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A Benthic Macroinvertebrate Survey of Secret Ravine: The Effects of Urbanization on Species Diversity and Abundance

Abstract

The population in Placer County, California, is growing four times faster than the state of California. With the increase in population comes a large increase in impervious surfaces such as residential developments, strip malls, roads, and a probable decline in local stream water quality. To test whether the recent developments have impacted a local stream, we compared macroinvertebrate populations in an undeveloped (upstream) and a developed (downstream) reach of Secret Ravine. We sampled macroinvertebrates with a Surber sampler, following the EPA Rapid Bioassessment Protocols. The mean number of 55 organisms per sample downstream was significantly higher ($p=0.02$) than the mean number of 23 organisms per sample upstream. Although there was not any significant difference between the mean %EPT (pollution sensitive organisms) at the upstream and downstream sites, there was a significant difference between moderately sensitive ($p=0.01$) and tolerant ($p=0.01$) organisms. The percent moderately sensitive organisms was 32% upstream and 6.8% downstream. The percent tolerant organisms was 52% downstream and 17% upstream. Further indication that the downstream site was impacted by development was the abundance of filamentous algae that indicate a eutrophic (nutrient-rich) stream. Another difference between the two sites was the lack of red Chironomid (midge) larvae upstream, compared to 49% of the downstream organisms as midge larvae. Midge larvae, which tolerate oxygen as low as 20% of saturation, indicated the sediment under the algae and pebbles was anoxic downstream. In addition, the upstream community contained 22% dragonfly larvae, which require high levels of oxygen, while the downstream site was only 4% dragonfly larvae. The abundance of pollution tolerant organisms and filamentous algae indicates the downstream site is receiving nutrient-rich urban runoff, but contained little or no toxins. Further studies should focus on measuring temperature, dissolved oxygen, and nutrient content of the upstream and downstream runoff to determine the extent of eutrophication due to urbanization of the watershed.

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Introduction

Cities in western Placer County, California, are some of the fastest growing regions in the state. For example, the county increase in population from April 1, 2000 to July 1, 2001 was 8.1%, more than quadruple that of the state of California's 1.9%. The total population in 2000 was 248,399--more than a 30% increase from the population count of 172,796 in 1990 (U.S. Census, 2003). With the increase in population comes an increase in residential development, strip malls, and roads.

Part of the Dry Creek Watershed is located in the middle of this extensive development. This watershed, located in Sacramento and Placer Counties, is approximately 101 square miles of rural, agricultural regions as well as high-density residential and commercial developments. The extent of development increases in the downstream direction. Secret Ravine, one of six tributaries to Dry Creek, traverses the Cities of Roseville, Rocklin, and Loomis (Figure 1)--all cities planning a great deal of future development. The cities of Roseville and Rocklin forbid development within the 100 year floodplain.

The Dry Creek Parkway Citizens Advisory Committee has proposed the establishment of many additional parks to preserve open space near the creek. Debra Bishop, author of *An Evaluation of Dry Creek and its Major Tributaries in Placer County*, states that "all local governmental entities in the region support the preservation of open space and riparian habitat in their planning documents" (Bishop, 1997).

Even though developments are not within the 100 year floodplain, the nearby development likely impacts the creek. Urbanization of a stream's watershed can result in decreased water quality, increased temperatures, sedimentation, loss of habitat, and loss of fish populations (USEPA, 2003). The increase in impervious surfaces (e.g. roads,

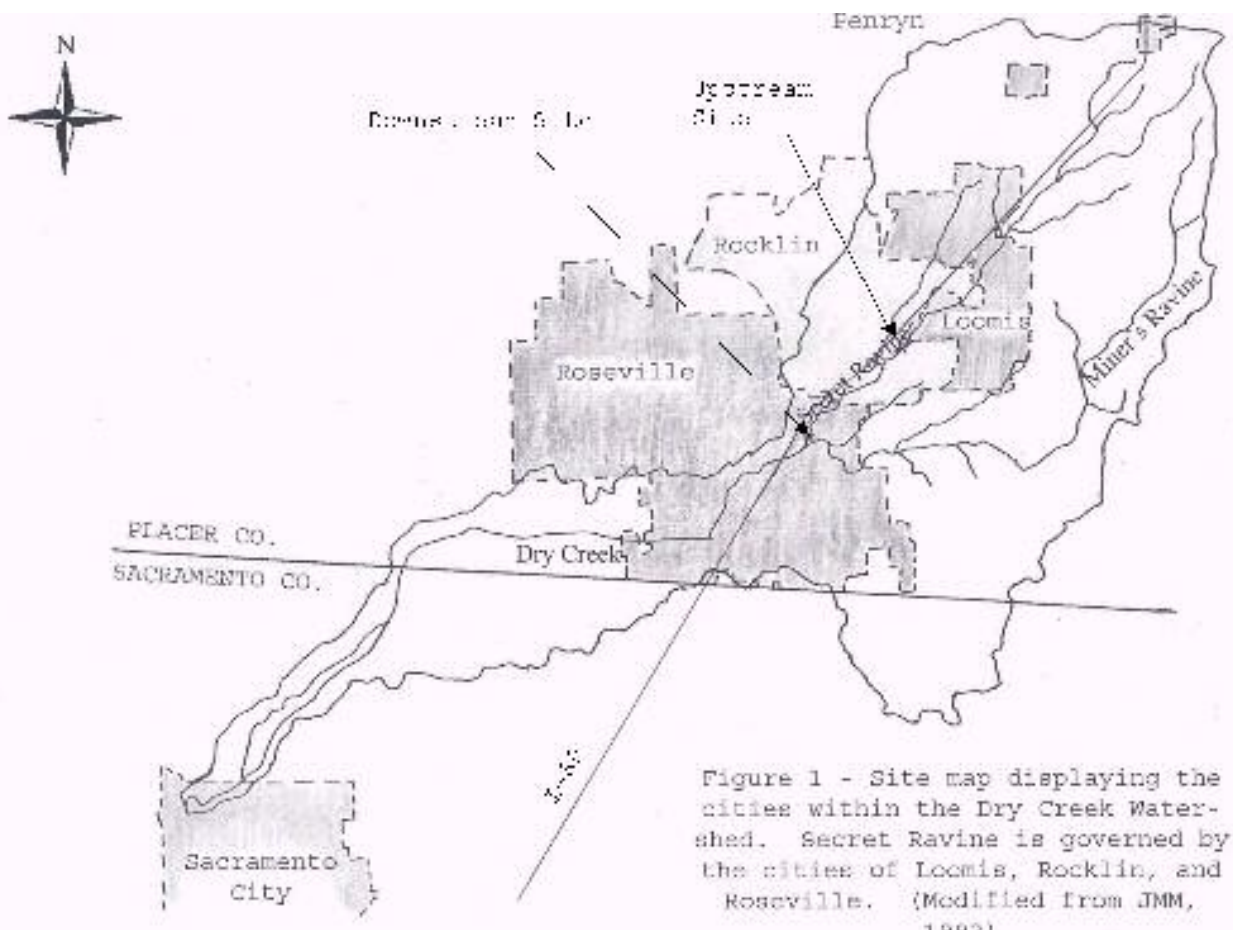


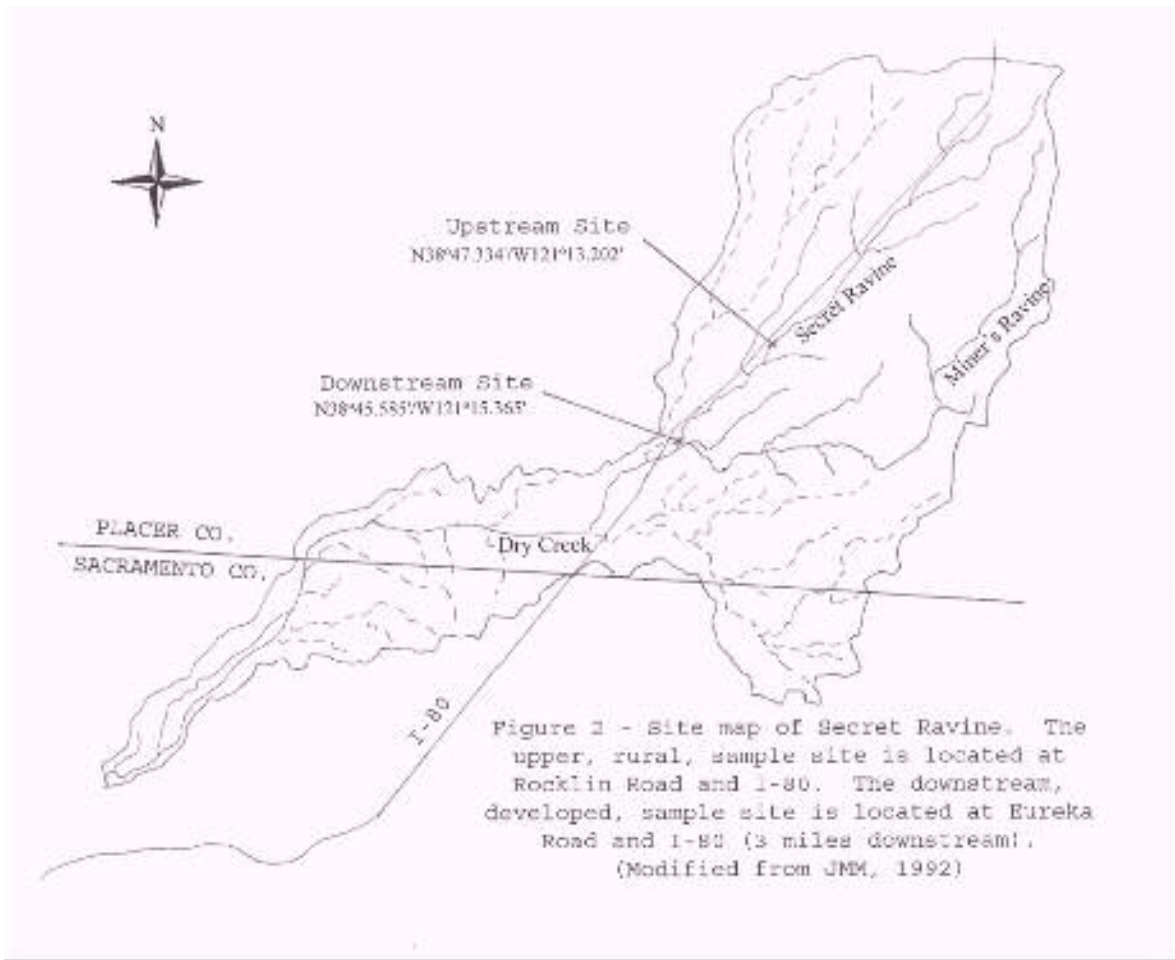
Figure 1 - Site map displaying the cities within the Dry Creek Watershed. Secret Ravine is governed by the cities of Loomis, Rocklin, and Roseville. (Modified from JMM, 1992)

parking lots, roofs, etc) increases the volume and velocities of runoff (Davis et al, 2003). These hydrologic changes impact water quality by increasing sedimentation and water temperature (USEPA, 1997). Conversion of agricultural areas to urban development can cause a decline in water quality by increasing the loading of oil, grease, nutrients, and heavy metals (Barbour, 1996).

Macroinvertebrates are important because they are a food source for Chinook salmon and steelhead, which spawn in Dry Creek (AFRP, 2003). In addition, differences in benthic macroinvertebrate populations can indicate perturbations such as pollution (Barbor et al, 1999). Aquatic macroinvertebrates are good indicators of stream quality because they have limited migration patterns and cannot escape pollution, so they show cumulative impacts of pollution as well as impacts of habitat loss not detected by traditional water quality assessments (McCarron et al, 1996; Horne, 2003). To better understand the effects of urbanization on the density and abundance of benthic macroinvertebrates, we examined a rural upstream location and an urbanized location three miles downstream in Secret Ravine. Our purpose is to document the existing conditions and to determine whether Placer County has preserved the creek habitat despite extensive development. In addition, we will compare our results with a macroinvertebrate study of Truckee River, California.

Site Description

Despite paralleling Interstate 80, Secret Ravine, in comparison to the other tributaries to Dry Creek, has an overall exceptional habitat value (Bishop, 1997) including abundant riparian vegetation. The upstream site (Figure 2), located just south of Sierra College, is in a relatively open space area consisting mainly of rural residential



land-uses. There is abundant riparian vegetation including mint, alder, and native grasses, but also a considerable amount of non-native and invasive Himalayan blackberry and star-thistle. The substrate of the stream-bed consists of gravel to boulder-sized rocks. The water flowed faster and appeared much clearer than at the downstream site. Salmon are reported to spawn in this location (Gregg Bates, Dry Creek Conservancy, personal communication).

The downstream site, just before the confluence with Miner's Ravine, is in an urbanized area. Recent developments in the stretch between the two sample sites have included residential communities, and strip malls, as well as a water park. This downstream site has considerable riparian overstory, but the understory is very disturbed and weed infested. The substrate consists of sand and fist-sized cobbles coated with decomposing filamentous algae. Abundant debris and trash has been deposited along the banks and within the stream. Bishop (1997) reported homeless impact at this site as well. There are four bridges, including a new major road crossing, between the two sample sites.

Materials and Methods

Pebble Counts

We conducted a pebble count in each riffle to compare the habitat available for benthic macroinvertebrates at each location. Using the protocol outlined by Brooke and Kondolf (2003), we randomly selected 100 pebbles from each riffle and categorized them according to the length of their intermediate axis.

Measurement of Physical/Chemical Characteristics

We used a measuring tape to estimate the length and width of both riffles and measured the depth at three points along each cross section selected for invertebrate sampling. We used a dissolved oxygen (DO) meter to measure temperature and DO and estimated water velocity by timing the speed of a floating leaf.

Macroinvertebrate Sampling

We followed the EPA Rapid Bioassessment Protocols for Use in Streams and Wadeable Waters (Barbour, et al 1999) with modifications from Karr and Chu (1999) for quantitative instead of qualitative data. We used 500-um-mesh Surber sampler to collect three samples across two-cross sections in each riffle. Placing the Surber sampler on the streambed, which marks off a one-foot square area, we disturbed the enclosed sediment for three minutes while brushing off the large cobbles by hand to remove any attached invertebrates. Using clean stream water, we emptied the contents of the Surber sampler into a white tray and visually inspected the net to ensure that all attached organisms were removed. We collected all the invertebrates from each sample and preserved everything except the Chironomid (midge) larvae, which were counted on site, in Formalin for later identification in the laboratory. We then emptied the tray and rinsed the Surber net in the stream. Using Merritt and Cummins' *An Introduction to the Aquatic Insects of North America* as a guide, we identified the invertebrates to the level of Order.

Statistical Analysis

Benthic macroinvertebrate data is usually analyzed by relative abundance, taxa richness, and perturbation tolerance/sensitivity in accordance to EPA protocols (Barbor et al, 1999). To measure abundance, we analyzed the number of total organisms in each sample. Richness measures the diversity of the aquatic assemblage. To measure species richness, we used the Simpson's index of diversity (1-D), which measures the probability that two randomly selected individuals in a community are of different categories (Horne, 2003). Simpson's index of diversity is calculated using the equation:

$$1 - D = 1 - \sum_{n=1}^i \frac{n_i(n_i - 1)}{N(N - 1)}$$

where N is the total number of organisms in a sample and n is the total number of individuals in each category.

To measure tolerance we divided the organisms into three categories according to their sensitivity to perturbation. Community sensitivity is usually expressed as %EPT (the percent of total organisms from the orders *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), and *Tricoptera* (caddisflies)). We classified all other organisms as either moderately sensitive or tolerant according to Barbor et al (1999) (Table 1). Regional tolerance values for Heminoptera and Lepidoptera are not listed in the EPA Rapid Bioassessment Protocols, so we did not include them in the analysis of sensitivity (Barbor et al, 1999). We performed statistical analyses (t-tests, 10 degrees of freedom) to determine if the means of the six samples differed between the developed and undeveloped riffles with respect to macroinvertebrate abundance, diversity, and tolerance/sensitivity.

Table 1. Collected benthic macroinvertebrates, categorized by their perturbation sensitivity/tolerance as defined by the EPA (Barbour, 1999).

Scientific Taxonomy	Common Name	Sensitivity to Perturbation
Ephemeroptera	mayflies	sensitive
Plecoptera	stoneflies	sensitive
Trichoptera	caddisflies	sensitive
Crustacea (amphipoda)	Shrimp	moderately sensitive
Diptera (excluding Chironomidae)	black flies	moderately sensitive
Odonata	damsel and dragon flies	moderately sensitive
Mollusca (corbicula)	clams	tolerant
Oligochaetae	worms	tolerant
Diptera (Chironomidae)	midges	tolerant

Results

The downstream site was shallower, wider, warmer, with lower dissolved oxygen (DO) and slower velocity than the upstream site (Table 2). However, the pebble count indicated the gravel within each riffle were similar. Size classes for both sites ranged from <8 to 128mm. The D_{50} (median diameter) was 35 mm downstream and the D_{50} was 42 mm upstream (Figure 3). While sampling, we observed the downstream pebbles were covered in filamentous algae, probably *Cladophora* (blanket weed) whereas the upstream pebbles were not.

Table 2. Measurement of physical characteristics at the two sample locations. Depth, width, length, and temperature were all higher at the downstream site. Dissolved oxygen and velocity were higher at the upstream site.

	Downstream	Upstream
Average Depth (feet)	1.2	1.4
Width (feet)	21	15
Riffle Length (feet)	27	16
Temperature (°C)	14.2	12.9
Dissolved Oxygen (mg/L)	8.6	9.9
Velocity (ft/s)	0.7	1.5

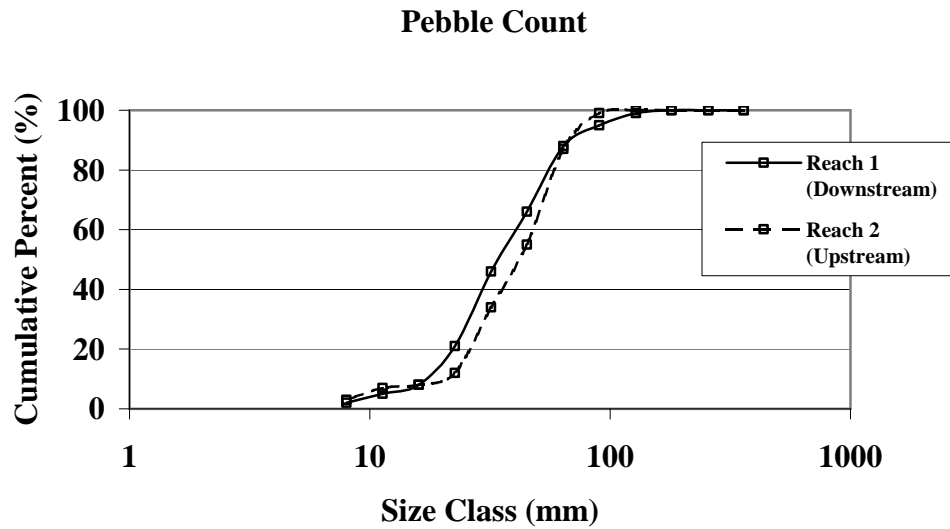


Figure 3. Cumulative pebble count graphs showing that the size distribution of the pebbles in both sites are similar.

The mean number of 23.0 organisms per sample at the upstream site was much lower and significantly different ($p=0.02$) than the mean number of 54.8 organisms per sample at the downstream site (Figure 4, Table 3). However, diversity between the two sites was not significantly different according to the t-test ($p=0.2$). The Simpson's Index of Diversity (1-D) was 0.7 at the upstream site and 0.6 at the downstream site (Figure 5, Table 3).

Table 3. Mean \pm standard deviation of taxa richness, relative abundance, and perturbation tolerance/sensitivity of the macroinvertebrate populations in the upstream and downstream locations.

	Downstream	Upstream
% EPT	37.0 \pm 24.0	51.5 \pm 28.2
Moderately sensitive	6.8 \pm 3.7	31.8 \pm 19.1
Tolerant	51.7 \pm 25.8	16.5 \pm 12.2
Abundance	54.8 \pm 24.4	23 \pm 14.8
1-D (Diversity)	0.6 \pm 0.2	0.7 \pm 0.2
% Chironomid	48.9 \pm 25.3	0
% Dragonfly	5.3 \pm 3.8	22.2 \pm 13.6

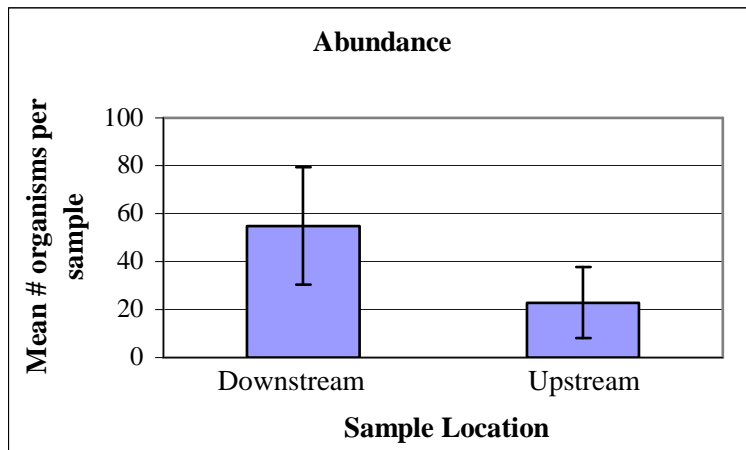


Figure 4. Mean number of organisms found in six samples at the upstream and downstream site. The mean number of organisms in each sample was significantly higher at the downstream site ($p=0.02$).

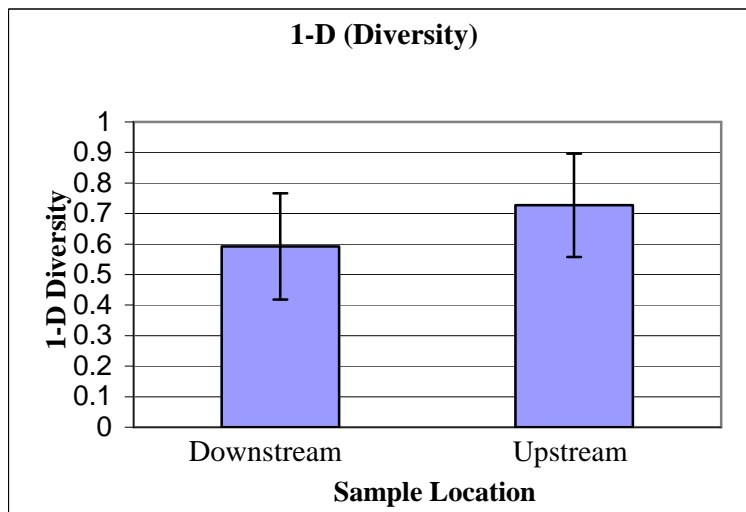


Figure 5. Simpson's index of diversity. Although diversity was higher at the upstream site, t-test showed no significant difference ($p=0.2$)

The mean percent *Ephemeroptera*, *Plecoptera*, and *Tricoptera* (%EPT) was 51.5% at the upstream site and 37.0% at the downstream site (Table 3, Figure 6). Results of the t-test indicate that the %EPT was not significantly different ($p=0.36$) between the sites. The mean percent of moderately sensitive organisms was 31.8% at the upstream site and 6.8% at the downstream site. The mean percent of tolerant organisms was much lower at the upstream site, 16.5%, than the 51.7% at the downstream site (Table 3, Figure 6). The t-test showed a significant difference of moderately sensitive organisms ($p=0.01$) and tolerant organisms ($p=0.013$) between the two sites.

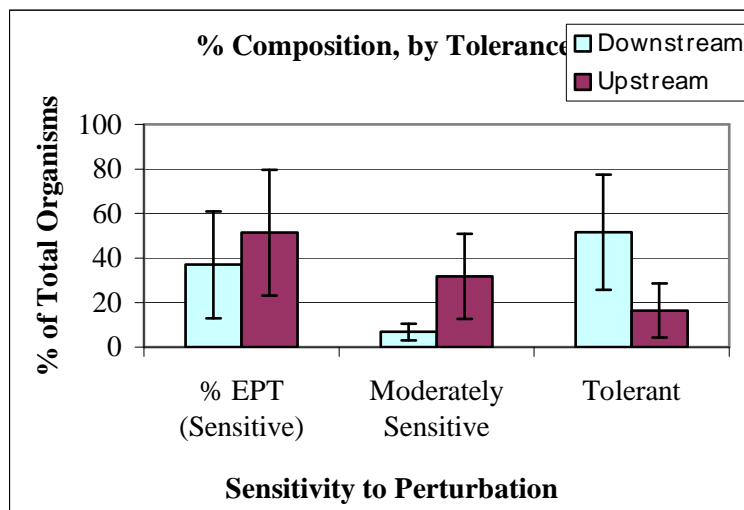


Figure 6. Mean percent sensitive (%EPT), moderately sensitive, and tolerant organisms. %EPT was not significantly different between the two sites. In contrast, the percent moderately sensitive organisms was significantly higher at the upstream site ($p=0.01$). The percent tolerant organisms was significantly higher at the downstream site ($p=0.013$).

One obvious difference between the two sites was the abundance of Chironomid (midge) larvae that were red in color at the downstream site. An average of 48.9% of the organisms in the downstream site were midge larvae. In contrast, no midge larvae were found in the upstream site (Table 3). A t-test showed a significant difference in the

Chironomid populations with a p-value = 0.001. Another significant difference (p=0.015) was the number of dragonfly larvae at the two sites. The upstream community was 22.2% dragonfly larvae while the downstream site was 3.5% dragonfly larvae.

Discussion

While both sites had bed material sizes in the range considered ideal for macroinvertebrate habitat, 1-128 mm (Gore et al, 1998), water quality was not as good at the downstream site. The abundance of filamentous green algae, *Cladophora*, was indicative of eutrophic conditions, specifically high nitrate. In low nutrient streams, the spring algal growths are eaten at the rate of production by insect larvae. At elevated nutrient levels attached algae grow faster than they can be grazed by invertebrates, resulting in mats of algae that last throughout the summer (Horne and Goldman, 1994). High concentrations of nitrogen and phosphorus in runoff from the surrounding development could cause high algal production in Dry Creek.

The total number of organisms at the downstream site was significantly greater than at the upstream site. Death (2002) showed a positive correlation between primary productivity and the number of benthic macroinvertebrates. Because some macroinvertebrates are grazers and scrapers that feed on filamentous algae, the number of macroinvertebrates would be expected to increase as their food source increases. These results also indicate that the runoff, although rich in nutrients, is not high in toxins. Urban runoff often contains high levels of heavy metals, pesticides, and polycyclic aromatic hydrocarbons (PAHs) from automobile emissions, streets, parking lots, rooftops, and construction sites. These toxins have a detrimental impact on aquatic organisms, including the number of benthic macroinvertebrates (Crunkilton et al, 1996).

The number of organisms would be expected to be lower at the downstream site if the urban runoff into Secret Ravine contained high levels of toxic compounds. With a few exceptions, urban runoff in California is not acutely toxic to aquatic organisms (Horne, 2003).

There was not a statistically significant difference in diversity between sites. Increasing diversity correlates with increasing community health, which indicates that the niche space, habitat, and food sources are adequate for the survival of many species (Barbour et al, 1999). In many situations, diverse populations are more stable because they are less affected by disturbance (Horne, 2003). However, some natural productive aquatic environments have low diversity and high productivity, e.g. estuaries where a stress (variable salt concentrations) is the cause of low diversity.

Although a difference in diversity could not be shown, the type of taxa in each population differed between the two sites. The mean percent *Ephemeroptera*, *Plecoptera*, and *Tricoptera* (%EPT) was lower at the downstream site, but due to the difference in population composition between the three samples in each cross section, the t-test did not show a significant difference between the two sites.

The percent of tolerant organisms at the downstream site was significantly higher due to the abundance of red Chironomid larvae. The percent midge larvae is expected to increase with increased perturbation (Barbour et al, 1999) and are typically abundant in eutrophic environments. Hemoglobin, present as Chironomids' blood pigment, binds oxygen and allows them to survive anoxic (low oxygen) environments; as little as 20% DO can be tolerated. Red chironomids, instead of brown, tend to dominate the benthos when DO is low. Hemoglobin production increases in response to a low oxygen

environment (Horne and Goldman, 1994). Almost half of the downstream macroinvertebrate population was red-colored midge larvae, which indicates the sediment under the algae and pebbles was anoxic. Because the water in Secret Ravine is not anoxic, the decomposing filamentous algae mats must be using all the available oxygen or be preventing oxygen from reaching the sediments.

The percent of moderately sensitive species was significantly higher at the upstream site due to the presence of dragonfly larvae. Anoxia also explains the lack of dragonfly larvae at the downstream site. Oxygen is vital for dragonfly larvae, which crawl along the bottom under the pebbles (O'Toole, 1995). Therefore, dragonfly larvae are limited to the higher reach of Secret Ravine where filamentous algae is not abundant.

Similar results were found in a 1977 macroinvertebrate study on the Truckee River, also located in Placer County. In this study, macroinvertebrate populations were sampled in both upstream and downstream sites (McLaren, 1977). The upstream, undeveloped site was located approximately three miles above the town of Truckee. The downstream site, located approximately 30 miles downstream of Truckee, was impacted by rapid development in the 1960's and 1970's.

As with Secret Ravine, the abundance of organisms at the downstream site was higher (Figure 7) although there was no difference in the macroinvertebrate diversity between the two sites (Figure 8). The %EPT (sensitive species) was higher at the upstream site (Figure 9), indicating less pollution. The percent tolerant species was higher at the downstream site (Figure 9), indicating higher perturbation and pollution. At the upstream site, Chironomid larvae were 16.3% of the macroinvertebrate population.

In contrast, the downstream site was 48.9% Chironomid larvae, a further indication of urban pollution (McLaren, 1977).

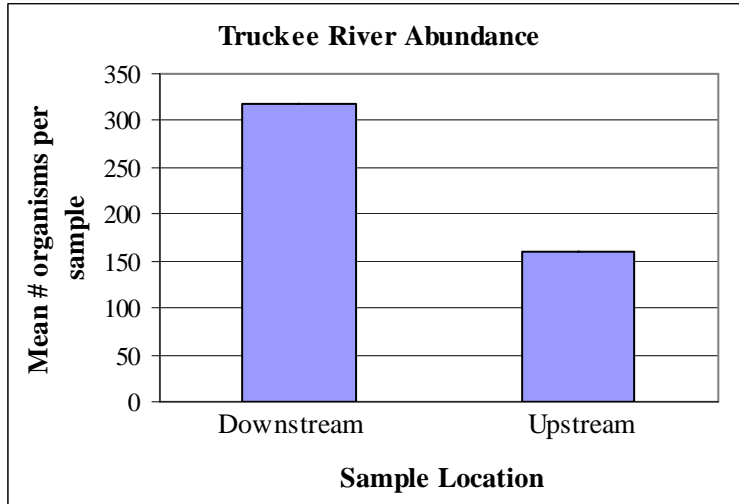


Figure 7. Mean number of organisms found at the upstream and downstream site in Truckee River. The mean number of organisms in each sample was higher at the downstream site (data from McLaren, 1977).

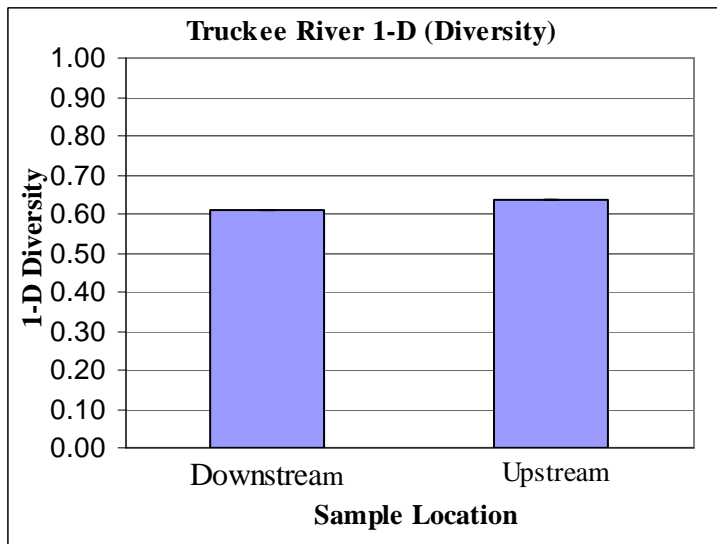


Figure 8. Simpson's index of diversity. There was no difference in diversity of macroinvertebrate communities in Truckee River (data from McLaren, 1977).

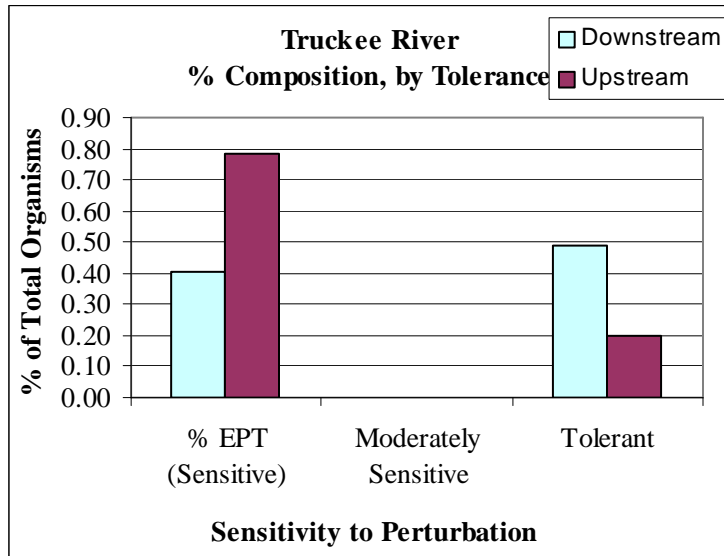


Figure 9. Mean percent sensitive (%EPT), moderately sensitive, and tolerant organisms. %EPT was higher at the upstream site. In contrast, the percent tolerant organisms was higher at the downstream site (data from McLaren, 1977)

Nutrient loading into the Truckee River began increasing in the 1960's. Increased nitrogen levels resulted in increased growth of attached algae (SWRCB, 2002). Plant respiration and decaying biomass decreased dissolved oxygen levels in the river (NDEP, 1994). The low DO levels have negatively impacted the threatened Lahontan cutthroat trout and the endangered cui-ui fish (NDEP, 1994).

Conclusion

Our results indicate that the macroinvertebrate populations in Dry Creek have been negatively impacted by urban development. The high algal productivity, probably in response to nutrient addition from runoff, in the downstream site has shifted the community to dominantly anoxia tolerant species. Further studies should focus on measuring the temperature, dissolved oxygen, and nutrient content of the upstream and

downstream runoff to determine the extent of eutrophication due to urbanization of the watershed.

In addition, because the mean number of individuals and the species composition varied greatly along a cross section, future studies should use a stratified sampling method instead of the random sampling method recommended by the EPA (Barbour et al, 1999). In a stratified method, all samples would be taken at the same depth and location across the channel. Depth, velocity, and pebble size, which can vary across a channel, could all affect the macroinvertebrate populations (Horne and Goldman, 1994) and explain the variation observed along the cross sections of Dry Creek. Samples collected in the center of the channel at both sites would be compared together and/or samples collected at the edges would be compared in order to eliminate the difference in macroinvertebrate populations across the channel.

The results of this, and future, studies of macroinvertebrates may provide useful information for preservation efforts. Community groups such as the Dry Creek Conservancy have formed to promote the preservation and restoration of parts of the Dry Creek watershed. To help preserve the creek habitat, urban runoff should be treated before entering the creek to remove nutrients, toxins, and sediment. Natural treatment systems (treatment wetlands) could be constructed to treat runoff before it enters the creek. Any preservation project should also consider monitoring changes in the macroinvertebrate populations, because they are good indicators of pollution and perturbation as well as a food source for salmon. The goal in a preservation or restoration project in Secret Ravine would be to maintain a healthy macroinvertebrate population like that found in the upstream, rural site.

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