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Article

The relationship between macroinvertebrates, water quality, and the health of Stevens Creek

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SUMMARY

Stevens Creek, which flows through Santa Clara County in California, provides a crucial habitat for federally designated threatened steelhead trout, with a portion of the trout's diet being dependent on the presence and abundance of macroinvertebrates that inhabit the creek. This led to the formation of our research question: how the water chemistry within the creek was associated with the abundance and diversity of macroinvertebrates, and subsequently the creek's health. We hypothesized that if the conditions within the creek were optimal for macroinvertebrate survival (specifically the pH range of 6.5-8.5), then there would be a higher abundance and diversity of macroinvertebrates found compared to areas of the creek with pHs outside of the aforementioned range. We conducted a qualitative analysis of macroinvertebrates and water quality to obtain a general understanding of the health of Stevens Creek. Macroinvertebrate sampling and water quality testing, including pH measurements, were carried out in two locations within Stevens Creek, with seven trials in each location. The overall total dissolved solids (TDS), as well as abundance and diversity of macroinvertebrates, between the two locations were found to be similar (not statistically significant), with pollution intolerant macroinvertebrates (Orders *Ephemeroptera and Plecoptera*) found within the 14 total trials, even though the pH was in the upper limit (8.4). These observations indicate that the portion of Stevens Creek sampled is likely to be healthy and relatively free from nonpoint source (NPS) pollution from the surrounding suburban area, boding well for the optimal conditions for freshwater macroinvertebrates.

INTRODUCTION

The quality of creeks and rivers is crucial to the well-being of freshwater ecosystems because most organisms low on the ecosystem's food chain, more specifically microbes, macroinvertebrates, and algae, have a large role in sustaining organisms higher up the food chain, but water quality heavily influences the presence of these organisms. Of the macroinvertebrates that can be found within aquatic systems, species in the Orders *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), and *Trichoptera* (caddisflies) tend to be used as bioindicators, as they have been found to be more sensitive to pollutants compared to other organisms (1). However, sources have reported varying estimates on the optimal conditions for freshwater macroinvertebrates. For example, in a study on how pH influences freshwater macroinvertebrate populations, Berezina found that a pH range of 4.09-8.65 resulted in the greatest species diversity among macroinvertebrates (2). Another study, conducted by Robertson-Brian, Inc. on the topic of optimal conditions for freshwater organisms, stated that freshwater macroinvertebrates would thrive with a water pH ranging from 6.5-8.5 (3). In fact, the latter range is also used as a guideline by the California State Water Resources Control Board in interpreting the relative health of surface water bodies within the San Francisco Bay Area, excluding the Pacific Ocean (4). The presence of sensitive macroinvertebrates generally indicates good stream health, but the absence of them does not necessarily mean the water quality of the creek is not optimal (1). The size of macroinvertebrate populations can be affected by factors other than pollution, such as water current speed, drought, or a change in the seasons (5).

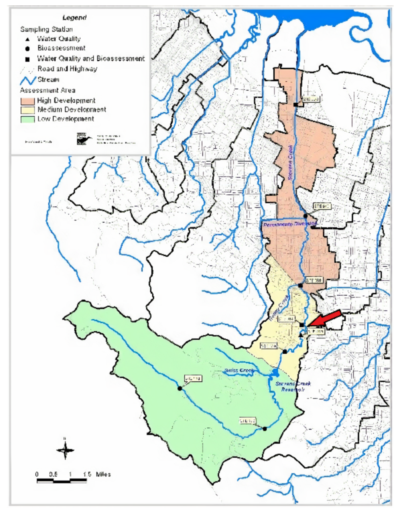

Figure 1: Levels of development for Stevens Creek (SCVURPPP FY 05-06 Watershed Monitoring and Assessment Summary Report). Sampling location in this study is depicted by the red arrow, and this figure is being used with permission from the Vice President of EOA, Inc., the author of this report.

The preferred diet of steelhead trout (*Oncorhynchus mykiss*) includes aquatic and terrestrial insects, as well as other crustaceans and smaller fishes (6). Thus, it is seen that macroinvertebrates (which include aquatic insects) do constitute a large portion of the trout's diet. In addition to macroinvertebrates, the steelhead trout, which are federally designated under the Endangered Species Act as threatened species within Northern California (7), reside within Stevens Creek, the creek at the focus of this study. Steelhead trout typically hatch in fast-flowing rivers and streams such as Stevens Creek, with some remaining within the freshwater body (rainbow trout) while others moving into a saltwater body, such an ocean or bay (7). All steelhead trout, including rainbow trout, return to a freshwater body to spawn (7).

A section of Stevens Creek is currently categorized as “medium development” by the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP)’s FY 05-06 Watershed Monitoring and Assessment Summary Report (**Figure 1**) (8). The characterization of “medium development” was influenced by the fact that the foothill region surrounding that section of Stevens Creek from 2005-2006 mostly contained residential areas, with impervious land taking up less than 20%, but greater than 5%, of the total region (8). In this suburban setting, nonpoint source (NPS) pollution, pollutants that originate from diffuse sources (agricultural fertilizer/pesticides and insecticides, oil and grease from urban runoff, sediment from construction sites, etc.) are factors potentially affecting the water quality in the creek (9). Furthermore, the construction of Stevens Creek Reservoir and spreader dams along Stevens Creek have presented great challenges to the life history of the trout, resulting in reductions in the population size (10). In fact, of the 58 watersheds that drain into the San Francisco Bay estuary, only 24 still have steelhead trout (including rainbow trout) populations (6). These fragile freshwater ecosystems are also going to be continuously threatened as humans continue to urbanize in the future. The UN has projected that by the year 2050, 68% of the human population will be living in urban areas (11). Numerous studies have linked this rapid urbanization to the degradation of creeks and rivers around the world, from the Huangpu River (1947-1996) in China (12), to the Han River (1960-1970) in South Korea (13), and the water system within Bucharest, Romania (14). Thus, increased urbanization, now and in the future, can exacerbate the issue of freshwater degradation, leading to the potential for already threatened species of aquatic organisms, such as the steelhead trout within Stevens Creek, to face even greater challenges. This further increases the need to investigate whether other biological stressors may have any additional impact on trout through a qualitative analysis of macroinvertebrates. Thus, we established the following research question: How is the water chemistry within Stevens Creek related to the abundance and diversity of macroinvertebrates within the creek and the resulting health of the creek itself? The hypothesis for this project was that in areas with suitable water conditions, defined as the pH range from 6.5-8.5 (due to its function as the guideline for interpreting surface water health in the local area), there would be a larger abundance and diversity of macroinvertebrates compared to areas with a pH outside of the 6.5-8.5 range. We found that across all of the 14 trials conducted in two locations of Stevens Creek the pH of the creek was 8.4, with there being no statistically significant difference with mean macroinvertebrate abundance, mean macroinvertebrate diversity, and mean total dissolved solids (TDS) between the two locations. Macroinvertebrates that were pollution intolerant, in the in-between group, and pollution tolerant were also found within the 14 trials. This meant that the portion of Stevens Creek sampled was likely to be relatively free from NPS pollution, which is beneficial to the federally designated threatened steelhead trout which inhabit the creek.

RESULTS

Macroinvertebrates within Stevens Creek were collected using a homemade kicknet, with macroinvertebrate abundance and diversity being calculated in each trial based on the number and types of macroinvertebrates photographed. Macroinvertebrate abundance represents the number of macroinvertebrates located in each trial, with mean macroinvertebrate abundance being the average macroinvertebrates found across all of the trials at Location A or B. Macroinvertebrate diversity represents the number of different orders of macroinvertebrates found in each trial, with mean macroinvertebrate diversity being the average number of orders of macroinvertebrates found across all of the trials at Location A or B. There was an overall higher mean and median macroinvertebrate abundance and macroinvertebrate diversity in the downstream location A than the upstream location B (**Figure 2A, 2B, Figure 3A, 3B**), Macroinvertebrates spanning from mayfly larvae and stonefly larvae (pollution intolerant, **Figure 4A)** to damselflies (in between group, **Figure 4B**) and leeches and midges (pollution tolerant, **Figure 4C**) were identified from the pictures taken. The presence of the pollution intolerant macroinvertebrates indicates that the water quality of the Stevens Creek sampled was healthy. Between the two areas of Stevens Creek, there was no statistically significant difference in mean macroinvertebrate abundance and mean macroinvertebrate diversity (p=0.580 and 0.302 respectively).

TDS measurements were made using a TDS meter, and water quality test strips were used to determine nitrate and nitrite concentrations, total hardness, total chlorine, total alkalinity, and pH. A higher mean and median TDS was measured in the upstream location B than the downstream location A (**Figure 2C, Figure 3C**). There was no statistically

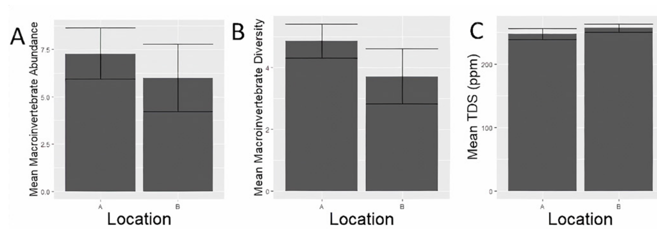

Figure 2: Bar graphs showing the average (A) macroinvertebrate abundance, (B) macroinvertebrate diversity, and (C) TDS measured at locations A and B within the Blackberry Farm segment of Stevens Creek. Error bars represent the standard error of the datasets.

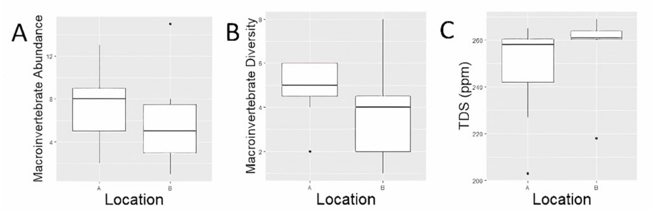

Figure 3: Box and whisker plots of (A) macroinvertebrate abundance, (B) macroinvertebrate diversity, and (C) TDS sampled at locations A and B within the Blackberry Farm segment of Stevens Creek. The thick black line dividing each white box represents the median of the data, with the bottom and top of each white box representing the first and third quartiles of the measured macroinvertebrate abundance, macroinvertebrate diversity, and TDS. The endpoints of the vertical black line extending from the top and bottom of each white box represent the maximum/minimum value of the datasets, and the dark dots represent the outliers within the measured macroinvertebrate abundance, macroinvertebrate diversity, and TDS.

significant difference in mean TDS between the two areas of Stevens Creek (p=0.408).

Total hardness is a scale depicting the concentration of dissolved calcium and magnesium in a body of water (15). Total alkalinity measures the ability for a body of water to neutralize additions of acid (16). The segment of Stevens Creek sampled contained no nitrate or nitrite, but a total hardness of 300 ppm and total alkalinity of 300 ppm were observed in each of the fourteen trials. The total hardness measured in all fourteen trials was on the higher end of the measurement scale (in the "very hard" category), indicating that there was a large amount of dissolved calcium and magnesium present within the creek. However, the measurements were also consistent with the levels typically found in surface waters in California (100-300 ppm (particles per million) hardness) (17). The total alkalinity was also found to be "high" in all trials, implying that the creek had a relatively large buffering capacity against inputs of acid.

The pH of the creek was 8.4 across all the trials, while chlorine levels fluctuated between 0.1 and 1 ppm within the fourteen trials conducted. The pH of the creek was basic and leaned greatly towards the upper limit of tolerance for mayflies, stoneflies, and caddisflies, using the threshold issued by Waterboards in California (6.5-8.5). Finally, total chlorine measurements fluctuated between "safe" and the lower end of the "danger" category.

DISCUSSION

The observed similarities in hardness and alkalinity within Stevens Creek to the average measurements within Northern California surface waters indicated that Stevens Creek was normal in these categories. The relatively high pH measured within the creek could be explained by natural factors, such as the presence of significant dissolved calcium and potassium ions (indicated by high hardness measured) in the creek. This hardness level, along with the high alkalinity measured, provided evidence that the source for the calcium ions was calcium carbonate, a common mineral found within soils and rocks in the western United States (18). Thus, there could be a higher level of calcium carbonate within the soil surrounding the creek, resulting in the relatively higher pH. This hypothesis is further supported by the fact that calcium carbonate can act as a buffer system when in solution, reacting with excess hydrogen ions to form bicarbonate (and calcium ions), thus explaining the high alkalinity measured within the creek (19). However, additional testing for calcium ion concentration would need to be performed to validate this hypothesis and to rule out potential human-related causes.

The macroinvertebrates photographed spanned all three categories in the identification chart according to pollution tolerance (**Figure 4**). In other words, although there were pollution tolerant macroinvertebrates such as leeches and midges within Stevens Creek, pollution intolerant and very sensitive mayfly larvae and stonefly larvae were also present. These findings support the conclusion that the conditions within the creek were likely healthy enough for sensitive macroinvertebrates to survive within it, despite the relatively high pH present. In addition, the conclusion bodes well for predators within Stevens Creek, including the endangered steelhead trout. The notion that potential sources of NPS pollution within the sections of the creek sampled (which were located within an area under medium development as was classified in 2005/2006) may be mostly nonexistent is also supported.

Also, the absence of statistically significant differences between the two locations pertaining to macroinvertebrate abundance (p=0.580), macroinvertebrate diversity (p=0.302), and TDS (p=0.408) using a paired t-test indicated that these

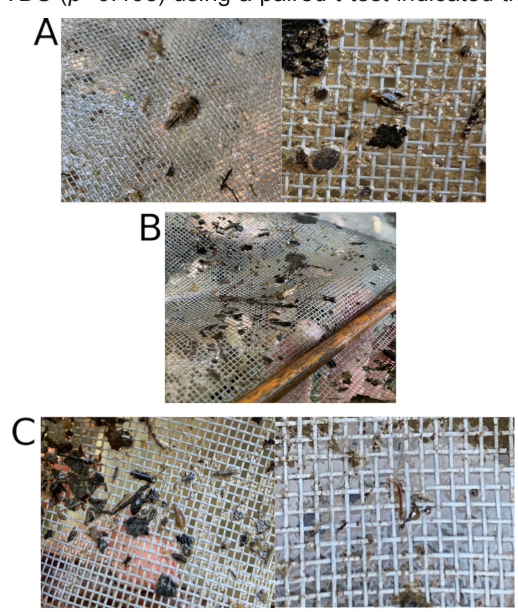

Figure 4: Photographs of (A) pollution intolerant mayfly larvae (left) and stonefly larvae (right), (B) in between group damselfly, and (C) pollution tolerant leech (left) and midge (right) found within the 14 trials conducted in the two locations of Stevens Creek. The mayfly larvae and damselfly were found in the downstream location and the stonefly larvae, leech, and midge were found in the upstream location.

variables remained similar between the two locations, even when a potential disrupting factor (the rapids) separated the two locations. This suggests that the results of the qualitative analysis of these aspects of the creek may be valid for a much broader portion of the creek than the two locations where the sampling occurred.

Limitations of this study include the water quality test strips used, which used a qualitative color code system to determine the measurements of different aspects of water quality. For this reason, the readings of these test strips were highly subjective, and the color displayed for each of the water chemistry variables could have been affected by the differing amounts of sunlight exposure between trials. Another limitation of the test strips was that the freshwater comparison chart used to decode the colors on the test strips had discrete color codes, meaning that shades that did not quite match with those present on the chart had to be estimated. Furthermore, the chart also did not account for values of the water quality variables that were higher than the color codes present, resulting in uncertainty surrounding the exact values at the extremes of the measurement range. For example, the measured pH had a value of 8.4 using the freshwater comparison chart, but it was also the highest value the chart contained, so the actual pH of the creek could have been higher than the chart's capacity without the test strip showing otherwise. Finally, the only figure found depicting development levels surrounding Stevens Creek was from 2005/2006, meaning there could have been additional construction since then that could have increased the percentage of impervious land to be greater than 40%. This would likely change the designation of the portion of the creek sampled from "medium development" to "high development", potentially meaning Stevens Creek had to be even more resistant to NPS pollution to yield the observations found within this study.

Next steps for this research include repeating the water quality testing and macroinvertebrate sampling at more locations within Stevens Creek. Performing the same analysis on that data would allow us to gain an even better understanding about the water chemistry and macroinvertebrate composition of Stevens Creek as a whole, as well as the health of the creek. In addition, testing for calcium ion concentration within Stevens Creek would help validate our reasoning for the relatively high pH within the creek. Also, a historical approach in analyzing the health of Stevens Creek would place these recorded measurements in relation to previous measurements, offering a point of reference to determine if the health of Stevens Creek has improved or declined over the period of study. Finally, a historical analysis of a similar layout of other surface waters within the San Francisco Bay Area can offer insight into the effects of urbanization within the San Francisco Bay Area as a whole on the health of these surface waters and freshwater ecosystems within the region.

MATERIALS AND METHODS

The test site location was the portion of Stevens Creek that ran through Blackberry Farm, indicated by the red arrow within **Figure 1**. Two areas, one downstream (Location A) and the other upstream (Location B) relative to a rapids area within the marked location, were ultimately sampled. The downstream area's streambed was filled with boulders throughout all of the trial sites, and the depth of the creek remained consistent throughout the trials conducted at the location. The streamflow was faster in this location relative to the upstream location. The creek bed in the upstream area was also mostly filled with boulders, with the streamflow being slow relative to downstream. Further down the creek in this area, the water depth decreased, and the creek bed consisted of more small rocks and pebbles. Two of the trials at the upstream area were conducted in this location.

Seven trials were performed at different places within each of the two locations, collecting both water chemistry and macroinvertebrate data. For water chemistry, the TDS content and temperature of the creek were both measured using a TDS meter (Hofun TDS, EC, & Temperature Meter 3 in 1) by dipping the meter into the creek until the measurements for each had stabilized. Nitrate, nitrite, total hardness, total chlorine, total alkalinity, and pH measurements were recorded using water quality test strips (Tetra EasyStrips 6-in-1). For each trial, a strip was dipped into the testing location for one second, then placed onto a flat surface for one minute. After, a picture was taken of the test strip for analysis later using the freshwater comparison chart provided with the test strips.

To make the kicknet for sampling macroinvertebrates, first, a 48 in x 39 in window screen was cut from the 48 in x 99 in MAGZO original product. Then, two 0.4 in x 0.4 in x 59.75 in wooden dowels were laid parallel to each other on either side of the 39 in side for the window screen, with one end of each dowel matching up with a corner of the window screen. After rolling the window screen one rotation around the dowels, utility wires were used to secure the rods in place. Finally, the remaining two 0.4 in x 0.4 in x 46 in wooden dowels were laid parallel to each other on either side of the 48 in side for the window screen, and the same method was used to secure these in place. This ensured the stability of the kicknet. The tips of these two dowels were trimmed off, and the final product resembled a rectangle with the top part of the two rods that were attached to the 39 in side of the screen serving as handles. Then, the kicknet was placed a foot and a half downstream of the testing point, and the rocks and sediment on the creek bed at the point of sampling were disturbed continuously for two minutes. This was done along the creek bed parallel to the length of the kicknet (48 in). After this period, the kicknet was lifted out of the creek, and macroinvertebrates that were caught in the kicknet were located and photographed.

These photos were later analyzed to estimate the macroinvertebrate abundance and diversity on the order level, as the identification to the specific species level required expert guidance. The macroinvertebrates photographed were identified using a macroinvertebrate identification sheet (20), with selected photographs of macroinvertebrates with varying levels of pollution tolerance being compiled into **Figure 4**. Using RStudio, the mean macroinvertebrate abundance, mean macroinvertebrate diversity, and mean TDS for all the trials were calculated, with each category's means being placed in separate bar graphs with standard error bars (**Figure 2**). Additionally, a box and whisker plot was created using RStudio for each of the three variables as well to visualize the spread of the data relative to the median of each dataset (**Figure 3**). Finally, a paired *t*-test was run for each of the three variables within RStudio, and the resulting p-values were generated.

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