The Initial Effects of Restoration on Macroinvertebrate Populations in Sausal Creek, Alameda County, California.

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Abstract Post-restoration evaluations are important in assessing the success of restoration strategies. Macroinvertebrates are important in post-restoration evaluations because they can affect stream conditions, and fish populations, which in turn affect the entire creek ecosystem. Thus, it is important to understand the successional period for macroinvertebrates after the restoration process. Water quality monitoring programs use macroinvertebrates as indicators of water quality, so a better understanding of successional processes in aquatic environments can reduce errors in water quality monitoring. In this study, the macroinvertebrate population in a urban creek restored 3 months ago in Oakland, CA was compared to other unrestored areas in the same creek, as well as an unrestored area in another creek in the same watershed. The restored site had lower EPT compared to the unrestored sites. The restored site also had a lower FBI, lower family richness, higher horsehair worm abundance, and lower Baetidae abundance compared to the unrestored sites. Macroinvertebrate composition changed after restoration, but did not decrease in abundance. These differences are probably due to the disturbance in the restored area caused by the restoration project. These results determined that with a low intensity small scale restoration, there can be no significant change in nutrient cycling or food availability for fish. The results also showed that recently restored habitats give inaccurate pollution estimates when monitored using macroinvertebrate populations.

Introduction

River and stream restoration projects are becoming popular in California and other parts of the United States (Kondolf 1998, Rhoads et al. 1999, Bryant 1995) due to the increased public awareness concerning the connection of stream health with community health (Middleton 2001). In recent years, it has become apparent that many of these projects lack post-restoration evaluations (Holmes 1991, Roper et al. 1997, Bryant 1995), and thus there is little known about the after effects of these projects. In evaluations done by Frissel and Nawa (1992) and O'Neil and Fitch (1992) it was found that most aquatic enhancement projects were ineffective or in some cases even detrimental to the aquatic environments. Understanding the reason for the high failure rate in restoration projects is important for increasing the success rate of these projects. A well studied unsuccessful project may be more valuable than an unstudied successful project, because then the reasons for failure can be understood and mistakes will be less likely to be repeated in the future (Kondolf 1995). Therefore, post-restoration evaluations are important to understanding the effects of restoration projects, which will lead to better planning of restoration projects.

There have been a few post-restoration evaluations done on macroinvertebrate population recovery after disturbance. In one restoration project there was a significant decrease in macroinvertebrate abundance, and diversity, and the recovery period of the community was on the scale of 1-3 years (Laasonen et al. 1998). The author concluded that the decrease in macroinvertebrate populations was caused by community disturbance from restoration. However, another study showed no significant species level or community level changes in macroinvertebrates within 10 days after restoration (Tikkanen et al. 1994). But, there was a distinct difference in the type of restoration performed in the two studies. The first study, which showed significant declines in macroinvertebrate abundance and long recovery periods, altered the stream bed, channel and riparian zone over a large area, while the second study, which showed no significant change in the macroinvertebrate community and a short recovery period, involved digging a few holes and inserting boulders in the stream bed over a smaller area. Thus, the intensity of the restoration probably has a major effect on the decline and recovery of macroinvertebrate populations.

The few studies conducted on disturbance affects on macroinvertebrate populations have similar conclusions. In one experiment at high intensity disturbance levels, macroinvertebrate abundance declined to almost zero (Quigley et al. 1999). In another study, less intensive disturbances to the aquatic community resulted in significant declines in macroinvertebrate abundance, but not a macroinvertebrate population crash as seen in the previous experiment (Englund 1991). Thus, the intensity of the disturbance is an important determinant of macroinvertebrate response to disturbance.

Stream restoration projects with similar intensity to the one in the Lassonen et al. (1998) study, but on a smaller scale, are common in urban stream restorations seen in California today. So, if the change in macroinvertebrate populations noticed by Lassonen et al. (1998) was caused by disturbance from restoration, there should be a similar reduction in macroinvertebrate abundance and diversity in these California restoration projects. But, since many of these restorations are done on a smaller scale than in the Lassonen et al. 1998 study, the reduction in macroinvertebrate abundance is probably less drastic. Also, the reduction in macroinvertebrate abundance could also be different, because the environmental conditions are different in California than in northern Europe, where all the other studies were conducted. These differences are mainly due to the dry season that occurs in California, and does not occur in northern Europe. Aquatic insects are sensitive to the change in water level and flow rate (Schowalter 2000), which occurs in the dry season in California. Thus, I hypothesized that there would be a decrease in macroinvertebrate abundance after small scale stream restorations in California, but scaling differences and environmental differences might result in reductions that differ from previous studies.

To examine the effects of small scale aquatic restoration projects on the macroinvertebrate populations in California, I chose to study Sausal Creek located in the Dimond Canyon watershed in Oakland, California. From May 2001 to November 2001 approximately 185m of Sausal Creek was restored by removing creek channelization, stabilizing the stream bank, removing concrete dams and planting native riparian vegetation (Sausal Creek Restoration in Dimond Canyon Project Description, March 2000)

Studying this initial recolonization of the restored area by macroinvertebrates is important for several reasons. First, it will give insight into the succession of aquatic ecosystems after disturbance. Most restored streams and creeks that are monitored after restoration are not monitored until many years after their restoration. This may be due to lack of funding, or the fact that many researchers believe that steady-state environments are more important in post-restoration evaluations (Laasonen et al. 1998). Yet, many researchers have realized the need to evaluate the biological effects of stream restoration on the macroinvertebrate community (Gortz et al. 1998, Friberg et al. 1994), because macroinvertebrates play a critical role in the nutrient processing and organic energy cycling in lotic environments (Merritt et al. 1996). Most of the organic matter that enters a stream is ingested and excreted by macroinvertebrates many times along the length of a stream. Macroinvertebrates also are food for fish, which could influence fish population dynamics (Gortz et al. 1998). Thus, the successional process for macroinvertebrates after the restoration process can greatly affect stream conditions, and fish populations, which in turn affect the entire creek ecosystem.

Second, macroinvertebrates are used as bioindicators of stream health (Merritt et al. 1996). Thus, macroinvertebrate surveys of restored areas could conclude that pollutants are a factor, when in actuality the stream is still recovering from the disturbance of restoration. Therefore, a better understanding of successional processes in aquatic environments can reduce errors in water quality monitoring.

Methods

Sausal Creek is a second order creek in the Dimond Canyon watershed in Oakland, Alameda County, California. Palo Seco Creek and Shephard Creek are the two tributaries in the Dimond Canyon watershed that drain into Sausal Creek (Fig.1).

Macroinvertebrates were sampled once a week from February 2002 to April 2002 at four sites: the restored site, a site 500 m upstream from the restored site, a site 500 m downstream of the restoration site, and Palo Seco creek, a tributary of Sausal Creek that is less anthropogenically impacted. At each site, five separate samples were taken 35 m apart. On each sampling date, samples were taken 1 m further upstream than the previous sampling location to prevent disturbance from the previous week's sampling. At the 185 m restored site of Sausal Creek sampling began 5 m downstream from the furthest upstream restoration point to 5 m upstream from the furthest downstream restoration point. At each sample location a .3 mm mesh D frame net was used to sample .6 m^2 of substrate selected at a random location in the creek cross section. All medium and large rocks within .6 m upstream of the net were picked up and rubbed by hand for 1.5 minutes, allowing the detached macroinvertebrates to float downstream into the net. Then the pebbles and sediments were kicked for 30 seconds. All organisms caught in the net were transferred to a 95 percent ethanol solution and stored for family level identification in the lab. Each day the current weather conditions, weather conditions of the last 24 hours and air temperature were recorded to account for variations in the macroinvertebrate populations due to these factors (Barbour et al. 1999).

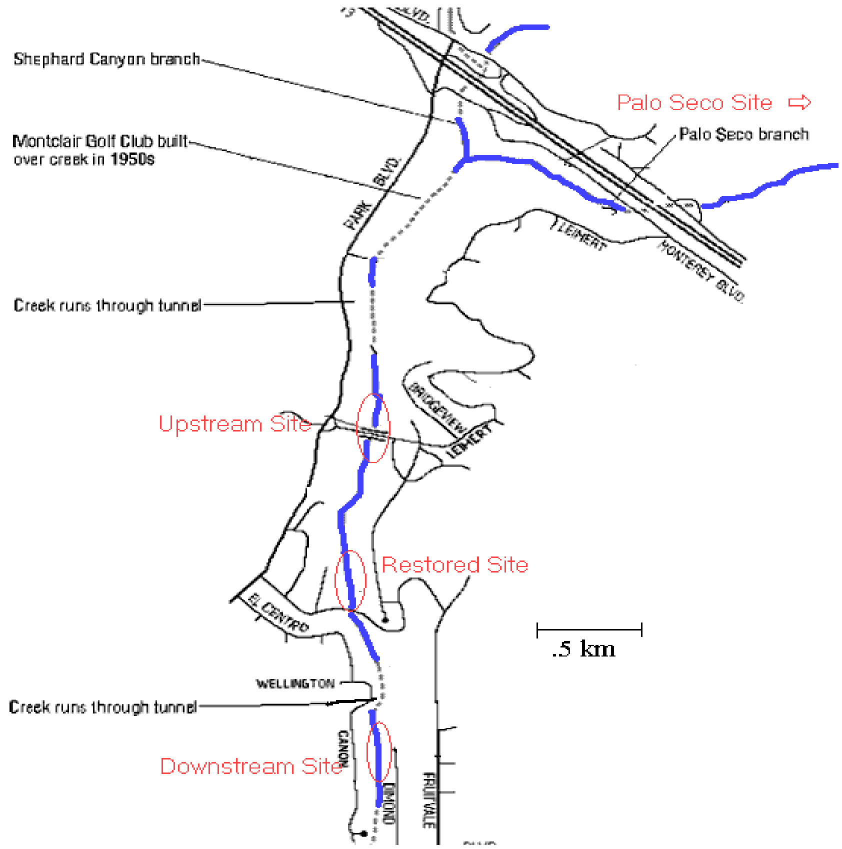

Figure 1. Map of Sausal Creek.
Areas circled indicate site locations. Palo Seco Site is not shown on map.

The upstream and downstream sites will be categorized the pre-restored sites, because they contain similar channelization and concrete obstructions as the pre-restored conditions of the restoration site. The Palo Seco site, which was used as the ideal conditions for the restored site, has had no major human alterations. Other studies have used pristine stream sites, like the Palo Seco site, in habitat comparisons with anthropogenically influenced sites like the Sausal Creek sites (Gortz 1998).

At each site, the macroinvertebrate abundance, EPT (Emphemeroptera, Plecoptera, Trichoptera) richness, family richness, Family Biotic Index (FBI, Hilsenhoff, 1988), percent of each functional feeding groups (scrapers, collectors/filterers, shredders and predators), percent of the most dominant taxa, and EPA habitat assessment for high gradient streams (Barbour et al. 1999) were all used to calculate overall health of the stream and the potentiality of negative responses do to perturbation (Barbour et al. 1999, Merritt et al. 1996). Functional feeding groups were determined by the guidelines set by Cummins and Wlizbach (1985). Using these calculations, the health of the restored stream areas was compared (paired t-test) to the unrestored stream sites and Palo Seco Creek.

During the last four weeks of sampling, the samples from the one unshaded site in the upstream area were collected in a separate container and evaluated (paired t-test) separately from the other data to determine the effects of light on species composition. This experiment could only be performed in the upstream site because the restored site had no shaded sites, the downstream sites had shading that varied with time of day, and all of the Palo Seco sites were shaded, leaving nothing for comparison at these sites.

Besides using the upstream and downstream sites as the pre-restoration conditions, the data was also compared to two years of pre-restoration sampling that was conducted by the volunteers from Friends of Sausal Creek (FSC). These samples were taken between sampling locations 2 and 3 located within the currently restored area, and the samples were taken with the same methodology with the exception of the number of samples. The number of FSC samples taken at each site varied from 1-3 samples per sampling day. Also, the samples were only taken once a month, which is less frequent than the 2-4 times per month sampling in this study. To account for the difference in number of samples taken per day, I converted the data to number of organisms per area, and to account for the difference in the frequency of sampling I compared data points taken during the same time period. For instance, FSC took two samples at the end of March, so in this study the March FSC data was only compared to the data of the two most closely corresponding dates in March. After these considerations, FSC data and the data in this study were compared (paired t-test) by calculating the total macroinvertebrate abundance, EPT richness, family richness, Family Biotic Index (FBI, Hilsenhoff, 1988), and percent of the most dominant family. Changes in functional feeding groups were not evaluated, because the FSC data did not examine functional feeding groups, and with a family level identification it is difficult to generalize functional feeding groups without examining the organisms in a lab.

At each site EPA Rapid Bioassessment Protocol for High Gradient Wadeable Rivers (Barbour et al. 1999) was used to score the quality of the aquatic habitat for biological organisms, mainly fish and macroinvertebrates. For the habitat assessment at each site, visual assessments were made on substrate, embeddedness, velocity, depth, sediment deposition, channel flow status, channel alteration, frequency of riffles and bends, bank stability, vegetative protection, and riparian zone width (Barbour et al. 1999). The habitat quality score was evaluated between sites to determine whether there was an improvement in habitat at the restored site. Once again the upstream and downstream sites were used as pre restored references, while the Palo Seco site will be considered the ideal conditions for the restored site.

Results

The restored area had significantly fewer total number of macroinvertebrates compared to all other sites during February (upstream Feb p=.03; downstream Feb p=.05; Palo Seco Feb p=.004), but there was no significant difference in total macroinvertebrate abundance over all the sampling dates (Table 1, for all further p-values). There was also no significant difference in total number of macroinvertebrates between the upstream and downstream sites. When the data was compared to the FSC data then there was no significant change in the total number of organisms in the restored site.

	Upstream P-value	Downstream P-value	Palo Seco P-value	FSC P-value	Down vs. Up P-value
Total # of macroinvertebrates	.44	.08	.05	.38	.35
EPT	.05	.07	.06	.40	.05
Family richness	.07	.05	.06	.001	.05
FBI	.002	.03	<<<.001	.05	.10
% dominant taxa	.16	.45	.18	.36	.32
Chironomidae	.11	.06	.06	.24	.25
Baetidae	.05	.07	.07	.22	.05
Horsehair worm	.05	.01	.03	.05	.10
Functional Feeding (# Collectors/Filterers)	.67	.70	.03	-	.45
Habitat	.05	.003	.006	-	.006

Table 1. P-values for post-restoration site comparisons

The first four columns and the last column are compared with restored site. FSC column is the Friends of Sausal Creek comparison data, which is the category per m². The last column is a comparison of upstream and downstream sites. All statistical analyses are paired t-tests.

The restored area had significantly less EPT per sample compared to the upstream site (Fig. 2), and the downstream and Palo Seco sites were close to having significantly higher (Table 1) EPT than the restoration site. Yet, when the data was compared to the FSC data there was no significant difference in the EPT per m².

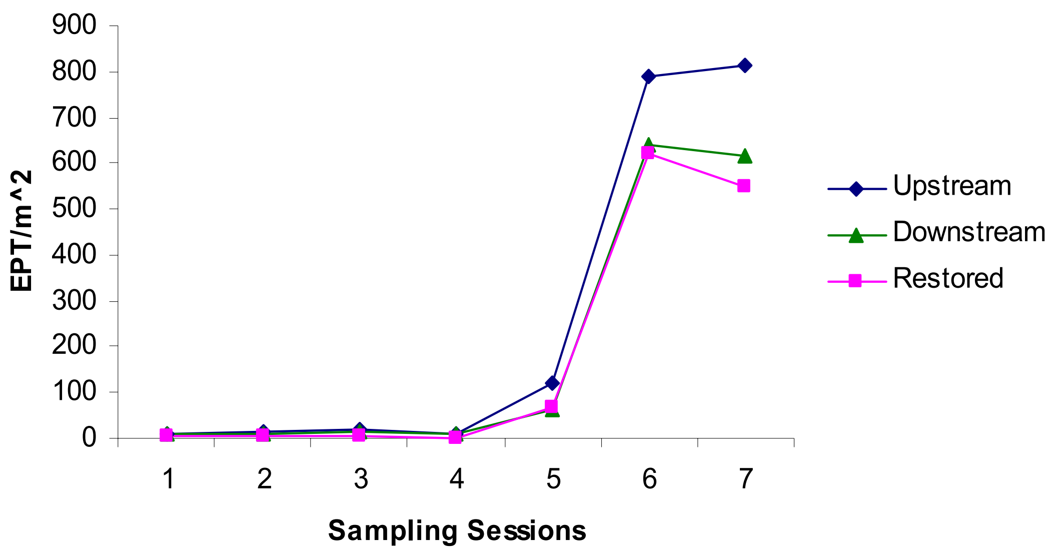

Fig. 2 Number of EPT/ m²

The difference in family richness was insignificant for the upstream and downstream sites, but family richness was significant for the Palo Seco site. The family richness comparison with the FSC data was significantly different (Fig 3).

The upstream, downstream and restored areas had similar percent dominance values. The most dominant species at these three sites was the horsehair worm, followed by Chironomidae, and Baetidae. 95.6% of the upstream site samples, 96.3% of the downstream samples, and 96.6% of the restored area samples were composed of these three families. Thus, all other families were relatively rare, most composing of 1% or less of the total collected species. The Palo Seco site had Baetidae as the most dominant family, followed by Simuliidae, Chloroperlidae, and Nemouridae. Baetidae and Simuliidae composed of 72.1% of the species collected, and Chloroperlidae and Nemouridae composed of 10.0% of the collected species.

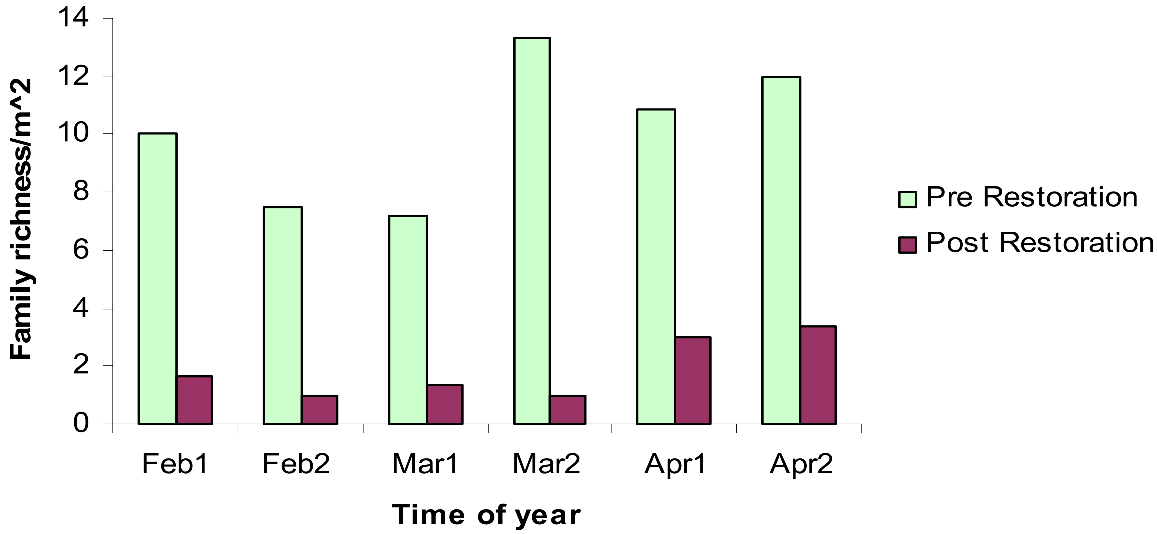

Figure 3. Family richness post-restoration and pre-restoration
Comparisons were made on the two closest corresponding dates between the FSC post-restoration data, and the pre-restoration data in this study.

While, there was no difference in dominance measures between sites, there were significantly more horsehair worms in the restored area than in all the sites. There were significantly less Baetidae in the restored area than the upstream site, but there was no significant difference between the downstream and the Palo Seco site, even though the p-values were relatively low for these sites (Table 1). There was also no significant difference in Chironomidae abundance at any site, but the downstream and Palo Seco Chironomidae abundances had low p-values when compared to restored sites (Table 1).

The FBI average was 7.3 in the restored area, 6.8 downstream, 6.5 upstream and 4.1 at the Palo Seco site. From Hilsenhoff (1988), these indices correspond to the restored site being ranked as very poor water quality and having severe organic pollution. The upstream and downstream sites are ranked as having fairly poor to poor water quality, which corresponds to substantial organic pollution. The Palo Seco site was ranked as having very good water quality, with slight organic pollution. The upstream site, downstream site, and Palo Seco site had significantly different FBI values from the restored site. There was also a significant difference in FBI between the FSC pre-restoration data and the post-restoration data in this study (Fig. 4).

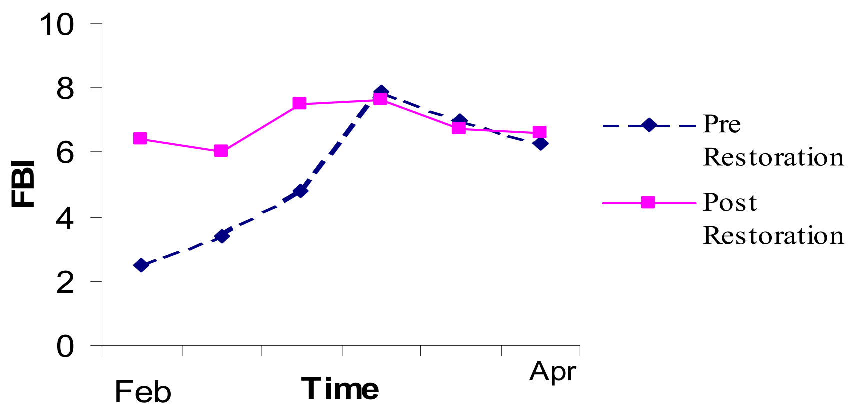

Figure 4. Difference in Family Biotic Index (FBI) between post-restoration and pre-restoration FSC data

At the upstream site, there was no significant effect ($p>.25$) of light and shade on the number Baetidae per m^2, and number of Chironomidae per m^2. There was no increase in the number of horsehair worms per m^2 at the light site, but there was a significant ($p=.04$) increase in the number of horsehair worms per m^2 at the shade sites. Also, only the rare families (# individuals $\leq$ 4), and the most tolerant families (tolerance $\leq$ 2) were found in the shade sites. There was also a higher family richness ($p=.02$) in the shade sites.

There is no difference in functional feeding groups between the three Sausal Creek sites ($p>.44$ for all sites). 63.3% of macroinvertebrates at the restored site were classified as filterers or collectors, while the upstream, and downstream sites had 66.0% and 62.1% filterers or collectors respectively. Most of the remaining organisms were classified as other, because they were predominantly horsehair worms, which feed on bacteria and detritus in the soil of the stream bed, and therefore they do not fit into one of the four functional group categories. So, filterers and collectors were the dominant functional feeding group in Sausal Creek. On the other hand, the Palo Seco site had significantly less filterers and collectors (Table 1), but significantly more ($p<.01$ for all cases) scrapers, shredders and predators.

There were significant differences in habitat assessment scores for all sites. The Palo Seco habitat score was 167.6, which was the highest of all the sites. But, the restored area had a habitat score of 123.0, which was significantly higher than the score of 108.2 in the upstream and the score of 88.0 in the downstream site.

Discussion

Since, the restoration was not finished until November 2001, this study was conducted on the first insect generation in a recently restored system. In a study by Laasonen et al. (1998) in which streams in Finland were found to have the highest species richness 1 year after restoration, but streams restored one month before the study had the lowest macroinvertebrate species abundance and richness caused by the disturbance resulting from restoration. As I mentioned before, the environment in California is different than the environment in Finland, but similar declines in family richness were noticed in this experiment, even though there was no reduction in macroinvertebrate abundance.

The total number of macroinvertebrates at each site did not differ between the restored area and any of the sites, but the composition of the organisms between the sites was quite different. The restored area had significantly more pollution tolerant organisms, such as horsehair worms , and possibly more pollution tolerant Chironomidae, because the p-values were very close to being significant (Table 1). This increase in pollution tolerant macroinvertebrates only occurred in the restored area. There was no increase in the macroinvertebrate composition between the upstream and downstream sites, which may indicate that the restoration is responsible for this change in species composition.

Baetidae, and EPT had lower abundances in the restored site as compared to the upstream site. Possibly with more sampling there would be a significant differences between the EPT and Baetidae in the restored area and the downstream site. Ephemeroptera, Plecoptera and Trichoptera (EPT), and Baetidae, which is a family of Ephemeroptera, are some of the most pollution intolerant organisms, and are important indicators of stream health (Barbour et al. 1999). Thus, there was an overall decrease in pollution tolerant organisms in the restored area that was not seen in the other sites in Sausal Creek.

Not surprisingly, with the reduction of the most abundant pollution intolerant family, Baetidae, in the restored site, there was a higher FBI in the restored site than in the other sites. The FBI average at each site showed that the restored area has very poor water quality, while the upstream and downstream sites have slightly better water quality. It is highly unlikely that a pollution source was the cause of the difference between sites, because a pollution source in the restored area would also have a great effect on the downstream site. There is also no significant difference between the upstream and downstream sites, which indicates that the disturbances occurring in the restored area has little or no effect on the downstream environment.

Yet, when comparing the EPT and Baetidae to the previous FSC data there was no significant change in EPT. I attribute the lack of change to the difference in sampling, and differences in weather conditions. In many cases I sample 5 times more area than the FSC samples, which even though they were standardized as #EPT/m^2 before analysis, the FSC data has less certainty, because less samples were taken. Also, the FSC samples were all taken at one site, while each of my samples were taken at a different site. Thus, my samples were more representative of the entire restored area, while the FSC samples were more representative of one area in the creek. The FSC site also differed from my site location. During this study I was asked to sample at least 10m upstream or downstream of the FSC sample site to avoid sampling interference if FSC wanted to begin sampling again. Thus, these sampling factors were probably the main reasons for the lack of a significant difference in EPT.

Weather conditions can cause changes in macroinvertebrate populations over both a short and long time scale. Over short periods of time, rain storms can wash macroinvertebrates downstream, and it can be hours to days before they become re-established in the stream bed (Adler et al. 1997). There could have been differences in the FSC data and the data in this study, due to the differing occurrences of rain storms between the sampling days. Over the long term, lower temperatures can cause variation in the survival of the many stages in the macroinvertebrate life cycle (Scholwalter, 2000). If there was a difference in the temperature ranges between the years that the FSC data and the data in this study were taken, then this could account for the differences between the data.

Some of the changes seen in the restored area are caused by the extra light on the creek in the restored area, due to the lack of overhanging vegetation. Throughout the duration of this project, most of the restored riparian vegetation was very small or non-existent as the native riparian plant restoration project was still in effect. The vegetative restoration of the stream bank probably resulted in a slight disturbance to the stream itself, due the ongoing bank alterations from the native seedling planting project. Since only the rare and more tolerant species were found in the shade area this lead to a higher family richness in the shade areas. This corresponds to the fact that family richness is highest in the shadier upstream site, but the downstream and restored sites have less shading and a lower family richness.

The main differences between the restored areas and the upstream and downstream areas are lower EPT, lower family richness, and FBI. These are all indicators of pollution and thus would indicate the presence of more pollutants in the restored area than the upstream and downstream area. However, because of the proximity of these sites to one another it is almost impossible to believe that pollution is being concentrated entirely in the restored area, and that the pollution has no effect on the upstream, and especially the downstream sites. Thus, at this stage after restoration, the restored area is of poorer water, and macroinvertebrate quality than it was previously, and therefore it is still recovering from the disturbance of the restoration. Any water quality assessments conducted in the restored site currently would falsely indicate higher pollution levels than actually exist.

The data shows some possible evidence for a restoration effect downstream of the restoration site. EPT, and number of Baetidae were significantly lower in the downstream than the upstream sites. Ephemeroptera, Plecoptera, and Trichoptera often become dislodged from their substrate during high stream flows that occur after rain events, and then drift to downstream habitats (Borchardt 1993). EPT also has natural drifting events that occur periodically throughout the organisms lifetime (Borchardt 1993). If the restored area has unsuitable habitat for these organisms, then EPT colonizing from upstream of the restored site would have lower survival rates in the restored site. Thus, there is a smaller pool of EPT to colonize the downstream site after rain events. This smaller colonization pool may be the cause of the lower levels of EPT, and Baetidae in the downstream site compared to the upstream site.

The differences in family richness between the upstream and downstream sites may have a similar explanation, but with many of the rarer species that were excluded from the downstream site, and subsequently resulted in a lower family richness, their dispersal methods were not well known. Therefore, no conclusions about the effect of drift on these organisms could be made. The difference in family richness between is most likely due to the light conditions mentioned previously. Only the rare families were found in the shade sites, and most of the upstream sites were shady, while most of the downstream sites were sunny. Therefore, the difference in family richness between upstream and downstream sites was probably due to light factors, and not colonization factors.

Fish have been seen, but not identified in Sausal Creek, and the changes in restored areas due to the disturbance have the potential to affect those populations. One may argue with the change in macroinvertebrate composition in the creek, that the nutrients and calories gained from each macroinvertebrate type may be different, changing the caloric and nutrient intake of fish. Fish that specialize on EPT could have a large drop in food resources due to the decrease in EPT at the restored site, which would lead to a decline in these specialist species. This change in diet composition could change competitive interactions between fish species, leading to changes in the fish population dynamics.

A decline in fish populations is probably unlikely, because of the dominant food resources in the stream and the small scale of the restoration. The stream is dominated by three families, which probably comprise of the majority of the food resources for fish. These three families, while they may have significantly smaller abundances in the restored area, have had no change in their dominance in the community, so they are still at high abundance levels. These high abundances still leave a large resource for fish. Also, the restoration project only occurred in 185 m of the creek, which is much smaller than the foraging ranges of most fish. Therefore, in a small scale restoration project that results in no significant reductions in total number of macroinvertebrates and percent of dominant taxa in the upstream and downstream sites, there should be no effect on fish populations.

One way that macroinvertebrates would have an effect on the fish of Sausal Creek would be through nutrient cycling. There was no difference in the functional feeding groups in the restored area compared with the other Sausal Creek sites. So, the same types of nutrients in the restored area are being cycled through the environment at a similar rate to the other areas in the creek. Therefore, no real changes occurred in the nutrient cycling ability of the macroinvertebrate community after restoration.

There were significant differences in the functional feeding groups between the Sausal Creek and Palo Seco sites, but this was indicative to the types of organic material that entered these sites. The functional feeding groups found in the Palo Seco site have larger numbers of shredders, which indicate large amounts of coarse particulate organic matter (CPOM) in the creek (Merritt et al. 1996). While, the functional feeding groups found in the Sausal Creek site have large numbers of collectors and filterers, which indicate large amounts of fine particulate organic matter (FPOM) in the creek (Merritt et al. 1996). This difference is not surprising, because the Palo Seco site was in a forested upstream environment, while the downstream Sausal Creek site has little surrounding vegetative inputs, and probably receives most of its organic matter from upstream sources. Thus, the differences between the Sausal Creek and Palo Seco sites are not due to disturbance caused by restoration.

The restored area had much higher habitat quality than the other Sausal Creek sites. Higher habitat quality is important, because it shows that the restoration was successful in improving the habitat. This improvement also means that in the future there will likely be higher levels of family richness, lower FBI and improvements in many other factors. The only reason that improvement in habitat quality does not correlate with improvements in the macroinvertebrate population in this study is the fact that disturbance caused by the restoration has reduced the quality of the macroinvertebrate population.

From this experiment, it is apparent that restoration changed the macroinvertebrate community within the restored area of Sausal Creek. This change in macroinvertebrates did not result in changes in nutrient cycling, or changes in the food resource availability for fish. However, this change did show that recently restored habitats give inaccurate pollution estimates when monitored using macroinvertebrate populations. When compared to previous studies, this study, also shows that the scale and intensity of the restoration projects can determine the effect it will have on macroinvertebrate populations. Lastly, this study is a beginning to understanding sucessional processes in aquatic ecosystems. Even though, the exact effects of the disturbance on each individual stream will be different due to the large variations between streams (Jefferies et al. 1990), a better understanding of the succession of aquatic communities can prevent possible irreversible damage to these systems after any type of perturbation, not just disturbances resulting from restoration.

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