A Step in the Right Direction: Restoration of Urban Streams and Benthic Macroinvertebrate Responses

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ABSTRACT

The installation of step pools is commonly used to restore valuable urban stream ecosystems. My study aims to understand how the installation of step pool restoration affects benthic macroinvertebrate communities within Strawberry Creek at the University of California, Berkeley. I collected samples for fourth months before and after restoration using a kick-net sampling regime with 2 control and 1 treatment site. Collections were sorted and identified by hand in the Resh Lab at UC Berkeley. I used a Before After Control Impact (BACI) study design to analyze control and treatment similarities, as well as understand shifts in percent abundance of sensitive Ephemeroptera, Plecoptera, and Trichoptera taxa both before and after restoration. I also used a non-metric multidimensional scaling (NMDS) statistical analysis to assess the relationship between control/treatment sample compositions and to identify benthic macroinvertebrate taxa driving change. Following restoration, stream water level and flow increased as macroinvertebrate assemblages decreased in richness and abundance. Control and treatment sites showed more similarity in post-restoration samples, perhaps due to seasonality and the recolonization of the treatment site by control site assemblages. Macroinvertebrate richness, abundance, and %EPT showed no statistically significant change at both treatment and control sites during the sampling period. While the installation of step pools did substantially improve the physical habitat of the main stem of Strawberry Creek, any significant improvement to the benthic macroinvertebrate communities remains to be determined. Further post-project monitoring would be required to identify seasonal fluctuations and determine the complete biological effects of step pool installation.

KEYWORDS

Strawberry Creek, step pool restoration, bioassessment, high-gradient stream, BACI

INTRODUCTION

Urban creeks streams are valuable environments; step pools and other restoration efforts are used to offset anthropogenic development and help protect the health of these increasingly endangered ecosystems. The majority of urban stream ecosystems suffer from "Urban Stream Syndrome", with symptoms that frequently include heavy contamination, overload of nutrients, intense seasonal hydrology changes, and lack of biotic diversity (Bernhardt et al. 2007, Cottingham et al. 2005). Urban pollution is the major stressor of stream ecosystems; pollution affects all communities downstream of the source and can affect trophic cascades and population dynamics throughout the entirety of the waterway (Cummins et al. 1980). Creation of step pools and other restoration efforts are used to offset anthropogenic development and help protect the health of these increasingly endangered ecosystems. While there are many biological, chemical, and physical characteristics by which urban stream health can be judged, the most comprehensive and widely used of these options being aquatic macroinvertebrate monitoring (Resh 2008).

Benthic macroinvertebrates have many ecological roles and are part of freshwater invertebrate communities that respond closely to changing waterway conditions. Macroinvertebrates are frequently used in both private and public water management; their populations react to minute environmental changes and provide a benchmark against which managers are able to measure severity of pollution and effectiveness of restoration (Friedrich et al. 2002, Leopold and Marchand 1968, Cummins et al. 1980, Hynes 1976, Mackay and Wiggins 1979, Alvarez-Cabria et al. 2011). Benthic macroinvertebrates are also large in number and variety. Present and easy to collect in nearly every urban stream, each order has its own specialized functional niche and ideal habitat within its community, and magnifies the biological effects of waterway alterations such as changes in pollutant levels, water turbidity, or temperature (Friedrich et al. 2002, Cummins et al. 1980, Hynes 1976, Mackay and Wiggins 1979, Alvarez-Cabria et al. 2011). Stream ecologists frequently use benthic macroinvertebrates to judge water quality. There are both tolerant and sensitive taxa that will react differently to environmental change and disturbance events. Using abundance, variety of macroinvertebrate communities, and percentage of sensitive taxa present within a site, researchers are able to gain a clear overview of the health of an urban stream.

Strawberry Creek, a Berkeley landmark prized by both UC students and community members, is impacted by both urban development and conservation efforts, as initiatives to maintain the health and beauty of Strawberry Creek are challenged by the ever-growing urbanity of Berkeley's cityscape. Urban development of the watershed has had profound effects on Strawberry Creek including increased flooding potential, causing unpredictable and dramatic seasonal changes in current and overflow risk (Hans and Maranzana 2006). The high concentration of pollutants and effective imperviousness of urban street surfaces leads to potent runoff that causes drastic changes in water composition and high mortality rates of resident populations of macroinvertebrates and aquatic insects (Hans and Maranzana 2006, Fletcher et al. 2005). The installation of step pools within the Main Stem of Strawberry Creek is an attempt to correct for a failing check-dam upstream of this area. The failing check-dam drastically lowers the turbidity of Strawberry Creek, an effect that depreciates oxygen levels and nutrient cycling efficiency within the waterway, negatively effecting macroinvertebrate populations in the area.

The direct effects of step pool restoration on local macroinvertebrate populations are not well documented; my study aims to understand these dynamics as a means of assessing restoration success. The ecological results of the step pools are difficult to predict; my project will provide insight regarding the biological effects of this restoration.

METHODS

Study system description

Strawberry Creek (Alameda County, CA, 37.870910 N, 122.263967 W) is an urban stream 5 miles long (Hans and Maranzana 2006), travelling sequentially through residential neighborhoods, the University of California, Berkeley (UC Berkeley) campus, the densely populated downtown Berkeley area, and residential neighborhoods before it finally outflows into the San Francisco Bay. The UC Berkeley campus was planned around this waterway to display the growing community's environmental priorities (Register 1987), and Strawberry Creek is still very much a part of campus culture and academics. Students regularly use Strawberry Creek for recreation, as it provides a park-like setting, and introductory biology courses use the stream as a prime local example from which to teach students about small-scale aquatic population dynamics.

Currently, the ecological condition of Strawberry Creek rides the balance of urban development and conservation efforts, as any initiatives to maintain the health and beauty of Strawberry Creek are challenged by on-campus construction and a failing check-dam, which was built to regulate water flow. Strawberry Creek is classified as a high gradient stream, with a slope of 9% upstream in the Berkeley hills and a slope closer to 3% in the UC campus area. The steep sloping banks of Strawberry Creek experience heavy erosion of soils and dramatic seasonal flooding which have greatly deteriorated the creek bed. Because of the failure of a check-dam near the confluence of the north and south forks of the stream (Figure 1), water flow has been left uncontrolled and unpredictable, particularly during storms. The installation of a new set of stone step pools and a submerged eucalyptus trunk should regulate the flow of water in this part of the stream as well as introduce more oxygen into the environment to improve ecological functioning throughout the waterway. Although the construction of a new series of step pools does involve further construction on the Strawberry Creek ecosystem, the installation of a new eucalyptus check-dam may offset some of the ongoing campus construction and promote an increase in ecological condition of the urban stream habitat on the UC Berkeley campus.

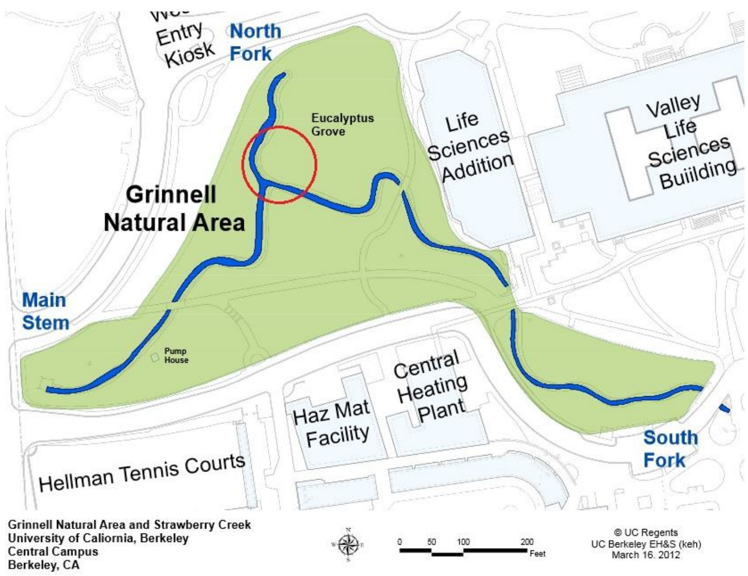

Figure 1. Map of the main stem of Strawberry Creek on the UC Berkeley campus. The red circle indicates the construction site of the new step pool restoration project.

Figure 2. Left photo shows the construction of the step pools on the UC Berkeley campus in October 2014. Right photo shows the completed step pools in early November of 2014, with planned riparian vegetation waiting to be planted.

Data collection methods

To collect benthic macroinvertebrates, I used a standard kick-net sampling method and following guidelines provided by the California Stream Bioassessment Procedure (CDFG 2003). At each site, I began by completing a Habitat Assessment for High Gradient Streams (Environmental Protection Agency) and described detailed environmental conditions within each site that would affect macroinvertebrate populations. I sampled from three unique cross-sections within each study site, kicking the substrate at the bottom of the stream three times within each location (for a total of 9 kicks per collection site) and waiting for 30-45 seconds after each kick to ensure that all of the substrate that I disturbed had been filtered through the net. I made an effort to sample within both riffles (areas of shallow, rapid-moving water) and pools (areas with deeper, more stagnant water) at each study site to ensure that I had a variety of depths and water velocities included in each sample (Figure 3).

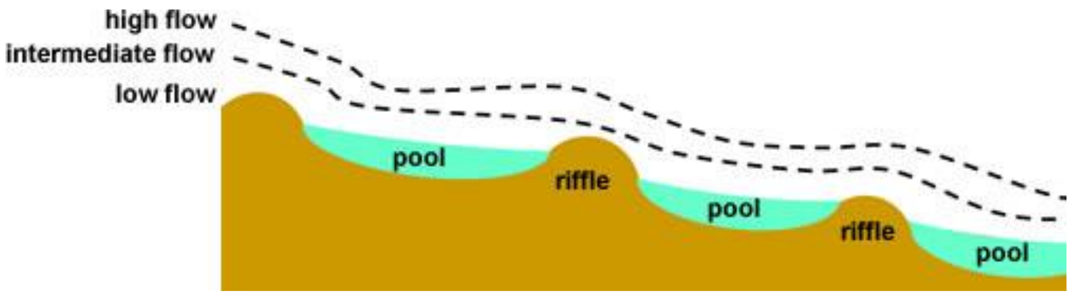

Figure 3. A comparison of riffles and pools. I collected from within both areas of Strawberry Creek to maximize coverage and macroinvertebrate diversity within each sample. (Arizona Board of Regents, 2007)

I then strained my samples through the 500-millimeter sieve, and placed them in 1-Liter Nalgene bottles filled with 95% ethanol (Figure 4). In the lab, I sorted out all macroinvertebrates by hand using forceps. Finally, all collected insects were be identified to family level using the taxonomic identification key by Merritt et al. (2008), counted, and placed in labeled 5-dram vials filled with 75% ethanol for long-term storage. Samples were collected every month beginning 4 months before restoration (June 2014) and continuing 4 months after (February 2015).

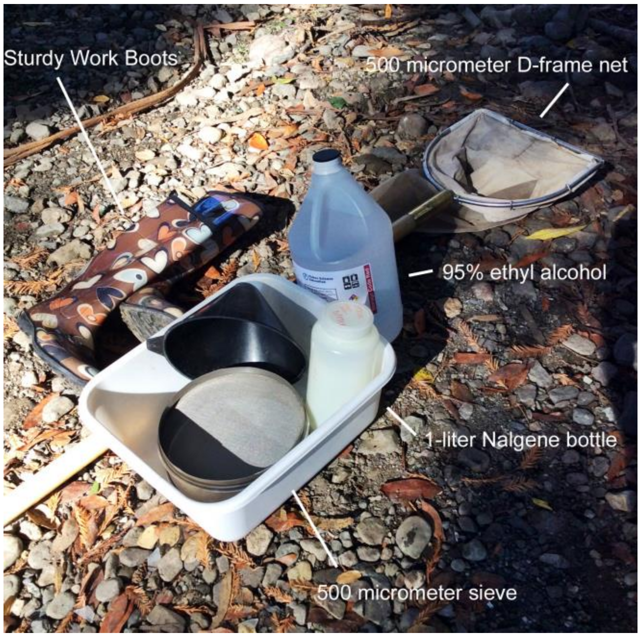

Figure 4. Materials I used to collect macroinvertebrates while in the field. This photo was taken during the November 5th collection at the main stem site of Strawberry Creek.

Data analysis

To determine whether there is a significant difference in macroinvertebrate abundance and both before and after the installation of step pools, I used statistical tests using the R software suite. (R Core Team 2014) I conducted a BACI (Before After Control Impact) analysis to compare the %EPT (% Ephemeroptera, Plecoptera, and Tricoptera) within each sample site both before and after the restoration. Ephemertoptera, Plecoptera, and Trichoptera are the three sensitive insect orders most commonly used to assess water quality. My North and South Fork study sites were my experimental controls, and my Main Stem collection site was my treatment site. I performed one-way ANOVAs between all 12 of the samples collected before restorations as well as on the 12 samples collected after restoration, and then performed one final ANOVA between my before group and my after group to understand the changes the macroinvertebrate communities had undergone.

I also performed a NMS (Non-Metric Multidimensional Scaling) statistical analysis to identify the macroinvertebrate taxa and physical habitat characteristics that most heavily influenced the species variation within each site. I used the R statistical software suite (R Core Team 2014) to create clusters of species in space and identify the most governing families of macroinvertebreates. I conducted NMS calculations on a log scale, fitting the most influential macroinvertebrate families according to treatment/control sites, seasonal changes, and per site diversity counts.

RESULTS

Study site

I found that the installation of step pools altered the physical habitat of Strawberry Creek by increasing channel flow, embeddedness of organic matter, and the diversity of available depth/velocity habitats present within the treatment site. The control did not change to the same degree as the treatment site, responding seasonally during increased rainfall events and lower temperatures in autumn and winter months.

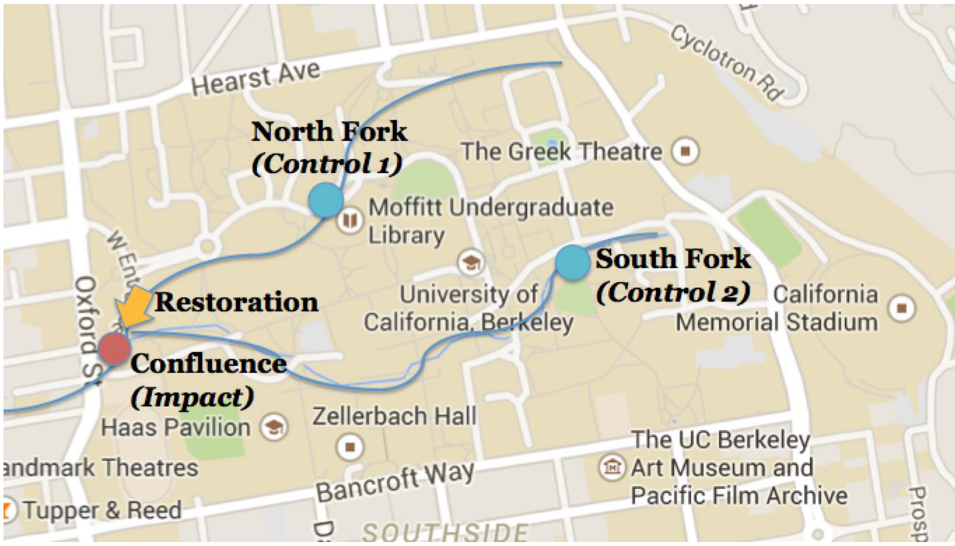

Figure 5. This map of the Berkeley campus shows the location of the restoration as well as the control and treatment sites. The North Fork of Strawberry Creek historically has low richness, abundance, and %EPT, while the South Fork is a previously restored site that generally exhibits the highest richness, abundance, and %EPT.

Although the two control sites at the North and South Forks of Strawberry Creek remained relatively unchanged throughout the experiment, the treatment site located near the confluence of the two forks experienced drastic physical changes (Figure 5). The treatment site initially had very low channel flow, organic matter embeddedness (leaf litter, branches, and other decomposing organic material present in the bottom of the stream), and a lacked varying velocity/depth regimes during the summer months. Physical habitat assessments performed during sampling show that during periods of high velocity flow (post-restoration), the treatment site's assessment scores are more similar to the unaffected control sites (Appendix 1).

After the restoration efforts of the Strawberry Creek Ecological Stabilization Project, the stream's channel fill level increased from a score of 10 (marginal) to a score of 17 (optimal). During monthly inspections while sampling, it became clear that as a result of the restoration in October that there was more water flowing through the treatment site than was present during the summer and early fall months. The treatment site exhibited a greater fill level within the bank and a faster flow than pre-restoration. The treatment site also displayed a wider variety of velocity/depth regimes (slow-shallow, slow-deep, fast-shallow, fast-deep), which increased the embeddedness of organic matter present within the site. Native riparian vegetation planted within a 15m zone along the banks of the treatment site also added shaded areas and protection from urban disturbances such as litter and sound pollution that was previously unavailable.

Figure 6. The treatment site of Strawberry Creek in February of 2015, 4 months after the installation of step pools. The site exhibited increased channel flow and embeddedness as well as increased riparian vegetation.

Analysis

Richness, abundance, and %EPT among the three sample sites were not significantly different before and after the restoration. The macroinvertebrate richness and abundance of all three sampling sites decreased after restoration. The most abundant taxa present at the control sites changed from Diptera Chironimidae (a gatherer-collector) to Odonata Coenagrionidae (a predator), both tolerant families that are resilient to habitat change. Abundance of the treatment site averaged 286 macroinvertebrates per sample prior to restoration, and decreased to 112 macroinvertebrates after restoration (Table 1). The most abundant taxa present within the treatment site also shifted during the sampling period. The relatively tolerant Dipteran, Simulidae (26% of community) dominated the confluence site before restoration, while after the restoration the sensitive gatherer-collector Ephemeroptera Baetidae was most abundant (26%).

Table 1. Average values of bioassessment metrics from all three sites before and after restoration. Site A is the North Fork, Site C is the South Fork, and Site D is the impact site located at the confluence of the North and South Forks.

	Site A	Site C	Site D
Before Restoration			
Richness	12	13	12
Abundance	726.8	634.3	286.3
%EPT	2.8	24.7	30.8
After Restoration			
Richness	7	9	10
Abundance	142	183.3	112.3
%EPT	6.4	50.9	35.2

Throughout my study, neither upstream control sites nor the downstream treatment site experienced a significant change in %EPT. In the North Fork control sample, %EPT remained relatively low and stable throughout the collection period, which is not surprising given the low quality historically associated with this sample site. In the South Fork control and Main Stem impact sites, %EPT showed a steady decrease during the summer months and similar patterns of increase and decrease following restoration (Figure 7). The derivative of %EPT over time shows the similar post-restoration rate of change in the percentage of sensitive taxa present in both the South Fork and Main Stem collection sites (Figure 8).

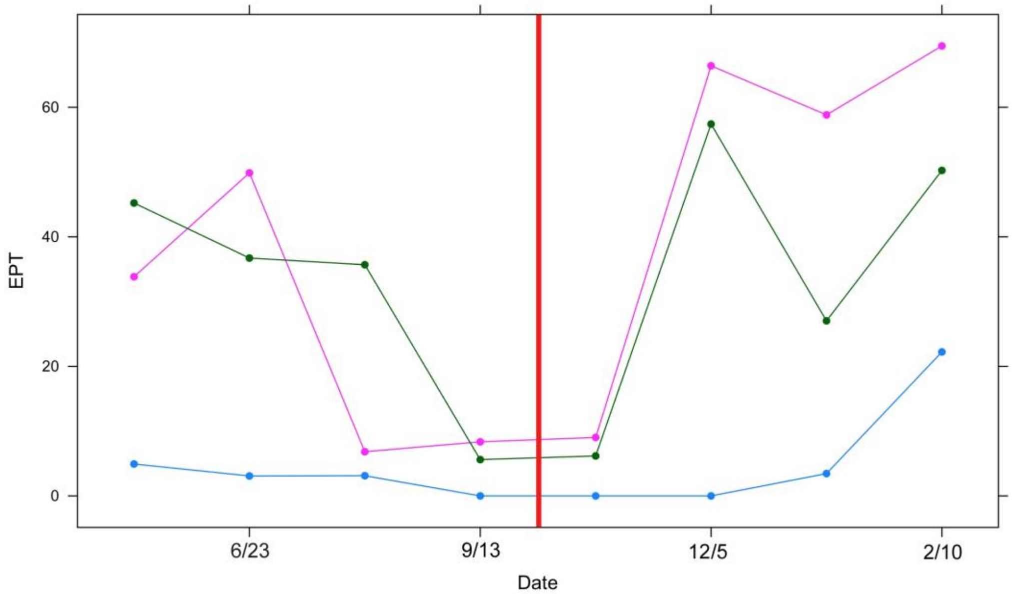

Figure 7. Changes in %EPT at all three sampling sites over time. The blue line represents the North Fork and the pink line represents the South Fork, while the green line shows the treatment site at the Main Stem. Installation of step pools is denoted by the vertical red line.

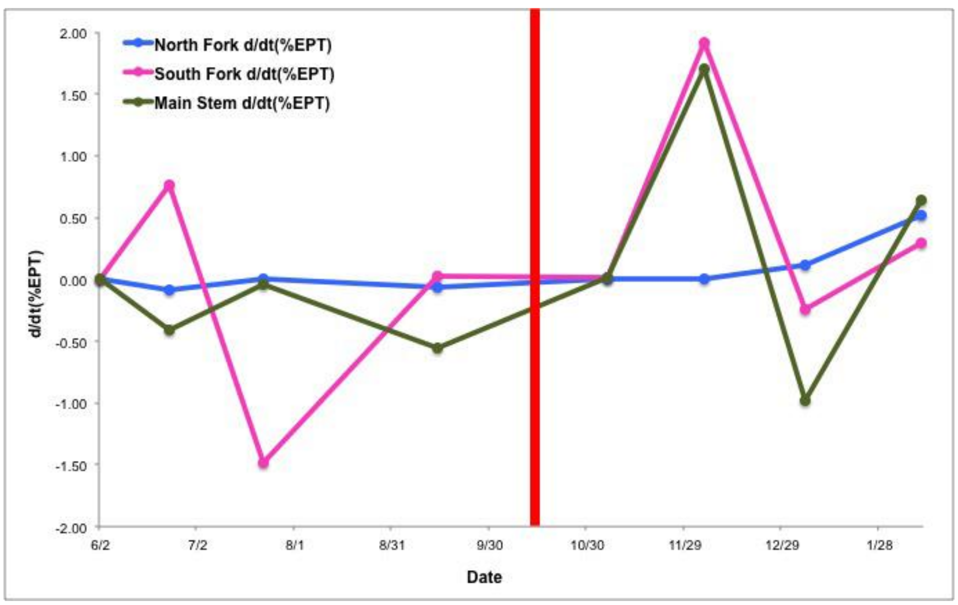

Figure 8. Derivative of %EPT at all treatment sites over time. Similarities between Main Stem and South Fork post-restoration suggest that sensitive communities from the South Fork are driving colonization within the impact site. Installation of step pools is shown by the vertical red line.

A BACI analysis did not detect a significant difference in the before-after changes in %EPT that occurred at the treatment site compared to the control sites ($p > 0.05$). At the treatment site, %EPT increased from 30.8% (+/- 17.3%) before restoration to 35.2% (+/- 23.3%) after restoration, while the %EPT present within the North Fork changed from 2.8% (+/- 2.05%) before restoration to 6.4% (+/- 10.6%) after restoration and the South Fork showed a shift from 24.7% (+/- 20.8%) to 50.9% (+/- 28.3%) (Figure 9).

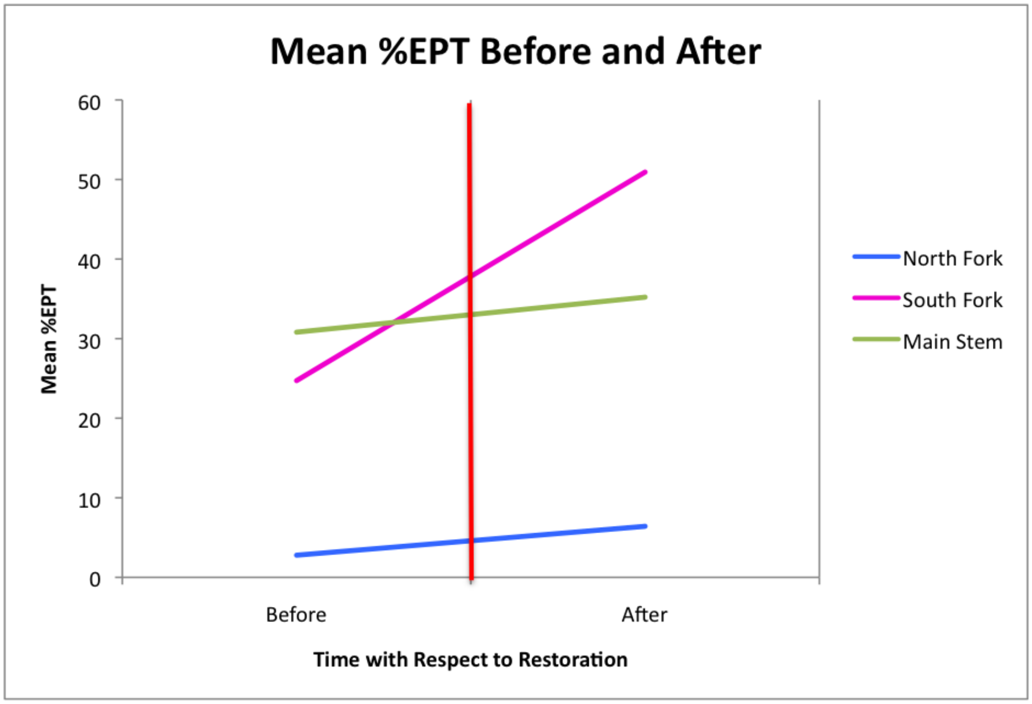

Figure 9. Mean %EPT before and after restoration at all three collection sites.

An NMS statistical analysis comparing prevalent species with sampling dates found that Ephemeroptera Baetidae was the taxa driving post-restoration assemblage changes at the treatment site. Plecoptera Nemouridae was most strongly correlated with post-restoration south fork samples, and Odonata Coenagrionidae showed a strong relationship with north fork samples.

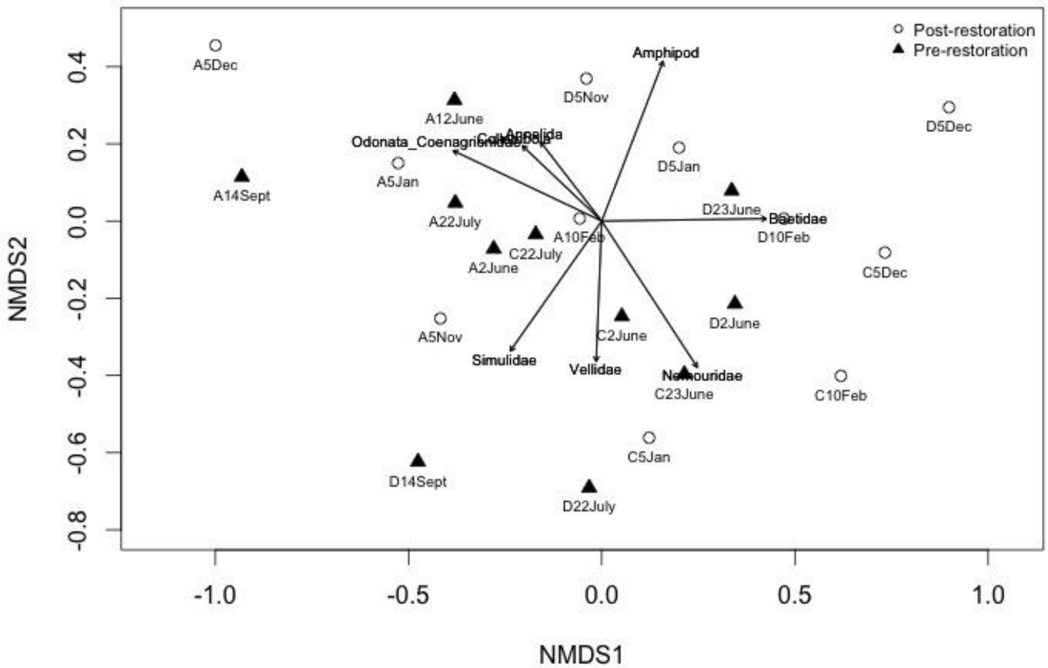

Figure 10. NMS analysis showing taxa trends with regards to sample composition. Baetids are heavily tied to post-restoration assemblages at the treatment site. Odonata is the most prevalent taxa group in the North Fork, and Nemouridae is heavily tied to pre-restoration South Fork assemblages.

DISCUSSION

The installation of step pools is a common restoration practice used to improve the water quality and natural habitat of urban streams (Purcell et al. 2002). In my study, I used benthic macroinvertebrate assemblages to analyze the impacts of the step pool restoration effort of Strawberry Creek in Berkeley, CA. I hypothesized that assemblages downstream of the restoration site would become more diverse and more abundant, an assumption that was not confirmed. Although physical habitat was altered by the restoration, and improved in some metrics, we did not detect significant changes in family richness, abundance, or % EPT, and therefore the restoration does not demonstrate a biological success at this time. I observed directional trends in the data suggesting that Baetidae (Ephemeroptera), Amphipoda, and Nemouridae (Plecoptera) were the taxa most greatly correlated with post-restoration macroinvertebrate assemblage shifts.

Benthic responses

Step pools create a diversity of habitat types within a stream, such as steps, riffles, and pools, which support aquatic life as well as improving the flow of the waterway. These increases in habitat diversity are expected to increase the richness and abundance of invertebrates post-restoration, and also provide habitat for sensitive Ephemeroptera, Plecoptera, and Trichoptera populations. Flow is the main physical component that shapes aquatic assemblages after restoration, directly transporting populations downstream as well as directing the distribution of organic matter, oxygen, and other resources required by macroinvertebrate species (Hart and Finelli 1999). The increased turbidity visually observed in Strawberry Creek during winter months after restoration (November 2014-February 2015) can be expected to decrease the concentration of pollutants within the waterway (Ponce and Lindquist 1990) as well as improve the flow of nutrients within the treatment site (Gasith and Resh 1999), creating a habitat more suitable for a variety of macroinvertebrate species.

I did not detect a significant change in richness, abundance, and %EPT before and after restoration at the treatment site during the sampling period. Changes that result from the installation of step pools are difficult to disentangle from the seasonal changes and increased rainfall within Strawberry Creek that can also act as main driving forces affecting benthic macroinvertebrate populations.

The short-term effects of the installation of step pools, or any restoration, is expected to reduce macroinvertebrate diversity, increase domination by a short-lived, faster-reproducing species, and decrease size of individuals (Gray 1989). A typical step pool restoration project similar to my own work has shown full recovery of macroinvertebrate populations within 3 years of installation (Purcell et al. 2002). In the current study of Strawberry Creek, which occurred in the immediate four months after restoration, seasonal change was a substantial factor shaping the assemblage composition and no difference was detected due to the restoration; increased time since restoration is needed to determine if the Strawberry Creek restoration is biologically consistent with Purcell et al. 2002. Due to the fact that I detected no significant changes to benthic macroinvertebrate community downstream of the step pool installation, further post-project monitoring would be necessary to determine whether the small changes that I observed were a part of larger restoration effects rather than simply being an effect of the typical seasonal change that occurs in Mediterranean stream ecosystems.

Although increased flow and turbidity are changes that can be attributed to the installation of step pools, seasonal change also greatly affects the benthic macroinvertebrate assemblage. The non-significant changes to benthic macroinvertebrate assemblages in Strawberry Creek may have resulted from the installation of step pools, however, the timing of the sampling is likewise important in assessing the assemblage shifts. Although increased flow and turbidity are changes that can be attributed to the installation of step pools, seasonal change also greatly affects the benthic macroinvertebrate assemblage. Typically, urban streams in the Mediterranean climate such as Strawberry Creek experience predictable and extreme flooding patterns during the winter months due to increased rainfall coupled with the many impervious surfaces that allow terrestrial rainfall to flow directly into the stream (Gasith and Resh 1999). This trend makes it difficult to differentiate which physical changes are due to artificial flow augmentation and which are due to regular seasonal fluctuations experienced in the area.

Macroinvertebrates and habitat characteristics

The changes to the benthic macroinvertebrate assemblages of Strawberry Creek before and after restoration were most closely related to the relative abundance of Ephemeroptera Baetidae, Amphipoda, and Plecoptera Nemouridae, according to an NMS statistical analysis. These taxa were most prevalent within the South Fork and Main Stem of Strawberry Creek, a correlation that suggests that macroinvertebrate communities from the South Fork were the main drivers of post-restoration recolonization at the Main Stem sampling site. This is further corroborated by the similarities in %EPT and derivative of %EPT at both the South Fork and Main Stem, as both sites show identical patterns of increase and decrease of percent sensitive families after restoration (Figures 7 and 8). Amphipoda, Baetidae, and Nemouridae are all shredders or collector-gatherers that rely upon coarse particulate organic matter for nutrients, a shared characteristic that suggests that the increase in embeddedness of organic matter observed at the treatment site promoted the establishment of these post-restoration communities (Hieber et al. 2005). Amphipoda, Baetidae, and Nemouridae are all shredders or collector-gatherers, a similarity that suggests that the increase in embeddedness of organic matter observed at the treatment site promoted the establishment of these post-restoration communities. The North Fork site was most closely tied to Coenagrionidae, and does not show much overlap with the other two sampling sites. This is not surprising, as past monitoring efforts have shown the North Fork to be of low richness, abundance, and %EPT. While taxa-site correlations are important to note, the fact that observed changes to species composition were not statistically significant suggest that seasonal change remains to be the most influential force affecting shifts in prevalent species during the sampling period. Similar assemblage shifts were observed at the treatment site and the control sites, furthering the idea that seasonal change throughout the Strawberry Creek system trumped any immediate biological effects due to restoration.

Step pool effects and success

The installation of step pools is a frequently used urban stream restoration tactic with normal, expected changes to the character of a stream (Chin 2009A). The most typical results of a manmade dam system include the improved growth of riparian vegetation, increased bank stability, and a deeper and more narrow stream channel (Ponce and Lindquist 1990, Chin 2009A). The installation of step pools did appear to cause substantial physical changes downstream of the waterway, as observed from the Habitat Assessment Field Data Sheet for High Gradient Streams (EPA) filled out during each sampling session. Strawberry Creek experienced increased channel flow, the creation of various velocity-depth regimes, and a wider buffer zone of native riparian vegetation after the restoration. The observed physical changes could have occurred due to the installation of step pools or simply be the result of expected seasonal change within the waterway.

Macroinvertebrate richness, abundance, and %EPT were used as metrics for judging the success of this restoration project. I found no significant changes in any of these measurements, leading to the conclusion that the installation of step pools within Strawberry Creek did not cause adverse or beneficial changes to the waterway during the period of observation. Biological effects of step pool restoration may require a longer monitoring period in order to be detected, however, my work only measured short-term change that took place during the first four months after installation.

Limitations and future directions

The ability to detect in differences biological communities associated with restoration events is heavily influenced by time scale. Aquatic organisms require time to colonize restored habitats and assemble into communities. Mediterranean streams show strong seasonal trends, which may hamper immediate assemblage of benthic macroinvertebrate communities. The nine-month timeline in my study was the biggest limiting factor to assessing ecological change. I collected for only four months pre- and post-restoration and a longer collection period would give me the seasonally-relevant samples needed to observe larger environmental trends and fully understand the processes leading to full ecological restoration. In addition, restoration studies similar to my own have shown that streams may take up to three years to fully recover (Purcell et al. 2002). Multiple years of post-project monitoring are necessary to show the long-term effects of this restoration initiative; and this thesis only addresses immediate to intermediate recovery effects.

Sampling variability and collection bias may also be limiting factors. I am continuously improving as an entomologist, and strived to make all collections and identifications of benthic macroinvertebrates consistent and replicable. The innate differences between each of my sampling sites are another source of error that I could not account for during collection events. Some sites are more easily sampled than others, but perhaps more importantly, I sampled 100m downstream of the step pool restoration rather than in the riffles and pools of the steps themselves. Finally, a reference stream would have increased the statistical power of my results because I would have been able to compare between streams. With regard to my research on Strawberry Creek, continued monitoring would be an important continuation of my own work that would also improve the significance of my results. Extending the length of the sampling period would ensure that all seasonal changes are taken into account, and that the stream has enough time to recover biologically from the construction that occurred during the installation of the step pools. University of California, Berkeley, with a large undergraduate student body, many ecologically focused graduate students, and a long history of institutional interest in Strawberry Creek (Charbonneau and Resh 1992), may be in a strong position to continue long-term monitoring in association with this restoration project.

Broader implications

As human communities grow and more water is used for anthropogenic activities, the importance of urban stream restoration and protection is often a forgotten issue (Purcell et al. 2002). Step pools are a common restoration approach, yet there are still knowledge gaps in need of filling regarding the ties between anthropological practices and benthic responses (Purcell et al. 2002). Sound, human litter, the installation of impermeable surfaces, and habitat alteration are all ways in which humans affect urban streams. While the installation of step pools did substantially improve the physical habitat of the main stem of Strawberry Creek, any significant improvement to the benthic macroinvertebrate communities remains to be determined. The overall stream network of this urban watershed remains severely impacted in some reaches, as areas in East Berkeley remain culverted and heavily polluted, which ultimately impacts the ecological condition on the creek. (Palmer et al. 2005) Uncovering the links between these practices and urban stream health would greatly improve restoration practices in urban environments and define clear restoration goals in the future. Urban creeks are anthropogenic, physical, and biological entities – it is important that we treat them as such and take into account the many components that maintain their balance.

ACKNOWLEDGEMENTS

I thank Dr. Patina Mendez for her guidance and support throughout the stressful thesis-writing process. I am also deeply grateful for the help provided by my mentors, Mike Peterson and Lisa Hunt, who not only guided me through my writing and statistical analysis, but also spent countless hours assisting me in the collection, sorting, and identification of invertebrates. This project was made possible by the hard work of the Resh Lab, UC Berkeley Environmental Health & Safety, Kurt Spreyer, and my workgroup members (particularly Alyssa Zhang, who edited nearly all sections of this thesis throughout the year). Finally, I would like to thank my parents, who have loved and supported me throughout all my endeavors, and who inspire me to work hard and make the most of my undergraduate experiences at UC Berkeley.

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Appendix A: Physical Habitat Data

Site	Date	Epifaunal Substrate/Available Cover	Embeddedness	Velocity/Depth Regime	Sediment Deposiition	Channel Flow Status	Channel Alteration	Frequency of Riffles (or bends)
A	2-Jun	15	14	16	10	8	13	16
A	23-Jun	14	11	12	12	7	12	15
A	22-Jul	13	15	14	13	7	12	16
A	14-Sep	15	13	11	11	6	14	14
A	5-Nov	16	13	14	15	8	14	16
A	5-Jan	12	17	16	17	14	13	17
A	10-Feb	12	18	16	14	13	14	16
A	5-Dec	11	17	14	13	14	12	15
C	2-Jun	14	10	14	14	9	9	16
C	23-Jun	16	16	11	14	8	11	11
C	22-Jul	14	14	13	14	9	9	15
C	14-Sep	16	16	13	15	11	10	14
C	5-Nov	17	18	14	16	14	12	16
C	5-Dec	12	16	16	16	11	10	13
C	5-Jan	10	14	14	14	13	11	14
C	10-Feb	11	13	15	16	12	11	15
D	2-Jun	16	8	14	6	10	16	14
D	23-Jun	17	11	10	15	8	13	16
D	22-Jul	15	16	12	14	11	12	18
D	14-Sep	15	14	11	12	8	13	18
D	5-Nov	16	5	15	16	14	16	17
D	5-Dec	17	17	18	18	16	16	17
D	5-Jan	17	16	17	18	16	14	18
D	10-Feb	18	18	17	19	17	16	19

Site	Date	Bank Stability L	Bank Stability R	Vegetative Protection	Vegetative Protection R	Riparian Vegetative Zone Width L	Riparian Vegetation Zone Width R
A	2-Jun	5	4	5	5	2	3
A	23-Jun	5	6	2	6	3	3
A	22-Jul	4	4	4	4	5	5
A	14-Sep	5	6	5	4	5	6
A	5-Nov	5	5	3	5	5	6
A	5-Jan	4	4	4	5	4	5
A	10-Feb	4	6	3	4	4	5
A	5-Dec	6	4	5	6	5	4
C	2-Jun	7	7	5	5	5	6
C	23-Jun	6	6	4	4	4	5
C	22-Jul	8	6	4	4	5	5
C	14-Sep	7	6	5	4	5	6
C	5-Nov	8	8	5	5	5	5
C	5-Dec	7	7	6	4	6	4
C	5-Jan	6	8	5	5	7	5
C	10-Feb	7	8	5	4	6	6
D	2-Jun	4	4	2	2	8	6
D	23-Jun	5	5	4	6	7	7
D	22-Jul	5	7	5	5	6	7
D	14-Sep	5	6	5	4	6	6
D	5-Nov	8	6	6	6	9	9
D	5-Dec	8	8	7	7	10	10
D	5-Jan	7	7	6	7	9	9
D	10-Feb	8	7	7	6	10	10