Self-Organizing Step-Pool System Restoration in Wildcat Creek in Tilden Park, Berkeley, California: Benthic Macroinvertebrate Community Response

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ABSTRACT

To stabilize stream bed channels and maximize its maximum biological community potential, stream restoration projects should closely heed to a stream's natural geomorphology. The objectives of this study are to 1) study how in-stream habitats form in high-gradient stream systems and 2) examine how benthic macroinvertebrate (BMI) communities form along with these in-stream habitats. To collect BMIs, I used a hard-frame D-net at reference and experimental reaches. After calculating bioassessment metrics using the BMI data, I used an analysis of variance (ANOVA) to analyze reference and experimental reach similarities and to examine how in-stream habitats differed with pre- and post- restoration BMI data. The two-way ANOVA between pre-restoration experimental and reference bioassessment metrics were generally not significantly different ($p > 0.05$), in contrast to post-restoration data. The three in-stream habitat types (e.g., pools, steps, and riffles) were significantly different ($p < 0.05$) for most pre-restoration bioassessment metrics. Non-metric multidimensional scaling (NMS) was also used to compare all pre- and post- restoration BMI communities concurrently. Post-restoration in-stream habitat types were generally not significantly distinct among one another. The NMS community analysis suggests that post-restoration in-stream habitat communities were more similar than pre-restoration conditions due to seasonality and underdeveloped in-stream habitat structures caused by the restoration.

KEYWORDS

high-gradient stream, urban system, geomorphological significance, stream engineering, bioassessment

INTRODUCTION

Stream restoration can repair a deteriorating ecosystem as well as helping surrounding communities that may be affected by stream erosion, flooding, and deposition (Shields et al. 2003). In order to stabilize streams and avoid future erosions, flooding and deposition, stream restoration projects should closely maintain stream's geomorphology. Matters concerning stream geomorphology focus on the range of its sloped areas. When constructing a stream restoration project based upon its geomorphology of step-pool systems should be taken into account and will help control its different flow patterns (Morris 1995). Step-pool systems should be considered for stream restoration projects in steep terrain/high sloping areas that have a higher chance of undergoing sedimentation destabilization than low sloping areas.

Natural step-pools are bedforms, which are areas throughout a stream that develop according to its stream flow and geomorphology, that usually occur in steep mountain streams as a result of slopes that are usually greater than 2% and consists of steps (accrual of boulders and cobbles), pools (filled by finer sediments), and occasionally riffles (exposed stones, sand, and gravel) (McCulloch 1986 and Chin and Wohl 2005). Step-pools cause beneficial hydraulic resistance within a stream, lessening the potential and kinetic energy components that would increase occurrences of sediment transport and erosion (Chin and Wohl 2005). Embedding step-pool systems into a stream requires accurate consideration of increased or decreased frequency and magnitude of peak water discharges, increased o reduced sediment supplies, and augmentation/reductions in streamflow (Chin et al. 2009A). These step-pools generate a size contrast of sediments and a sporadic staircase-like longitudinal profile (Chin and Wohl 2005) in a stream that help shape maximum bed stability, which is the major stabilization characteristic for steep streams (Weichert et al. 2008). Past stream restoration projects have consisted of fixed step-pool systems, which is when the step-pools are systematically placed at carefully measured intervals throughout the stream. On the other hand, the effectiveness of self-organizing step-pool systems, which is when different gradients of rocks, pebbles and sediments are placed upstream and theoretically travel downstream and naturally form step-pools, is currently unknown.

Benthic macroinvertebrates can be used as bioassessment tools in determining whether fixed versus self-organizing step-pool systems are more effective for a stream's ecological community. Benthic macroinvertebrate community bioassessment help determine a stream's biological condition (e.g., revealing localized healthy/degraded conditions and water quality monitoring) (Wang et al. 2009). Macroinvertebrates virtually reside in all streams, are normally abundant, and are affected by factors such as physical (e.g., vegetation, streamflow) and chemical disturbances (e.g., dissolved O2 concentrations, acidity, pollutants), and stream morphology (e.g., straightening and channelization) (Purcell et al. 2002 and Spaenhoff and Arle 2007). Also, decreased streamflow leads to: 1) decreases or increases benthic macroinvertebrate abundance and 2) benthic macroinvertebrate richness almost always diminishes as a result of decreases in habitat diversity (caused by the decreased streamflow) (Dewson et al. 2007). Benthic macroinvertebrates serve as bioindicators that integrate the effects of short-term and long-term variables (Wang et al. 2009) and are reasonably easy to sample, they are informative components when trying to assess a step-pool stream restoration project's ecological effectiveness. Previous stream restoration projects in high-sloping areas have shown an inclination towards elevated physical qualities in micro habitats that are beneficial for benthic macroinvertebrate in streams that utilize fixed step-pools versus those that are not fixed step (Chin et al. 2009B). Despite these conclusions, academic knowledge lacks in benthic macroinvertebrate response to habitat change in restorations that involve self-organizing step-pools (Chin et al. 2009A and Chin et al. 2009B).

The objectives of this study in Wildcat Creek of Berkeley, California are to 1) study how in-stream habitats form in high-gradient stream systems and 2) examine how benthic macroinvertebrate (BMI) communities form along with these in-stream habitats. I hypothesized that high-gradient in-stream habitats develop into step-pool systems in order to dissipate the maximum amount of stream energy. I also hypothesized that benthic macroinvertebrate diversity will gradually become richer as the in-stream habitats become more developed. More developed in-stream habitats can provide more stable micro-habitats for benthic macroinvertebrate diversity to flourish.

METHODS

Study design

Wildcat Creek, a 21.6 kilometers long stream, is located between San Pablo Ridge and Berkeley Hills, ultimately expelling into Contra Costa County, through the San Pablo Bay. The two sampling locations will be located in Wildcat Creek.

One sampling location was the restoration area (also referred to as the self-organizing experimental reach), which is 54 meters of Wildcat Creek in the Tilden Park Golf course. The second sampling location was the reference site, which was 49 meters of Wildcat Creek upstream of the Padre Group Picnic Area *(*Fig.1).

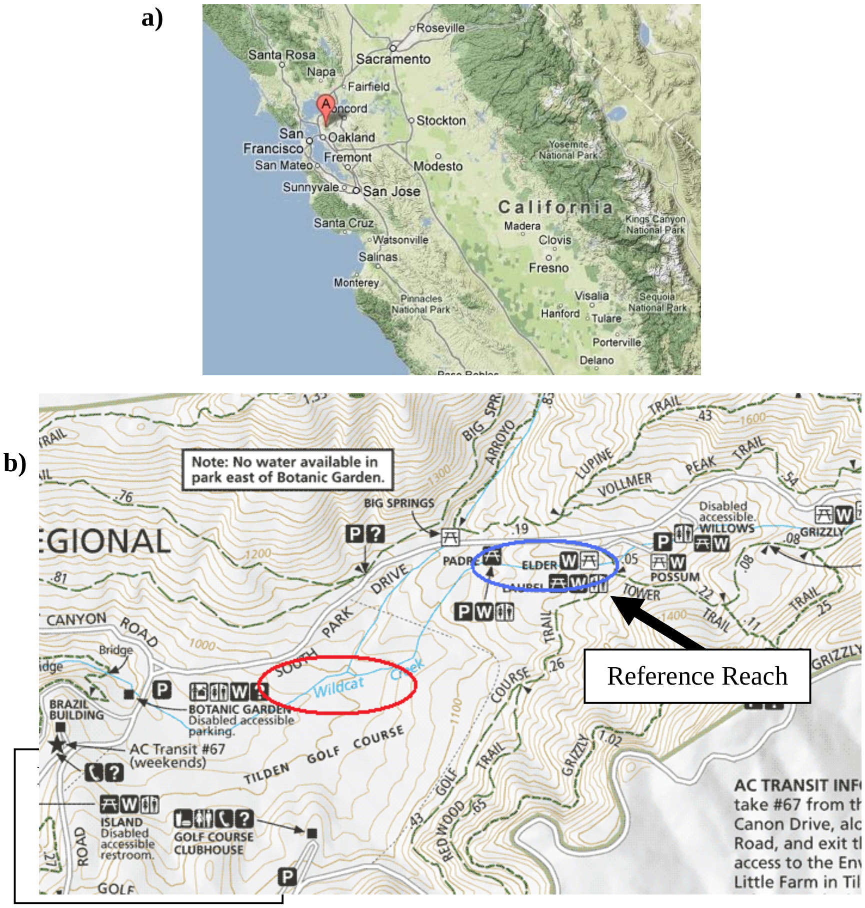

Figure 1. Study Design Location. a) Study design situated in Northern California. b) Reference and experimental reaches located within Padre Group Picnic Area and Tilden Golf Course respectively.

Data sources

There were two periods of sampling benthic macroinvertebrates at the reference and experimental reaches: pre-restoration period (Aug 2012) and post-restoration period (December 2013). Prior to the pre-restoration sampling, a research permit was obtained through the East Bay Regional Park District. Dr. Patina Mendez and I collected collect 7 step-pool pairs and 6 riffle samples at the reference site for all three sampling periods. During the pre-restoration period, 4 steps, 8 pools, and 6 riffles were sampled in the self-organizing experimental reach. 4 step, 4 pool and 6 riffle samples were sampled in the self-organizing experimental reach.

For the self-organizing experimental reach, we started downstream and ran a 100 meter tape through the channel's middle 54 meters upstream to avoid disturbance in the downstream samples. At the reference site, we started downstream and ran a 100 meter tape through the channel's middle 49 meters upstream. To have reference spots for future sampling and to aid in my data analysis, we demarcated each step, pool and riffle that was sampled. The date, time, tape distance, GPS coordinates, width and height of step, a sketch looking up stream, and the intermediate axis length of the 5 largest rocks in the step were recorded for each sample.

Data processing

Benthic macroinvertebrate sampling: pools and riffles

While agitating the pool/riffle's bottom with my foot for one minute, I swooped through the water with a hard-frame D-net (Stein et al. 2008) in order to collect benthic macroinvertebrates.

Benthic macroinvertebrate sampling: steps

In order to collect benthic macroinvertebrates, I placed a flexible D-net on the step's downstream side while Dr. Mendez agitated the rocks at the top of the step for 1 minute. We made sure to sample all ports of the step (e.g., if water flows down at more than one part). Those samples were poured into a white tub filled with 2 to 3 inches of clear water.

Preservation of samples

I poured each sample separately into a white rectangular tub about 2 to 3 inches deep that was filled with clear water from the stream and eradicated large leaves, sticks and large rocks during this process (prior to removal of these contents, I examined and doused them in the white tub). To preserve the samples, I sieved them through a #35 micron sieve and transfer it into a plastic Ziploc bag with 95% ethanol.

Sorting and identification of samples

I sorted and identified each sample to the family level separately prior to statistical analysis. I sieved the samples through a #35 micron sieve and transferred it into a rectangular white tub filled with approximately 1.5 inches of de-ionized water. I filled a small vial with 75% ethanol and place a label with the sample site's location into that vial. Using a petri dish with 4 partitions, I filled each partition with approximately 1 tablespoon of the white tub's contents (which was filled with the sample currently being sorted). Through a microscope, I observed and removed the BMIs with forceps. After fully sorting the contents in the white tub, I identified and sorted the benthic macroinvertebrates in vials according to their family and recorded the identifications onto an excel spreadsheet.

Analysis

Bioassessment metrics

Various bioassessment metrics (Table 1) were calculate. Bioassessment metrics calculate benthic macroinvertebrate assemble processes and elements (Barbour et al. 1999). The bioassessment metrics calculated focused on diversity and composition, richness, composition structure, tolerance/intolerance, and feeding measures to help assess comparisons and BMI community changes in the reference and experimental reaches and among in-stream habitats. With the calculated bioassessment metrics, I examined comparisons between the pre-restoration reference and experimental reaches and analyzed post-restoration comparisons among in-stream habitats (steps, pools and riffles) using an analysis of variance (ANOVA) model (Li et al. 2001).

Table 1. Various benthic metrics (Barbour et al. 1999 and Mendez 2007)

Community Measure	**Metric**	**Description**
Diversity and Composition		
	Total Abundance	Sum of BMI individuals
	Total EPT Individuals	Sum of EPT BMI individuals
Richness Measures - Representation of sample's diversity		
	Family Richness	Measures the overall variety of the macroinvertebrate assemblage. A higher richness implies higher habitat diversity generally is associated with higher water quality.
	EPT Richness	# of taxa in the orders Ephemeroptera, Plecoptera, and Trichoptera. Higher EPT scores imply higher water quality.
Composition Structure - Determines proportion of sample/community made up of individual taxa.		
	% EPT Abundance	% of the individuals in the sample which belong to the following pollution sensitive orders of aquatic insects (EPT).
	Ratio of EPT to EPT + C Abundance	Uses the relative abundance of indicator groups (EPT and Chironomidae) as a measure of community balance.
	% Contribution of Dominant Taxon	Uses the % contribution of the dominant taxon related to the total number of organism. A community dominated by relatively few families (a high %) would indicate environmental stress.
Tolerance/Intolerance Measures - Representative of the relative sensitivity to perturbation.		
	Family Biotic Index	Hilsenhoff's (1988) Family Biotic Index (FBI) uses tolerance values on a 0 (low tolerance) to 10 (high tolerance) scale based on individual aquatic insect family tolerance to organic pollution.
Feeding Measures - Encompass functional feeding groups and provide information on the balance of feeding strategies in the benthic assemblage.		
	% Scraper Abundance	
	% Filtering-Collector Abundance	
	% Shredder Abundance	
	% Predator Abundance	
	% Gatherer-Collector Abundance	

Visually comparing ecological communities

For each metric calculated, I calculated a box plot of the average benthic metric calculated. I used these box plots to help visualize the findings from the averaged bioassessment values.

Similarity/variations among benthic communities: a multivariate approach

Utilizing non-metric multidimensional scaling (NMS), which is a multivariate approach (Roy et al. 2003), will display how these benthic macroinvertebrate communities might be similar or different all at once. Family names and abundances will be used when calculating values for NMS.

RESULTS

Analysis of bioassessment metrics

Reach comparisons

I found all pre-restoration bioassessment metrics (Table 2), except for % scraper abundance, not significantly different between the reference and experimental reaches (Table 4, Figure 2). These findings suggest that that the reference and experimental reaches are comparable in terms of metrics for steps, pools and riffles.

I found an increase in significantly differences (Table 6, Figure 3) for post-restoration bioassessment metrics between the reference and experimental reaches (Table 3). The two-way ANOVA tests comparing post-restoration reference and experimental reach bioassessment metrics exhibited significant differences in composition measures (e.g., % contribution of dominant taxon), tolerance/intolerance measures (e.g., family biotic index), and feeding measures (e.g., % scraper abundance, % gatherer-collector abundance).

In-stream habitat comparisons

I analyzed significant differences (Table 4, Figure 3) in bioassessment metrics among pre-restoration in-stream habitat types (Table 2) that were characteristic of diversity and composition, composition measures and feeding measures. The pre-restoration bioassessment metrics among the in-stream habitat types that were significantly different were total abundance, total EPT abundance, % contribution of dominant taxon, % scraper abundance, % filtering-collector abundance, and % gatherer-collector abundance (Table 4). The majority of post-restoration bioassessment metrics among the in-stream habitat types (Table 3) were not significantly different (Table 5, Figure 3). The family richness, % scraper abundance, and % gatherer-collector abundance were significantly different for the post-restoration in-stream habitats from the two-way ANOVA.

Table 2. Pre-Restoration average values of bioassessment metrics. I averaged the pre-restoration bioassessment metric means and standard deviations from three different in-stream habitat sites.

Bioassessment Metrics	Reach	In-Stream Habitat		
		Step	Pool	Riffle
Diversity and Composition				
Total Abundance	Reference	613.7 ± 320.5	894.3 ± 303.1	170.3 ± 138.6
	Experimental	429.6 ± 91.0	2060.3 ± 1253.4	308.0 ± 300.8
Total EPT Individuals	Reference	270.6 ± 114.5	657.3 ± 275.9	110.0 ± 107.8
	Experimental	251.33 ± 151.91	691.33 ± 211.40	203.00 ± 214.42
Community Structure				
Family Richness	Reference	22.3 ± 2.1	23.0 ± 2.6	17.7 ± 2.9
	Experimental	20.0 ± 3.6	9.7 ± 3.8	8.0 ± 6.7
EPT Richness	Reference	8.3 ± 1.2	9.7 ± 1.5	8.0 ± 1.0
	Experimental	9.0 ± 0.0	8.3 ± 2.1	7.7 ± 2.3
Composition Structure				
% EPT Abundance	Reference	45.6 ± 4.7	71.8 ± 11.8	58.2 ± 12.1
	Experimental	55.5 ± 21.3	43.8 ± 32.2	55.7 ± 23.9
Ratio of EPT to EPT + C Abundance	Reference	0.7 ± 0.0	0.8 ± 0.1	0.7 ± 0.1
	Experimental	0.7 ± 0.3	0.5 ± 0.3	0.7 ± 0.3
% Contribution of Dominant Taxon	Reference	28.8 ± 5.1	39.2 ± 10.7	34.2 ± 5.5
	Experimental	34.6 ± 16.9	62.6 ± 11.3	31.8 ± 19.9
Tolerance/Intolerance Measures				
Family Biotic Index	Reference	5.1 ± 0.1	3.9 ± 0.7	4.5 ± 0.2
	Experimental	4.5 ± 0.4	4.4 ± 1.0	4.3 ± 0.6
Feeding Measures				
% Predator Abundance	Reference	3.1 ± 0.6	2.7 ± 0.6	6.1 ± 0.1
	Experimental	5.5 ± 3.3	3.2 ± 1.9	6.4 ± 3.4
% Scraper Abundance	Reference	5.9 ± 0.7	2.7 ± 1.9	4.0 ± 0.9
	Experimental	9.5 ± 3.6	2.6 ± 3.1	20.3 ± 8.0
% Shredder Abundance	Reference	5.9 ± 1.7	6.4 ± 2.2	7.1 ± 0.9
	Experimental	13.1 ± 2.8	3.2 ± 4.8	10.0 ± 3.2
% Predator Abundance	Reference	35.0 ± 7.2	9.3 ± 4.5	10.7 ± 6.4
	Experimental	25.1 ± 16.5	2.2 ± 1.0	11.1 ± 7.2
% Gatherer-Collector Abundance	Reference	50.2 ± 9.0	78.9 ± 7.2	72.2 ± 5.7
	Experimental	46.8 ± 23.4	88.9 ± 7.1	52.3 ± 4.4

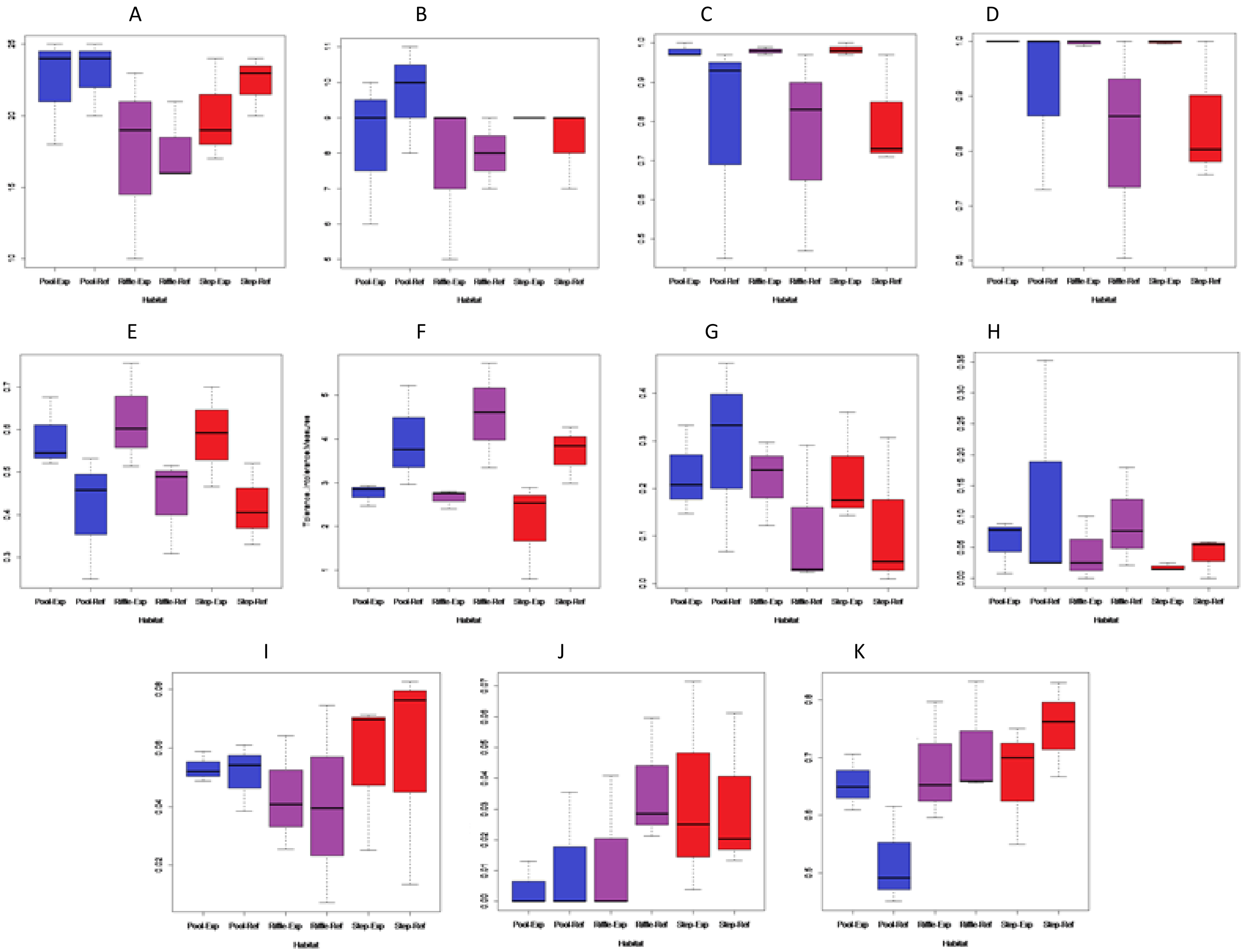

Figure 2. Boxplots of pre-restoration bioassessment metric values. I depicted the values used for the pre-restoration mean and standard deviations into their respective bioassessment metrics with boxplots. The in-stream habitats are displayed as: pools (blue), riffles (purple), and steps (red). Each in-stream habitat has a value from the experimental (left side) and reference (right side) reaches. A) Family Richness. B) EPT Richness. C) % EPT Abundance. D) Ratio of EPT to EPT + C Abundance. E) % Contribution of Dominant Taxon. F) Family Biotic Index. G) % Scraper Abundance. H) % Filtering-Collector Abundance. I) % Shredder Abundance. J) % Predator Abundance. K) % Gatherer-Collector Abundance.

Table 3. Post-Restoration average values of bioassessment metrics. I averaged the post-restoration bioassessment metric means and standard deviations from three different in-stream habitat sites.

Bioassessment Metrics	Reach	In-Stream Habitat		
		Step	Pool	Riffle
Diversity and Composition				
Total Abundance	Reference	114.00 ± 35.68	87.33 ± 48.69	42.00 ± 32.08
	Experimental	107.67 ± 34.49	84.33 ± 48.01	39.33 ± 32.93
Total EPT Individuals	Reference	103.00 ± 23.58	115.67 ± 123.35	85.67 ± 28.04
	Experimental	100.67 ± 22.90	114.00 ± 121.31	84.00 ± 26.85
Community Structure				
Family Richness	Reference	11.3 ± 2.5	7.0 ± 1.0	7.0 ± 1.7
	Experimental	8.3 ± 0.6	7.7 ± 1.5	8.0 ± 1.7
EPT Richness	Reference	6.7 ± 1.5	5.0 ± 1.0	5.7 ± 0.6
	Experimental	6.3 ± 1.5	6.3 ± 0.6	6.7 ± 1.5
Composition Structure				
% EPT Abundance	Reference	94.3 ± 1.3	96.0 ± 2.2	90.1 ± 15.1
	Experimental	97.7 ± 1.2	98.8 ± 1.1	98.2 ± 1.6
Ratio of EPT to EPT + C Abundance	Reference	1.00 ± 0.00	1.00 ± 0.00	0.96 ± 0.06
	Experimental	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
% Contribution of Dominant Taxon	Reference	48.9 ± 5.8	49.6 ± 13.2	47.0 ± 7.4
	Experimental	52.7 ± 15.4	64.0 ± 4.6	62.3 ± 9.7
Tolerance/Intolerance Measures				
Family Biotic Index	Reference	3.5 ± 0.3	3.9 ± 1.6	2.9 ± 0.4
	Experimental	2.8 ± 0.1	2.0 ± 1.1	2.6 ± 0.2
Feeding Measures				
% Predator Abundance	Reference	1.6 ± 1.5	3.3 ± 2.8	2.8 ± 2.5
	Experimental	0.4 ± 0.7	2.3 ± 1.9	2.4 ± 4.1
% Scraper Abundance	Reference	49.2 ± 5.9	26.4 ± 6.0	31.1 ± 2.7
	Experimental	26.0 ± 6.5	21.9 ± 12.5	19.6 ± 8.8
% Shredder Abundance	Reference	8.6 ± 4.0	1.4 ± 0.7	11.5 ± 9.9
	Experimental	5.5 ± 0.8	4.5 ± 2.3	5.2 ± 2.4
% Predator Abundance	Reference	4.5 ± 1.8	2.2 ± 2.2	6.9 ± 9.8
	Experimental	6.2 ± 4.8	1.4 ± 1.3	4.3 ± 4.0
% Gatherer-Collector Abundance	Reference	36.1 ± 7.9	66.7 ± 0.7	48.1 ± 22.0
	Experimental	61.8 ± 2.8	69.9 ± 13.1	68.6 ± 2.9

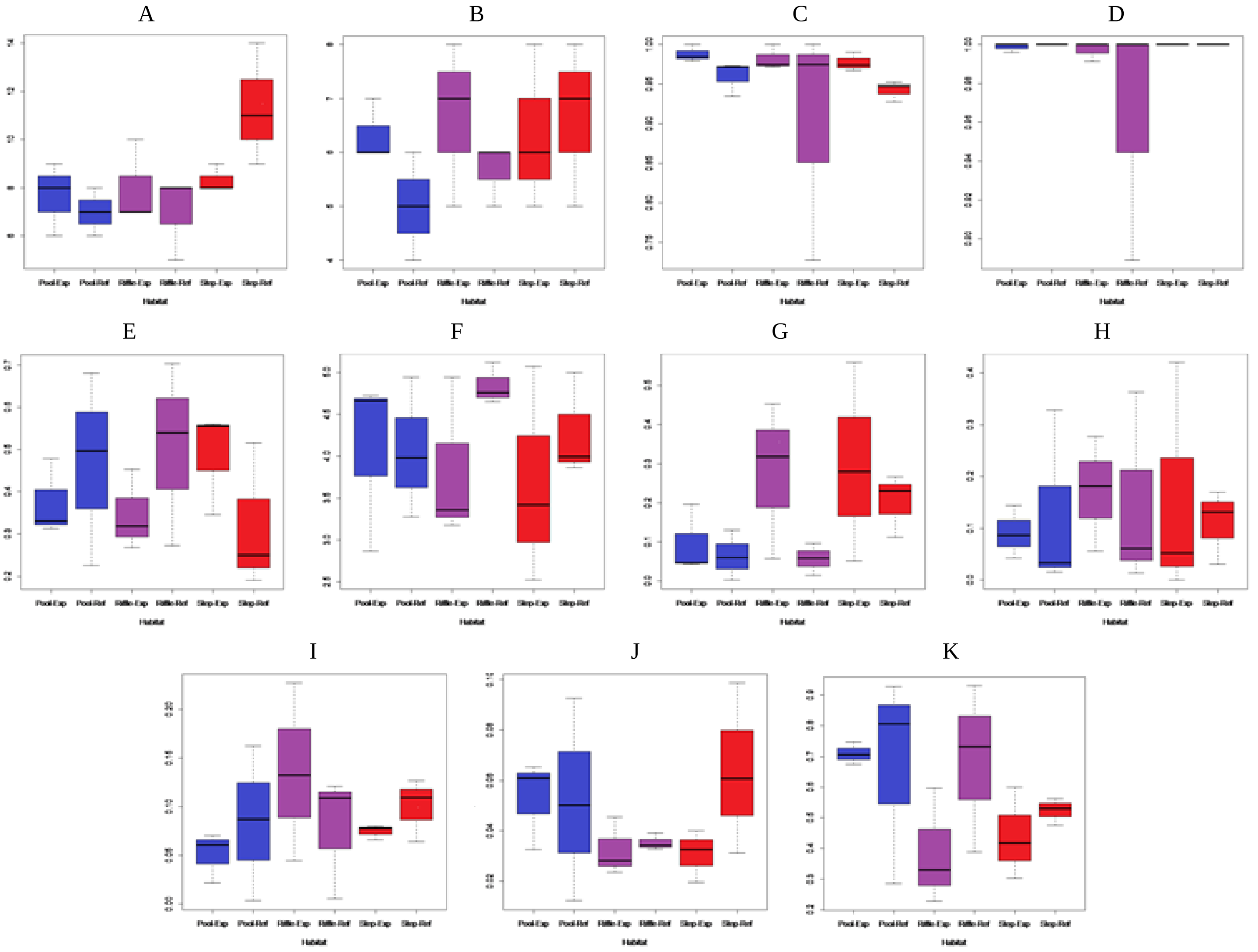

Figure 3. Boxplots of post-restoration bioassessment metric values. I depicted the values used for the post-restoration mean and standard deviations into their respective bioassessment metrics with boxplots. The in-stream habitats are displayed as: pools (blue), riffles (purple), and steps (red). Each in-stream habitat has a value from the experimental (left side) and reference (right side) reaches. A) Family Richness. B) EPT Richness. C) % EPT Abundance. D) Ratio of EPT to EPT + C Abundance. E) % Contribution of Dominant Taxon. F) Family Biotic Index. G) % Scraper Abundance. H) % Filtering-Collector Abundance. I) % Shredder Abundance. J) % Predator Abundance. K) % Gatherer-Collector Abundance.

Table 4. Pre-Restoration Two-Way ANOVA Tests Results. I conducted a Two-Way ANOVA to determine whether the reference and experimental sites were comparable in terms of bioassessment metrics for steps, pools, and riffles.

	***p* values**	
Bioassessment Metrics	**In-Stream Habitat**	**Site**
Diversity and Composition		
Total Abundance	**0.0011***	0.6944
Total EPT Abundance	**0.0061***	0.1830
Richness Measures		
Family Richness	0.1015	0.5570
EPT Richness	0.4297	0.6555
Composition Measures		
%EPT Abundance	0.7917	0.4775
Ratio of EPT to EPT + C Abundance	0.7925	0.3220
% Contribution of Dominant Taxon	**0.0312***	0.1436
Tolerance/Intolerance Measures		
Family Biotic Index	0.2771	0.6642
Feeding Measures		
% Scraper Abundance	**0.0042***	**0.0037***
% Filtering-Collector Abundance	**0.0009***	0.1924
% Shredder Abundance	0.0369	0.1171
% Predator Abundance	0.0602	0.2998
% Gatherer-Collector Abundance	**0.0006***	0.4276

Statistically significant *p* values ($p < 0.05$) are asterisked (*) and highlighted in bold. Site refers to the experimental and reference reaches.

Table 5. Post-Restoration Two-Way ANOVA Tests Results. I conducted a Two-Way ANOVA to determine whether there were differences among the in-stream habitats and between the experimental and reference reaches.

	***p* values**	
Bioassessment Metrics	**In-Stream Habitat**	**Site**
Diversity and Composition		
Total Abundance	0.4039	0.4823
Total EPT Abundance	0.4155	0.4316
Richness Measures		
Family Richness	**0.0370***	0.5744
EPT Richness	0.5018	0.2621
Composition Measures		
%EPT Abundance	0.6768	0.1316
Ratio of EPT to EPT + C Abundance	0.3592	0.3941
% Contribution of Dominant Taxon	0.5110	**0.0206***
Tolerance/Intolerance Measures		
Family Biotic Index	0.7419	**0.0352***
Feeding Measures		
% Scraper Abundance	**0.0189***	**0.0036***
% Filtering-Collector Abundance	0.3520	0.8134
% Shredder Abundance	0.1467	0.3469
% Predator	0.4143	0.9680
% Gatherer-Collector Abundance	**0.0335***	**0.0082***

Statistically significant *p* values ($p < 0.05$) are asterisked (*) and highlighted in bold. Site refers to the experimental and reference reaches.

Multivariate approach: benthic community analysis

The first two NMS axes explained a collective total of 81.8 % of the variability in the family abundances observed (Figure 3). The first axis explained 59.4 % of the variability. The second axis explained 22.4% of the variability.

In terms of the pre-restoration and post-restoration samples, the NMS analysis shows that they are visually separated on axis NMS2 by their seasons (i.e. summer and winter). Within those summer and winter seasons of sampling, axis NMS1 shows the summer in-stream habitats with more separation in comparison to the winter in-stream habitats.

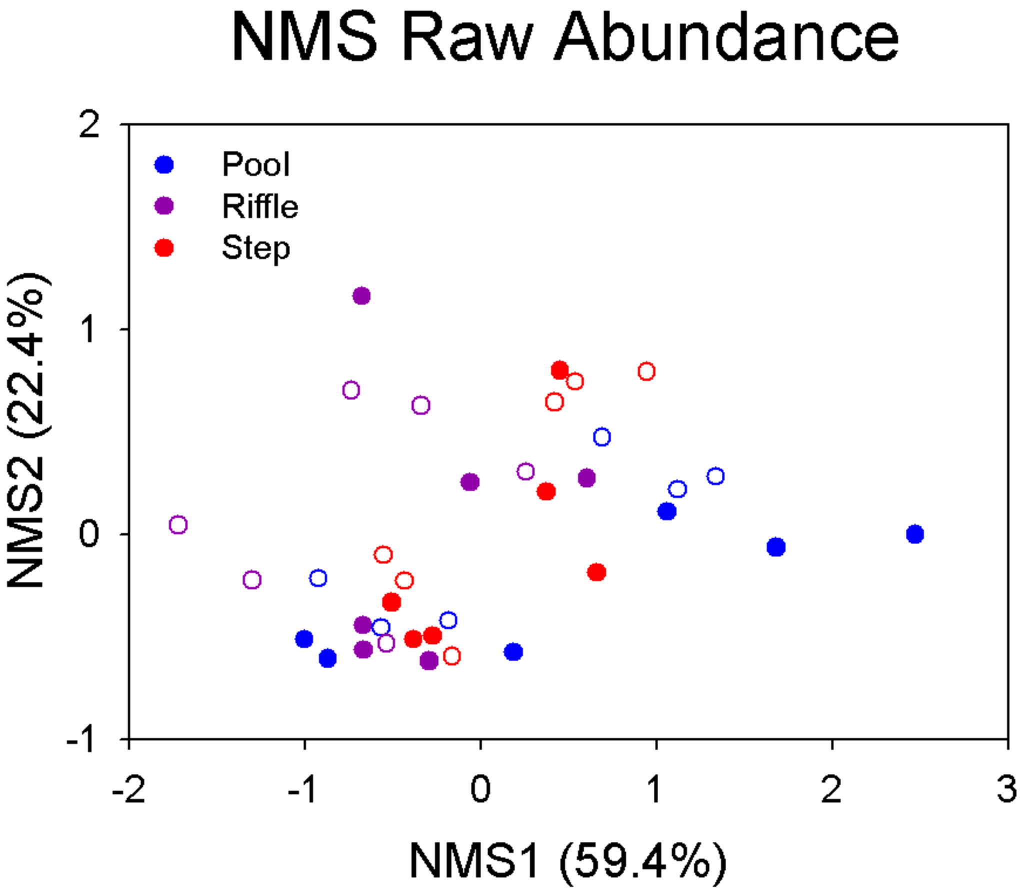

Figure 4. NMS of family distribution grouped by in-stream habitats. Axes NMS1 and NMS2 represent in-stream habitat types and seasons respectively.

DISCUSSION

BMI community development following self-organizing step-pool stream restoration conditions suggests a process-based development in terms of in-stream habitat structures and BMI community richness (Voelz et al. 2000). In this study, I assessed whether a reference and experimental reach were comparable and how their in-stream habitats (i.e. steps, pools and riffles) differed prior to a restoration project. Following the restoration project, I assessed whether the experimental reach in-stream habitats differed and how those in-stream habitats compared to those of the reference reach. I found that BMI pre-restoration reference and experimental reach conditions were comparable. Immediately after the restoration project, I found a lack of significant differences among the experimental reach in-stream habitats in terms of BMI diversity and composition, richness, and feeding measures. I also observed less significant differences among in-stream BMI communities during post-restoration conditions for the reference and experimental reaches. This suggests that immediate post-restored streams have rapid colonization of new in-stream habitats, yet the richness among these new in-stream habitats are not distinct from one another. This study also suggests that self-organizing step-pool restorations changes BMI diversity, but not the seasonality of BMI life stages (Boyle and Fraleigh 2003).

Anthropogenic and seasonal considerations

The lack of significant differences in the bioassessment metrics examined between the pre-restoration reference and experimental reaches suggests that the sites are comparable. Although benthic macroinvertebrate richness in terms of the percentage of sensitive taxa found may differ, overall density should not differ in these communities when comparing the upstream reference reach and downstream experimental reach (Stranko et al. 2012). The reference reach's significantly higher % scraper abundance suggests that the reference reach is healthier than the experimental reach (Park et al. 2008). Because the experimental reach was situated in a more anthropogenic prevalent area (i.e. Tilden Golf Course), anthropogenic practices such as insecticide and fertilizer use may have affected the availability and quality of food – especially for specialist function feeding groups that are more susceptible to disturbances (Zilli et al. 2008). Overall macroinvertebrate richness depends on feeding resources and hydraulic characteristics such as water velocity, pollutant levels (Alvarez-Cabria et al. 2011), geographical factors (i.e. latitude and longitude), and climate gradient (Beauchard et al. 2003). Because the reference and experimental reaches were somewhat in water velocity and minimum pollutant levels, their overall macroinvertebrate abundance and richness levels were not significantly different.

The increase of significant differences in the bioassessment metrics examined between the post-restoration reference and experimental reaches shows that the experimental reach has yet to recover and the reference and experimental reaches are less comparable than they were during pre-restoration conditions (Stranko et al. 2012). The post-restoration experimental reach's significantly higher % contribution of dominant taxon suggests more unbalanced and stressed environment than the reference reach (Park et al. 2008). The post-restoration's significantly higher family biotic index suggests that the restoration conditions led to BMI communities with higher tolerance to organic pollution (Barbour et al. 1999**)**. Although the family biotic index metric is usually utilized for pollutant perturbations, this metric can also be utilized for physical perturbations that affect organic pollutant levels. The significantly lower values in % scraper abundance and % gatherer-collector abundance for the post-restoration experimental reach conditions reflect more an unhealthier environment, less fine particulate organic matter, and more lotic habitats than the reference reach (Chin et al. 2009A). Because the in-stream habitats throughout the experimental reach recently underwent the apparent restoration conditions, they step-pool system has yet to fully form to effectively dissipate energy characteristic throughout its steep gradient (Chin et al. 2009A).

Geomorphological processes: in-stream habitat formation

By comparing several metrics, I quantified a comparison between macroinvertebrate richness and biota density (Purcell et al. 2002). Because there were a larger percentage of sensitive benthic macroinvertebrate families in steps when compared with pools and riffles in the pre-restoration than post-restoration period, this suggests that the restored experimental reach has yet to form towards significantly similar pre-restoration step-pool frequency conditions that would have helped dissipate flow energy in the most efficient manner (Chin 1999, Chin et al. 2009B, and Curran 2007). However, the significantly higher family richness among the post-restoration steps suggests that the newly formed steps have begun to dissipate enough flow energy, similar to more developed steps.

Although macroinvertebrates have a high resilience in terms of recovery and recolonization (Voelz et al. 2000), they are characteristic of being very sensitive to disturbances (both physically and chemically). Macroinvertebrate sensitivity is apparent in the experimental reach post-restoration in-stream habitats' feeding measure metrics. However, the lack of in-stream diversity and composition significant differences suggests that the in-stream habitats are very similar and have not completely formed their distinctly different microhabitat characteristics.

Limitations and future directions

Environmental pollutants (pollutant runoff into the experimental reach from the golf course), and location differences may have critically affected the benthic macroinvertebrate richness and density findings. The indistinct post-restoration experimental in-stream habitats were caused by two factors: 1) the lack of time for the BMI communities to evolve after the restoration and 2) habitats are less distinct in the winter, as suggested by the NMS community analysis. This was because we only studied half a seasonal cycle after the restoration cycle. Although other studies have found that seasonal variability most likely does not need to be considered in interpretations, future studies should try to monitor this restoration project for several seasons to analyze the BMI community development in relation to the stream's morphological changes (Stark and Phillips 2009).

Further studies that also monitor stream flow during pre- and post-restoration macroinvertebrate development would be beneficial in examining how trophic levels of a stream's food web alters over time (Mcintosh et al. 2008). Also urban factors at both the reference and experimental (though minor factors) may have limited overall benthic macroinvertebrate density and richness (Louhi et al. 2011), skewing accurate findings from the ANOVA tests.

Broader implications

From a self-organizing step-pool system restoration in Wildcat Creek in California, I conclude that over time, post-restoration benthic macroinvertebrate communities and step-pool frequencies will develop in a manner similar to pre-restoration and reference site conditions despite the restoration's physical disturbance on the experimental reach. Additionally, differences between step and pool macroinvertebrate richness and density remain similar despite the pre- and post- restoration sampling periods. Thus, self-organizing step-pool systems mirror physical (step-pool habitats) and biological (benthic macroinvertebrate communities) characteristics of natural occurring step-pool systems.

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