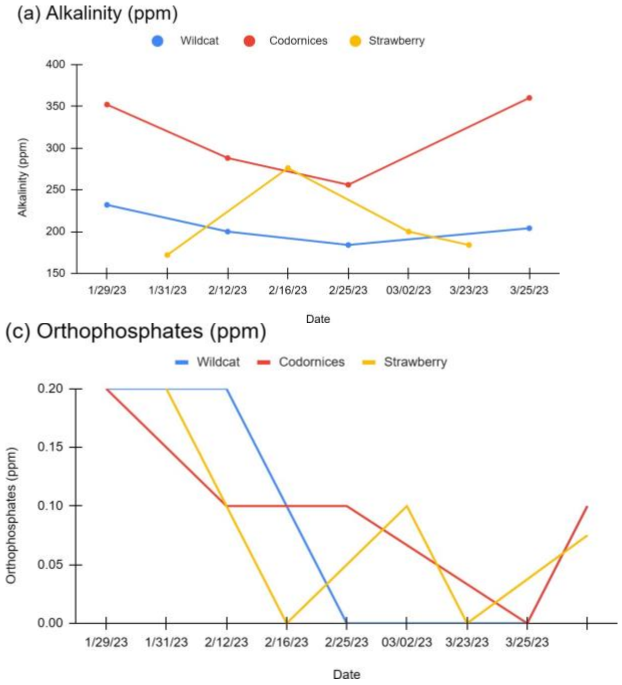

Figure 3. Water chemistry in the 3 urban steams. (a) Alkalinity, (b) nitrate-N, and (c) orthophosphates over the study period.

Benthic Macroinvertebrate Analysis

Benthic macroinvertebrate community abundance differed significantly among the three sites, with the one-way ANOVA test yielding a p-value of p=0.017. The site responsible for this statistically significant difference was Codornices Creek, with the Tukey's HSD post hoc test between Wildcat Creek and Codornices Creek yielding a p-value of p=0.048 and p=0.033 between Codornices Creek and Strawberry Creek. The remaining metrics, however, were not statistically significant between the three sites. Taxon richness, EPT richness, % contribution from dominant taxon, % EPT abundance, and the ratio of EPT to EPT + Chironomidae abundance had a p-value of p=0.13, p=0.12, p=0.45, p=0.37, and p=0.38, respectively, which are higher than the standard p-value of 0.05. While the Tukey's HSD post hoc test didn't show a significant difference between all three creeks, it did show significant differences between Wildcat Creek and Codornices creek for % EPT abundance, taxon richness, and EPT richness. There was a significant difference of p=0.038 for % EPT abundance; a significant difference of p=0.013 for taxon richness; and a significant difference of p=0.032 for EPT richness.

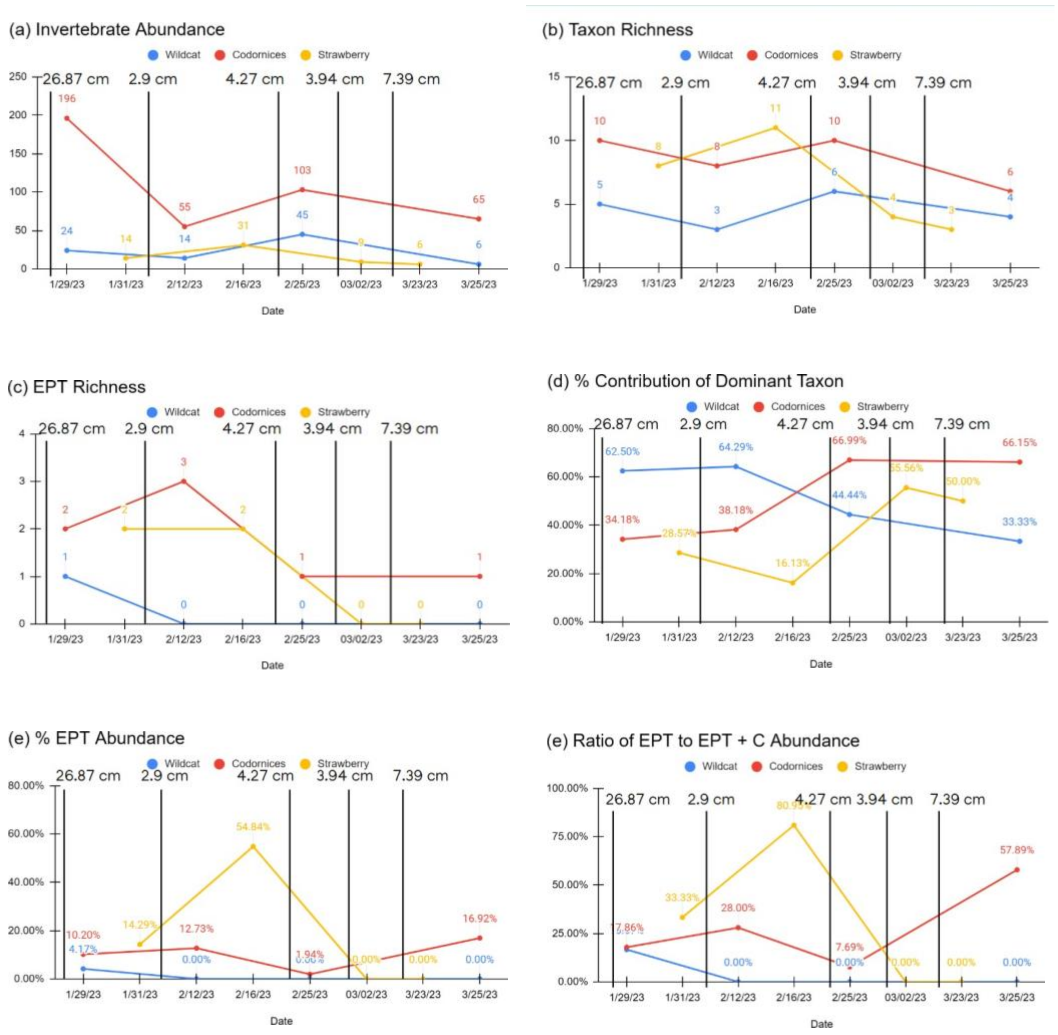

Figure 4. Community metrics determined for the three sites. Includes invertebrate abundance, taxon richness, EPT richness, % contribution of dominant taxon,% EPT abundance, and the ratio of EPT to EPT + C abundance. Vertical dark lines indicate rainfall events and the quantity of rainfall during these events.

Lastly, the NMDS analysis for the three sites showed that the community composition of Wildcat Creek and Codornices Creek was very similar, as seen by their overlap at the center of the ordination (Figure 2). However, Strawberry Creek was shown to be more variable in its composition, as shown by their spread across the figure. Significantly abundant organisms characterizing Strawberry Creek communities were Leptophlebiidae and Nematoda. Although Strawberry Creek was different from other creeks during most of the study, the community was more similar to the other streams during the 4th sampling period.

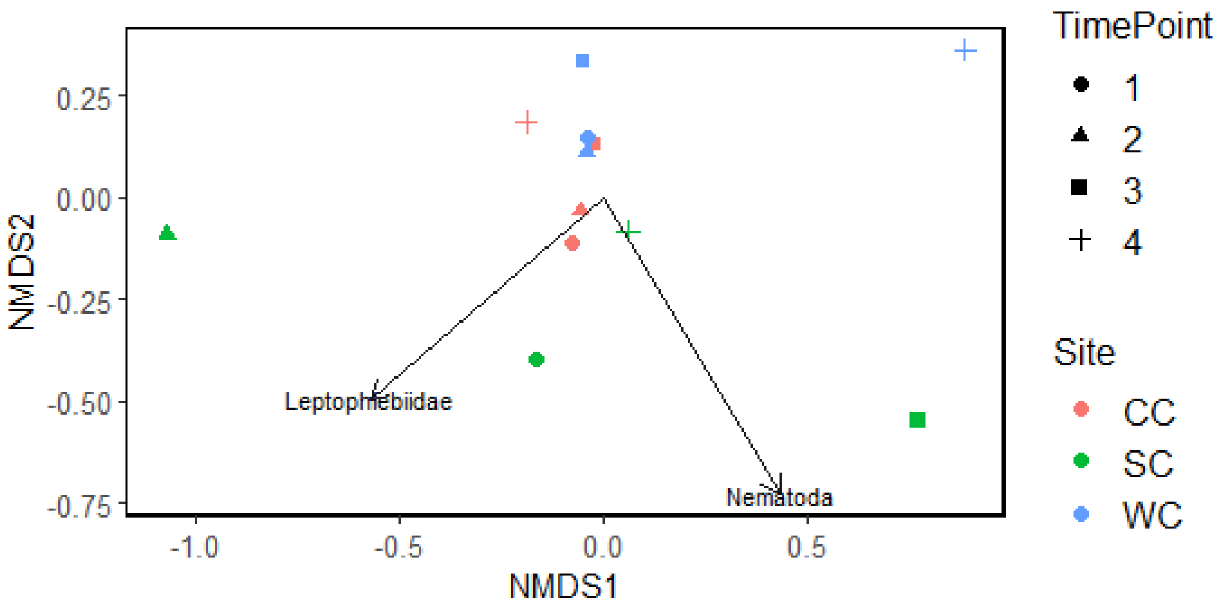

Figure 5. NMDS analysis of the three sites for all four time points.

DISCUSSION

The aim of this study was to assess the health of urban streams in the East Bay of the San Francisco Bay Area in terms of monitoring water chemistry and benthic macroinvertebrate communities. The main finding was based in the benthic macroinvertebrate communities, specifically in the Family Biotic Index (FBI) of the streams. Although Codornices Creek and Wildcat Creek exhibited higher quantities of macroinvertebrates, their FBI was much higher than Strawberry Creek, averaging 6.81 and 7.23, as opposed to Strawberry Creek's 5.51, with higher values indicating higher tolerance to pollution and vice versa. Strawberry Creek being the reference site, this indicates that the water quality of the other two streams is poorer. However, rain storms that occurred during this time may also have contributed to the differences in quantities, taxa present, and water chemistry during this study by increasing stream flow and having diluting effects on the streams. Further looking at both and the literature provides insight on the accuracy of these metrics during this study, especially during the rainy season.

Benthic Macroinvertebrates

Differences in benthic macroinvertebrate assemblages between the three sites suggest that, with the exception of a few community metrics, they are all very similar in their community structure. Though there was scarcely a difference between all three creeks throughout the study period, there were some differences between at least two of the creeks: Wildcat Creek and Codornices Creek. These streams demonstrated a difference in their % EPT abundance, taxon richness, and EPT richness levels, with Codornices Creek proving to have higher quantities for all of these metrics, implying that Wildcat Creek was more polluted during the study period. Overall, there was a statistically significant difference between the three creeks in terms of their abundance, with Codornices Creek being the dominant site, and while the % contribution of the dominant taxon of all three sites has no significant difference, the difference is in the type of taxon that was dominant. At Codornices Creek, the dominant taxon throughout the entire study period (at each sampling date) was oligochaeta, a taxon with a pollution tolerance value of 8/10; and the same is true for Wildcat Creek. Strawberry Creek, however, had more variance, and while it was also dominated by pollution tolerant taxa (e.g., diptera chironomidae - 6) for two of the sampling dates, it also included nematoda and ephemeroptera, both of which are pollution sensitive, and the latter of which is part of the EPT index for biomonitoring (Schenk et al. 2020). but it should also be noted that the majority of the invertebrates found at this site were pollutant tolerant. Figure 4 illustrates this dissimilarity from Wildcat Creek and Codornices Creek in community structure. Thus, it is clear that the two study sites, despite restoration efforts, require increasingly frequent maintenance to achieve comparable levels to stream benthic macroinvertebrate structure as the reference stream.

In regards to season, the rainy season is expected to decrease the density of benthic macroinvertebrates in terms of rainfall frequency and intensity, with intensity being a stronger driving factor for the decrease than frequency, and the downstream sites being impacted the most due to increased flow rate and sediment disturbance rate (Kim et al. 2018). The recent intense rainy season in the Bay Area, particularly at my study sites, accounted for more rain than the previous two years had received, according to gauges from the Balance Hydrologics group (Figure 5), which could explain the apparent low abundance of invertebrates at the sites.

While sorting through samples, I also found that there was a high presence of microplastics across all sites. Although I did not uses these in my health assessment of the streams, the increasing frequency of plastics in urban streams and other small freshwater ecosystems should be monitored due to the accumulation of these in invertebrates and other organisms in streams (Luo et al. 2019, Simmerman and Coleman Wasik 2020)

Water Chemistry

Water chemistry results do not reveal a very clear image of the water chemistry of the creeks. The most significant chemistry metric was alkalinity, which varied considerably between sites. Alkalinity levels were much higher for Codornices Creek (Figure 3) than the other two sites. Alkalinity's purpose is to buffer acids or bases in water, maintaining the pH of a body of water relatively safe (i.e. pH 7) until enough acid or base is added to create an impactful change, and the range of alkalinity safe for freshwater ecosystems is from 20-200 ppm ("[EnvirSci Inquiry] Lehigh River Watershed Explorations" n.d.). Although there were significant differences between sites for alkalinity during the study period, these differences likely did not affect the pH of streams as they fell well within the range of pH that allows for proper buffering of pH changes. In terms of the nutrients nitrate-N and orthophosphate, the only other two chemicals which demonstrated changes throughout the study period, no significant differences between the three sites was observed. While the observed nitrate levels, averaging 0.15-0.2 ppm for the three sites, are well within the threshold set by the EPA of 10 ppm, the orthophosphate levels, averaging 0.075-0.1 ppm, are at the verge of the threshold set by the EPA of 0.1 ppm for flowing waters to prevent eutrophication (US EPA 1986). Maintenance at these or lower levels is important because of orthophosphates being the limiting nutrient in the growth of algae, meaning that prolonged periods of slightly increased levels of orthophosphates could result in eutrophication at these sites (Schindler et al. 2016).

In the San Francisco East Bay Area, urbanization has begun to increase the risk for eutrophication. The East Bay Regional Park District leases a golf course in Tilden Regional Park which utilizes fertilizers and pesticides that are transported by surface runoff to streams around the area, including Wildcat Creek and Lake Anza, and has resulted in these areas having detectable levels of nitrates and phosphates that surpass the EPA threshold (Grande et al. 2019).

Due to the streams debauching to the San Francisco Bay, nutrient loading has increased, and though various factors, such as high suspended sediment concentrations, have prevented the Bay from experiencing eutrophication effects, the most effective measure to completely prevent these in the Bay is to reduce this nutrient loading (Looker 2022). Nutrient loading is especially high in the summer months, when algal blooms are more frequent, and since this study was conducted in winter and in a rainy season, the nutrients needed for these blooms are flushed throughout the streams (Grande et al. 2019, Wang et al. 2022).

The remaining tests (i.e. copper, zinc, TRC), yielded no detectable levels of contaminants, which indicates that they were not present at these sites during the study period. This is most likely due to rainfall occurrence in the Bay during the study period (Kus et al. 2010). However, physical observations of Wildcat Creek and Strawberry Creek indicate the presence of oil/oil-like substances and large amounts of foaming (e.g. capable of forming a small structure with collected debris), respectively. Thus, testing of other chemicals could return more conclusive results in regards to the chemicals affecting the sites' water quality. Rainfall has been shown to aid urban runoff in entering freshwater streams, thus, other chemical categories that are regulated by the EPA included bleach, salts, pesticides, and other metals (US EPA 2014, 2015d). Testing for these in these and other urban streams could provide key insights into the chemical composition of the streams, as well as the impacts that they have on the community structure of benthic macroinvertebrates. However, these may also suffer from the issue of non-detection if they're not measured during a certain mobilization period.

Limitations and Future Directions

In regards to benthic macroinvertebrates, there were factors that impacted my results, including sample size, season (rainy season), and temperature. My study was only conducted for about two and a half months, during which I only procured 8 samples from each site, 2 from each sampling date. The recorded 4 time points presented in this study resulted from aggregating the two samples collected during each visit into one due to within site conditions being relatively equal. Disregarding rainfall events and hazardous conditions, a sampling method more representative of the community structure of the creeks would be weekly rather than biweekly.

The temperature of the water also has a direct correlation with the density of the invertebrates due to the dissolved oxygen content in the waters (Bergey and Thorp 1981, Khani and Rajaee 2017). Although my study was conducted during the winter/spring season, which should be rich in dissolved oxygen, the abundance of invertebrates was low. Sample sizes could have played a part in this, but one last variable that probably impacted my results, as well as the efforts of biomonitoring with benthic macroinvertebrates, was the usage of community structure to gauge health. In rapidly changing streams, a more comprehensive method for evaluating stream health would be to determine and use community functions of the invertebrates (Brooks et al. 2002). Thus, future studies of urban creek health in the Bay Area should also include on invertebrate function rather than only community structure.

Another metric that could have added to my assessment could have been the implementation of benthic algae to better capture the health of the streams in terms of metal contaminants and eutrophication. While I did collect benthic algae samples, I had difficulties accessing proper equipment to conduct assessment based on these samples. Despite this, benthic algae are considered great biomonitors due to their varying degrees of tolerance to heavy metals based on their taxa, meaning that presence of high tolerance taxa is indicative of heavy metal contaminants and vice versa (Lavoie et al. 2012). Furthermore, their response to nutrients such as nitrates and phosphates provides a look into nutrient loading and possible algal blooms in these streams.

The health of urban streams requires a lot of work in regards to monitoring and restoration efforts. Many monitoring methods must be implemented together to capture an accurate picture of stream health. Future monitoring methods to include in these assessments include benthic algae community diversity and abundance, as well as the effects of microplastics on the organisms in the streams. Along with this, neglect from urban communities has increased the importance of restoration efforts to restore and maintain the water quality of these streams, with some metrics being benthic macroinvertebrate community structure and water chemistry assessment (Brooks et al. 2002, Harman 2018).

Conclusion

Studying the health of urban streams in the Richmond and Berkeley Bay Area demonstrated the direct impact that urbanization has on nearby ecosystems. Despite restoration efforts, benthic macroinvertebrate communities have been revealed to be quite homogenous in terms of pollution tolerant species at all three sites, demonstrating the importance of species richness in water quality. However, past studies revealed that the rainy season's intensity can reduce both the richness and abundance of invertebrates in streams richness, so the effect of rainstorms on richness must be accounted for to accurately assess stream health (Kim et al. 2018). Low water chemistry metrics during the study period demonstrate the need to test other water quality metrics, especially during the rainy season, when other anthropogenic pollutants are washed into freshwater systems. Finally, future studies into urban stream health could investigate the effects of nutrient loading at these sites, as well as microplastic accumulation.

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