Renewing Urban Streams with Recycled Water:
Evaluating the Effects of Tertiary Treated Water on Freshwater Biodiversity

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ABSTRACT

Urban water infrastructure should be redesigned to improve ecological conditions by counteracting the deleterious effects of anthropogenic influences on the natural flow regime of streams in Mediterranean climate regions. Calera Creek in Pacifica, California, was selected as a case study of an innovative, small-scale wastewater treatment plant that was designed with the intention to rehabilitate a highly degraded riparian ecosystem to provide both ecological and aesthetic benefits. The effluent released from this treatment plant is tertiary treated through a state-of-the-art process involving a sequencing batch reactor (SBR) and ultraviolet disinfection. This is a higher level of treatment than is often used for discharges to streams and rivers. Quarterly water quality measurements taken by the treatment facility reflected that the effluent is higher in temperature, lower in dissolved oxygen, and lower in ammonia nitrogen than upstream water, depending on the season. Physical habitat surveys showed more optimal habitat downstream of the recycled water output due primarily to increased bank vegetation and higher stream velocity, although the higher flows were provided in unnatural diurnal pulses because of the SBR. Initial assessments using benthic macroinvertebrates as biological indicators revealed a significant decrease in taxa richness in the summer in Calera Creek, a significant increase in % Amphipoda in the spring, and a significant reduction in Shannon diversity in both seasons. Compared to the downstream reach of the reference stream in spring, the downstream reach of Calera Creek was significantly lower in taxa richness, Shannon diversity, %EPT, and higher in %Amphipoda. In contrast, the Shannon diversity index in spring was significantly higher in the upstream reach of Calera Creek than in the upstream reach of the reference stream. In summer, the only significant difference between Calera Creek and the reference site was a lower Shannon diversity in Calera Creek downstream compared to the reference site downstream. This project illustrates that the ecological outcome of a habitat restoration project involving recycled water in a Mediterranean climate region is highly seasonal and such projects will require seasonal considerations. This study will guide future restoration efforts leading to better management of urban watersheds to meet ecosystem needs and protect freshwater biodiversity.

KEYWORDS

flow augmentation; resource recovery; benthic macroinvertebrates; biological monitoring; stream restoration

INTRODUCTION

Ecological communities are threatened in urban streams by alterations to water quality and the natural flow regime, which includes streamflow’s magnitude, frequency, duration, timing, and rate of change (Poff et al. 1997). For example, aquatic organisms in urban streams are subject to intensified disturbances, such as larger temperature spikes, greater chemical exposure, more dramatic fluctuations in nutrient input, higher floods, and more severe droughts (Paul and Meyer 2001**.** Stream inhabitants are adapted to natural seasonal variations, such as cool, wet winters and hot, dry summers in Mediterranean climate regions (Gasith and Resh 1999). Despite the organisms' adaptability to large natural environmental variations, extreme environmental variability from urbanization and climate change can result in habitat loss and consequent reductions in freshwater biodiversity (Booth et al. 2004; Konrad and Booth 2005).

Tertiary treated wastewater that approaches drinking water standards (i.e., recycled water) is one potential source that may be used by watershed managers to augment streamflow during periods of extreme low flow in summer and thereby provide an overall benefit to streams degraded by urban sprawl. However, if the releases that augment streamflow result in poor water quality or highly unnatural hydrological regimes, they can negatively impact aquatic biota and ecosystem processes (Benda et al. 2002). For example, effluent released at timed intervals from a wastewater treatment plant throughout the day can create a highly unnatural flow regime. Higher temperatures are also a common characteristic of recycled effluent, and can affect aquatic communities more than other physical or chemical factors (Lamberti and Resh 1983). Projects that attempt to restore urban streams must tailor to the natural flow regime. However, case studies of recycled water used for streamflow augmentation to date lack a comprehensive biological assessment that includes benthic macroinvertebrate communities (Bischel et al. 2012).

A comprehensive assessment must encompass both abiotic and biotic factors because habitat features and species assemblages are inherently intertwined (Schaeffer et al. 1988; Reynoldson and Metcalfe-Smith 1992). For example, benthic macroinvertebrates are freshwater organisms that exhibit a wide range of responses to changes in water quality and physical habitat. In addition to changes in benthic community composition, emergence pattern, foraging behavior, and survival rates might shift as a result of an altered flow regime (Dallas and Rivers-Moore

2012). The coupling of physical and biological systems is a very active area of current research in stream ecology (e.g., Belmar et al. 2012; Ceola 2013, Maskell et al. 2013).

This objective of this study was to measure the response of benthic macroinvertebrate communities in an urban stream that was augmented with recycled water as part of an innovative habitat restoration project in a Mediterranean climate region. I predicted that there would be differences in the benthic macroinvertebrate communities above and below the recycled water discharge point because the augmented flow created water-quality conditions and habitats that were different from those historically present in this basin. Under a negative impact scenario, the benthic macroinvertebrate community downstream of the discharge was expected to exhibit: (1) less taxonomic diversity, fewer pollution-sensitive organisms, and (2) less seasonal variation in community structure, relative to both upstream and a nearby reference site.

METHODS

Study site

I investigated Calera Creek Water Recycling Plant, which is a tertiary-level treatment facility that services the city of Pacifica, California (37°36' N; 122°29' W). The treatment plant includes a sequencing batch reactor (which is an innovative process not found in most older plants that enhances efficiency by combining the basins for aeration and clarification), it incorporates ultraviolet (UV) disinfection at the end of the treatment train, and it directly discharges its tertiary treated effluent into the adjacent Calera Creek (Figure 1). Part of the facility's design goals was to rehabilitate wetland ecosystems (Lee 1996). The riparian area surrounding the creek is now a park that has been enjoyed by the community since the plant began operation in 2000. Ecological assessments have been conducted at the site, such as frog and vegetation surveys, but do not include assessments of benthic macroinvertebrates that live in the stream habitat (Pacifica, 2010). San Pedro Creek served as a reference site for this project. Similar in stream order, it lies two miles south of Calera Creek, and has no recycled water input (Figure 1).

Fig. 1. Map of study sites along Calera Creek (recycled water input) and San Pedro Creek (reference site). Points labeled 1 through 5 are where benthic macroinvertebrate samples were taken.

Data collection

Water quality parameters

The Calera Creek Water Recycling Plant measures the water quality along the creek once every three months. The monitoring is conducted with handheld instruments, and water samples are brought into the laboratory for additional chemical analysis. Temperature, dissolved oxygen, and pH are measured using a HACH HQ 40 d meter device. Ammonia nitrogen is determined by first distilling the water samples using Labconco Rapid Still, then the concentration is determined using an Orion 920A Ph/ISE meter and Orion Ammonia gas sensing electrode. I communicated with the plant operator and acquired the data collected on April 18th and July 18th of 2012.

Physical habitat assessment

To evaluate the physical habitat differences between upstream and downstream sites, a visual habitat assessment was conducted. As a part of the EPA Rapid Assessment Protocol, physical parameters such as bank erosion and vegetation coverage were ranked on a scale of 1 to 20, with stream conditions matched to standardized descriptions (Barbour et al. 1999). This allows for quantifying qualitative means and determining the validity of comparing different stream sites to each other (Maddock 1999).

Benthic macroinvertebrates

Benthic macroinvertebrates are aquatic organisms that are ubiquitous in stream environments, relatively long lived, exhibit a wide spectrum of tolerance values to pollution, and are extensively used as biological indicators (Rosenberg and Resh 1993). I selected benthic macroinvertebrate sampling sites to correspond with the locations where water samples were taken by the facility (Figure 1). There are two sites above the treatment plant, one at the outlet, and two downstream of the effluent discharge. I collected benthic macroinvertebrates on the same field days the facility conducted their quarterly measurements in the spring and summer. I also sampled at five sites along the reference stream, San Pedro Creek, based on both point of access and an attempt to approximate similar elevations as the sites selected along Calera Creek.

Field sampling. Using the EPA Rapid Assessment Protocol (Barbour et al. 1999), I collected three replicate benthic macroinvertebrate samples within a 100-m reach at each site. I used a 0.5mm mesh D-frame kicknet to capture material in the streamflow moving downstream. I disturbed the stream substrate for 1-minute to standardize each collection. All the organic and inorganic materials were preserved in 70% ethanol in Ziploc bags.

Laboratory processing. I first sorted the samples by separating the benthic macroinvertebrates from debris (e.g., leaf litter and substrate). The individuals were then identified to the family level using taxonomic dichotomous keys (Harrington and Born 2003, McCafferty 1981, Merritt et al. 2008) and stored in 4ml borosilicate clear glass vials with phenolic cap. All organisms in the samples were identified to family level and were counted for abundance.

Statistical analysis

To quantify and characterize the benthic macroinvertebrate communities in the stream, I calculated six bioassessment metrics, including both structural and functional measures: (1) abundance measures the total number of individuals at each site; (2) taxa richness measures diversity by counting the families of organisms in the sample; (3) shannon's diversity (H') is a biotic index that accounts for both the species richness and evenness (Eq. 1), in which R is number of taxa present and p_i is the proportional abundance of a particular taxa;

$$H' = -\sum_{i=1}^{R} p_i \ln p_i$$

Eq. 1 (Hill 1973)

(4) the percent EPT metric is the weighted abundance of three insect orders that are particularly sensitive to pollution (e.g., Ephemeroptera, Plecoptera, and Trichoptera); 5) the percent Amphipoda metric is the proportion of the generalist organism, amphipods, relative to the benthic macroinvertebrate population; 6) lastly, in addition to these structural metrics, I also investigated the percent filter-feeders functional metric.

I conducted a Welch's t-test, which accounts for unequal variances, to explore the differences between upstream and impacted sites at Calera Creek, across seasons, and against the reference stream.

RESULTS

Water quality parameters

The greatest impacts on water quality were observed for water temperature, with lesser impacts observed for dissolved oxygen, pH, and ammonia (Table 1). For example, water temperature spiked by about 6 ºC in the spring and 9 ºC in the summer upon recycled water impact at Site 3, then gradually cooled downstream. Dissolved oxygen was lower below the wastewater discharge outlet during the spring by 1.4 mg/L, but higher in the summer by 1.55 mg/L. The pH level dropped by 0.36 in the spring and 0.05 in the summer upon effluent discharge at site 3, but rose above pre-impact level at Site 4 by 0.62 in the spring and 0.39 in the summer. Ammonia nitrogen declined downstream in the spring, but increased downstream and was more variable in the summer.

Table 1. Hydrological parameters at sampling sites along Calera Creek. Quarterly data provided by the treatment plant facility. Spring measurements were taken on April 18, 2012; summer measurements were taken on July 18, 2012. Measurements were not taken at Site 1.

Season	*Hydrological Parameter*	Upstream		Impacted		
		Site 1	*Site 2*	*Site 3*	*Site 4*	*Site 5*
Spring	Temperature (ºC)	-	12.3	18.2	16.8	17.0
	pH	-	7.58	7.22	7.84	7.86
	Ammonia nitrogen (mg/L)	-	0.165	0.084	0.066	0.059
	Dissolved oxygen (mg/L)	-	10.21	8.84	9.54	9.51
Summer	Temperature (ºC)	-	14.6	23.3	19.9	19.8
	pH	-	7.21	7.16	7.55	7.72
	Ammonia nitrogen (mg/L)	-	0.036	0.053	0.044	0.040
	Dissolved oxygen (mg/L)	-	6.57	8.12	8.68	8.35

Physical habitat assessment

Along Calera Creek, the physical conditions downstream received a higher score than those upstream, and the greatest differences between upstream and downstream were observed in the streamflow velocity parameter. For example, recycled water input at sites 3, 4, and 5 occurred year-round, and thus streamflow downstream was perennial. In contrast, streamflow above the treatment plant dried up in the summer (i.e., ephemeral flow). As a result of its proximity to the point of recycled water discharge, site 3 showed minimal bottom substrate or instream cover (5), a low pool/riffle ratio (5), and poor substrate embeddedness in sediment (5).

Table 2. Comparison of habitat assessment scores at sampling sites along Calera Creek.

Habitat Parameter	Upstream		Impacted		
	Site 1	*Site 2*	*Site 3*	*Site 4*	*Site 5*
Bottom substrate/instream cover	14	15	5	18	17
Embeddedness	14	18	5	19	18
Stream flow/velocity	1	3	2,20*	15,20*	15,20*
Canopy cover	14	17	17	18	18
Channel alteration	16	19	18	18	18
Pool/riffle ratio	14	18	5	18	15
Bank stability	10/10	9/10	10/10	10/10	10/9
Bank vegetative protection	10/7	9/9	9/9	10/10	10/10
Streamside cover	15	20	15	18	19
Riparian vegetation zone width	5/5	8/10	10/10	10/10	10/10
Total Score	**135**	**165**	**125-143**	**187-189**	**179-184**

* indicates stream flow/velocity parameter during effluent release
/ separates the left and right bank scores, respectively

Benthic macroinvertebrates

I observed differences in benthic macroinvertebrate communities above and below the wastewater discharge at Calera Creek that were dependent on season. In the spring, for example, total abundance was lower upstream (110 at Site 1, 338 at Site 2), peaked at 1,082 number of individuals just below the discharge, and rapidly declined downstream (812 at Site 4, 465 at Site 5) (Figure 2). In contrast, in summer, the number of individuals was relatively low just below the discharge compared to some of the sites farther upstream and downstream. Taxa richness and percent EPT dropped upon the wastewater input (in mean ± s.d, 14 ± 1 to 5 ± 1, and 15.7% ± 9.5% to 0.0% ± 0.0%, respectively) (Figure 2). Abundance fluctuated irregularly in the summer, while other metrics followed a relatively similar pattern to that of spring. Compared to Calera Creek, the reference stream (i.e. San Pedro Creek) had more consistent metric values among all of the five sites examined (Figure 2).

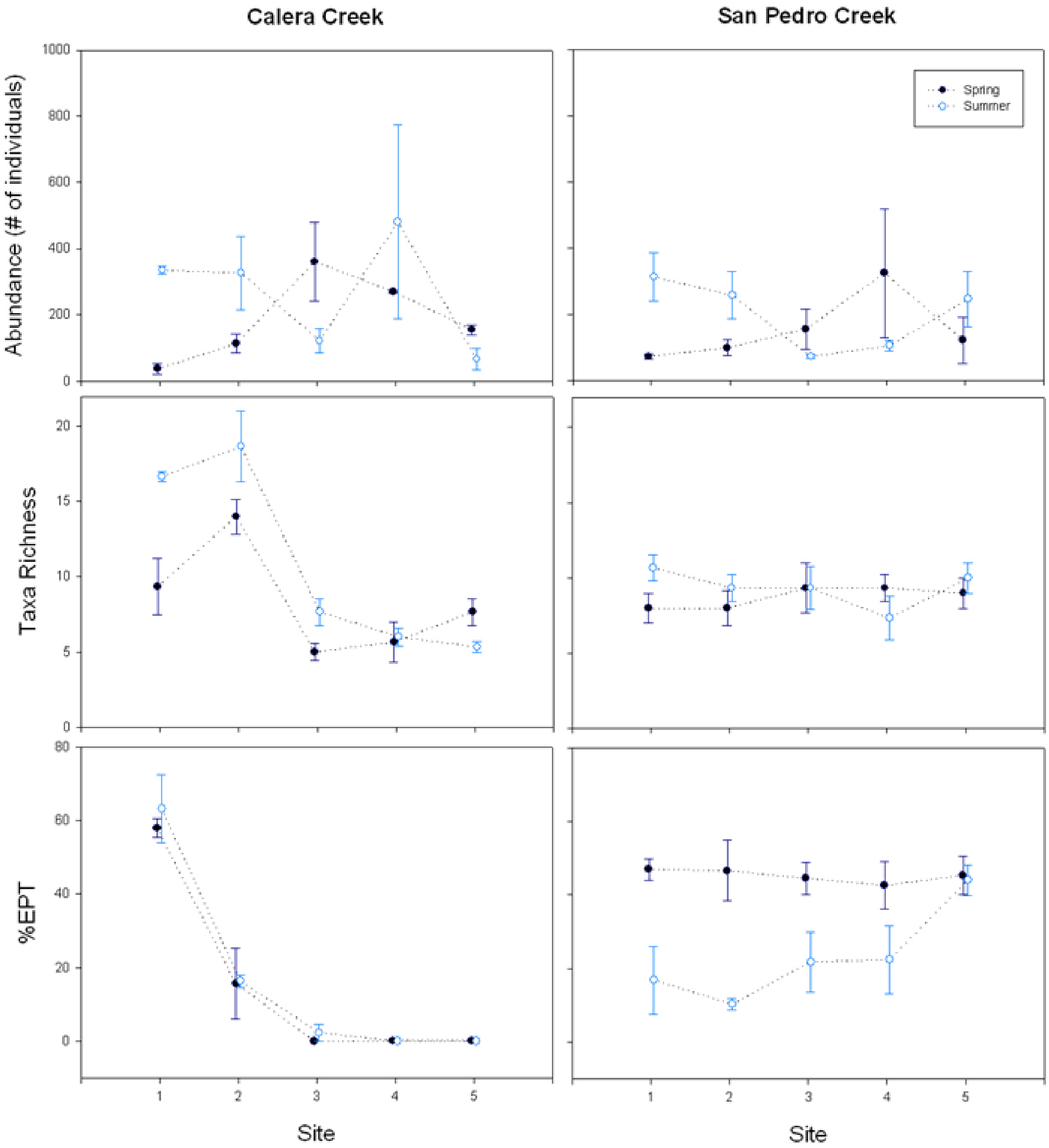

Fig. 2. Calculated metrics of Calera Creek and San Pedro Creek. Select metrics: Abundance, Taxa Richness, and %EPT.

Statistical analysis

Within Calera Creek, Welch's t-tests revealed significant differences that were seasonally dependent. For example, Shannon's diversity index was significantly lower downstream of the recycled water input in both seasons (Table 5). In the spring, percent Amphipoda was significantly greater downstream of the recycled water discharge, but the difference was not significant in the summer (Table 5). In summer, taxa richness was significantly lower downstream of the effluent, but the difference was not significant in the spring (Table 5).

Table 5. Calculated select metrics at Calera Creek, comparing Upstream and Impacted collections.

	Spring			**Summer**		
Metrics	Upstream	Impacted	p-value	Upstream	Impacted	p-value
Abundance	224(161)	786(327)	0.0858	991(17)	669(676)	0.4956
Taxa richness	19(3)	9(2)	0.0665	26(4)	10(4)	0.0283*
Shannon(H')	2.2(0.0)	0.7(0.1)	0.0008*	2.1(0.2)	0.9(0.2)	0.0284*
%EPT	35.5(29.6)	0.1(0.1)	0.3406	39.5(34.3)	0.5(0.8)	0.3542
%Amphipoda	4.5(6.3)	84.0(2.3)	0.0236*	14.3(19.9)	59.4(31.0)	0.1420
%Filter Feeders	5.3(1.6)	2.4(1.8)	0.1703	5.0(0.6)	6.1(9.1)	0.8650

*indicates $p<0.05$

Metrics comparing Calera Creek to the reference site using Welch's t-test also revealed several significant differences that were dependent on the season. In the spring, for example, Shannon diversity index is significantly lower in the reference site upstream compared to Calera Creek upstream. In contrast, in the downstream sites, taxa richness, Shannon diversity, and percent EPT were significantly higher in the reference stream than in Calera Creek, whereas percent Amphipoda was significantly lower in the reference stream. Considering the summer, only the Shannon diversity metric in the downstream reaches is significantly different between Calera Creek and the reference site, and it continues to be lower in Calera Creek (Table 6).

Table 6. Calculated select metrics at Calera Creek and San Pedro Creek (reference site) in the Spring and Summer.

Spring	**Upstream**			**Downstream**		
Metrics	Calera	San Pedro	p-value	Calera	San Pedro	p-value
Abundance	224(161)	257(57)	0.82	786(327)	602(327)	0.53
Richness	19(3)	13(1)	0.17	9(2)	13(2)	0.06*
Shannon(H')	2.2(0.0)	1.5(0.1)	0.05*	0.7(0.1)	1.3(0.2)	0.03*
%EPT	36(30)	46(2.4)	0.71	0.1(0.1)	41(2.5)	0.001*
%Amphipoda	4.5(6.3)	0.8(0.4)	0.56	84(2.3)	0.5(0.6)	0.0001*
%Filter Feeders	5.3(1.6)	1.0(0.1)	0.16	2.4(1.8)	2.0(0.9)	0.78

Summer						
Metrics	Calera	San Pedro	p-value	Calera	San Pedro	p-value
Abundance	991(17)	858(121)	0.36	669(676)	423(277)	0.61
Richness	26(4)	16(4)	0.14	10(4)	13(1)	0.26
Shannon(H')	2.1(0.2)	1.3(0.1)	0.12	0.9(0.2)	1.5(0.2)	0.03*
%EPT	39.5(34.3)	12.3(1.8)	0.46	0.5(0.8)	30.2(14.4)	0.07
%Amphipoda	14.3(19.9)	0.1(0.1)	0.50	59.4(31.0)	1.0(0.7)	0.08
%Filter Feeders	5.0(0.6)	52.0(6.1)	0.06	6.1(9.1)	9.6(7.5)	0.63

*indicates $p<0.05$

DISCUSSION

Habitat metrics

The physical habitat value scores showed that the physical conditions were more optimal downstream of the recycled water input, which was largely because of the bank vegetation that was planted as a part of the restoration effort as well as the increased flow from the treatment plant. However, there is an inherent issue in the subjectivity of assigning scores based on visual assessment techniques (Fritz et al. 2006). While the valuation did not take into account the physicochemical properties of water, it is a measurement of the habitat form and function that juxtaposes the benthic macroinvertebrate data (Barbour et al. 1992). Linking ecological theory with stream restoration efforts is just as important as the physical beautification aspect that aims at improving aesthetics of urbanized streams (Hart and Finelli 1999; Lake et al. 2007).

Although the higher physical habitat scores downstream of the recycled water discharge imply the potential to support healthier aquatic communities, the benthic macroinvertebrate metrics nonetheless suggest a stressed community, which is in fact often the case below wastewater treatment plants. For example, reductions in benthic macroinvertebrate taxa richness, declines in %EPT, and increases in the abundances of cosmopolitan species, such as aquatic amphipods, have been shown in many other studies to be a sign of impact from wastewater treatment plants (e.g., Lydy et al. 2000; Álvarez-Cabria et al. 2011; Grantham et al. 2012).

Even though the habitat and biological metrics demonstrate that the environment created downstream of the effluent induced differences in the biotic and abiotic interactions and ultimately shifted assemblage structure and watershed ecosystem dynamics, Calera Creek is in better condition than it was prior to the restoration. Thus this project can be considered a success. Further upgrades to the treatment plant may result in even greater success in terms of ecology.

Benthic macroinvertebrate metrics

Benthic macroinvertebrate assemblage data showed that the intended ecologically beneficial effect of the tertiary treated water has not been fully realized, although some benefits have been achieved in terms of the revitalization of a federally listed California red-legged frog population and reduced adult mosquito abundances downstream (Halaburka et al. *In review*). The higher total abundance of benthic macroinvertebrates observed downstream might be driven by the heightened stream temperature that facilitates more primary production (Lamberti and Steinman 1997), although the observed abundances were not significantly different above and below the discharge given the very high variability in this metric. The lowere percent EPT metric downstream of the recycled water discharge implies that the effluent cultivates an environment that is more suitable for cosmopolitan or pollution-tolerant taxa, which in this case were primarily amphipods and aquatic earthworms. The numerical dominance of these taxa is potentially reflective of the unnatural flow regime and water quality problems (Biles et al. 2003). Potential variables that were measured which could have contributed to this include water temperature, dissolved oxygen, and nutrient availability, which have been found to favor pollution tolerant taxa in other studies (Lamberti and Resh 1983, Odume and Miller 2011, Drury et al. 2013). No correlation could be drawn between the benthic macroinvertebrates and the water pH level and ammonia nitrogen concentration, possibly because of seasonal fluxes.

The downstream habitats in Calera Creek are profusely dominated by the amphipod *Hyalella azteca* (Rogers 2005), which is a cryptic species that is polyphyletic and currently in the process of being described (Witt et al. 2006; Graening et al 2012). The genus *Hyalella* is a common grazer in freshwater habitat that is hardy in the sense that it can survive in a wide range of temperature and nutrient conditions (Wellborn et al. 2005). However, *Hyalella* are sensitive to pesticide pollution, such as pyrethroids (Weston et al. 2004; Amweg et al. 2005). They are present in the upstream habitat in Calera Creek as well, but with lower abundance, as reflected by the Shannon diversity index. In the case where multiple species are differentiated, potential implications include a higher richness in the benthic macroinvertebrate community downstream if the specimens were identified to a higher taxonomic resolution than family. Lastly, more life history information on *Hyallela* would allow better inferences to be drawn on their behavior.

The Natural Flow Regime

Many streams in Mediterranean climate regions tend to dry up in the arid summer seasons (i.e. they are often ephemeral); annual cycles of abiotic influences and biotic responses to predictable seasonal events are expected (Gasith and Resh 1999). As demonstrated by the collections from the reference site, San Pedro Creek did reveal a detectable difference in %EPT over the summer, whereas the spring and summer %EPT measurements in the downstream reaches of Calera Creek did not. This is so because the sites at Calera Creek continue to receive recycled water inputs even during seasons when they would expect natural dryness to occur.

Moreover, the treatment plant uses the SBR that releases water in pulses resulting in sudden elevation in water flow at high velocity. Some treatment plants use SBRs because they combine the basins for aeration and clarification, allowing for more effective and efficient sedimentation and nutrient removal than the continuous-flow systems that are more common in old plants (Prendergast et al. 2005). The lowered percent filter-feeders downstream of the recycled water output could be reflective of lowered suspended organic matter that is available for these specialized organisms. A similar response has been observed by Rosi-Marshall (2004) in a previous study in which suspended fine particulate organic matter as food resource for aquatic insects was degraded. One hypothesis is that the particulate organic matter gets flushed down the stream by these relatively large diurnal pulses, or direct mortality by force. An alternative hypothesis is that the treatment plant removes so much of the suspended organic matter during its treatment train with the SBR that insufficient food remains for these organisms.

Limitations and future directions

This study is an exploratory project that attempted to determine if differences could be detected in the stream ecosystem at an innovative water utility that used recycled water for habitat restoration. The information generated provides a valuable baseline for future studies at this site as well as comparative studies at other sites. The number of samples collected in this study was tightly constrained by time and budgetary considerations, and thus the statistical power of the variables measured was not maximized. If such a study was commissioned by a federal, state, or local agency, they would likely have much more resources at their disposal. Some ways to improve the study design include collecting more replicates of benthic macroinvertebrate samples at each site (e.g., 5 samples instead of 3), taking water measurements on shorter time intervals (e.g. hourly or monthly instead of quarterly), or comparing more streams with augmented flows to better understand site-specificities.

This project could also benefit from future research that seeks a better understanding of life history of the organisms that are able to survive in recycled water habitats. These types of habitats are almost certain to become more prevalent in the future as the human population grows and urban water infrastructure is reinvented to better balance the needs of humans and the environment. Perhaps the less diverse benthic macroinvertebrate community observed downstream of the tertiary treated effluent in this study is not as prominent as it would be in cases where the water is not tertiary-treated, and also the diversity observed may have in fact have been higher downstream if the samples were instead identified to genus or species level.

Moreover, maximizing taxonomic diversity should not necessarily be the chief goal in conservation. Some argue that preservation of evolutionary lineages should be a higher priority than preservation of species (e.g., it may be better to preserve two species that are on two disparate branches of the tree of life than three species that are at the end of the same branch). Future studies that compare stream communities in similar geographic settings at higher taxonomic resolution between tertiary treated recycled water input and secondary treated wastewater input (e.g., Carey and Migliaccio 2009) will help address these pressing questions. A combined approach considering structural, functional, and molecular data would be best.

Implications for management

Using recycled water for ecosystem benefit is a novel idea that requires further research that evaluates the anthropogenic impact on watershed ecology. One potential application of addressing ecosystem dynamic would be the tailored use of recycled water, in which effluent is released depending on the quality and quantity needed by the system (Achilli et al. 2009). For instance, if the aquatic insects are adapted to cooler temperature, heat in the recycled water output could potentially be dissipated by evaporative cooling, effluent flow blending, wetland treatment, or cooling towers (Polson 2009). In real policy contexts, conservation efforts and development options are often evaluated on a scale to determine the monetary value of an operation (Turner et al. 2010). The importance of freshwater biodiversity should be recognized since it is in rapid decline, yet many of the ecosystem services that society values is dependent on diversity richness (Dudgeon et al. 2006). Understanding how the ecology is impacted by anthropogenic activity is a step forward for the public to become better stewards of the environment so that human waste can be managed without jeopardizing the integrity of nature.

ACKNOWLEDGEMENTS

To my family and friends that are ever so supportive, you are in all of these pages. I want to especially thank my mentors −Dr. Vincent Resh and Dr. Justin Lawrence − for introducing me to the field of aquatic ecology and providing a safe space that allowed me to develop as a scientist. This project would not have been possible without the invaluable feedback from Patina Mendez, Nick Cash, Ryan Salladay, Katrina Velasco, Sara Winsemius, Howard Li, Amy Foo, and Chris Pavia. One quick shout out to Essig Museum's Pete Oboyski for his infectious enthusiasm for bugs of all sorts; he helped identified many of my unknowns. A sincere thank you to Mike Peterson, Carrie Cizauskas, Ken Schwab, Oscar Chang, Houston Wilson, and Blanca Rios Touma − for their never-ending patience at answering my R and statistical inquiries. Finally, much love to all the volunteers that assisted in the process of counting/identifying over 13,000 insects (Alan Bach, Bianca Safai, Connor Jackson, David Strachan-Olson, Elyse Will, Erika So, Franny Diehl, Jenny Bratburd, Maya Garcia, Pete Moniz, Vicheth Kaing, Vivian Hsiao, and Winni Wang), I want to be at all of your weddings. This project is a collective effort and I am genuinely grateful for all the incredible people in my life.

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