An Exploration of Nutrient and Community Variables in Effluent Dependent Streams in Arizona

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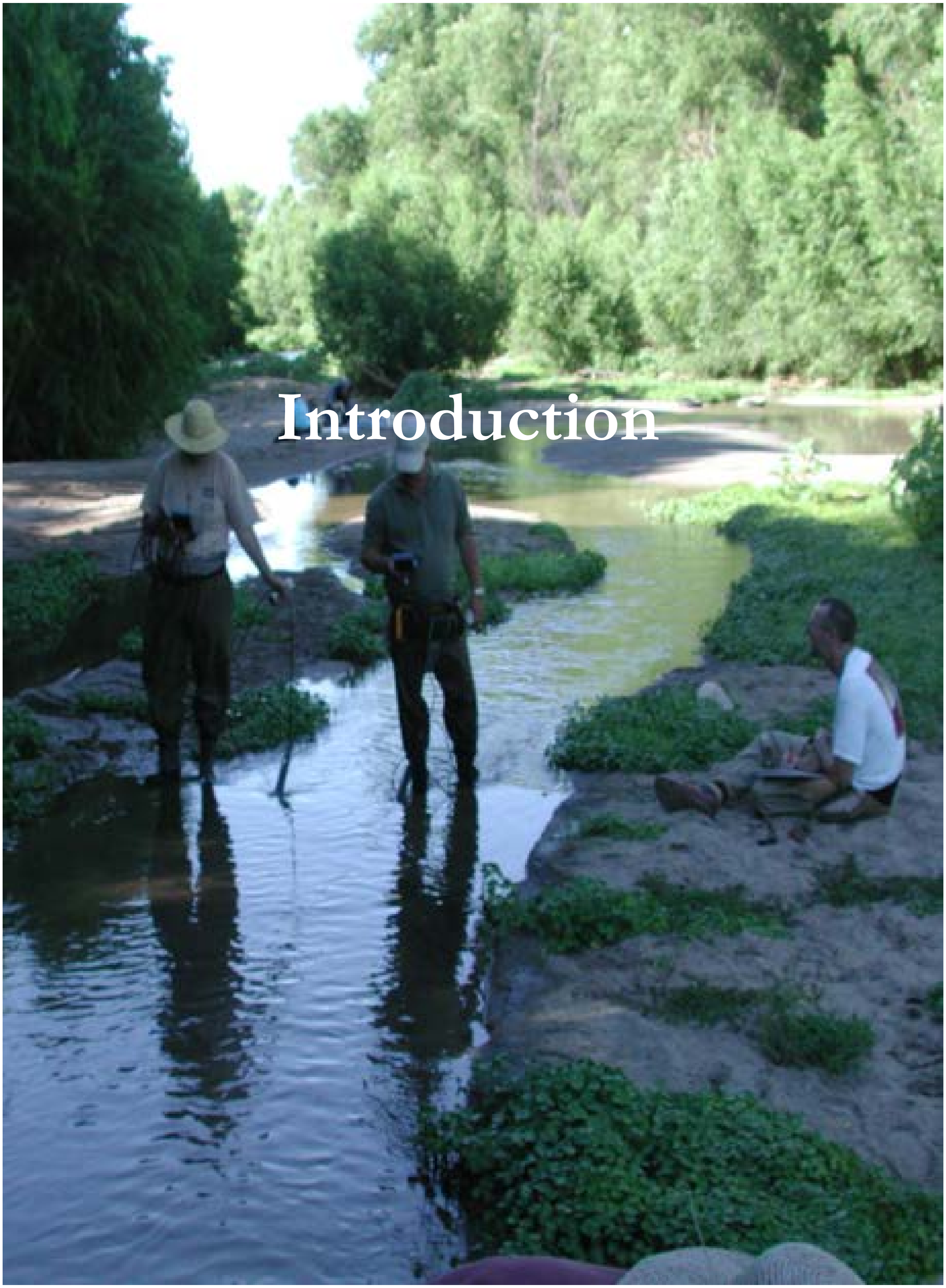
Abstract

We sampled from 5 effluent-dependent waters (EDW's) within Arizona and collected information on physical, chemical, and biological attributes to determine how these variables affected the diversity of aquatic macroinvertebrate assemblages. Each site was sampled once during the summer and winter of 2003-2004 as close to the respective outfalls as possible and at some distance downstream. The downstream site was determined by attempting to find a recovery zone where dissolved oxygen increased to "normal" levels. This recovery zone was not found in some of the EDW's analyzed for this study. We propose that diversity and pollution tolerance of aquatic macroinvertebrate assemblages are inversely proportional and that decreasing levels of the former equates to increasing levels of pollutant loading to the receiving stream. We examined the data using descriptive, comparative, and ordinal techniques and found the above statement to be true in every case. Physical variables, while of obvious importance in aquatic systems with a relatively low number of stressors, were of limited significance where other, perhaps more important stressors, existed. Of particular detriment to the diversity of aquatic macroinvertebrates were levels of reduced and organic forms of nitrogen particularly un-ionized ammonia, total ammoniacal nitrogen, and total kjeldahl nitrogen, combined with low levels of both dissolved oxygen (measured as a point) and mean diel dissolved oxygen (measured over a 24 hour period).

Introduction



In Southwestern U.S. hot desert ecosystems, water is a precious resource that is quickly disappearing from the landscape. Natural and anthropogenic reductions in surface water flows such as drought, groundwater withdrawal, and impoundment only increase the ecological value of any new surface water resource.   Effluent dependent waters (EDW's), those waters comprised solely of effluent discharged to an ephemeral watercourse are one of the few "new" sources of water and as such, their ecological importance will only increase as more natural aquatic ecosystems disappear.

Discernible differences between streams designated as aquatic and wildlife cold or warm water and those designated as effluent dependent may seem readily apparent; yet, a closer look presents a continuum of aquatic ecosystems from minimally disturbed and perennial to pooled effluent. Within this range there are large overlaps in biotic assemblage and ecosystem variables. While one might visualize an effluent dominated stream as purely a disposal alternative for municipal effluent, it is also true that EDWs exist having ecosystem structure and function resembling those found in more natural streams.

An understanding of this continuum is difficult because large data sets regarding EDW's are not yet available. This puts additional emphasis on more nascent research efforts where the data gaps are often larger than data sets. Are Clean Water Act goals best served by drawing arbitrary and artificial boundaries? Additionally, has the need to efficiently and cheaply dispose of effluent required compromises that might restrict the development of more robust and diverse aquatic assemblages?

Since most EDW's in Arizona contain few, if any, fish, we chose aquatic macroinvertebrates as our indicator trophic group for this study. Aquatic macroinvertebrates are often used in aquatic research because they are ubiquitous and have species-specific life history requirements and pollution tolerances. While metrics have been devised using aquatic macroinvertebrates to determine the health of naturally-occurring freshwater streams in Arizona, we believe that EDW's are too dissimilar from their "natural" counterparts for this metric to be of much significance. We chose instead a more simplistic approach which characterizes the species diversity of aquatic macroinvertebrates and correlates this with other variables collected from five EDW's throughout the state. To quantify diversity, we chose the Shannon-Weiner index which places emphasis on the relative abundance of each species. We believe this is important, especially in aquatic systems where known of pollutant loading occurs because these areas are often typified by having a large biomass comprised of only a few species. A high biomass of only pollution tolerant species does not mean that an area is attaining any standard of ecosystem structure or function. The formula for the Shannon-Weiner Diversity Index is:

$$H' = [\sum (p_i)(\ln p_i)]$$

-Where H' represents the amount of diversity in an ecosystem and will be greatest if species are equally abundant.

- p_i represents the proportion, or "relative abundance", of each individual species to the total.

For this study, we chose 5 effluent dependent waters within Arizona.

Rio de Flag serving the city of Flagstaff.
Bitter Creek serving the city of Jerome
Jack's Canyon (Big Park WWTP) serving the Village of Oak Creek
The Santa Cruz River (Roger Road WWTP) serving much of the city of Tucson
The Santa Cruz River (Nogales IWWTP) serving the cities of Nogales Arizona and Nogales, Sonora Mexico.

Variables chosen are from 4 major categories; biological, physical, chemical, and physico-chemical.

Physical variables consisted of measuring gradient, embeddedness, floodprone and bankfull width, substrate classification and fractionation by category sizes, and flow.

Chemical variables consisted of nutrients such as ammonia-N, nitrate+nitrite-N, TKN, orthophosphate, total phosphorous, total and dissolved organic carbon, general chemistry (hardness, alkalinity, etc.), and suites of total and dissolved metals.

Physico-chemical variables consisted of dissolved oxygen (mg/L and percent saturation), pH, temperature, specific conductivity, oxidation-reduction potential, total suspended solids, turbidity, and mean diel dissolved oxygen.

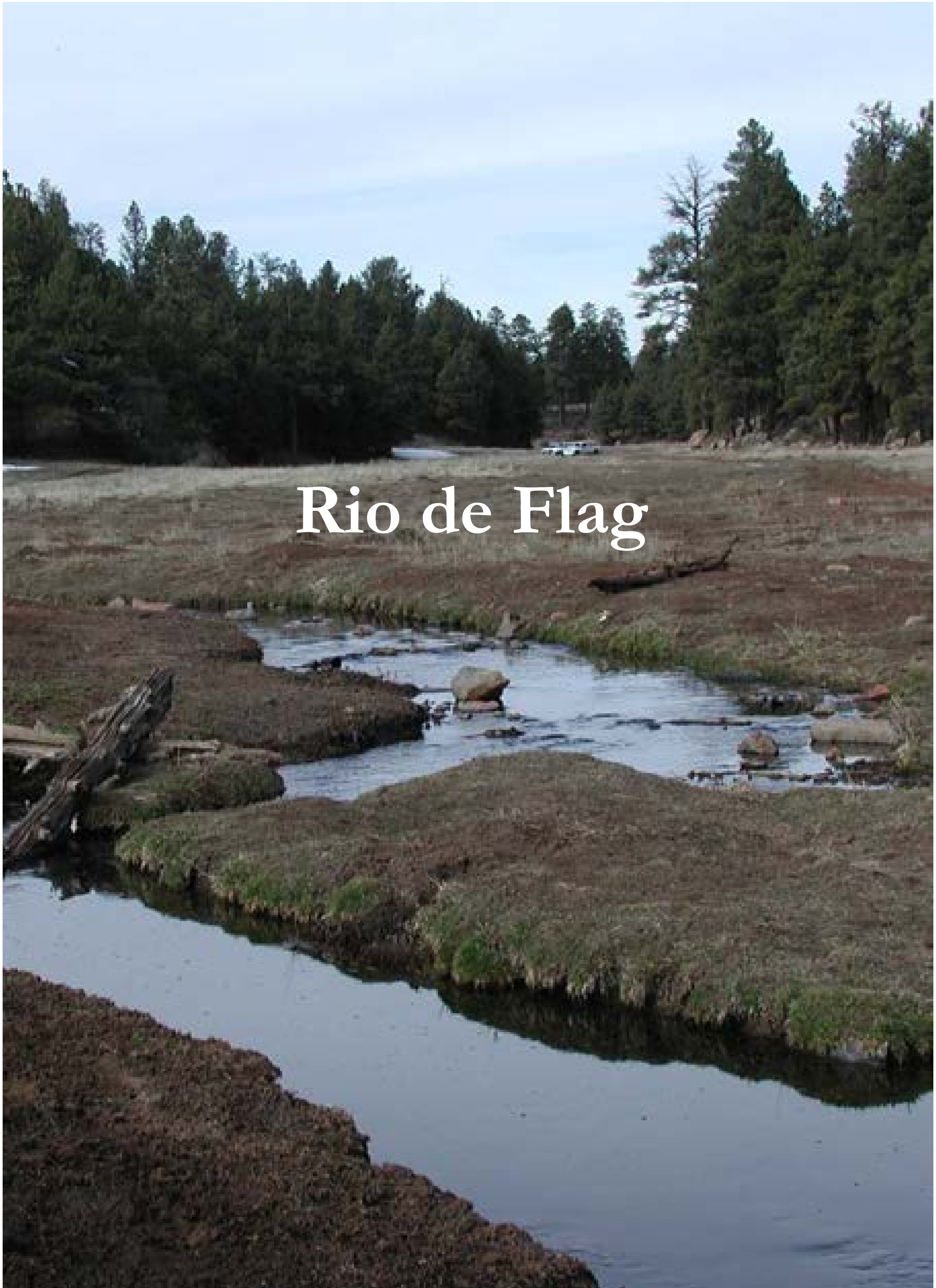
Biological variables included chlorophyll *a* (peri- and phytoplankton), peri- and phytoplankton identification and enumeration, and macroinvertebrate collection (using ADEQ protocol), identification, and enumeration (sub-sampled using a Caton tray).

Aquatic Consulting and Testing performed all of the chemical analyses. Biological analyses were performed at the University of Arizona's Environmental Research Laboratory. Physicochemical data was collected using a Hydrolab Surveyor 4 sonde and data collector.

In order to examine correlations between response variables and diversity, we used principal components analysis (PCA). Principal components analysis is a classical statistical method also called a Karhounen-Louve transformation or a Hotteling transformation. PCA uses linear transformation and matrix algebra to choose a new coordinate system for the data cloud so that the centroid is set to zero and the first principal component axis goes through the maximum amount of variation with the second axis exactly orthogonal to the first. This sets the framework for the remaining principal component axis. In essence, PCA reduces dimensionality of a data set so that correlations among several variables can be examined simultaneously. We used a 3-dimensional representation of the data cloud (Gabriel bi-plot) so that the PCA axes could be visualized. The relative distances between each axis are eigenvectors and a vector report is published below each bi-plot. The method in which the bi-plot represents the 3-dimensional correlations is that axes that are closest to one another have some degree of positive correlation (the closer they are, the higher the positive correlation) while those in opposite quadrants are inversely correlated.

We sampled once during the summer and once during the winter at each EDW and chose the upstream site as close as feasible to the outfall in every case. The second site was chosen based upon linear profiles of dissolved oxygen where we attempted to find a "recovery zone" where dissolved oxygen levels began to once again increase. We were able to find this recovery zone in some of the less polluted EDW's while others were never found as dissolved oxygen actually decreased with distance from the outfall.

All field data as well as laboratory samples were collected and analyzed using ADEQ protocol and QA/QC.


Rio de Flag

Background

The Rio de Flag (RDF) wastewater treatment plant (WWTP) is a 4 MGD plant that serves the city of Flagstaff Arizona. This plant produces class A+ water through a process involving screening, primary sedimentation, aeration, secondary sedimentation, filtration, and disinfection using ultraviolet sterilization. A two-stage anoxic/aerobic Bardenpho process is used and is designed to reduce nitrogen content in wastewater. The use of UV sterilization greatly reduces the need or use of chlorine.

Wastewater that is not used for irrigation is released into the drainage of the same name, the Rio de Flag. Influent to the RDF WWTP and amount discharged into the Rio de Flag drainage from June 2003 to June 2004 is listed below.

Month	Influent (MG)	Discharge (MG)
June	61.190	15.346
July	69.432	18.783
August	70.522	51.971
September	66.862	49.085
October	62.739	31.255
November	55.987	49.515
December	56.916	50.233
January	57.107	50
February	54.16	43.737
March	62.739	7.4845
April	56.591	28.911
May	62.739	7.4845*
June	67.447	7.7838*
Total for Year	**799.460**	**445.580**
Average/month	**61.497**	**34.275**

* Much of the discharge that would have gone to the Rio de Flag drainage was diverted to irrigate a new golf course.

The Rio de Flag drainage originates on the southwestern slopes of the San Francisco Peaks near Big Leroux and Little Leroux Springs (Figure 2a). Along its length, the Rio de Flag drainage has many tributaries and is itself a tributary of San Francisco Wash, which is a tributary of the Little Colorado River. The total drainage area of the watershed is 302 km^2. The elevation changes along the length of the drainage from approximately 12,000 feet at the height of the San Francisco Peaks to about 6800 feet in the wide, flat valleys southeast of Flagstaff.

Besides discharge from the RDF WWTP, snowmelt from the San Francisco Peaks in winter and spring and rainfall during the summer monsoons of July and August contribute to flow in the Rio de Flag. Average annual precipitation for the drainage area is approximately 20 inches in Flagstaff to 35 inches on the San Francisco Peaks with 25 inches of this precipitation occurring as snowfall. In this study, the Rio de Flag had no contribution of flow from upstream areas other than the effluent released from the WWTP. Lack of attenuation of flood peaks due to urbanization along the middle reach of the Rio de Flag may mean that flows are more flashy and sporadic than what they have been historically.

The Rio de Flag floodplain is intensively developed upstream of the sampling sites as it crosses through the center of Flagstaff. Nearly half of the land use within the 100-year floodplain is considered residential with other land uses consisting of recreation, schools, light industry, railroad, utility easements, and retail businesses (U.S. Army COE).

Site Description, Substrate, and Geomorphological Data

The effluent stream empties into a ponded area a few meters below the outfall. Channel length from outfall to the ponded area was not long enough for a good characterization so the decision was made to sample from below the pond where the water flows back into the thalweg of the stream. This makes this site non-typical in that we are actually sampling water that has been released from the pond, which may have an effect on nutrient levels and cycling. Unfortunately, there was no other alternative at this site.

RDF1 and RDF2 lie at approximate elevations of 2071 and 2069 meters above sea level at 35^{o}11’03”N., 111^{o}37’45”W. and 35^{o}10’51” N., 111^{o}37’19” W. latitude and longitude respectively.

The channel length from site RDF1 to RDF2 was approximately 966 meters and had the lowest relative slope of all sites at 0.003%. This site was sampled for the first time on 1/23/03 and again on 8/12/03. Upon first impression there was little vegetation (dormant or otherwise) along the banks and it appeared to be heavily grazed, presumably by elk (Figure 1a). This situation improved during the summer of 2003 but heavy grazing was still evident.

Sedimentation within the channel appeared high even though bank stability appeared moderately stable. Embeddedness increased from RDF1 to RDF2 (Figure 4a) and was higher during the summer rather than the winter of 2003 (Figure 5a). This could have been due to higher velocity at RDF1 (mean = 0.27 m/s) than RDF2 (mean = 0.18 m/s). The higher velocity at RDF1 could explain why the percentage of silt and clay was much higher at RDF2 (Figure 6a). The particle size difference between RDF1 and RDF2 is also shown in Figure 6a.

The extent of riffle habitat increased slightly from RDF1 to RDF2, however any positive impact of this was probably negated by slightly increased sedimentation of fine material at RDF2. The habitat for aquatic macroinvertebrates, as calculated using metrics for cold water streams in Arizona, can be described as impaired.

Geomorphological Data from Rio de Flag

Channel length: 966 m

Bankfull width: 11.1 m

Floodprone width: 68.6 m

Slope: .003

Figure 1a. ***View of Rio de Flag looking southwest***

Figure 2a*. Topographical map of the Rio de Flag watershed*

Figure 3a. ***Topographical map of the sampling sites***

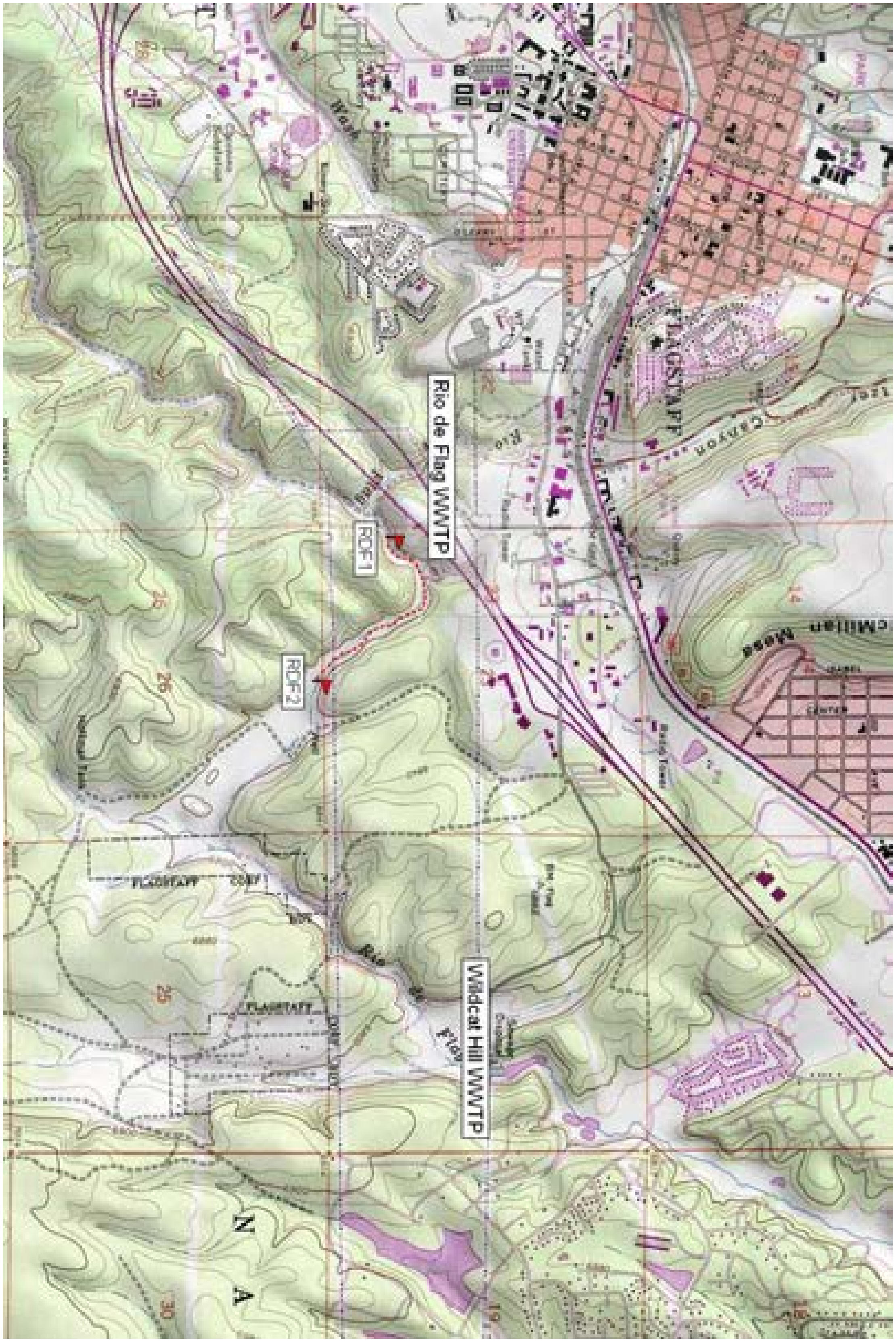
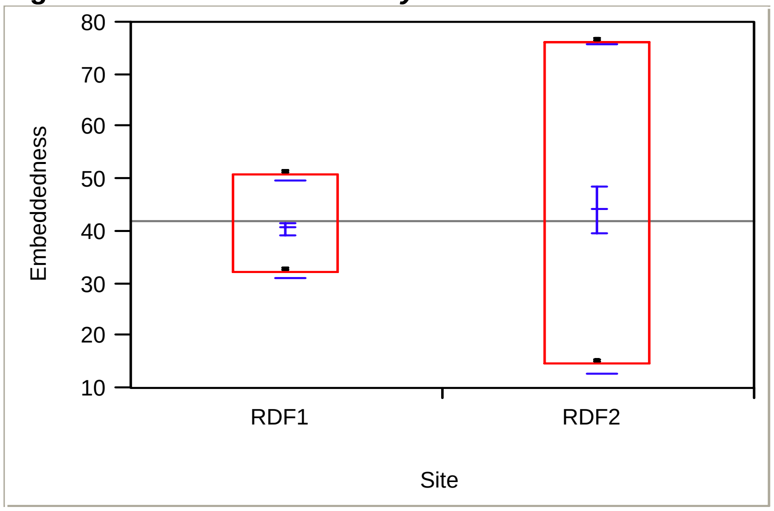


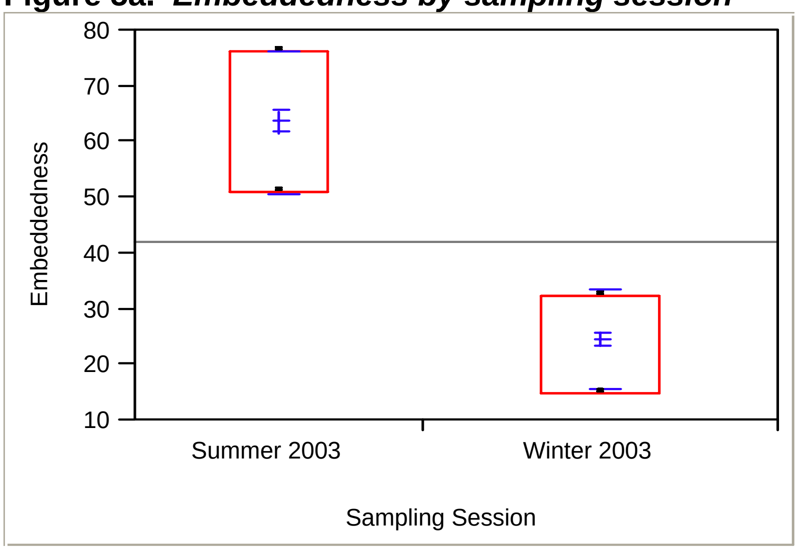
Figure 4a. ***Embeddedness by site***



Means

Level	Number	Mean
RDF1	2	40.4648
RDF2	2	44.2565

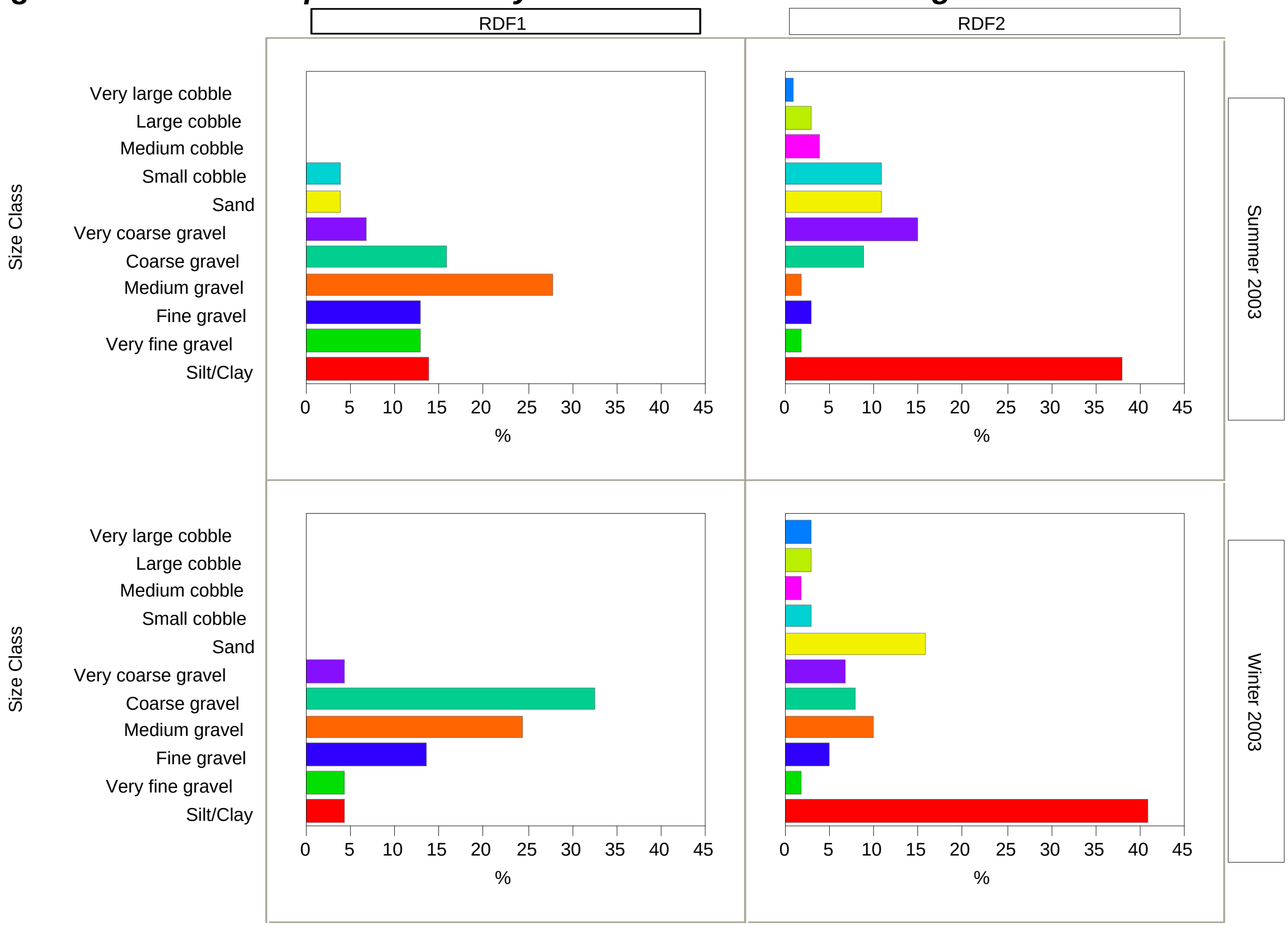
Figure 5a. ***Embeddedness by sampling session***



Means

Level	Number	Mean
Summer 2003	2	63.5689
Winter 2003	2	24.7327

Figure 6a. ***Substrate particle size by site and date at Rio de Flag***



Physico-chemical Data

Linear profiles of physico-chemical data were obtained for both sampling dates starting at RDF1 and taken at roughly equidistant locations to RDF2. (See Appendix A for data.)

Figure 7a. ***RDF linear profile, 1/23/03***

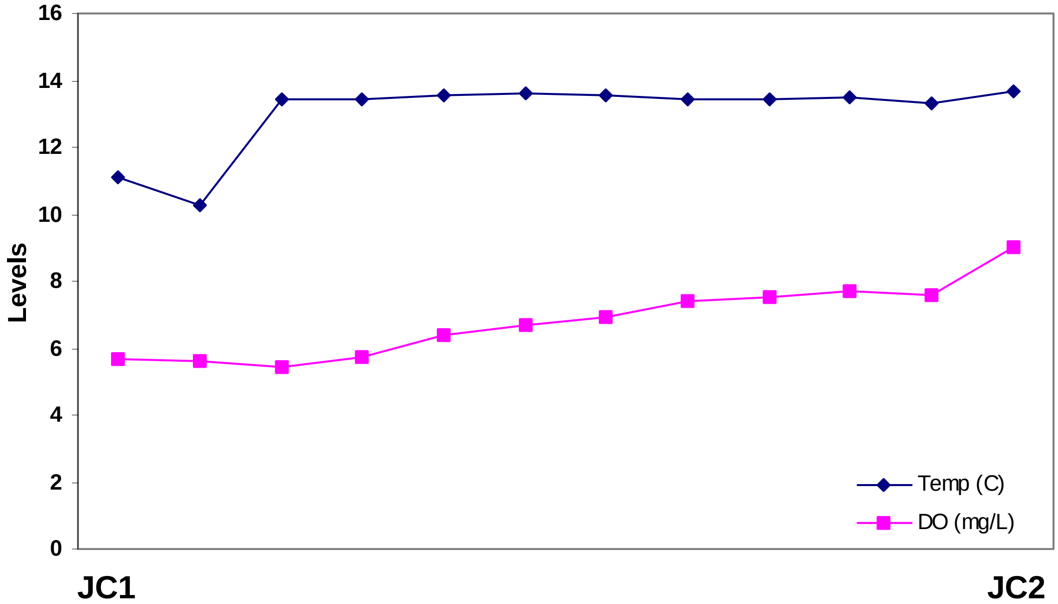
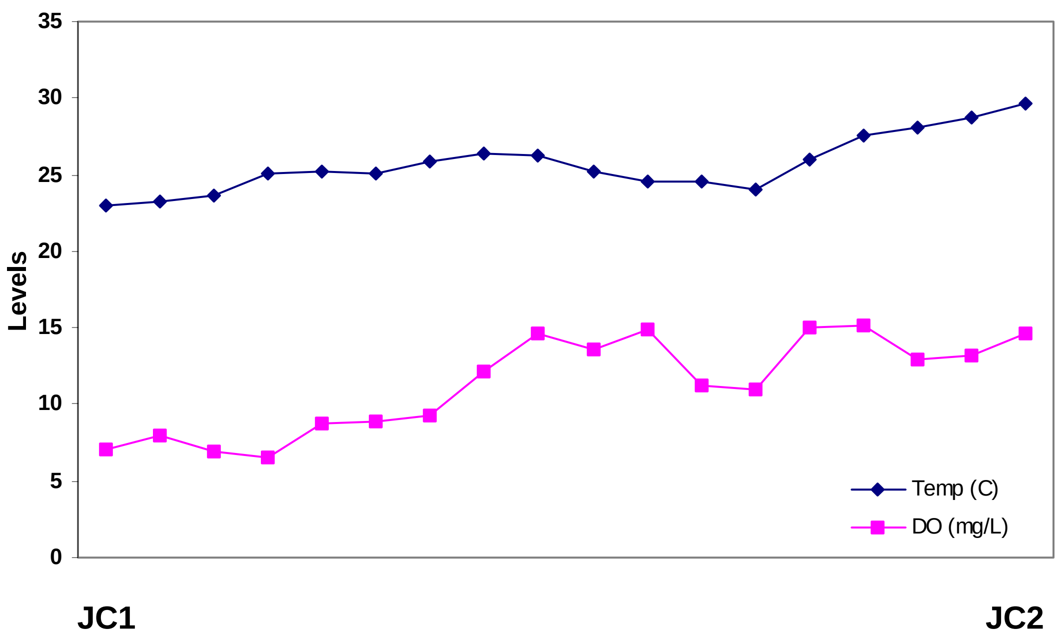


Figure 8a. ***RDF linear profile, 8/12/03***



In addition to the linear profiles, physico-chemical readings were taken every 30 minutes over a 24-hour period (diel profiles) during both samplings at RDF2. (See Appendix B for data.)

Figure 9a. ***Diel pattern at RDF2 on 1/23/03***

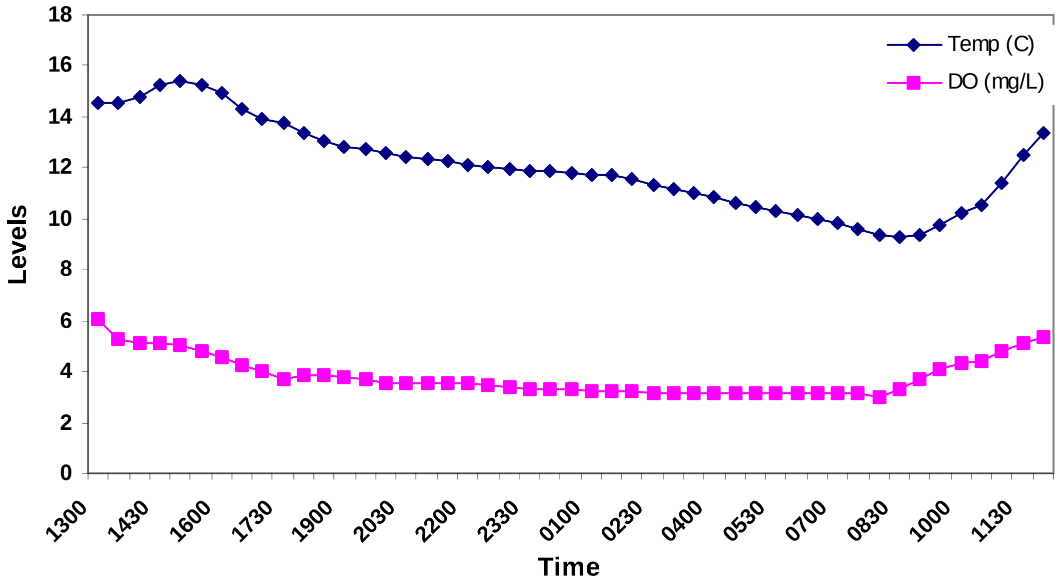
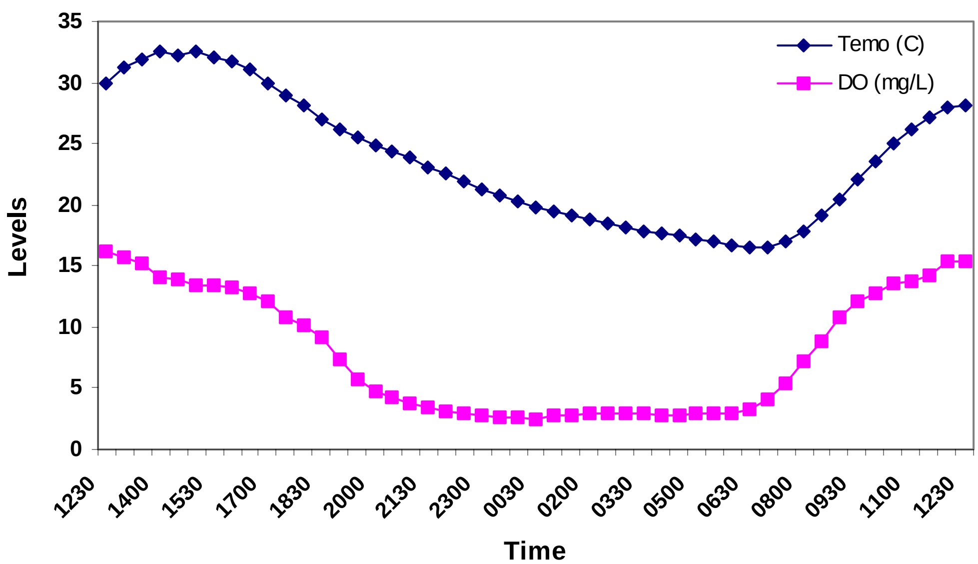


Figure 10a. ***Diel pattern at RDF2 on 8/12/03***

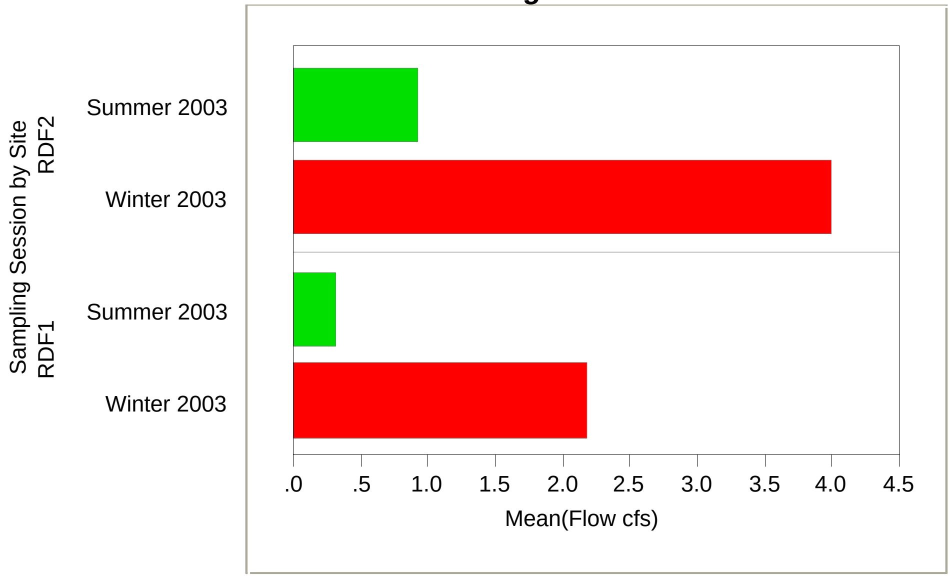


Dissolved oxygen and pH levels increased from RDF1 to RDF2 on both sampling dates, presumably due to increased primary production. While RDF1 emanates from a ponded area fed by a small reach of flowing water instead of the more typical outfall pipe, it would appear that most of the dissolved oxygen and pH level increases were due to an increase in primary production within the stream from RDF1 to RDF2. There were very few, if any, vascular macrophytes during the winter sampling, so most of the increase in DO and pH levels with distance from RDF1 are presumably due to increased periphytic growth. During the summer sampling, there were abundant vascular macrophytes (mostly species of *Potamogeton)* in addition to macroscopic periphytic growth (mostly species of *Cladophora*) and dissolved oxygen was quickly elevated to supersaturated levels. Water temperatures during the summer of 2003 were very warm and again, increased from RDF1 to RDF2. Even during the winter sampling, water temperatures were much warmer than would be expected at such a high altitude. Air temperatures over the 24-hour period are unknown, but during the winter the ground alongside the stream was frozen and ice readily formed on it overnight. The large discrepancy between air and water temperature during the winter may mean that this EDW behaves differently in an ecological sense than naturally occurring surface water in the region at a similar altitude.

There were differences in flow rates between the summer and winter samplings (Figure 11a). The relatively higher flow, density, and thermal mass of water during winter means that it will "hold" heat more efficiently than the summer. This is noted in the higher change in water temperature over a 24-hour period during the summer sampling.

Dissolved oxygen levels during the summer were often supersaturated from mid-day to sunset and beyond the limit the calibrated Hydrolab could read. Levels of pH followed a similar trend. As previously stated, this is probably due to extremely high levels of photosynthesis by vascular macrophytes and/or periphyton. Even though dissolved oxygen levels were much higher during the day in the summer compared to the winter, the extremely warm temperatures during the summer means it is less capable of maintaining DO levels when respiration exceeds photosynthesis. A 12°C temperature rise roughly doubles the rate of many chemical reactions including the dissolution of oxygen into water. With water temperatures over 30°C in the summer, the rate of photosynthesis of submerged aquatic vegetation must be incredibly high to supersaturate the water (>200% saturation) with dissolved oxygen, but these very warm temperatures also cause oxygen gas to leave the water quickly in the dark. It is the combination of relatively low flow, exceedingly warm water temperatures, abundant light for photosynthesis, and little or no nutrient limitation (discussed later) that leads to the supersaturation that was observed. The summer diel pattern in EDW's may have profound implications regarding the amount, type, and diversity, of higher aquatic organisms these areas can sustain. This will be discussed in detail later in this report.

Figure 11a. ***Flow at RDF1 and RDF2 during the summer and winter of 2003***



Nutrients

Compared to naturally occurring surface waters within the state, most nutrient levels found at Rio de Flag were elevated (Figure 12a). Of special interest is the relatively large amount of total- and ortho-P during the winter as compared to the summer sampling. It appears that phosphorous is quickly assimilated into biomass during the summer and approaches a 16:1 ratio indicating phosphorous limitation (Figure 13a). When biomass, especially vascular macrophytes and periphyton, is decreased during the winter, both N and P are available in abundance in the water and nutrient spiraling appears to be at a minimum.

There appears to be significant nitrification from RDF1 to RDF2 during the summer. This would be expected with the supersaturation of dissolved oxygen noted during this sampling. There was little or no difference in TOC or DOC by either site or sampling session (Figure 14a).

Critical data about nutrient spiraling length cannot be determined using the data collected for this study. The spiraling length represents the distance over which the average nutrient atom travels as it completes one cycle of utilization from a dissolved available form, passes through one or more metabolic transformations and is returned to a dissolved available form. Quantitatively, it is the ratio of the downstream flux of nutrient to the uptake of nutrient per unit length of stream. More intense utilization of the nutrient, along with more effective retention of particulate forms, shortens the spiraling length so that an individual nutrient atom completes more cycles in its passage through the stream.

How nutrients are processed and “spiraled” in any given area of stream may have a variety of implications for downstream ecological processes. The time nutrients are sequestered in one area by biological uptake or other means may result in seasonal alterations in downstream nutrient loads. Partitioning of nutrient forms by processing mechanisms in upstream areas may also have implications regarding the type and availability of nutrients being released downstream. A complete evaluation of uptake length, requiring the use of isotopic tracers, would provide needed data on ecosystem function and set boundaries on the amount and type of nutrients a WWTP could release to an EDW with minimal impact on down stream ecosystem function.

Without data on spiraling length, the only generality that can accurately be made about nutrients in Rio de Flag is that bio-available phosphorous is quickly incorporated into biomass during the summer and that nitrification occurs between the two sites.

Figure 12a. ***Nutrient levels at Rio de Flag by site and sampling session (all units in mg/L).***

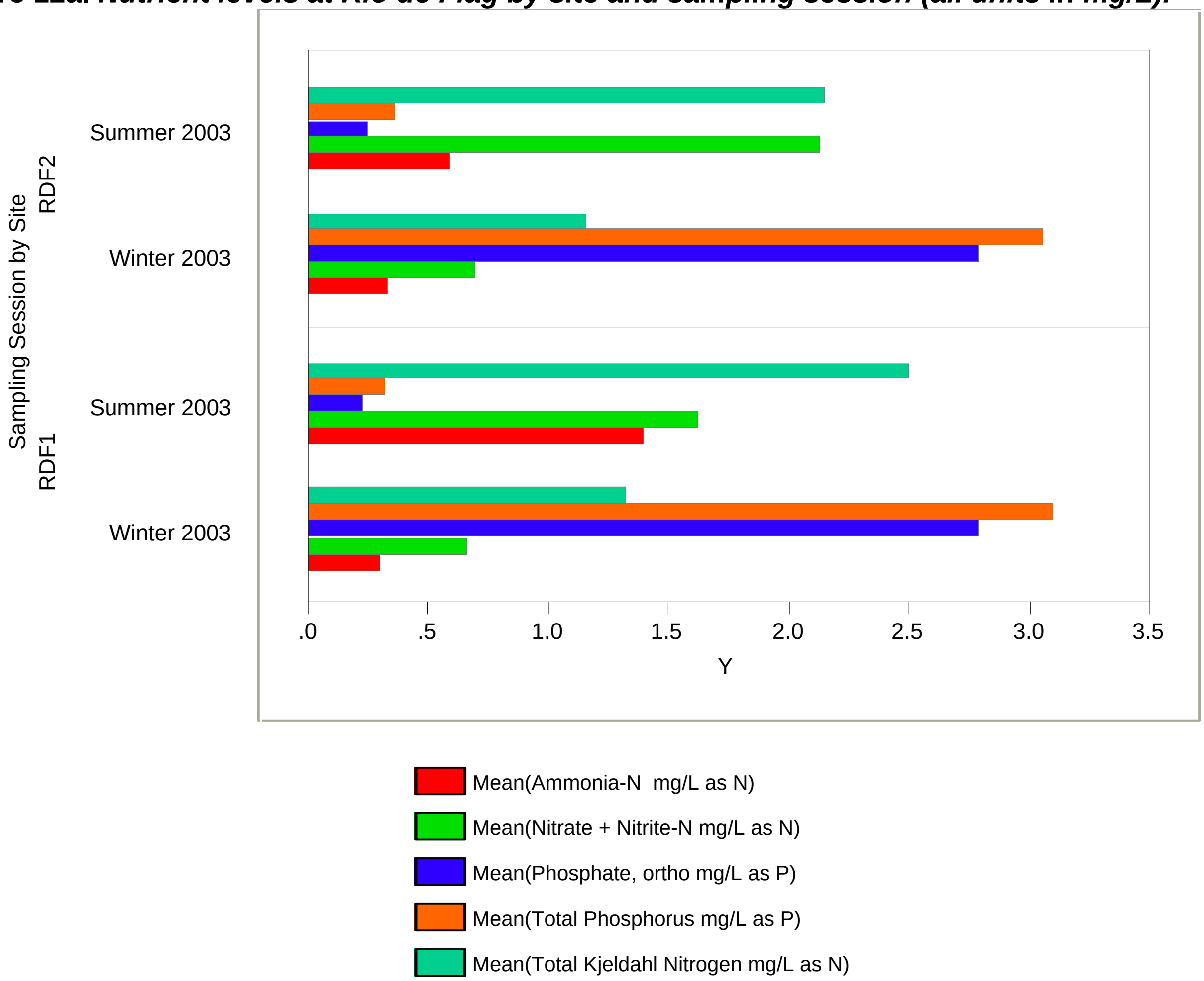


Figure 13a. ***N:P ratio by sampling session and site*** (total N calculated as the sum of ammonia, nitrate, nitrite, and TKN)

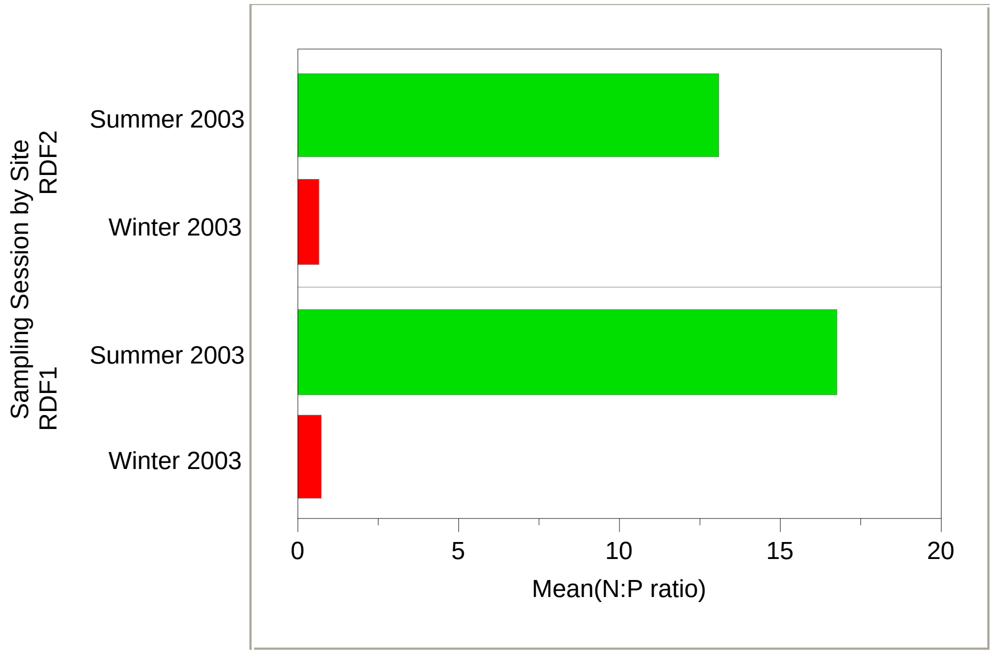
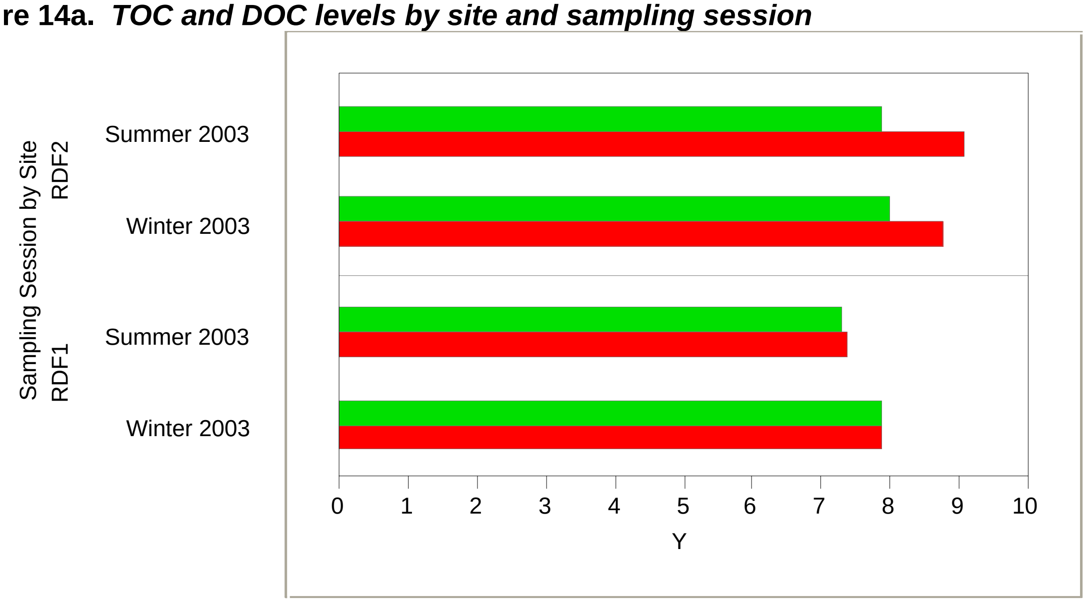


Figure 14a. ***TOC and DOC levels by site and sampling session***



Biological Data

Algae

Comprehensive analyses of both periphyton and phytoplankton were performed for both sites and sampling periods. Because the Rio de Flag sites were close to the outfall from the pond, it's difficult to determine how this affected phytoplankton dynamics. Some of the species were those commonly found in lentic rather than lotic environments (e.g., species of *Chlamydomonas, Chlorella,* and *Microcystis*) but it appeared that the phytoplankton was largely comprised of species that had become dislodged as periphyton.

While RDF1 had slightly higher levels of phytoplankton chlorophyll *a*, RDF2 had much higher levels of periphyton chlorophyll *a*. As there was apparently no true potomoplankton at either site for either date, the periphyton probably plays a larger role in primary production than does the phytoplankton.

The periphyton was largely comprised of two divisions of algae, Chlorophyta and Chrysophyta, and to a smaller extent, Cyanophyta. It's interesting that RDF1 had relatively low numbers of periphyton compared to RDF2 and had higher numbers during the winter compared to summer. Both sites were dominated by pennate species of diatoms during the winter and filamentous species of chlorophytes during the summer. During the summer, there were several species of diatoms growing epiphytically on the filamentous chlorophytes.

During the summer of 2003, there were large, macroscopic growths of filamentous algae, primarily *Cladophora glomerata*, growing attached to the substrate. This growth increased linearly with distance from RDF1 to RDF2. This filamentous growth form and overall increased biomass probably led to observed large swings in dissolved oxygen and pH from day to night. There were several species of pennate diatoms growing epiphytically on the *Cladophora*, and some were suspended by mucilaginous stalks, such as species of Gomphonema.

The algal community at Rio de Flag is one that is often found in nutrient-enriched lotic systems within the state. Overall, biomass is relatively high, especially during the summer months when filamentous forms dominate. These filamentous forms provide increased habitable area for species of aquatic macroinvertebrates. During the summer, this benefit may be outweighed by large diel swings in dissolved oxygen and pH levels.

Figure 15a. ***Phytoplankton chlorophyll a levels by site and date***

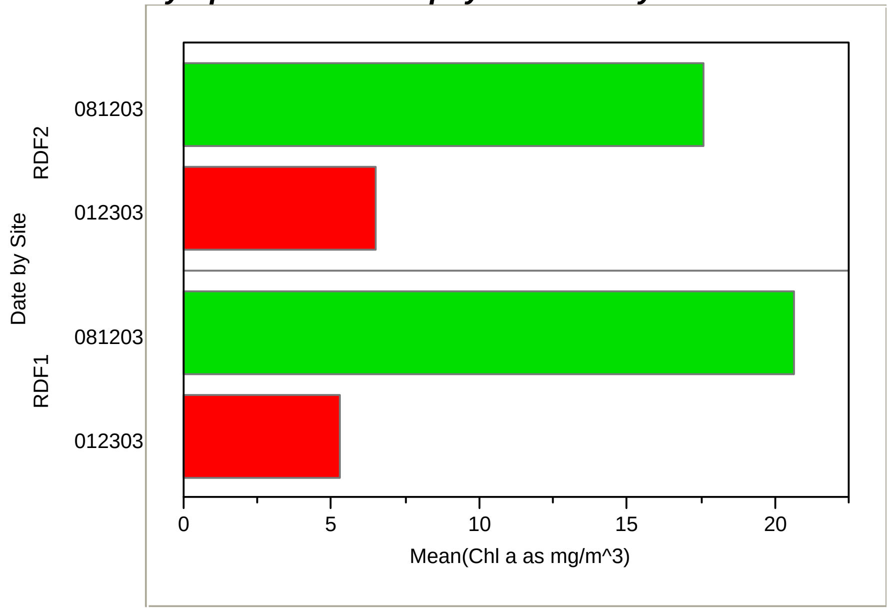


Figure 16a. ***Periphyton chlorophyll a by site and date***

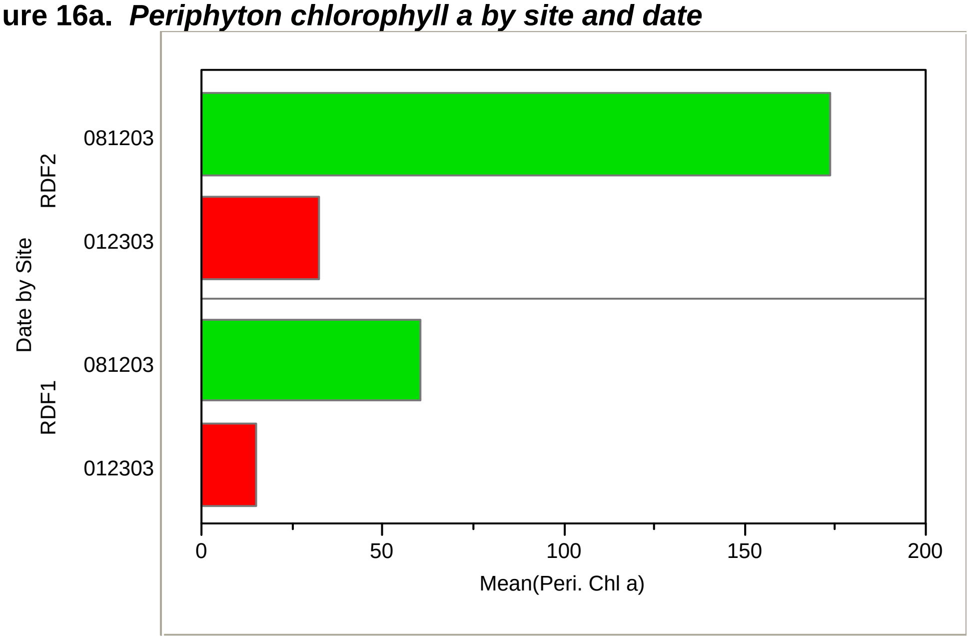


Figure 17a. ***Periphyton counts by division***

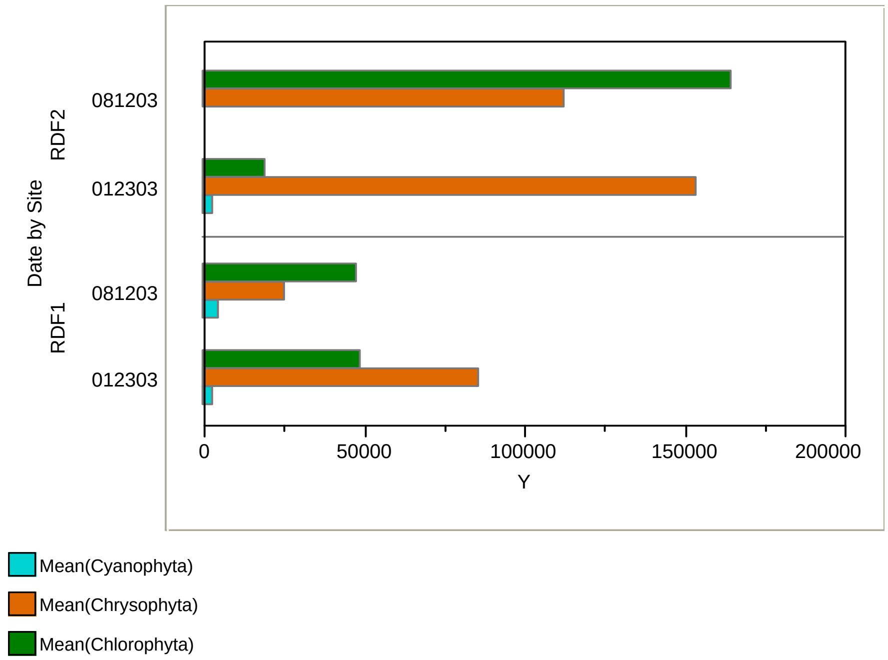


Figure 18a. ***Periphyton counts at RDF1 by genus for 01/23/03***

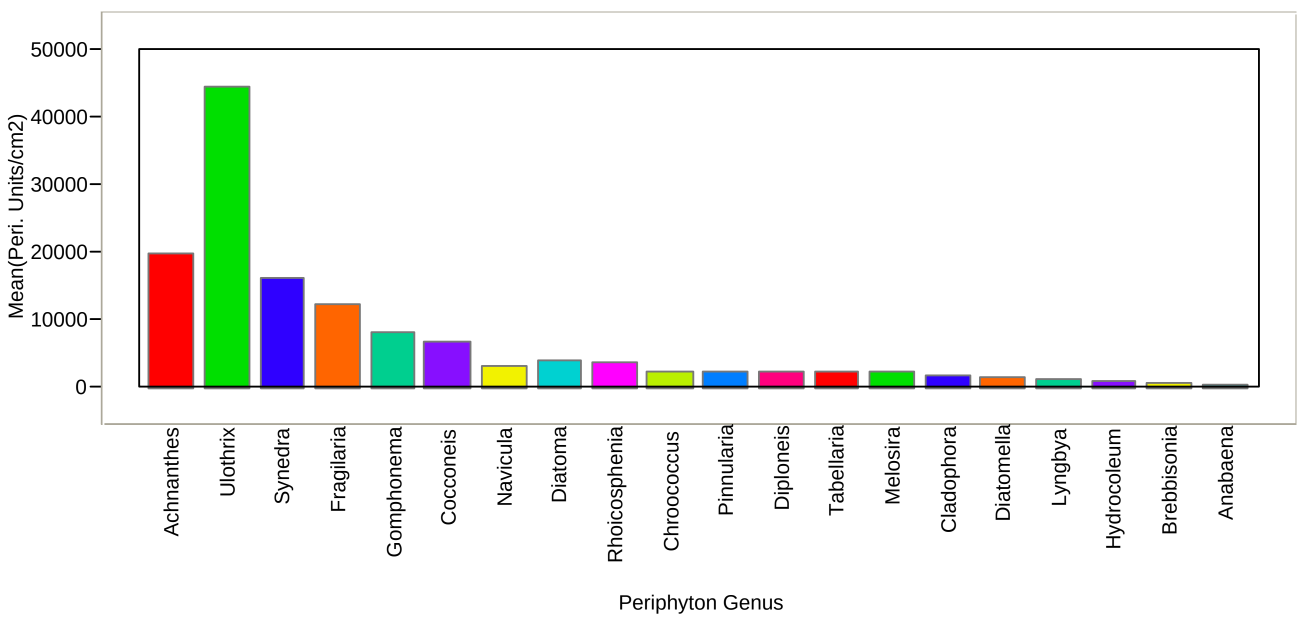


Figure 19a. *Periphyton counts at RDF1 by genus for 08/12/03*

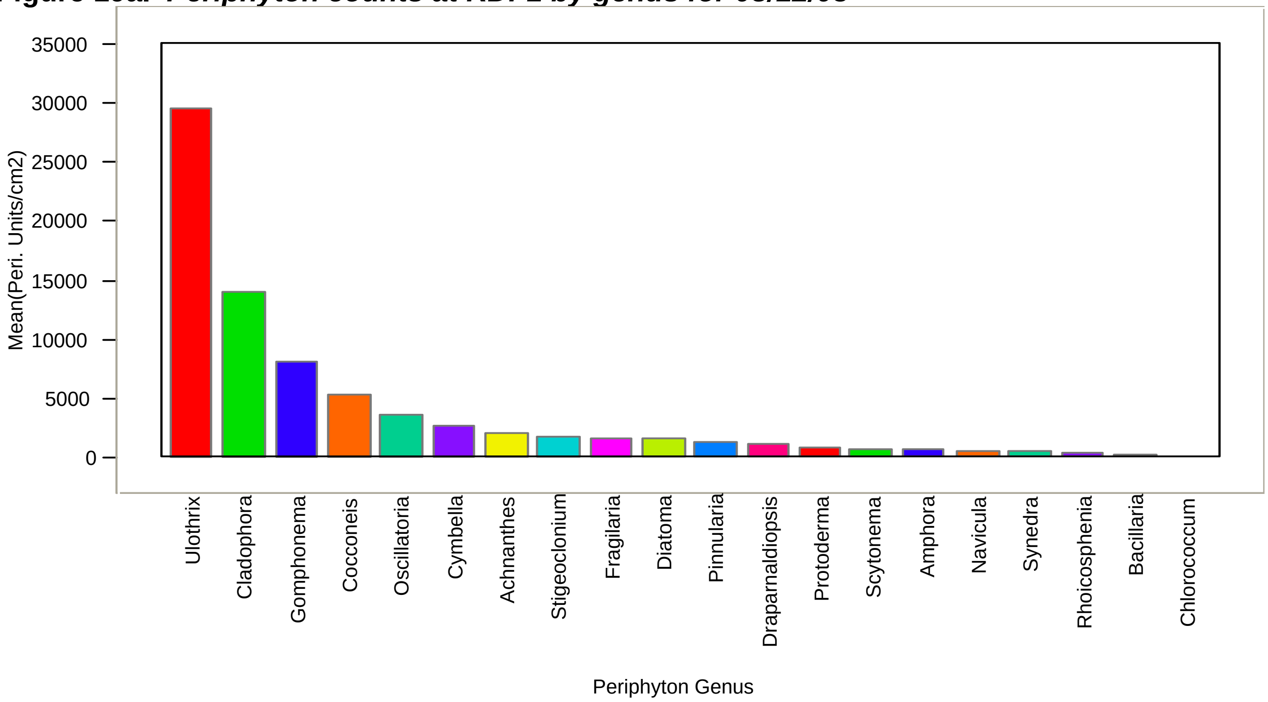


Figure 20a. *Periphyton counts by genus at RDF2 by genus for 01/23/03*

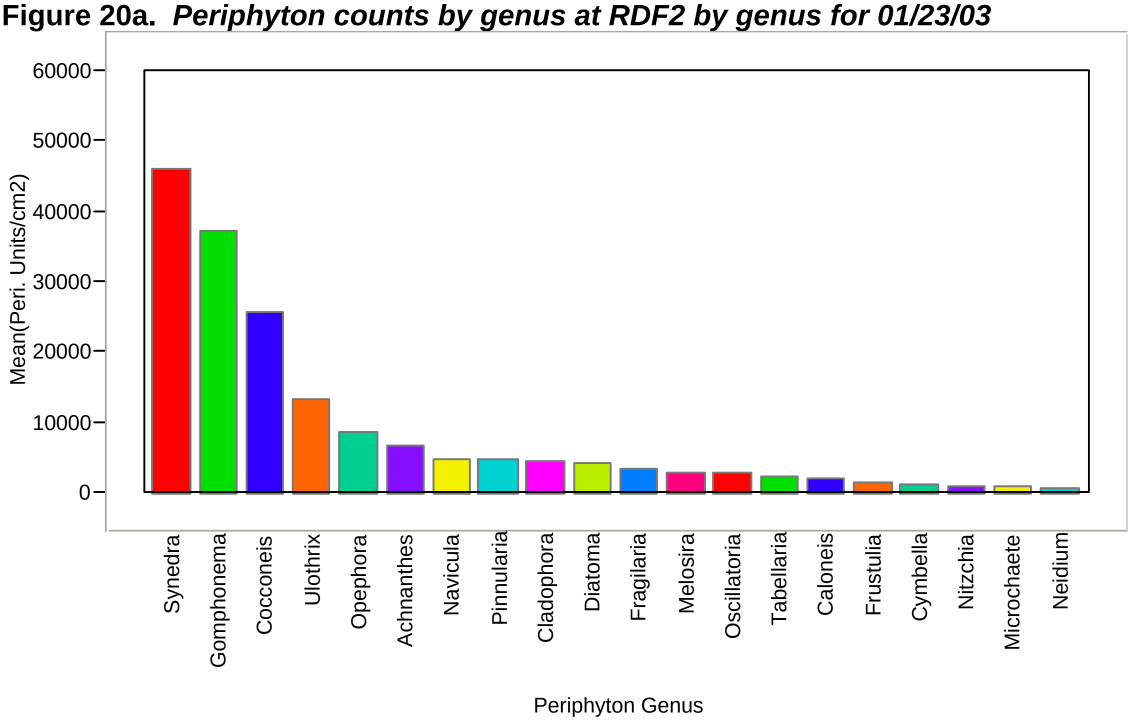
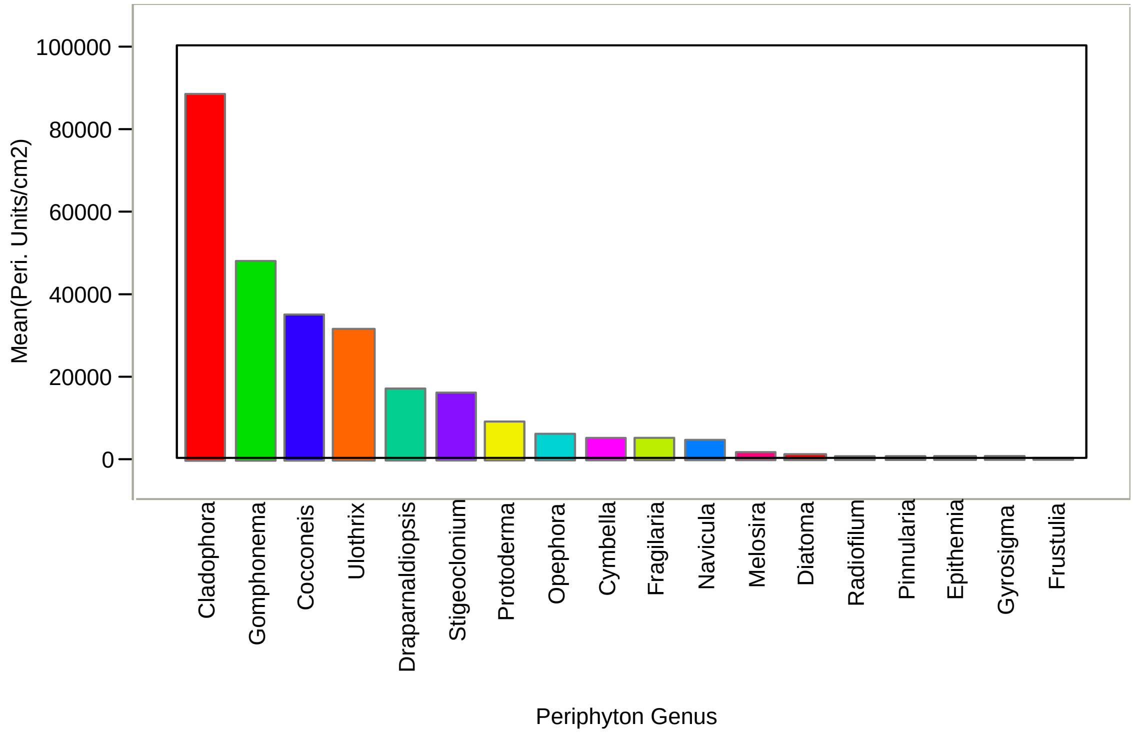


Figure 21a. ***Periphyton counts by genus at RDF2 by genus for 08/12/03***



Aquatic Macroinvertebrates

There was no discernible difference in overall numbers of macroinvertebrates between sites. As expected, numbers were higher during the summer compared to winter. While overall biomass was greater during the summer, there was little difference in the types of macroinvertebrates present at least to the ordinal level. Tubificid worms dominated during the winter followed by the ectoparasitic nematode *Dorylaimida* whereas the summer was dominated by ostracods in the order Podocopida followed by gastropods in the order Limnophila.

There was virtually no difference in pollution tolerance, as measured by the Hilsenhoff Biotic Index (HBI), between sites or date; pollution tolerance by macroinvertebrates always scored between 7 and 8. These are high values compared to most naturally occurring surface waters.

Diversity values, as quantified by the Shannon-Weiner diversity index (S-W Index), were not useful in describing community composition of macroinvertebrates. Numbers were slightly higher during the summer than winter and slightly higher at RDF2 compared to RDF1.

The macroinvertebrates found during the course of this study are listed in Appendix C.

Figure 22a. ***Aquatic macroinvertebrate numbers for RDF1 and RDF2 by date***

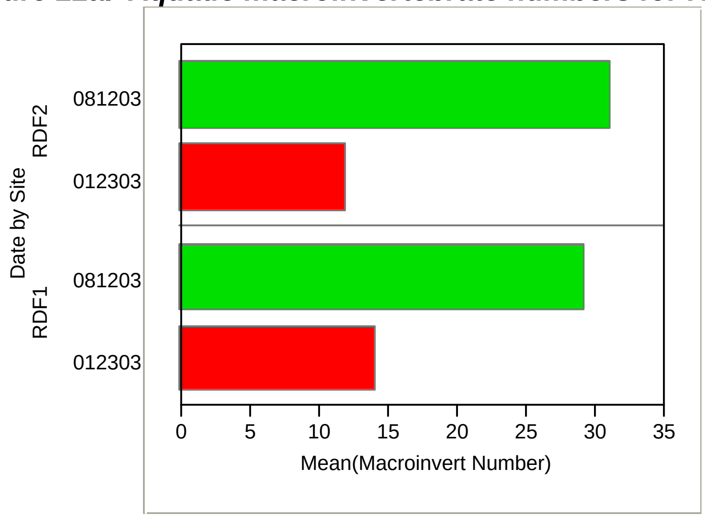


Figure 23a. ***Macroinvertebrate order by date***

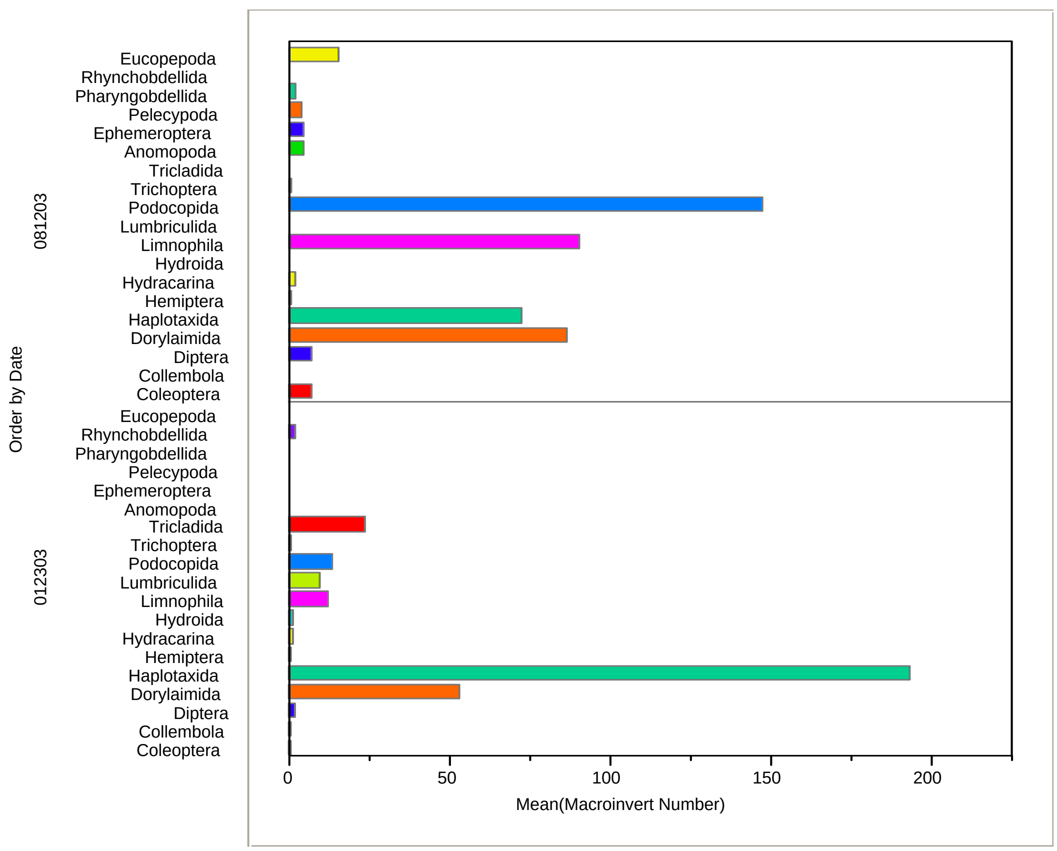
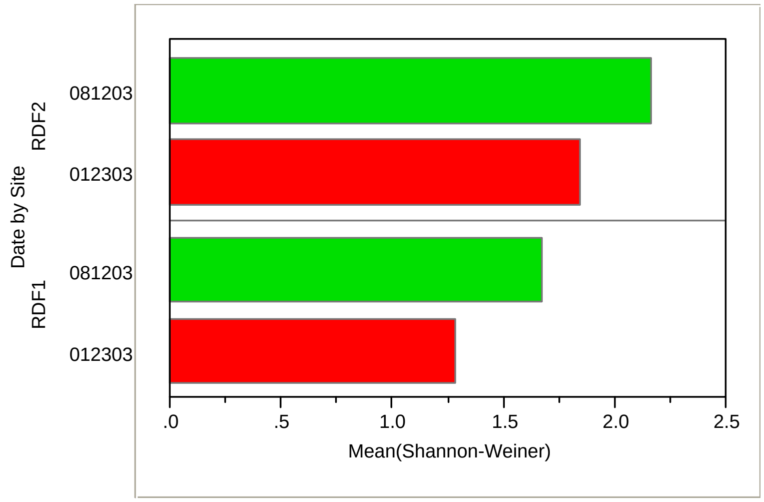


Figure 24a. ***Shannon-Weiner diversity index by site and date***



Correlations

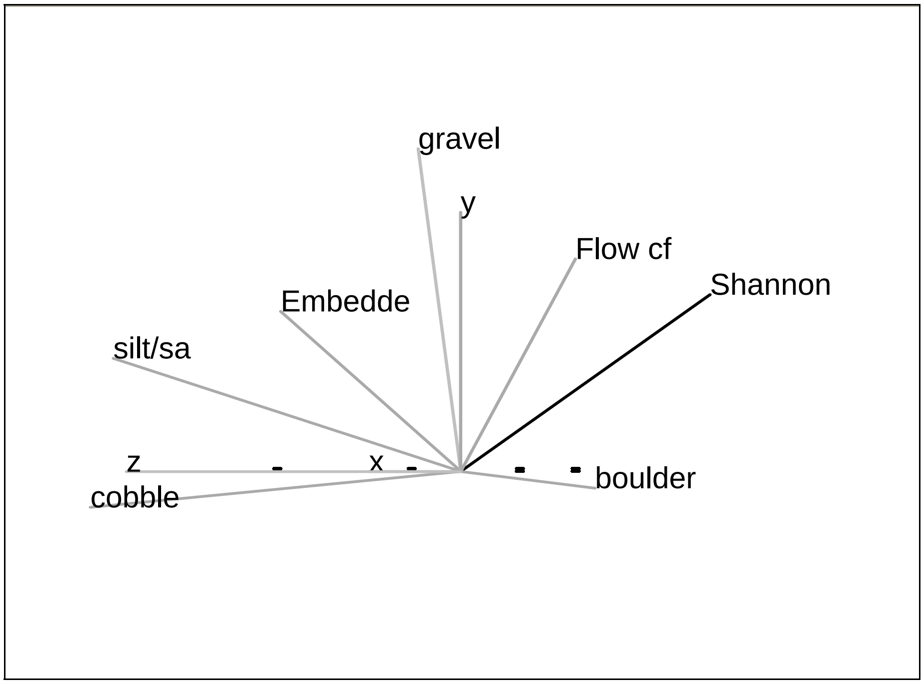
With any ordination, it is not particularly useful to lump all variables into a single analysis. This is especially true with principal components analysis, where adding more variables will increase the chance of nonsensical autocorrelations. Teasing out the most important categories of at least semi-related variables and determining how these are related to either species diversity or pollution tolerance is of greater biological interest. In this case, diversity may or may not be a good indicator of proper ecosystem function because it is possible to have relatively high diversity at a site while the macroinvertebrate assemblage largely consists of pollution tolerant organisms. However, in EDW's, pollution tolerant organisms may be more of the norm than the exception and the range of values for "good" and "bad" need to be modified so that more realistic goals for EDW's can be established. It is much better to have a higher species diversity of pollution tolerant organisms than little or no diversity of the same. Without at least some degree of pollution tolerance, macroinvertebrates probably wouldn't be able to tolerate conditions in any EDW. Diversity levels at least tell us whether competitive exclusion has occurred and if so, to what degree. We are forfeiting species values for biodiversity values. It is doubtful that pollution intolerant organisms will be able to live in the conditions found in any effluent dominated water. Measures of pollution tolerance only have meaning when comparing different EDW's, not when determining ecological constraints to any one in particular.

The useful categories of variables that make the most sense when determining constraints to aquatic macroinvertebrates are:

- Physical (e.g. habitable area)
- Physico-chemical
- Chemical (e.g. nutrients)

S-W Diversity Index and Physical Attributes

The PCA for substrate type/embeddedness and flow shows that higher diversity values are correlated with higher flow rates and boulder substrates. Inverse correlations existed for fines (sand/silt/clay), cobble, percent embeddedness, and species diversity. This makes sense given that tubificid worms, ostracods, and the limnophilid snails often dominated the samples and decreased diversity values. All of these species would be largely tolerant of sand/silt/clay and high percentages of embeddedness. Tubificid worms, in fact, require such conditions.

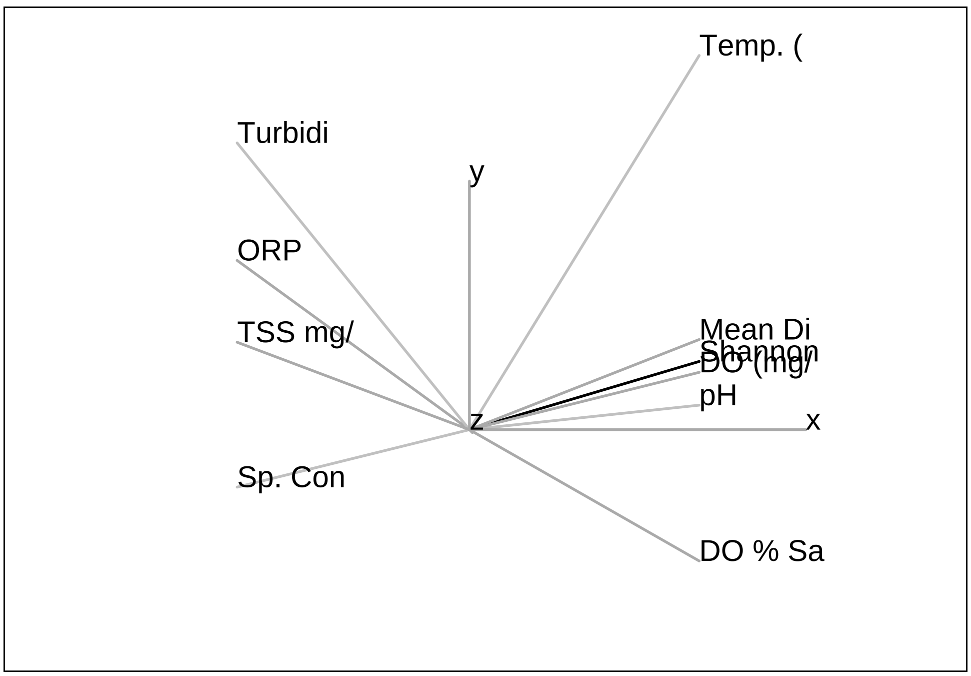


Eigenvectors							
Shannon-Weiner	0.45995	0.03864	-0.58111	0.37664	0.06598	0.04413	-0.54873
Embeddedness	0.24147	0.55361	0.14361	0.34245	-0.62903	-0.21964	0.23106
Flow cfs	-0.00397	-0.63171	0.40757	0.45274	-0.37090	0.23333	-0.19450
silt/sand/clay	0.38580	-0.38026	-0.01639	0.24212	0.31428	-0.57105	0.47201
gravel	-0.43570	0.26553	0.00860	0.68605	0.43575	0.21195	0.18473
cobble	0.47809	-0.00861	-0.06812	-0.07482	0.04481	0.72411	0.48453
boulder	0.40358	0.27888	0.68600	-0.03186	0.41443	0.00034	-0.34056

S-W Diversity Index and Physico-chemical Attributes

The Gabriel bi-plot shows that there was an extremely close correlation between diversity levels and both mean diel levels of dissolved oxygen and DO. Due to the high degree of correlation, this is a significant finding: at Rio de Flag, levels of dissolved oxygen may be more important than the physical attributes previously analyzed. Diversity levels showed an inverse correlation to turbidity, oxidation-reduction potential (ORP), total suspended solids, and specific conductivity.

Obviously, dissolved oxygen is an important variable for any aerobic organism. However, there may be a degree of autocorrelation between high DO levels and amount of either filamentous algae or vascular aquatic vegetation, both of which will increase DO levels in the water due to photosynthesis.   Aquatic vegetation and/or filamentous algae also increase habitable area for many species, the exclusion of which would decrease diversity values. We often found that the filamentous *Cladophora glomerata* contained several taxa of macroinvertebrates.



Eigenvectors									
Shannon-Weiner	0.31623	-0.40374	-0.03188	0.23695	0.12750	0.33139	-0.19086	0.51855	0.21183
Mean Diel DO	0.31623	-0.38757	0.58966	-0.34339	0.16759	-0.22140	0.24427	-0.18656	0.32865
Temp. (C)	0.31623	-0.08350	-0.18831	0.25895	0.68627	-0.09057	-0.30206	-0.37757	-0.22805
Sp. Cond.	-0.31623	-0.26068	0.47133	0.60416	-0.10430	0.35517	0.09882	-0.22016	-0.15624
pH	0.31623	0.21276	0.17527	0.29102	0.04744	-0.28258	0.27454	0.58732	-0.23668
DO % Sat.	0.31623	0.46383	0.33748	0.29872	-0.23669	-0.26674	-0.18799	-0.23566	0.00213
DO (mg/L)	0.31623	0.46783	-0.05044	0.00312	0.10886	0.62634	0.29821	-0.15021	0.36530
ORP	-0.31623	0.02048	-0.23754	0.35797	0.31160	-0.34087	0.52671	-0.02739	0.38861
Turbidity_NTU	-0.31623	0.28822	0.37414	-0.29320	0.52852	0.18930	0.07628	0.20895	-0.34626
TSS mg/L	-0.31623	0.22159	0.22386	0.07643	0.16514	-0.10717	-0.56570	0.19448	0.55707

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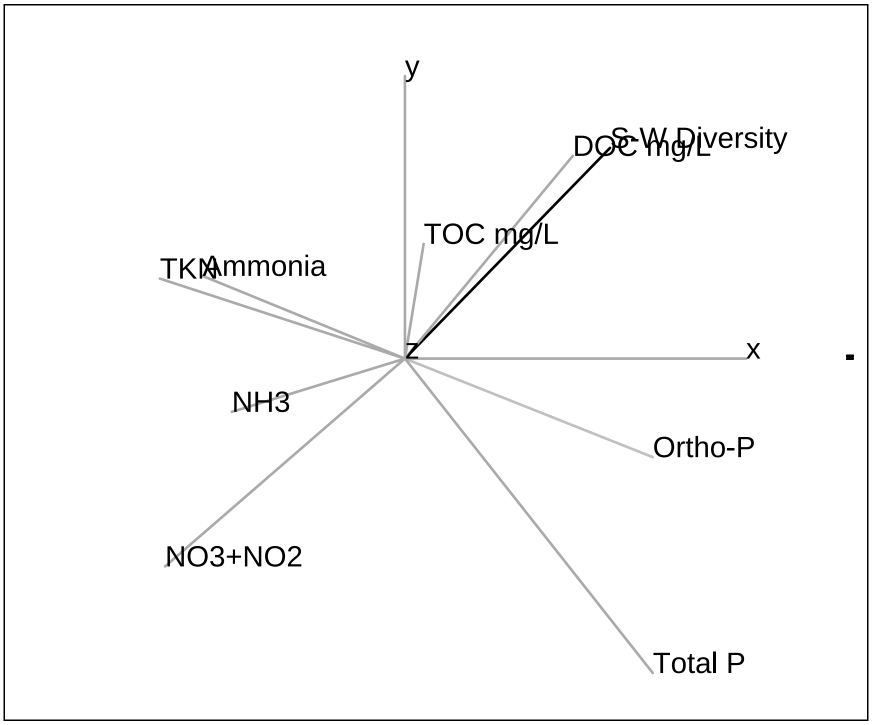
S-W Diversity Index and Nutrient Levels

There were strong positive correlations between diversity and levels of organic carbon. This correlation makes little sense but could be due to organic carbon being released from the upstream pond during the summer. There were inverse correlations between levels of almost all forms of nitrogen and diversity. The potentially toxic effect of un-ionized ammonia to macroinvertebrates makes this inverse correlation plausible. The inverse correlation between diversity and more oxidized forms of nitrogen, however, makes less sense. One explanation could be that during intense photosynthesis, and subsequent supersaturation of the water with DO, nitrification occurs at an accelerated pace. Since diversity was highest during the summer, there may be several autocorrelations between the forms of nutrients and diversity due to extreme changes in the physico-chemical properties of the water.

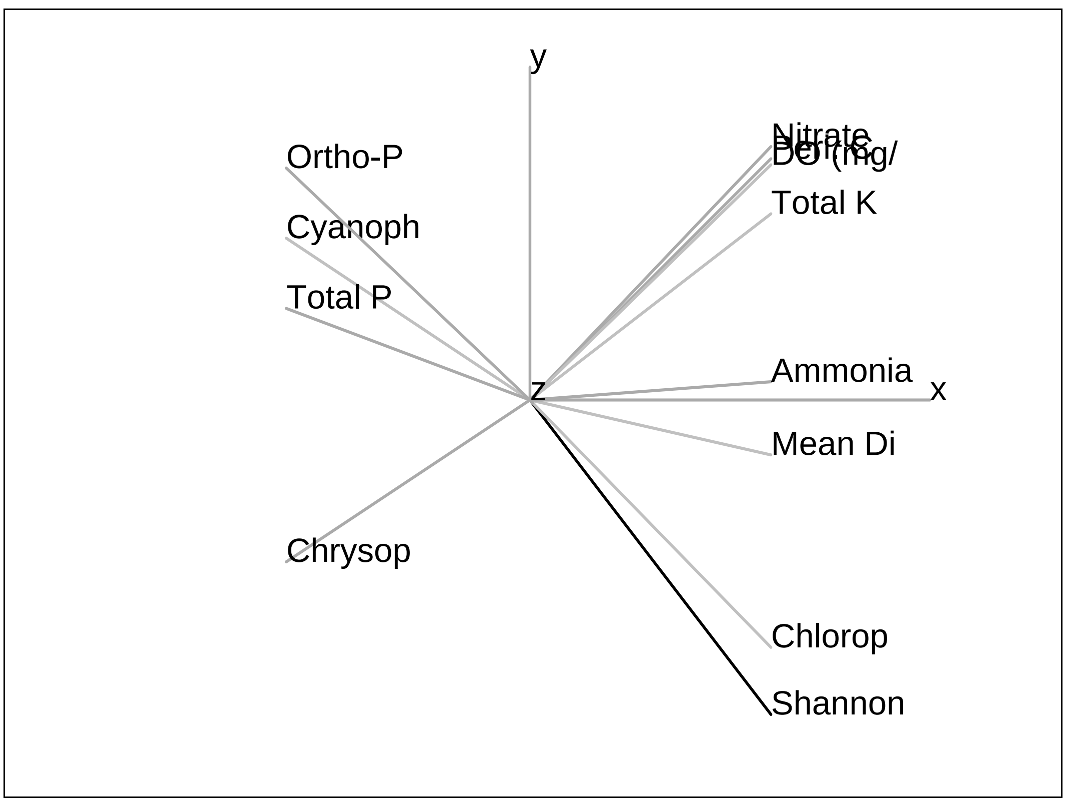


Eigenvectors									
S-W Diversity	0.33467	-0.31907	0.46145	-0.19848	0.41328	0.31139	0.41676	-0.17573	0.24803
Ammonia	-0.32574	-0.34169	-0.43920	-0.30448	0.16125	-0.02379	0.07948	0.44130	0.51371
NO3+NO2	-0.38437	0.17826	0.21575	-0.07546	-0.39870	0.75698	0.06791	0.17749	0.01179
Ortho-P	0.40353	-0.01336	-0.06754	0.28916	-0.18836	-0.03622	0.49419	0.64898	-0.21589
Total P	0.40367	-0.01174	-0.03981	0.09109	-0.60549	-0.04644	-0.07746	-0.20192	0.64146
TKN	-0.39351	-0.12953	0.16917	0.82337	0.15715	-0.05337	0.11488	-0.05945	0.27847
DOC mg/L	0.27322	0.44787	0.16681	0.10585	0.39445	0.14832	-0.50733	0.41288	0.28336
TOC mg/L	0.03155	0.59439	-0.50310	0.04864	0.22708	0.17195	0.44694	-0.29993	0.13925
NH3	-0.27904	0.42271	0.48158	-0.28069	-0.10141	-0.52112	0.30792	0.13020	0.19781

S-W Diversity Index, Periphyton, Nutrients, and Dissolved Oxygen.

Due to the obvious association of nutrients and periphyton, we decided to run an analysis with both of these variables and diversity. As previously stated in this report, most of the phytoplankton found in the stream were species of dislodged periphyton. The importance of phytoplankton is therefore questionable and excluded from this analysis.

There appears to be the same inverse correlation between diversity and phosphorous as in the previous analysis and the logic behind this is probably the same. This time, however, there is a very close correlation between diversity and levels of chlorophytes. The same correlation between mean diel DO exists, though not as significantly as in the previous analysis. The correlation between dissolved oxygen and diversity, while still evident, is significantly diminished. This means that chlorophytes, especially filamentous forms, are of primary importance, followed by mean diel DO levels and dissolved oxygen. The significance of the nutrient levels lies in their degree of inverse correlation. In other words, phosphorous levels are more important to increasing levels of diversity due to their incorporation into biomass, especially filamentous forms of chlorophytes, and this manifests itself as an inverse correlation. Although a positive correlation with diversity is evident, nitrogen levels are of little or no importance in a system that approaches phosphorous limitation during the summer months, the time when the biomass of filamentous green algae is at a maximum.



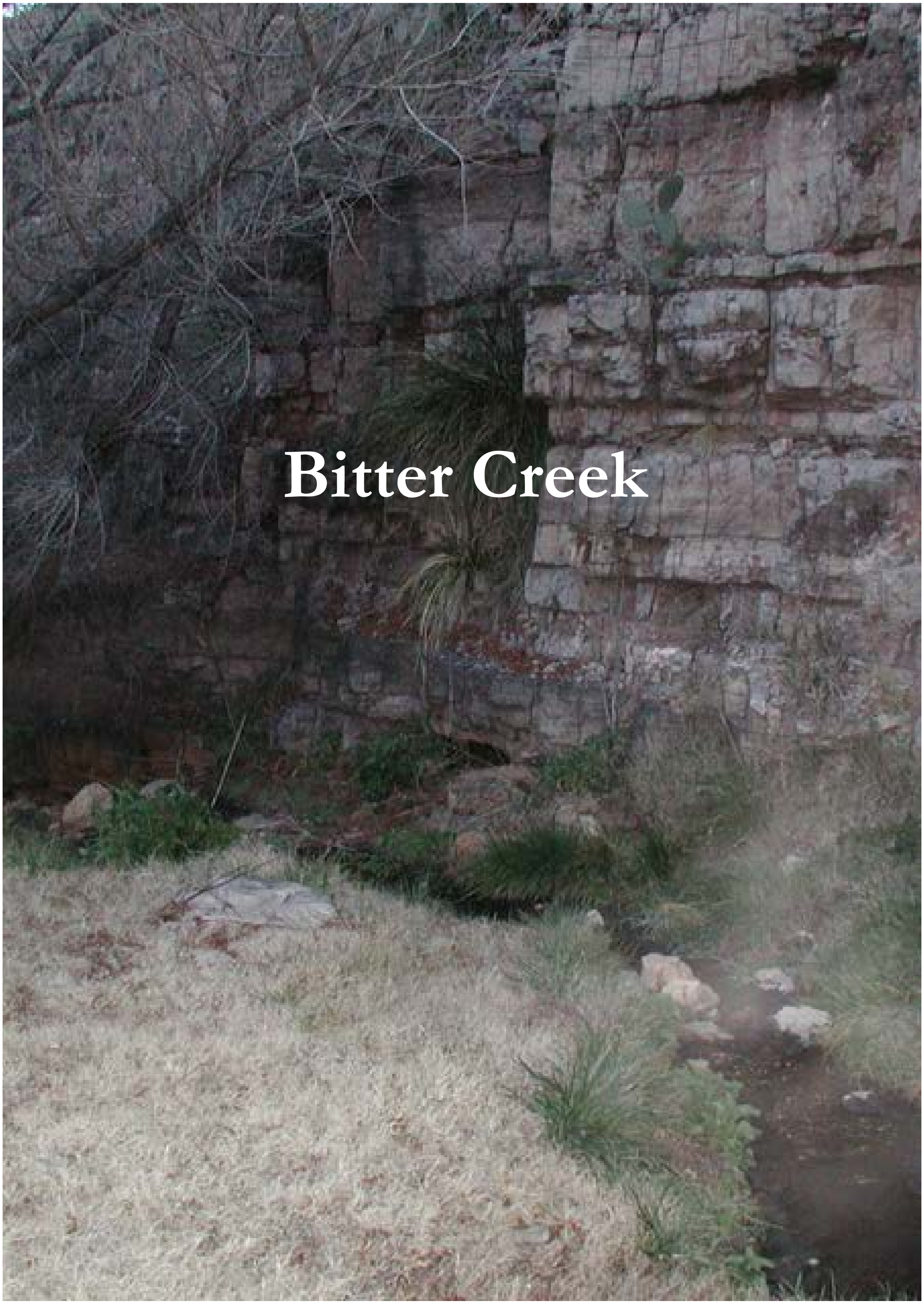
Eigenvectors											
Shannon-Weiner	0.28868	0.02170	0.27523	-0.44137	0.33592	-0.44438	0.25254	0.21996	0.07542	0.16600	0.38593
Peri. Chl a	0.28868	-0.17484	-0.13833	0.21623	0.59318	0.34734	-0.48175	0.16984	0.12584	-0.08692	0.14783
Cyanophyta	-0.28868	-0.06447	0.32040	-0.06690	0.51964	0.23274	0.28845	0.14468	-0.12074	-0.12689	-0.16677
Chrysophyta	-0.28868	-0.08716	-0.55601	0.11673	0.18826	-0.22820	0.01434	-0.12853	0.17805	0.44459	0.35087
Chlorophyta	0.28868	0.08555	-0.07238	0.53308	0.06443	-0.35121	0.23504	0.40474	0.19856	0.11900	-0.46559
Ammonia-N mg/L as N	0.28868	-0.36497	0.16352	0.49193	-0.05889	0.02762	0.31827	-0.25497	-0.45188	0.00723	0.37271
Nitrate + Nitrite-N mg/L as N	0.28868	0.23845	-0.08008	-0.00635	-0.33956	0.36393	0.17484	0.34896	0.32433	-0.19460	0.42866
Ortho-P (mg/L)	-0.28868	0.36084	-0.05698	0.19972	0.19521	0.33384	0.51357	-0.13299	0.18317	0.07501	0.07996
Total Phosphorus mg/L as P	-0.28868	-0.10615	0.56385	0.22095	-0.20988	0.13107	-0.26016	0.25826	0.17079	0.54093	0.13739
Total Kjeldahl Nitrogen mg/L as	0.28868	-0.50841	0.01026	-0.24498	-0.05366	0.26862	0.24263	-0.31179	0.46995	0.25005	-0.28834
DO (mg/L)	0.28868	0.26979	-0.19572	-0.21561	0.00392	0.33508	0.02164	0.14176	-0.51551	0.57299	-0.17440
Mean Diel DO	0.28868	0.53580	0.30877	0.13756	0.14788	-0.07754	-0.20701	-0.57708	0.18457	0.09990	-0.00535

Summary

Diversity of aquatic macroinvertebrates in Rio de Flag can be used as an indicator of ecosystem function and, therefore, as an assessment tool. The habitable area provided by filamentous green algae during the summer months is extremely important to diversity levels. Had there been closer correlations to other physical attributes, the correlation to filamentous green algae and diversity may not have been as prominent. We can assume, therefore, that Rio de Flag may be “substrate-limited” to some degree. Percent embeddedness increased considerably during the summer, possibly due to lower water velocity, and this could have added additional importance to the alternative habitat that the filamentous green algae provided.

Of near-equal importance, and probably interrelated to the increase in filamentous green algae during the summer, are the diel dissolved oxygen levels. Super-saturation during the day does little for aerobic life forms when dissolved oxygen drops to inadequate, or at least stressful, levels to aquatic organisms during the night. Low dissolved oxygen levels at night during the summer may be the limiting factor determining the diversity of aquatic organisms in Rio de Flag.

The argument can be made that without the nutrients provided by treated wastewater, Rio de Flag may have lower aquatic macroinvertebrate diversity than currently exists. If lower nutrient levels resulted in a decrease of filamentous green algae, less habitable area may result in a decrease in biodiversity of aquatic species.


Bitter Creek

Background

The Jerome WWTP was built in 1920 and serves the Town of Jerome. Treated effluent from this plant is discharged into Bitter Creek, part of the Verde River drainage. This WWTP can handle a capacity of 265 m^3/day of wastewater. The maximum and average daily flow rates are approximately 185 m^3/day and 170 m^3/day respectively. There are no industrial water users that discharge to the treatment plant, so all wastewater is from domestic use only. Total population served is approximately 480 people all residing in the town of Jerome.

Treatment consists of head works, a primary clarifier, trickling filter, secondary clarifier, Parshall flume for flow measurement, chlorination, wetlands, and ultraviolet disinfection. The UV sterilizer was not working during any of the site visits for this study.

There is a large amount of mining activity in the Bitter Creek watershed. Indeed, a mine dump can be found within just a few feet of the outfall. Iron III (Fe^{3+}) is often released into surface waters as a result of pyrite weathering in mine tailings. When the acidic mine drainage meets either surface water or another mineral that will raise pH, such as limestone, soluble Iron III ions will hydrolyze and precipitate out of solution as $Fe(OH)_{3.}$

$$Fe^{3+}_{(aq)} + 3\ H_2O_{(l)} \ \ \text{--->} \ \ Fe(OH)_{3(s)} + 3H^+_{(aq)}$$

The "yellow boy" precipitate that forms can coat streambeds and have severe, negative impacts on aquatic life. This precipitate was noticed within just a few feet from the outfall and was "streaking" toward the creek. During periods of heavy rainfall, this could be problematic if large amounts enter the stream. Despite this, very low levels of both total and dissolved iron were noticed in the creek. We did not sample during any period of rainfall.

Site Description, Substrate, and Geomorphological Data

The Bitter Creek watershed drains the eastern slope of Woodchute Mountain in the Prescott National Forest and comprises an area of approximately 44 km^2. Elevation changes are from 2200 meters on the slopes of Woodchute Mountain to 1065 meters at the confluence of the Verde River. These elevational differences exist in a linear distance of only approximately 13 kilometers, meaning that the Bitter Creek drainage has a relatively high slope. The slope from BC1 to BC 2 (Figure 4b) was the steepest of all EDW's sampled for this project at 0.092.

The sites BC1 and BC2 lie at approximate elevations of 1373 and 1263 meters and 34^{o}45'19"N., 112^{o}06'24"W. and 34^{o}45'44"N., 112^{o}005'50"W. latitude and longitude respectively. Distance between sites (channel length) is 1126 meters. This site was first sampled on 2/06/03 and again on 7/1/03. The section of stream between BC1 and BC2 lies in a steep-walled canyon with a relatively dense canopy of riparian trees more than 5m high. Dominant species include Fremont cottonwood (*Populus fremontii),* Arizona sycamore (*Juglans major)*, and Gooding willow (*Salix goodingi)*. Due to the steep terrain and dense canopy cover, large parts of the stream were continually shaded.

Grazing by cattle within and adjacent to Bitter Creek was observed during both sampling trips. Cattle were often seen standing and defecating in the stream. Usually banks were degraded and streambed trampling was evident.

Even though Bitter Creek is classified as a warm water stream based upon elevation (<1524m), it functioned more like a cold water system. Ice was observed on the edges of the stream during the winter sampling and water temperatures over a 24-hour period were low, ranging from 1.7°C at night to a high of only 7.6°C during the day. Summer water temperatures were among the lowest of the EDW's analyzed and were significantly lower over a 24-hour period than Rio de Flag, a cold water stream based upon elevation (Figures 1b and 2b). The differences might be attributable to canopy density which was almost non-existent at Rio de Flag, as well as a possible cold air inversion occurring at Bitter Creek.

There was significant biofilm development at the outfall to Bitter Creek that extended some meters downstream. Biofilms were observed close to the outfalls of several EDW's but Bitter Creek seemed to have the heaviest growth. Evolutionarily, biofilm development "anchors" microorganisms to a substrate for a nutritionally advantageous environment. When this environment is no longer advantageous, individual organisms are free to escape the biofilm environment and be carried elsewhere. There are several distinct phases to biofilm development including, primary and reversible adhesion, secondary and irreversible adhesion, and biofilm formation. Each phase is controlled by the expression of one or more genes. Bacterial biofilms are made up of a community of organisms in complex-shaped colonies embedded within an extracellular glycolayx. Nutrient exchange is handled through complex channels within the colony. Bacteria found within biofilms are physiologically different from their planktonic counterparts and often more pathogenic to humans. Bacteria often found within biofilms include species of *E. coli*, *Pseudomonas, Vibrio,* and *Staphylococcus,* to name a few.

Biofilms are often used to treat wastewater and have been proven to remove organic compounds as well as nutrients. Excessive biofilm growth, however, may indicate that pathogens are passing through the treatment process and proliferating in the stream outside of the WWTP. An excessive growth of pathogenic bacteria and biofilm formation may constitute a potential risk to humans and other species in EDW's. A better quantification of these biofilms may be an important variable in the assessment of any individual EDW.

Flow in Bitter Creek was the lowest of all EDW's measured. Flow decreased with distance from the outfall and was higher during the winter than the summer (Figure 5b). Embeddedness was relatively high and was higher during the winter than the summer sampling. As flow and velocity increased during the winter, this finding seems counter-intuitive, however herbaceous plants found in the understory during summer were largely absent during winter. These plants probably helped to stabilize the stream channel during the summer and their absence could have led to increased siltation and, therefore, embeddedness during the winter.

Geomorphological Data from Bitter Creek

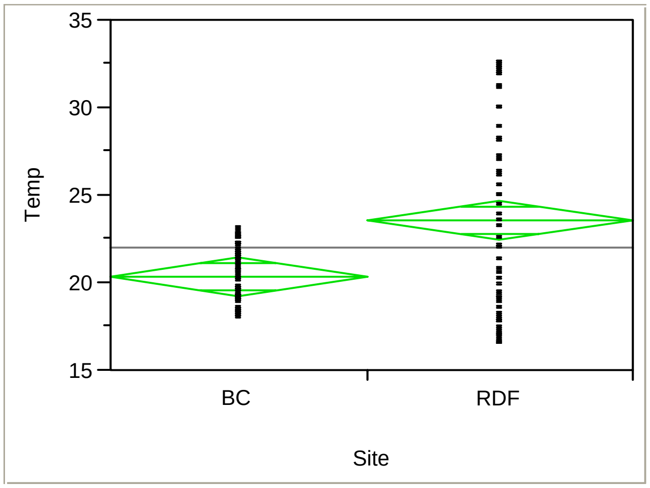
Channel length: 1126 m

Bankfull width: 7.3 m

Floodprone width: 14.6 m

Slope: 0.092

Figure 1b. ***Mean temperature over a 24 hr. period during the summer of 2003 for RDF2 and BC2***



Analysis of Variance

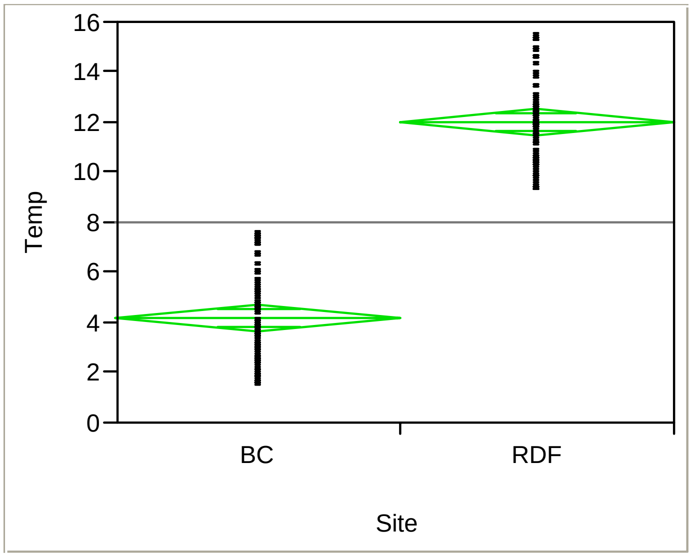
Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Site	1	254.1538	254.154	16.1549	0.0001
Error	95	1494.5722	15.732		
C. Total	96	1748.7260			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BC	49	20.4104	0.57250	19.274	21.547
RDF	49	23.6480	0.56663	22.523	24.773

Std Error uses a pooled estimate of error variance

Figure 2b. ***Mean temperature over a 24 hr. period during the summer of 2003 for RDF2 and BC2***



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Site	1	1458.5027	1458.50	439.0945	<.0001
Error	94	312.2318	3.32		
C. Total	95	1770.7345			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BC	49	4.2357	0.26036	3.719	4.753
RDF	49	12.0330	0.26584	11.505	12.561

Figure 3b. ***Bitter Creek watershed***

Figure 4b. ***Sampling sites BC1 and BC2***

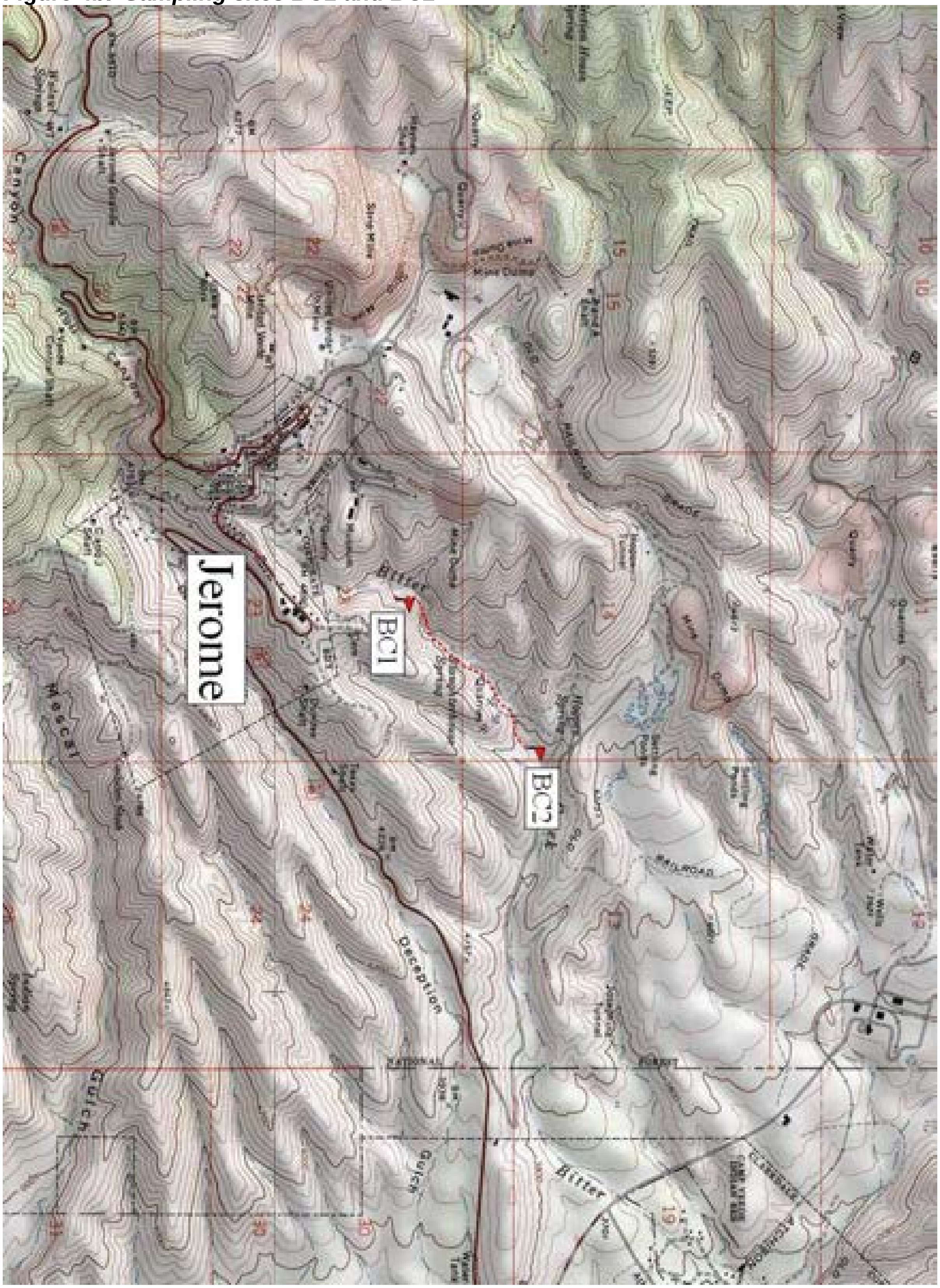


Figure 5b. ***Flow at Bitter Creek by site and date***

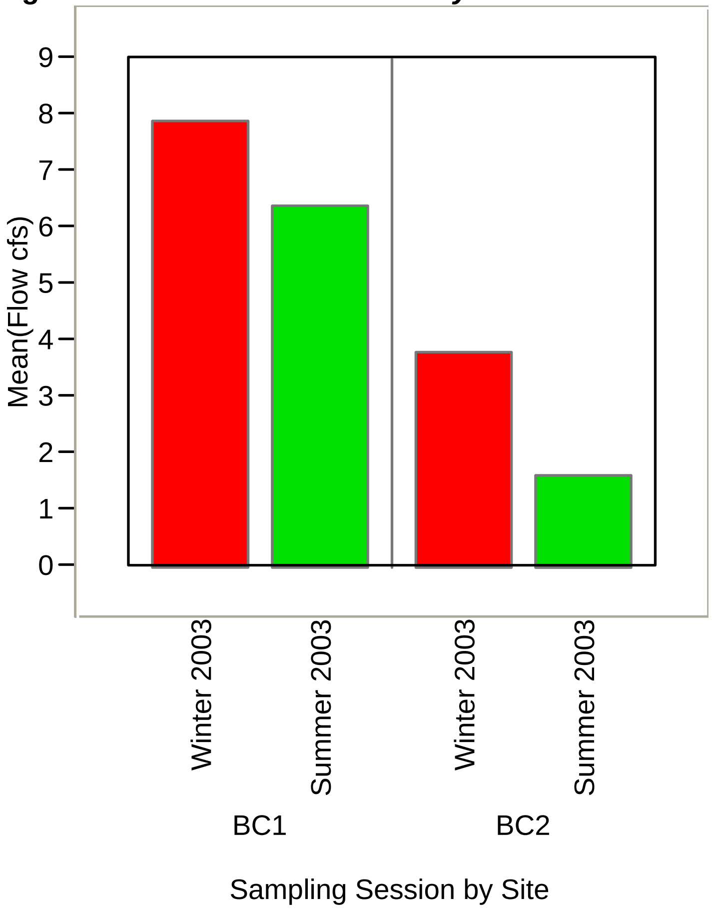
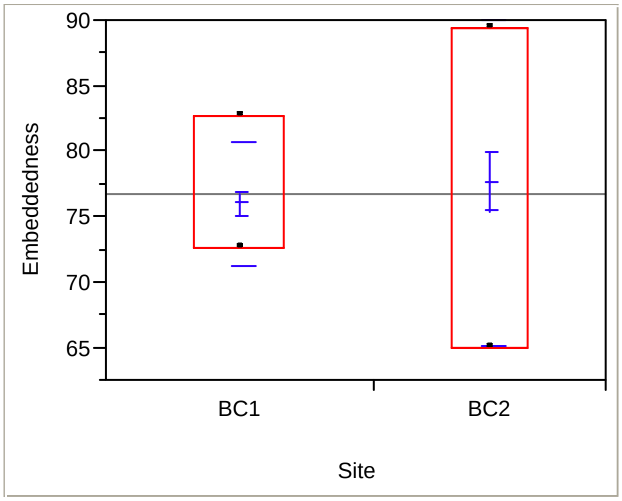


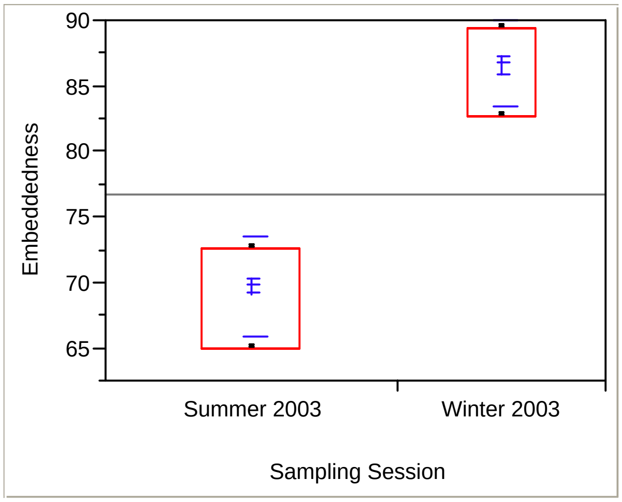
Figure 6b. ***Embeddedness by site***



Means

Level	Number	Mean
BC1	2	75.9676
BC2	2	77.6724

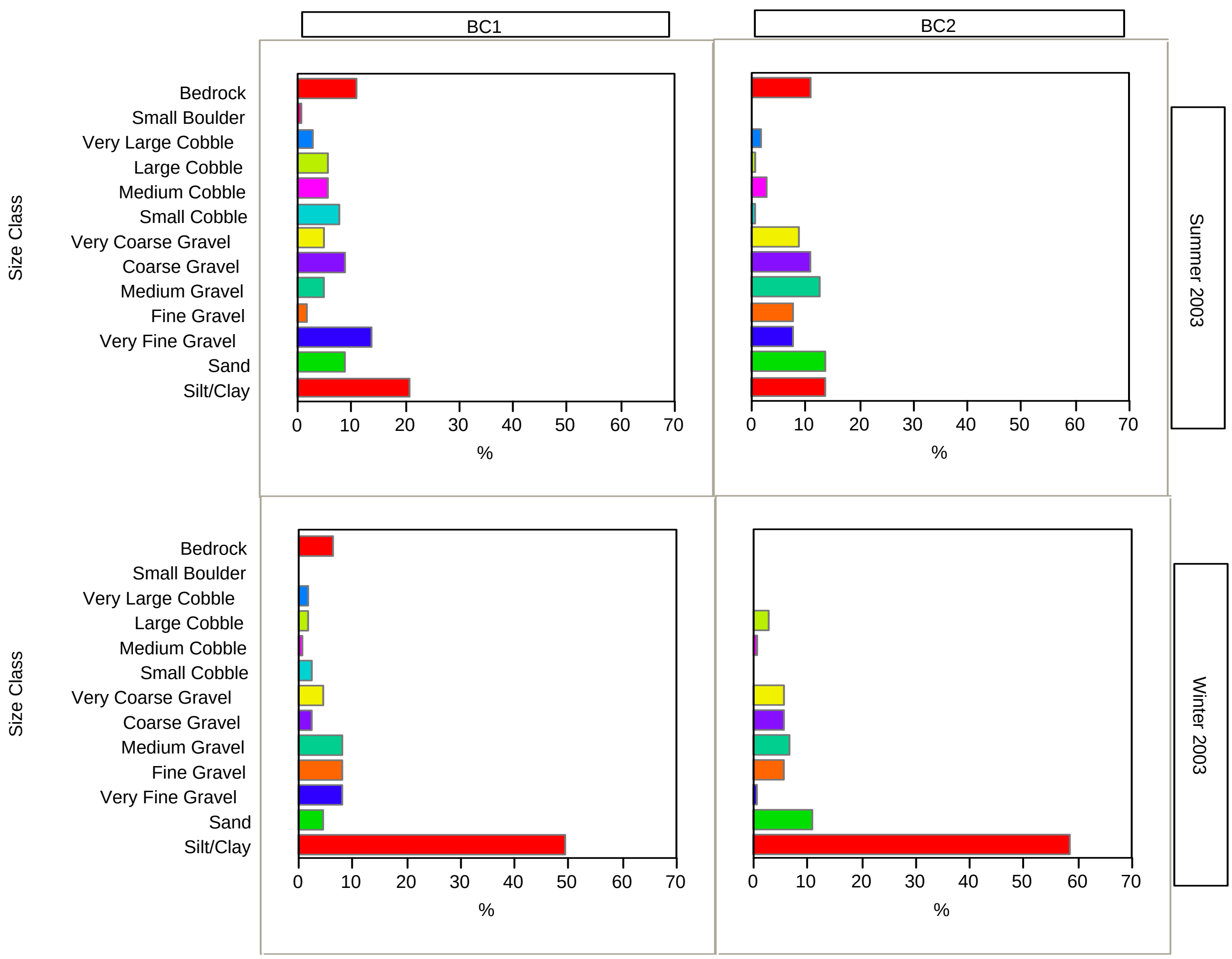
Figure 7b. *Embeddedness by sampling season*



Means

Level	Number	Mean
Summer 2003	37	69.7865
Winter 2003	26	86.6654

Figure 8b. *Substrate particle size by site and date at Bitter Creek*



Physico-chemical Data

Linear profiles of physico-chemical data were obtained for both sampling dates starting at BC1 and taken at roughly equidistant locations to BC2. (See Appendix A for data.)

Figure 9b. ***BC linear profile, 01/30/03***

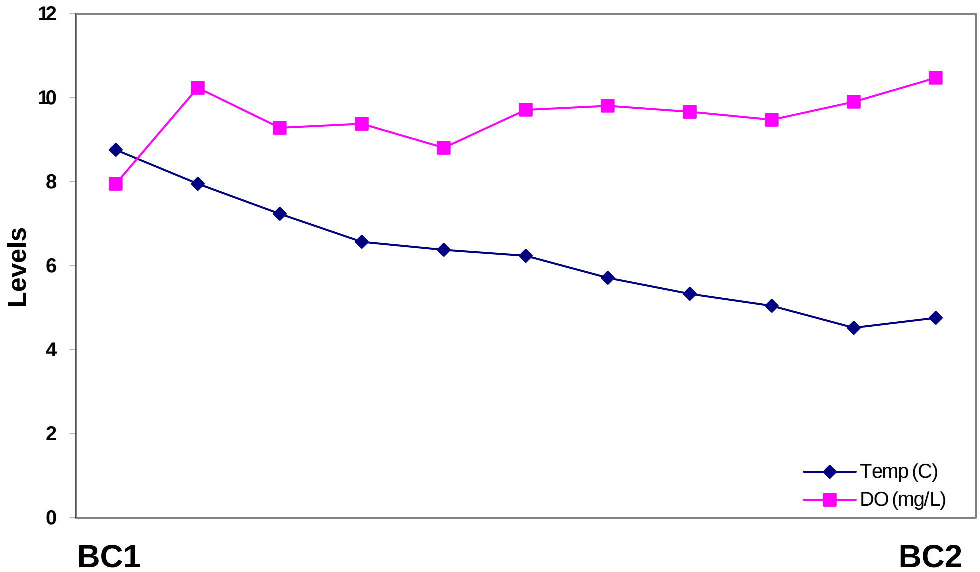
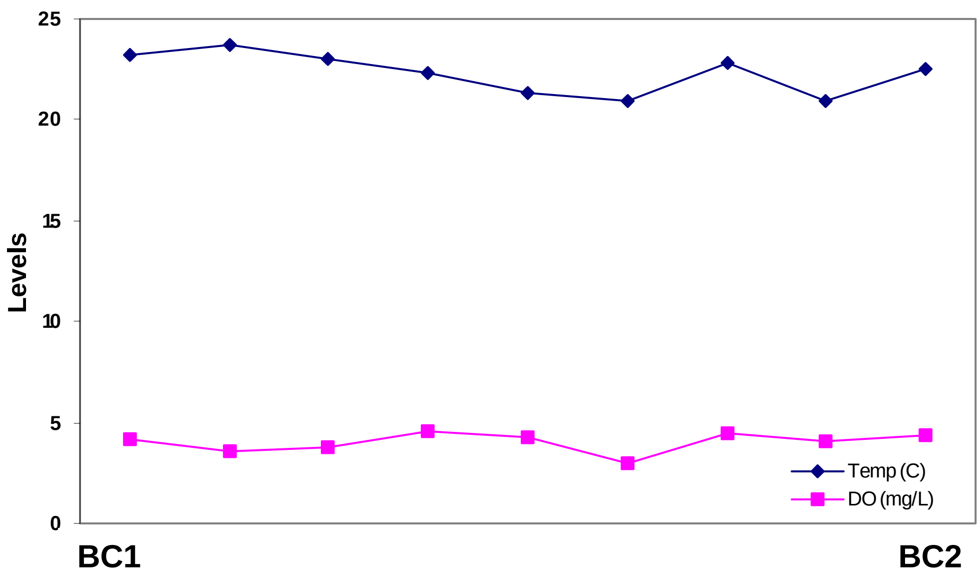


Figure 10b. ***BC linear profile, 06/30/03***



In addition to the linear profiles, physico-chemical readings were taken every 30 minutes over a 24-hour period (diel profiles) during both samplings at BC2. There was an apparent power loss from 11:30 am to 12:30 pm on 02/07/03. This hour was dropped from all ensuing analyses. (See Appendix B for data.)

Figure 11b. ***Diel pattern at BC2 on 02/06/03***

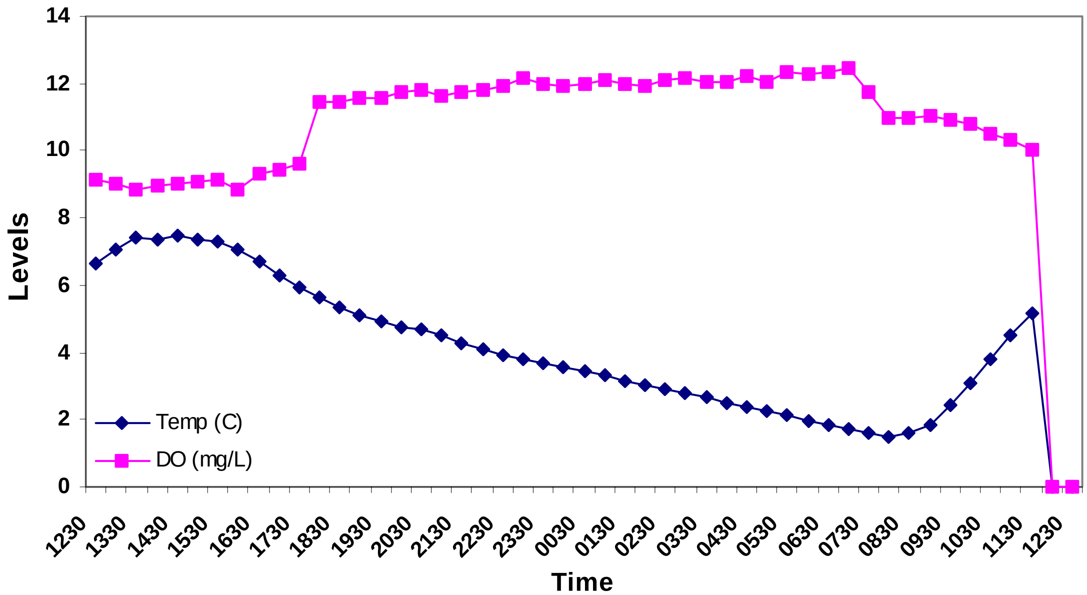
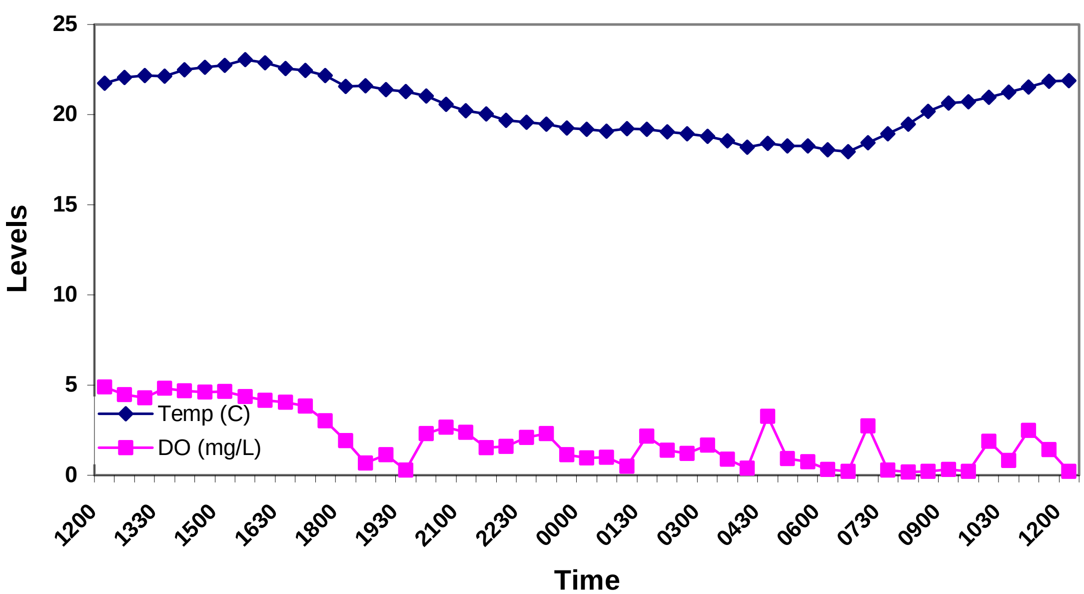


Figure 12b. ***Diel pattern at BC2 on 07/01/03***



Dissolved oxygen levels were fairly consistent with distance from the outfall. Both samplings showed DO levels that are considered adequate to sustain aquatic life at least during the day. Large differences existed between the winter and summer diel profiles. The drastic drop in dissolved oxygen and temperature the morning of 2/7/03 was due to a loss of power to the sonde. Dissolved oxygen levels plummeted just after sunset during the summer. There appeared to be some "spikes" in DO levels during the night which may correlate to changes or pulses in flow. Regardless of these spikes, DO levels remained low for a good portion of the night and well into the following day. Most of the overnight DO levels recorded during the summer sampling should be regarded as too low to support many species of aquatic life. This is in contrast to the diel profile taken during the winter when DO levels actually increased at night and during the following morning, presumably due to decreased water temperatures.

Bitter Creek had little periphytic growth and aquatic vegetation in general was lacking. There was little difference in pH values overnight during the summer diel profiles. Indeed, the values seemed to increase at night, a phenomenon that would be reversed if there were copious amounts of primary production as was noticed at Rio de Flag. This lack of periphyton or other aquatic vegetation puts added importance on streambed substrate as physical habitat for aquatic macroinvertebrates.

Nutrients

Levels of nutrients at Bitter Creek were much higher than those found at Rio de Flag and orders of magnitude higher than what would typically be found in most naturally-occurring surface waters of the state.

A significant amount of nitrification did occur between the sites, however, even at the lower levels found at BC2, it's doubtful there was any type of nutrient limitation (Figure 13b). As previously stated, there was little periphytic growth in the stream itself so uptake of nutrients was probably limited to either vascular woody plants or herbaceous annuals. A probable explanation for the comparably decreased amount of periphyton may be due to shading by either riparian vegetation or local topography.

The ammonia levels observed at Bitter Creek, especially closer to the outfall, should be a concern because of ammonia toxicity to aquatic organisms. Calculating the amount of NH_3 (after Emerson et al. 1975) from TAN (total ammoniacal nitrogen: $NH_3 + NH_4$) shows that potential toxicity was much greater during the winter than summer, even though pH levels were higher during the winter (Figure 15b). Although the pool of TAN was higher during the summer, the pH values were lower and explains the increased potential toxicity during the winter. Total ammoniacal nitrogen, as is typical at most WWTP's, was much higher during the winter because biological treatment of ammonia is more difficult during the winter.

Ammonium ions can also contribute to toxicity of aquatic organisms. Studies have shown that mechanisms exist for the transport of ammonium across gill epithelia (Wood 1983) and any calculation of ammonia toxicity should take TAN into consideration. However, it is still generally agreed that un-ionized ammonia is more toxic to aquatic organisms at a given pH, hardness, and temperature.

At the pH levels observed during the winter at Bitter Creek, especially at BC1, the chronic EC20 for several test species have been exceeded (US EPA 1999), including *Hyalella azteca* (amphipod), *Musculium transversum* (fingernail clam), *Ceriodaphnia sp*., *Daphnia magna*, *Pimephales promelas* (fathead minnow), *Catostomus commersoni* (white sucker), *Ictalrus punctatus* (channel catfish), *Oncorhynchus sp*. (salmonids), and *Lepomis macrochirus* (bluegill). While fish generally show an increased toxicity to TAN at decreased temperatures, aquatic macroinvertebrates generally exhibit the inverse trend, i.e. acute toxicity decreases with decreasing temperature (Arthur 1987). It is unknown to what extent ammonia toxicity affected aquatic macroinvertebrates at Bitter Creek. Biomass of aquatic macroinvertebrates is generally lower during the winter anyway; however, the ammonia levels noticed at Bitter Creek during the winter of 2003 have been proven to be both acutely and chronically toxic to several species of aquatic macroinvertebrates in other studies and it is likely we would see the same results in this stream.

Figure 13b. ***Nutrient levels at Bitter Creek by site and sampling season (all units in mg/L)***

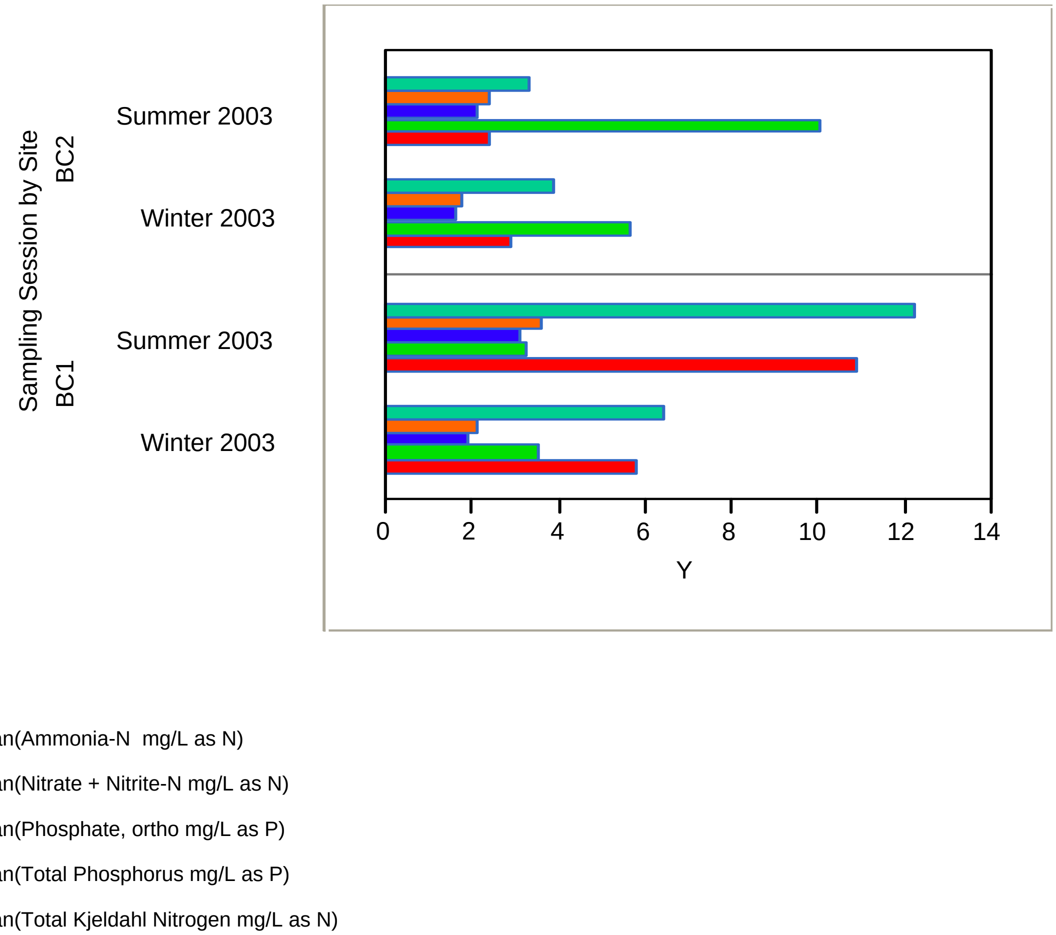


Figure 14b. ***N:P ratio by sampling session and site*** *(total N calculated as the sum of ammonia, nitrate, nitrite, and TKN)*

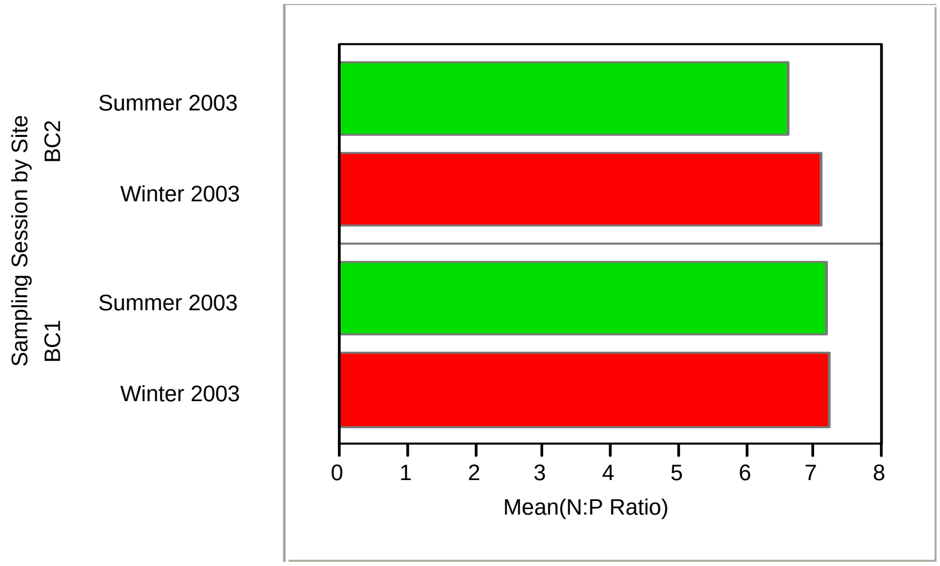
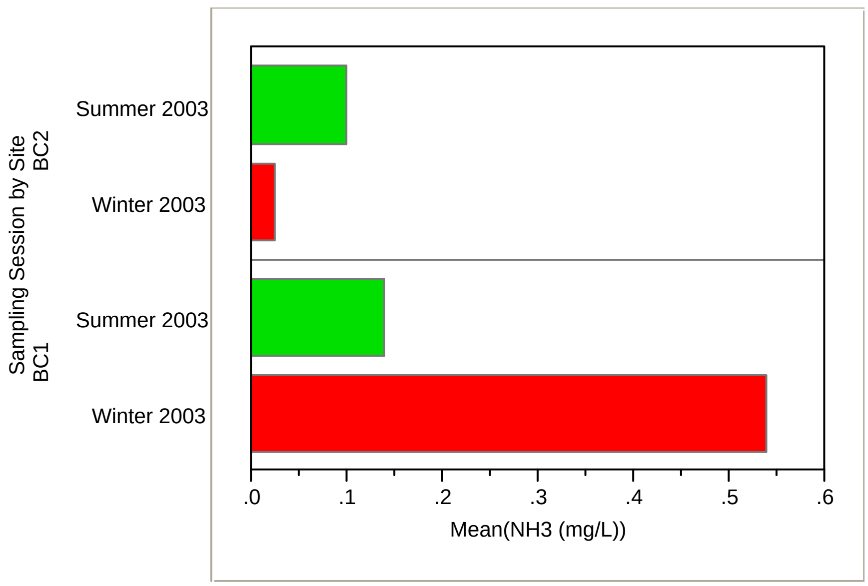


Figure 15b. ***Un-ionized ammonia (calculated) at Bitter Creek by site and date***



Biological Data

Algae

Even though nutrient levels were relatively high, overall periphytic biomass was low. This is probably due to heavy shading provided by surrounding riparian canopy. Scouring of periphyton at this site, in lieu of any input from a source other than the outfall, appears to be minimal due to the very low flows and velocities. Species of *Rorippa* were found growing in the stream, sometimes covering the entire open water area. This could have additionally led to the relatively low periphytic biomass. While diel DO levels did sag during the summer, often approaching anoxic conditions, the huge day-to-night swings observed at Rio de Flag were largely absent at Bitter Creek. Again, this is likely due to relatively low periphytic biomass.

Figure 16b. ***Phytoplankton chlorophyll a (mg/L) levels by site and date***

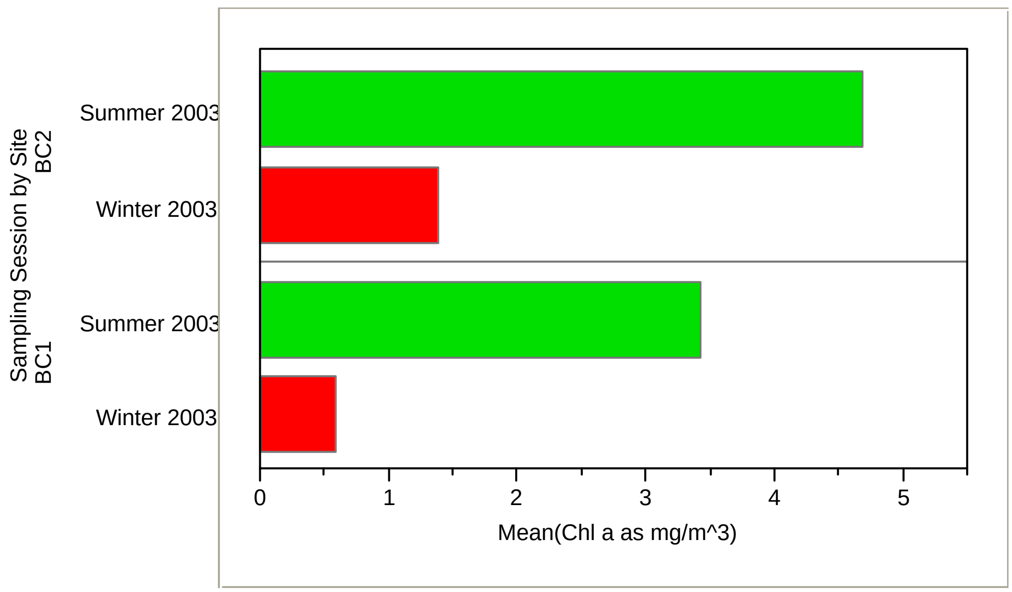


Figure 17b. ***Periphyton chlorophyll a (mg/m²) by site and date***

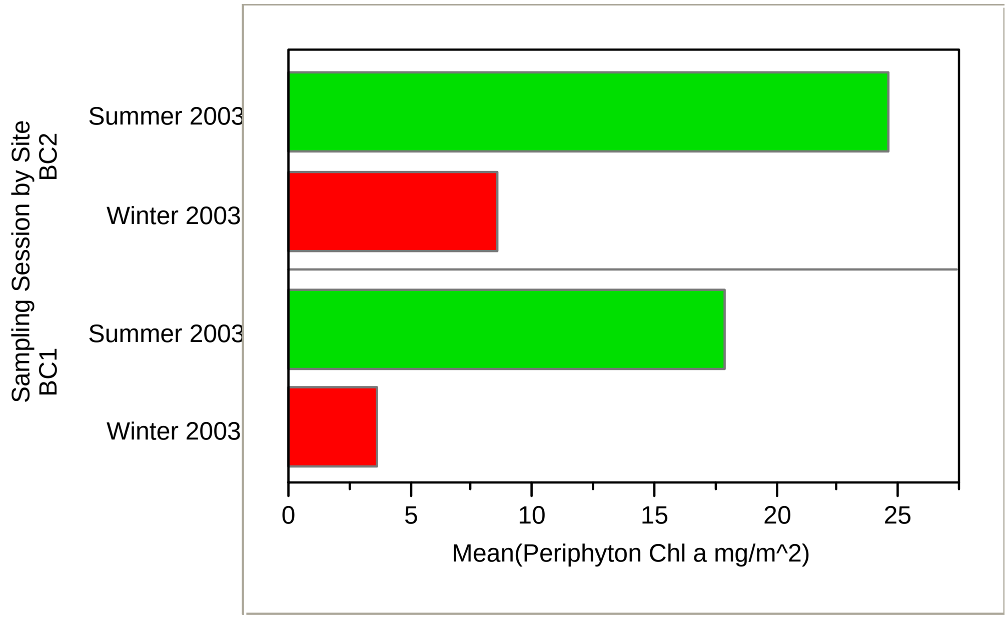


Figure 18b. ***Periphyton divisions by date and site***

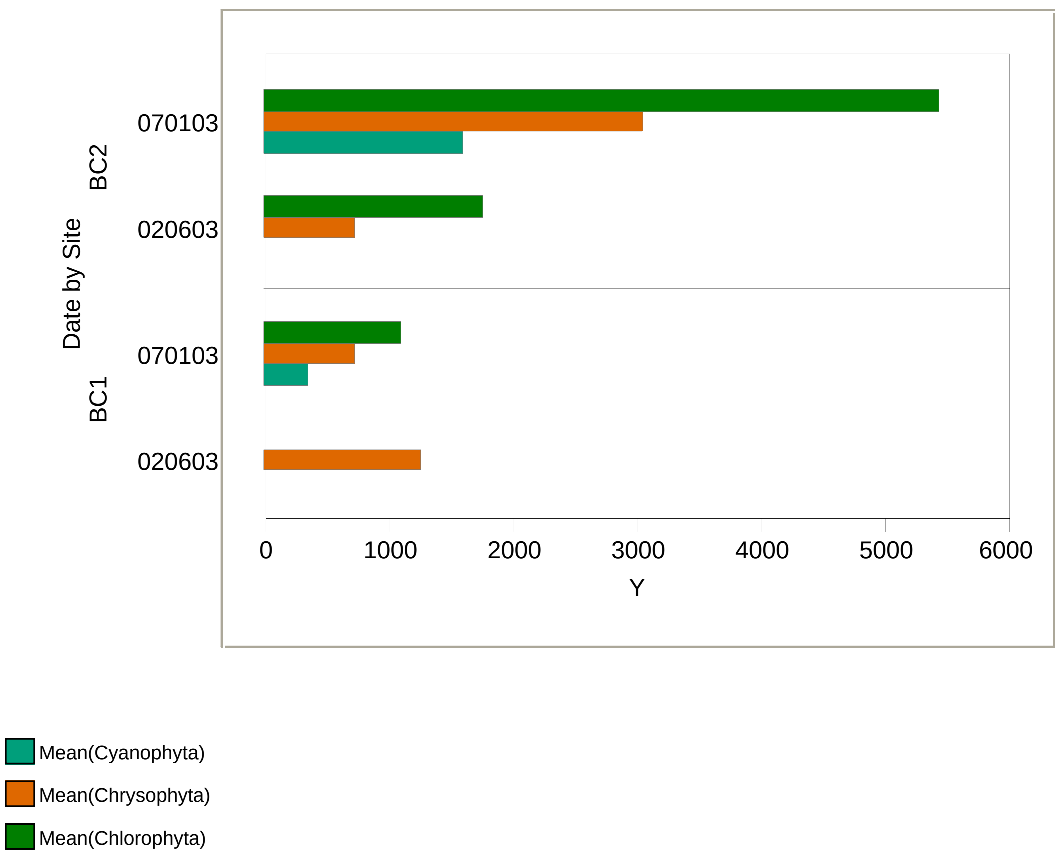


Figure 19b. ***Periphyton counts by genus at BC1 for 02/06/03***

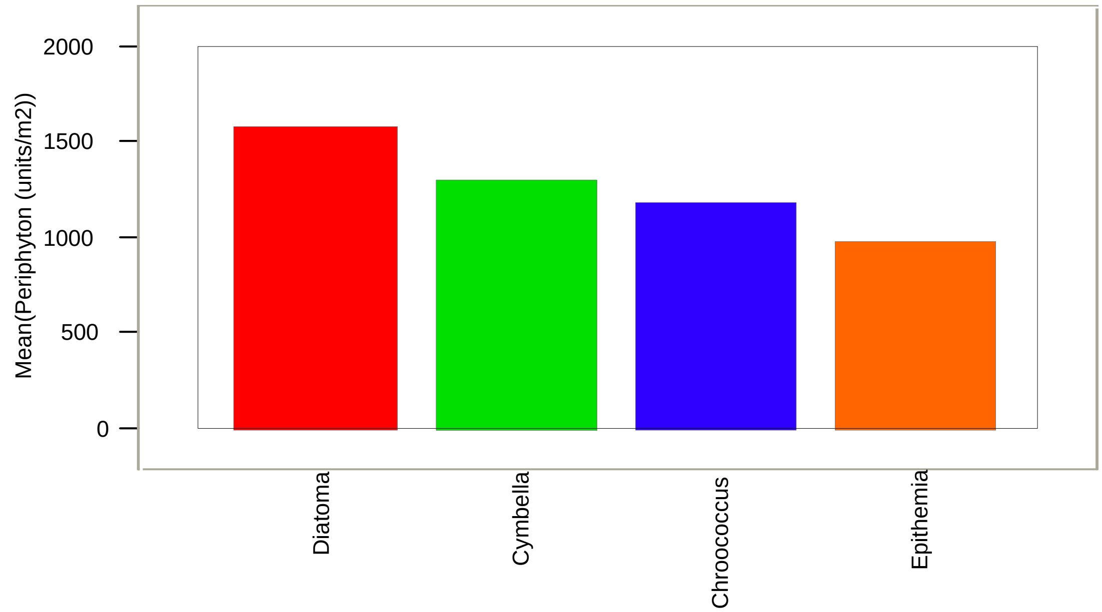


Figure 20b. ***Periphyton counts by genus at BC1 for 07/01/03***

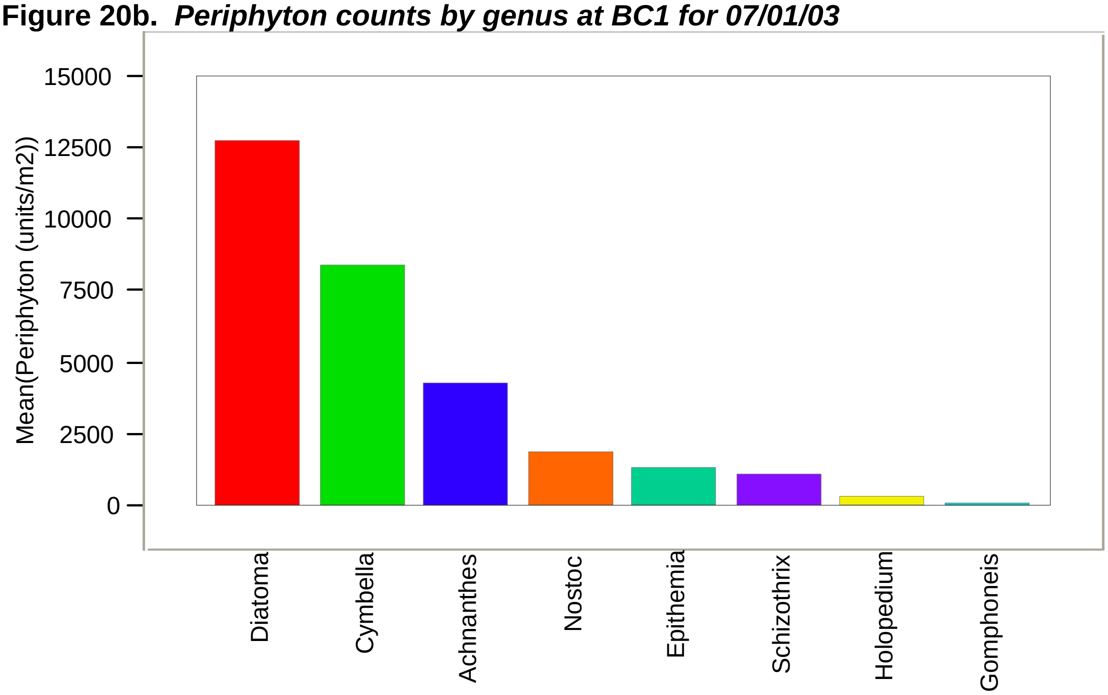


Figure 21b. ***Periphyton counts by genus at BC2 for 02/06/03***

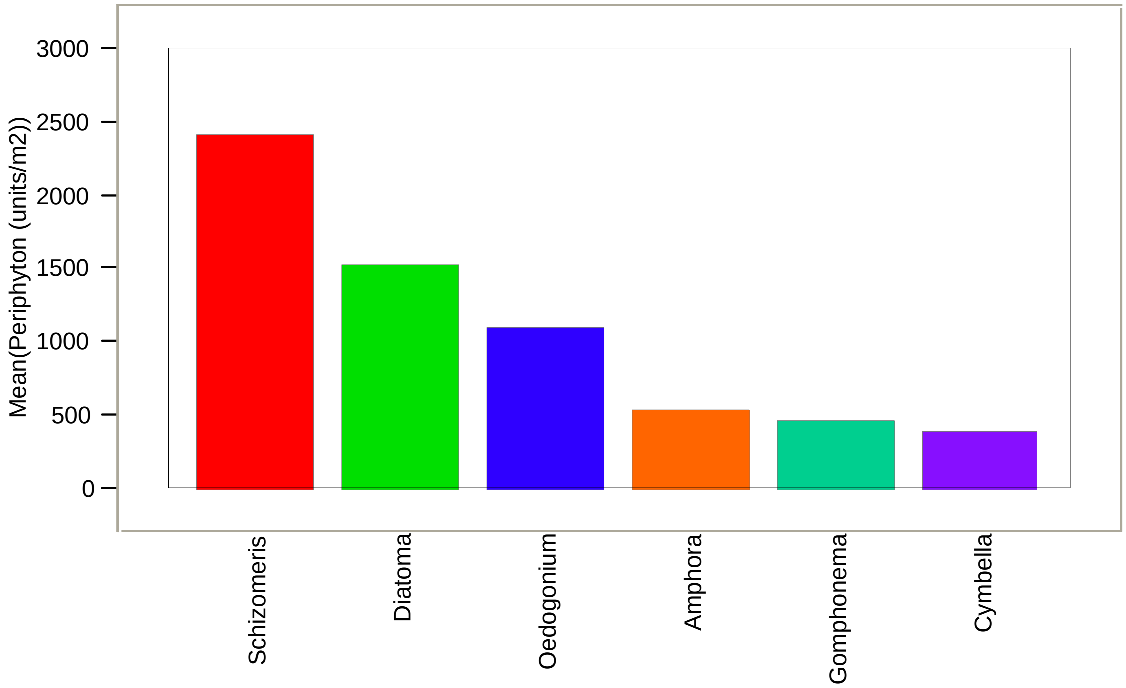
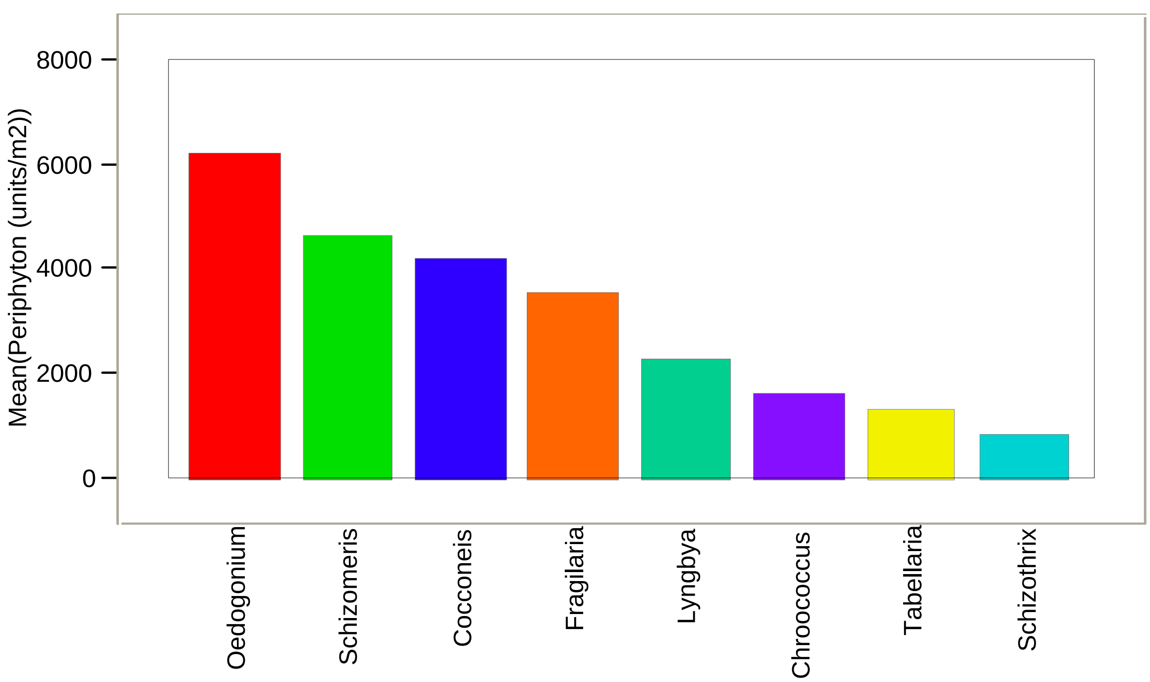


Figure 22b. ***Periphyton counts by genus at BC2 for 07/01/03***



Aquatic Macroinvertebrates

Despite the relatively cold temperatures, macroinvertebrate biomass was actually higher during winter than the summer of 2003 and numbers were higher at BC1 than BC2. The higher biomass during the winter could have been due to slightly higher flows during this time. The reason the biomass was higher near the outfall was probably because the community was often dominated by pollution-tolerant organisms such as tubificid worms and chironomids. Temperatures were also slightly higher during the winter near the outfall (approximately 9^{o} C at BCI and 5^{o}C at BC2) and this could have contributed to higher biomass compared to BC2.

Overall, Bitter Creek is depauperate in terms of non-pollution tolerant species. It's probable that water quality conditions were such that only the most pollution tolerant organisms could survive. This usually has the effect of suppressing biodiversity, which was already low. This isn't to say that water quality was the only limiting factor for diversity. Extremely low flows during the summer, especially at BC2, undoubtedly plays a role in suppressing overall numbers as well as diversity.

Figure 23b. ***Aquatic macroinvertebrate numbers by site and date.***

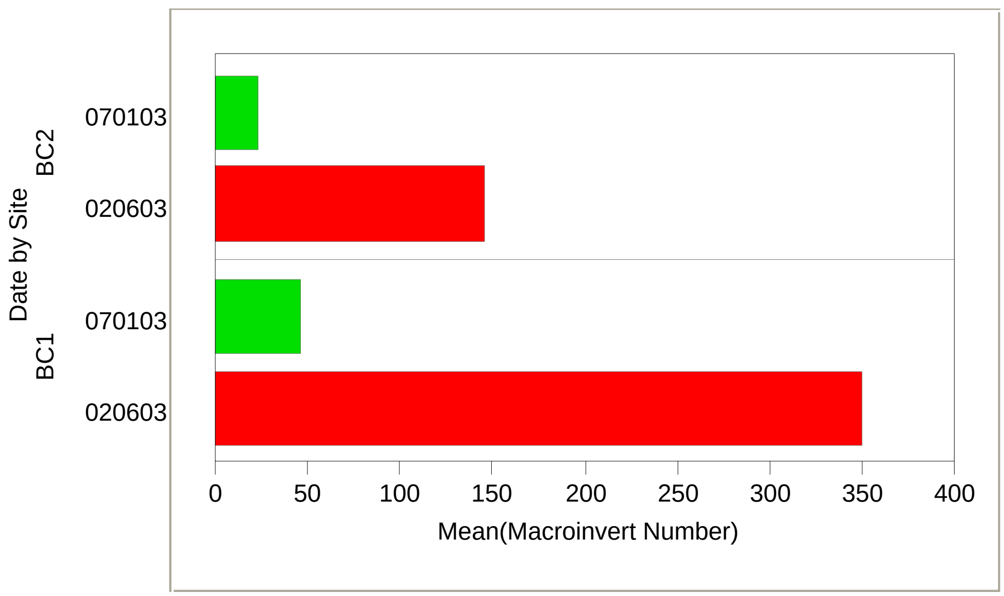


Figure 24b. ***Macroinvertebrate order by date.***

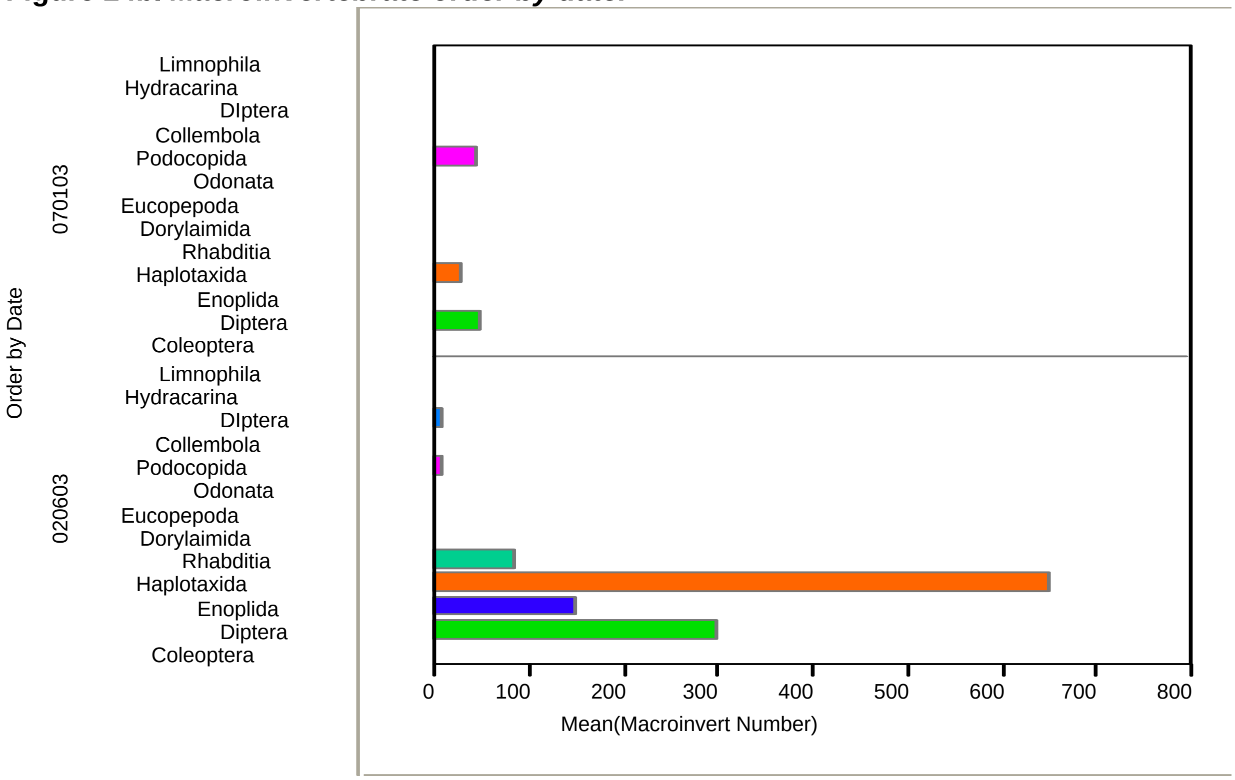
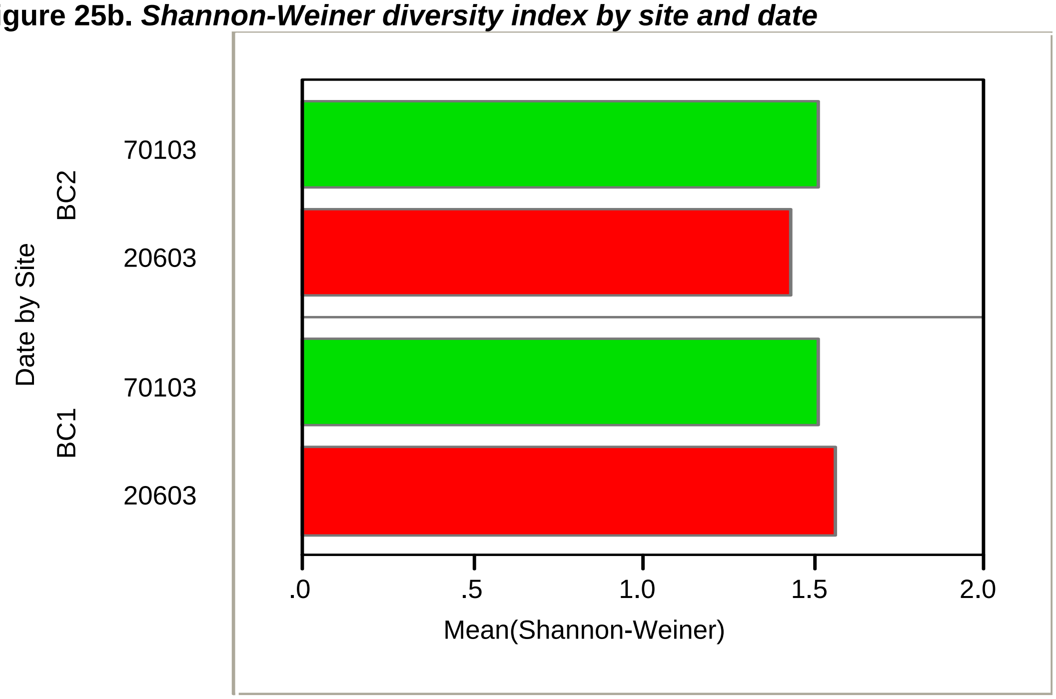


Figure 25b. ***Shannon-Weiner diversity index by site and date***

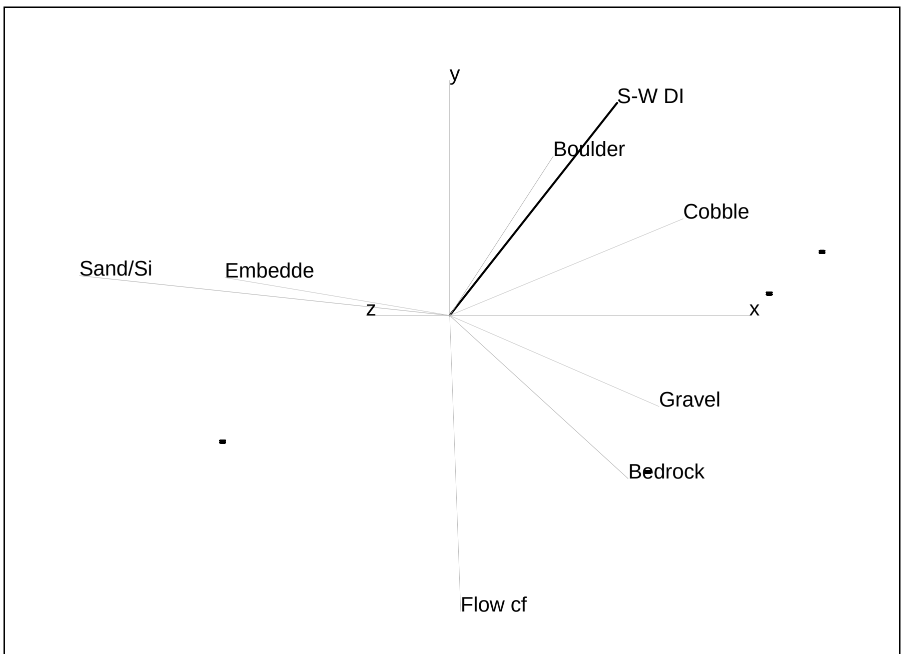


Correlations

The same variables ("factors" in PCA) that were used for Rio de Flag were analyzed for Bitter Creek using the same methodology. While it is obvious that each EDW will have different constraints simply because they are different sites, each EDW should be analyzed in the same manner for eventual comparison. This is imperative to evaluate EDW's *as a regional whole*, something that will be the most meaningful for management purposes and what this report strives for.

S-W Diversity Index and Physical Attributes

Diversity was correlated with percent boulder and cobble substrate and inversely correlated with gravel, bedrock, sand/silt/clay, and percent embeddedness. Remarkably, there was an inverse correlation with flow and diversity but we believe this is an auto-correlation. The percentage of sand/silt/clay was much higher during the winter, as was the percent embeddedness. Winter was also when the highest flows were observed. The fine material washed into the stream during the winter and the corresponding increase in embeddedness could have been due to the lack of aquatic vegetation that may stabilize this material during the summer. Cattle were observed during the winter at this site, and trampling of the streambed enhances movement of fine material into the stream.

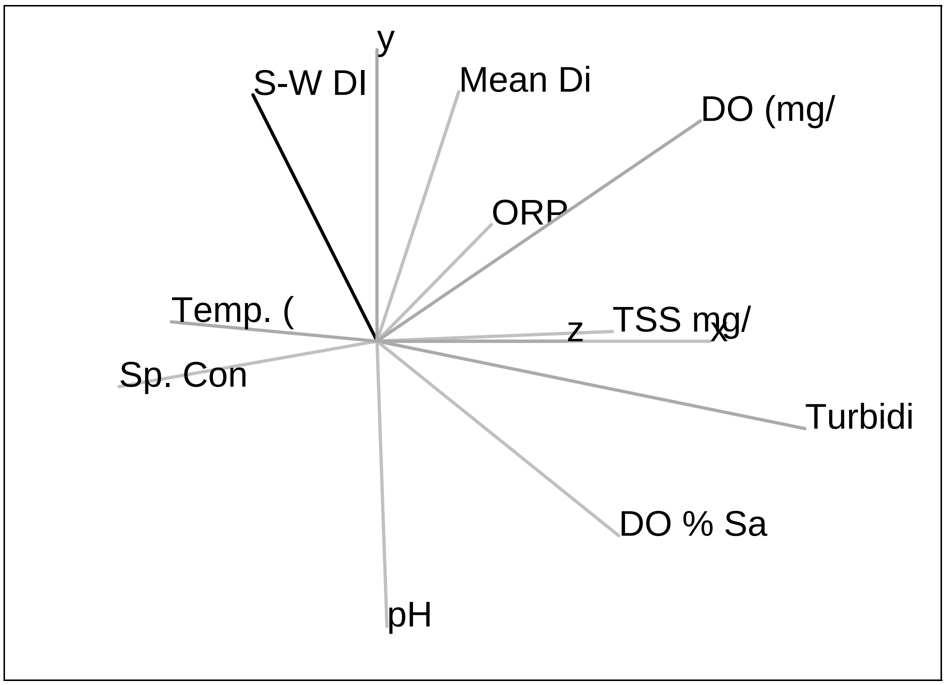


Eigenvectors								
S-W DI	0.29195	-0.04523	0.83230	0.46904	-0.00000	-0.00000	0.00000	-0.00000
Bedrock	0.45697	-0.03554	0.03965	-0.35823	-0.07977	0.32936	-0.50544	0.53824
Boulder	0.28478	0.47666	-0.27443	0.35567	-0.07791	0.24733	0.52788	0.37945
Cobble	0.32458	0.44837	-0.20994	0.21374	0.52394	-0.21067	-0.44308	-0.29773
Gravel	0.33276	-0.45339	-0.02830	-0.20062	0.63364	0.24376	0.41102	-0.11318
Sand/Silt/Clay	-0.46452	0.01498	0.11418	0.08796	0.52346	-0.25675	-0.03237	0.64980
Embeddedness	-0.43930	0.21136	0.11734	0.08561	0.17974	0.80398	-0.16661	-0.18654
Flow cfs	-0.00204	0.56391	0.39839	-0.65128	0.07242	-0.11933	0.26800	-0.08843

S-W Diversity Index and Physico-chemical Attributes

The correlation between diversity and physico-chemical attributes can be misleading if not carefully interpreted. Diversity values were slightly higher for the summer than the winter so some of the physico-chemical attributes, and their subsequent correlation, may be artifacts based upon seasonal differences in these parameters rather than having any true ecological meaning.

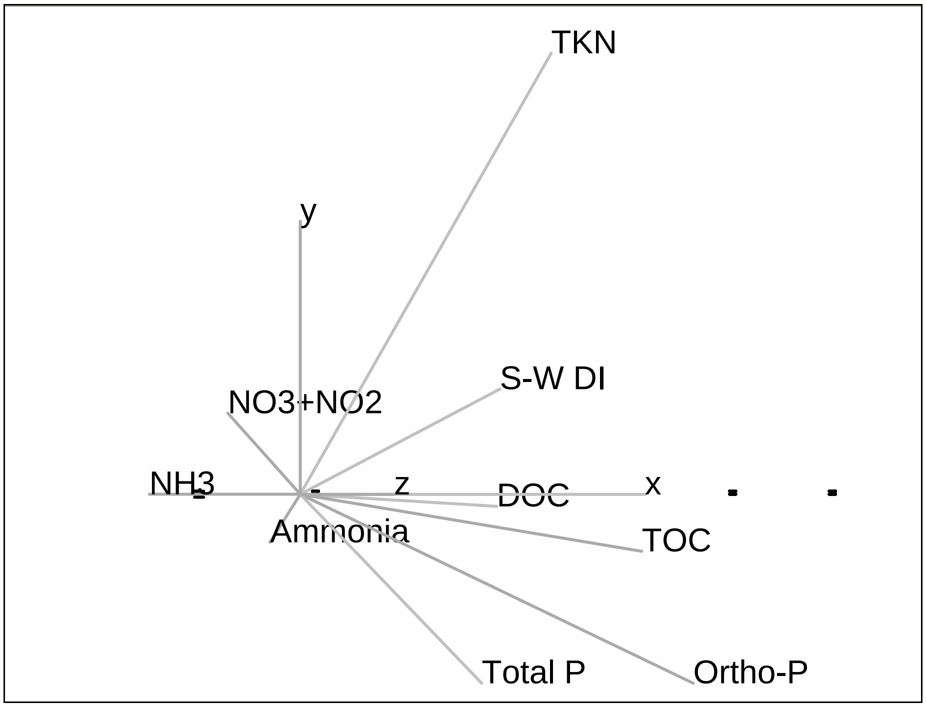
The positive correlation between mean diel DO levels, temperature, and diversity, and the inverse correlation to total suspended solids and turbidity make sense. The inverse correlation to percent dissolved oxygen saturation, however, seems counter-intuitive at first. It makes sense given the low water temperatures during the winter increasing both dissolved oxygen levels and percent saturation but yet having lower diversity during this time possibly due to temperature and strictly physical parameters such as embeddedness, turbidity, total suspended solids, etc.



Eigenvectors										
S-W DI	-0.25417	0.49773	-0.14775	0.13224	0.44177	0.16357	0.61409	0.16774	-0.08462	0.11843
Mean Diel DO	0.36998	-0.00893	0.10728	0.53786	0.44706	-0.01869	-0.25140	0.35225	0.08958	-0.40830
TSS mg/L	0.31477	-0.28608	0.40886	-0.03217	0.01960	-0.35846	0.59243	-0.02497	0.40144	0.09617
Turbidity	0.27923	0.40102	0.38629	0.15347	-0.15361	0.02479	-0.24119	0.19635	-0.07920	0.67913
ORP	0.33100	0.29829	0.17399	-0.76599	0.21192	0.20110	-0.08213	0.14070	0.07558	-0.25854
DO (mg/L)	0.35785	-0.17181	-0.12373	0.07379	0.39486	0.41592	-0.02439	-0.65022	0.01355	0.26306
DO % Sat.	0.32072	-0.27071	-0.39086	0.01783	-0.34418	0.50558	0.22967	0.47443	0.08885	0.10473
pH	0.24998	0.51187	0.00353	0.25666	-0.50395	0.10264	0.16669	-0.37507	0.12855	-0.40015
Sp. Cond.	-0.28798	-0.21804	0.67178	0.09413	-0.07903	0.55194	0.11120	0.00415	-0.22959	-0.18273
Temp. (C)	-0.36817	0.09043	0.02495	0.03734	0.03868	0.24407	-0.22430	0.01564	0.85695	0.09095

S-W Diversity Index and Nutrient Levels

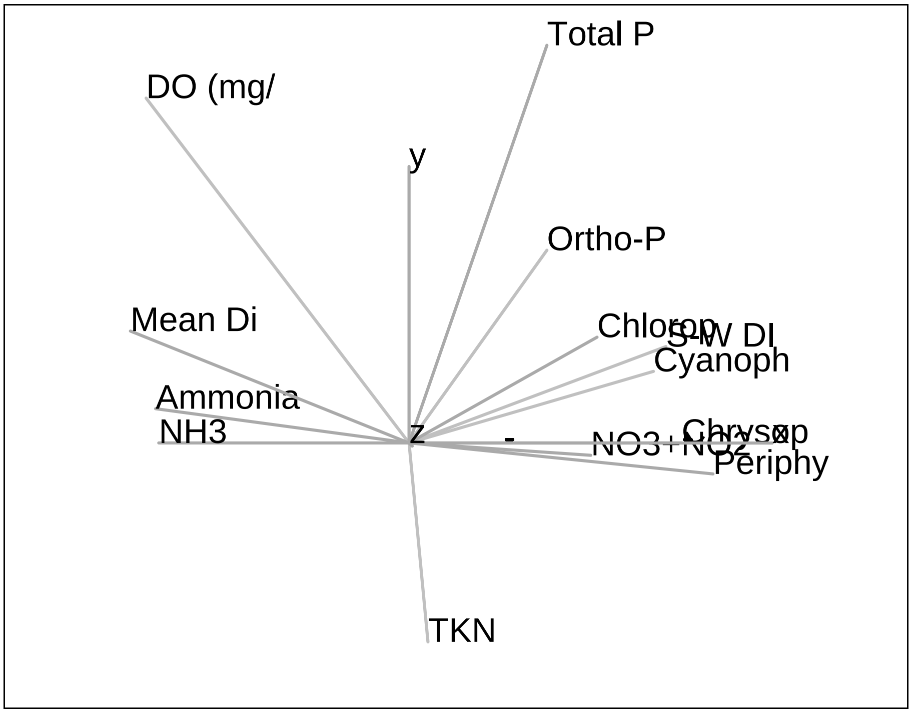
There was a definitive inverse correlation between levels of diversity and NH_3, ammonia, and nitrate+nitrite levels. This is a significant finding and has implications for the maintenance or enhancement of the bio-diversity of aquatic organisms in other EDWs. Other relationships between diversity and nutrient levels were ambiguous.



Eigenvectors									
S-W DI	0.31167	-0.35704	0.38928	0.11007	0.19640	0.43558	0.41719	-0.45752	-0.00657
NH3	-0.20576	0.41845	0.31475	0.82674	0.00000	-0.00000	-0.00000	0.00000	0.00000
Ammonia	-0.06761	0.49274	0.45555	-0.43966	-0.08586	0.42034	0.15479	0.35377	0.13651
NO3+NO2	-0.13624	-0.56893	0.05505	0.23309	0.15642	0.22839	-0.03539	0.70403	0.16387
Ortho-P	0.42354	0.09638	-0.30872	0.17417	-0.34884	0.35406	-0.25913	-0.06511	0.60601
Total P	0.42858	0.10382	-0.27651	0.15939	-0.34817	0.08974	0.40962	0.33133	-0.54482
TKN	0.36779	0.32142	-0.24691	0.02286	0.82198	0.00157	-0.00040	0.14843	0.04750
DOC	0.40764	-0.06780	0.40526	-0.01852	-0.02010	0.03134	-0.71242	0.04818	-0.39168
TOC	0.41580	-0.05462	0.37664	-0.01227	-0.10307	-0.66860	0.24138	0.17743	0.36705

S-W Diversity Index, Periphyton, Nutrients, and Dissolved Oxygen.

The autocorrelation between diversity and both mean diel DO and DO levels is evident in this analysis. The strong inverse correlation between diversity and un-ionized ammonia and total ammoniacal nitrogen (deemed as “ammonia” in the analysis) is evident as well. As nutrients are not a limiting factor for periphytic growth in this system, correlations between growth of certain divisions and nutrient levels shows no clear distinction between nitrate + nitrite, ortho-P, or total P. It is likely that within Bitter Creek, light may be limiting periphytic growth. There is a strong positive correlation between overall periphytic growth, regardless of type of algae, and diversity levels.

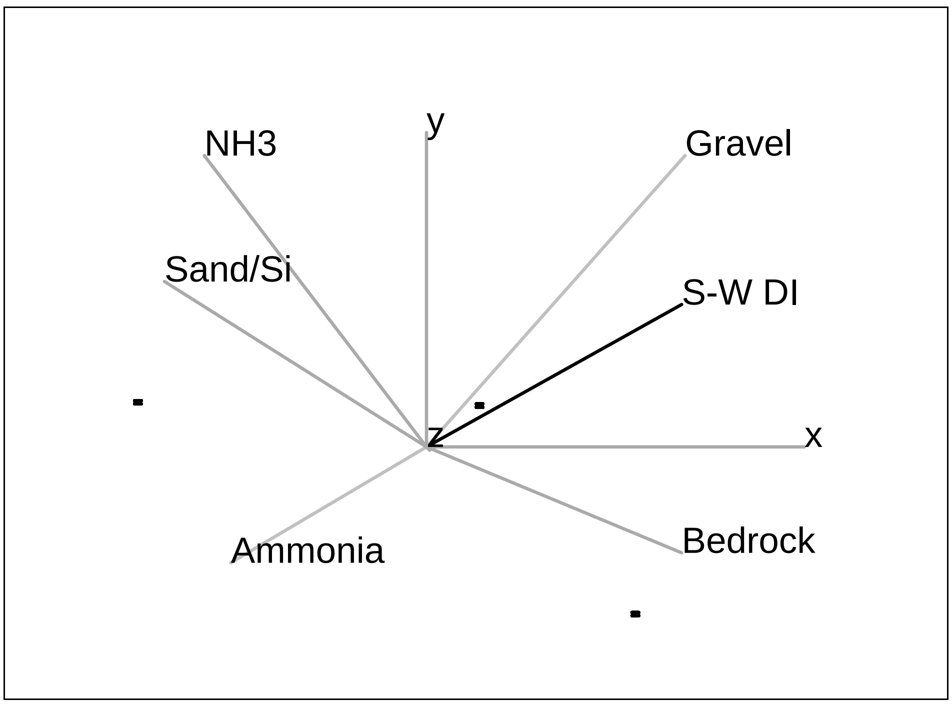


Eigenvectors												
S-W DI	0.31540	-0.03013	0.59084	-0.10902	-0.39277	0.15620	0.18939	-0.07786	-0.08908	-0.24735	0.32017	-0.03247
Periphyton Chl a	0.37122	-0.06502	-0.08942	0.15891	-0.08855	-0.04776	0.30660	0.76600	0.11515	0.11994	-0.07905	-0.31196
Cyanophyta	0.29855	0.27391	0.12685	0.05158	-0.21763	0.11769	0.04738	-0.22683	-0.09624	0.33924	-0.74966	0.09227
Chrysophyta	0.33256	0.13742	0.38777	-0.02980	0.84810	-0.00000	-0.00000	0.00000	0.00000	0.00000	-0.00000	0.00000
Chlorophyta	0.23110	0.35649	-0.10837	0.11386	-0.09483	0.16879	0.03828	-0.03615	0.69718	-0.18792	0.13468	0.42214
Ammonia	-0.30755	-0.11402	0.53990	-0.30010	-0.11833	0.05637	-0.26289	0.29664	0.24400	0.42188	-0.01086	0.14590
NH3	-0.30295	0.00965	0.32687	0.89515	-0.00077	-0.00000	-0.00000	-0.00000	0.00000	0.00000	-0.00000	0.00000
NO3+NO2	0.22256	0.36562	-0.08488	0.10229	-0.10411	-0.01952	0.01367	-0.06977	-0.41808	0.48433	0.51196	0.09443
Ortho-P	0.17157	-0.40355	-0.08987	0.09527	0.04255	0.30840	0.00804	-0.41023	0.37764	0.40531	0.15431	-0.44107
Total P	0.16863	-0.40681	-0.04905	0.07938	0.02501	0.63281	-0.08253	0.10467	-0.32491	-0.22349	-0.09418	0.28919
TKN	0.02616	-0.45445	-0.02590	0.02327	0.07604	-0.31295	0.52044	-0.07772	0.02074	0.25880	0.02561	0.57286
DO (mg/L)	-0.31927	0.23198	-0.17744	-0.04562	0.16713	0.54974	0.13586	0.23025	-0.02011	0.25615	0.10080	0.14029
Mean Diel DO	-0.33646	0.19599	0.12859	-0.16291	0.03566	0.17808	0.70777	-0.15250	-0.01216	-0.12111	-0.07337	-0.24225

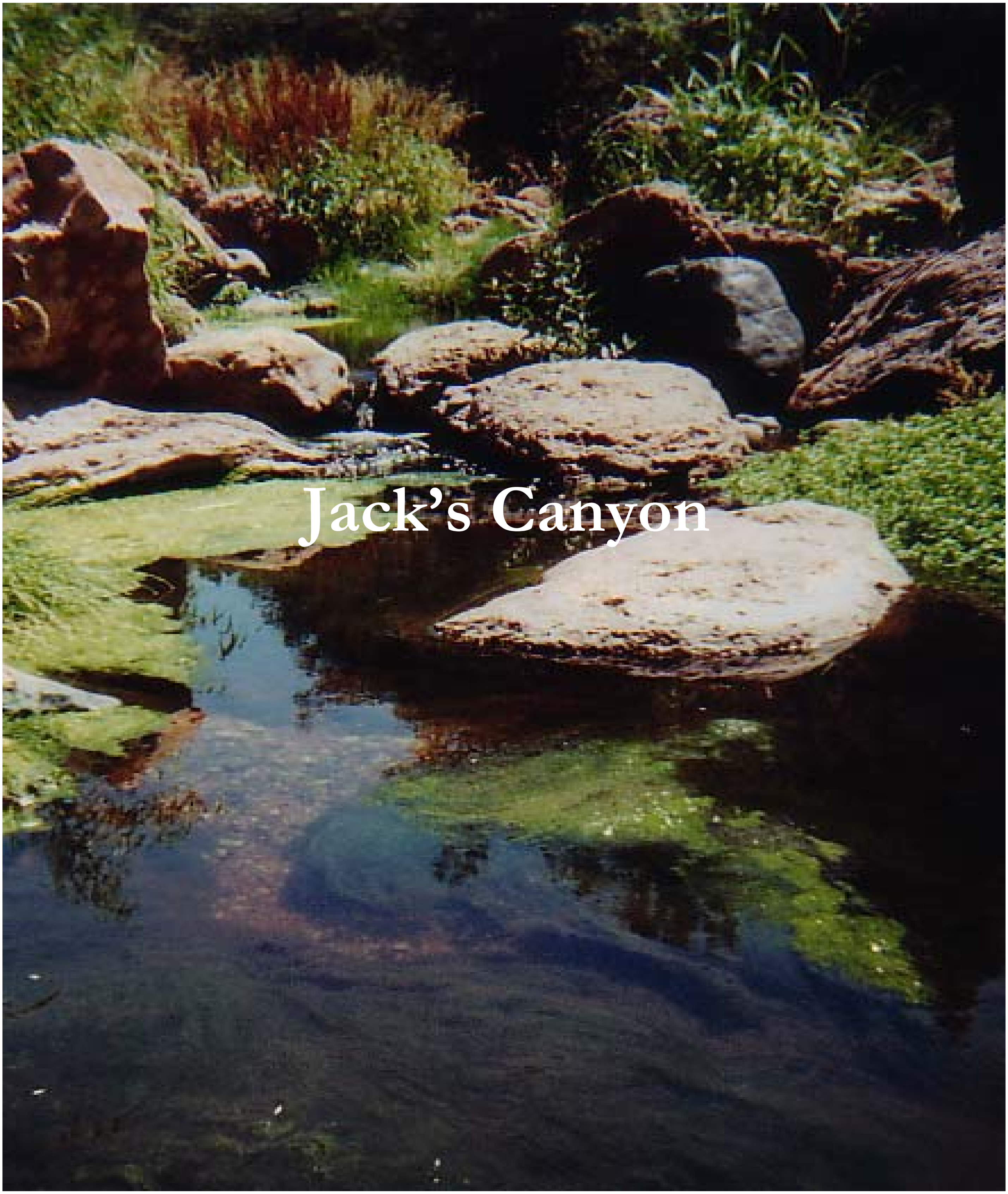
Summary

Within Bitter Creek, there appear to be at least a few variables limiting the diversity of aquatic macroinvertebrates. Realizing that it is often meaningless to determine which one may be the “most” limiting, it is still possible to get an idea if we include variables that, through previous analyses, have proven to have an inverse correlation with diversity levels. Dissolved oxygen (as measured in the stream during the day and the mean diel DO levels) was proven not to be a good predictor of diversity in Bitter Creek due to the strong autocorrelation of dissolved oxygen levels with other variables and was therefore excluded from this analysis.

Percent of gravel and bedrock, in this analysis, proved not to be as limiting a factor for diversity levels as did TAN (“ammonia”), percent fines (“sand/silt/clay”), and un-ionized ammonia (“NH3”). Within Bitter Creek, trampling by cattle and the inability of low flows to wash away fine material appear to be major constraints to the biodiversity of macroinvertebrates. Additionally, toxicity to macroinvertebrates by both ionized and un-ionized forms of ammonia is another constraint of equal importance/detriment to diversity.



Eigenvectors						
S-W DI	0.43070	0.35862	0.29151	0.30105	-0.32602	0.63560
NH3	-0.37129	0.43905	0.59184	-0.56489	-0.00000	-0.00000
Ammonia	-0.32600	0.68895	-0.23364	0.50496	-0.05242	-0.32673
Sand/Silt/Clay	-0.43853	-0.23072	0.33949	0.46460	0.55655	0.33705
Gravel	0.43609	-0.07584	0.59207	0.27475	0.09000	-0.60823
Bedrock	0.43345	0.38077	-0.21061	-0.20961	0.75705	0.07562


Jack's Canyon

Background

The Big Park WWTP has a service area of approximately 3000 mostly-residential homes in the village of Oak Creek, Arizona. Yearly average flow through the plant is 0.33 mgd. Water is treated using extended aeration, activated sludge, secondary clarification, and ultraviolet disinfection. Effluent from the WWTP is of relatively high quality.

The Jack's Canyon drainage exists both above and below the WWTP and is a tributary of Dry Beaver Creek, a tributary of the Verde River. Jack's Canyon originates on the side of Munds Mountain and Schnebly Hill and drains a relatively small, but steep, localized drainage on the west side of the Mogollon Plateau (Figure 1c). The approximate drainage area of the watershed is 31 square kilometers. The elevation changes along the length of the drainage from approximately 2000 m at the height of the watershed to about 1200 m at the outfall to the Big Park WWTP.

Besides discharge from the Big Park WWTP, winter snowmelt from higher elevations on the Mogollon Rim in winter and spring, and rainfall during the summer monsoons of July and August contribute to flow in Jack's Canyon. Average annual precipitation for the drainage area is approximately 18 inches in Sedona to almost 30 inches in nearby Oak Creek Canyon with the majority of this precipitation occurring as snowfall in the upper elevations.

The flow in Jack's Canyon had no contribution from upstream areas during the course of this study.

Site Description, Substrate, and Geomorphological Data

The effluent stream from the WWTP enters into a dirt-lined canal prior to entering the Jack's Canyon drainage. The dirt-lined canal is only a few tens of meters in length from outfall to confluence with the drainage. The canal itself is not lined and the bed material is composed of mostly fine-grained material. It is possible that this canal, under certain flow regimes, may contribute to the amount of fine-grained material into Jack's Canyon proper.

The sites JC1 and JC2 lie at approximate elevations of 1240 and 1211 m above sea level, $34^{o}46'09"$ N., $111^{o}45'45"$ W. and $34^{o}46'09"$ N., $111^{o}45'45"$ W. latitude and longitude respectively.

The channel length from site JC1 to JC2 was approximately 643 meters and had the second largest slope of all sites at 0.018%. This site was sampled for the first time on 1/30/03 and again on 6/30/04. The sites sampled at Jack's Canyon are characterized by having several step-pool-riffle formations, relatively large amounts of boulders in the stream channel, and large mats of filamentous green algae streaming from the bottom. These mats sometimes covered entire pools, even during the winter (Figure 3c). In addition to the filamentous green algae, there were extensive beds of *Rorippa* sp. lining the edge during winter and covering the entire water surface during summer (Figure 4c).

Sedimentation of fine material within the channel itself (other than material that might be brought in from the dirt-lined ditch) appeared minimal. Measures of embeddedness at Jack's Canyon are misleading. Large amounts of coarse-grained sand were evident at both sites, but these were mostly thin, well-oxygenated layers on top of bedrock. Additionally, since we often sampled gravel selected from a patch of gravel, the embeddedness score is automatically calculated at 100%. When performing biological assessments, embeddedness measures need to more accurately reflect biological significance. Since we believe embeddedness scores for Jack's Canyon do not accurately reflect biological condition, we analyze them with caution. There was no difference between sites but the winter sampling showed higher embeddedness than the summer (Figures 5c and 6c).

Of all EDW's sampled, Jack's Canyon had the highest diversity of aquatic habitat types owing to the step-pool-riffle formations between sites. The amount of fine material (silt/clay) decreased with distance from JC1 to JC2 where coarse sand and gravels dominated (Figure 7c). Additionally, the winter sampling showed increased levels of fine material compared to the summer. Again, measures of embeddedness are biologically misleading within Jack's Canyon due to the underlying bedrock. Also, areas under small waterfalls leading from one pool into the adjacent riffle were generally scoured where velocity increases resulted in larger grained material such as large gravel, cobble, and boulder.

Geomorphological Data from Jack's Canyon

Channel length: 643 m

Bankfull width: 14.02 m

Floodprone width: 35.0 m

Slope: 0.018

Figure 1c. ***Topographical map of Jack's Canyon watershed***

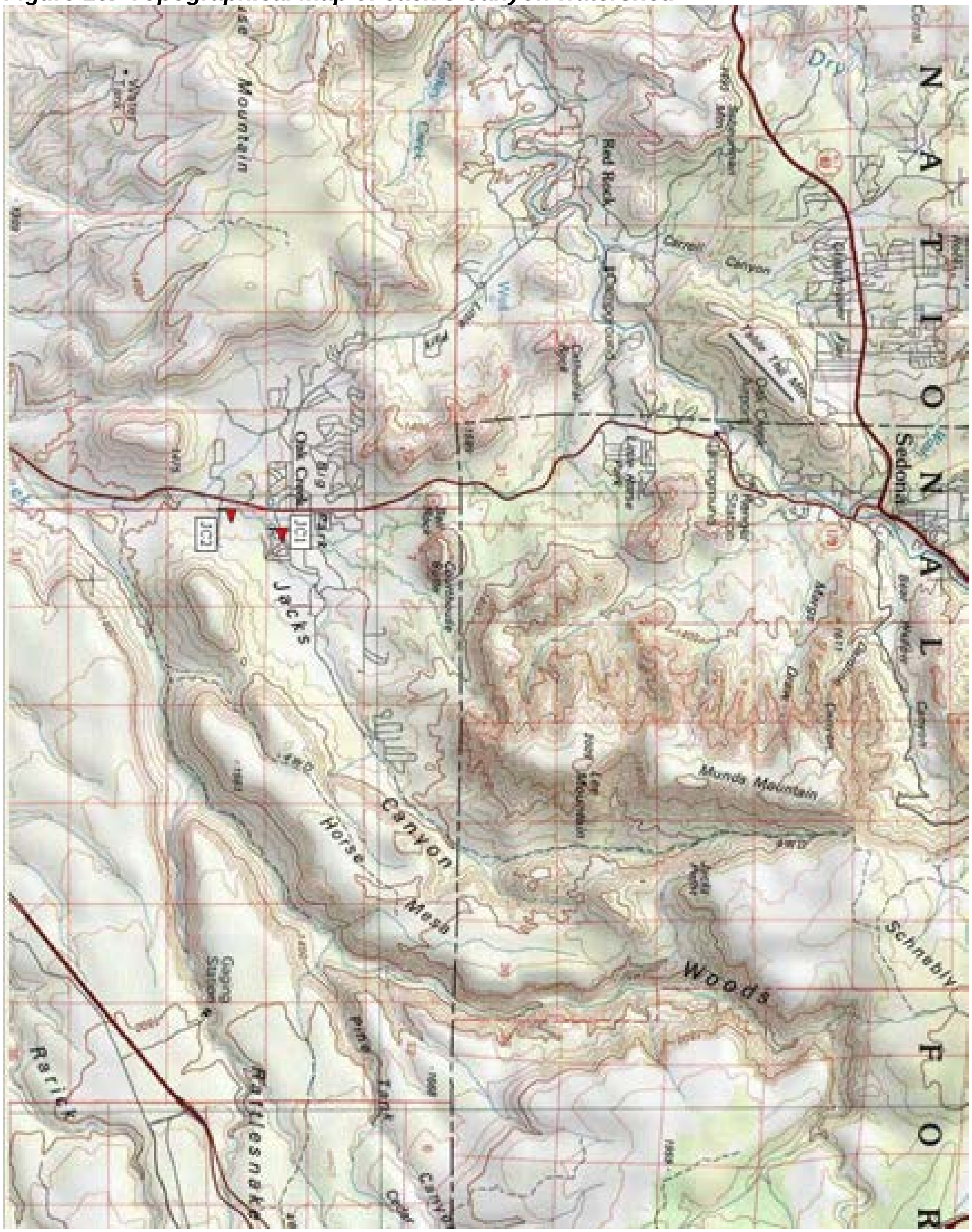


Figure 2c. ***Topographical map of the sites JC1 and JC2***

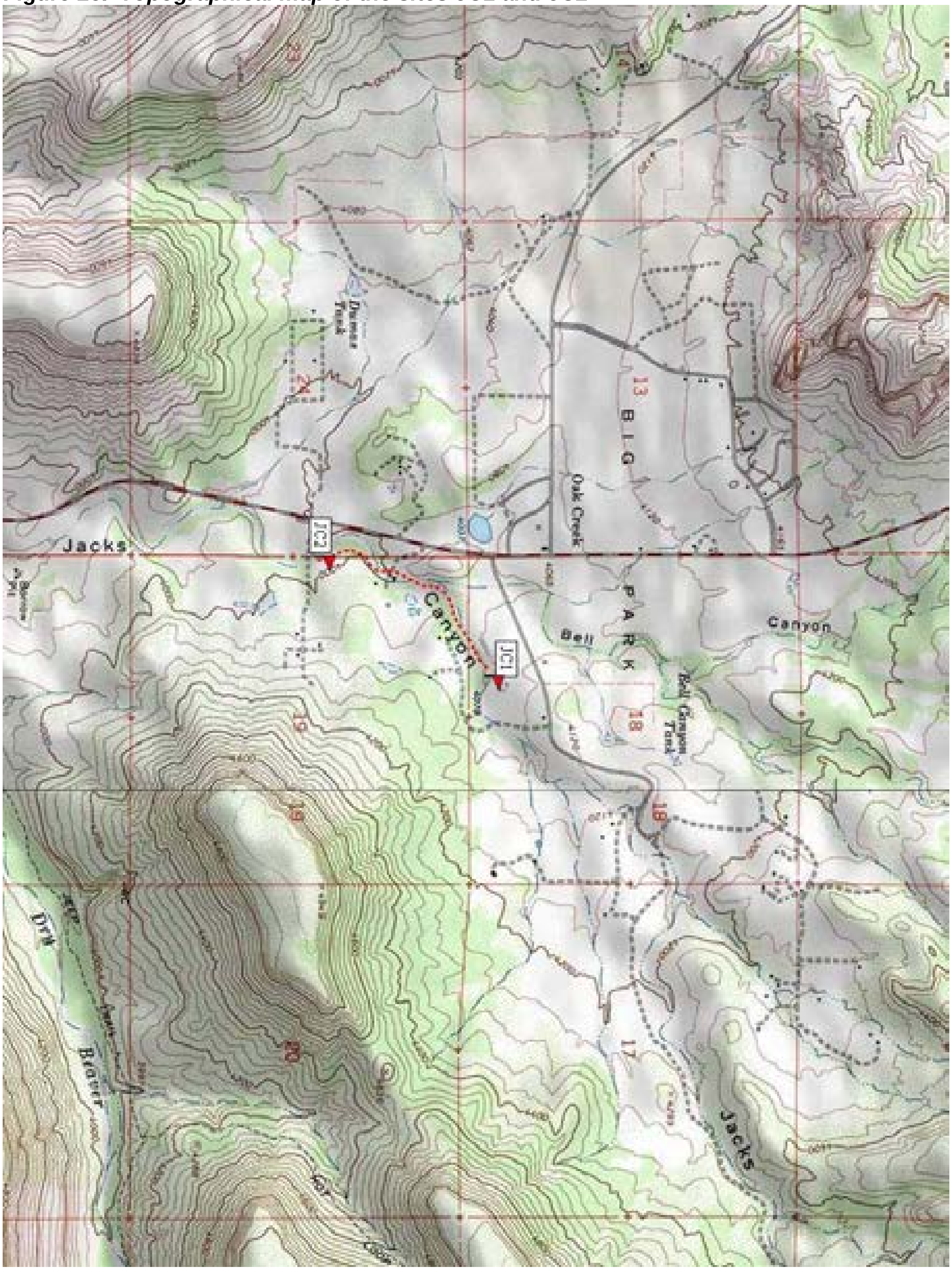


Figure 3c. ***Jack's Canyon with filamentous green algae,*** **Rorippa** ***sp., and herbaceous grasses lining the stream***

Figure 4c. Rorippa ***sp. completely covering the water surface of Jack's Canyon***

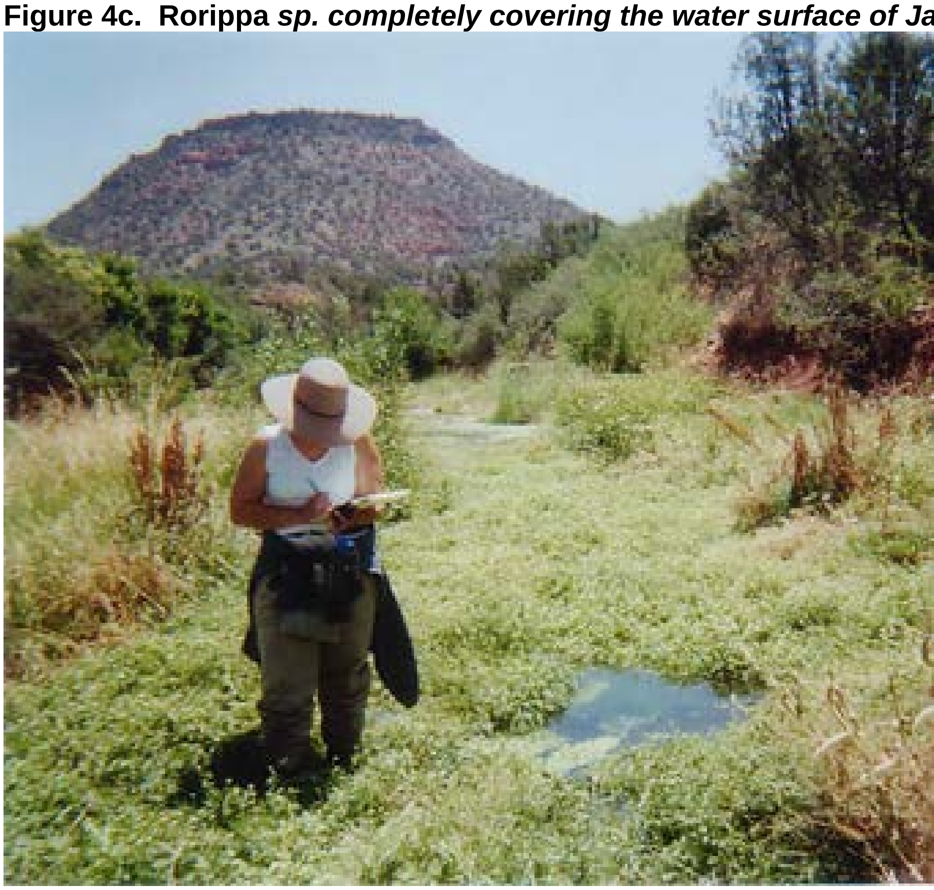
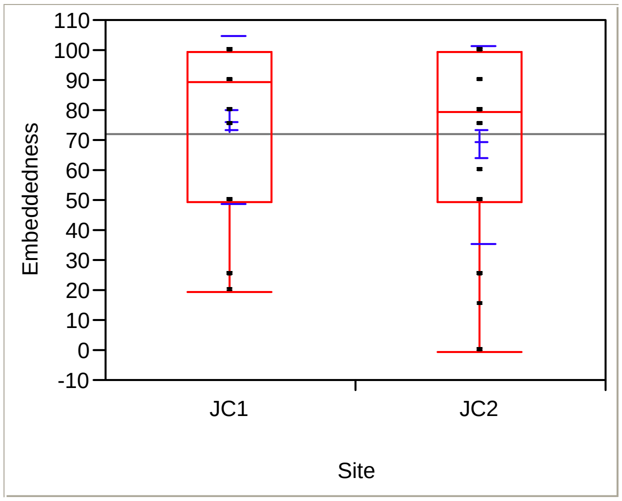


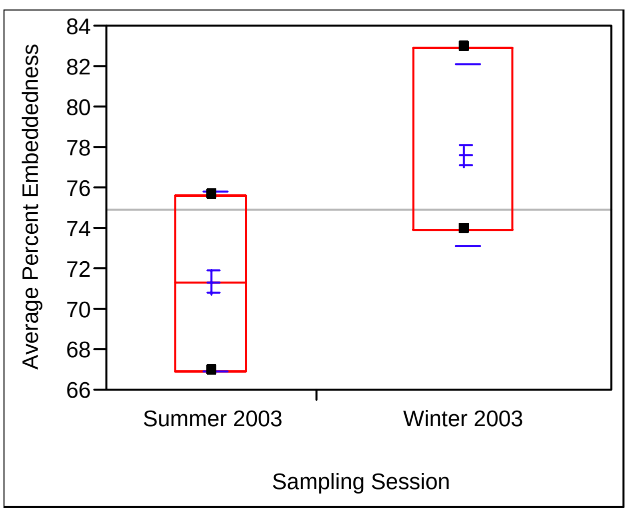
Figure 5c. ***Embeddedness by site***



Means

Level	Mean
JC1	76.4754
JC2	68.6885

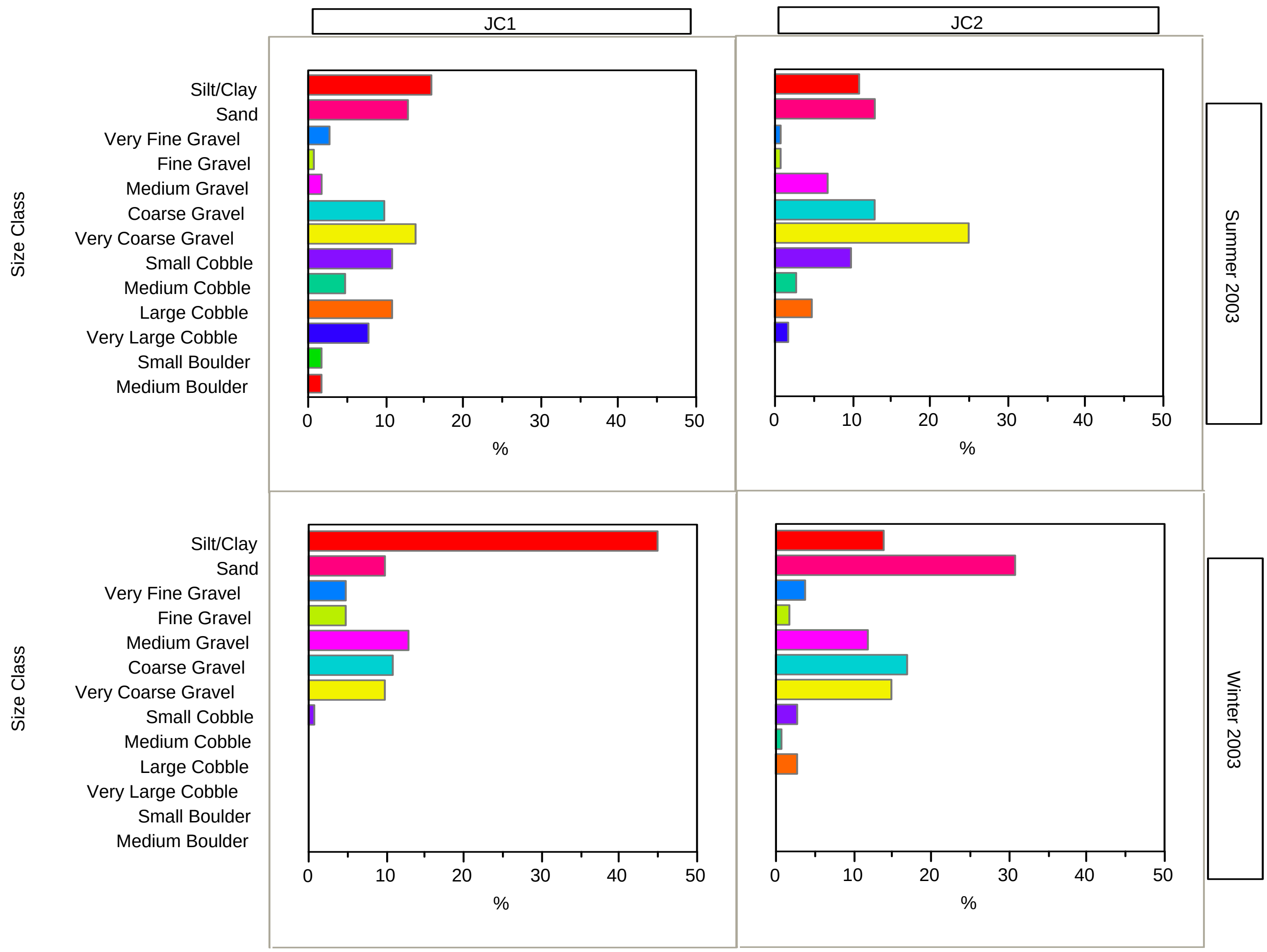
Figure 6c. ***Embeddedness by sampling season***



Means

Level	Mean
Summer 2003	71.3500
Winter 2003	77.5753

Figure 7c. ***Substrate particle size by site and date at Jack's Canyon***



Physico-chemical Data

Linear profiles of physico-chemical data were obtained for both sampling dates starting at JC1 and taken at roughly equidistant locations to JC2 (see Appendix A for data).

Figure 8c. ***Jack's Canyon linear profile, 01/30/03***

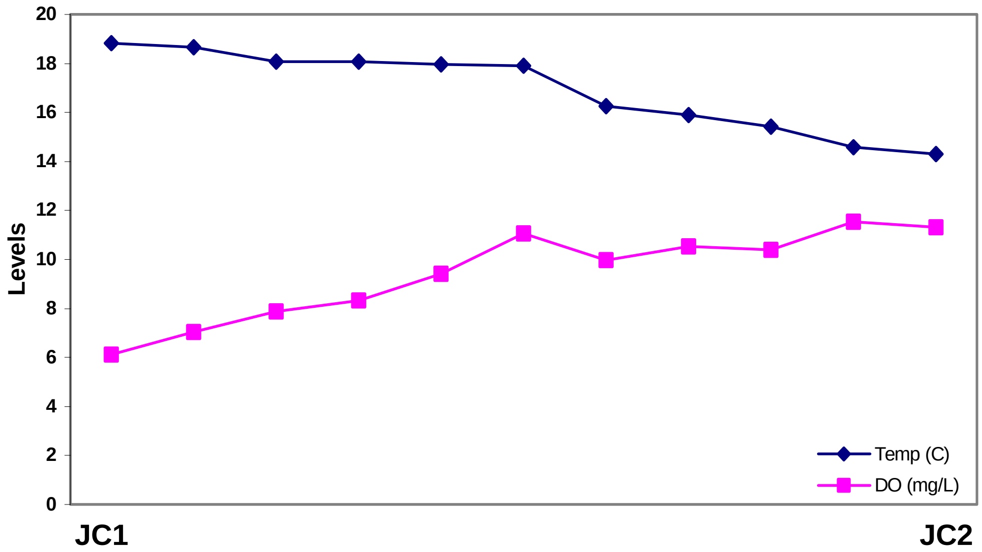
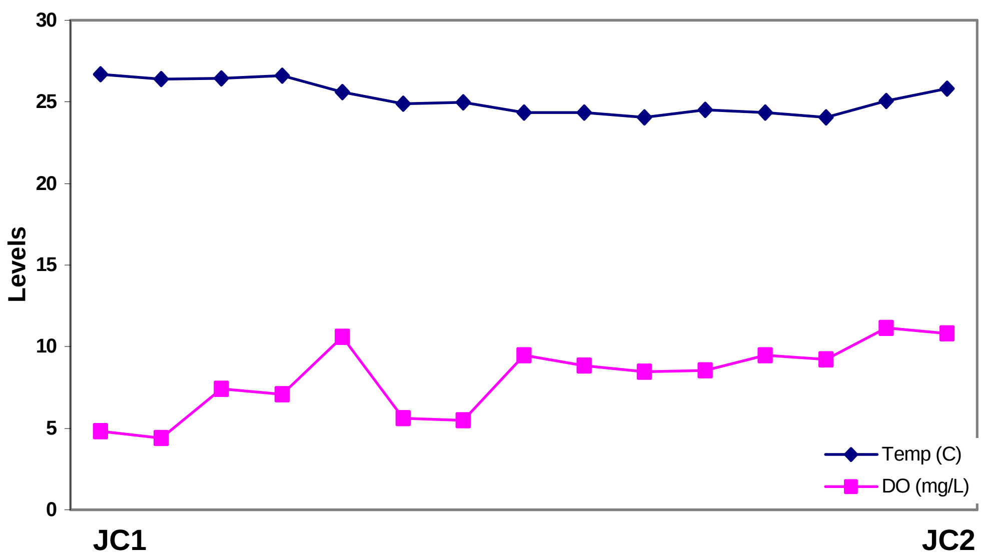


Figure 9c. ***Jack's Canyon linear profile, 06/30/03***



In addition to the linear profiles, physico-chemical readings were taken every 30 minutes over a 24 hour period (Diel profiles) during both samplings at RDF2 (see Appendix B for data).

Figure 10c. ***Diel pattern at JC2 on 01/30/03***

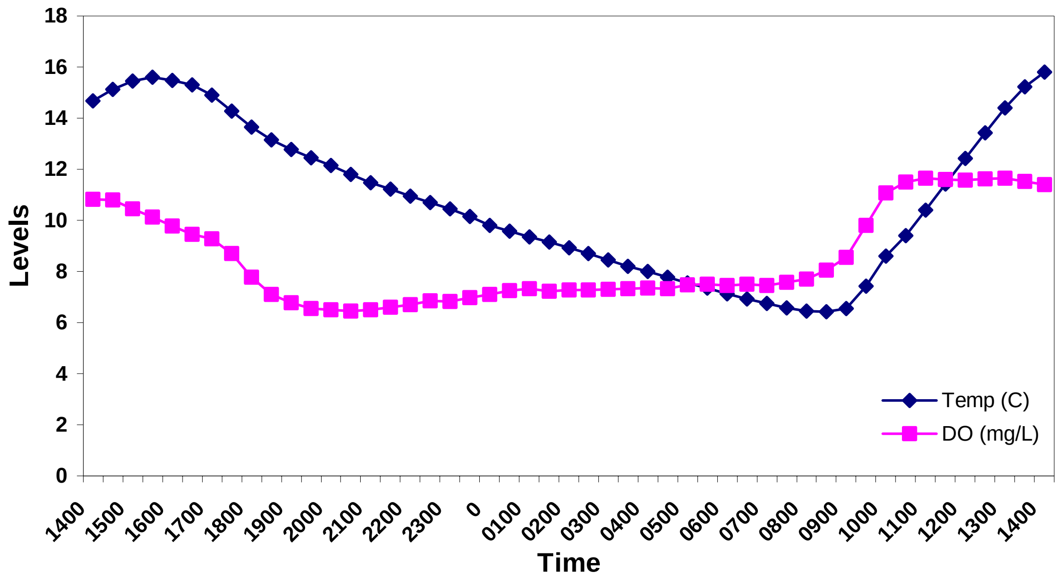
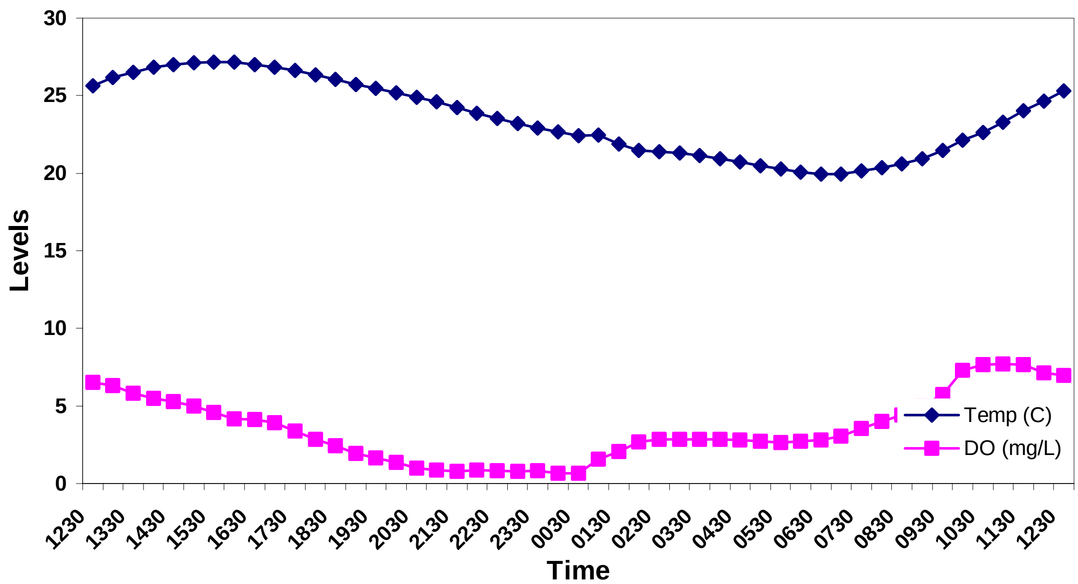


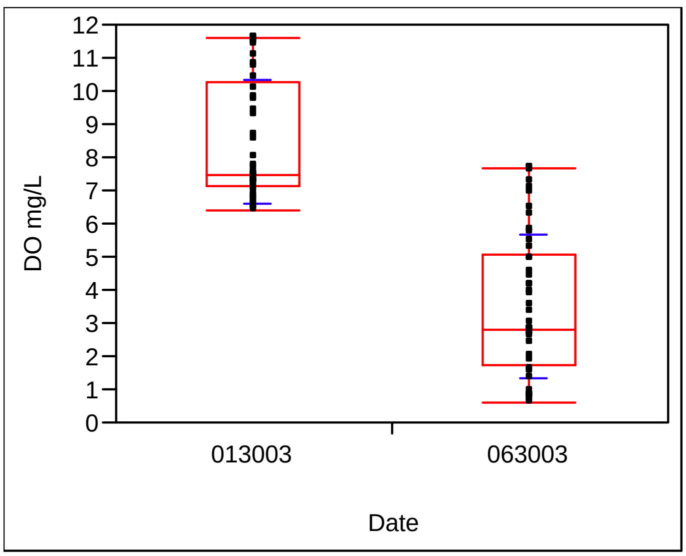
Figure 11c. ***Diel pattern at JC2 on 06/30/03***



Dissolved oxygen levels increased from JC1 to JC2. Interestingly, while Jack's Canyon appeared to have more aquatic vegetation growing in the stream than Rio de Flag, it never experienced the same type of extreme super-saturation observed at Rio de Flag. This may be attributable to the increased riparian canopy density at Jack's Canyon. While in-stream biomass was higher at Jack's Canyon, available light for photosynthesis was not as abundant as at Rio de Flag.

The summer diel profile showed that dissolved oxygen levels dropped to less than 1.0 mg/L between 8:30 pm and 12:30 am when, inexplicably, levels rose to greater than 2.0 mg/L until sunrise. At sunrise, dissolved oxygen levels began to increase again due to photosynthesis. Increases in dissolved oxygen could have been due to increased flows and turbulence, but the true reason for this increase in DO levels is not understood. Although dissolved oxygen levels did drop below 1.0 mg/L, the increase in DO after 12:30 am led to a relatively high 24-hour mean of dissolved oxygen when compared to other EDWs in this study. This is an important finding as the mean diel DO level is undoubtedly a very important limiting factor regarding diversity of aquatic macroinvertebrates in EDWs.

Figure 12c. ***Mean dissolved oxygen levels (mg/L) over a 24-hour period for both summer and winter of 2003 in Jack's Canyon***

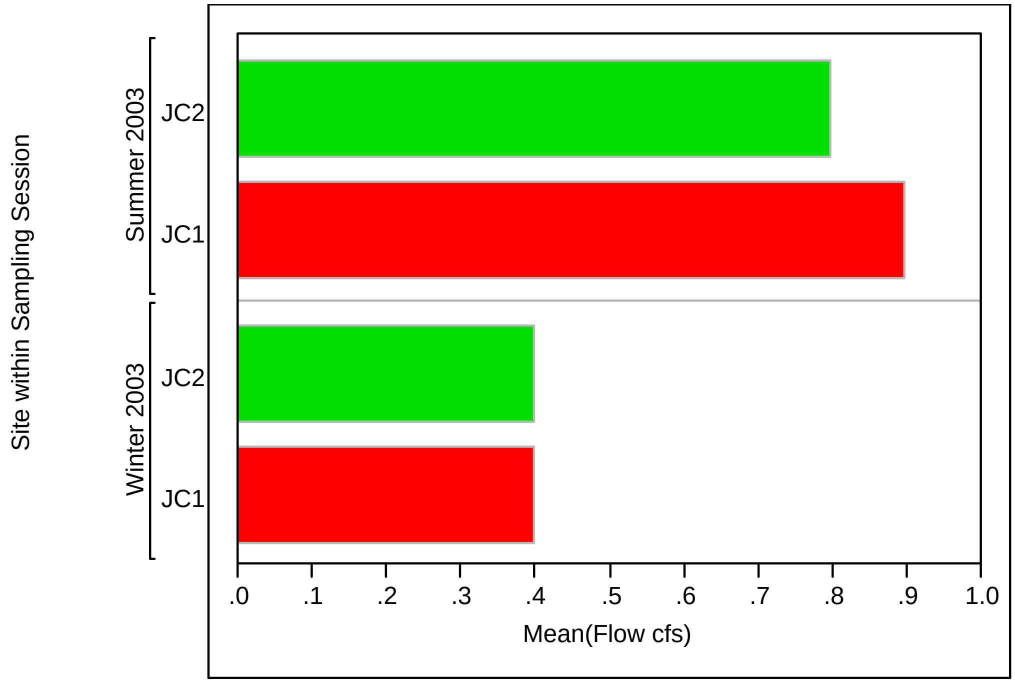


Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean
013003	49	8.49837	1.83584	0.26226
063003	49	3.54163	2.15358	0.30765

There were differences in flow rates between the summer and winter samplings (Figure 13c). Even with presumably higher evapo-transpiration rates during the summer, flow was still higher than the winter sampling. The increased velocity could have contributed to the lower percentage of embeddedness during the summer.

Figure 13c. ***Mean flow in Jack's Canyon by sampling period***



Nutrients

Nutrients in Jack's Canyon, like most EDW's, were elevated compared to naturally occurring surface waters (Figure 14c). Nutrient levels decreased slightly with distance from the outfall, presumably as it is incorporated into biomass. This decrease with distance was most evident during summer. It is doubtful that any nutrient was truly limiting in the traditional sense (Figure 15c). Phosphorous was relatively more limiting during the summer compared to winter as expected with increasing in-stream biomass, but at the levels of limitation observed in Jack's Canyon, this probably has little biological significance.

Unlike Rio de Flag, which showed significant uptake of phosphorous by aquatic plants and periphyton, this phenomenon was significantly reduced at Jack's Canyon. Levels of all nutrients, including total phosphorous, were much higher at Jack's Canyon than Rio de Flag, therefore some limitation of phosphorous was possible and observed at the latter. Biomass of emergent aquatic plants and periphyton appeared to be much higher at Jack's Canyon than Rio de Flag (see Figures 3c and 4c), but even so, nutrient uptake and incorporation into biomass did little at Jack's Canyon to affect the overall level of nutrients with distance from the outfall. The ability to determine what the threshold level of nutrients should be for an EDW, given the amount incorporated into biomass and other environmental variables, is of paramount importance. Judging from this preliminary data and given the amount of biomass and "un-used" nutrients with distance at Jack's Canyon, Rio de Flag approaches the bottom end while Jack's Canyon goes well over this threshold.

Levels of un-ionized ammonia, while lower than those found at Bitter Creek, could be considered stressful (if not acutely toxic) to species of aquatic macroinvertebrates. Levels were highest at JC2, probably due to elevated pH and temperature at this site compared to JC1.

Figure 14c. ***Nutrient levels at Jack's Canyon by site and sampling session (all units in mg/L)***

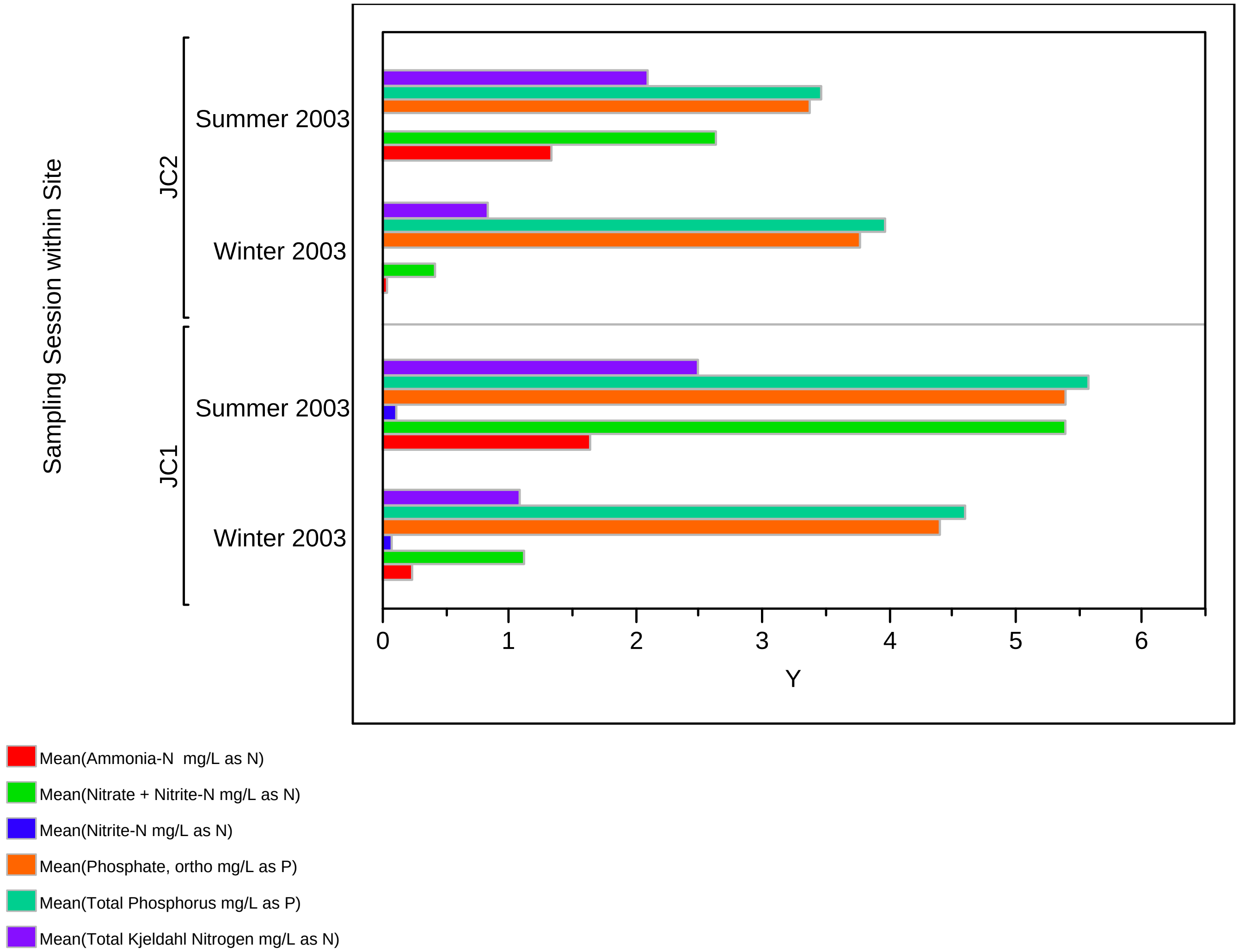


Figure 15c*.* *N:P ratio by sampling session and site* (total N calculated as the sum of ammonia, nitrate, nitrite, and TKN)

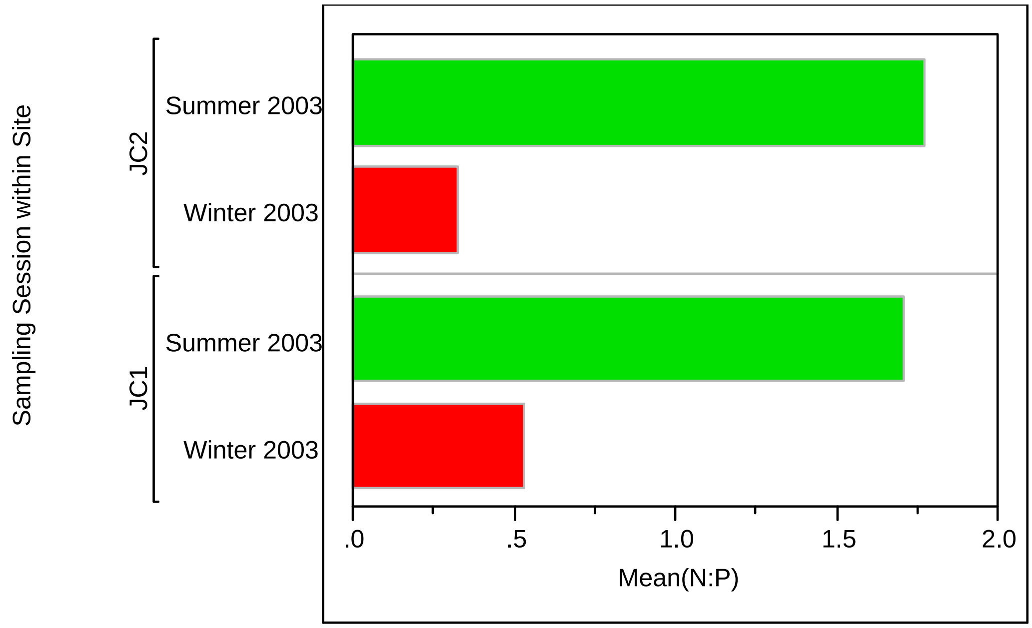


Figure 16c. ***TOC and DOC levels by site and sampling session***

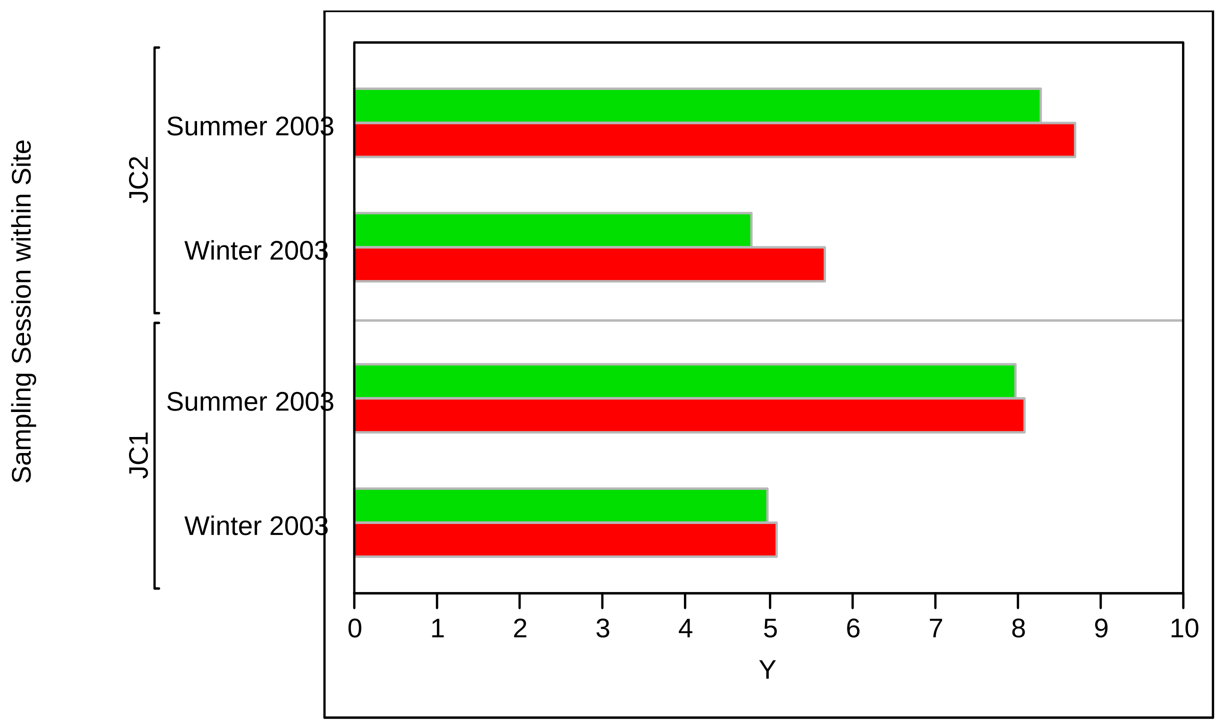
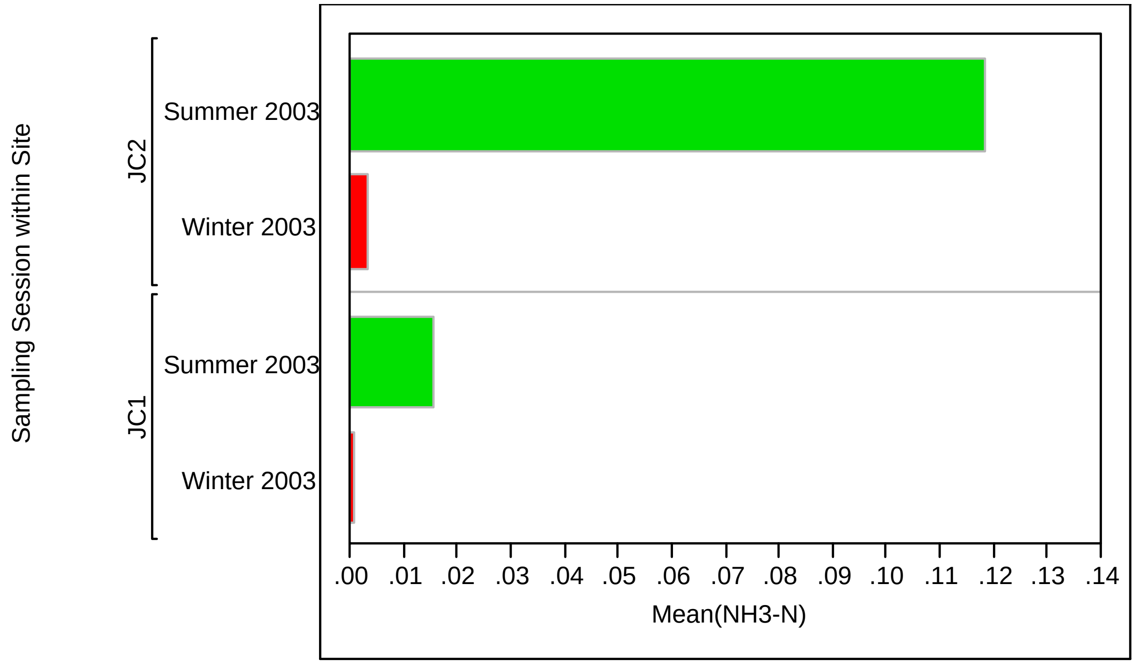


Figure 17c. ***Un-ionized ammonia levels in Jack's Canyon by site and date***



Biological Data

Algae

Jack's Canyon had a large amount of periphytic biomass that was dominated mostly by filamentous forms such as *Cladophora.* These large filamentous mats are likely very important habitat components for aquatic macroinvertebrates as they increase available habitable area, create possible refuges from predation, and act as a food source. Several species of periphyton were found growing epiphytically on filaments of other species so that even macroinvertebrate species not directly feeding on the filament could indirectly feed on epiphytic species of periphyton.

Numbers of periphytic species increased from JC1 to JC2, especially during the summer sampling. Interestingly, during the summer sampling, *Stigeoclonium* dominated at JC1, but was rapidly replaced by *Cladophora* at JC2 though the former probably has a higher pollution tolerance than the latter. Epiphytic species (e.g., *Cocconeis, Draparnaldia, Epithemia, Gomphonema,* etc.) were observed on both of the dominant filamentous species, *Cladophora* and *Stigeoclonium.* In areas where vascular aquatic macrophytes were observed, numbers of periphyton appeared to be reduced, probably due to shading as nutrients never appeared to be limiting. Also, in areas where macrophytes dominated, areas of attachment for filamentous forms of periphyton were lacking and the substrate was mostly large-grained sand or gravel. Since filamentous forms of periphyton appear to be important components of habitat for macroinvertebrates, especially during the summer, areas where basal holdfasts of filamentous forms are unable to attach may result in a depleted diversity of macroinvertebrates.

Figure 18c. ***Periphyton levels of chlorophyll a (mg/m^2) at Jack's Canyon by site and sampling period***

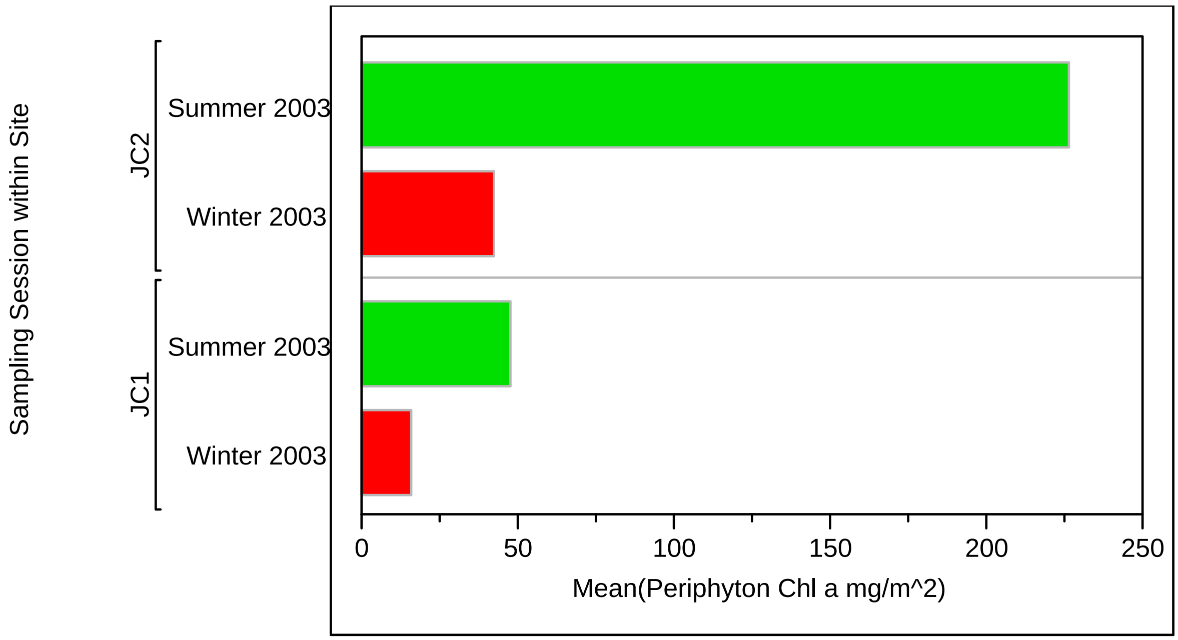


Figure 19c. ***Periphyton counts (units/m^2) by division***

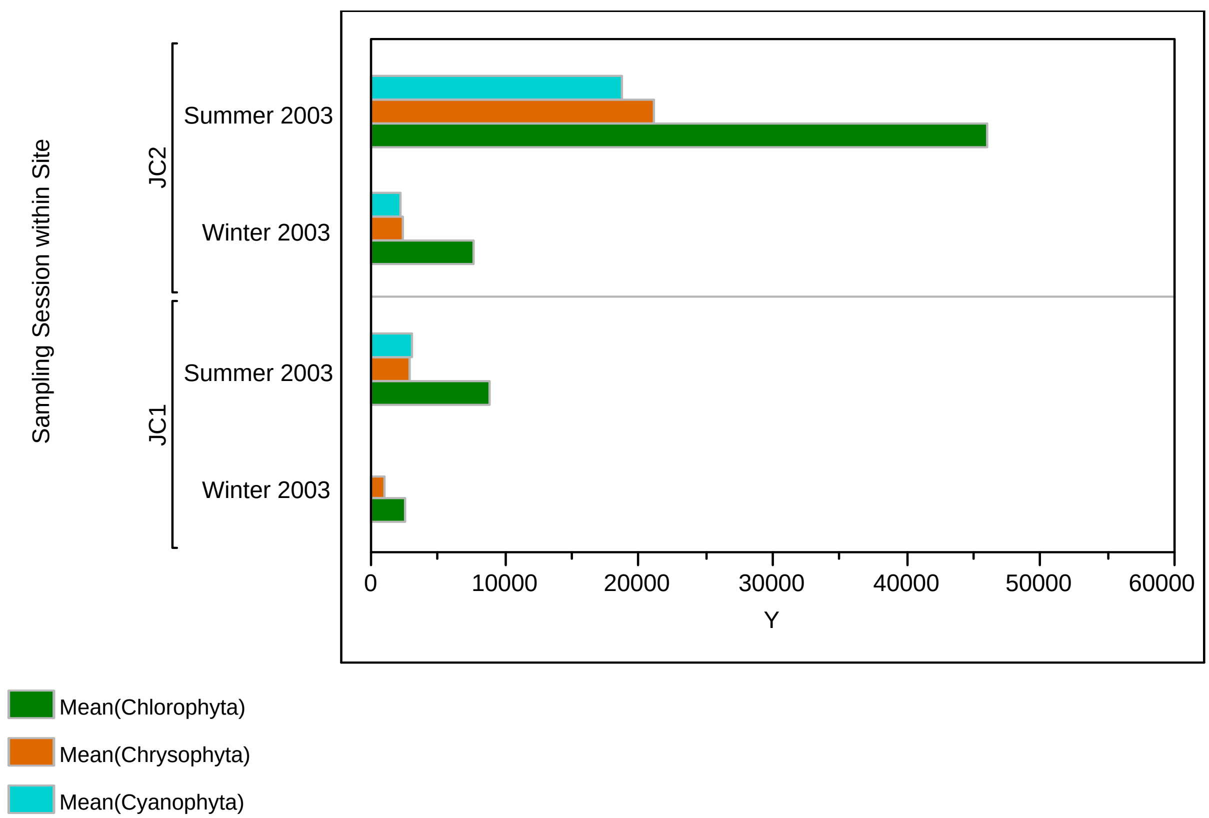


Figure 20c. ***Periphyton counts at JC1 by genus on 01/30/03***

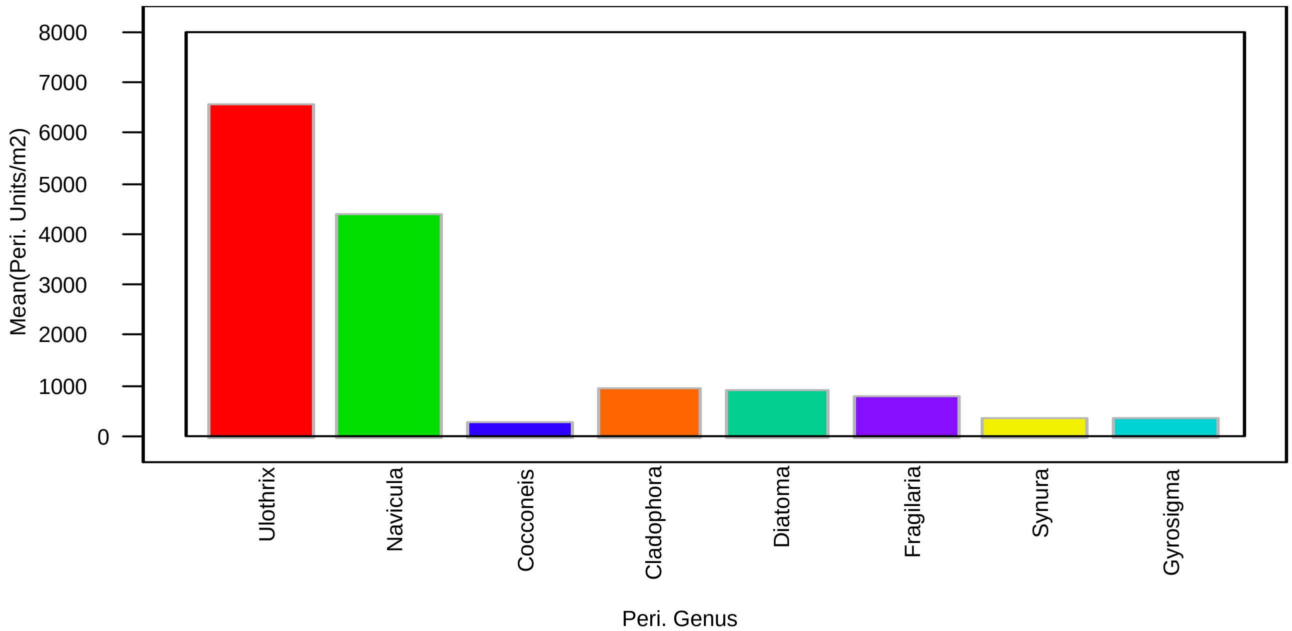


Figure 21c. ***Periphyton counts at JC1 by genus on 06/30/03***

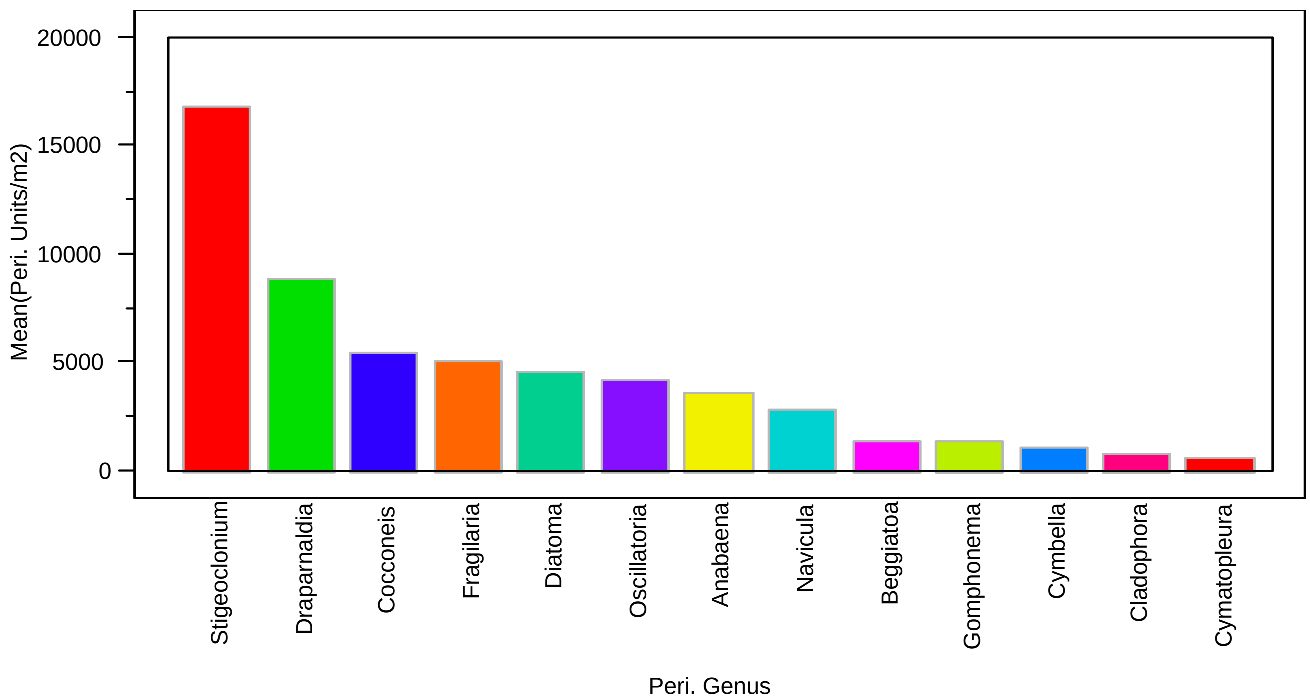


Figure 22c. ***Periphyton counts by genus at JC2 on 01/30/03***

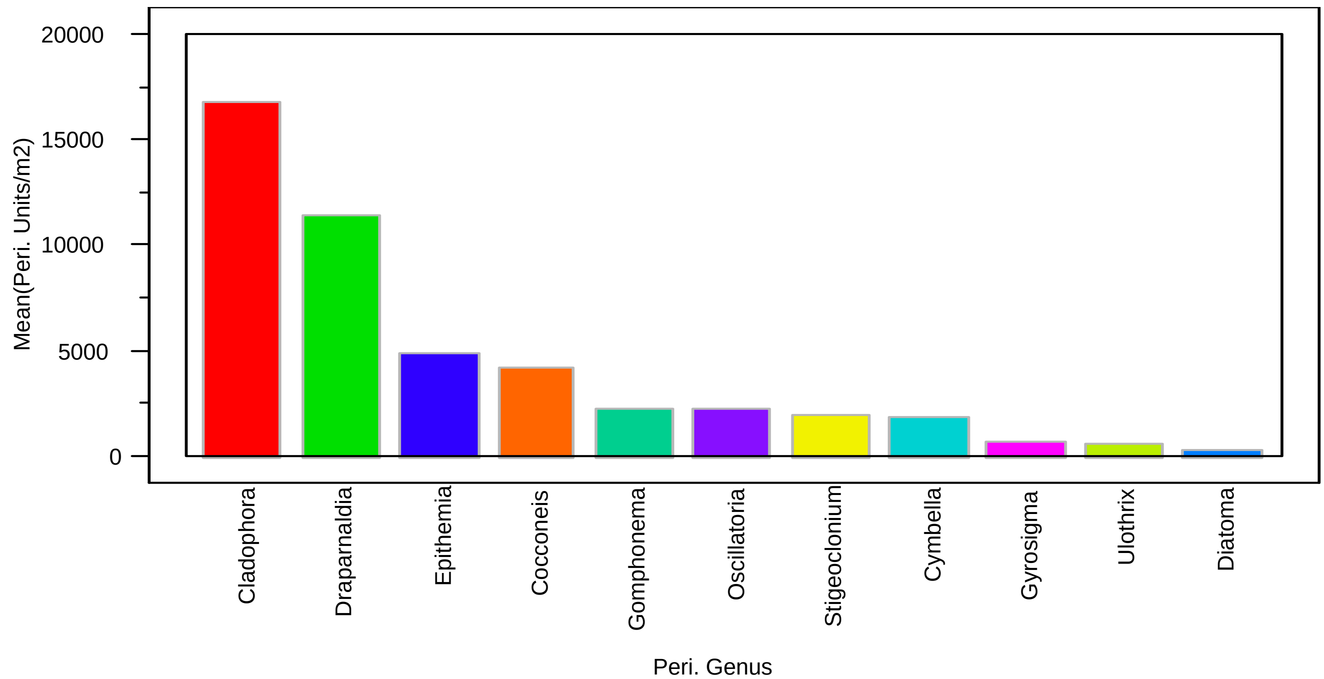
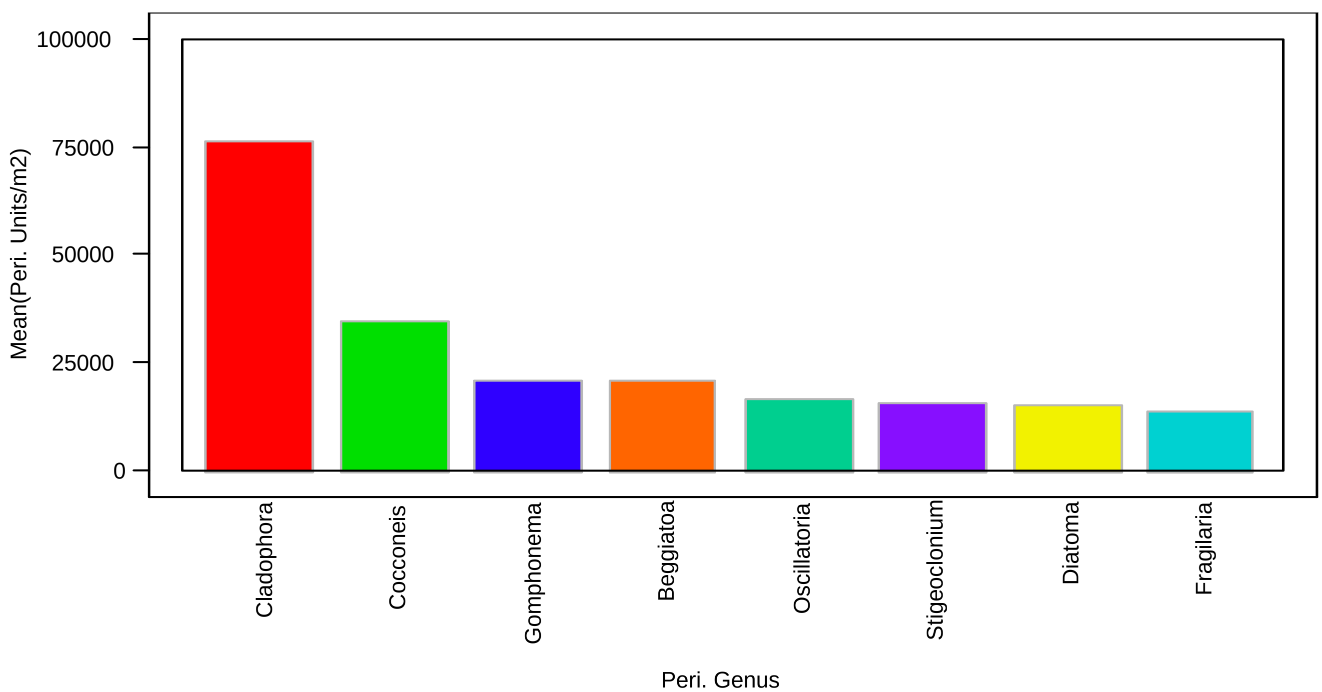


Figure 23c. ***Periphyton counts by genus at JC2 on 06/30/03***



Aquatic Macroinvertebrates

There was a significant difference in number of macroinvertebrates between sites. There was no difference between dates for JC1 but a large difference by date at JC2. Ephemeropterans and ostracods were the dominant taxa and numbers of both greatly increased during the summer. Ephemeropterans were mostly found in the filamentous mats of *Cladophora* and as these mats increased in biomass, so did the number of ephemeropterans.

While pollution tolerance of macroinvertebrates, as measured by the Hilsenhoff Biotic Index (HBI), was high compared to naturally occurring surface waters, it was relatively low compared to other EDW's examined during this study. Tolerance values were generally between 7 and 8 with a low of 6.5 at JC2 during the summer. On a spatial scale, it appeared that Jack's Canyon "recovered" from its contaminant load at a relatively faster rate than did other EDW's.

Diversity values, as quantified by the Shannon-Weiner diversity index (S-W Index), were relatively high compared to other EDW's. Because Jack's Canyon also contained macroinvertebrates with relatively low pollution tolerances compared to other EDW's, this suggests that diversity levels and pollution tolerance are indeed correlated.

Figure 24c*. Aquatic macroinvertebrate numbers for JC1 and JC2 by date*

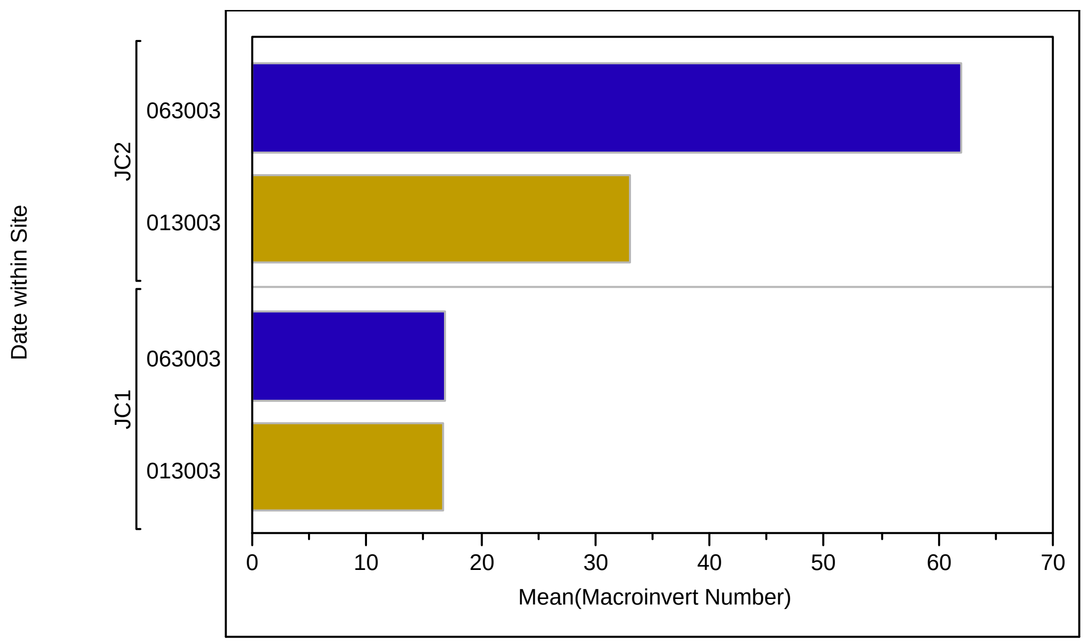


Figure 25c. ***Macroinvertebrate order by date***

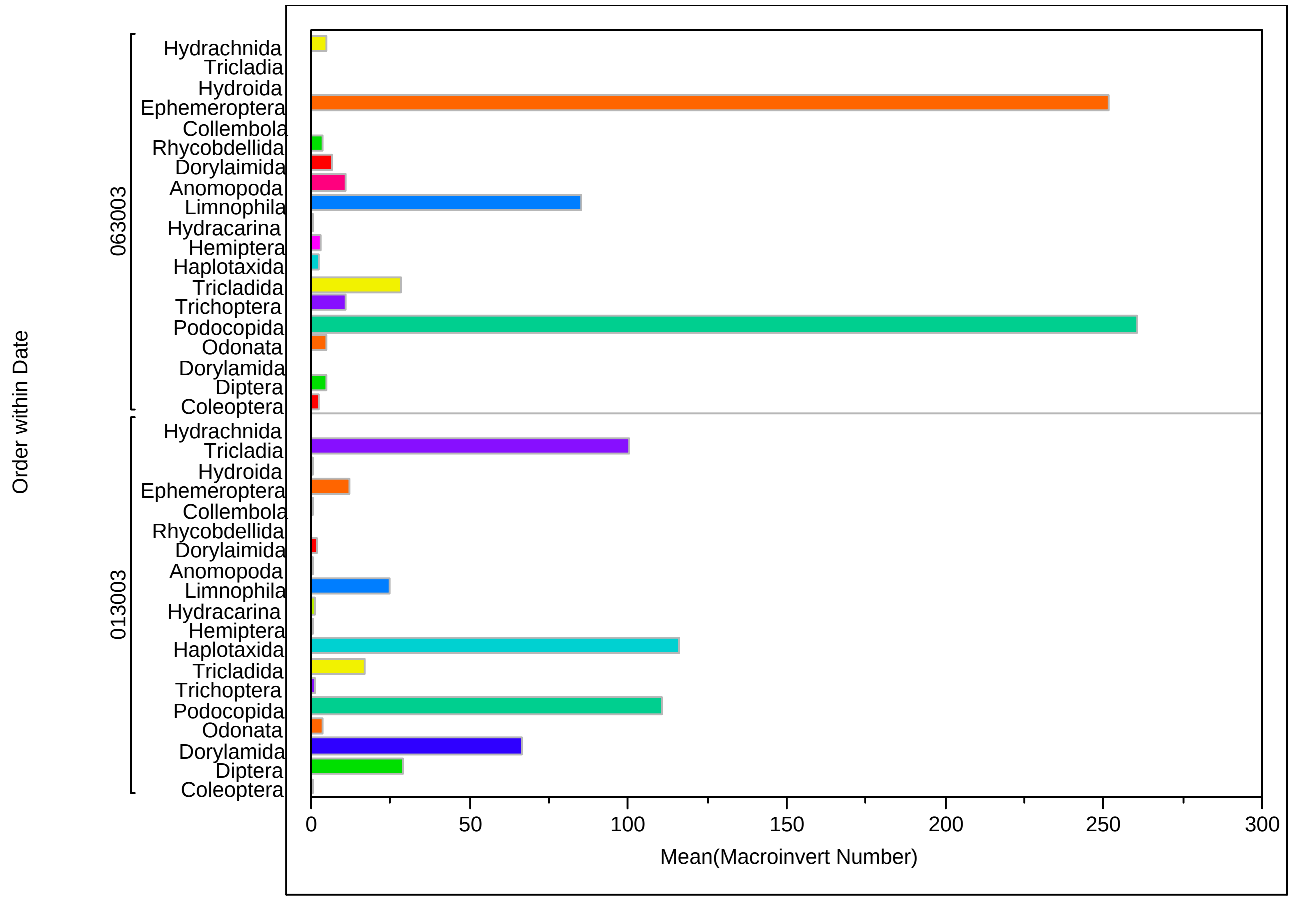
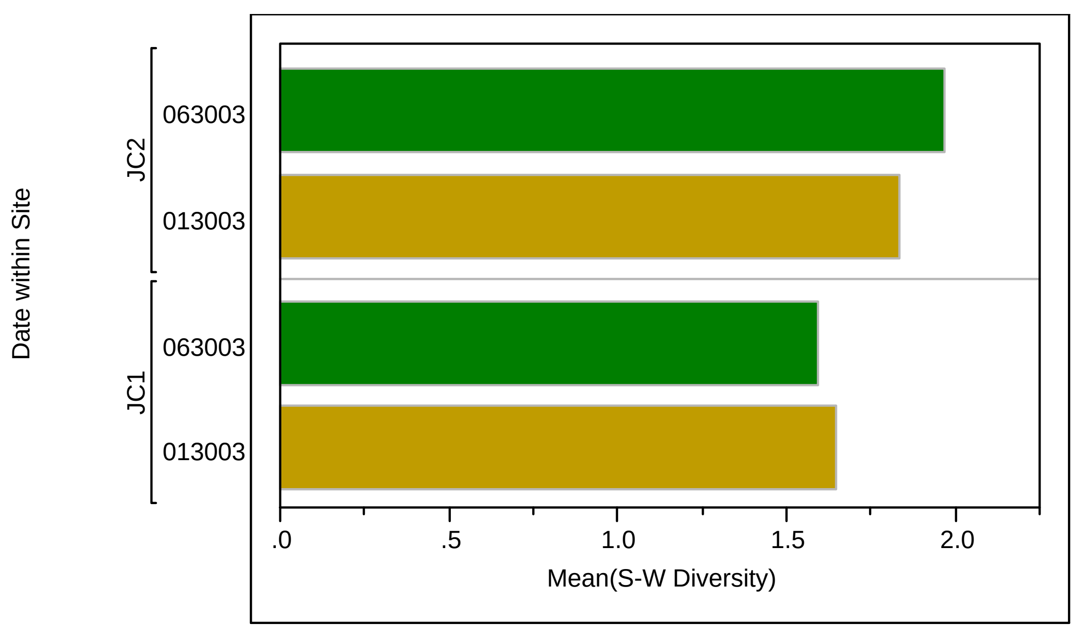


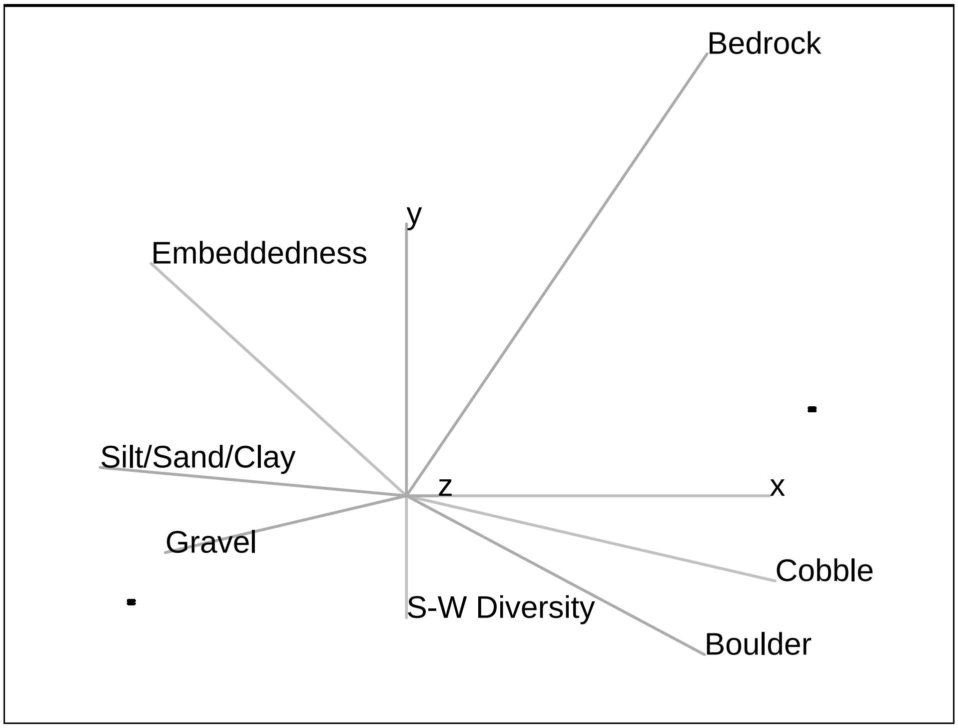
Figure 26c. ***Shannon-Weiner diversity index by site and date***



Correlations

S-W Diversity Index and Physical Attributes

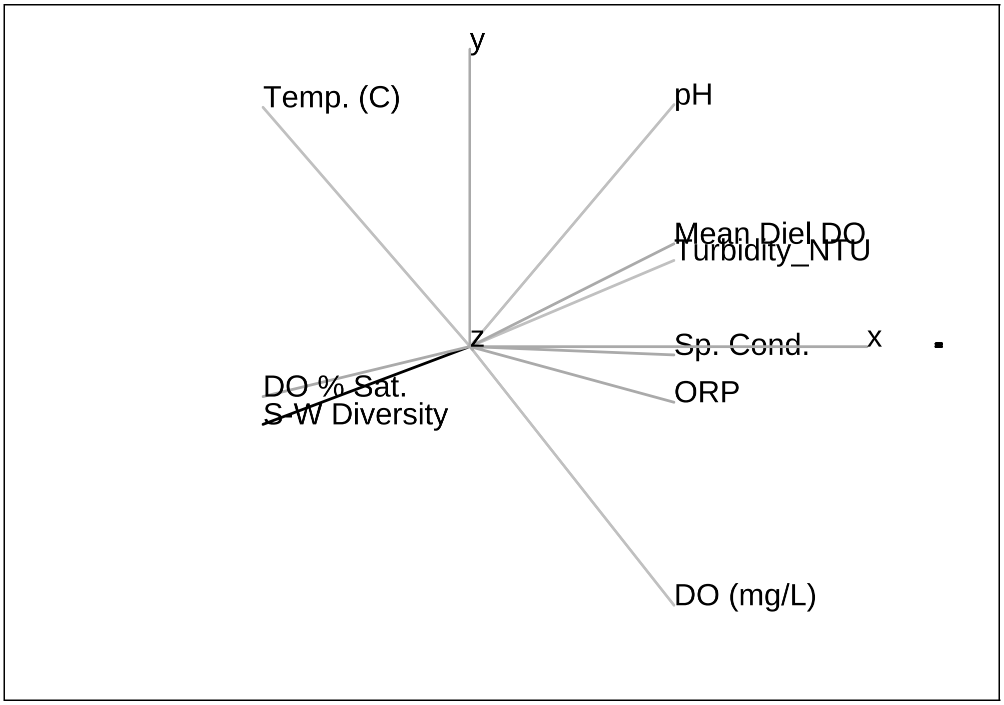
Diversity was inversely correlated to percent embeddedness, silt/sand/clay, and gravel and was positively correlated to percent cobble, boulder, and bedrock. The largest positive correlation with diversity was percent cobble and the largest inverse correlation was percent of sand/silt/clay. As stated earlier, levels of embeddedness may be erroneously high at Jack's Canyon because of the relatively thin layer of gravel and sand on top of bedrock.



Eigenvectors							
S-W Diversity	0.00402	0.56461	-0.22105	0.79520	0.00000	0.00000	0.00000
Embeddedness	-0.30711	-0.44372	0.42544	0.43486	0.34660	0.14238	-0.44530
Silt/Sand/Clay	-0.49224	-0.19358	0.05617	0.15555	-0.06639	0.28771	0.77826
Gravel	-0.32647	0.44393	-0.10287	-0.34215	0.73291	0.17612	-0.02284
Cobble	0.51063	-0.11827	-0.15317	0.03882	0.09587	0.83133	-0.00230
Boulder	0.38137	-0.38104	-0.28651	0.18898	0.55834	-0.41355	0.32985
Bedrock	0.38808	0.30100	0.80676	0.00859	0.13179	-0.06169	0.29443

S-W Diversity Index and Physico-chemical Attributes

This PCA further solidifies the importance of dissolved oxygen to the diversity of aquatic macroinvertebrates. There were strong positive correlations with diversity and levels of dissolved oxygen and strong inverse correlations between diversity and turbidity, specific conductivity, and mean diel dissolved oxygen. Jack's Canyon had relatively high diel DO levels, and this could explain the inverse correlation. In other words, it's not that diversity benefited from low mean diel DO levels rather, they were not as important at this site because they are not significantly limiting diversity.



Eigenvectors								
S-W Diversity	0.58642	0.30408	-0.25154	-0.16696	-0.00667	0.39946	0.44272	0.07592
Temp. (C)	0.19658	0.03950	0.35631	0.52091	0.38159	0.39086	0.09893	-0.37711
pH	-0.13252	0.03044	-0.16288	0.52563	-0.48310	-0.06447	0.57177	-0.05589
DO % Sat.	0.24919	0.36949	0.42397	-0.10813	0.05190	-0.45376	0.36820	0.39326
DO (mg/L)	0.45467	0.18763	-0.06406	-0.55963	0.19430	0.22160	0.34090	-0.35580
ORP	-0.24406	0.17616	0.71481	-0.11763	-0.39192	0.32106	-0.12916	0.01180
Sp. Cond.	-0.32729	-0.54114	0.24509	-0.01460	0.47808	-0.11004	0.40118	0.16444
Turbidity_NTU	-0.35406	0.57082	-0.04084	0.18757	0.32581	-0.41127	-0.13003	-0.32961
Mean Diel DO	-0.19757	0.28916	-0.16337	0.22447	0.30365	0.37969	-0.14481	0.65714

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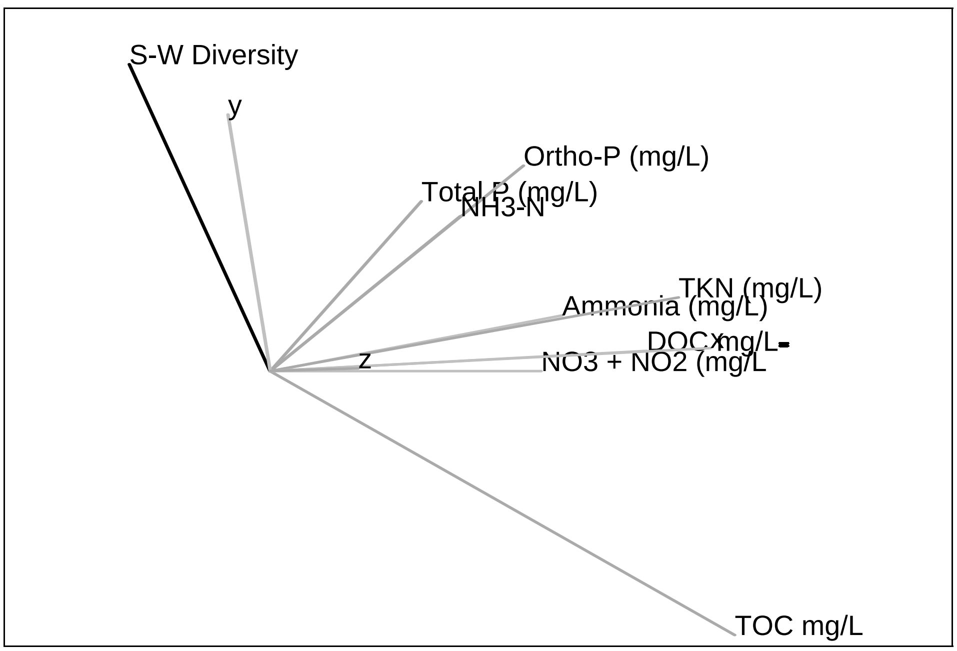
S-W Diversity Index and Nutrient Levels

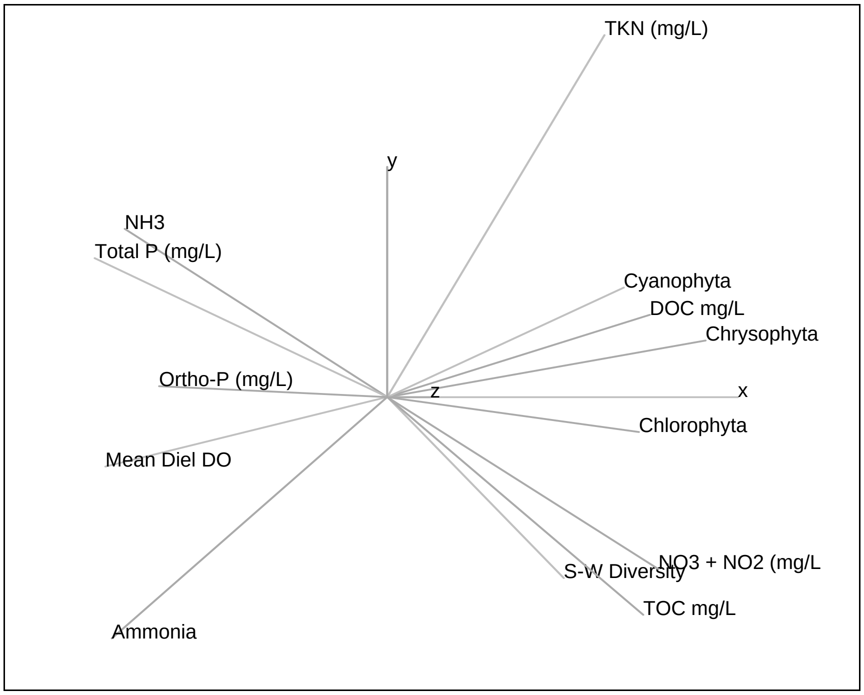
Correlations between diversity and nutrient levels were ambiguous. This may have been because of the relatively high levels of nutrients found in the water and the fact that they never appeared to be limiting. Unlike Rio de Flag where phosphorous was found to be limiting for algal growth during the summer, and the critical use of that algae as alternative substrate for macroinvertebrates, this relationship was less clear at Jack's Canyon. Phosphorous had a relatively stronger relationship than other nutrients at Jack's Canyon, however, overall positive correlations between diversity and nutrients at Jack's Canyon were lacking. Consequently, the lack of a relationship between nutrient levels and diversity may mean that substrate as habitat for macroinvertebrates is not limiting at Jack's Canyon and, therefore, the importance of filamentous algae as an alternative source of substrate was not as great as found at Rio de Flag. There appeared to be an inverse correlation between diversity and total, but not dissolved, organic carbon. This correlation is difficult to interpret in an ecological sense and may be an artifact of the inverse correlation between diversity and turbidity. As turbidity (and presumably suspended solids) levels increase, organic carbon may adhere to particles. As these particles are filtered out, the correlation between the dissolved organic carbon fraction and diversity is diminished.



Eigenvectors									
S-W Diversity	-0.09903	0.50782	0.60521	0.60501	0.00000	-0.00000	-0.00000	-0.00000	-0.00000
Ammonia (mg/L)	0.42872	0.05921	-0.06055	0.08105	-0.63708	0.03711	0.16013	-0.42004	-0.43947
Total P (mg/L)	0.19096	-0.47729	0.12079	0.31104	-0.15903	0.35307	0.41672	0.54587	0.05315
DOC mg/L	0.40913	0.16875	-0.07748	0.00283	0.18246	0.72222	-0.48508	-0.03182	0.08320
TOC mg/L	0.38290	0.23442	0.41624	-0.55047	-0.01750	-0.02141	0.37126	-0.02375	0.42778
Ortho-P (mg/L)	0.22591	-0.45377	0.04626	0.37157	0.19300	-0.15898	-0.01958	-0.56903	0.46493
NO3 + NO2 (mg/L)	0.42068	-0.11389	0.18997	-0.02558	0.61612	-0.23041	0.07082	0.05639	-0.57656
TKN (mg/L)	0.43061	0.03197	-0.05981	0.10348	-0.26260	-0.51817	-0.48133	0.43881	0.19383
NH3-N	0.20615	0.45550	-0.62801	0.27963	0.22233	-0.07102	0.43645	0.06702	0.16725

S-W Diversity Index, Periphyton, Nutrients, and Dissolved Oxygen.

Interestingly, the usual inverse correlation with mean diel DO levels and diversity are not apparent when this group of factors is loaded. What is apparent is the inverse correlation between diversity and un-ionized ammonia. The strongly positive correlation between diversity and nitrate + nitrite is probably an autocorrelation due to the positive correlation with DO. The positive correlation with TOC and diversity is interesting given that when only nutrients are factored, this is an inverse relationship. There was a correlation between diversity and biomass of chlorophytes.

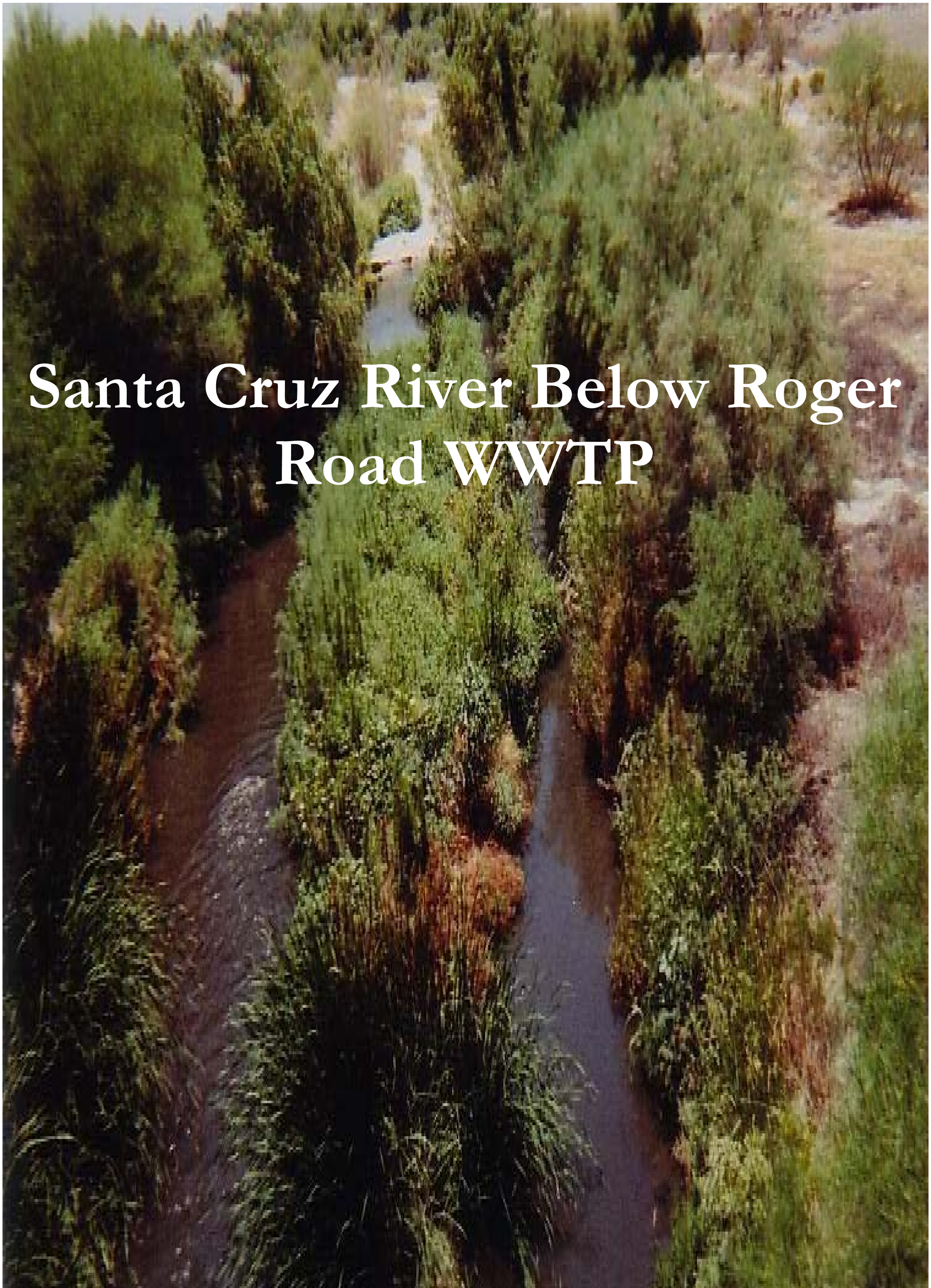


Eigenvectors												
S-W Diversity	0.02076	0.46297	-0.01102	-0.32211	0.03311	-0.29328	-0.01513	0.37370	-0.26777	0.01923	-0.00126	-0.55260
Mean Diel DO	-0.01086	0.22789	0.02408	0.29623	0.13574	-0.11266	0.16187	-0.31016	-0.38573	0.65616	0.21535	-0.05884
Ammonia	0.08195	-0.39432	0.03580	-0.01553	0.42881	-0.39288	-0.39597	0.37440	0.09697	0.26977	-0.20485	0.00296
NH3	-0.05501	0.37748	-0.07348	-0.55379	0.22454	0.27727	-0.06165	-0.04658	0.48501	0.23655	0.17100	0.10857
Total P (mg/L)	-0.33012	-0.08053	0.35779	0.13131	0.22483	0.22863	0.56910	0.44581	0.02318	-0.11933	0.04973	-0.14021
DOC mg/L	0.45119	-0.29478	-0.00654	-0.18990	0.31489	0.13514	0.12179	0.11050	-0.21427	-0.02398	0.62123	0.14012
TOC mg/L	-0.12109	0.26597	0.51302	0.30495	0.20132	-0.35556	-0.17033	-0.13180	0.36987	-0.13535	0.32062	0.10113
Ortho-P (mg/L)	0.39494	0.48683	-0.19129	0.34799	-0.02935	0.01927	-0.06603	0.41232	-0.07066	-0.21815	0.00419	0.37976
NO3 + NO2 (mg/L)	-0.40807	-0.05413	-0.59366	0.11863	-0.05904	-0.27889	0.24829	0.24777	0.22092	0.19967	0.20769	0.22586
TKN (mg/L)	-0.21227	0.06090	-0.18284	0.36853	0.32291	0.59214	-0.42588	0.09526	-0.03630	0.08076	-0.01409	-0.22733
Chlorophyta	0.25914	0.12205	-0.13135	0.04418	0.54538	-0.05389	0.41849	-0.24043	0.11695	-0.03025	-0.52008	0.05875
Chrysophyta	-0.28875	0.10340	0.31340	-0.25314	0.01294	0.09286	-0.09052	0.15272	-0.39582	0.18899	-0.24267	0.61247
Cyanophyta	0.38000	-0.04904	0.25189	0.13507	-0.38693	0.18111	0.12062	0.26810	0.35519	0.52593	-0.13601	-0.06616

Summary

Aquatic macroinvertebrate diversity in Jack's Canyon was relatively high. The relationship between nutrient levels and diversity is ambiguous. This may be due to the abundance of non-periphytic habitat within Jack's Canyon, and therefore the importance of filamentous algae as an alternative source of habitat was reduced. Additionally, mean diel DO levels, while an important variable, was not as limiting at Jack's Canyon as some other EDW's because they were relatively high. The limitations to macroinvertebrate diversity found at other EDW's were relatively eased at Jack's Canyon, which may mean that this EDW could be prototypical.

Santa Cruz River Below Roger Road WWTP



Background

The Roger Road Wastewater Treatment Plant (RRWWTP) was built in 1951 to serve the city of Tucson. Today, it is the major treatment facility for the city south of the Rillito River. Treated effluent from this WWTP is discharged into the Santa Cruz River near the facility or is diverted into the city's reclaimed water system. The treatment facility has a capacity of 41 mgd and treated an average of 37.52 mgd during the course of the study. It treats the wastewater generated by about 419,000 members of Tucson's population of about 550,000 people. It also treats the waste generated by five of Tucson's hospitals.

Treatment consists of separating solids and passing the remaining effluent through biotowers where bacteria and algae consume organic waste, followed by chlorination/dechlorination. The treated water is either discharged into the Santa Cruz or further treated before entering Tucson's reclaimed wastewater system.

Site Description, Substrate, and Geomorphological Data

The Santa Cruz River below RRWWTP (designated as "Pima County, Santa Cruz" or "PCSC" in this report) can be described as a highly disturbed aquatic system. There is a floodwall approximately 8-10m high constructed of soil-crete along the eastern edge from PCSC1 to PCSC2 (Figure 1d). Material immediately outside the stream is extremely fine sand, silt, and clay. Floodprone width was the largest of any EDW studied and was often difficult to determine because the soil-crete floodwall along the eastern edge meant that only one side could be used for this determination. The channel along the western side of the Santa Cruz was long and sloping contributing to the relatively large flood prone width.

Further downstream from PCSC2, treated effluent from the Ina Road WWTP mixes with the treated effluent from Roger Road WWTP in the Santa Cruz River. We did not sample below this confluence because this would have confounded the results and, for this study, we only wanted to examine the effects of Roger Road WWTP. The confluence with Ina Road WWTP determined where the site PCSC2 would be located; PCSC2 is just above this confluence. The sites PCSC1 and PCSC2 resided at N32.38848, W111.0325 and N32.32830, W111.0325 longitude and latitude respectively.

Riparian vegetation consisted primarily of salt cedar (*Tamarix petandra*) interspersed with mesquite (*Prosopis spp.*), ash (*Fraxinus velutina*), and seep willow (*Baccharis glutinosa*). Older, senescent riparian vegetation could be found outside of the active channel consisting primarily of highly water-stressed cottonwoods.

Human activity around this reach of the Santa Cruz is very high. Homeless persons and associated "camps" were observed during each sampling event. It is some distance to the nearest source of freshwater and it's possible that homeless persons may be ingesting treated effluent from the stream. This scenario is even more likely during the hot summer months.

There are several no trespassing signs between Silverbell Road to the west and the Santa Cruz River. We witnessed "wildcat" dumping of waste material such as motor oil, anti freeze, and industrial solvents between Silverbell Road and the river (Figure 2d).

The substrate was dominated by relatively fine material. Flow was higher during the winter so the sand, silt, and clay fraction was less than during the summer (Figure 8d). Overall, gravel of various size classes dominated the substrate. Point and sand bars were often observed within the stream. Interestingly, percent embeddedness was relatively low and was much lower than at Jack's Canyon (Figures 6d and 7d). One major difference in substrate type and embeddedness between this site on the Santa Cruz and Jack's Canyon is the type of material underlying the surficial substrate. At Jack's Canyon, the surficial gravel substrate was underlain mostly by bedrock, meaning that material was constantly being flushed through the gravel. In contrast, the surficial substrate below RRWWTP is underlain by presumably more fine material i.e., sand and gravel. In lieu of a major flushing event, the hyporheos of the Santa Cruz below RRWWTP probably exhibits minimal flushing and interstitial spaces may become "clogged".

Geomorphological Data from Pima County Santa Cruz

Channel length: 5150 m

Bankfull width: 16.2 m

Floodprone width: 120.4 m

Slope: 0.004

Figure 1d. ***View of the Santa Cruz River near PCSC1 looking north.***

Figure 2d. ***Wildcat dumping near the Santa Cruz River below RRWTP.***

Figure 3d. ***Flow at Pima County Santa Cruz by site and date***

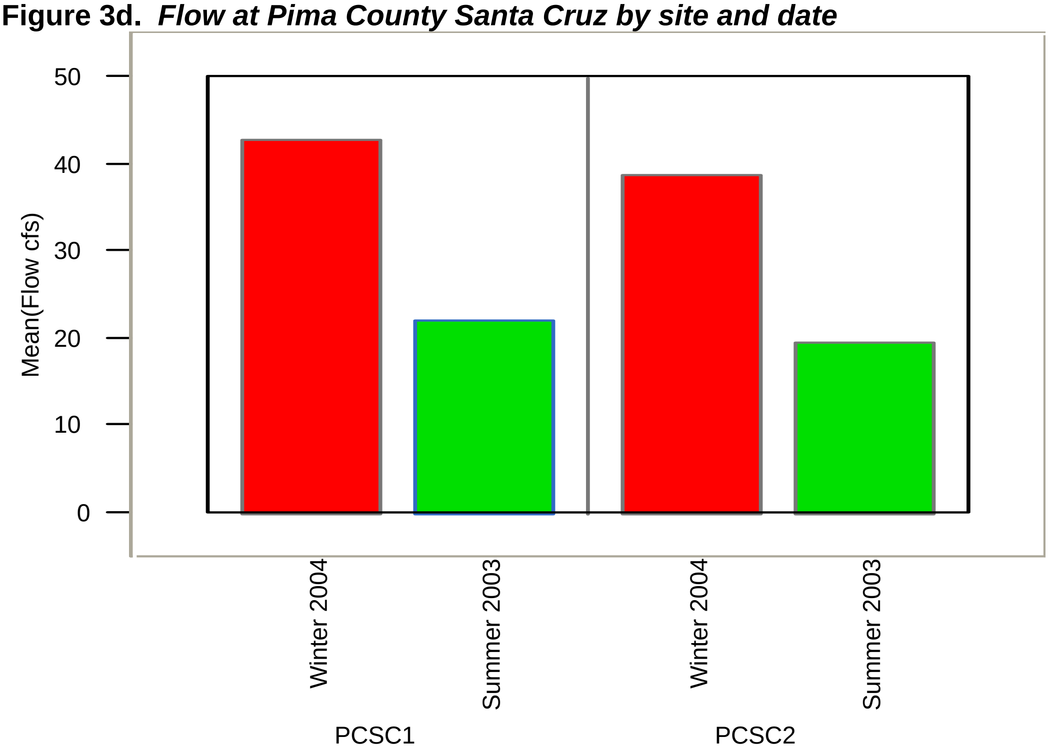
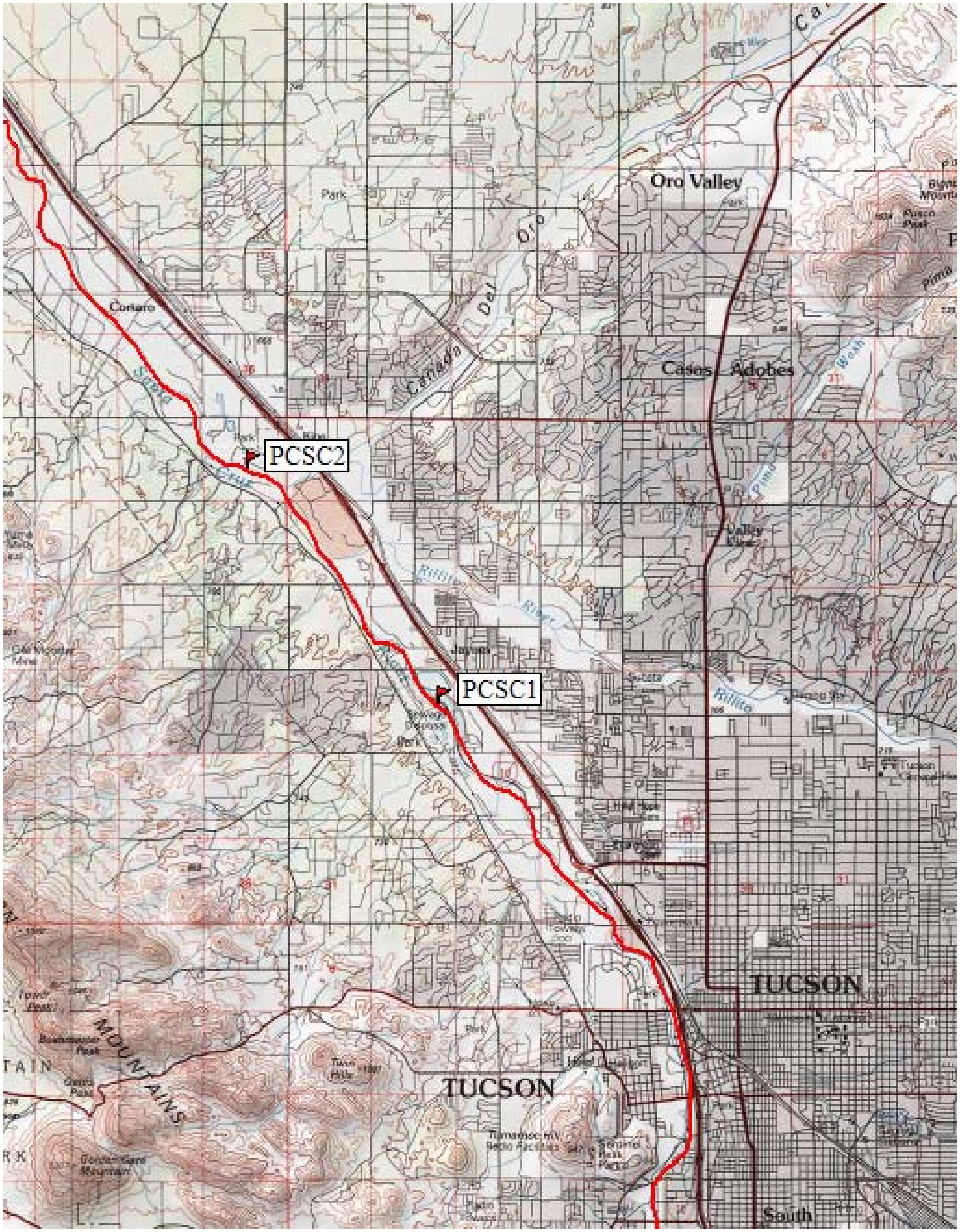


Figure 4d. Santa Cruz watershed, Pima County



Picture 5d. ***Sampling sites PCSC1 and PCSC2***

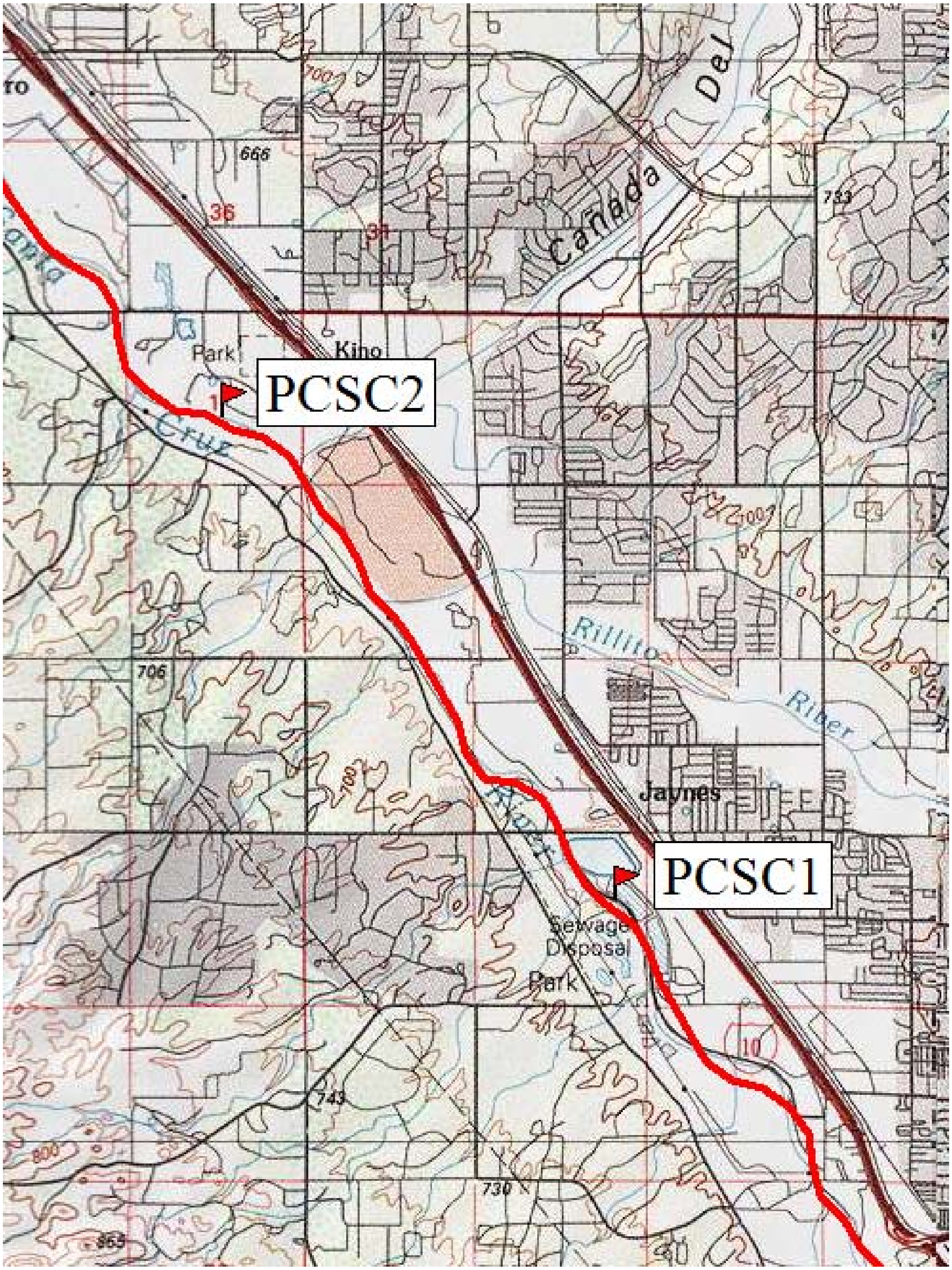
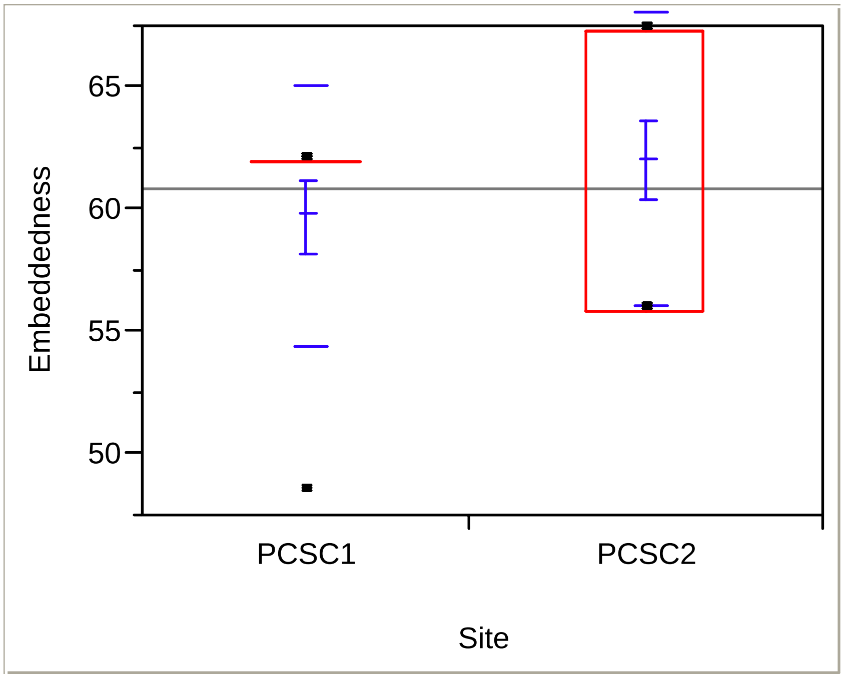


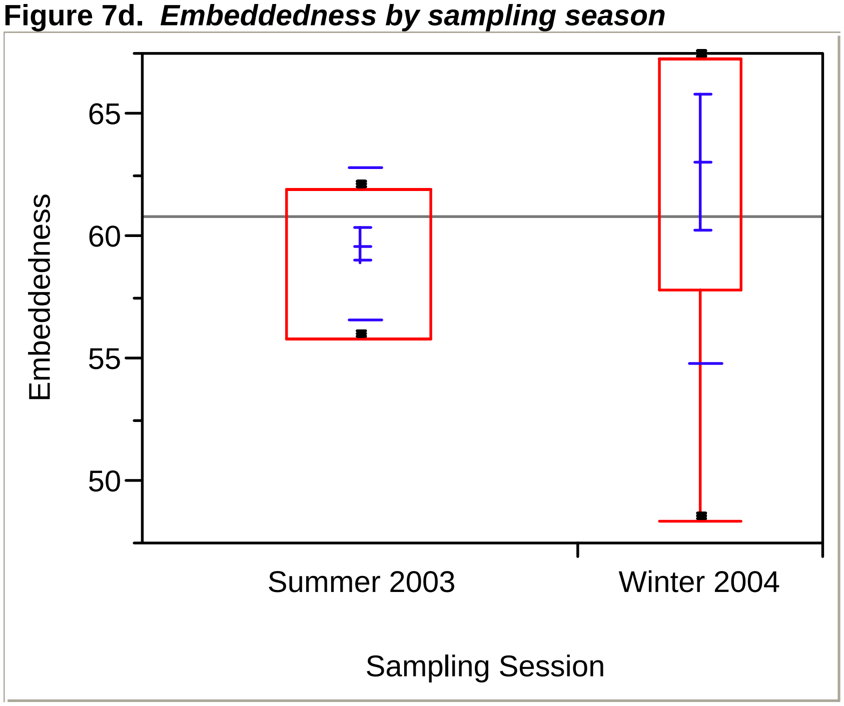
Figure 6d. ***Embeddedness by site***



Means

PCSC1	59.7500
PCSC2	62.0385

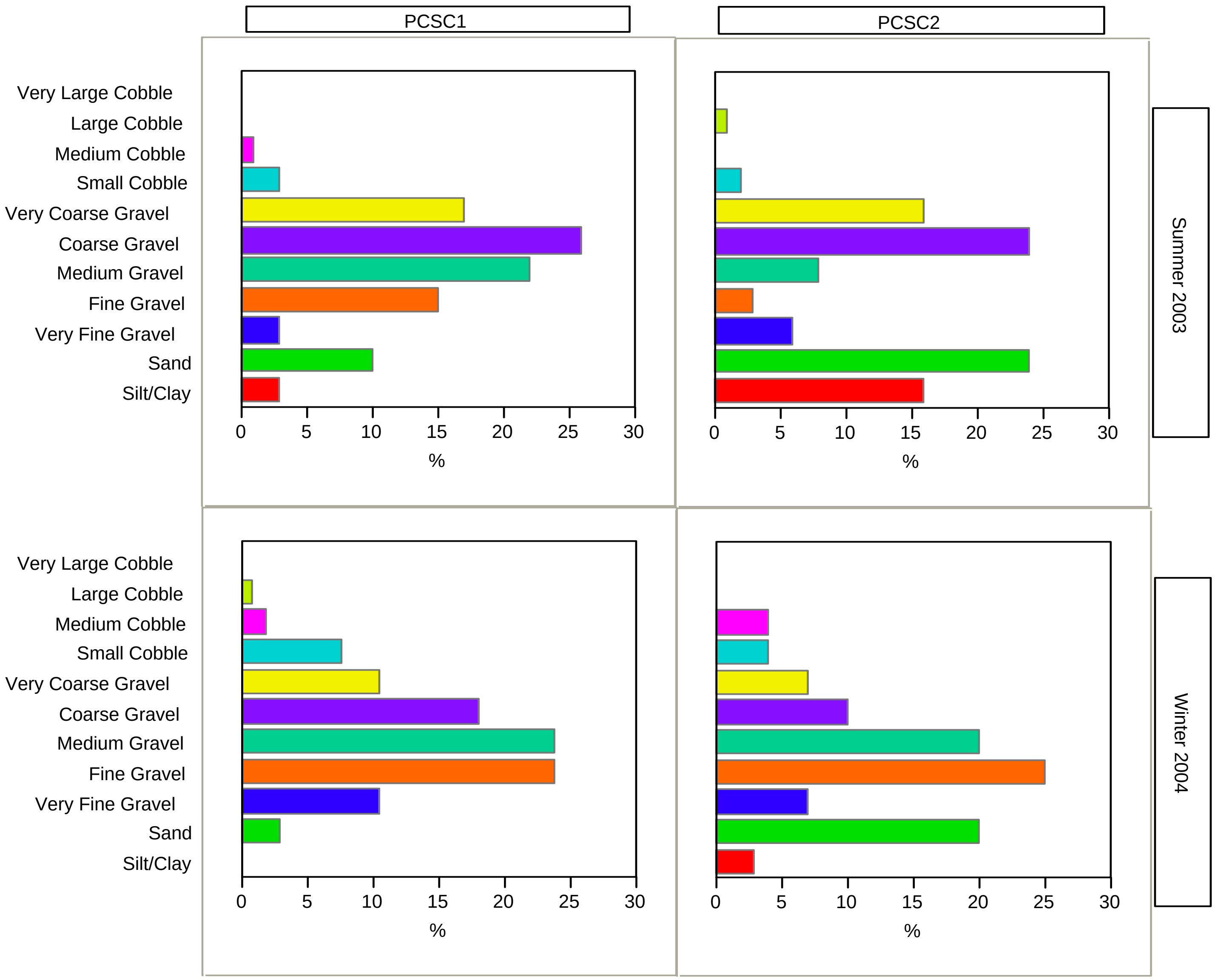
Figure 7d. ***Embeddedness by sampling season***



Means

Summer 2003	59.7125
Winter 2004	63.1222

Figure 8d. ***Substrate particle size by site and date at Pima County Santa Cruz***



Physico-chemical Data

Linear profiles of physico-chemical data were taken for both sampling dates starting at PCSC1 and taken at roughly equidistant locations to PCSC2. (See Appendix A for data.)

Figure 9d. ***PCSC linear profile, 02/28/04***

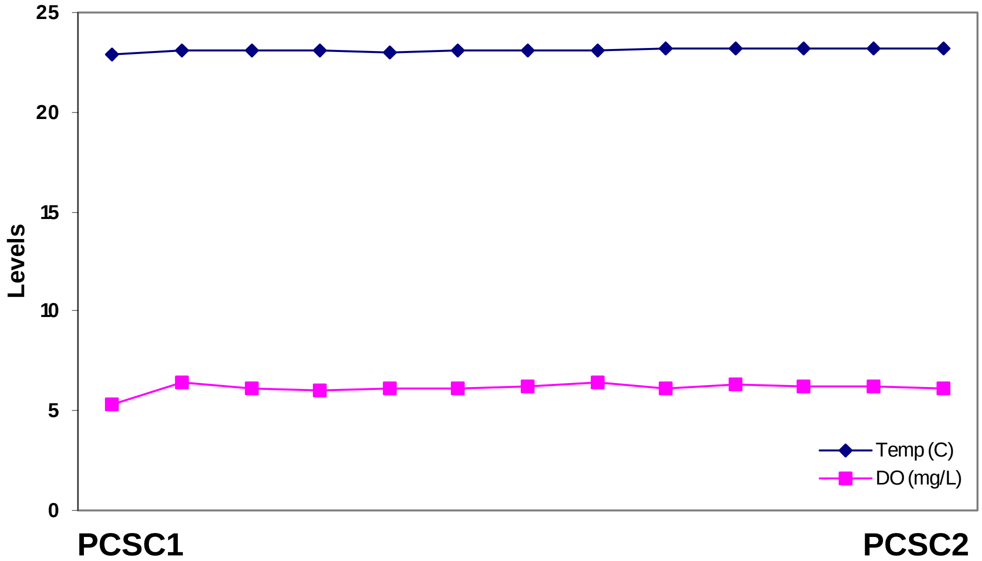
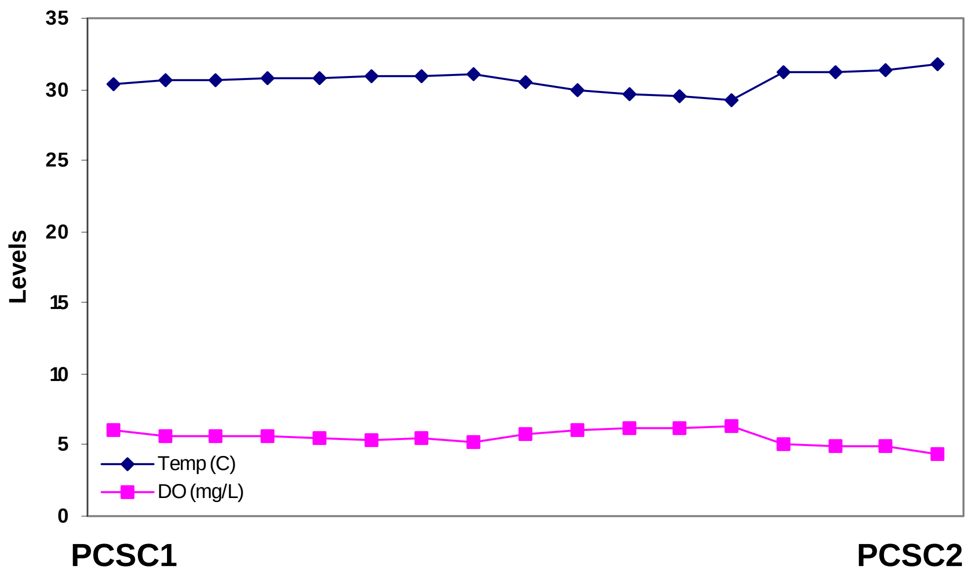


Figure 10d. ***PCSC Linear Profile, 06/25/03***



In addition to the linear profiles, physico-chemical readings were taken every 30 minutes over a 24-hour period (Diel profiles) during both samplings at PCSC2. (See Appendix B for data.)

Figure 11d. ***Diel pattern at PCSC2 on 02/28/04***

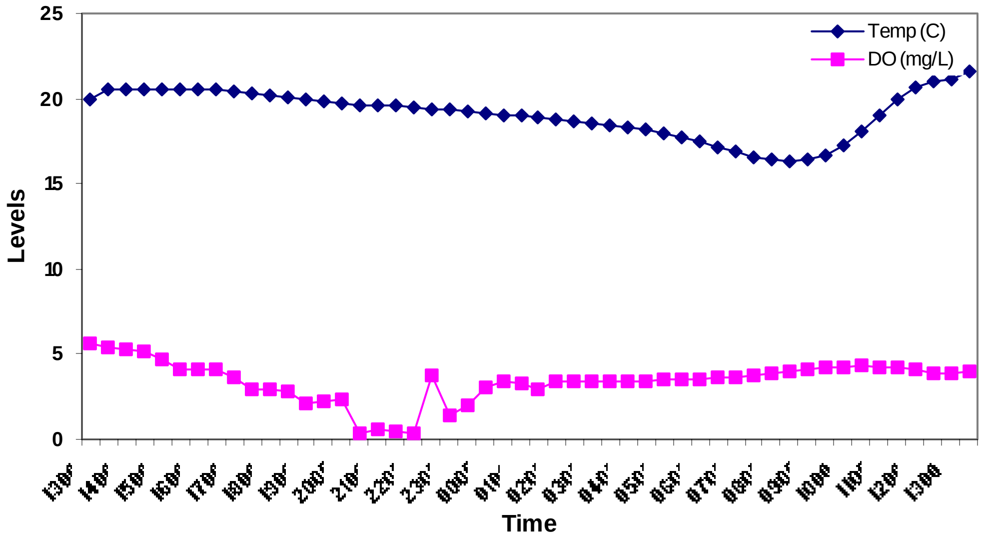


Figure 12d. ***Diel pattern at PCSC2 on 06/25/03***

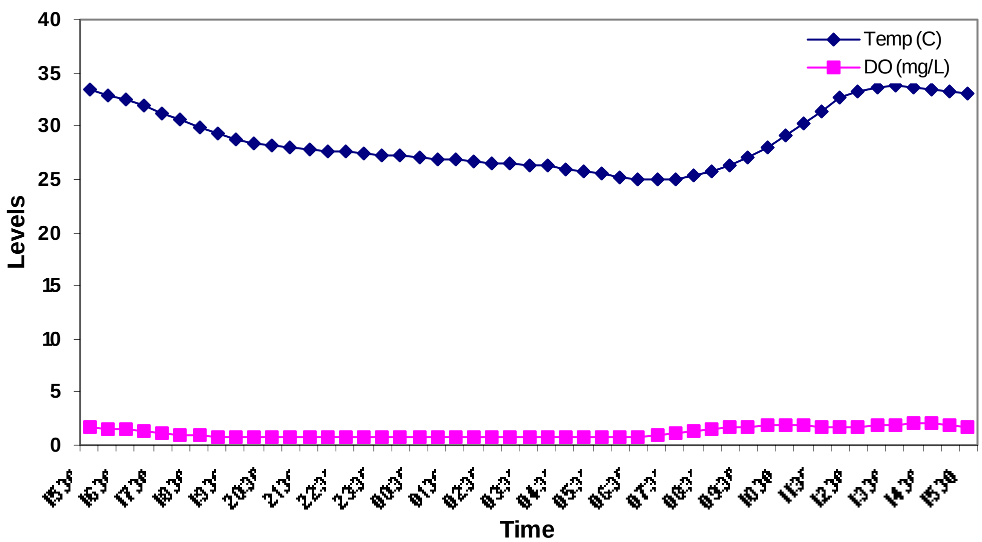
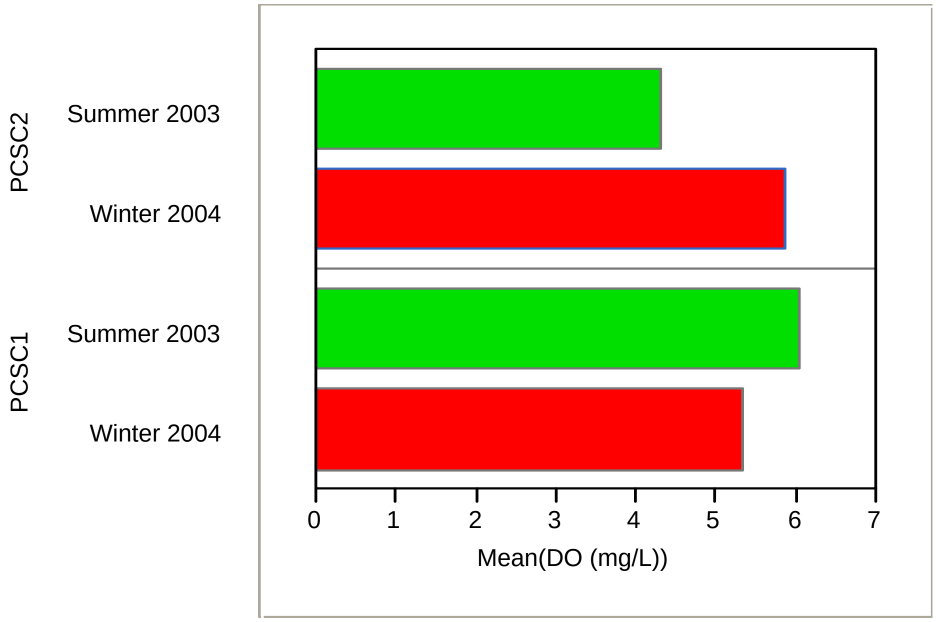


Figure 13d. ***Dissolved oxygen levels by site and sampling session.***



Dissolved oxygen levels were relatively low along the entire channel length, especially so during the summer sampling when they decreased slightly with distance from the outfall. The higher levels near the outfall may be due to the turbulent conditions in this area, but oxygen-consuming substances retained within the effluent may be the cause of the net loss of dissolved oxygen with distance, especially when temperatures are elevated during the summer. Higher trophic levels of aquatic organisms were observed at all other EDW's besides the Santa Cruz below RRWTP. Their absence is significant considering the close proximity of an urban fishery (Silverbell Lake); it is highly unlikely that fish are not entering the Santa Cruz through either emigration or human transport.

Diel profiles taken from PCSC2 show that dissolved oxygen levels are extremely low for a substantial period of time over a 24-hour period. The summer sampling revealed that DO levels were not adequate to support aquatic life for long periods of time. During the summer sampling, dissolved oxygen levels were highest while taking the linear profile but dropped precipitously thereafter so that, even at the beginning of the diel profile, DO levels hovered between 1 and 2 mg/L and dropped to near zero throughout the night. The drastic temporal variability in DO levels, from approximately 4-5 mg/L at the end of the linear profile to between 1 and 2 mg/L at the beginning of the diel profile is likely due to changing water quality from the outfall as all instrumentation was calibrated before and after taking the linear profile and also before and after taking diel profiles.

Temperature obviously has an effect on dissolved oxygen levels. The water was extremely warm during the summer (> 33°C during the day) and this undoubtedly exacerbated the loss of dissolved oxygen from the water. The winter diel DO profile, while much higher than the summer, still exhibited downward spikes in DO at night. The large, rapid depressions in DO levels during the summer makes it unlikely that this area could become colonized by any but the most pollution tolerant organisms, i.e. those that have some physiological adaptation to extremely low DO levels.

Nutrients

Levels of reduced and organic nitrogen (as measured by ammonia-N and total kjeldahl nitrogen respectively) as well as organic carbon were the highest of any EDW sampled during this study. Ammonia and TKN levels decreased with distance from the outfall, but they were still higher at PCSC2 than at the outfall of other sites. Levels of un-ionized ammonia found during the summer at the Santa Cruz below RRWWTP were likely toxic for most aquatic life, but especially so for aquatic macroinvertebrates due to elevated temperatures. Levels of un-ionized ammonia at PCSC during the summer were over twice as high as those found at Bitter Creek and over 11 times higher than the highest level found at Jack's Canyon. This may have had negative consequences not only on diversity of aquatic macroinvertebrates, but their ability to survive in the first place. Additionally, the high organic carbon load found during both seasons may have exacerbated the consumption of dissolved oxygen.

The N:P ratio is misleading in that, the ratio itself shows phosphorous may be limiting year-round. This probably is not the case as nutrient levels in this EDW were probably high enough that no nutrient ever becomes limiting in the traditional sense. Instead, the high ratios are likely an artifact of having such high levels of nitrogen.

Figure 14d. ***Nutrient levels at Pima County Santa Cruz by site and sampling season (all units in mg/L).***

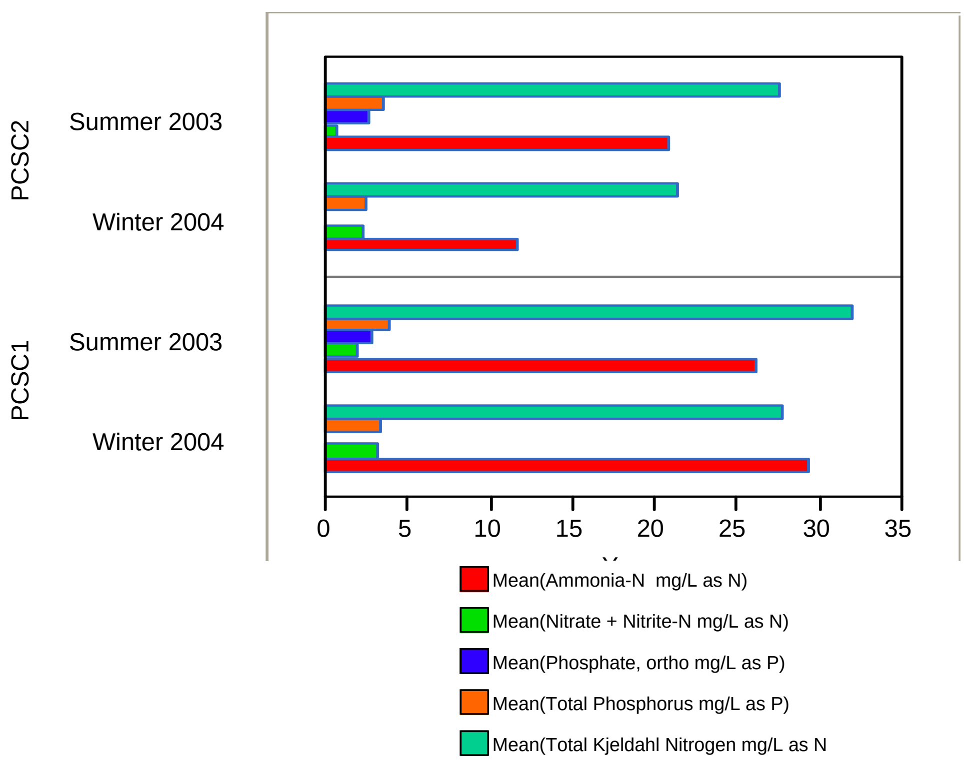


Figure 15d. ***N:P ratio by sampling session and site*** *(total N calculated as the sum of ammonia, nitrate, nitrite, and TKN)*

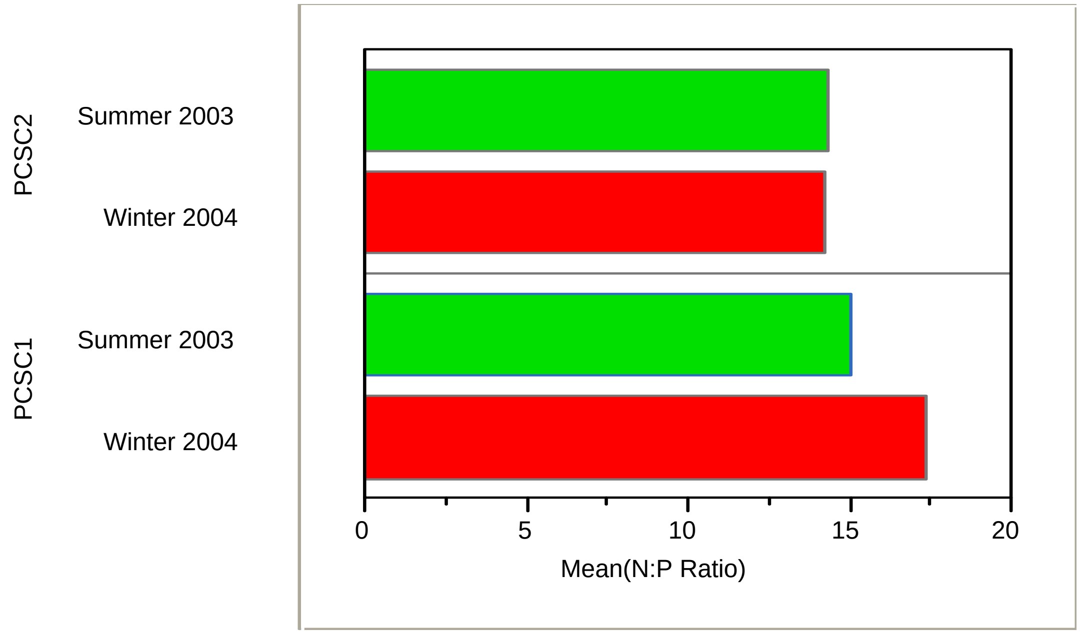


Figure 16d. ***TOC and DOC levels (in mg/L) by site and sampling season***

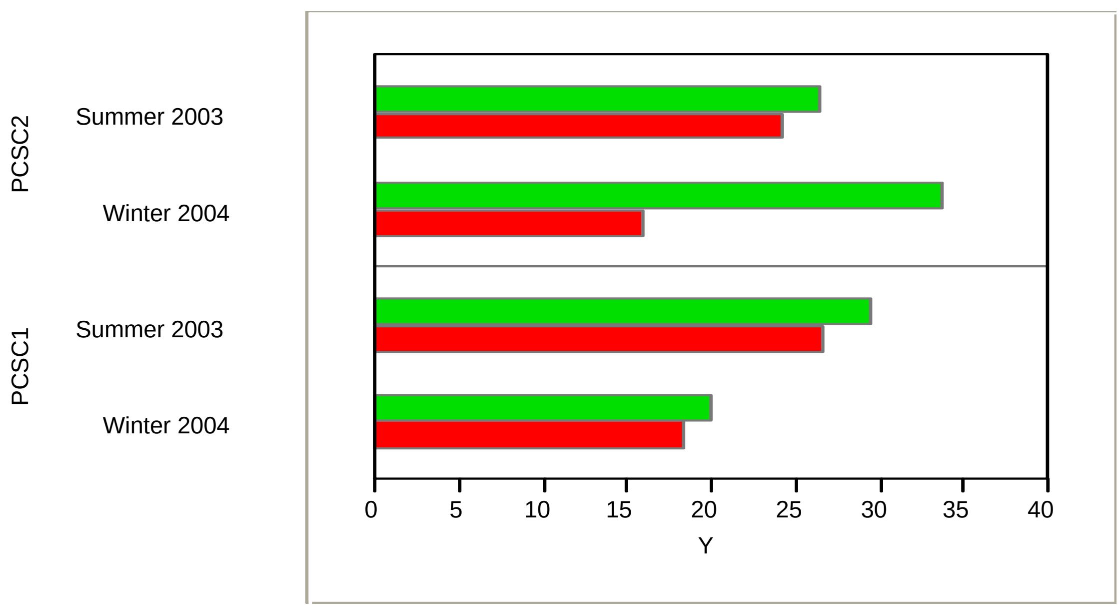
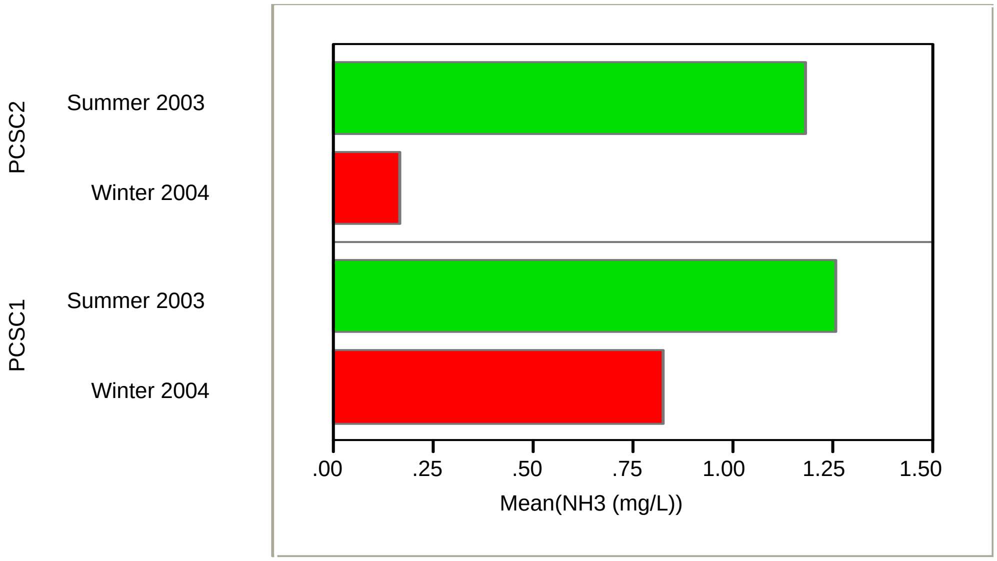


Figure 17d. ***Un-ionized ammonia (calculated) at Pima County, Santa Cruz by site and date***



Biological Data

Algae

Given the large amount of available nutrients, periphytic biomass was lower than expected. This is probably due to the lack of suitable substrate at PCSC. Strands of filamentous algae were observed wherever substrate was available, such as submerged vegetation or artificial substrate like tires or shopping carts. However, there was not enough filamentous algae to be considered a viable alternative substrate for macroinvertebrates. Even if there had been, it's unlikely it would have increased diversity of macroinvertebrates because of other limiting factors for their survival. The diel profiles taken during the summer showed that dissolved oxygen from photosynthesis was not high enough to be a factor in supplying dissolved oxygen into the water. At night, respiration combined with a relatively large oxygen demand, quickly depleted the water of dissolved oxygen.

Figure 18d. ***Phytoplankton chlorophyll a by site and sampling period.***

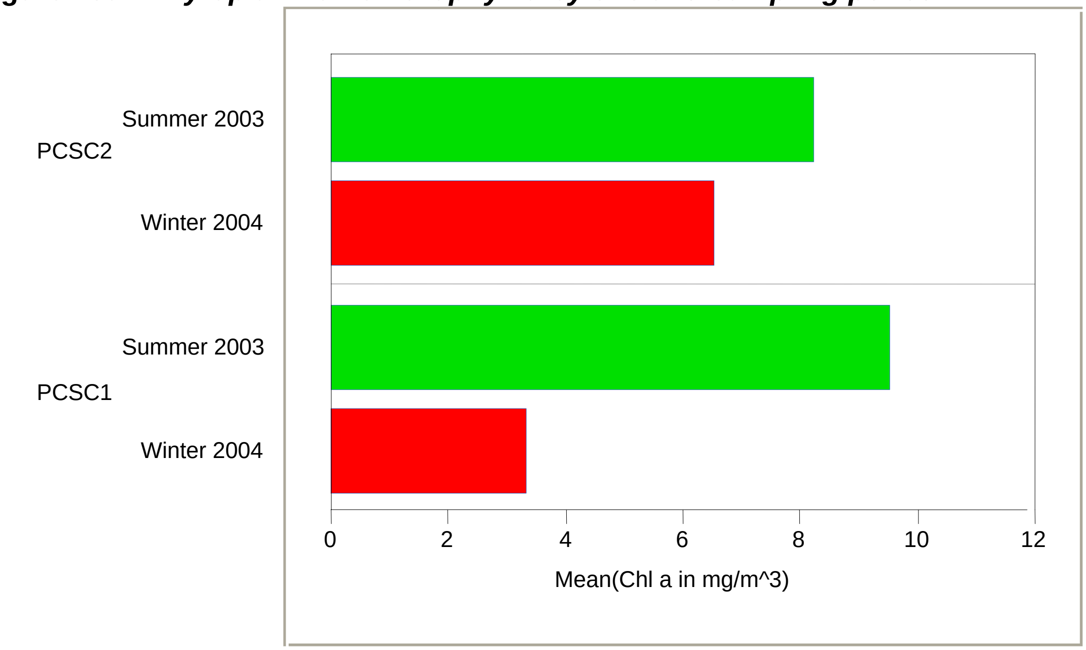


Figure 19d. ***Periphyton chlorophyll a by site and sampling period.***

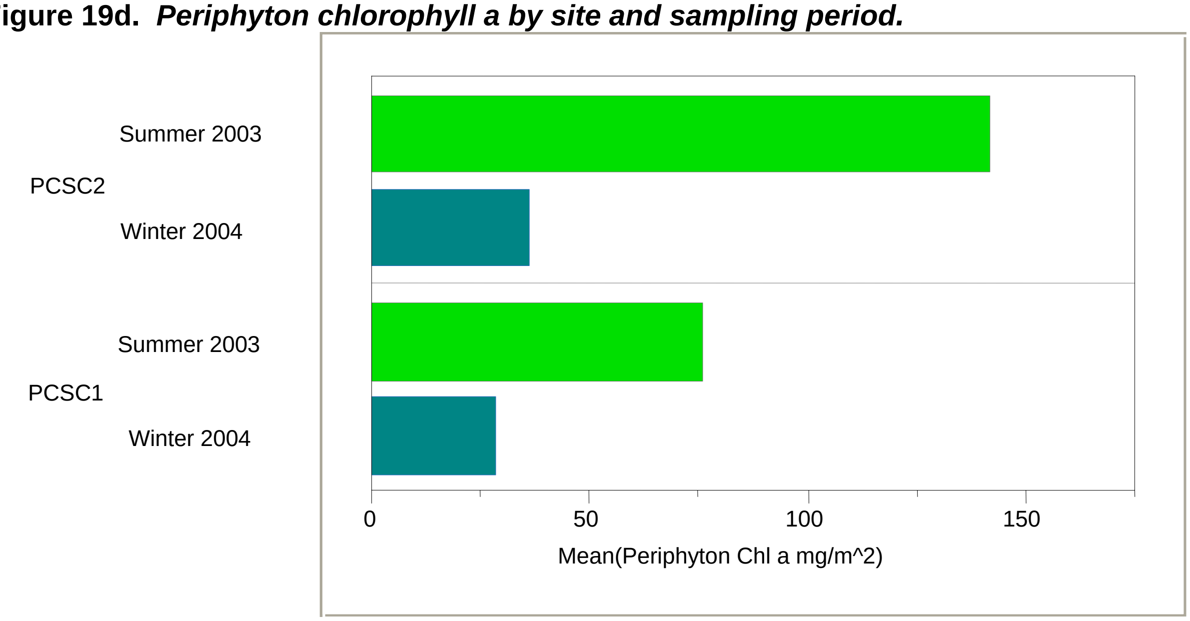


Figure 20d. ***Mean periphyton counts by division, site and date***

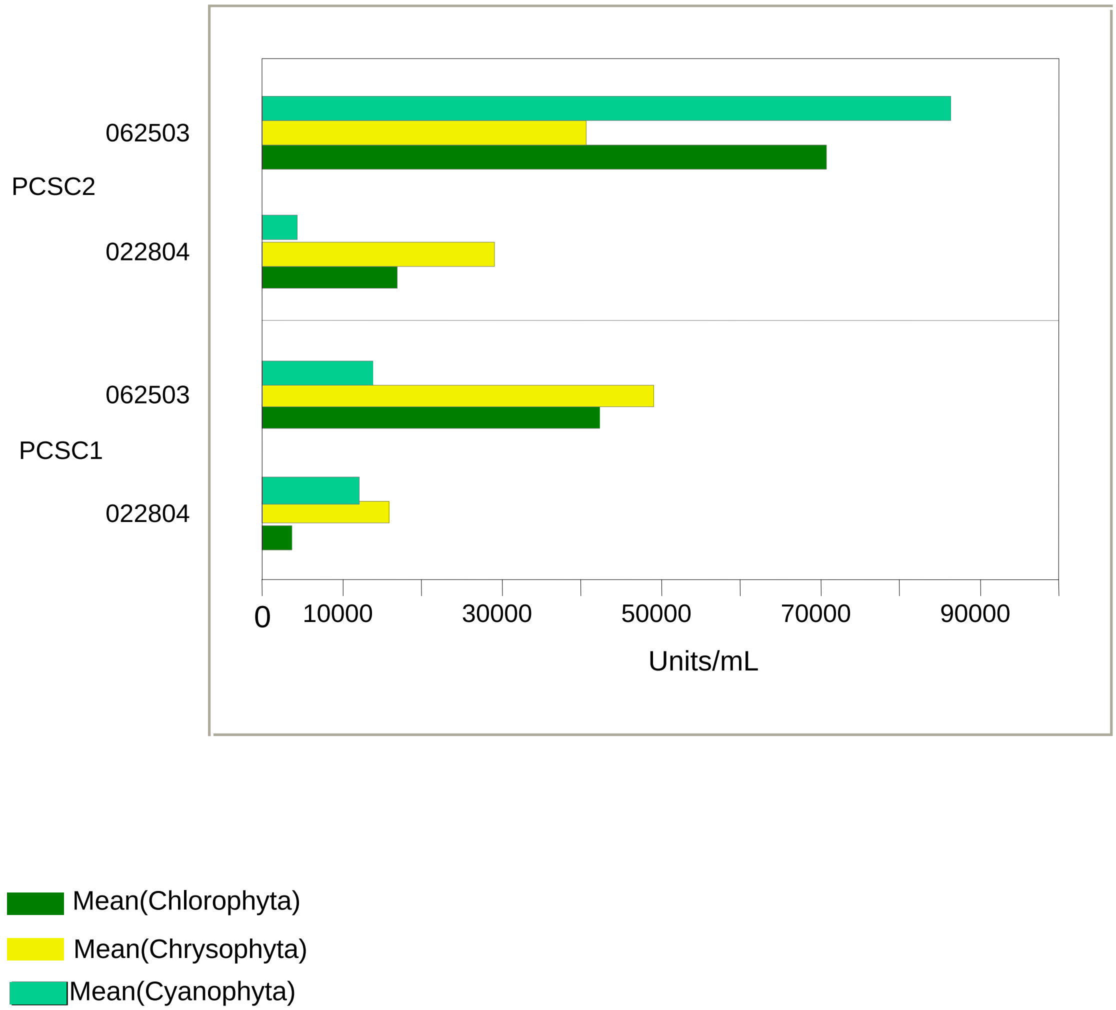


Figure 21d. ***Mean periphyton counts by genus at PCSC1 for the winter sampling, 2004.***

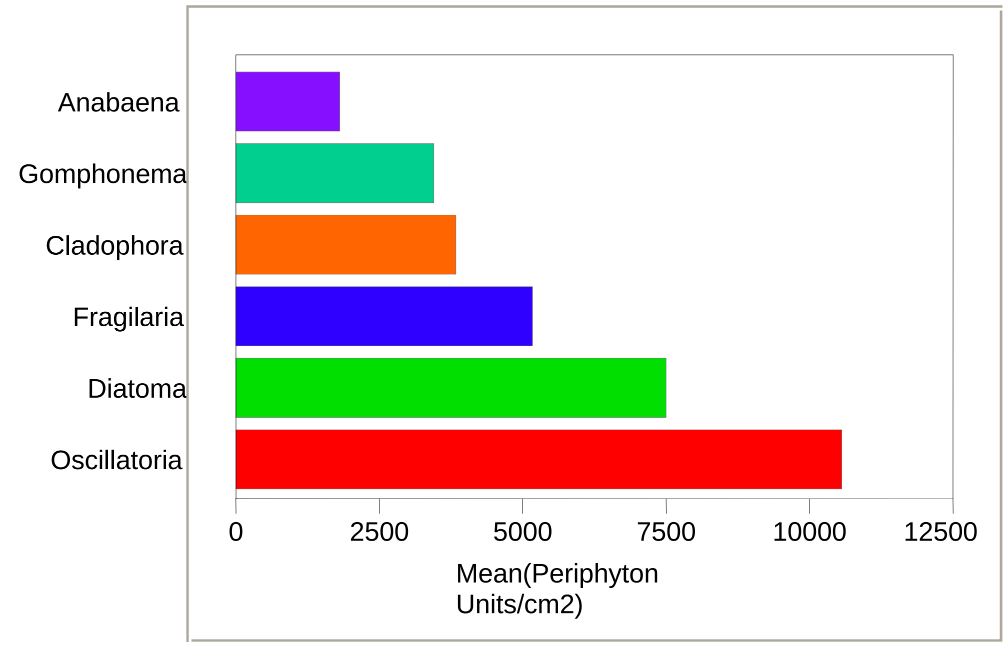


Figure 22d. ***Mean periphyton counts by genus at PCSC1 for the summer sampling, 2003.***

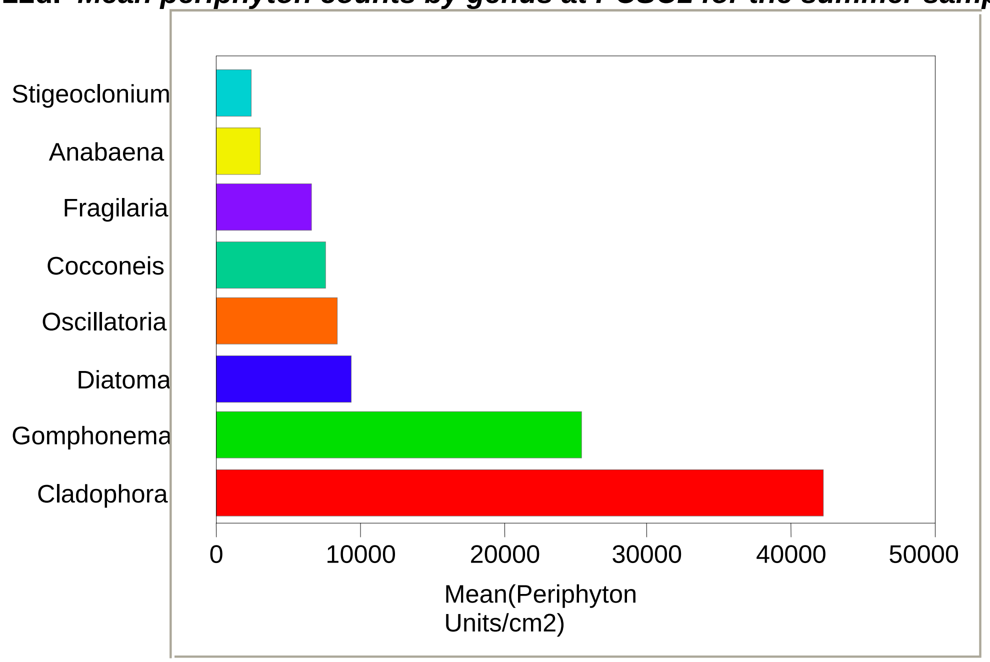


Figure 23d. ***Mean periphyton counts by genus at PCSC2 for the winter sampling, 2004.***

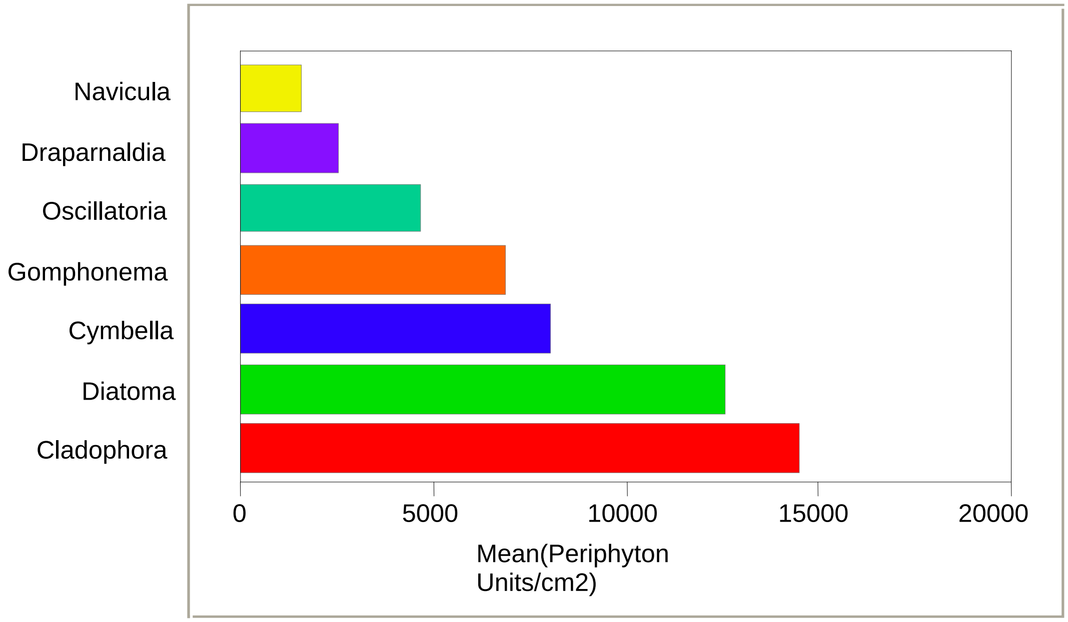
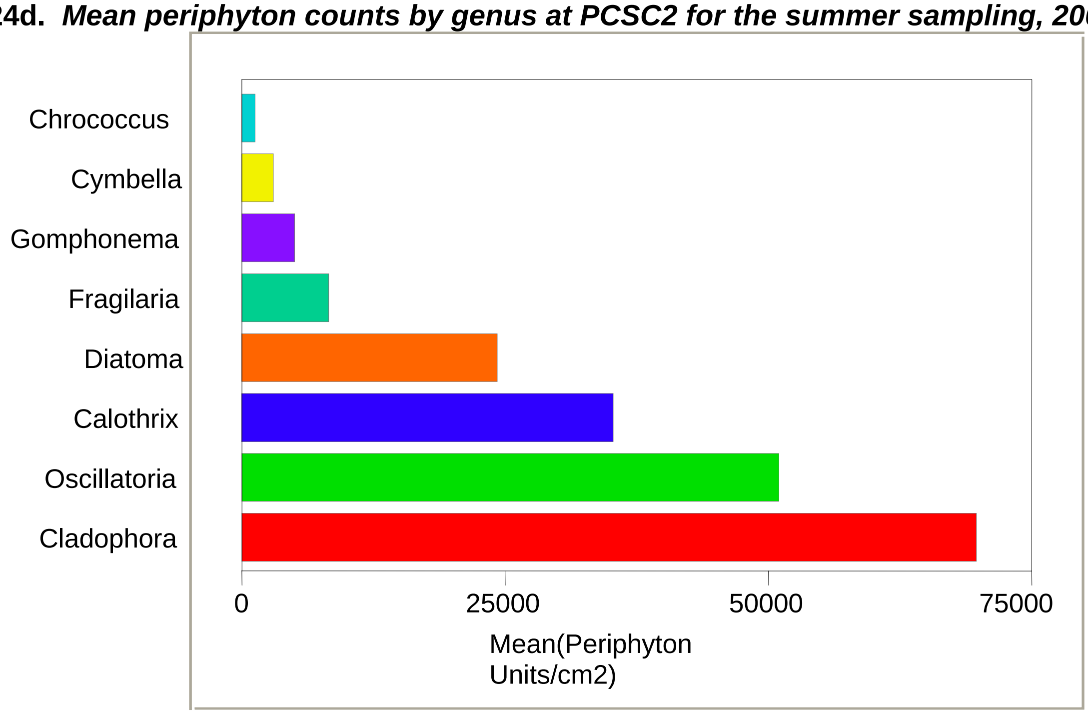


Figure 24d. ***Mean periphyton counts by genus at PCSC2 for the summer sampling, 2003.***



Aquatic Macroinvertebrates

Diversity of macroinvertebrates within the Pima County, Santa Cruz sampling site was the lowest of any EDW measured during this study. The entire invertebrate assemblage consisted of oligochaetes, hemipterans, and chironomid, tipulid, and psychodid flies, making the diversity of aquatic macroinvertebrates low. The highest diversity value was at PCSC2 during the winter. This comparatively high value is largely based on the presence of two taxa that were not found at any other time or site and the low total number of invertebrates taken from the stream. However, both of these taxa consisted of only a single individual capable of flying relatively long distances and were not likely typical residents of this stream.

The dominant macroinvertebrates at both sites, the chironomids and the oligochaetes, have high pollution tolerance values. Both are also well adapted to low oxygen conditions such as those observed at PCSC. Chironomids are among the few insects containing and using hemoglobin as a respiratory pigment and are especially well adapted to low oxygen environments because of it. Considering the relatively low levels of dissolved oxygen over a 24 hr period, it is not surprising that the dominant organisms are well adapted to oxygen-deprived conditions. Only the most pollution tolerant species seem capable of surviving in this EDW.

Figure 25d. ***Mean aquatic macroinvertebrate numbers by site and date***

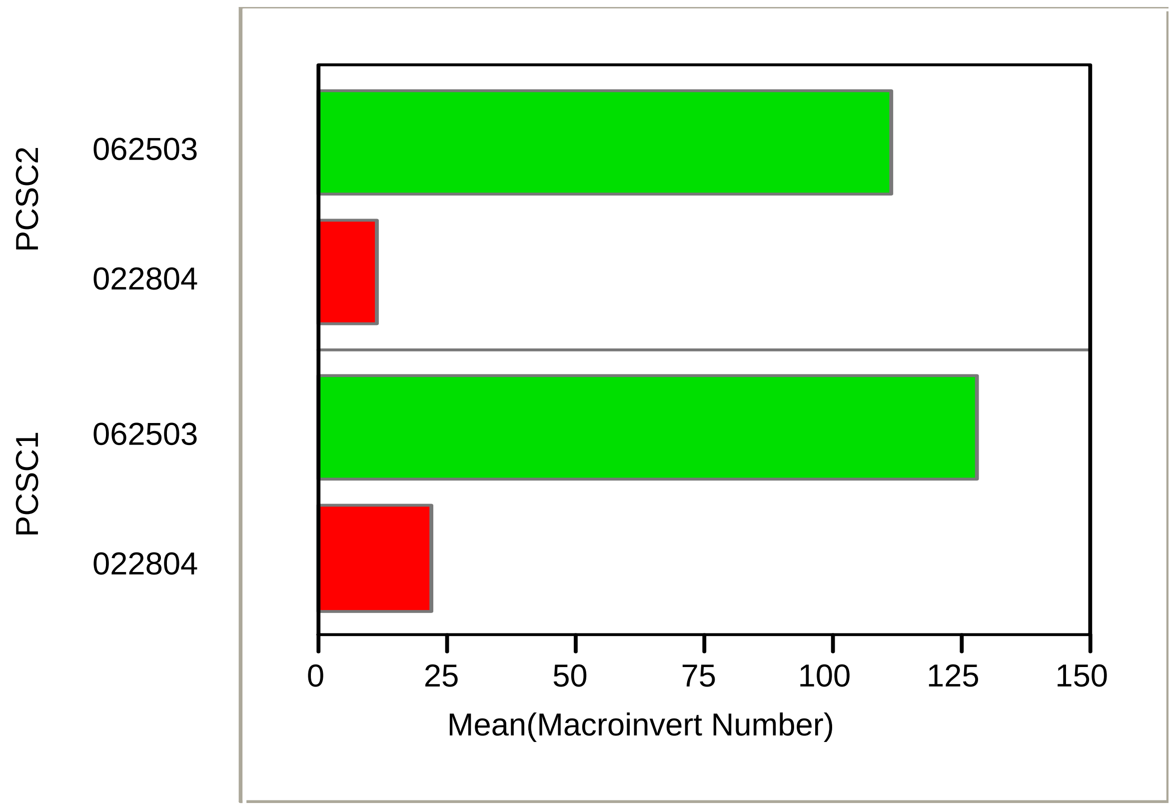


Figure 26d. ***Macroinvertebrate order by date.***

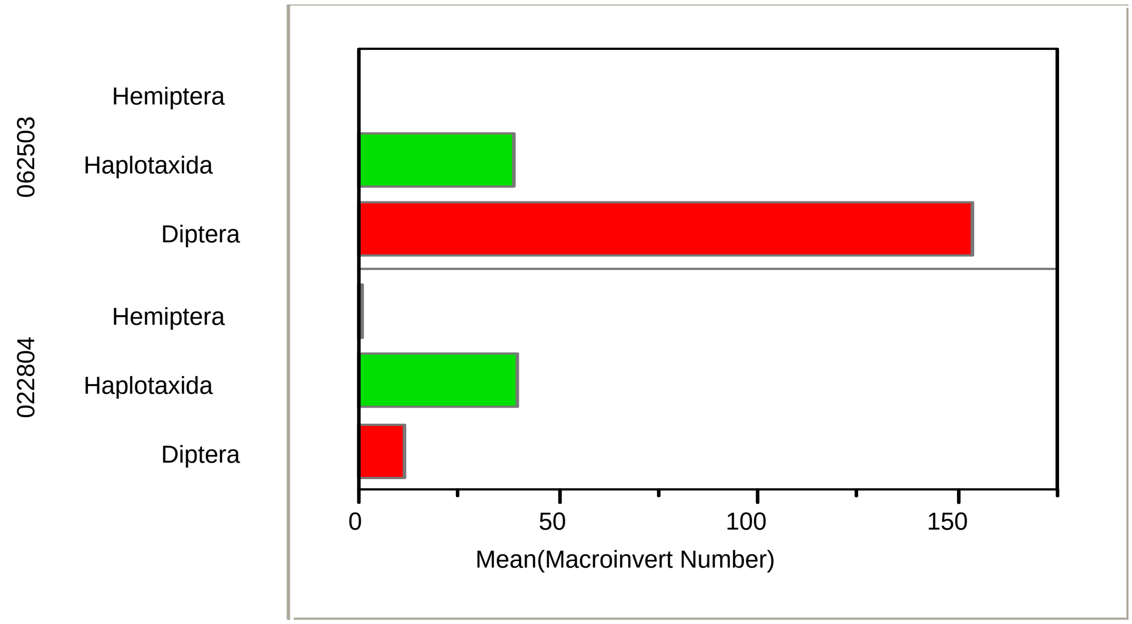
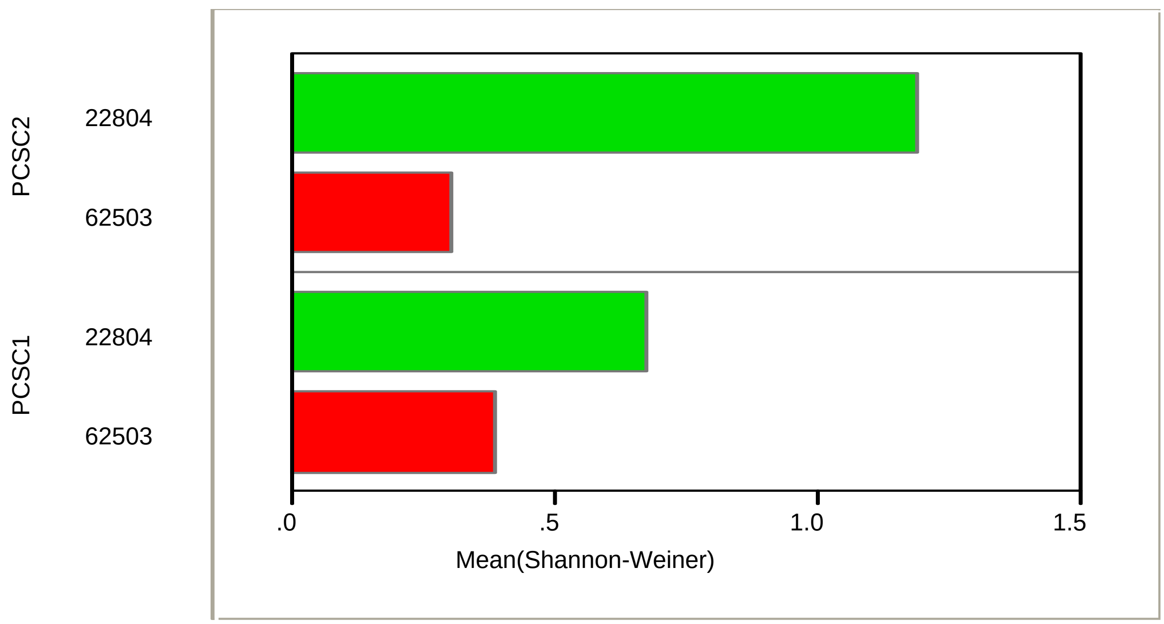


Figure 27d. ***Shannon-Weiner diversity index by site and date***



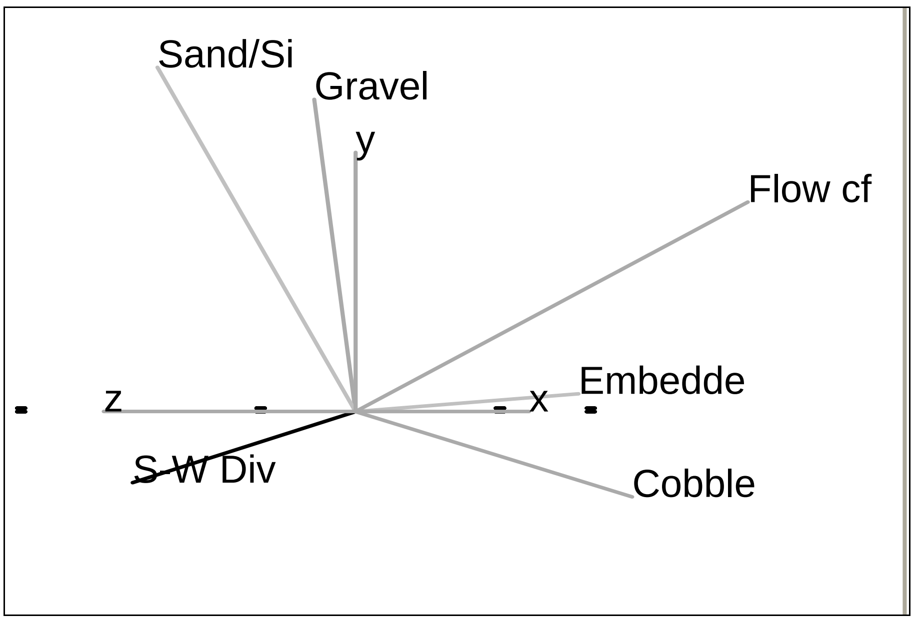
Correlations

S-W Diversity Index and Physical Attributes

Diversity was negatively correlated with percent embeddedness, but the other correlations were ambiguous. This is likely due to low diversity values and the relatively homogenous substrate. Usually, increases in substrate complexity results in increases in diversity.

Diversity was also negatively correlated with flow. This is likely because there is little stable substrate in the streambed. If one of the few taxa present in the stream is ineffective at remaining in place during higher flows, a decrease in diversity will result.

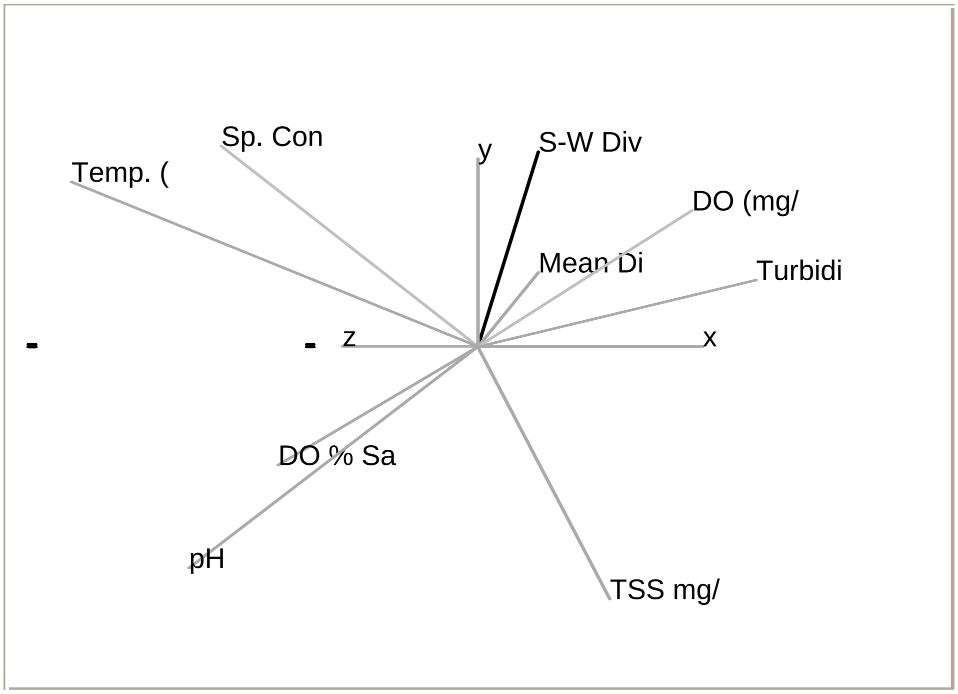
Diversity was not positively correlated with any of the physical attributes included in this analysis.



Eigenvectors						
S-W Diversity	0.44568	0.42652	0.05915	-0.12915	-0.16484	0.75637
Cobble	0.54000	0.04097	-0.31390	-0.15744	0.74182	-0.18195
Gravel	0.27157	-0.56590	0.37290	0.59863	0.18525	0.27252
Sand/Silt/Clay	-0.36581	0.50431	-0.26885	0.65953	0.29638	0.12940
Embeddedness	0.12378	0.47554	0.77799	0.03572	0.13029	-0.36745
Flow cfs	0.53562	0.12525	-0.28524	0.40486	-0.53235	-0.41081

S-W Diversity Index and Physico-chemical Attributes

As expected, diversity was positively correlated with DO and mean diel DO levels. Thus, the DO levels in the stream help explain why the diversity is so low. The diel DO levels at PCSC were the lowest of any of the streams measured during the summer sampling. Diversity in the stream was highest when the average DO over a 24-hour period remained relatively high.

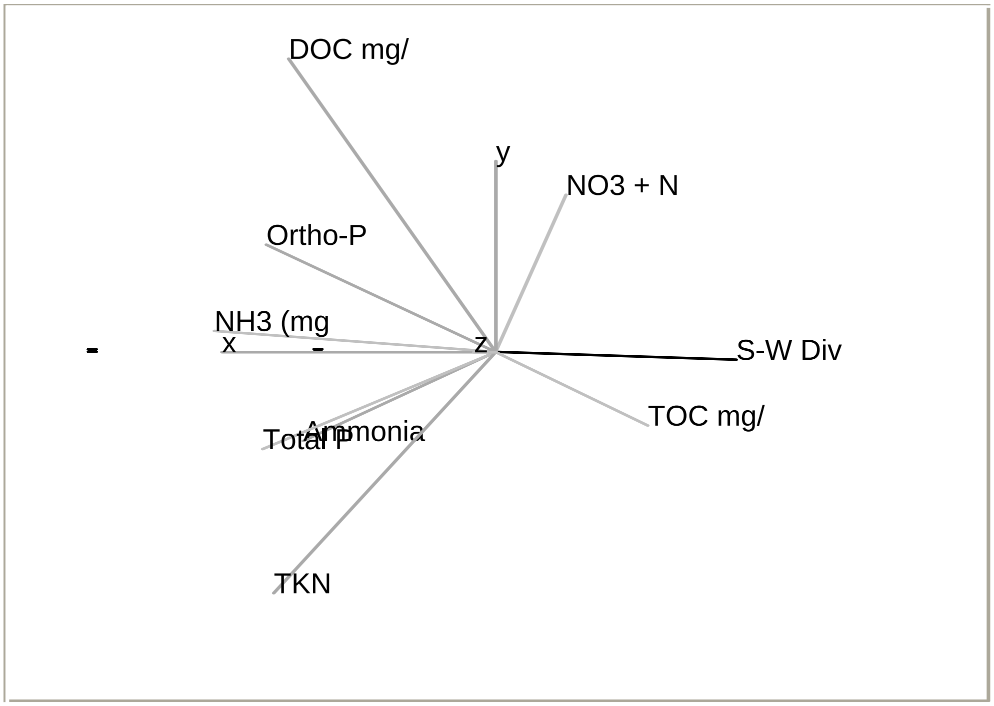


Eigenvectors									
S-W Diversity	0.39062	-0.01730	0.08458	-0.01233	0.38604	-0.40809	0.00074	-0.54535	0.47627
Mean Diel DO	0.34291	-0.25473	0.38852	0.06791	0.14693	0.30300	-0.30317	0.54188	0.40376
TSS mg/L	0.38374	0.07376	-0.19519	0.20970	-0.49193	0.51944	0.33376	-0.26471	0.26824
Turbidity_NTU	0.38289	0.08075	-0.20261	0.23518	0.13377	-0.37987	0.56596	0.50111	-0.13002
DO (mg/L)	0.17888	0.57684	0.53812	-0.20448	0.26851	0.29194	0.21941	-0.09208	-0.29989
DO % Sat.	-0.11629	0.74363	-0.06757	0.23797	-0.23083	-0.22829	-0.33487	0.18665	0.34628
pH	-0.31676	-0.14795	0.60577	-0.03649	-0.42843	-0.29724	0.41155	0.01974	0.26043
Sp. Cond.	-0.38979	-0.03829	0.09919	0.77364	0.39412	0.21201	0.14765	-0.11782	0.04779
Temp. (C)	-0.37171	0.11733	-0.30302	-0.44459	0.32439	0.23853	0.35345	0.17374	0.49126

S-W Diversity Index and Nutrient Levels

As with other sites, the diversity at PCSC was negatively correlated with ammonia, unionized ammonia, and TKN levels. Because the levels of these compounds are above observed toxic levels for many aquatic organisms, these findings suggest that many of the invertebrates that might otherwise colonize this stream are excluded due to high levels of reactive nitrogenous compounds. Of course, this assumes that other limitations to diversity, such as extremely low levels of dissolved oxygen, are also lifted.

Conversely, the diversity at PCSC was positively correlated with levels of nitrate+nitrite. This would be expected due to the requirement of dissolved oxygen for nitrification so this positive correlation is probably an artifact of the relationship between diversity and dissolved oxygen. Additionally, while high levels of nitrates and nitrites may not benefit the macroinvertebrates, they are at least not as harmful as the high levels of ammonia, unionized ammonia, and TKN.

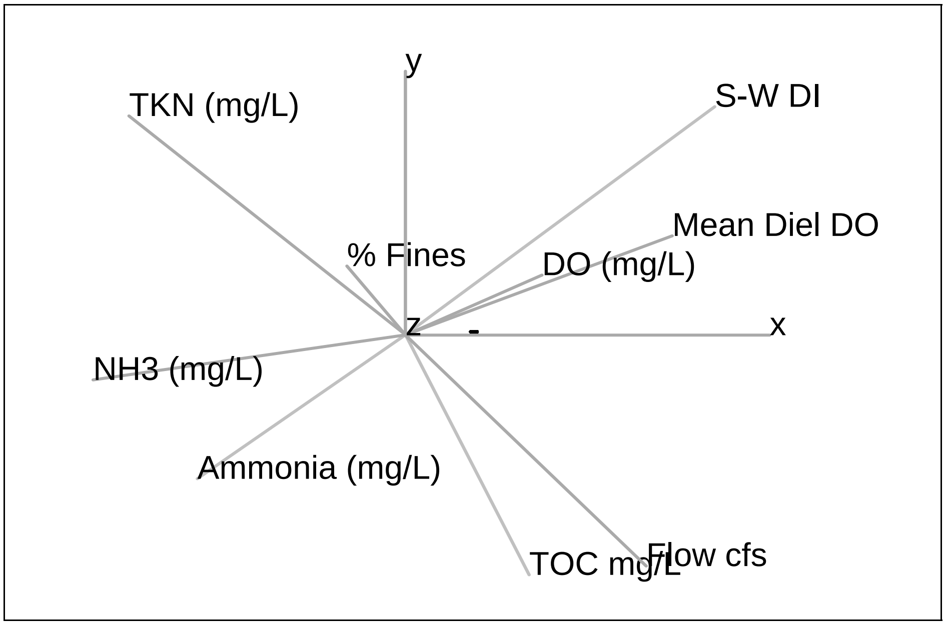


Eigenvectors									
S-W Diversity	-0.37110	0.10692	0.19795	-0.01385	0.54367	0.29334	0.65406	0.01622	-0.04223
NH3 (mg/L)	0.37664	-0.06891	-0.03674	0.04652	0.35028	-0.08395	0.03396	0.14324	0.83574
Ammonia	0.33676	0.37037	0.01944	-0.19565	0.32761	0.00809	-0.19465	0.66453	-0.35197
NO3 + NO2	-0.12014	0.72472	0.46471	0.35193	-0.13651	0.02524	-0.20101	-0.13583	0.20593
Ortho-P	0.36936	-0.17017	0.06631	0.24271	-0.04491	0.86102	-0.12857	-0.08387	-0.06618
Total P	0.37029	0.09557	0.23352	-0.21426	-0.58554	-0.01497	0.61140	0.18398	0.05072
TKN	0.36755	0.07209	0.30781	-0.53024	0.26901	-0.08636	-0.08553	-0.61647	-0.12894
DOC mg/L	0.35611	-0.23547	0.24305	0.65115	0.19259	-0.39641	0.17955	-0.07214	-0.32093
TOC mg/L	-0.23902	-0.47191	0.72827	-0.15983	-0.03788	-0.00508	-0.25071	0.30503	0.08299

Limitations to Diversity

Due to a relatively high amount of potentially limiting factors to diversity of aquatic macroinvertebrates in the Santa Cruz River below Roger Road WWTP, we decided to use those stressors believed to have the largest negative effect on diversity as found in previous analyses, in one comprehensive analysis. Trying to determine what is “most limiting” to diversity of any population is somewhat futile in as much as any one stressor can be ultimately limiting and without simultaneously addressing all stressors, there will likely be little change in population structure, diversity, or survivability. However, in this particular case, we believe ranking stressors is a worthwhile exercise due to the low amount of diversity found. We also caveat this analysis by stating that several of these stressors are inter-related and easing any one individually may also ease others.

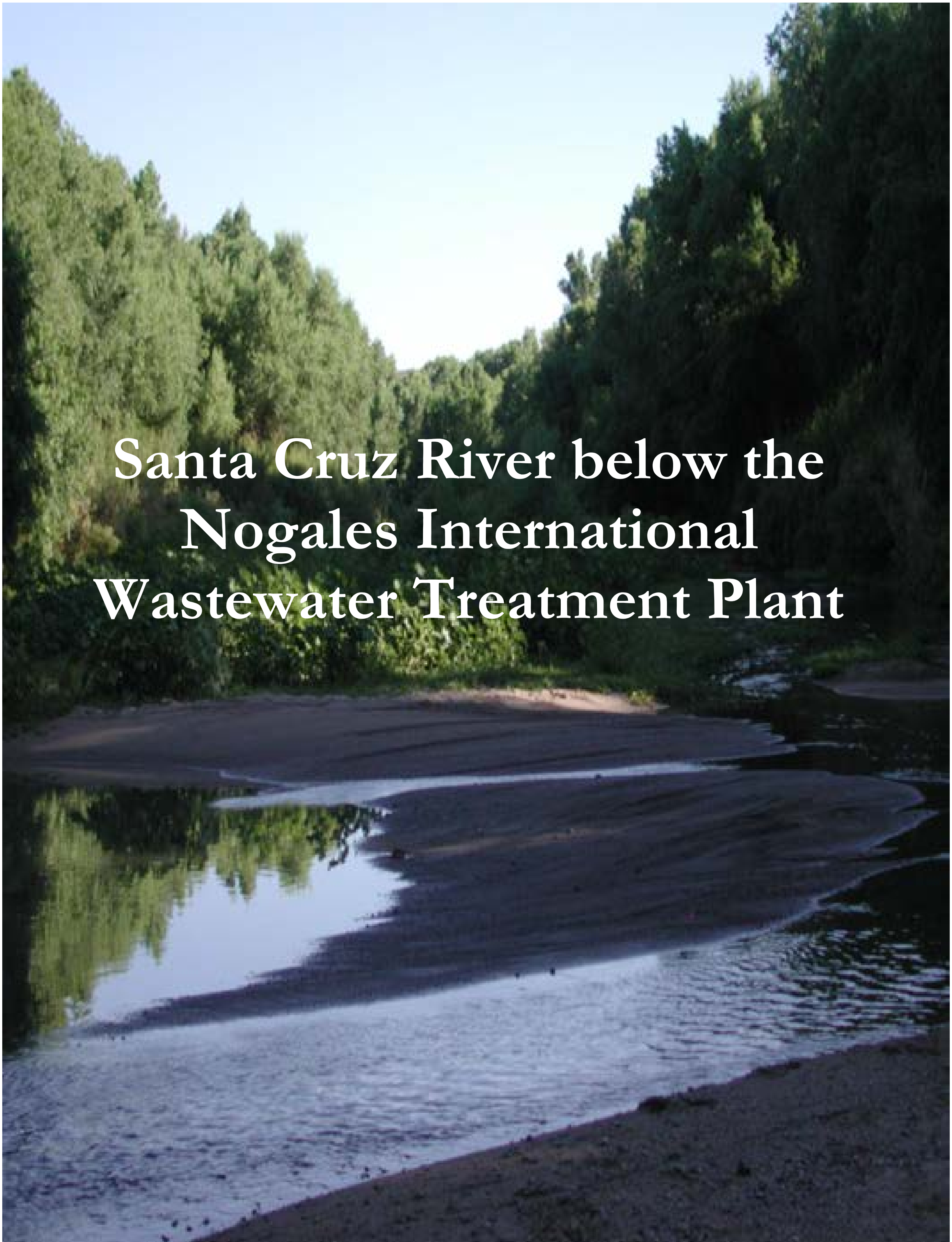
Based upon this analysis, it becomes apparent that there are at least 4 major limitations to diversity in PCSC: ammonia-N, un-ionized ammonia, dissolved oxygen, and mean diel dissolved oxygen. Dissolved oxygen and mean diel dissolved oxygen are very positively correlated with diversity while ammonia and unionized ammonia were very negatively correlated with diversity. This analysis suggests that if levels of dissolved oxygen and mean diel dissolved oxygen are increased, while ammonia and unionized ammonia are decreased, diversity of aquatic macroinvertebrates should increase.



Eigenvectors									
S-W DI	0.44902	0.00418	0.04378	0.45906	0.42633	0.03508	0.28438	0.33432	-0.45835
Ammonia (mg/L)	-0.29641	0.45715	-0.02773	-0.28496	-0.12178	0.31487	0.64892	-0.04082	-0.29059
TKN (mg/L)	-0.39784	0.20820	0.27187	0.43955	0.12785	-0.57005	0.30849	-0.05868	0.30224
TOC mg/L	0.18326	-0.43047	0.49649	-0.47367	-0.16496	-0.31404	0.32822	0.27588	-0.02398
Mean Diel DO	0.38633	0.27117	-0.21601	0.20176	-0.59518	-0.00015	0.15432	0.39619	0.39349
NH3 (mg/L)	-0.44718	0.04516	0.06257	-0.08806	0.23972	0.22594	-0.21960	0.77874	0.15214
% Fines	-0.08257	-0.56688	-0.26987	0.13900	0.18123	0.36245	0.46075	-0.09427	0.44079
Flow cfs	0.35031	0.35783	-0.18679	-0.45538	0.55943	-0.17927	0.06675	-0.03468	0.39526
DO (mg/L)	0.19979	0.19332	0.72014	0.12389	0.04852	0.51136	-0.07971	-0.18309	0.29161

Summary

There are several limitations to the diversity of aquatic macroinvertebrates in the Santa Cruz River below Roger Road WWTP. Diversity is low, but water quality conditions may be such that acute toxicity to all but the most pollution tolerant aquatic organisms of any trophic level are likely to occur. Stressors that exert the greatest influence on diversity are low dissolved oxygen and high ammonia levels including un-ionized forms. It should be mentioned that a lack of suitable substrate was found at other EDW's (e.g., Rio de Flag) but water quality was of a standard high enough that diversity, while low, was still maintained to some degree. The possible combination of poor water quality combined with a lack of suitable substrate may have resulted in extraordinarily low diversity of aquatic organisms.



Santa Cruz River below the Nogales International Wastewater Treatment Plant

Background

The Nogales International Wastewater Treatment Plant (NIWWTP) was built in 1954 to serve the populations of Nogales, Sonora, Mexico and Nogales, Arizona, USA. 70% of the water flowing into the WWTP originates in Mexico. This WWTP treats an average of 13 mgd and treated effluent from this plant is discharged into the Santa Cruz River near Rio Rico, Arizona. The total population impacted by the treatment facility is made up of the populations of Nogales, Sonora (about 250,000 people), Nogales, Arizona (about 21,000 people), and Rio Rico, Arizona (about 1500 people).

Treatment currently consists of oxygenated ponds technology (nitrification/denitrification) and industry standard chlorination/dechlorination. A $60 million upgrade that will utilize best available technology is planned to be online by 2008.

Site Description, Substrate, and Geomorphological Data

The Santa Cruz River watershed drains large portions of northern Mexico and southern Arizona, USA, including the Sierra Madres in Sonora and their offshoots in Arizona (the Patagonias, Santa Ritas, Atascosas, and others). Elevations in the watershed range from about 3050 m in the montane regions to about 760 m in the valleys. The Santa Cruz flows from the south to the north across the international border. A majority of the water entering the system comes from the WWTP, though during monsoonal storms and spring snowmelt in higher elevations, runoff may significantly impact the flow in the stream.

The sites SC1 and SC2 are located at 31.45843N, 111.96992W and 31°56184N, 111°04605W at elevations of about 1050m and 993m respectively. These sites are located just north of Rio Rico and just south of Tumacocori, Arizona. The channel length (distance between sites) is 14,806m with a very low slope of 0.004. The channel length of the sites in the Santa Cruz was the longest of any of the sites. The sites were first sampled on 6/23/03 and again on 3/6/04. The stream between the two sampling sites lies in a broad, open area on the valley floor. SC1 has little vegetation, and is dominated by seep willow (*Baccharis salicifolia)*. SC2 has a fairly rich riparian area dominated by Fremont cottonwood (*Populus fremontii*), Arizona sycamore (*Juglans major*), seep willow (*Baccharis salicifolia*), and Gooding willow (*Salix goodingi*). SC1 is almost entirely exposed to the sun with very low canopy density, but the majority of SC2 is shaded by riparian vegetation. SC1 was located approximately 100 meters downstream of the outfall. SC2 is located just upstream from Tumacocori, Arizona.

Stream flow in the Santa Cruz at SC2 was much higher during the winter than the summer (see Figure 1e). This can be accounted for by the increase in evapotranspiration during the summer. The site SC1 showed a much smaller change in flow, but is located much closer to more stable conditions near the outfall.

The substrate at both sites in the Santa Cruz, like the Santa Cruz River in Pima County, was comprised mostly of sands, silts, and clays (see Figure 7e). These shifted readily in the current and provided a very unstable steam bed. The streambed was more stable at SC2, mostly due to an increase in substrate size, but SC1 did not fare as well. There was little to no cobble at either site and riffles were uncommon.

Geomorphological Data from Santa Cruz

Channel length: 14806 m.

Bankfull width: 27.10 m

Floodprone width: 90.07 m

Slope: 0.004

Figure 1e. ***Flow (cfs) at the Santa Cruz River downstream of the NIWTP by site and date***

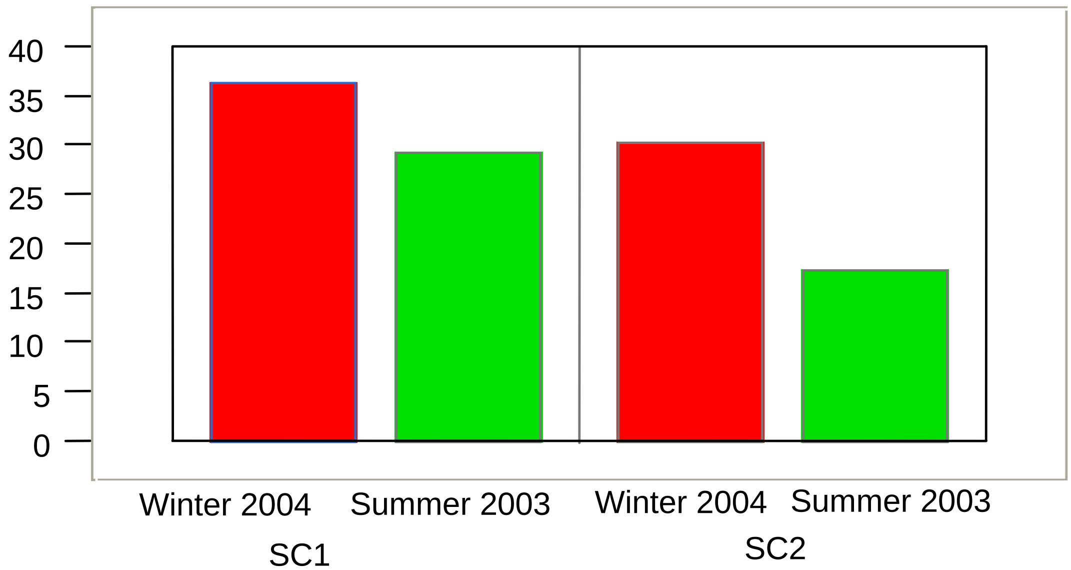


Figure 2e. ***Santa Cruz watershed***

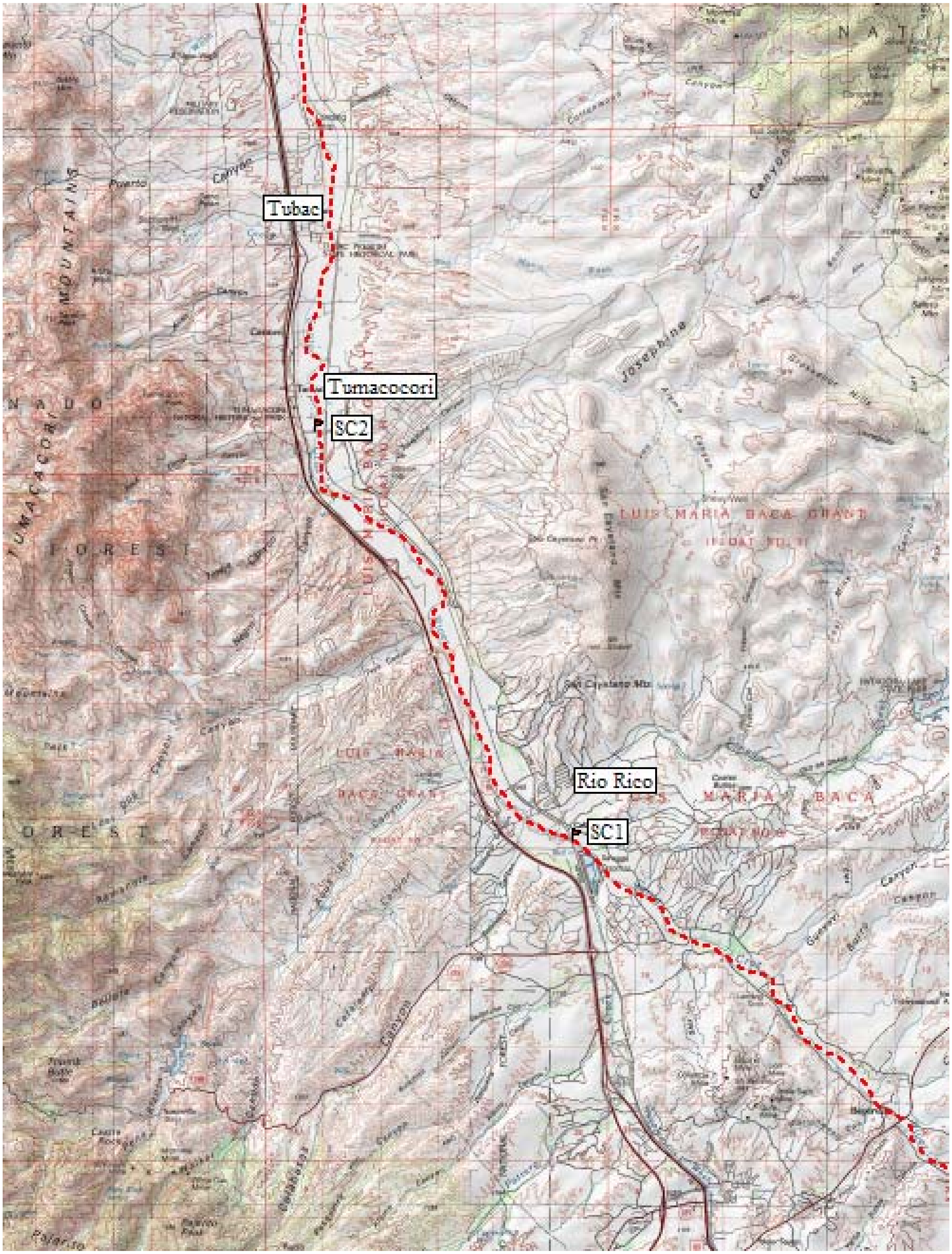


Figure 3e. ***Sampling site SC1***

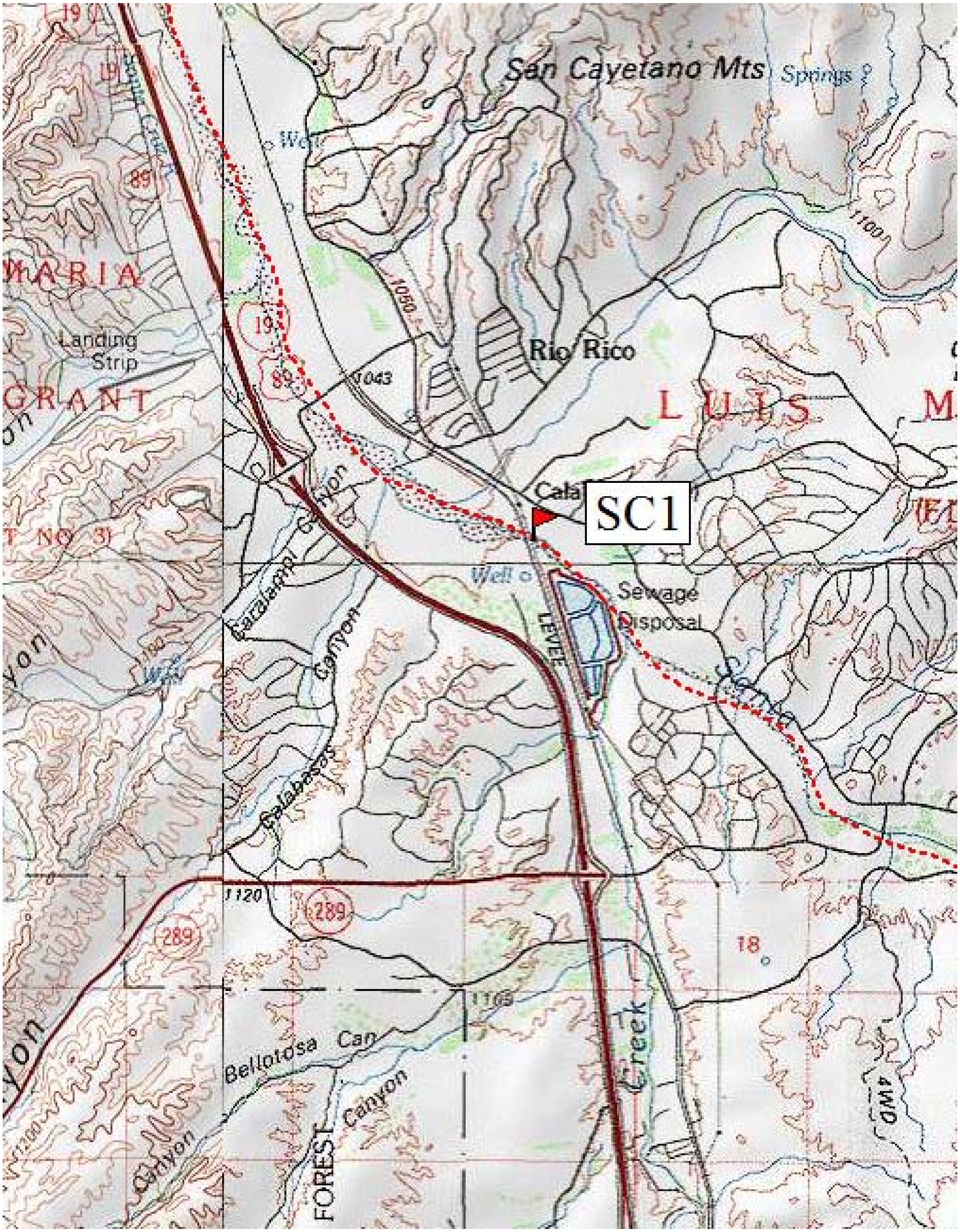


Figure 4e. ***Sampling site SC2***

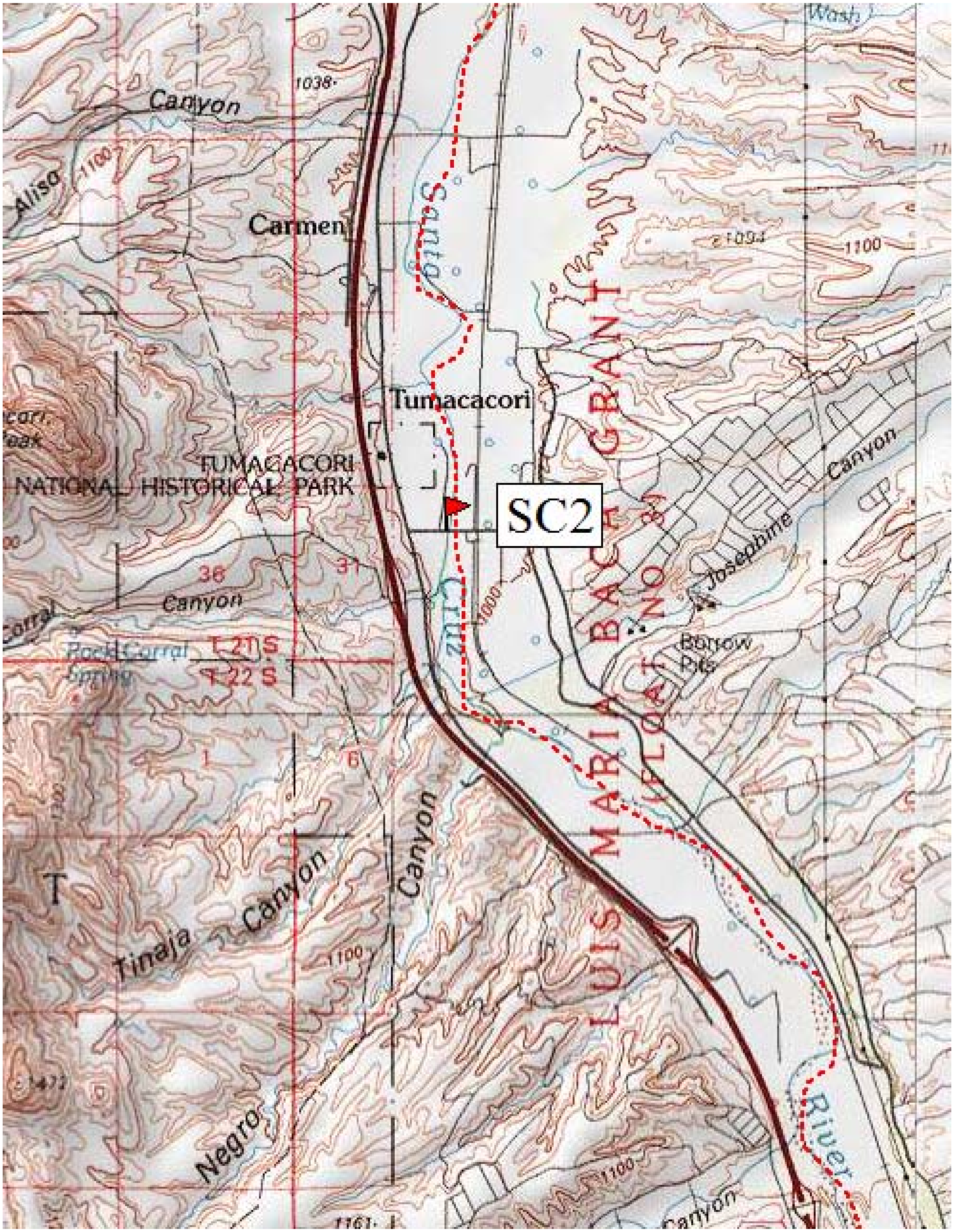
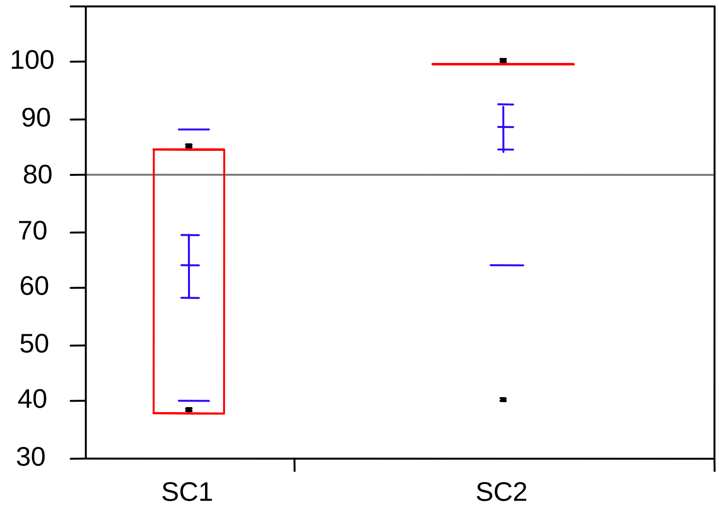


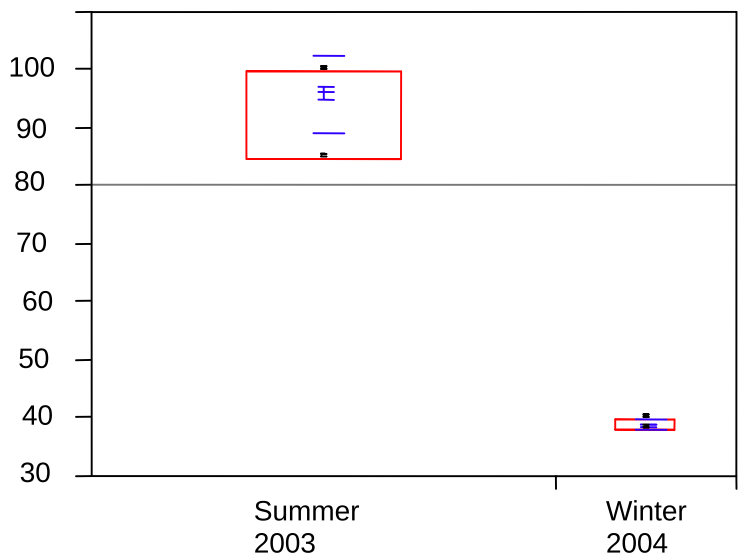
Figure 5e. ***Percent embeddedness by site***



Means

Level	Mean
SC1	64.2444
SC2	88.3333

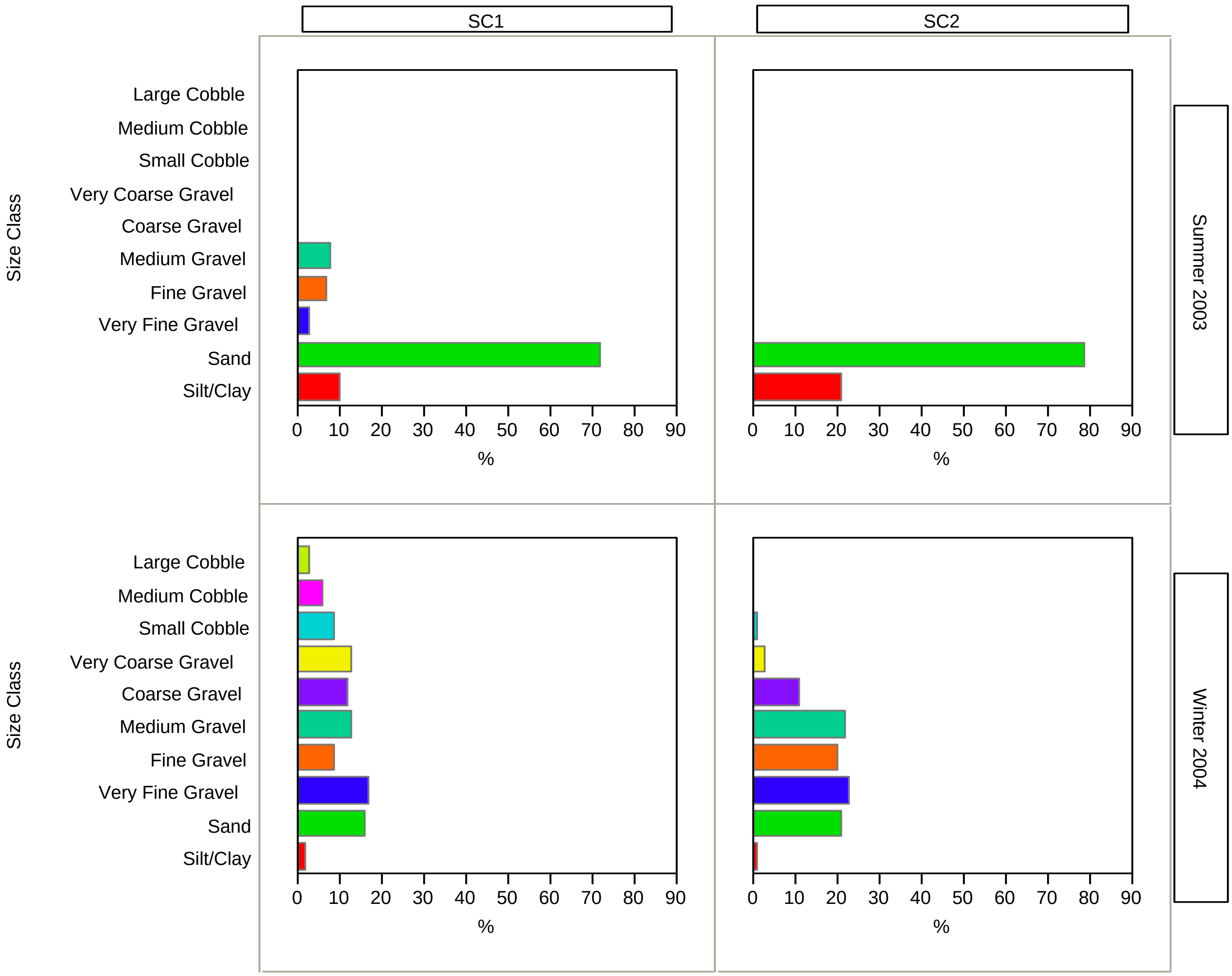
Figure 6e. ***Percent embeddedness by sampling season***



Means

Level	Mean
Summer 2003	96.1538
Winter 2004	39.0933

Figure 7e. ***Substrate particle size by site and date at the Santa Cruz River below the NIWTP***



Physico-chemical Data

Linear profiles of physico-chemical data were for both sampling dates starting at SC1 and taken at roughly equidistant locations to SC2. (See Appendix A for data.)

Figure 8e. ***SC linear profile, 03/06/04***

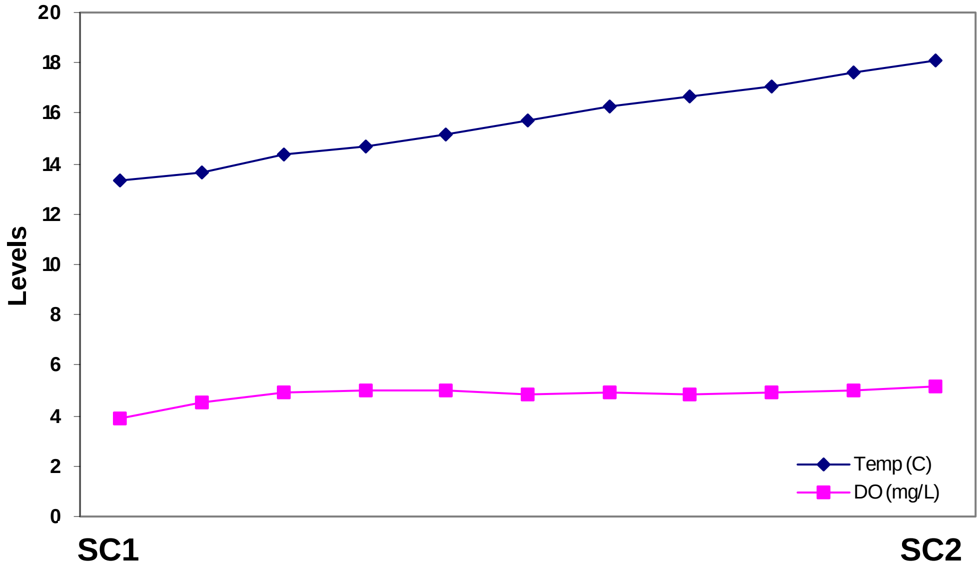
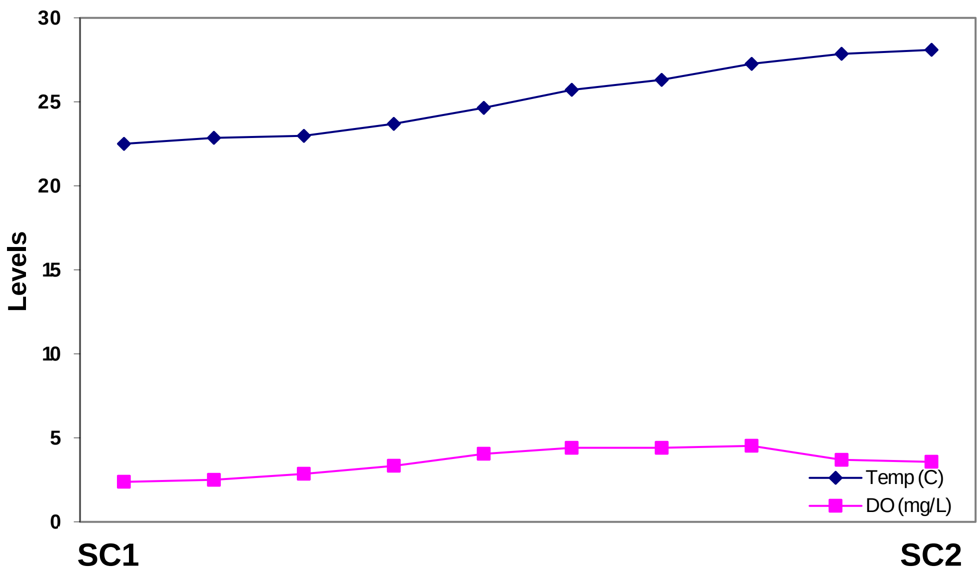


Figure 9e. ***SC linear profile, 06/23/03***



In addition to the linear profiles, physico-chemical readings were taken every 30 minutes over a 24-hour period (Diel profiles) during both samplings at SC2. (See Appendix B for data.)

Figure 10e. ***Diel pattern at SC2 on 03/06/04***

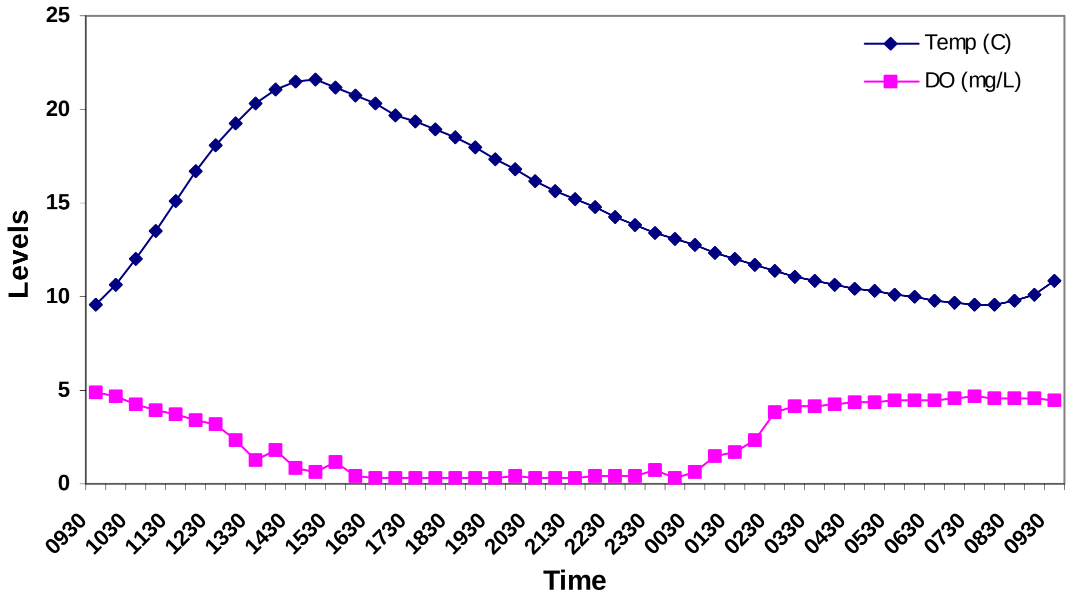
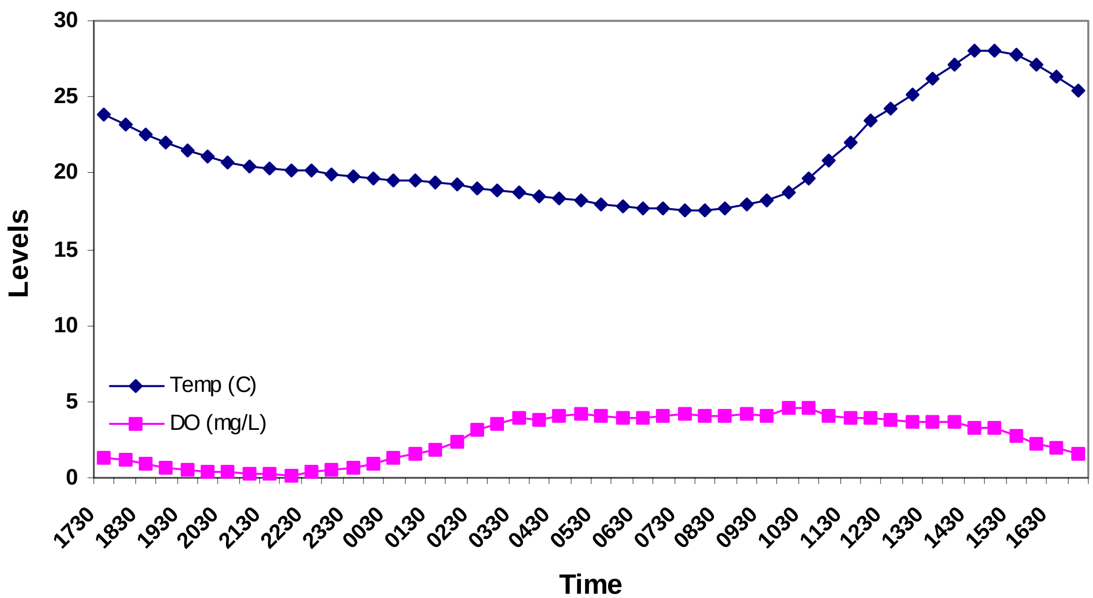


Figure 11e. ***Diel pattern at SC2 on 06/23/03***



Dissolved oxygen levels were consistently low along the entire channel length and never raised much above the levels measured near the outfall. Like the reach below Roger Road WWTP, DO levels were lower at the farthest site from the outfall, SC2. Also like the Santa Cruz River below RRWWTP, the Santa Cruz here became anoxic for portions of the night. However, the amount of time the DO sagged at this site was much less than the amount of time it was anoxic below RRWWTP. Surprisingly, DO levels at SC2 rose during the middle of the night (after approximately 12:30 am) on each sampling date. Also surprising is that the DO levels were anoxic for a longer period of time during the winter rather than the summer. This could have been due to a combination of temperature and flow. As previously stated, these sites were the farthest apart of any EDW measured for this study and the contribution of uncontaminated baseflow at SC2 is unknown. If the contribution of treated effluent is decreased at night at SC2, and the contribution from baseflow is maintained, then DO levels may increase. We did not take flow measurements simultaneously with the diel profiles but this is recommended for future studies.

The diel patterns on the two sampling dates showed similar trends. Each showed a peak DO of about 5 mg/L during the day dropping to about zero at night. DO levels recovered soon after it became light, but never rose very high. The DO levels recorded during the dark hours should be considered too low to support many species of aquatic organisms. Diel patterns of temperature showed similar trends on the two sampling dates. The summer temperatures were higher than the winter temperatures, but the amount of change between the low and high temperatures and the pattern of change did not vary drastically between the sampling dates.

Nutrients

Similar to the Santa Cruz below Roger Road WWTP, levels of nutrients in the Santa Cruz River below the Nogales International WWTP were very high, but dropped significantly with distance from the outfall. It must be kept in mind that the distance between the 2 sites at this stretch of the Santa Cruz is the greatest of any EDW sampled for this study and this makes comparisons between sites difficult. Distance between sites at PCSC were constrained by the contribution of another treatment plant (Ina Road WWTP), so it is unknown if nutrient levels would have decreased in the same manner as seen in the Santa Cruz below the Nogales IWWTP. Nitrification obviously occurs between SC1 and SC2 whereas little occurs between PCSC1 and PCSC2. Comparisons between these two sites is difficult since the distances been the sites are not equal. It's worth mentioning that the Bitter Creek, Jack's Canyon, and Rio de Flag sites were much closer together than any site on the Santa Cruz, yet ammonia, un-ionized ammonia, TKN, and organic carbon levels at the former sites were much lower than the latter. Dissolved oxygen levels at Jack's Canyon and Rio de Flag were also higher than either site on the Santa Cruz.

Levels of ammonia and TKN at SC1 were similar to those found at PCSC1 and PCSC2, but levels of un-ionized ammonia (calculated) were much lower. This is a significant finding because even though total nutrient levels are just as high as below RRWTP, it should be somewhat less toxic to aquatic organisms. While ammonia itself can be toxic, the higher the un-ionized fraction, the higher the probable toxicity.

Levels of organic carbon at SC1 were similar to what they were at the Santa Cruz below RRWTP. These high levels, along with other nutrients, undoubtedly contribute to the consumption of dissolved oxygen from the water.

Figure 12e*. Nutrient levels at Santa Cruz by site and sampling season (all units in mg/L).*

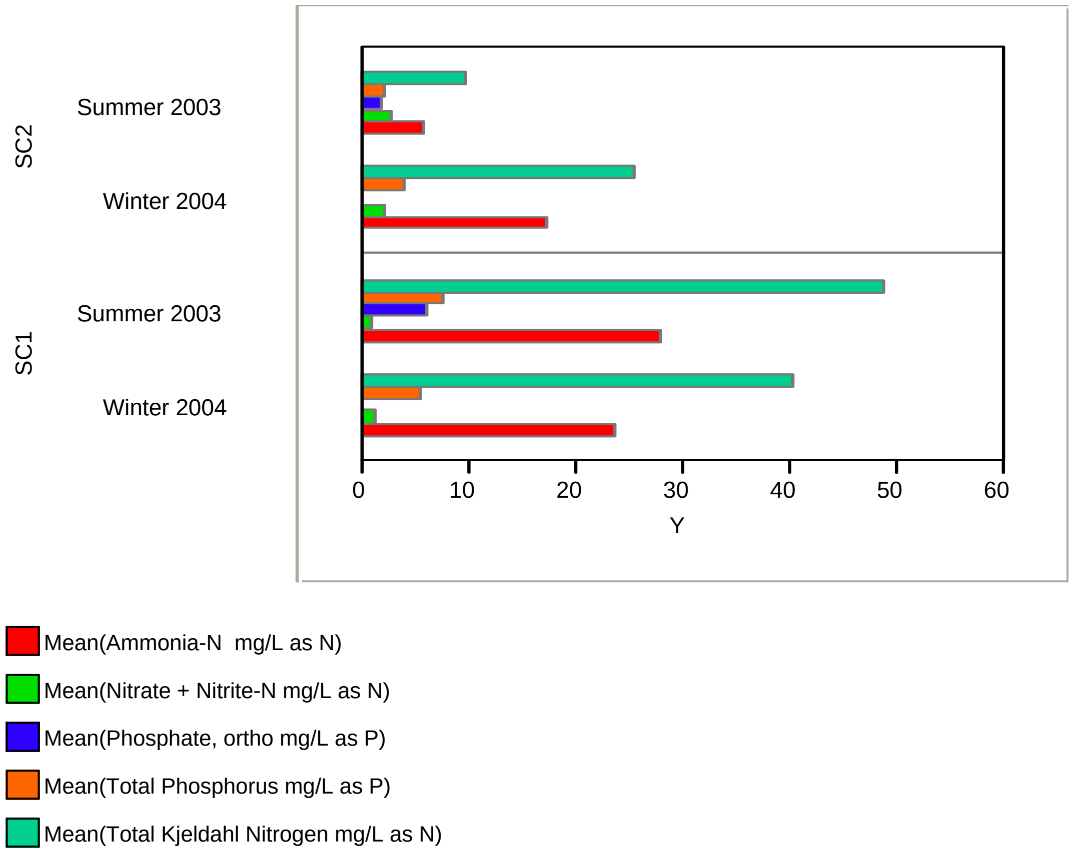


Figure 13e. *N:P ratio by sampling session and site* *(total N calculated as the sum of ammonia, nitrate, nitrite, and TKN)*

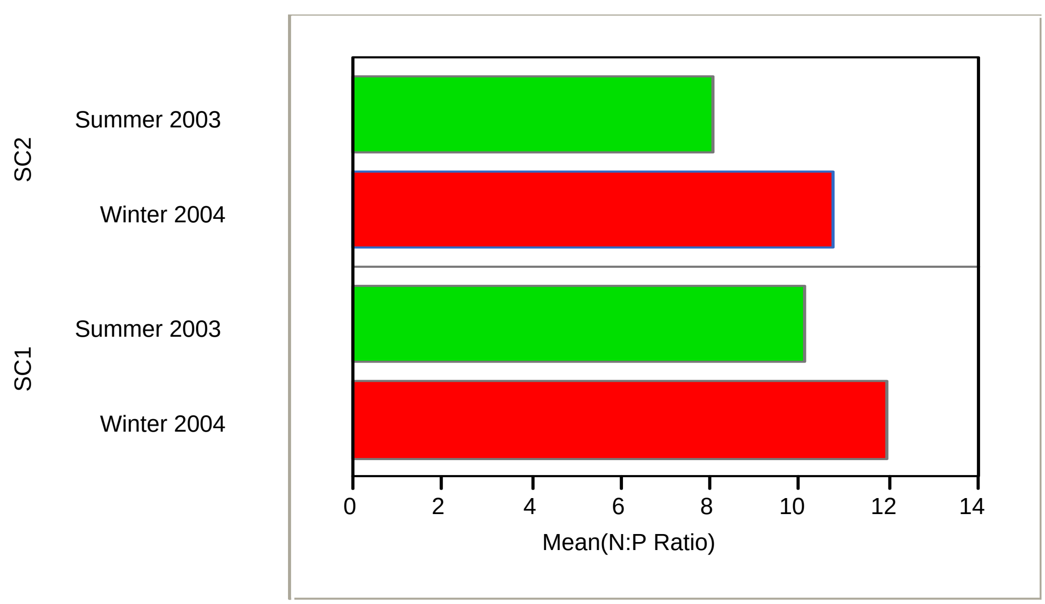


Figure 14e. ***TOC and DOC levels by site and sampling season***

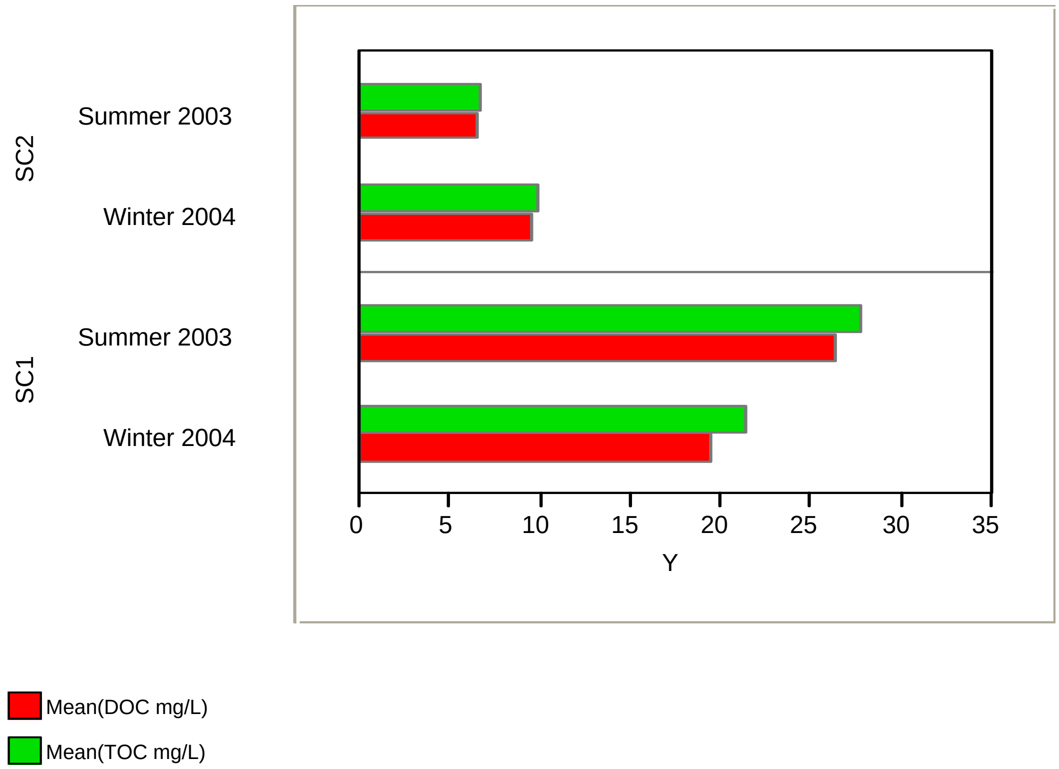
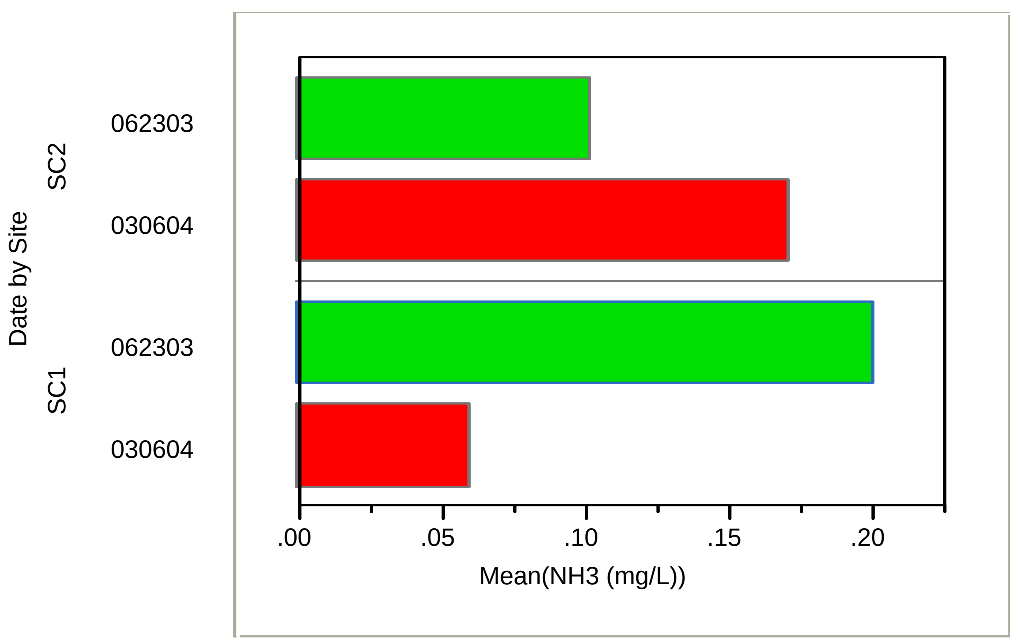


Figure 15e. ***Un-ionized ammonia (calculated) at Santa Cruz by site and date***



Biological Data

Algae

Similar to the Santa Cruz River below Roger Road WWTP, periphytic growth, given the amount of available nutrients in the water, was relatively low. Substrate for attachment of periphyton is limiting and periphyton could be found opportunistically growing in limited areas where suitable substrate could be found. Filamentous growth was found in relatively small amounts, which means that it would be largely unavailable for aquatic macroinvertebrates as an alternative substrate. The relatively small biomass of periphyton at both PCSC and SC means that the DO depletion at night may be more a function of contaminant load during that particular time of the day rather than respiration. This is not to say that respiration does not occur at either SC or PCSC; just not to the extent as at other EDW's. The nightly ratio in oxygen demand between respiration and contaminant load is a component of EDW's that needs to be further scrutinized.

Figure 16e. ***Phytoplankton chlorophyll a (mg/L) levels by site and date***

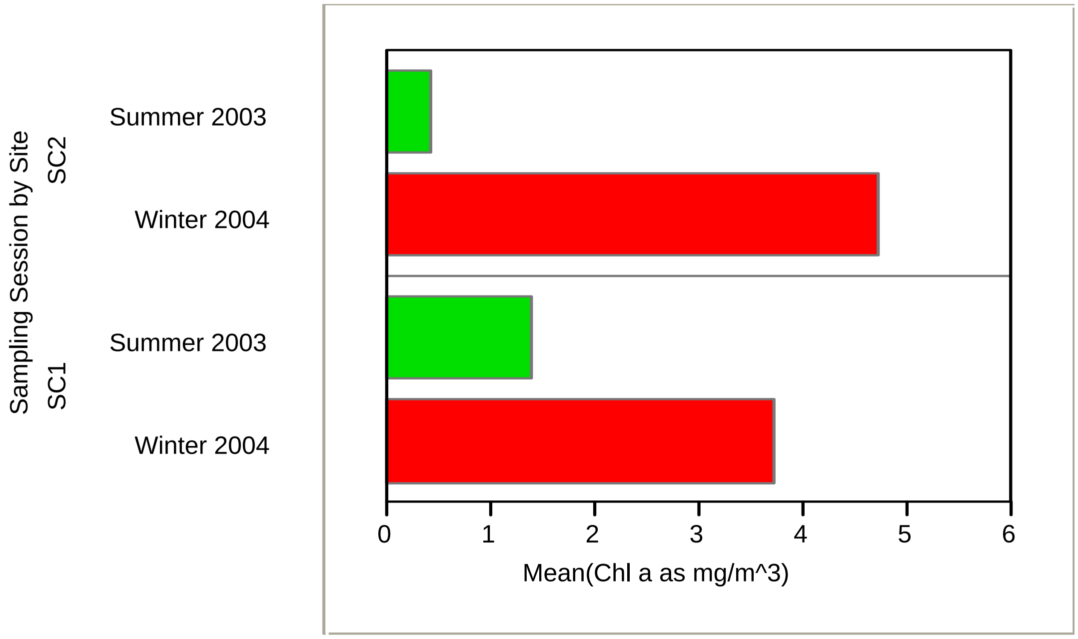


Figure 17e. ***Periphyton chlorophyll a (mg/m²) by site and date***

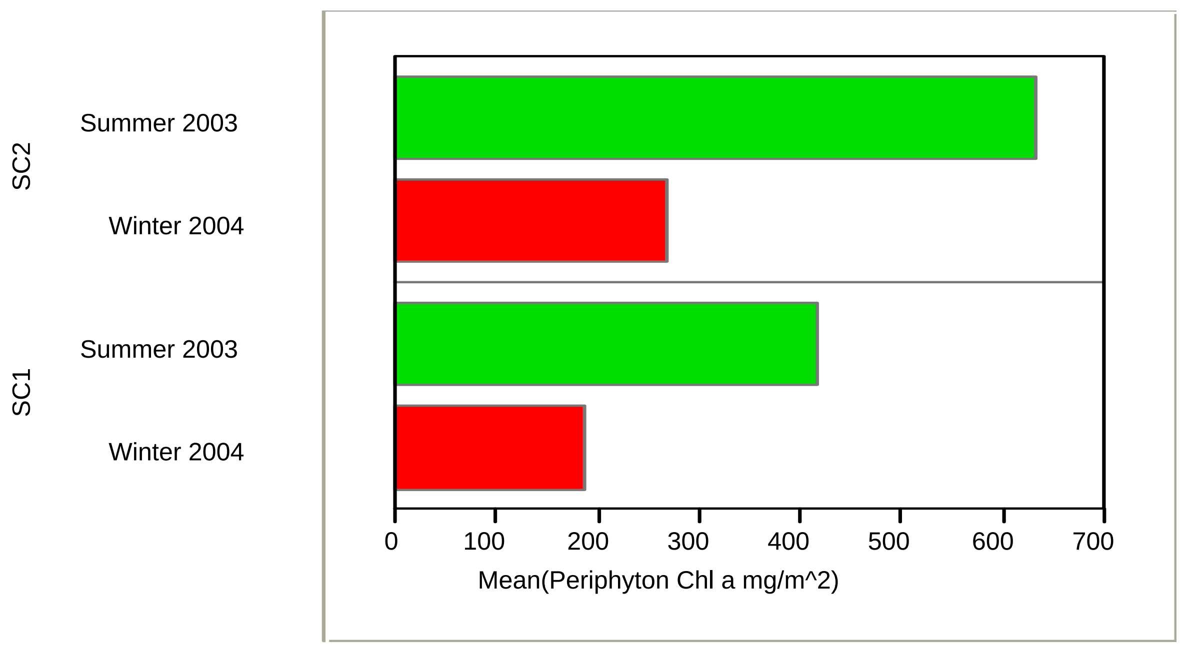


Figure 18e. ***Periphyton divisions (units/m2) by date and site***

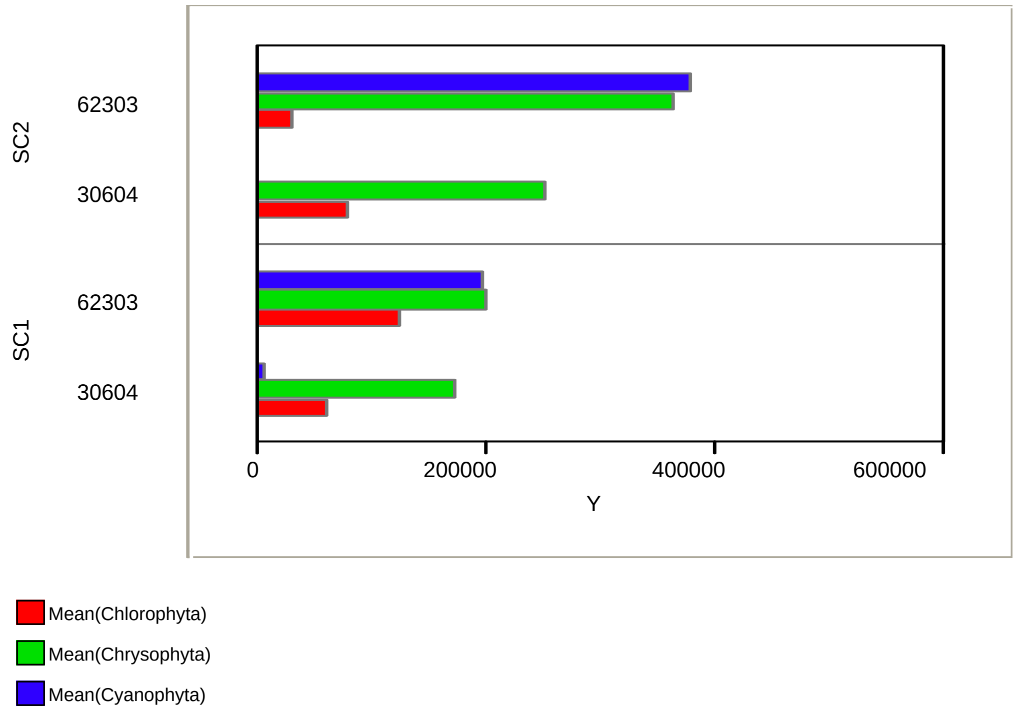


Figure 19e. ***Periphyton counts (units/m^2) by genus at SC1 for 03/06/04***

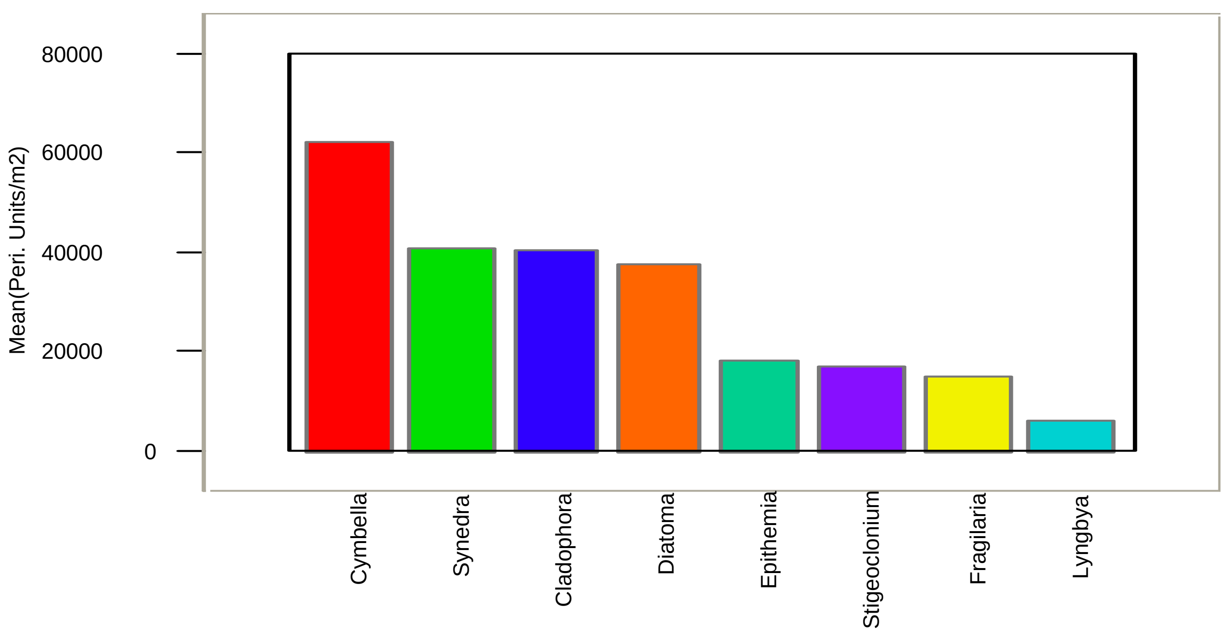


Figure 20e. ***Periphyton counts (units/m2) by genus at SC1 for 06/23/03***

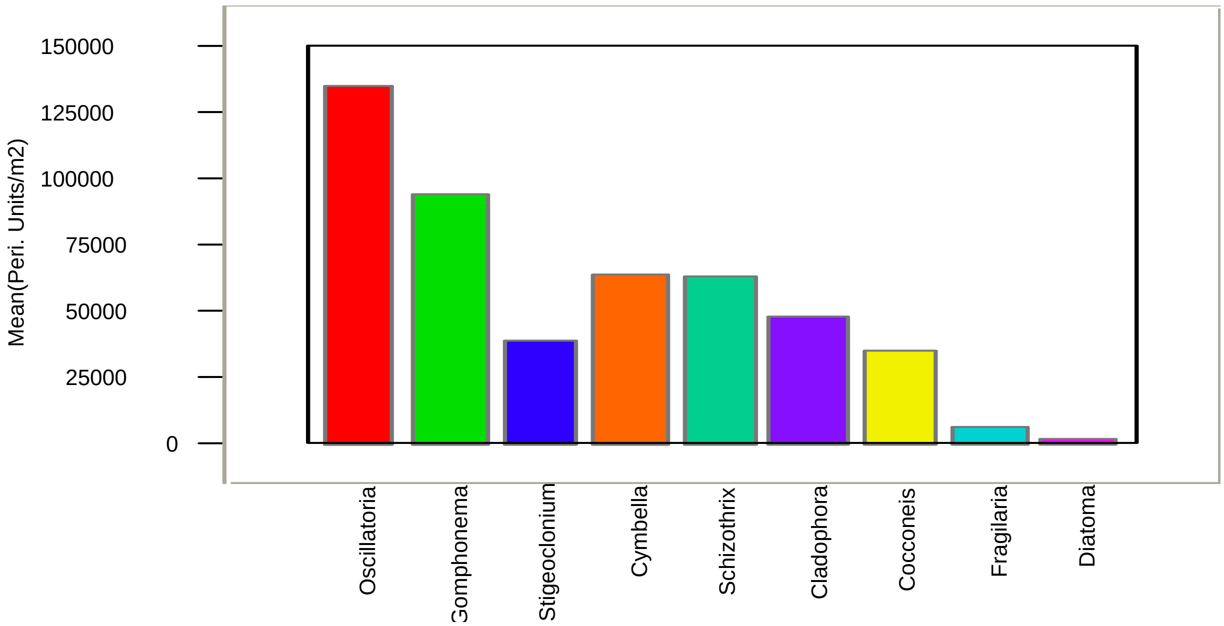


Figure 21e. ***Periphyton counts (units/m^2) by genus at SC2 for 03/06/04***

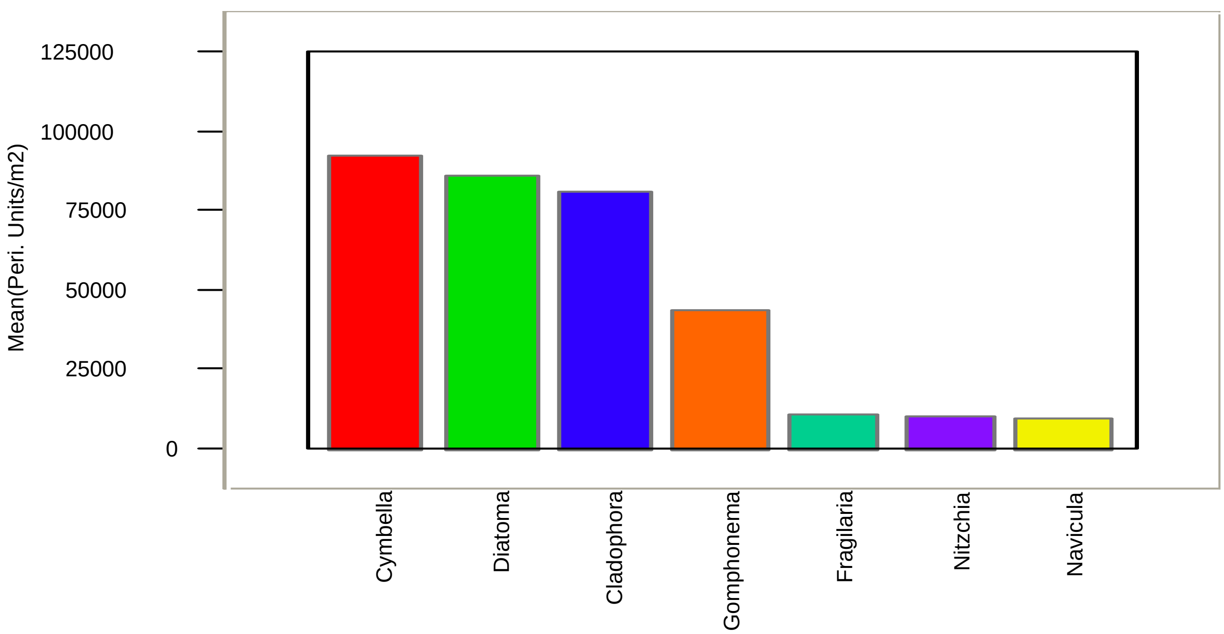
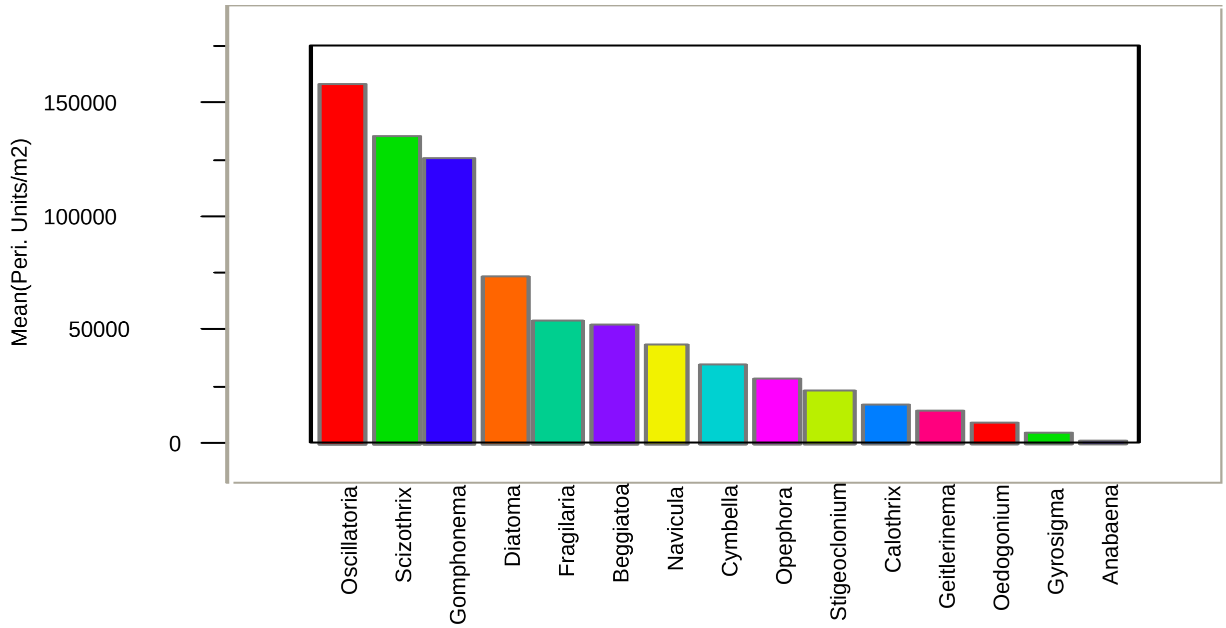


Figure 22e. ***Periphyton counts (units/m^2) by genus at SC2 for 06/23/03***



Aquatic Macroinvertebrates

Diversity of aquatic macroinvertebrates at the Santa Cruz River below the Nogales International WWTP was low at both sites during each sampling. The dominant invertebrate in all samples were oligochaetes. These organisms not only tolerate poor water quality, but are capable of living in a habitat made up of shifting sands like those found at both sites. Although the total number of invertebrates found in a sample was quite high, most of the organisms collected were of only one taxa. The highest diversity was measured at SC2 during the summer. This is not surprising considering it had the most aquatic vegetation observed at either site during each sampling and provided a more stable substrate for invertebrates to colonize than the predominant shifting sands. Samples were taken partially from vegetation whenever feasible. In the Santa Cruz, this was only possible during the summer at site SC2. There was no other appreciable aquatic vegetation when other samples were taken.

The invertebrates collected from the Santa Cruz generally had high tolerance values. As in PCSC, it is likely that only the most pollution tolerant invertebrates will be able to colonize this reach of the Santa Cruz River. Between poor substrate conditions, low dissolved oxygen, and relatively high ammonia levels, diversity of macroinvertebrates will remain relatively low.

Figure 23e*. Aquatic macroinvertebrate numbers by site and date*.

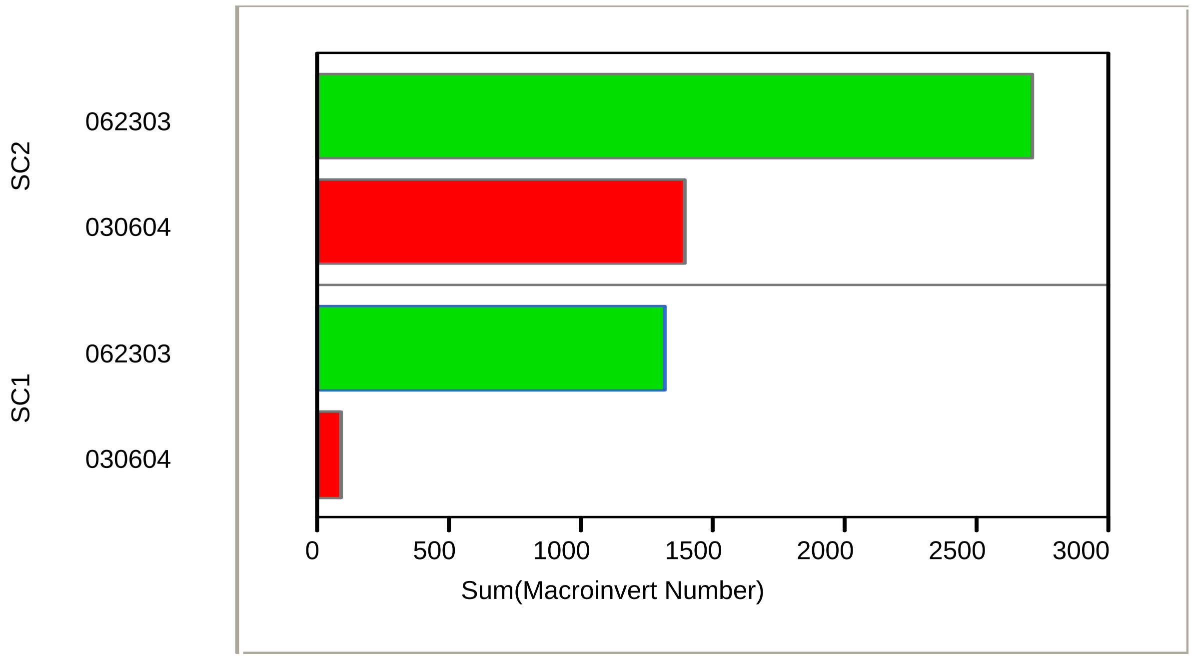


Figure 24e. ***Mean aquatic macroinvertebrate numbers by site and date***

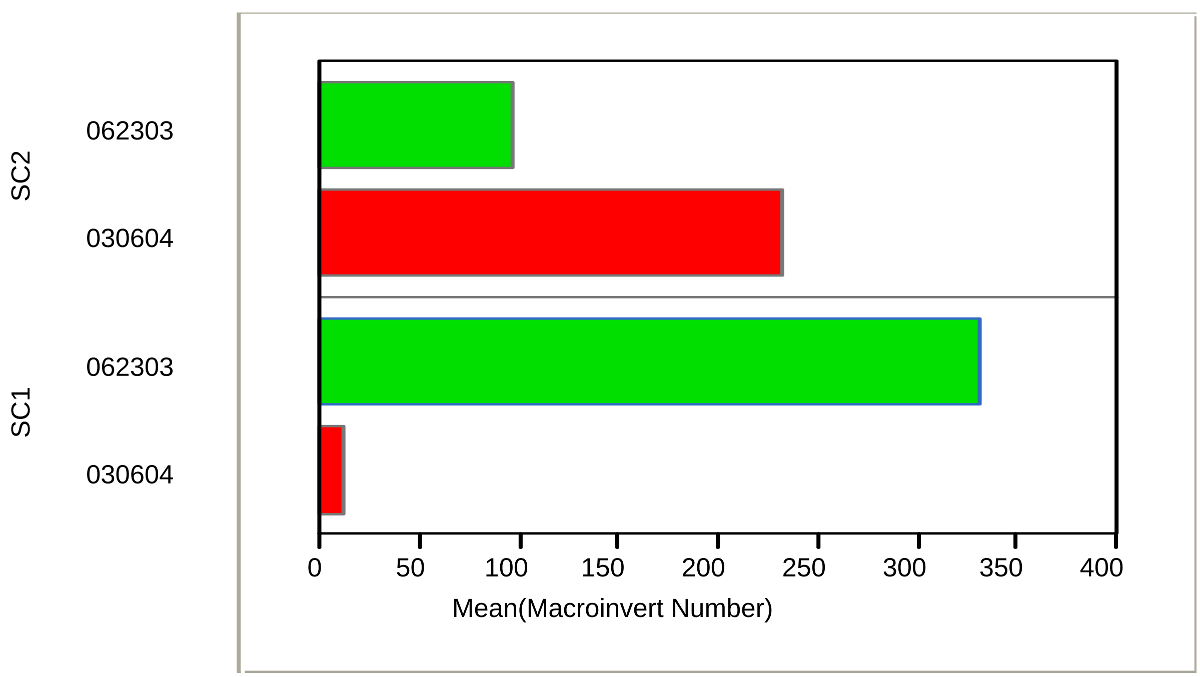


Figure 25e. ***Macroinvertebrate orders by date.***

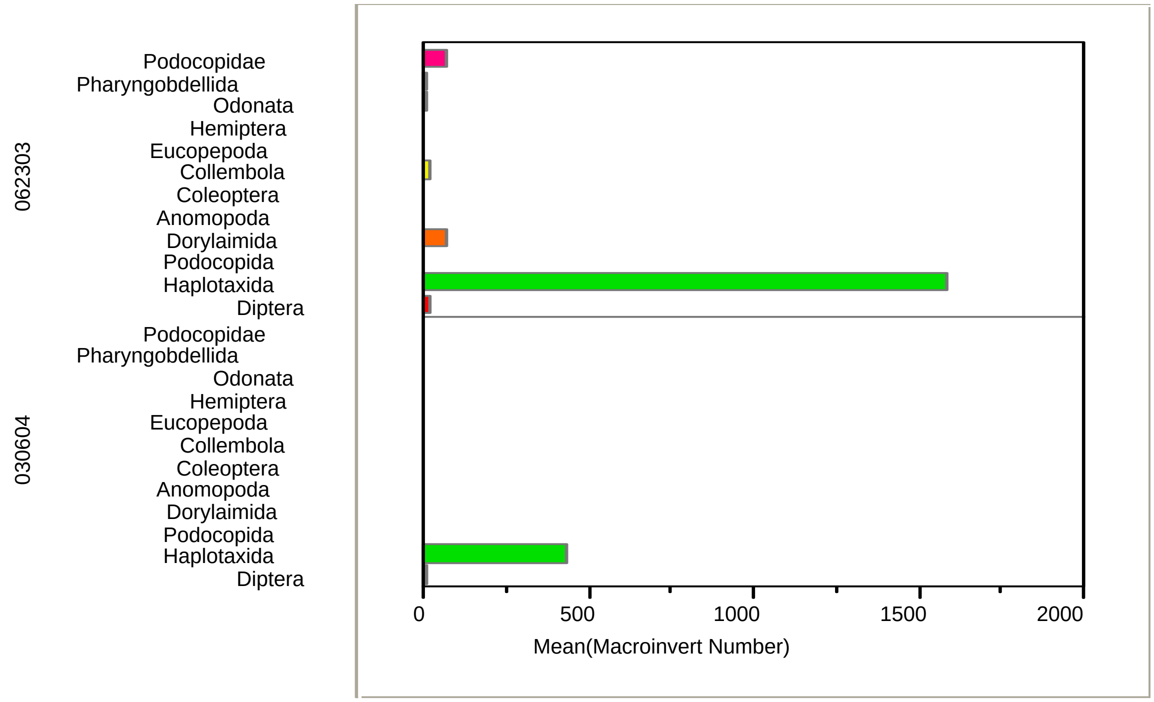
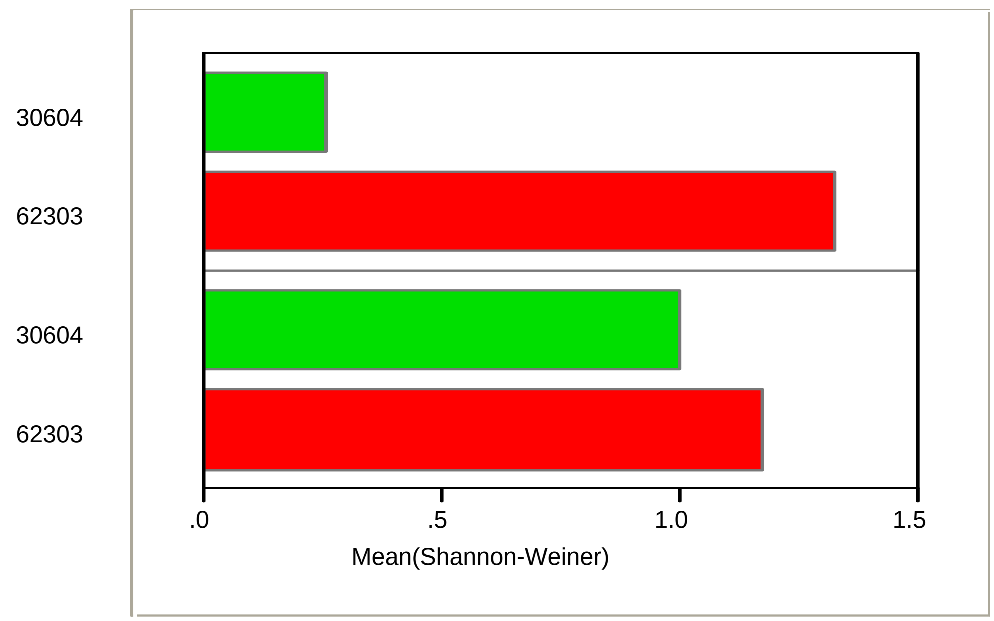


Figure 26e. ***Shannon-Weiner diversity index by site and date***

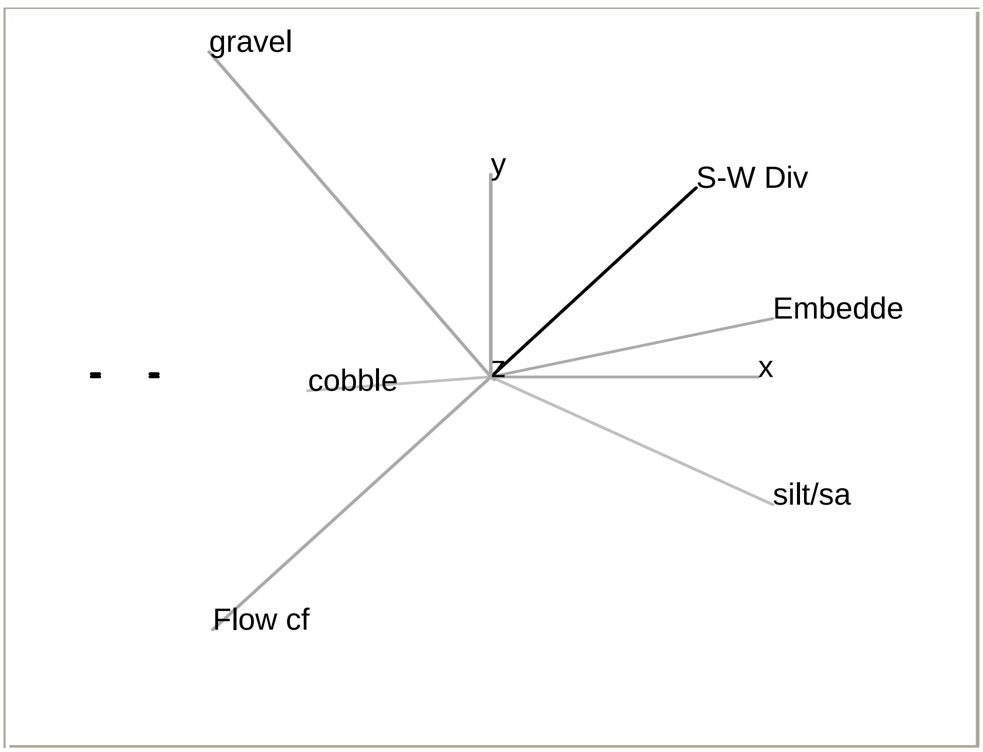


Correlations

S-W Diversity Index and Physical Attributes

Diversity was positively correlated with embeddedness. This might seem to be an error at first glance, but makes sense. Embeddeness was highest at SC2 during the summer sampling, but it also had the highest invertebrate counts. This is likely due to the large amount of vegetation found in the stream at that site. Also, the main constituent of the sample was oligochaetes, which are capable of inhabiting a shifting sand substrate. Even though the substrate was very poor and few invertebrates are capable of colonizing the thalweg of the stream, there were enough alternative substrates to promote some diversity and biomass of invertebrates.

Diversity was negatively correlated with flow. In this system, as in PCSC, high flows shift the sandy substrate and make it very unstable. Invertebrate diversity and biomass is typically highest during the summer, but flows were also lower during the summer than the winter in this system. These lower flows likely contributed to a higher diversity and invertebrate biomass because it stabilized the substrate to a greater extent and allowed more invertebrates to colonize the stream.

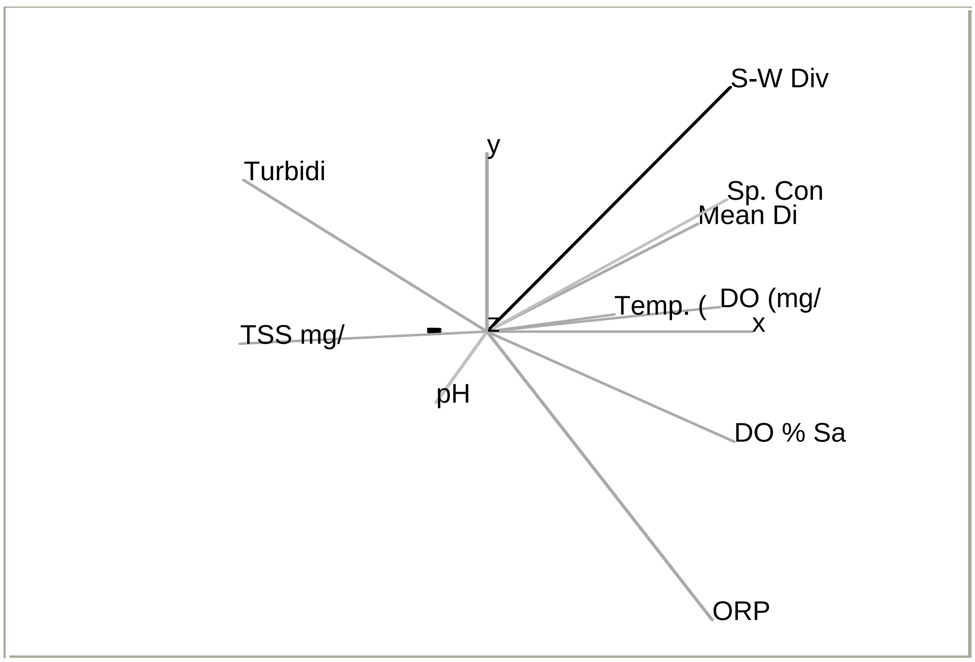


Eigenvectors						
S-W Diversity	0.32936	0.63941	0.40068	-0.26002	0.46329	0.19973
cobble	-0.29004	0.71429	-0.02547	0.27514	-0.44929	-0.35702
gravel	-0.44620	-0.17807	0.68874	0.49377	0.21614	0.06562
silt/sand/clay	0.45464	0.00789	-0.26662	0.65112	0.41496	-0.35496
Embeddedness	0.45450	0.02397	0.12395	0.38792	-0.50766	0.60769
Flow cfs	-0.44163	0.22045	-0.52725	0.19605	0.32693	0.57711

S-W Diversity Index and Physico-chemical Attributes

Diversity correlated most strongly with DO and mean diel oxygen levels. This finding makes sense – the diversity of invertebrates increases when the oxygen levels remain relatively high throughout the diel cycle. Most of the invertebrate assemblage was comprised of oligochaetes, which not only tolerate poor water quality, but also low oxygen levels. Few invertebrates utilizing oxygen directly from the water were collected during samplings, further suggesting that DO levels in the water are insufficient to support most aquatic invertebrates.

Temperature and diversity are positively correlated. This is not an unusual finding as diversity is often higher during the summer than the winter in many aquatic systems. Most of the organisms collected at SC that are fully aquatic and probably never leave the system breed most heavily during the summer months. The increase in diversity seen at SC2 during the summer was likely due to immigration of insects from terrestrial sources (i.e. terrestrial adults depositing their eggs into the stream) or from other bodies of water, both of which occur more often during the summer than the winter.

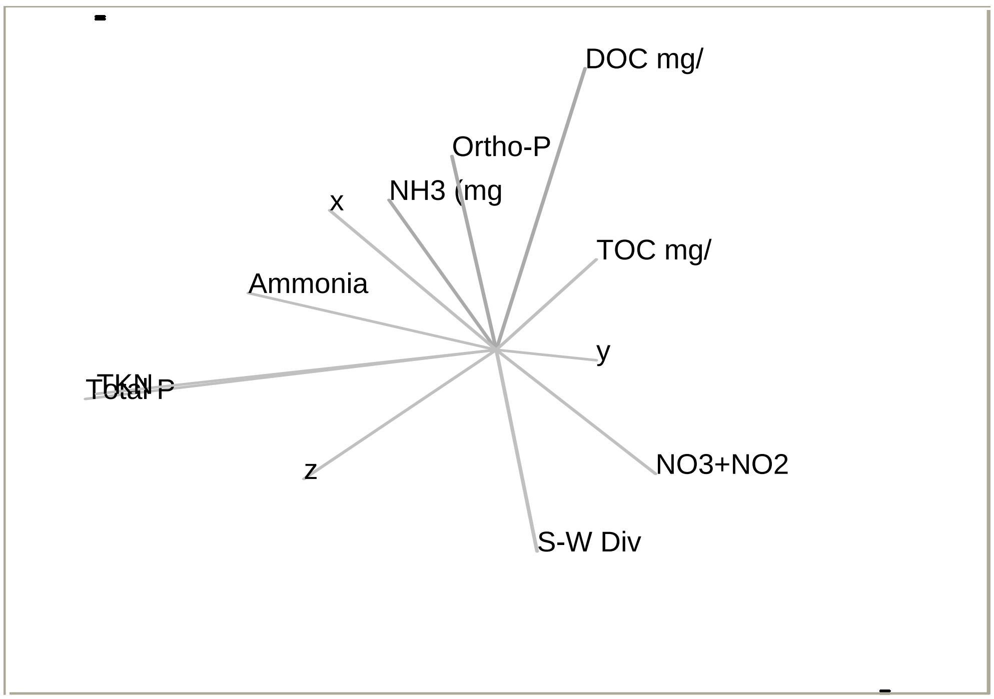


Eigenvectors										
S-W Diversity	0.35556	-0.11494	-0.39200	0.21538	0.53214	0.41943	0.34534	-0.17545	0.22623	0.00110
Mean Diel DO	0.31047	0.33443	-0.02553	-0.25867	0.23385	-0.62400	0.27149	-0.16648	-0.05476	0.41919
TSS mg/L	-0.35892	-0.07289	0.18001	-0.17766	-0.02182	0.40979	0.13416	0.01114	0.09979	0.77808
Turbidity	-0.35281	-0.14003	0.06448	0.63085	0.33209	-0.40794	-0.02922	0.30431	0.24956	0.14611
ORP	0.33316	-0.25274	-0.10244	0.40389	-0.62166	-0.06313	0.41448	0.12662	-0.17027	0.21031
DO (mg/L)	0.34040	-0.21877	0.32717	0.30128	0.05563	0.01091	-0.53830	-0.52652	-0.10492	0.23926
DO % Sat.	0.36108	0.01483	0.00685	-0.16360	-0.23328	-0.03163	-0.25953	0.25219	0.80642	0.07684
pH	-0.07103	0.64179	0.41686	0.33816	-0.15341	0.16479	0.28344	-0.28303	0.24202	-0.15883
Sp. Cond.	0.35416	-0.12831	0.66659	-0.09886	0.28697	0.12654	0.17728	0.48235	-0.17835	-0.09863
Temp. (C)	0.19015	0.55651	-0.27097	0.22886	0.03891	0.22822	-0.38406	0.42326	-0.30479	0.23493

S-W Diversity Index and Nutrient Levels

Diversity is positively correlated with nitrate/nitrite levels at SC. These forms of nitrogen are the most oxidized forms and are likely the least harmful to aquatic organisms. Like most other EDW's studied, diversity is negatively correlated with ammonia and unionized ammonia levels. These compounds are likely toxic to most aquatic organisms but those with very high pollution tolerances. While un-ionized levels of ammonia were much lower at SC than PCSC, it still likely has an adverse effect on diversity especially when coupled with other stressors.

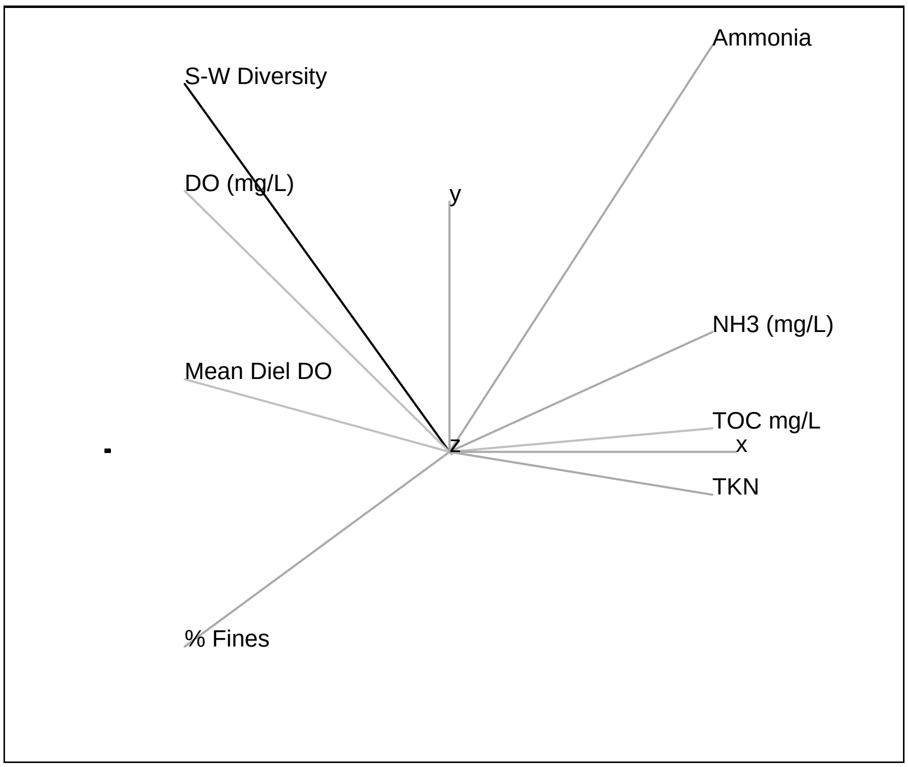
Levels of organic carbon were also negatively correlated with the diversity of macroinvertebrates. These compounds consume oxygen, stressing an already low oxygen system further and driving O_2 levels down to dangerously low levels.



Eigenvectors									
S-W Diversity	-0.33333	0.29539	0.32555	0.28162	0.11785	-0.07914	0.45552	0.56967	0.25332
NH3	0.33333	-0.41662	0.10075	-0.10641	-0.11785	0.63659	0.09520	0.49943	-0.12734
Ammonia	0.33333	0.07005	-0.46993	0.76588	-0.11785	0.02066	-0.14046	0.11091	0.17388
NO3+NO2	-0.33333	-0.04204	0.46838	0.42999	0.11785	0.48896	-0.33092	-0.34691	0.00358
Ortho-P	0.33333	-0.06132	0.54569	0.13635	-0.11785	-0.49206	-0.42001	0.25725	-0.26489
Total P	0.33333	-0.39736	0.31769	0.08421	-0.11785	-0.15170	0.41163	-0.37996	0.52180
TKN	0.33333	0.60187	0.14619	-0.30561	-0.11785	0.24966	-0.29329	0.02212	0.49915
DOC	0.33333	0.45673	0.15355	0.13720	-0.11785	0.14666	0.47153	-0.28700	-0.54569
TOC	0.33333	0.00000	0.00000	0.00000	0.94281	0.00000	0.00000	0.00000	0.00000

Limitations to Diversity

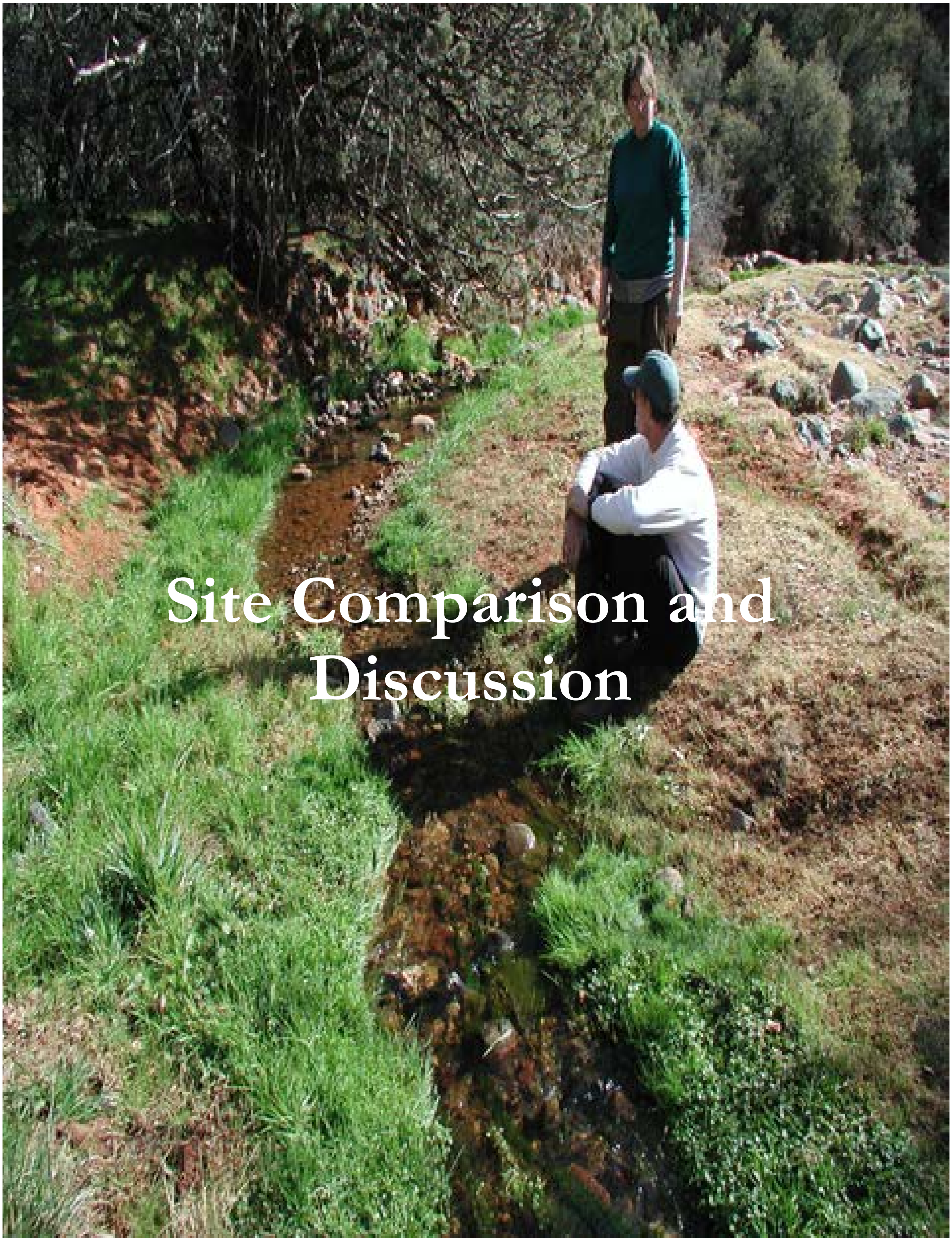
While the correlation with both DO and mean diel DO are positively correlated with diversity, as found in PCSC and other EDW's, the inverse correlation between diversity and either ammonia or un-ionized ammonia was not as great as it was at PCSC. This is a very significant finding. A possible explanation is that levels of un-ionized ammonia were far less at SC than PCSC so that overall toxicity to aquatic organisms is relatively lessened. Organic carbon and TKN were more inversely correlated with diversity than was any level of ammonia. These variables are likely to also consume dissolved oxygen. In this system it appears that dissolved oxygen, and contaminants that consume dissolved oxygen, are more likely to depress levels of diversity than is either ammonia or un-ionized ammonia at the levels observed. This does not mean that total ammoniacal nitrogen does not exert some level of toxicity to aquatic macroinvertebrates, but it does indicate that the higher the fraction of un-ionized ammonia, the higher the level of toxicity.



Eigenvectors							
S-W Diversity	-0.14600	-0.11931	0.56155	0.28101	-0.63559	0.07184	0.18976
DO (mg/L)	-0.10992	0.11867	0.40052	0.02997	0.53270	0.54804	-0.32157
Ammonia	0.41049	0.39244	0.62059	-0.28963	0.09405	-0.18669	0.19941
TKN	0.51928	-0.21745	-0.06316	0.54604	0.01338	0.47854	0.16348
TOC mg/L	-0.15881	0.42511	0.03830	0.38873	-0.24501	-0.09906	-0.66832
% Fines	0.05964	0.73487	-0.29458	0.28750	0.03427	0.02582	0.40018
Mean Diel DO	0.35737	-0.20963	0.11295	0.41271	0.31168	-0.62495	-0.18041
NH3 (mg/L)	-0.26988	-0.07550	0.18471	0.36605	0.38064	-0.17205	0.39338

Summary

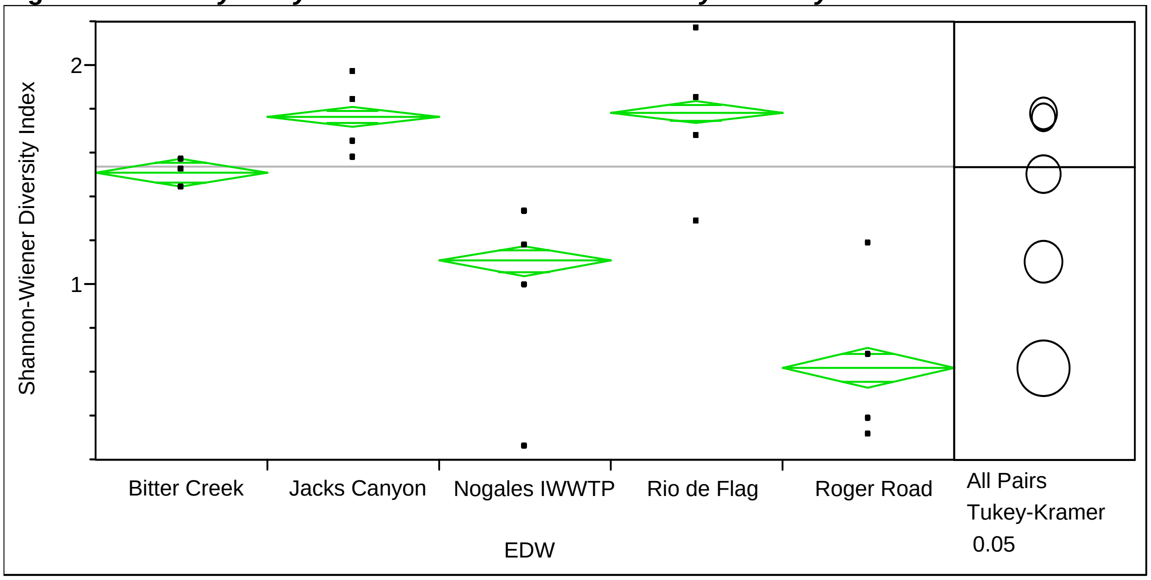
The Santa Cruz River below the Nogales International WWTP is similar to the Santa Cruz River below Roger Road WWTP. The main difference is that at SC, un-ionized levels of ammonia are much lower than they are at PCSC. Easing this single constraint only resulted in marginally higher diversity levels, which could also be caused by lower levels of overall nutrients at SC2 due to the relatively long distance between this site and the outfall. Easing one constraint to diversity in a matrix of stressors apparently does little to improve ecological condition.


Site Comparison and
Discussion

Site Comparison

While the statistical power within any individual EDW is not high, the data become more robust when used collectively. According to our data, there is no statistical difference in diversity between Jack's Canyon and Rio de Flag with both of these having the highest levels. The remaining 3 EDW's are different from each other and different from the clustering of Jack's Canyon and Rio de Flag. Roger Road has, by a large margin, the lowest diversity values with Nogales IWWTP and Bitter Creek having the next highest values respectively.

Figure 1f. ***Oneway analysis of Shannon-Wiener diversity index by EDW***



Summary of Fit

Rsquare	0.673142
Adj Rsquare	0.669479
Root Mean Square Error	0.251778
Mean of Response	1.541768
Observations (or Sum Wgts)	20

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Bitter Creek	4	1.51066	0.03224	1.4473	1.5741
Jacks Canyon	4	1.76820	0.02279	1.7234	1.8130
Nogales IWWTP	4	1.11057	0.03458	1.0426	1.1786
Rio de Flag	4	1.78742	0.02556	1.7371	1.8377
Roger Road	4	0.62103	0.04675	0.5291	0.7130

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.74178	0.05

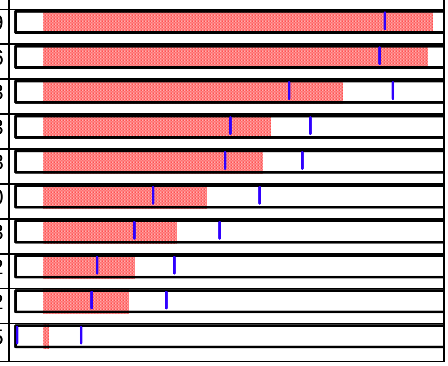
Abs(Dif)-LSD	Rio de Flag	Jacks Canyon	Bitter Creek	Nogales IWWTP	Roger Road
Rio de Flag	-0.0991	-0.0747	0.1640	0.5589	1.0203
Jacks Canyon	-0.0747	-0.0884	0.1493	0.5441	1.0045
Bitter Creek	0.1640	0.1493	-0.1250	0.2705	0.7339
Nogales IWWTP	0.5589	0.5441	0.2705	-0.1341	0.3301
Roger Road	1.0203	1.0045	0.7339	0.3301	-0.1813

Positive values show pairs of means that are significantly different.

Level					Mean
Rio de Flag	A				1.7874227
Jacks Canyon	A				1.7681967
Bitter Creek		B			1.5106557
Nogales IWWTP			C		1.1105660
Roger Road				D	0.6210345

Levels not connected by same letter are significantly different

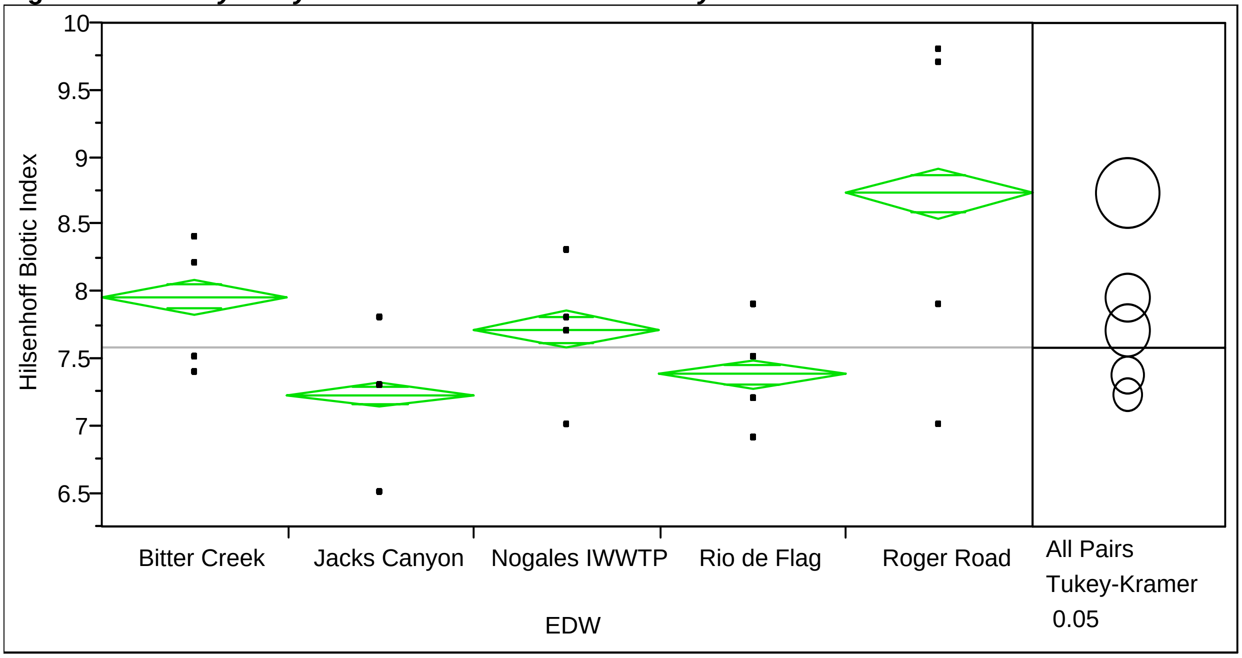
Level	- Level	Difference	Lower CL	Upper CL	Difference
Rio de Flag	Roger Road	1.166388	1.02029	1.312489	
Jacks Canyon	Roger Road	1.147162	1.00455	1.289776	
Bitter Creek	Roger Road	0.889621	0.73391	1.045328	
Rio de Flag	Nogales IWWTP	0.676857	0.55894	0.794773	
Jacks Canyon	Nogales IWWTP	0.657631	0.54406	0.771198	
Nogales IWWTP	Roger Road	0.489532	0.33008	0.648980	
Bitter Creek	Nogales IWWTP	0.400090	0.27046	0.529718	
Rio de Flag	Bitter Creek	0.276767	0.16396	0.389572	
Jacks Canyon	Bitter Creek	0.257541	0.14929	0.365792	
Rio de Flag	Jacks Canyon	0.019226	-0.07468	0.113135	



While some degree of pollution tolerance will probably always be required by organisms living in EDW's, the degree of pollution tolerance can still be an insightful tool for comparison of sites. Using Hilsenhoff's Biotic Index, we calculated the pollution tolerance of individual aquatic macroinvertebrates and used this mean to compare the EDW's. According to our data, Jack's Canyon and Rio de Flag are once again statistically similar and contained macroinvertebrates with the lowest tolerance for pollution. This time, both Nogales IWWTP and Bitter Creek are statistically similar and contain macroinvertebrates that are more pollution tolerant than the clustering of Jack's Canyon and Rio de Flag. The macroinvertebrate community at Roger Road, by a relatively large margin, had the highest tolerance to pollution.

Taken together, these analyses are very significant and can serve as a check upon one another. If we are assuming that diversity decreases with increasing levels of pollution, and the simultaneous assumption that the higher the level of pollution tolerant organisms the lower the level of diversity, then these analyses confirm that both of these assumptions are indeed true.

Figure 2f. ***Oneway analysis of Hilsenhoff Biotic Index by EDW***



Summary of Fit	
Rsquare	0.41612
Adj Rsquare	0.409578
Root Mean Square Error	0.511395
Mean of Response	7.591436
Observations (or Sum Wgts)	20

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Bitter Creek	4	7.96557	0.06548	7.8368	8.0943
Jacks Canyon	4	7.23852	0.04630	7.1475	7.3296
Nogales IWWTP	4	7.72075	0.07025	7.5826	7.8589
Rio de Flag	4	7.38763	0.05192	7.2855	7.4897
Roger Road	4	8.73448	0.09496	8.5477	8.9212

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.74178	0.05

Abs(Dif)-LSD	Roger Road	Bitter Creek	Nogales IWWTP	Rio de Flag	Jacks Canyon
Roger Road	-0.3682	0.4526	0.6899	1.0501	1.2063
Bitter Creek	0.4526	-0.2539	-0.0185	0.3488	0.5072
Nogales IWWTP	0.6899	-0.0185	-0.2724	0.0936	0.2516
Rio de Flag	1.0501	0.3488	0.0936	-0.2013	-0.0416
Jacks Canyon	1.2063	0.5072	0.2516	-0.0416	-0.1795

Positive values show pairs of means that are significantly different.

Level				Mean
Roger Road	A			8.7344828
Bitter Creek		B		7.9655738
Nogales IWWTP		B		7.7207547
Rio de Flag			C	7.3876289
Jacks Canyon			C	7.2385246

Levels not connected by same letter are significantly different

Level	- Level	Difference	Lower CL	Upper CL	Difference
Roger Road	Jacks Canyon	1.495958	1.20629	1.785626	
Roger Road	Rio de Flag	1.346854	1.05010	1.643604	
Roger Road	Nogales IWWTP	1.013728	0.68987	1.337590	
Roger Road	Bitter Creek	0.768909	0.45265	1.085171	
Bitter Creek	Jacks Canyon	0.727049	0.50718	0.946922	
Bitter Creek	Rio de Flag	0.577945	0.34882	0.807067	
Nogales IWWTP	Jacks Canyon	0.482230	0.25156	0.712900	
Nogales IWWTP	Rio de Flag	0.333126	0.09362	0.572629	
Bitter Creek	Nogales IWWTP	0.244819	-0.01847	0.508112	
Rio de Flag	Jacks Canyon	0.149104	-0.04164	0.339846	

Determining why the differences exist between each EDW is paramount in our understanding of the range of values from “good” to “bad” as well as recommendations for future EDW’s. As proven through earlier correlations in this report, logical sets of variables such as nutrients, substrate type, and dissolved oxygen have profound impacts on diversity of aquatic macroinvertebrates. Comparing these variables between EDW’s provides further insight into the limitations of any given one.

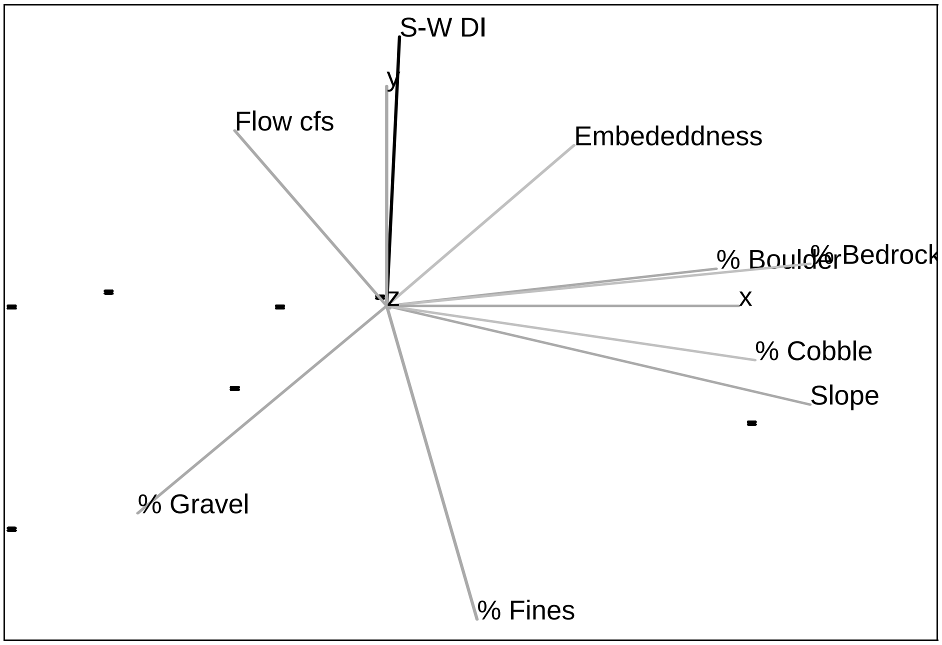
<u>Physical Variables and Diversity</u>

For the EDW’s as a whole, there were very few correlations either positive or negative between diversity and physical habitat. Undoubtedly, physical habitat does play an important role in determining the diversity of organisms in an area; however, in this study there appear to be other constraints to diversity that may be more important.

There were weakly positive correlations between diversity, flow, and percent embeddedness and a fairly strong inverse correlation with percent fine material (lumped together as sand/silt/clay). The positive correlation with embeddedness seems counter-intuitive but considering that Jack’s Canyon had a relatively high degree of embeddedness as measured, and relatively high diversity, this could have added weight to this positive correlation. Jack’s Canyon, for reasons previously mentioned, had a percent embeddedness that may be insignificant because of the way it was measured. The very weakly positive correlation between flow and diversity also seems counter-intuitive especially when the sites with the lowest diversity had the highest flow (e.g., PCSC and SC). The reasoning behind both flow being weakly positively correlated with diversity may be more a function of temperature and dissolved oxygen than flow. Flow was usually highest in the winter at most EDW’s, especially at the downstream site which always had higher diversity. Dissolved oxygen levels were also highest during this time so that sites that went anoxic during the summer (e.g., PCSC and SC), had this constraint somewhat eased during the winter; the period of highest flow (e.g., autocorrelation). The same temporal aspect could have contributed to the inverse correlation between percent fine material and diversity in that the former was more abundant during the summer low flow period, again, a time of dissolved oxygen stress.

At any rate, correlations between levels of diversity and physical variables as measured are ambiguous.

Figure 3f. ***PCA of diversity and physical variables***



Principal Components

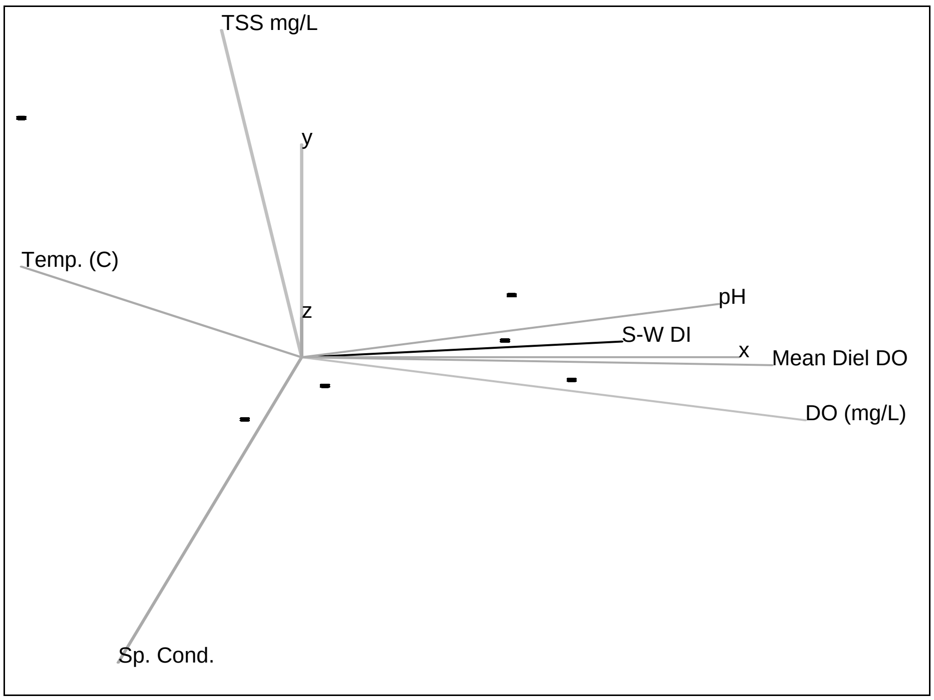
Eigenvalue	2.5671	2.3205	1.7624	1.1637	0.5600	0.2921	0.1430	0.1303	0.0610
Percent	28.5229	25.7833	19.5824	12.9305	6.2225	3.2450	1.5886	1.4476	0.6773
Cum Percent	28.5229	54.3062	73.8885	86.8190	93.0415	96.2865	97.8752	99.3227	100.0000
Eigenvectors									
S-W DI	0.01604	-0.13567	-0.67310	-0.14339	-0.24478	0.50467	0.41325	0.08499	0.12293
Flow cfs	-0.17491	0.18981	0.61417	0.20350	-0.32504	0.32868	0.42328	0.12704	0.32523
Slope	0.49518	0.02984	-0.12574	0.48815	0.01738	-0.18251	0.20306	-0.55831	0.33653
Embededdness	0.21835	-0.46514	0.22807	0.15022	0.61204	0.30340	0.31676	0.11121	-0.28642
% Fines	0.10679	-0.57541	0.05945	-0.12861	-0.30353	-0.58364	0.27892	0.31783	0.16078
% Gravel	-0.28822	0.45405	-0.23796	0.11815	0.43763	-0.38621	0.46816	0.27558	0.06619
% Cobble	0.43229	0.35319	0.12647	-0.32498	-0.24927	-0.10128	0.36624	-0.10771	-0.59047
% Boulder	0.38739	0.15423	0.12742	-0.62344	0.31993	0.07238	-0.05237	0.07808	0.55208
% Bedrock	0.49482	0.20624	-0.09757	0.39036	-0.10673	0.08140	-0.27322	0.67669	-0.01192

Physico-chemical Variables and Diversity

Similar to the individual analyses, the physico-chemical analyses showed a very strong correlation between levels of diversity, dissolved oxygen, and mean diel dissolved oxygen. This makes sense given that the sites with the lowest DO levels also had the lowest diversity and vice versa. There was also a strong positive correlation with pH and a strong inverse correlation with temperature. The diversity/temperature inverse correlation seems logical as diversity was higher during the summer. The pH/diversity positive correlation is probably an artifact due to increased photosynthesis during the summer and the fact that sites with the highest diversity also had relatively high amounts of periphyton leading to the photosynthetic increase in pH.

The mean diel DO positive correlation with diversity in almost every case so far makes this an extraordinarily important variable in scoring EDW's. Taking point samples of dissolved oxygen during the day may be misleading due to the combined effect of photosynthesis and respiration on a daily scale. Supersaturation of dissolved oxygen during the day does little to increase survivability when, during nightly respiration, DO levels fall below what is required for aquatic life. Also, the period of time that DO levels remain low is of utmost importance. Most aquatic organisms are adapted to some daily fluctuations in dissolved oxygen levels, however, the longer-term the stressor, the lower the chance of survivability. In the EDW's we studied, the sites that had the lowest mean diel DO levels had little in-stream photosynthesis from periphyton so the large spikes in DO during the day were absent and DO levels were continually suppressed but plummeted to anoxic levels for substantial periods of time during the night. The continually suppressed dissolved oxygen levels at Roger Road and the Nogales International WWTP are probably due to relatively poor in-stream water quality.

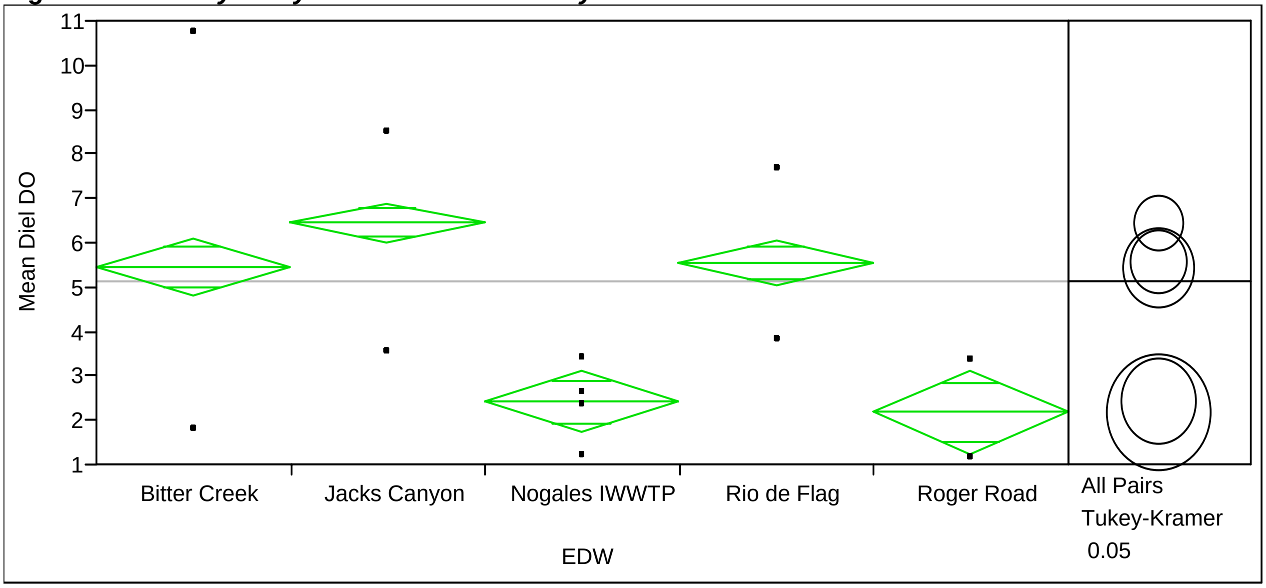
Figure 4f. ***PCA of diversity and physico-chemical variables.***



Principal Components

Eigenvalue	2.6779	1.3015	1.0856	0.9713	0.5830	0.2887	0.0922
Percent	38.2553	18.5927	15.5083	13.8752	8.3282	4.1236	1.3166
Cum Percent	38.2553	56.8480	72.3563	86.2315	94.5598	98.6834	100.0000
Eigenvectors							
S-W DI	0.34298	-0.46989	0.00339	-0.35284	0.66630	0.21751	0.21400
Mean Diel DO	0.50525	-0.09547	-0.06762	0.22278	-0.49750	0.58433	0.30406
Temp. (C)	-0.29778	0.60555	0.17768	-0.38523	0.14236	0.56771	0.14864
Sp. Cond.	-0.19446	0.13912	-0.67315	0.53545	0.39403	0.20508	0.07539
pH	0.44864	0.52235	0.02585	0.05482	0.14935	-0.46876	0.52930
DO (mg/L)	0.54054	0.32993	0.00691	0.04757	0.18199	0.11050	-0.74251
TSS mg/L	-0.08446	-0.04843	0.71415	0.62088	0.27855	0.12225	0.04987

Figure 5f. ***Oneway analysis of mean diel DO by EDW***



Oneway Anova

Summary of Fit

Rsquare	0.272775
Adj Rsquare	0.264604
Root Mean Square Error	2.549007
Mean of Response	5.134329
Observations (or Sum Wgts)	10

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Bitter Creek	2	5.47028	0.32637	4.8284	6.1121
Jacks Canyon	2	6.46131	0.23078	6.0075	6.9152
Nogales IWWTP	2	2.43736	0.35013	1.7488	3.1259
Rio de Flag	2	5.57546	0.25881	5.0665	6.0845
Roger Road	2	2.19735	0.48172	1.2500	3.1447

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.74182	0.05

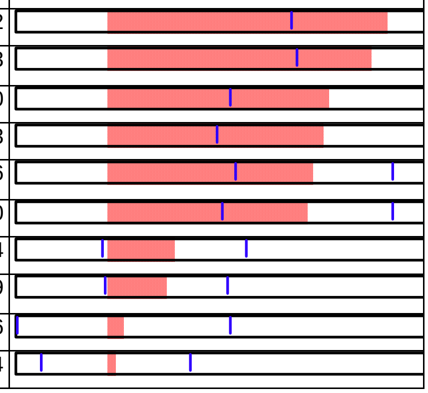
Abs(Dif)-LSD	Jacks Canyon	Rio de Flag	Bitter Creek	Nogales IWWTP	Roger Road
Jacks Canyon	-0.8948	-0.0649	-0.1049	2.8742	2.7994
Rio de Flag	-0.0649	-1.0036	-1.0369	1.9443	1.8788
Bitter Creek	-0.1049	-1.0369	-1.2655	1.7205	1.6776
Nogales IWWTP	2.8742	1.9443	1.7205	-1.3576	-1.3928
Roger Road	2.7994	1.8788	1.6776	-1.3928	-1.8679

Positive values show pairs of means that are significantly different.

Level			Mean
Jacks Canyon	A		6.4613115
Rio de Flag	A		5.5754639
Bitter Creek	A		5.4702787
Nogales IWWTP		B	2.4373604
Roger Road		B	2.1973464

Levels not connected by same letter are significantly different

Level	- Level	Difference	Lower CL	Upper CL	Difference
Jacks Canyon	Roger Road	4.263965	2.79944	5.728492	
Jacks Canyon	Nogales IWWTP	4.023951	2.87418	5.173723	
Rio de Flag	Roger Road	3.378117	1.87878	4.877460	
Bitter Creek	Roger Road	3.272932	1.67756	4.868303	
Rio de Flag	Nogales IWWTP	3.138104	1.94430	4.331906	
Bitter Creek	Nogales IWWTP	3.032918	1.72054	4.345300	
Jacks Canyon	Bitter Creek	0.991033	-0.10492	2.086984	
Jacks Canyon	Rio de Flag	0.885848	-0.06490	1.836599	
Nogales IWWTP	Roger Road	0.240014	-1.39280	1.872826	
Rio de Flag	Bitter Creek	0.105185	-1.03687	1.247244	



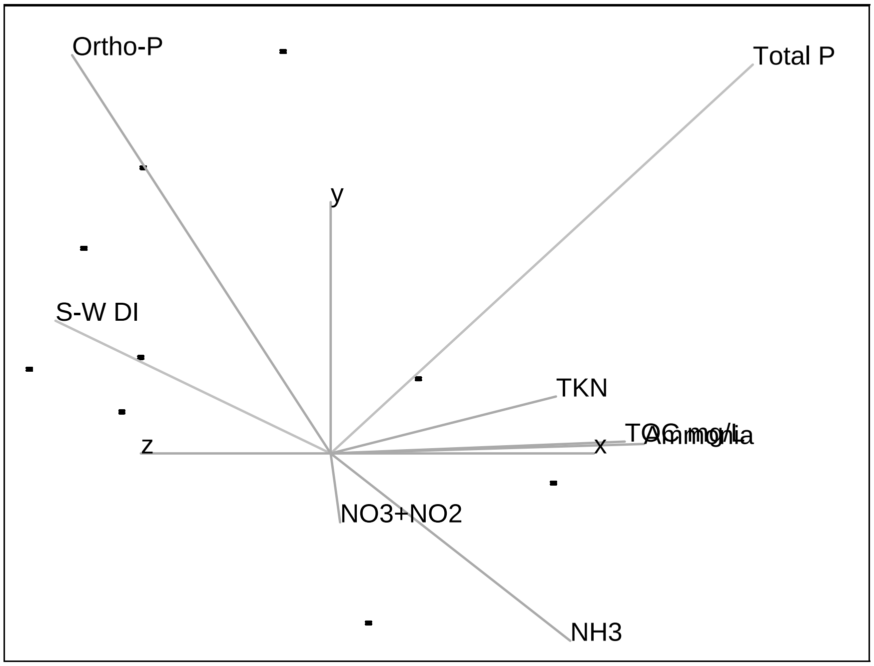
Nutrients and Diversity

The same very strong inverse correlation between un-ionized ammonia and diversity as found in almost every individual analyses still exists when the data is examined as a whole. Undoubtedly, toxicity to aquatic organisms by un-ionized ammonia is a very important variable to their survival and overall diversity. There was also an inverse correlation between diversity and levels of ammonia, TOC, TKN and nitrate+nitrite. We did no fractionation of organic carbon so it's impossible to determine what constituents contributed most to the collective whole but it's possible that compounds within the TOC pool are directly toxic to aquatic macroinvertebrates. In lieu of any direct toxicity, the organic carbon pool, if significantly large, will consume dissolved oxygen from the water so there may be some autocorrelative effect. The negative correlation between diversity and nitrate/nitrite may be due to the inter-convertability of these variables to a more reduced form. Overall, there were negative correlations between diversity and basically all forms of nitrogen but especially un-ionized ammonia.

Levels of phosphorous appear to have little or no effect on diversity. There was a weakly positive correlation with orthophosphate and a weak inverse correlation with total P. This doesn't mean that these variables are unimportant to diversity rather that, as compared to the negative effect of nitrogenous species on diversity, phosphorous is of much less importance.

Jack's Canyon had the lowest levels of un-ionized ammonia. Bitter Creek, Rio de Flag, and the Nogales International WWTP had no statistical difference between them and contained intermediate amounts of un-ionized ammonia. Roger Road WWTP had, by a relatively large margin, the highest levels of un-ionized ammonia.

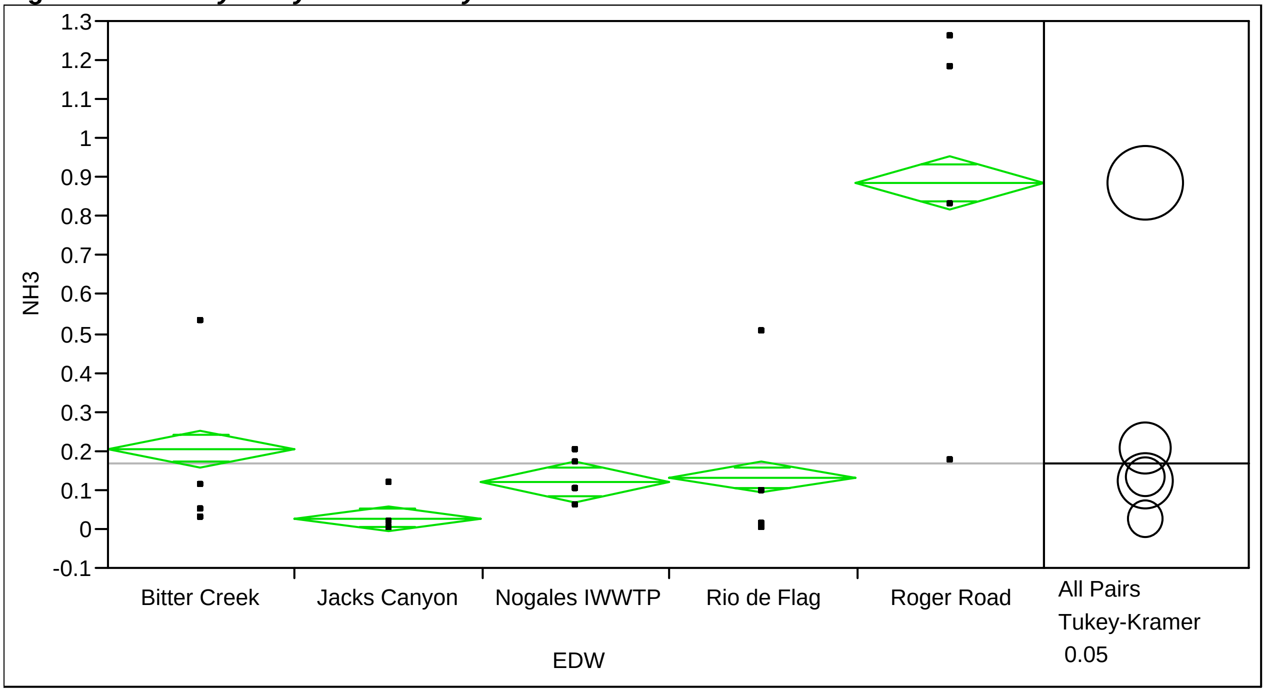
Figure 6f. ***PCA of nutrient levels and diversity***



Principal Components

Eigenvalue	4.1272	2.1730	1.0330	0.3723	0.2025	0.0656	0.0250	0.0014
Percent	51.5901	27.1626	12.9122	4.6535	2.5311	0.8199	0.3126	0.0180
Cum Percent	51.5901	78.7527	91.6649	96.3185	98.8495	99.6694	99.9820	100.0000
Eigenvectors								
S-W DI	-0.41269	0.21847	-0.17025	0.36861	0.72909	0.27534	0.09603	0.02203
NH3	0.38077	-0.30602	-0.10103	-0.61503	0.42640	0.35700	0.25222	0.00462
Ammonia	0.47492	0.01726	0.01164	0.32769	-0.01942	0.53488	-0.61611	-0.02399
NO3+NO2	0.01376	-0.11158	0.96399	0.07983	0.21974	-0.00356	0.05826	-0.00354
Ortho-P	0.07987	0.65348	0.10581	-0.29897	0.00293	0.03149	-0.07629	0.67763
Total P	0.14789	0.63976	0.07912	-0.18556	-0.00004	0.03620	0.09416	-0.71970
TKN	0.46018	0.09568	-0.04121	0.48203	-0.15594	0.10028	0.69925	0.14733
TOC mg/L	0.46792	0.01964	-0.11063	0.12626	0.46219	-0.70589	-0.20136	0.00702

Figure 7f. ***Oneway analysis of NH3 by EDW***



Oneway Anova

Summary of Fit

Rsquare	0.585771
Adj Rsquare	0.58113
Root Mean Square Error	0.187276
Mean of Response	0.170365
Observations (or Sum Wgts)	20

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Bitter Creek	4	0.207705	0.02398	0.1605	0.25486
Jacks Canyon	4	0.029111	0.01696	-0.0042	0.06246
Nogales IWWTP	4	0.123104	0.02572	0.0725	0.17369
Rio de Flag	4	0.135695	0.01901	0.0983	0.17309
Roger Road	4	0.888400	0.03478	0.8200	0.95679

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.74178	0.05

Abs(Dif)-LSD	Roger Road	Bitter Creek	Rio de Flag	Nogales IWWTP	Jacks Canyon
Roger Road	-0.13484	0.56488	0.64403	0.64670	0.75321
Bitter Creek	0.56488	-0.09297	-0.01190	-0.01182	0.09808
Rio de Flag	0.64403	-0.01190	-0.07373	-0.07512	0.03673
Nogales IWWTP	0.64670	-0.01182	-0.07512	-0.09975	0.00952
Jacks Canyon	0.75321	0.09808	0.03673	0.00952	-0.06574

Positive values show pairs of means that are significantly different.

Level				Mean
Roger Road	A			0.88840000
Bitter Creek		B		0.20770492
Rio de Flag		B		0.13569474
Nogales IWWTP		B		0.12310377
Jacks Canyon			C	0.02911147

Levels not connected by same letter are significantly different

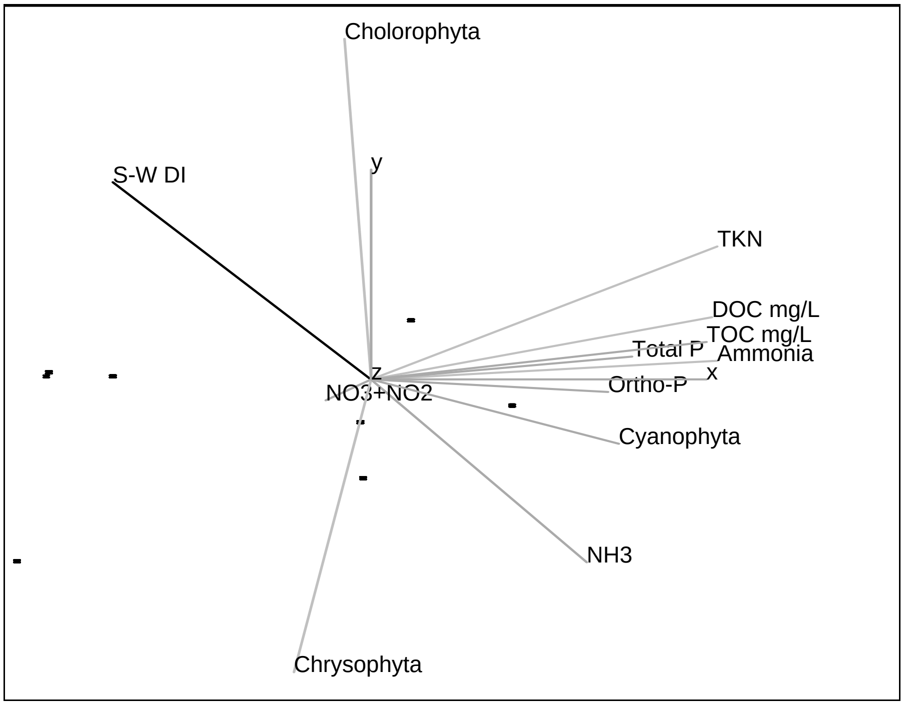
Level	- Level	Difference	Lower CL	Upper CL	Difference
Roger Road	Jacks Canyon	0.8592885	0.753211	0.9653663	
Roger Road	Nogales IWWTP	0.7652962	0.646696	0.8838962	
Roger Road	Rio de Flag	0.7527053	0.644034	0.8613766	
Roger Road	Bitter Creek	0.6806951	0.564878	0.7965120	
Bitter Creek	Jacks Canyon	0.1785935	0.098075	0.2591119	
Rio de Flag	Jacks Canyon	0.1065833	0.036733	0.1764340	
Nogales IWWTP	Jacks Canyon	0.0939923	0.009520	0.1784649	
Bitter Creek	Nogales IWWTP	0.0846011	-0.011818	0.1810205	
Bitter Creek	Rio de Flag	0.0720102	-0.011896	0.1559161	
Rio de Flag	Nogales IWWTP	0.0125910	-0.075116	0.1002984	

Diversity, Nutrients, and Periphyton

Due to the normally close association between aquatic macroinvertebrates, periphyton, and nutrient levels, we examined the correlations between these different trophic levels. In this analysis, diversity was not positively correlated with any nutrient except perhaps weakly with nitrate/nitrite. Interestingly, the same very strong inverse correlation between diversity and un-ionized ammonia still exists but there is also an inverse correlation between numbers of cyanobacteria and diversity. This makes sense as cyanobacteria would be unpalatable, and potentially toxic, to macroinvertebrates. Cyanobacteria would also be useless as a potential alternative substrate. Correlations between any nutrients and either chlorophytes or chrysophytes were non-existent and this is not unexpected in systems where nutrients are rarely, if ever, limiting for periphytic growth. There was a weakly positive correlation between cyanobacteria and levels of un-ionized ammonia and perhaps orthophosphate.

Sites that had the highest levels of cyanobacteria were Nogales IWWTP followed by Roger Road WWTP, Jack's Canyon, Rio de Flag, and Bitter Creek respectively. Bitter Creek was depauperate in overall periphytic biomass. Due to the large discrepancy in numbers of cyanobacteria between EDW's, data was log transformed for comparison.

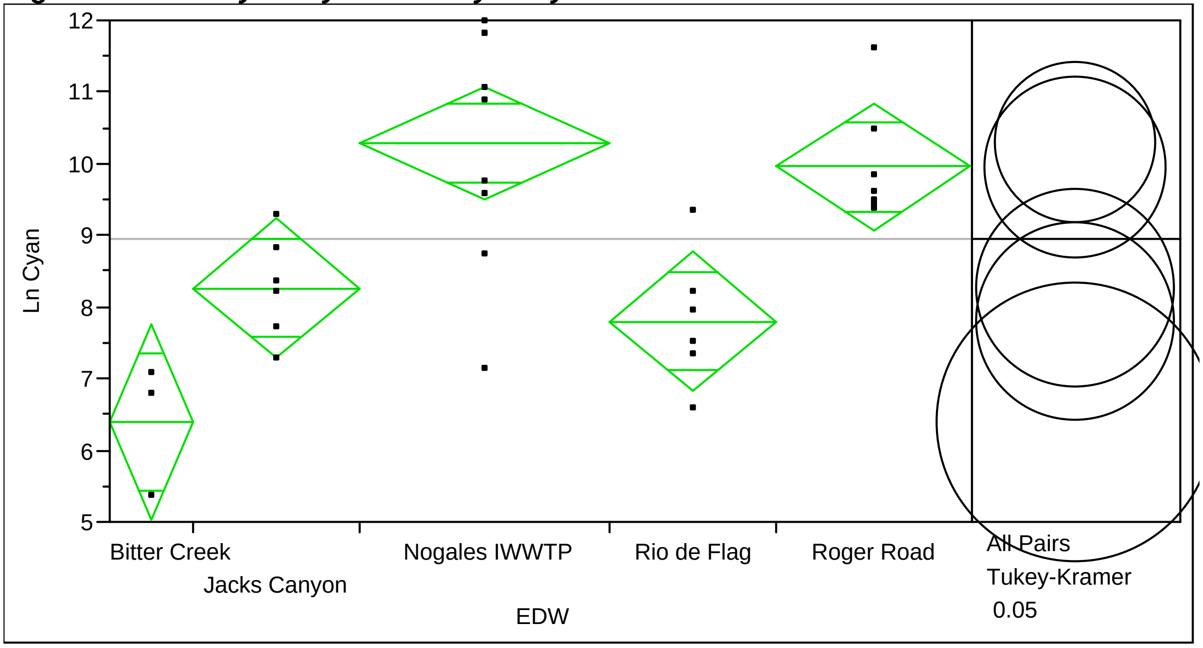
Figure 8f. ***PCA of nutrients, periphyton by division, and diversity*.**



Principal Components

Eigenvalue	6.1219	2.2611	1.8881	0.6740	0.4616	0.3330	0.1302	0.0807	0.0377	0.0115	0.0001	0.0000
Percent	51.0161	18.8429	15.7342	5.6167	3.8467	2.7752	1.0853	0.6724	0.3143	0.0958	0.0005	0.0001
Cum Percent	51.0161	69.8589	85.5932	91.2099	95.0566	97.8318	98.9170	99.5894	99.9037	99.9994	99.9999	100.0000
Eigenvectors												
S-W DI	-0.29119	-0.30972	0.29649	0.16083	-0.08338	0.36139	0.01372	0.58416	0.37898	0.27996	0.04256	0.05202
NH3	0.24610	0.42763	-0.15953	0.32276	-0.14144	-0.33094	0.56968	0.32091	0.11869	0.23542	0.01830	0.00693
Ammonia	0.39169	-0.00195	-0.10494	0.02086	-0.13630	0.03584	-0.16059	-0.14306	0.80126	-0.35469	-0.03418	-0.00465
NO3+NO2	-0.04992	-0.16214	-0.59137	0.09745	0.74295	-0.03625	-0.07357	0.15138	0.13393	0.11082	0.01271	0.00406
Ortho-P	0.26850	-0.41707	0.24068	0.17240	0.19433	-0.02241	0.35727	-0.06297	-0.10944	-0.28404	0.63544	0.00119
Total P	0.29786	-0.37365	0.22398	0.16737	0.17667	0.04526	0.29343	-0.10897	-0.08628	-0.00089	-0.74482	0.00630
TKN	0.39353	-0.05095	-0.00156	-0.10347	-0.01864	0.24467	-0.05993	-0.37592	0.06367	0.76518	0.19273	-0.00372
DOC mg/L	0.38661	0.09760	0.06025	0.18483	0.02380	0.11543	-0.36823	0.33768	-0.22718	-0.05197	0.00398	-0.69669
TOC mg/L	0.38242	0.13261	0.07028	0.19657	0.04387	0.06838	-0.38735	0.26123	-0.23261	-0.06324	0.00851	0.71381
Cyanophyta	0.28129	-0.05519	0.05000	-0.84441	0.08599	-0.11451	0.14639	0.39870	0.00545	-0.01112	-0.02214	0.02743
Cholorophyta	-0.02769	0.55684	0.21078	-0.07065	0.38783	0.61939	0.25922	-0.08578	0.04338	-0.17100	-0.00345	-0.00200
Chrysophyta	-0.08630	0.19628	0.60193	0.02765	0.41579	-0.52925	-0.22910	-0.08153	0.22634	0.16081	0.01564	-0.03863

Figure 9f. ***Oneway analysis of ln cyan by EDW***



Oneway Anova

Summary of Fit

Rsquare	0.610428
Adj Rsquare	0.550494
Root Mean Square Error	1.147815
Mean of Response	8.977428
Observations (or Sum Wgts)	31

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Bitter Creek	3	6.4017	0.66269	5.0395	7.764
Jacks Canyon	6	8.2777	0.46859	7.3145	9.241
Nogales IWWTP	9	10.3034	0.38260	9.5170	11.090
Rio de Flag	6	7.8162	0.46859	6.8530	8.779
Roger Road	7	9.9716	0.43383	9.0798	10.863

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.92845	0.05

Abs(Dif)-LSD	Nogales IWWTP	Roger Road	Jacks Canyon	Rio de Flag	Bitter Creek
Nogales IWWTP	-1.5845	-1.3621	0.2542	0.7156	1.6609
Roger Road	-1.3621	-1.7967	-0.1762	0.2852	1.2503
Jacks Canyon	0.2542	-0.1762	-1.9407	-1.4792	-0.5008
Rio de Flag	0.7156	0.2852	-1.4792	-1.9407	-0.9622
Bitter Creek	1.6609	1.2503	-0.5008	-0.9622	-2.7445

Positive values show pairs of means that are significantly different.

Level				Mean
Nogales IWWTP	A			10.303429
Roger Road	A	B		9.971553
Jacks Canyon		B	C	8.277672
Rio de Flag			C	7.816247
Bitter Creek			C	6.401673

Levels not connected by same letter are significantly different

Level	- Level	Difference	Lower CL	Upper CL	Difference
Nogales IWWTP	Bitter Creek	3.901756	1.66087	6.142638	
Roger Road	Bitter Creek	3.569880	1.25035	5.889413	
Nogales IWWTP	Rio de Flag	2.487182	0.71561	4.258755	
Roger Road	Rio de Flag	2.155306	0.28524	4.025374	
Nogales IWWTP	Jacks Canyon	2.025757	0.25418	3.797329	
Jacks Canyon	Bitter Creek	1.875999	-0.50081	4.252813	
Roger Road	Jacks Canyon	1.693881	-0.17619	3.563948	
Rio de Flag	Bitter Creek	1.414574	-0.96224	3.791388	
Jacks Canyon	Rio de Flag	0.461425	-1.47924	2.402086	
Nogales IWWTP	Roger Road	0.331876	-1.36207	2.025823	

Constraints to Diversity in Effluent Dominated Waters

The inter-relatedness of physical, chemical, and biological variables often makes determination of what constitutes “habitat” for an organism difficult at best. In lieu of external physical or chemical stressors, populations of organisms have methods to regulate their own numbers. Diversity of the biotic assemblage, in such a situation, is at a maximum given available resources. Once a stressor is applied, population structure and function changes as a result. The layering and interaction of a multitude of stressors results in changes in population structure and function and, by definition, resulting changes in overall biological diversity. The correlation between changes in population structure, function, and diversity is a result of the iterative complexity of all external stressors exerting simultaneous pressure. The adaptation(s) of an organism to best utilize available resources in the face of a continuous array of stressors results in speciation. If stressors become too great, then only a very few species will be able to utilize available resources and biological diversity within an area will decrease as a result. The correlation between stressors and biological diversity is rarely, if ever, linear. The type and magnitude of stressors continually change so that the matrix of pressure exerted results in ever-changing levels of diversity. If it weren’t for some disturbance within an area, diversity would decrease due to only a few species ability to utilize available resources to the exclusion of others. The magnitude and frequency of disturbances, to a large extent, regulate diversity within an area. Prolonged disturbances (i.e. stressors) of a high magnitude result in a continual suppression of diversity.

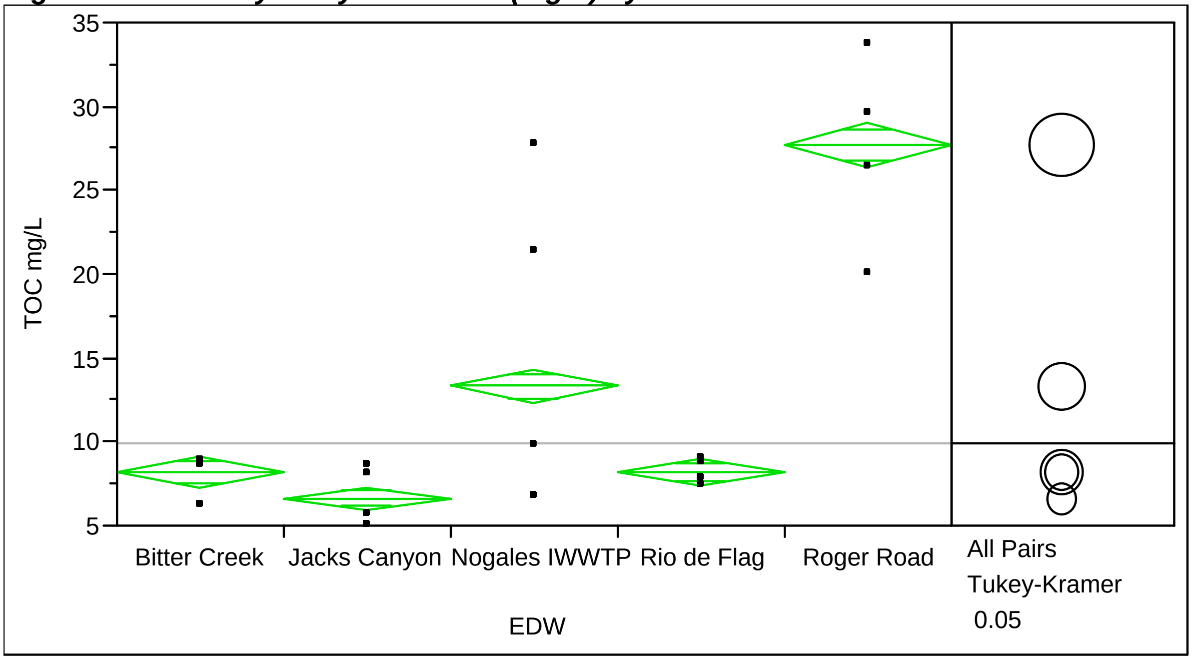
Attempting to determine, or quantify, any individual stressor affecting biological diversity is difficult due to the inter-relatedness of all stressors. For example, in aquatic systems having large ammonia and simultaneously low dissolved oxygen levels, which one is exerting the greater influence over the other? If dissolved oxygen levels were increased, nitrification would occur at a faster rate and ammonia levels would decrease but what if the low dissolved oxygen is a result of the oxygen demand of organic waste of which ammonia is a constituent? Lowering the organic waste load would, by definition, lower ammonia and therefore increase dissolved oxygen. The chicken and egg approach rarely gets to the heart of the problem and it’s safe to assume that, in effluent-dependent waters, it is the organic waste load, as well as the treatment plants efficacy in removing oxygen-consuming compounds in that waste load, that leads to dissolved oxygen depletion. The positive feedback that occurs in a stream with extremely low dissolved oxygen levels is that in-stream nitrification is limited perpetuating the problem. In other words, a streams ability to recover from a pollutant load, as well as the linear distance it takes to do so, is in direct proportion to the contaminant load entering it at any given point. The lower the contaminant load, the less distance it will take the stream to return to whatever background levels are in the vicinity. We attempted to find this “recovery” zone in every case and this is the rationale behind having the sites between EDW’s at different distances from the outfall. While no EDW ever returned to whatever background levels would be in the local geographic area, some did better than others. The ones that fared the best were those that either had some form of advanced treatment, or had relatively low waste loads entering the treatment plant in the first place. We believe that overall contaminant loading to the EDW at the outfall, and the inherent ability of the stream to assimilate, convert, and otherwise absorb this contaminant loading determines what organism(s) will ever become capable of living in any EDW.

In order to make comparisons of relative rate of assimilation and conversion of contaminants would have required flow-weighted sampling equidistant from each outfall which we did not do. However, the EDW’s that had the least amount of diversity of aquatic macroinvertebrates were the sites having the longest distances between the outfall and the downstream site simply because a recovery zone was never found. It is, therefore, still fair to make comparisons of contaminant loading into each EDW. In some cases, such as Bitter Creek, flow became subsurface after some distance and above this point, obviously, determined where the second site was located.

For this analysis we lumped nitrogen species (nitrate, nitrite, ammonia, and TKN) into a total N category, and used TOC to determine the organic carbon load. Since there was only a weak positive correlation with orthophosphate, and an equally weak negative correlation with total P, the effect of either on diversity appears to be minimal. The same results were found in most individual analyses as well (except for Rio de Flag which may approach phosphorous limitation during the summer). If nitrogen and carbon loads were lessened, the effect of phosphorous may be more pronounced but since we are trying to determine the major constraints to diversity, it makes little sense to include phosphorous in further analyses. Totals were a mean of both sites and both winter and summer samplings at each EDW.

For TOC, there was no statistical difference between Jack’s Canyon, Rio de Flag, and Bitter Creek all of which had relatively low levels. There was a jump in TOC at Nogales International WWTP and then a very large relative increase at Roger Rd WWTP. The sites with the highest diversity and levels of dissolved oxygen were the sites with the lowest levels of TOC. Total nitrogen exhibited almost the exact same trend except Bitter Creek had intermediate levels of total N, Jack’s Canyon and Rio de Flag were statistically similar and had the lowest levels, and both Nogales International WWTP and Roger Road WWTP had the largest levels respectively.

Figure 10f. ***Oneway analysis of TOC (mg/L) by EDW***



Oneway Anova

Summary of Fit

Rsquare	0.702972
Adj Rsquare	0.699644
Root Mean Square Error	3.710271
Mean of Response	10.0279
Observations (or Sum Wgts)	362

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Bitter Creek	4	8.2213	0.47505	7.287	9.156
Jacks Canyon	4	6.6639	0.33591	6.003	7.325
Nogales IWWTP	4	13.3755	0.50964	12.373	14.378
Rio de Flag	4	8.2546	0.37672	7.514	8.996
Roger Road	4	27.7931	0.68898	26.438	29.148

Std Error uses a pooled estimate of error variance

Means Comparisons

Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.74178	0.05

Abs(Dif)-LSD	Roger Road	Nogales IWWTP	Rio de Flag	Bitter Creek	Jacks Canyon
Roger Road	-2.671	12.068	17.385	17.277	19.028
Nogales IWWTP	12.068	-1.976	3.383	3.244	5.038
Rio de Flag	17.385	3.383	-1.461	-1.629	0.207
Bitter Creek	17.277	3.244	-1.629	-1.842	-0.038
Jacks Canyon	19.028	5.038	0.207	-0.038	-1.302

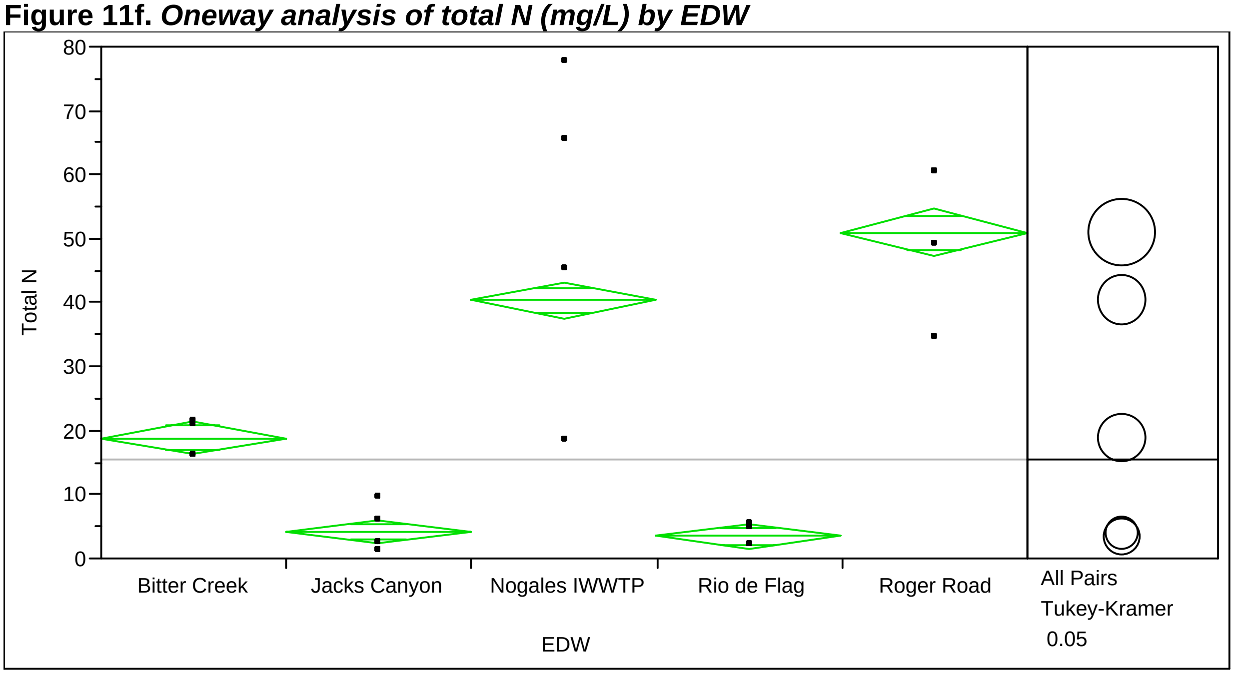
Positive values show pairs of means that are significantly different.

Level					Mean
Roger Road	A				27.793103
Nogales IWWTP		B			13.375472
Rio de Flag			C		8.254639
Bitter Creek			C	D	8.221311
Jacks Canyon				D	6.663934

Levels not connected by same letter are significantly different

Level	- Level	Difference	Lower CL	Upper CL	Difference
Roger Road	Jacks Canyon	21.12917	19.0276	23.23076	
Roger Road	Bitter Creek	19.57179	17.2772	21.86634	
Roger Road	Rio de Flag	19.53846	17.3855	21.69144	
Roger Road	Nogales IWWTP	14.41763	12.0680	16.76731	
Nogales IWWTP	Jacks Canyon	6.71154	5.0380	8.38509	
Nogales IWWTP	Bitter Creek	5.15416	3.2439	7.06440	
Nogales IWWTP	Rio de Flag	5.12083	3.3832	6.85848	
Rio de Flag	Jacks Canyon	1.59070	0.2068	2.97457	
Bitter Creek	Jacks Canyon	1.55738	-0.0378	3.15259	
Rio de Flag	Bitter Creek	0.03333	-1.6290	1.69566	

Figure 11f. ***Oneway analysis of total N (mg/L) by EDW***



Oneway Anova

Summary of Fit

Rsquare	0.726401
Adj Rsquare	0.723336
Root Mean Square Error	10.25599
Mean of Response	15.62583
Observations (or Sum Wgts)	362

Analysis of Variance

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Bitter Creek	4	19.0064	1.3131	16.424	21.589
Jacks Canyon	4	4.2702	0.9285	2.444	6.096
Nogales IWWTP	4	40.4645	1.4088	37.694	43.235
Rio de Flag	4	3.5986	1.0413	1.551	5.646
Roger Road	4	51.1214	1.9045	47.376	54.867

Std Error uses a pooled estimate of error variance

Means Comparisons
Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.74178	0.05

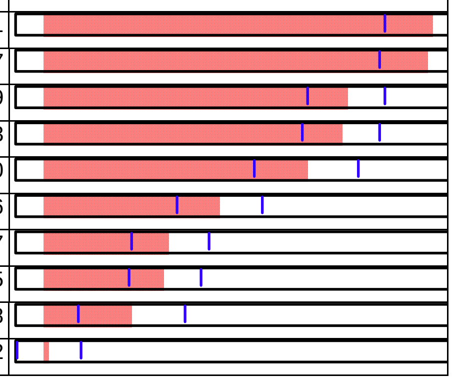
Abs(Dif)-LSD	Roger Road	Nogales IWWTP	Bitter Creek	Jacks Canyon	Rio de Flag
Roger Road	-7.385	4.162	25.772	41.042	41.572
Nogales IWWTP	4.162	-5.462	16.178	31.568	32.063
Bitter Creek	25.772	16.178	-5.092	10.327	10.813
Jacks Canyon	41.042	31.568	10.327	-3.600	-3.154
Rio de Flag	41.572	32.063	10.813	-3.154	-4.038

Positive values show pairs of means that are significantly different.

Level					Mean
Roger Road	A				51.121379
Nogales IWWTP		B			40.464528
Bitter Creek			C		19.006393
Jacks Canyon				D	4.270164
Rio de Flag				D	3.598557

Levels not connected by same letter are significantly different

Level	- Level	Difference	Lower CL	Upper CL	Difference
Roger Road	Rio de Flag	47.52282	41.5715	53.47411	
Roger Road	Jacks Canyon	46.85122	41.0420	52.66047	
Nogales IWWTP	Rio de Flag	36.86597	32.0627	41.66919	
Nogales IWWTP	Jacks Canyon	36.19436	31.5683	40.82043	
Roger Road	Bitter Creek	32.11499	25.7724	38.45760	
Nogales IWWTP	Bitter Creek	21.45813	16.1778	26.73846	
Bitter Creek	Rio de Flag	15.40784	10.8128	20.00287	
Bitter Creek	Jacks Canyon	14.73623	10.3267	19.14575	
Roger Road	Nogales IWWTP	10.65685	4.1618	17.15188	
Jacks Canyon	Rio de Flag	0.67161	-3.1537	4.49692	

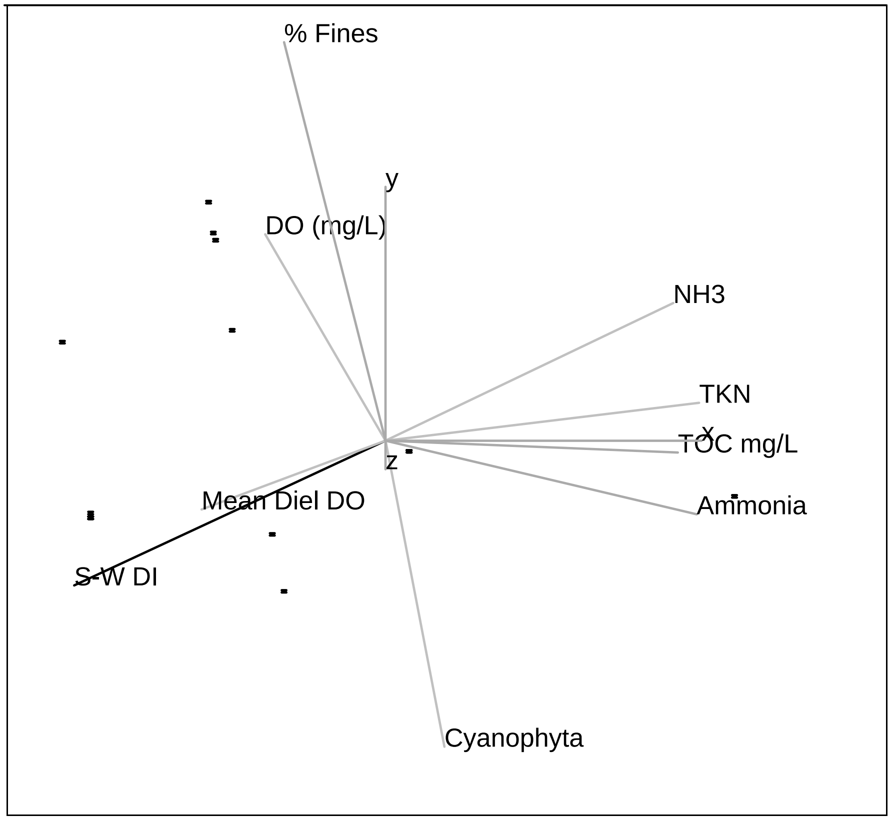


From all of the individual analyses and subsequent comparison of sites it becomes clear that large levels of nitrogen, particularly un-ionized ammonia, and organic carbon have devastating effects on stream organisms both directly through potential toxicity and indirectly through chronic losses of dissolved oxygen. We have also found through our analyses that other variables can also lower diversity such as, percent fine material, TKN, and the presence of cyanobacteria. In order to rank these stressors, we performed a PCA using only those variables proven to be the most detrimental to diversity.

Overwhelmingly, high levels of un-ionized ammonia coupled with low levels of mean diel dissolved oxygen proved to be the most detrimental to diversity. Total Kjeldahl nitrogen followed by TOC, ammonia, and point samples of DO also proved to be highly detrimental. Percent fine material and biomass of cyanobacteria proved, in this matrix, to be the least detrimental to diversity.

Tiered layering of stressors means that as one or more of the most detrimental constraints are lifted, others will emerge as being the next in line in order of importance. It has been proven time and again that physical habitat is an extremely important aspect of the life history requirement of several species of aquatic macroinvertebrates and these analyses do nothing to dispute that. However, the first tier of stressors regarding diversity of macroinvertebrates in the EDW's studied is the individual treatment plants ability to cope with, and remove, large amounts of reduced and organic nitrogen and carbon. One option in maintaining diversity within an EDW is, as may be the case with Jack's Canyon, relatively low organic loading to the plant in the first place. The Big Park WWTP, while relatively small, seems more than adequate in treating the 3000 residential customers in its service area. Rio de Flag produces class A+ water which has low levels of nitrogenous compounds leaving the plant. The two-stage Bardenpho process utilized at this plant, combined with UV sterilization, seems to be very efficient at reducing organic loading into Rio de Flag and diversity is maintained as a result. Rio de Flag is probably a "substrate limited" system and there was therefore, an added importance of the filamentous algae as an alternative substrate source. Had Rio de Flag not been substrate limited, it would have probably scored higher. Bitter Creek, like Jack's Canyon, also only serves a relatively small, residential population. However, unlike Jack's Canyon, it seems just capable of meeting current demand and removal of organic pollutants, while adequate, could be improved especially given the small population served. There was a UV sterilizer at the outfall; however, this was not in operation during either site visit so any potential improvement this could have had is unknown. Bitter Creek had a relatively verdant riparian canopy and, in some ways, may be "flow limited" especially during the summer when evapotranspiration rates are high. Roger Road and Nogales International WWTP's serve a large population of both industrial and residential users and in the case of Nogales International WWTP, serve populations in 2 countries. Both WWTP's may have organic loading into the Santa Cruz River at levels that are possibly detrimental to aquatic organisms which might otherwise inhabit the 2 reaches of the river if this organic loading was decreased. This may result in acute and chronic toxicity of aquatic organisms that immigrate into these areas with the resulting diversity near non-existent levels. Both systems, like Rio de Flag, are probably substrate limited to varying degrees but the difference between Nogales International, Roger Road, and Rio de Flag WWTP's is that the latter has much lower organic loading into the receiving stream. The argument can be made that both Santa Cruz sites would be dry for the majority of the year if it weren't for the treated effluent currently emptied into them, however, in terms of aquatic macroinvertebrates at least; diversity is currently extremely low in any case. It appears that only the most pollution tolerant organisms are currently able to inhabit either area of the Santa Cruz. If pollution tolerance and diversity are inversely correlated, as we propose they are, then an analysis of pollution tolerance weighed against the same factors as those previously used for diversity should also be inversely correlated. Figures 12f and 13f prove that this is indeed the case with levels of diversity and pollution tolerances almost mirror images of one another.

Figure 12f. ***PCA of diversity and variables proven to be constraints to it.***



Principal Components

Eigenvalue	4.8452	1.8667	0.8675	0.4963	0.4609	0.2589	0.1337	0.0482	0.0225
Percent	53.8356	20.7415	9.6393	5.5145	5.1211	2.8765	1.4856	0.5354	0.2504
Cum Percent	53.8356	74.5771	84.2164	89.7309	94.8521	97.7286	99.2143	99.7496	100.0000
Eigenvectors									
S-W DI	-0.42949	0.08685	-0.14341	-0.16536	-0.23194	0.07781	-0.10627	0.82285	0.10888
NH3	0.39868	0.13919	0.11660	-0.08255	0.22057	-0.74747	0.17823	0.37306	-0.15156
Cyanophyta	0.08234	-0.50735	0.60610	-0.28073	-0.52551	-0.03621	0.09152	0.02056	-0.05815
Mean Diel DO	-0.25233	0.33296	0.49969	0.71783	-0.12361	-0.01853	0.18879	0.06514	-0.07066
DO (mg/L)	-0.16325	0.47977	0.52262	-0.52307	0.34855	0.16128	-0.19934	-0.08739	-0.03954
TOC mg/L	0.40498	0.19562	-0.00631	-0.11222	0.00135	0.48503	0.69324	0.18657	0.18559
Ammonia	0.43256	0.06136	0.17234	0.18176	-0.04957	0.03290	-0.48138	0.11320	0.70591
TKN	0.43453	-0.00116	0.02573	0.16173	-0.00128	0.38413	-0.39413	0.26138	-0.64276
% Fines	-0.13986	-0.57672	0.21274	0.16236	0.69438	0.15388	0.07438	0.23557	0.09663

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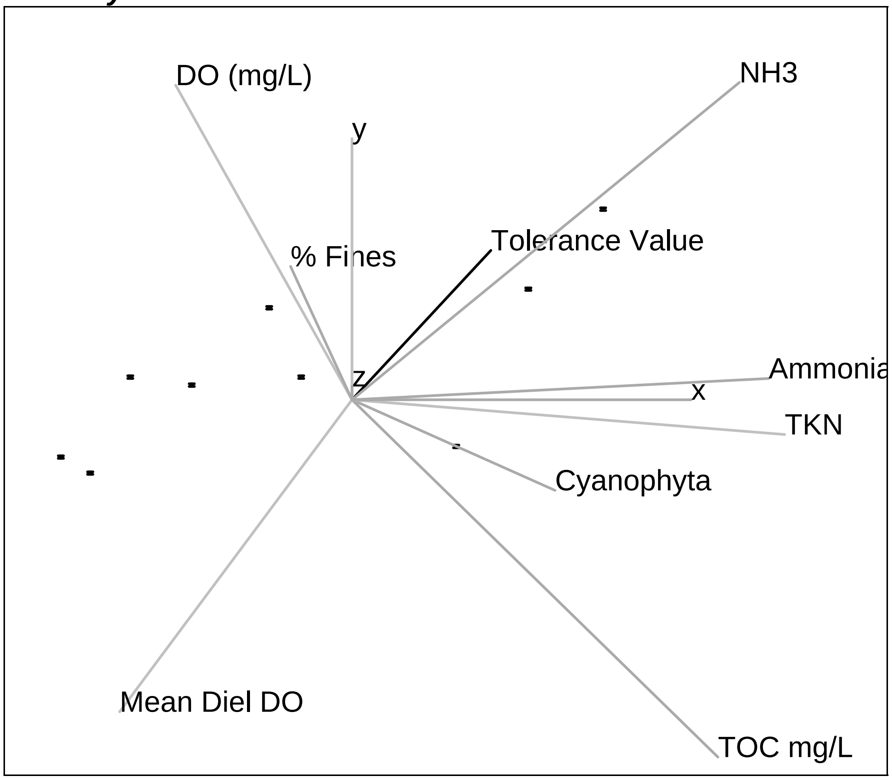
Figure 13f. ***PCA of HBI tolerance values and contaminants proven to be constraints to diversity.***



Principal Components

Eigenvalue	4.0794	1.8205	1.0987	0.8659	0.5046	0.3060	0.2657	0.0483	0.0109
Percent	45.3263	20.2273	12.2074	9.6213	5.6071	3.3999	2.9524	0.5370	0.1213
Cum Percent	45.3263	65.5536	77.7610	87.3823	92.9894	96.3893	99.3418	99.8787	100.0000
Eigenvectors									
Tolerance Values	0.15752	0.31911	-0.59638	0.55330	0.05410	0.21655	0.39585	0.02198	0.06733
NH3	0.43525	0.15068	0.13704	-0.04439	0.30901	0.45505	-0.37407	0.54834	0.15470
Cyanophyta	0.22772	-0.38037	0.21523	0.59146	-0.55814	-0.13037	-0.15248	0.23567	0.00317
Mean Diel DO	-0.25978	0.34755	0.33472	0.47952	0.47819	-0.44491	-0.15156	0.09259	-0.10766
DO (mg/L)	-0.19705	0.41469	0.58576	0.04688	-0.31632	0.46069	0.35815	-0.05524	-0.01640
TOC mg/L	0.41062	0.20131	0.13330	-0.26658	-0.08143	-0.53281	0.48262	0.29607	0.30154
Ammonia	0.46720	0.05563	0.20440	0.13898	0.11744	0.01201	-0.16555	-0.72469	0.38861
TKN	0.48602	-0.01624	0.10863	-0.03099	0.11615	-0.00335	0.16152	-0.12831	-0.83349
% Fines	-0.06691	-0.62781	0.22961	0.13630	0.47689	0.18658	0.49240	0.04880	0.15169

Summary

Diversity of aquatic macroinvertebrates has been shown to be exceptional indicators of relative impairment of EDW's. While there are limits to diversity within any area, even those that are relatively undisturbed by humans, diversity of aquatic macroinvertebrates in the EDW's studied are most affected by levels of nitrogenous species, especially un-ionized ammonia, and mean diel dissolved oxygen. While physical variables are undoubtedly important to macroinvertebrates and other aquatic organisms, this physical constraint was only approached in EDW's where the stressor of water quality was diminished through adequate treatment processes prior to leaving the wastewater treatment plant (Rio de Flag and Jack's Canyon). The EDW's that had the highest amount of organic loading into the receiving stream, had the lowest diversity in every case.

In terms of diversity of aquatic macroinvertebrates, the ranking of EDW's was as follows (from most to least):

1) Rio de Flag
2) Jack's Canyon
3) Bitter Creek
4) Nogales IWWTP
5) Roger Road WWTP

In terms of total N released to receiving streams, the ranking of EDW's was (from most to least):

1) Roger Road WWTP
2) Nogales IWWTP
3) Bitter Creek
4) Jack's Canyon
5) Rio de Flag

In terms of un-ionized ammonia found in receiving streams, the ranking of EDW's was (from most to least):

1) Roger Road WWTP
2) Bitter Creek
3) Rio de Flag
4) Nogales IWWTP
5) Jack's Canyon

In terms of TOC released to receiving streams, the ranking of EDW's was (from most to least):

1) Roger Road WWTP
2) Nogales IWWTP
3) Rio de Flag
4) Bitter Creek
5) Jack's Canyon

In terms of containing the highest amounts of pollution tolerant organisms, the ranking of EDW's was (from most to least):

1) Roger Road WWTP
2) Bitter Creek
3) Nogales IWWTP
4) Rio de Flag
5) Jack's Canyon

There is no denying that all EDW's had relatively positive effects on adjacent riparian areas, however, this should not be the sole criterion by which EDW's are judged. If EDW's can ever become refuge for aquatic species, then treatment processes must be adequate to ensure that as many stressors as possible are lifted prior release into the receiving stream.

Recommendations for Future Research

1) Fate and transport of nutrients needs to be addressed. We currently have little idea of how nutrients are processed or "spiraled" (see the Rio de Flag section) downstream. By examining how nutrients are utilized by, and passed from, different trophic levels, insight as to what the "optimal" amount and mixture of nutrients that should enter an EDW can be ascertained. This work should expand into riparian areas as well so that the total spectrum of organisms utilizing nutrients from an EDW can be studied. This would require the use of radioisotopes of oxygen, nitrogen, and carbon.

2) Determine the effect of endocrine disrupting compounds on stream organisms. This study only dealt with more or less acute stressors but other stressors (i.e. endocrine disrupting compounds) can exert huge influences on population structure, such as fecundity and sex ratio. The author has an on-going project examining the effects of endocrine disrupting compounds collected from EDW's on sex hormone levels in a native fish species (bonytail chub, *Gila elegans*). This should be expanded to include other organisms and trophic levels, both aquatic and terrestrial, as well.

3) Determine the amount of pathogenic viruses and bacteria, as well as their effect on humans and wildlife, which survive past the treatment process and are released into receiving streams. EDW's should be compared to similar surface waters not receiving treated effluent for baseline purposes.

4) Determine the feasibility of utilizing EDW's as refugia for native, threatened and/or endangered species. The reason several native species are either threatened or endangered with extinction is due to water withdraws for urban use. Effluent-dependent or dominated waters may represent a vital habitat and resource for native fish species provided adequate treatment results in water of sufficient quality.

5) Track and analyze changes in diversity as a function of change or improvement in treatment technology. This would entail locating a currently discharging WWTP that is scheduled to undergo a substantial improvement in treatment process. Data gathered prior to the installation of new treatment technology will then be compared to data gathered after the process has been online long enough to equilibrate.

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Appendix A. Linear Profile Data

BC Linear Profile, 01/06/03

Temp. (C)	Sp Cond ($\mu S/cm^2$)	pH	DO (%Sat)	DO (mg/L)	ORP (mV)
8.77 *(BC1)*	752.7	8.87	68.4	7.94	64
7.93	757.6	8.71	86.3	10.22	75
7.26	756.7	8.29	77.1	9.29	44
6.57	754.8	8	76.7	9.4	46
6.37	753.1	7.84	71.4	8.79	56
6.26	750.9	7.86	78.7	9.71	61
5.7	748.6	7.95	78.4	9.82	49
5.33	749.5	7.95	76.5	9.67	49
5.04	749.9	7.88	74.6	9.5	75
4.53	746.3	7.96	76.7	9.9	82
4.76 *(BC2)*	740.5	7.86	81.5	10.46	105

BC Linear Profile, 07/01/03

Temp. (C)	Sp Cond ($\mu S/cm^2$)	pH	DO (%Sat)		ORP (mV)
23.24 *(BC1)*	812.7	7.34	61.3	4.14	156
23.67	798.5	7.76	53.8	3.61	164
22.97	789.4	7.8	56	3.8	178
22.37	781.4	7.88	66.9	4.6	159
21.36	768	7.86	61.2	4.28	147
20.92	759.9	7.75	42.1	2.98	143
22.78	754.6	7.98	65.7	4.48	136
20.93	770.3	7.97	57.9	4.09	141
22.56 *(BC2)*	753.5	7.94	64.3	4.4	140

JC Linear Profile, 01/30/03

Temp. (C)	Sp Cond ($\mu S/cm^2$)	pH	DO (%Sat)	DO (mg/L)	ORP (mV)
18.83 *(JC1)*	778.4	6.7	66.1	6.13	289
18.65	790.3	7.46	75.7	7.05	266
18.08	797.1	7.56	83.7	7.89	266
18.08	795.9	7.8	88.4	8.33	263
17.96	792.4	8.09	99.6	9.41	263
17.9	1.2	8.4	116.9	11.05	261
16.27	787	8.4	101.8	9.96	261
15.88	786.2	8.5	106.8	10.54	257
15.42	1.2	8.55	103.9	10.38	256
14.58	0.7	8.55	113.3	11.53	258
14.31 *(JC2)*	789.6	8.59	111	11.32	256

JC Linear Profile, 06/30/03

Temp. (C)	Sp Cond (µS/cm^2)	pH		DO (mg/L)	
26.69 *(JC1)*	702	7.12	60.4	4.82	287
26.4	714.3	7.25	54.1	4.38	269
26.43	717.6	7.66	92.2	7.43	259
26.6	714.9	7.84	88.1	7.08	237
25.6	714.5	8.14	129.5	10.6	248
24.9	703.6	7.42	67.7	5.61	253
24.99	726.7	7.58	66.5	5.5	253
24.35	711.3	7.82	113.3	9.49	255
24.35	729.9	7.83	105.6	8.84	245
24.06	731	7.98	100.5	8.46	205
24.52	731	7.97	102.2	8.54	222
24.33	730.8	8	113.1	9.47	216
24.03	733.2	8.06	109.2	9.2	233
25.05	729.8	8.35	135.6	11.15	234
25.82 *(JC2)*	732	8.27	132.4	10.79	240

PCSC Linear Profile, 02/28/04

Temp. (C)	Sp Cond (µS/cm^2)	PH		DO (mg/L)	ORP (mV)
22.9 *(PCSC1)*	992.3	7.82	61.5	5.34	200
23.14	990.1	7.87	75.1	6.43	212
23.14	990.5	7.85	71.2	6.09	214
23.12	990.6	7.84	71	6.02	219
23.02	985.8	7.81	71.4	6.11	226
23.1	5.7	7.87	71.6	6.13	215
23.12	990.5	7.86	74.9	6.27	222
23.09	990.8	7.85	75	6.43	223
23.17	2.1	7.86	71.4	6.12	228
23.2	991	7.86	73.8	6.31	223
23.17	991.6	7.88	72.8	6.23	214
23.2	991.9	7.88	73	6.24	210
23.18 *(PCSC2)*	993	7.88	71.8	6.11	189

PCSC Linear Profile, 06/25/03

Temp. (C)	Sp Cond ($\mu S/cm^2$)	PH	DO (%Sat)	DO (mg/L)	ORP (mV)
30.31 *(PCSC1)*	1046	7.76	68.4	6.05	189
30.58	1041	7.76	65.6	5.69	185
30.63	1043	7.76	64.8	5.66	186
30.72	1045	7.76	64.5	5.64	186
30.83	1047	7.76	62.7	5.5	186
30.93	1047	7.75	58.2	5.41	184
30.96	1047	7.75	59.5	5.45	179
31.06	1045	7.74	55.1	5.23	165
30.5	1044	7.72	54.3	4.79	168
29.99	1046	7.74	53.2	4.05	164
29.65	0	11.13	53.2	4.06	152
29.45	0.2	11.82	55.8	4.2	163
29.26	0	12.39	55.8	4.26	155
31.18	1054	7.74	53.3	4.08	158
31.19	1050	7.74	55.6	3.96	149
31.28	1060	7.74	56.6	3.93	145
31.74 *(PCSC2)*	0	7.76	49.7	3.33	146

RDF Linear Profile, 01/23/03

Temp. (°C)	SpCond ($\mu S/cm^2$)	pH	DO (mg/L)	DO (% sat.)	ORP (mV)
11.1 *(RDF1)*	718.9	7.39	5.68	51.6	156
10.26	717.1	7.45	5.63	50.3	142
13.41	723.3	7.49	5.44	52.2	115
13.44	724.5	7.46	5.75	55.2	126
13.54	723.1	7.5	6.36	61.1	135
13.60	723.1	7.57	6.68	64.6	139
13.54	721.8	7.66	6.94	66.7	137
13.44	717.9	7.73	7.41	71.1	147
13.41	720.6	7.64	7.50	71.8	154
13.47	716.6	7.76	7.68	73.7	153
13.29	715.4	7.81	7.57	72.3	147
13.67 *(RDF2)*	708.5	8.32	9.03	87.1	130

RDF Linear Profile, 08/12/03

Temp. (°C)	SpCond (µS/cm^2)	pH	DO (mg/L)	DO (% sat.)	ORP (mV)
22.98 *(RDF1)*	647.6	8.13	7.00	99.4	113
23.30	647.3	8.13	7.99	114.2	116
23.68	649.8	8.14	6.89	99.1	123
25.05	650.5	8.17	6.53	96.4	120
25.16	646.5	8.45	8.69	128.6	120
25.1	642.5	8.6	8.83	130.5	111
25.91	638.3	9.33	9.24	183.2	105
26.35	623.4	9.33	12.12	>200	86
25.15	609.5	9.70	14.61	>200	68
24.55	612.3	9.52	14.88	>200	74
24.50	612.0	9.46	11.22	164	88
24.02	621.0	9.26	10.96	158.7	102
25.99	616.5	9.42	15.01	>200	96
27.55	612.9	9.63	15.11	>200	85
28.09	610.6	9.63	12.87	>200	83
28.74	606.7	9.72	13.21	>200	78
29.62 *(RDF2)*	601.8	9.72	14.66	>200	82

SC Linear Profile, 03/06/04

Temp. (°C)	SpCond (µS/cm^2)	pH		DO (% sat.)	ORP (mV)
13.1 *(SC1)*	755.8	7.16	3.92	29.6	211
14.6	755.8	7.19	4.55	35.7	207
14.4	748.6	7.22	4.92	40.7	219
15.8	745.3	7.19	4.97	43.1	225
16.4	748.6	7.15	4.99	43.8	227
17.1	755.4	7.16	4.88	41.2	217
17.5	748.9	7.20	4.95	43.9	234
18.3	749.7	7.23	4.84	42.8	257
18.8 *(SC2)*	750.7	7.20	4.89	47.4	260

SC Linear Profile, 06/23/03

Temp. (°C)	SpCond (µS/cm^2)	pH	DO (mg/L)	DO (% sat.)	ORP (mV)
22.48 *(SC1)*	933.7	7.23	2.35	27.1	248
22.85	933.1	7.31	2.49	28.4	248
23.03	935.1	7.28	2.82	33.1	257
23.65	932.8	7.33	3.31	39.2	261
24.69	931.2	7.45	4.06	49	271
25.68	931.5	7.39	4.4	54.1	254
26.34	919.5	7.4	4.46	56.1	248
27.24	923.2	7.39	4.51	58.9	236
27.87	919.9	7.41	3.65	46.8	246
28.15 *(SC2)*	919	7.38	3.62	46.2	250

Appendix B. Dissolved Oxygen Diel Pattern Data

Diel Pattern at BC2 on 02/06/03

Time	Temp (C)	SpCond ($\mu S/cm^2$)	pH	DO (%sat)	DO (mg/L)	ORP (mV)
1230	6.63	737.8	8.06	74.8	9.15	68
1300	7.03	735.8	8.01	74.2	8.99	68
1330	7.41	735.3	7.97	73.4	8.81	69
1400	7.33	731.6	7.93	74.6	8.98	69
1430	7.47	733.7	7.93	75.1	9	68
1500	7.37	728.6	7.92	75.7	9.09	68
1530	7.28	729	7.91	75.8	9.12	68
1600	7.03	727.5	7.88	72.9	8.84	69
1630	6.71	723.6	7.91	76.3	9.32	68
1700	6.28	725.8	7.95	76.6	9.46	68
1730	5.94	730.5	7.98	77	9.59	69
1800	5.62	731	7.95	91.1	11.43	69
1830	5.31	730	7.95	90.3	11.43	70
1900	5.09	731.4	7.97	91.1	11.59	71
1930	4.9	731.2	7.97	90.5	11.57	71
2000	4.73	732.3	7.98	91.4	11.74	71
2030	4.66	732.7	7.99	91.6	11.79	71
2100	4.49	731.1	7.98	90.1	11.65	71
2130	4.27	731.1	7.99	90.5	11.76	71
2200	4.08	732.4	8	90.5	11.8	71
2230	3.93	732.1	8.01	90.7	11.9	71
2300	3.81	732.9	8.02	92.4	12.15	71
2330	3.69	733.7	8.02	90.7	11.98	71
0000	3.54	730.5	8.03	90.1	11.95	71
0030	3.42	734.3	8.04	90.2	11.99	71
0100	3.31	733.7	8.05	90.6	12.08	71
0130	3.15	732	8.04	89.5	11.99	73
0200	3.01	731.6	8.04	88.7	11.92	73
0230	2.89	731.1	8.06	89.8	12.11	73
0300	2.77	730.6	8.06	89.7	12.14	73
0330	2.64	724.4	8.07	88.6	12.03	73
0400	2.49	721.3	8.06	88.5	12.07	75
0430	2.37	710.7	8.08	89.2	12.2	75
0500	2.24	707.4	8.08	87.9	12.07	75
0530	2.13	701.1	8.09	89.7	12.35	75
0600	1.98	693.5	7.93	88.9	12.29	75
0630	1.82	696.3	7.93	88.9	12.34	76
0700	1.73	691.1	7.95	89.3	12.43	77
0730	1.59	692.3	7.97	84	11.74	76
0800	1.51	688.6	8.01	78.3	10.97	73
0830	1.58	699.6	8.05	78.4	10.96	71
0900	1.83	732.4	8.09	79.4	11.02	69
0930	2.44	743.3	8.1	79.9	10.91	67
1000	3.1	749.5	8.06	80.5	10.79	67
1030	3.81	754.2	8.02	79.9	10.51	67
1100	4.51	756.3	7.98	79.9	10.32	67
1130	5.17	751.9	7.93	78.9	10.02	67
1200	5.14	739.6	8.00	79.1	10.14	67
1230	5.69	742	7.96	78.7	10.07	65

Diel Pattern at BC2 on 07/01/03

Time	Temp (C)	(µS/cm^2)	pH	DO (%sat)	DO (mg/L)	ORP (mV)
1200	21.74	759.2	7.88	70.2	4.88	105
1230	22.06	754.9	7.87	64.8	4.46	108
1300	22.16	749.7	7.84	62.4	4.3	102
1330	22.13	743.4	7.85	69.8	4.82	105
1400	22.47	743.5	7.87	68.2	4.68	105
1430	22.61	738.6	7.87	67.6	4.62	102
1500	22.72	735	7.88	67.9	4.64	100
1530	23.06	716.1	7.9	64.5	4.37	95
1600	22.87	718.6	7.89	61	4.15	83
1630	22.55	694.8	7.91	59.3	4.06	81
1700	22.46	690.9	7.91	55.8	3.83	74
1730	22.17	679.2	7.91	43.6	3.01	65
1800	21.55	670.3	7.92	27.3	1.9	48
1830	21.6	650.4	7.91	9.8	0.68	31
1900	21.37	637.8	7.9	16.2	1.14	38
1930	21.29	668.2	7.9	4.3	0.3	21
2000	21.04	641.8	7.92	32.7	2.3	28
2030	20.55	638.8	7.91	37.2	2.65	31
2100	20.23	648.1	7.91	33.3	2.39	35
2130	20.03	646.9	7.92	21.1	1.52	31
2200	19.67	646.1	7.92	22	1.6	25
2230	19.57	646.1	7.94	28.9	2.1	27
2300	19.47	644.7	7.93	31.7	2.31	26
2330	19.25	641.2	7.92	15.6	1.14	31
0000	19.19	638.9	7.95	13.3	0.97	24
0030	19.08	636.4	7.94	13.7	1	26
0100	19.22	635.8	7.92	6.9	0.5	22
0130	19.17	634.6	7.9	29.8	2.18	32
0200	19.06	642.4	7.93	18.8	1.38	33
0230	18.94	632.9	7.91	16.5	1.21	24
0300	18.81	629.8	7.87	22.8	1.68	28
0330	18.54	634.3	7.87	12.2	0.9	29
0400	18.19	634.4	7.9	5.4	0.4	29
0430	18.42	629.4	7.91	44.1	3.28	28
0500	18.26	628	7.9	12.4	0.92	24
0530	18.27	629.4	7.88	9.9	0.74	31
0600	18.05	624.3	7.89	4.4	0.33	43
0630	17.95	628.2	7.87	3	0.22	36
0700	18.44	628.6	7.86	36.9	2.74	38
0730	18.95	628.5	7.86	4	0.29	46
0800	19.47	628.9	7.91	2.5	0.19	68
0830	20.18	626.3	7.89	3.2	0.23	59
0900	20.65	624.7	7.88	4.7	0.33	65
0930	20.7	627.1	7.86	3.2	0.22	72
1000	20.94	619.1	7.89	26.6	1.88	75
1030	21.23	619.4	7.86	21.8	1.83	69
1100	21.53	616.8	7.88	35.7	2.49	72
1130	21.84	611.6	7.87	20.5	1.42	76
1200	21.89	621.1	7.85	34.6	2.23	77

Diel Pattern at JC2 on 01/30/03

Time	Temp (C)	SpCond ($\mu S/cm^2$)	pH	DO (%sat)	DO (mg/L)	ORP (mV)
1400	14.67	784.2	8.8	107	10.83	227
1430	15.13	781.5	8.91	107.6	10.79	217
1500	15.46	780.6	8.95	104.7	10.45	210
1530	15.59	776.1	8.98	102	10.13	203
1600	15.48	775.1	9	98.1	9.77	198
1630	15.29	774.1	9.01	94.7	9.46	194
1700	14.9	773.7	9.01	92	9.27	193
1730	14.28	774.4	8.97	85	8.69	193
1800	13.64	777	8.93	75.1	7.78	192
1830	13.14	779.4	8.88	67.8	7.1	192
1900	12.78	781.5	8.85	64.2	6.78	192
1930	12.46	783.5	8.79	61.5	6.54	192
2000	12.14	786.1	8.72	60.8	6.51	193
2030	11.79	788.1	8.65	59.9	6.46	194
2100	11.47	790.6	8.57	59.7	6.49	195
2130	11.23	793.3	8.5	60.4	6.61	195
2200	10.96	796.7	8.32	61	6.71	196
2230	10.71	800	8.31	62	6.86	196
2300	10.45	801.7	8.18	61.3	6.83	197
2330	10.14	803.8	8.09	62.3	6.98	199
0000	9.8	802.8	8.04	62.9	7.11	199
0030	9.57	799.7	8.01	63.9	7.26	199
0100	9.34	797.1	7.98	64	7.32	200
0130	9.14	795.1	7.96	62.9	7.22	201
0200	8.93	793.8	7.94	63	7.27	201
0230	8.71	792.4	7.94	62.7	7.28	201
0300	8.45	791.7	7.93	62.5	7.3	202
0330	8.21	790.7	7.93	62.3	7.32	203
0400	7.99	790.2	7.92	62.2	7.35	203
0430	7.77	790	7.91	61.8	7.33	205
0500	7.55	790	7.9	62.6	7.47	206
0530	7.34	789.9	7.89	62.4	7.49	207
0600	7.12	789.9	7.89	61.6	7.44	208
0630	6.93	789.8	7.88	61.8	7.5	209
0700	6.75	789.7	7.88	61.2	7.45	210
0730	6.57	789.5	7.87	62	7.58	211
0800	6.45	788.5	7.88	62.7	7.69	213
0830	6.42	787.6	7.9	65.7	8.06	214
0900	6.56	786.9	7.95	70	8.56	215
0930	7.43	782.7	8.13	81.9	9.8	214
1000	8.59	776.5	8.32	95.1	11.07	216
1030	9.39	769.7	8.43	100.6	11.49	216
1100	10.39	765.4	8.58	104.4	11.64	215
1130	11.43	761.5	8.7	106.5	11.59	213
1200	12.43	756.5	8.78	108.8	11.58	212
1230	13.43	753.1	8.86	111.8	11.63	211
1300	14.39	750.5	8.93	114.4	11.66	209
1330	15.22	745.1	8.97	115.1	11.52	208
1400	15.81	743.2	9.01	115.4	11.4	207

Diel Pattern at JC2 on 06/30/03

Time	Temp (C)	SpCond (µS/cm^2)		DO (%sat)	DO (mg/L)	ORP (mV)
1230	25.64	728.9	8.17	79.6	6.51	257
1300	26.17	727.5	8.22	77.7	6.3	261
1330	26.5	727.6	8.23	72.1	5.82	264
1400	26.81	727.1	8.24	68.5	5.48	264
1430	27.01	726.2	8.25	66.1	5.27	265
1500	27.13	726.5	8.23	62.4	4.97	266
1530	27.14	726.7	8.18	57.3	4.57	267
1600	27.17	727.8	8.12	52.5	4.18	266
1630	27	732.8	8.01	51.9	4.14	265
1700	26.84	734.3	7.9	48.7	3.9	266
1730	26.62	736	7.76	42	3.38	267
1800	26.34	735.1	7.62	35.2	2.84	271
1830	26.03	739.2	7.52	30.1	2.44	276
1900	25.72	737.5	7.4	23.2	1.92	281
1930	25.45	739.1	7.34	20.2	1.66	285
2000	25.18	740	7.28	16.5	1.36	287
2030	24.88	744.2	7.24	12.1	1	289
2100	24.59	743.5	7.22	10.2	0.85	289
2130	24.25	746.1	7.21	9.5	0.8	289
2200	23.87	749.5	7.2	10.2	0.86	291
2230	23.54	750.5	7.19	9.7	0.82	290
2300	23.18	748	7.17	9.2	0.78	295
2330	22.91	747.5	7.16	9.4	0.83	299
0000	22.67	752.7	7.15	7.8	0.67	303
0030	22.42	749.9	7.13	7.4	0.66	297
0100	22.44	746.4	7.27	18	1.57	306
0130	21.89	746.8	7.21	23.3	2.06	321
0200	21.49	745.4	7.24	30.1	2.68	335
0230	21.38	742.9	7.26	31.9	2.83	346
0300	21.29	744.9	7.26	31.5	2.83	354
0330	21.14	751.4	7.26	31.7	2.85	361
0400	20.93	754	7.26	31.8	2.84	367
0430	20.71	757.2	7.26	31.4	2.82	373
0500	20.47	762	7.25	30	2.71	378
0530	20.26	761	7.25	29.1	2.64	382
0600	20.05	761.8	7.25	29.9	2.72	385
0630	19.93	762.1	7.25	30.7	2.82	388
0700	19.94	762.8	7.26	33.4	3.06	390
0730	20.14	762.8	7.29	39	3.54	393
0800	20.35	763.1	7.33	44.1	3.99	395
0830	20.62	763.4	7.35	48.8	4.41	398
0900	20.92	763.7	7.39	55.7	4.98	401
0930	21.49	762.5	7.46	64.9	5.74	402
1000	22.14	766	7.77	83.1	7.29	399
1030	22.63	762.2	7.88	88.2	7.65	394
1100	23.3	762.6	7.99	89.9	7.72	390
1130	24.01	759.1	8.09	90.9	7.68	385
1200	24.66	757.9	8.14	85.3	7.13	380
1230	25.29	756.1	8.18	84.7	6.97	379

Diel Pattern at PCSC2 on 02/28/04

Time	Temp (C)	SpCond ($\mu S/cm^2$)	pH		DO (mg/L)	ORP (mV)
1300	19.96	644	7.38	76.2	5.69	99
1330	20.58	682.1	7.68	75.7	5.45	79
1400	20.59	725.4	7.5	75.1	5.3	70
1430	20.55	728.6	7.48	74.7	5.16	65
1500	20.54	735.9	7.44	58.4	4.66	40
1530	20.51	743.9	7.49	52.6	4.11	43
1600	20.51	748.9	7.45	52.6	4.12	46
1630	20.53	767.7	7.44	52.4	4.11	46
1700	20.43	771.7	7.43	44.8	3.61	35
1730	20.32	804	7.44	34.2	2.91	32
1800	20.17	826.2	7.44	34.1	2.9	37
1830	20.03	868	7.42	33.6	2.85	31
1900	19.9	880.8	7.42	29.5	2.17	27
1930	19.79	908.5	7.41	29.1	2.26	29
2000	19.69	931.4	7.4	28.4	2.33	31
2030	19.62	928.5	7.39	4.8	0.36	19
2100	19.58	961.1	7.38	7.3	0.55	16
2130	19.55	987.1	7.39	6	0.45	19
2200	19.51	1014	7.38	5.4	0.41	23
2230	19.42	1053	7.34	49.7	0.75	13
2300	19.34	1044	7.39	19.2	0.45	17
2330	19.23	1038	7.41	26.1	1.97	12
0000	19.14	1028	7.41	40.9	3.1	17
0030	19.05	1019	7.46	45.2	3.43	65
0100	18.98	1013	7.48	43	3.27	52
0130	18.88	1008	7.48	37.8	2.88	86
0200	18.77	1007	7.46	44.5	3.4	55
0230	18.68	1002	7.46	44	3.36	52
0300	18.57	995.6	7.47	44.1	3.38	27
0330	18.45	989.8	7.46	44.1	3.39	34
0400	18.31	986	7.46	44	3.39	38
0430	18.16	980.3	7.48	43.9	3.39	35
0500	17.99	973.3	7.48	44.7	3.47	38
0530	17.74	968.8	7.48	44.4	3.47	81
0600	17.48	963.4	7.47	45	3.53	51
0630	17.17	958.9	7.47	45.4	3.58	56
0700	16.86	954.8	7.47	45.9	3.65	40
0730	16.58	953.3	7.47	47.1	3.77	42
0800	16.42	952	7.47	48.3	3.88	56
0830	16.37	952.1	7.47	49.8	3.99	64
0900	16.39	953	7.47	50.9	4.09	71
0930	16.66	959.9	7.47	52.8	4.21	76
1000	17.24	968.3	7.47	54.3	4.28	65
1030	18.07	977.3	7.46	55.7	4.32	83
1100	19	984	7.45	55.2	4.2	93
1130	19.92	987.5	7.44	55.9	4.17	99
1200	20.62	984.3	7.43	55	4.05	83
1230	20.97	980.8	7.42	53.6	3.92	88
1300	21.14	973.2	7.44	54	3.93	99

Diel Pattern at PSCC2 on 06/25/03

Time	Temp (C)	SpCond ($\mu S/cm^2$)	pH	DO (%sat)	DO (mg/L)	ORP (mV)
1530	33.35	1103	7.65	28.7	1.62	36
1600	32.94	1111	7.66	27	1.53	32
1630	32.49	1109	7.66	24.9	1.43	31
1700	31.89	1116	7.65	22.1	1.28	36
1730	31.22	1114	7.64	19.8	1.16	41
1800	30.52	1112	7.63	17	1.01	31
1830	29.8	1113	7.62	15	0.9	28
1900	29.24	1111	7.62	13.9	0.84	21
1930	28.74	1106	7.61	13.6	0.83	20
2000	28.39	1107	7.61	13.6	0.84	-5
2030	28.16	1103	7.6	13.4	0.82	-15
2100	27.91	1100	7.6	13	0.81	-24
2130	27.72	1095	7.6	12.9	0.8	-34
2200	27.59	1084	7.59	12.8	0.8	-38
2230	27.53	1067	7.59	12.4	0.77	-40
2300	27.41	1053	7.59	11.9	0.74	-46
2330	27.26	1048	7.59	12	0.75	-39
0000	27.16	1048	7.59	12.3	0.77	-40
0000	27.04	1054	7.59	11.8	0.75	-35
0030	26.92	1063	7.59	12	0.76	-36
0100	26.82	1060	7.59	12	0.76	-41
0130	26.7	1063	7.59	11.7	0.74	-38
0200	26.57	1061	7.59	11.9	0.76	-52
0230	26.48	1061	7.58	11.7	0.74	-47
0300	26.37	1054	7.58	12.3	0.78	-53
0330	26.21	1051	7.58	11.5	0.73	-55
0400	25.97	1043	7.58	12	0.77	-64
0430	25.74	1035	7.59	11.7	0.75	-48
0500	25.47	1033	7.6	11.8	0.77	-40
0530	25.24	1030	7.61	12.7	0.83	-31
0600	25.03	1026	7.62	12.9	0.84	-24
0630	24.95	1024	7.62	14.1	0.92	-14
0700	25.05	1012	7.63	17.7	1.15	-8
0730	25.3	1010	7.64	20.4	1.32	15
0800	25.68	1009	7.65	22.2	1.44	22
0830	26.2	1009	7.66	25.6	1.64	24
0900	27.03	1002	7.67	28	1.76	28
0930	28.03	1001	7.67	29.2	1.8	34
1030	29.03	997.4	7.68	30.6	1.86	30
1100	30.2	988.6	7.7	30.9	1.84	32
1130	31.36	973.4	7.71	30.2	1.76	38
1200	32.63	967.3	7.7	30.2	1.72	43
1230	33.33	973.7	7.69	30.2	1.7	41
1300	33.61	979.3	7.67	32.1	1.81	45
1330	33.76	986.8	7.68	34.5	1.93	40
1400	33.67	1001	7.69	36.8	2.07	41
1430	33.5	1023	7.68	37.3	2.1	44
1500	33.32	1037	7.66	32.9	1.86	45
1530	33.08	1055	7.66	31	1.76	41

Diel Pattern at RDF2 on 01/23/03

Time	Temp. (°C)	SpCond (µS/cm^2)	pH	DO (mg/L)	DO (% sat.)	ORP (mV)
1300	14.54	706.8	8.29	6.03	59.2	107
1330	14.54	710.8	8.15	5.24	51.5	115
1400	14.79	710.8	8.14	5.14	50.8	115
1430	15.23	709.5	8.14	5.11	50.9	115
1500	15.39	709.5	8.11	5.06	50.6	116
1530	15.28	709.5	8.08	4.77	47.7	118
1600	14.91	706.8	8.02	4.59	45.4	122
1630	14.28	695.1	7.96	4.26	41.6	126
1700	13.92	715.0	7.90	3.99	38.7	130
1730	13.72	715.1	7.83	3.72	35.9	133
1800	13.37	719.3	7.74	3.87	37.1	137
1830	13.03	719.7	7.65	3.89	37.0	140
1900	12.82	721.2	7.57	3.81	36.1	143
1930	12.71	721.3	7.51	3.68	34.7	144
2000	12.58	718.9	7.46	3.56	33.5	143
2030	12.44	719.1	7.42	3.53	33.1	142
2100	12.33	719.8	7.40	3.52	32.9	143
2130	12.23	722.1	7.38	3.51	32.8	144
2200	12.10	720.9	7.36	3.51	32.7	142
2230	11.99	722.4	7.33	3.43	31.9	140
2300	11.92	723.9	7.30	3.35	31.1	139
2330	11.87	725.3	7.28	3.31	30.7	136
0000	11.83	724.1	7.27	3.31	30.6	136
0300	11.78	726.8	7.26	3.29	30.4	135
0100	11.75	728.2	7.25	3.26	30.1	133
0130	11.69	729.6	7.24	3.22	29.7	132
0200	11.52	730.0	7.22	3.20	29.4	133
0230	11.35	733.0	7.21	3.18	29.1	133
0300	11.19	732.0	7.20	3.18	29.0	134
0330	11.03	732.4	7.20	3.16	28.7	136
0400	10.83	732.9	7.19	3.15	28.5	138
0430	10.63	736.0	7.19	3.15	28.4	139
0500	10.47	736.4	7.19	3.14	28.1	139
0530	10.33	735.5	7.19	3.13	28.0	140
0600	10.16	736.0	7.19	3.12	27.8	140
0630	9.98	739.2	7.19	3.12	27.7	139
0700	9.79	738.5	7.20	3.12	27.5	139
0730	9.57	737.9	7.21	3.14	27.5	136
0800	9.36	738.6	7.26	3.00	26.2	126
0830	9.25	736.3	7.35	3.30	28.8	117
0900	9.33	737.4	7.44	3.67	32.1	112
0930	9.72	736.0	7.56	4.05	35.7	111
1000	10.24	737.1	7.64	4.29	38.3	111
1030	10.50	735.0	7.66	4.39	39.4	115
1100	11.42	734.1	7.78	4.82	44.1	115
1130	12.46	732.2	7.85	5.11	48.0	118
1200	13.38	731.2	7.91	5.35	51.3	121
1230	14.28	728.4	8.11	5.98	58.7	127
1300	14.49	710.4	8.17	6.17	60.3	124

Diel Pattern at RDF2 on 08/12/03

Time	Temp. (°C)	SpCond (µS/cm^2)	pH	DO (mg/L)	DO (% sat.)	ORP (mV)
1230	29.92	587.5	9.94	16.21	>200	84
1300	31.19	598.3	10.04	15.74	>200	73
1330	31.93	594.6	10.04	15.22	>200	66
1400	32.49	600.5	10.07	14.08	>200	68
1430	32.30	607.2	10.08	13.83	>200	67
1500	32.47	609.0	10.12	13.44	>200	66
1530	32.12	609.8	10.21	13.40	>200	64
1600	31.81	610.9	10.27	13.29	>200	62
1630	31.03	608.2	10.29	12.83	>200	60
1700	29.93	606.7	10.22	12.18	196.1	58
1730	28.88	604.0	10.28	10.83	171.3	57
1800	28.06	603.8	10.27	10.16	158.4	58
1830	26.99	602.5	10.21	9.20	140.6	62
1900	26.09	602.1	10.07	7.41	111.5	64
1930	25.47	604.8	9.92	5.70	84.8	66
2000	24.93	607.5	9.79	4.79	70.6	68
2030	24.39	612.7	9.66	4.19	61.1	72
2100	23.80	619.6	9.50	3.70	53.4	78
2130	23.14	627.4	9.32	3.37	48.1	88
2200	22.51	634.5	9.14	3.12	43.9	98
2230	21.89	639.1	8.97	2.91	40.5	107
2300	21.28	642.3	8.82	2.75	37.8	121
2330	20.72	644.1	8.69	2.64	35.9	131
0000	20.22	645.2	8.57	2.61	35.1	139
0300	19.79	643.0	8.49	2.4	32.1	151
0100	19.43	642.9	8.43	2.76	36.6	161
0130	19.12	642.9	8.39	2.86	37.7	170
0200	18.80	642.9	8.34	2.93	38.4	178
0230	18.49	643.6	8.28	2.94	38.2	185
0300	18.16	644.9	8.22	2.98	38.5	190
0330	17.90	646.9	8.17	2.95	37.9	194
0400	17.67	646.5	8.13	2.82	36.1	197
0430	17.43	646.8	8.09	2.77	35.2	203
0500	17.18	647.5	8.07	2.87	36.3	209
0530	16.95	648.0	8.04	2.87	36.1	213
0600	16.70	648.5	8.02	3.02	37.9	216
0630	16.53	648.1	8.06	3.35	41.9	219
0700	16.55	646.9	8.15	4.05	50.7	224
0730	16.95	644.8	8.34	5.35	67.4	226
0800	17.77	642.1	8.57	7.22	92.5	227
0830	19.06	638.0	8.79	8.88	116.8	223
0900	20.51	633.9	8.99	10.72	145.1	216
0930	22.03	629.3	9.16	12.05	168.0	203
1000	23.52	625.1	9.32	12.76	183.1	188
1030	24.99	621.5	9.44	13.65	>200	172
1100	26.23	620.0	9.52	13.76	>200	159
1130	27.22	617.8	9.59	14.21	>200	148
1200	28.02	614.1	9.72	15.45	>200	131
1230	28.19	610.5	9.86	15.30	>200	114

Diel Pattern at SC2 on 03/06/04

Time	Temp. (°C)	SpCond (µS/cm^2)	pH	DO (% sat)	DO (mg/L)	ORP (mV)
0930	9.57	758.7	7.61	52.5	4.91	91
1000	10.63	783.9	7.62	50.8	4.63	147
1030	11.99	787.2	7.62	48.7	4.3	157
1100	13.5	781.8	7.61	45.8	3.92	160
1130	15.07	783.4	7.61	44.5	3.68	158
1200	16.68	783.2	7.6	42.3	3.37	154
1230	18.13	785.2	7.59	40.9	3.17	151
1300	19.28	607	7.57	31.1	2.36	126
1330	20.36	503	7.46	17.2	1.28	48
1400	21.09	537.8	7.45	24.4	1.78	21
1430	21.51	541.1	7.44	11.7	0.85	-11
1500	21.62	555.5	7.44	8.6	0.62	-37
1530	21.22	569.2	7.45	16.6	1.21	-50
1600	20.74	509.4	7.45	5.7	0.42	-63
1630	20.31	476.7	7.44	4.9	0.36	-70
1700	19.72	466.1	7.43	4.2	0.31	-78
1730	19.32	464	7.43	4.9	0.37	-83
1800	18.94	442	7.43	4.1	0.31	-96
1830	18.49	446.1	7.44	4	0.31	-82
1900	17.94	448	7.44	3.8	0.3	-79
1930	17.33	431.6	7.44	3.9	0.3	-80
2000	16.76	431.8	7.43	4.8	0.38	-80
2030	16.2	460.3	7.44	4	0.32	-80
2100	15.67	469.6	7.45	3.5	0.28	-82
2130	15.2	500	7.45	3.9	0.32	-77
2200	14.74	549.5	7.43	4.8	0.4	-74
2230	14.27	586.5	7.43	5.3	0.45	-72
2300	13.84	588.3	7.44	4.4	0.38	-71
2330	13.43	635.5	7.43	8.4	0.72	-71
0000	13.07	658.4	7.43	3.9	0.34	-72
0300	12.74	673.5	7.43	8	0.69	-77
0100	12.36	679.1	7.42	16.7	1.47	17
0130	11.99	692.5	7.43	19.8	1.75	-43
0200	11.66	710.5	7.47	26.3	2.34	65
0230	11.37	781.1	7.46	42.2	3.78	79
0300	11.08	788	7.61	46	4.15	82
0330	10.82	790.5	7.62	46.1	4.18	71
0400	10.59	787	7.62	46.3	4.23	64
0430	10.43	784	7.62	47.5	4.35	60
0500	10.29	783.8	7.62	47.3	4.34	58
0530	10.13	782.4	7.63	48.4	4.46	54
0600	9.95	784.9	7.63	48.2	4.47	56
0630	9.79	785.1	7.63	48.2	4.49	54
0700	9.66	784.2	7.63	48.9	4.57	61
0730	9.59	785.2	7.64	49.7	4.64	75
0800	9.61	784.5	7.64	49.2	4.6	89
0830	9.77	784.9	7.64	49.4	4.6	99
0900	10.13	785.8	7.64	49.4	4.56	106
0930	10.86	788.8	7.65	49.4	4.48	111

Diel Pattern at SC2 on 06/23/03

Time		SpCond (µS/cm[2])		DO (% sat)	DO (mg/L)	ORP (mV)
1730	23.79	682.5	7.34	8.1	1.31	240
1800	23.21	678.5	7.38	7.2	1.17	243
1830	22.52	687.1	7.43	6.4	0.97	244
1900	21.97	691	7.42	5.0	0.62	245
1930	21.51	694.7	7.42	4.9	0.58	245
2000	21.11	694.7	7.4	3.1	0.41	246
2030	20.65	698.1	7.41	2.1	0.35	243
2100	20.43	699.5	7.42	1.8	0.31	243
2130	20.3	700.6	7.41	1.8	0.32	244
2200	20.2	697.1	7.42	0.8	0.19	244
2230	20.12	698.2	7.41	2.2	0.42	244
2300	19.97	698.1	7.4	2.6	0.57	245
2330	19.84	699.6	7.4	3.0	0.72	244
0000	19.69	699.7	7.41	6.1	0.93	244
0300	19.58	700.9	7.4	7.5	1.27	244
0100	19.48	703.1	7.4	9.5	1.53	244
0130	19.33	704.4	7.41	11.6	1.87	243
0200	19.2	706.6	7.42	13.8	2.3	243
0230	19.06	707.5	7.41	19.7	3.16	243
0300	18.88	709.1	7.44	23.4	3.59	241
0330	18.71	710.5	7.43	26.4	3.97	242
0400	18.52	711.5	7.46	25.5	3.86	240
0430	18.37	712.2	7.38	27.7	4.08	243
0500	18.15	712.1	7.43	28.1	4.13	240
0530	17.99	712.9	7.45	27.5	4	239
0600	17.85	713.8	7.46	27.1	3.92	239
0630	17.72	714.1	7.43	26.8	3.88	239
0700	17.63	715.6	7.46	27.7	4.06	238
0730	17.6	717.8	7.43	28.2	4.18	238
0800	17.62	719.1	7.43	28.1	4.1	238
0830	17.72	721.8	7.45	28.1	4.07	235
0900	17.94	724.3	7.4	28.1	4.13	237
0930	18.27	726.5	7.39	28.0	4.02	236
1000	18.77	731	7.41	32.1	4.57	233
1030	19.59	735.2	7.39	32.1	4.59	233
1100	20.81	739.7	7.45	28.1	4.11	229
1130	21.97	744.9	7.43	27.3	3.98	226
1200	23.39	745.4	7.38	27.2	3.96	215
1230	24.29	751	7.32	25.6	3.85	193
1300	25.19	758.6	7.37	24.9	3.7	196
1330	26.17	760.7	7.37	25.0	3.72	196
1400	27.11	768.9	7.28	23.8	3.61	202
1430	28	768.9	7.31	22.4	3.32	198
1500	28.07	766.1	7.34	21.7	3.21	181
1530	27.76	764.3	7.35	18.1	2.74	186
1600	27.11	762.1	7.15	14.8	2.21	183
1630	26.37	757.8	7.24	13.0	2.03	153
1700	25.44	752.9	7.25	10.3	1.62	136

Appendix C. Macroinvertebrate identification by site and date.

BC1 Macroinvertebrate Identification for 02/06/03

Order	Family		Number	Functional Feeding Group
Coleoptera	Dytiscidae	Oreodytes	3	predator
Diptera	Ceratopogonidae	Ceratopogon	3	predator or collector-gatherer
Diptera	Ceratopogonidae	Dasyhelea	9	scraper, collector-gatherer
Diptera	Ceratopogonidae	Forcipomyia	3	predator
Diptera	Chironomidae	Eukiefferiella	1938	collector-gatherer, scraper, predator
Diptera	Chironomidae	Lopescladius	516	collector-gatherer
Diptera	Chironomidae	Micropsectra	75	collector-gatherer
Diptera	Chironomidae	Omisus	3	Unknown
Enoplida	Enoplidae	Rhabdolaimus	150	collector-gatherer
Haplotaxida	Tubificidae		1002	collector-gatherer
Rhabditia	Rhabditidae	Rhabditis	159	collector-gatherer

BC1 Macroinvertebrate Identification for 07/01/03

Order	Family	Genus	Number	Functional Feeding Group
Coleoptera	Hydrophilidae	Tropisternus	1	predator
Diptera	Ceratopogonidae		2	
Diptera	Ceratopogonidae	Ceratopogon	2	predator
Diptera	Ceratopogonidae	Dasyhelea	2	collector-gatherer, scraper
Diptera	Chironomidae	Chironomus	230	collector-gatherer, shredder
Diptera	Chironomidae	Corynoneura	1	collector-gatherer
Diptera	Chironomidae	Eukiefferiella	121	collector-gatherer, scraper, predator
Diptera	Chironomidae	Lopescladius	555	collector-gatherer
Diptera	Chironomidae	Paramerina	5	predator
Diptera	Chironomidae	Paraphaenocladius	1	collector-gatherer
Diptera	Chironomidae	Polypedilum	2	collector-gatherer, shredder, predator
Diptera	Chironomidae	Radotanypus	13	unknown
Diptera	Chironomidae	Sublettea	1	unknown
Diptera	Chironomidae	unidentifiable	74	
Diptera	Muscidae		1	
Diptera	Simuliidae	Simulium	4	collector-gatherer
Diptera	Tabanidae	Hybomitra	1	predator
Diptera	Tipulidae	Ormosia	4	collector-gatherer
Dorylaimida	Dorylaimidae	Dorylaimus Osphranticum	3	predator
Eucopepoda	Centropagidae	labronectum	2	collector-gatherer
Haplotaxida	Tubificidae		48	collector-gatherer
Odonata	Coenagrionidae	Argia	3	predator
Podocopida	Candoniidae	Candona	6	collector-gatherer

BC2 Macroinvertebrate Identification for 02/06/03

Order	Family		Number	
Collembola	Hypogastruridae	Frisea	3	collector-gatherer
Collembola	Poduridae	Podura	3	collector-gatherer
Diptera	Ceratopogonidae	Dasyhelea	3	predator
Diptera	Chironomidae	Eukiefferiella	1098	collector-gatherer, scraper, predator
Diptera	Chironomidae	Lopescladius	573	collector-gatherer
DIptera	Chironomidae	Micropsectra	9	collector-gatherer
Diptera	Chironomidae	Omisus	6	collector-gatherer
Diptera	Psychodidae	Pericoma	3	collector-gatherer
Diptera	Tipulidae	Erioptera	9	collector-gatherer
Diptera	Tipulidae	Tipula	3	shredder
Rhabditia	Rhabditidae	Rhabditis	18	collector-gatherer
Haplotaxida	Tubificidae		306	collector-gatherer
Odonata	Coenagrionidae	Amphiagrion	3	Predator
Podocopida	Candoniidae	Candona	12	collector-gatherer

BC2 Macroinvertebrate Identification for 07/01/03

Order	Family	Genus	Number	Functional Feeding Group
Diptera	Chironomidae	Hydrobaenus	6	scraper, collector-gatherer
Diptera	Chironomidae	Lopescladius	135	collector-gatherer
Diptera	Chironomidae	Orthocladius	6	collector-gatherer
Diptera	Chironomidae	Polypedilum	3	collector-gatherer, shredder, predator
Diptera	Chironomidae	Radotanypus	45	unknown
Diptera	Chironomidae	Sublettea	3	unknown
Diptera	Simuliidae	Simulium	3	collector-filterer
Diptera	Tipulidae	Limonia	3	shredder
Haplotaxida	Tubificidae		9	collector-gatherer
Hydracarina	Limnocharidae	Limnochares	3	predator
Limnophila	Limnaeidae	Stagnicola	3	unknown
Odonata	Coenagrionidae		3	predator
Podocopida	Candoniidae	Candona	8	collector-gatherer

JC1 Macroinvertebrate Identification for 01/30/03

Order	Family	Genus	Number	Functional Feeding Group
Coleoptera	Dytiscidae	Liodessus	1	predator
Coleoptera	Hydrophilidae	Tropostemus	1	predator
Coleoptera	Hydrochidae	Hydrochus	1	shredder
Diptera	Ceratopogonidae	Ceratopogon	1	predator or collector-gatherer
Diptera	Chironomidae	Hydrobaenus	21	scraper, collector-gatherer
Diptera	Chironomidae	Eukiefferiella	12	collector-gatherer, scraper, or predator
Diptera	Chironomidae	Lopescladius	2	collector-gatherer
Diptera	Chironomidae	Boreochlus	2	collector-gatherer
Diptera	Chironomidae	Epoicocladius	2	collector-gatherer
Diptera	Chironomidae	Pseudochironomus	9	collector-gatherer
Diptera	Chironomidae	Orthocladius	1	collector-gatherer
Diptera	Chironomidae	Paramerina	2	unknown
Diptera	Chironomidae	Brillia	2	shredder
Diptera	Chironomidae	Parakeifferiella	3	collector-gatherer
Diptera	Chironomidae	Acricotopus	1	unknown
Diptera	Chironomidae	unidentifiable	5	
Diptera	Empididae	Hemerodromia	1	predator
Diptera	Empididae	unidentifiable	1	
Dorylamida	Dorylamidae	Dorylaimus	67	predator
Odonata	Coenagrionidae	Argia	8	predator
Podocopida	Candoniidae	Candona	215	collector-gatherer
Trichoptera	Helicopsychidae	Helicopsyche	2	scraper
Trichoptera	unidentifiable		1	
Tricladida	Planariidae	Girardia	17	scraper, collector-gatherer
Haplotaxida	Tubificidae		57	collector-gatherer
Hemiptera	Saldidae	unidentifiable	1	predator
Hydracarina	Limnesiidae	Kwamuracarus	1	predator
Limnophila	Physidae	Physella	48	collector-gatherer
Odonata	Coenagrionidae	unidentifiable	2	predator

JC1 Macroinvertebrate identification for 06/30/03

Order	Family	Genus	Number	Functional Feeding Group
Anomopoda	Daphniidae	Daphnia	1	collector-gatherer
Coleoptera	Dytiscidae	Oreodytes	1	predator
Coleoptera	Haliplidae	Peltodytes	4	shredder, predator
Coleoptera	Hydrophilidae	Tropisternus	1	predator
Diptera	Chironomidae	Chironomus	1	collector-gatherer
Diptera	Chironomidae	Hydrobaenus	1	scraper, collector-gatherer
Diptera	Chironomidae	Paramerina	2	predator
Diptera	Chironomidae	Rheosmittia	1	unknown
Diptera	Chironomidae	Tanypus	2	predator, collector-gatherer
Diptera	Chironomidae	unidentifiable	1	
Diptera	Psychodidae	unidentifiable	1	
Diptera	Simuliidae	Simulium	1	collector-filterer
Diptera	Tipulidae	Limonia	1	shredder
Dorylaimida	Dorylaimidae		7	predator
Haplotaxida	Tubificidae		3	collector-gatherer
Hemiptera	Veliidae	Microvelia	3	predator
Hydracarina	Limnesiidae	Kawamuracarus	1	predator
Limnophila	Physidae	Physella	128	collector-gatherer
Odonata	Coenagrionidae	unidentifiable	5	predator
Odonata	Libellulidae	Libellula	3	predator
Podocopida	Candoniidae	Candona	38	collector-gatherer
Podocopida	Cypridae	Eucypris	200	collector-gatherer
Rhycobdellida	Glossiphoniidae	Helobdella	4	predator
Trichoptera	Helicopsychidae	Helicopysche	1	scraper
Tricladida	Planariidae	Girardia	14	scraper, collector-gatherer

JC2 Macroinvertebrate identification for 01/30/03

Order	Family	Genus	Number	
Anomopoda	Daphnidae	Daphnia	1	collector-gatherer
Coleoptera	Dytiscidae	Agabus	1	predator
Coleoptera	Elmidae	Stenelmis	1	scraper, collector-gatherer
Collembola	Entomobryiidae	Sinella	1	collector-gatherer
Diptera	Ceratopogonidae	Ceratopogon	7	predator or collector-gatherer
Diptera	Ceratopogonidae	Dashyhelea	2	scraper, collector-gatherer
Diptera	Chironomidae	Antillocladius	5	unknown
Diptera	Chironomidae	Boreochlus	9	collector-gatherer
Diptera	Chironomidae	Brillia	1	shredder
Diptera	Chironomidae	Bryophaenocladius	25	unknown
Diptera	Chironomidae	Corynoneura	3	collector-gatherer
Diptera	Chironomidae	Diamesa	1	collector-gatherer
Diptera	Chironomidae	Epoicocladius	8	collector-gatherer
Diptera	Chironomidae	Eukiefferiella	761	collector-gatherer, scraper, or predator
Diptera	Chironomidae	Heterotrissocladius	6	scraper, collector-gatherer
Diptera	Chironomidae	Hydrobaenus	10	scraper, collector-gatherer
Diptera	Chironomidae	Lopescladius	12	collector-gatherer
Diptera	Chironomidae	Nanocladius	4	collector-gatherer
Diptera	Chironomidae	Orthocladius	49	collector-gatherer
Diptera	Chironomidae	Pseudochironomus	1	collector-gatherer
Diptera	Chironomidae	Smittia	74	collector-gatherer
Diptera	Chironomidae	Symbiocladius	4	predator
Diptera	Chironomidae	unidentifiable	94	
Diptera	Ephydridae	Lytogaster	1	scraper
Diptera	Phsychodidae		1	
Diptera	Simuliidae	Simulium	6	collector-gatherer
Diptera	Stratiomydae	Oxycera	1	scraper
Diptera	Tabanidae	Chrysops	1	predator
Dorylaimida	Dorylaimidae	Dorylaimus	2	predator
Ephemeroptera	Baetidae	Centroptilum	1	scraper, collector-gatherer
Ephemeroptera	Baetidae	Fallceon	27	unknown
Ephemeroptera	Baetidae	unidentifiable	9	collector-gatherer
Haplotaxida	Tubificidae		176	collector-gatherer
Hydracarina	Axonopsidae	Brachypoda	1	predator
Hydracarina	Eylaidae	Eylais	1	predator
Hydracarina	Limnesiidae	Kwamuracarus	2	predator
Hydracarina	Limnesiidae	Limnesia	2	predator
Hydroida	Hydridae	Hydra	1	predator
Limnophila	Physidae	Physella	2	collector-gatherer
Odonata	Coenagrionidae	Amphiagron	2	predator
Podocopida	Candoniidae	Candona	7	collector-gatherer
Trichoptera	Helicopsychidae	Helicopsyche	1	scraper
Tricladia	Planariidae	Dugesia	101	scraper, collector-gatherer

JC2 Macroinvertebrate identification for 06/30/03

Order	Family	Genus	Number	Functional Feeding Group
Anomopoda	Daphniidae	Daphnia	21	collector-gatherer
Coleoptera	Dytiscidae	Oreodytes	5	predator
Coleoptera	Haliplidae	Peltodytes	4	shredder, predator
Coleoptera	Hydrophilidae	Tropisternus	2	predator
Diptera	Certopogonidae	Dasyhelea	2	scraper, collector-gatherer
Diptera	Certopogonidae	Probezzia	2	predator
Diptera	Chironomidae	Dicrotendipes	13	scraper, collector-gatherer
Diptera	Chironomidae	Oxycera	3	unknown
Diptera	Chironomidae	Paramerina	23	unknown
Diptera	Chironomidae	Sublettea	20	scraper
Ephemeroptera	Baetidae	Callibaetis	6	collector-gatherer
Ephemeroptera	Baetidae	Fallceon	498	unknown
Haplotaxida	Tubificidae		2	collector-gatherer
Hemiptera	Belostomatidae	Abedus herberti	3	predator
Hemiptera	Veliidae	Microvelia	4	predator
Hydrachnida	Limnesiidae	Kawamuracarus	5	predator
Limnophila	Physidae	Physella	43	collector-gatherer
Odonata	Calopterygidae	Haeterina americana	1	predator
Odonata	Coenagrionidae	Argia	12	predator
Odonata	Coenagrionidae	Enallagma	4	predator
Podocopida	Candoniidae	Candona	675	collector-gatherer
Podocopida	Cypridae	Eucypris	130	collector-gatherer
Trichoptera	Helicopsychidae	Helicopsyche	13	scraper
Trichoptera	Hydroptilidae	Metrichia	19	shredder
Tricladida	Planariidae	Girardia	43	scraper, collector-gatherer

PCSC1 Macroinvertebrate Identification for 02/28/04

Order	Family	Genus	Number	Functional Feeding Group
Diptera	Chironomidae	Chironomus	18	collector-gatherer
Diptera	Psychodidae	Pericoma	26	collector-gatherer

PCSC1 Macroinvertebrate Identification for 06/25/03

Order	Family	Genus	Number	Functional Feeding Group
Diptera	Chironomidae	Chironomus	456	collector-gatherer
Diptera	Psychodidae	Pericoma	2	collector-gatherer
Diptera	Psychodidae		4	collector-gatherer
Haplotaxida	Tubificidae		51	collector-gatherer

PCSC2 Macroinvertebrate Identification for 02/28/04

Order	Family	Genus	Number	Functional Feeding Group
Diptera	Chironomidae	Chironomus	15	collector-gatherer
Diptera	Chironomidae	Eukiefferiella	3	collector-gatherer
Diptera	Psychodidae	Pericoma	11	collector-gatherer
Diptera	Tipulidae	Ormosia	1	collector-gatherer
Haplotaxida	Tubificidae		40	collector-gatherer
Hemiptera	Corixidae		1	predator

PCSC2 Macroinvertebrate Identification for 06/25/03

Order	Family	Genus	Number	Functional Feeding Group
Diptera	Chironomidae	Chironomus	306	collector-gatherer
Diptera	Psychodidae	Pericoma	1	collector-gatherer
Haplotaxida	Tubificidae		28	collector-gatherer

RDF1 Macroinvertebrate Identification for 01/23/03

Order	Family	Genus	Number	Functional Feeding Group
Coleoptera	Dytiscidae	Laccodytes	1	predator
Collembola	Hypogastruridae	Pseudachorutes	1	collector-gatherer
Diptera	Ceratopognidae	Ceratapogon	1	predator, collector-gatherer
Diptera	Ceratopogonidae	unidentifiable	1	------------
Diptera	Chironomidae	Bryophaenocladius	1	unknown
Diptera	Chironomidae	Eukiefferiella	3	collector-gatherer, scraper, predator
Diptera	Chironomidae	Hydrobaenus	3	scraper, collector-gatherer
Diptera	Chironomidae	Lopescladius	2	collector-gatherer
Diptera	Chironomidae	Metriocnemus	1	collector-gatherer
Diptera	Chironomidae	Pseudochironomus	1	collector-gatherer
Diptera	Chironomidae	Symbiocladius	1	predator
Diptera	Chironomidae	Synorthocladius	1	collector-gatherer
Diptera	Chironomidae	unidentifiable	2	--------------
Diptera	Simuliidae	Cnephia	1	collector-filterer
Diptera	Simuliidae	Metacnephia	1	collector-filterer
Diptera	Simuliidae	Simulium	1	collector-filterer
Diptera	Simuliidae	unidentifiable	1	collector-filterer
Diptera	Stratiomyiidae	unidentifiable	2	predator
Dorylaimida	Dorylaimidae	Dorylaimus	28	predator
Haplotaxida	Tubificidae	---------------	303	collector-gatherer
Hemiptera	Veliidae	Rhagovelia	1	predator
Hydracarina	Eremaeidae	Hydrozetes	1	collector-gatherer
Hydracarina	Hydrachnnidae	Hydrachna	1	predator
Hydroida	Hydridae	Hydra	1	predator
Limnophila	Physidae	Physella	3	collector-gatherer
Limnophila	Planorbidae	Gyraulus	1	collector-gatherer
Lumbriculida	Lumbriculidae	Rhynchelmis	10	collector-gatherer
Podocopida	Candoniidae	Candona	24	collector-gatherer
Trichoptera	Hydropsychidae	Hydropsyche	1	scraper
Tricladida	Planariidae	Girardia	24	scraper

RDF1 Macroinvertebrate Identification for 08/12/03

Order	Family	Genus	Number	Group
Anomopoda	Daphnia	Daphnidae	4	collector-gatherer
Coleoptera	Hydrophilidae	Berosus	1	predator
Diptera	Ceratopogonidae	Dasyhelea	1	scraper, collector-gatherer
Diptera	Ceratopogonidae	Mallocohelea	1	predator
Diptera	Chironomidae	Chironomus	1	collector-gatherer
Diptera	Chironomidae	Eukeiferiella	10	collector-gatherer, scraper, predator
Diptera	Chironomidae	Hydrobaenus	4	scraper, collector-gatherer
Diptera	Chironomidae	Lopescladius	16	collector-gatherer
Diptera	Chironomidae	Paratanytarsus	4	unknown
Diptera	Chironomidae	Rheotanytarsus	3	collector-gatherer
Diptera	Chironomidae	Thienemannimyia	1	collector-gatherer
Diptera	Simuliidae	Simulium	3	collector-gatherer
Dorylaimida	Dorylaimidae	Dorylaimus	5	predator
Ephemeroptera	Baetidae	Calibaetis	4	collector-filterer
Haplotaxida	Tubificidae	---------------	99	collector-gatherer
Hydracarina	Eremaeidae	Hydrozetes	3	collector-gatherer
Limnophila	Physidae	Physella	75	collector-gatherer
Limnophila	Planorbidae	Gyraulus	96	collector-gatherer
Pelocypoda	Sphaeridae	Pisidium	4	collector-gatherer
Pharyngobdellida	Erpobdellidae	Erpobdella	2	predator
Podocopida	Candoniidae	Candona	331	collector-gatherer
Podocopida	Cypridae	Eucypris	5	collector-gatherer
Trichoptera	Helicopsychidae	Helicopsyche	1	scraper

RDF2 Macroinvertebrate Identification for 01/23/03

Order	Family	Genus	Number	Functional Feeding Group
Diptera	Ceratopogonidae	Ceratopogon	1	predator, collector-gatherer
Diptera	Chironomidae	Eukiefferiella	5	collector-gatherer, scraper, predator
Diptera	Chironomidae	Lopescladius	2	collector-gatherer
Diptera	Chironomidae	Metrionemis	1	collector-gatherer
Diptera	Chironomidae	Orthocladius	1	collector-gatherer
Diptera	Chironomidae	Paracladopelma	1	unknown
Diptera	Chironomidae	Paramerina	1	unknown
Diptera	Chironomidae	Parochlus	1	unknown
Diptera	Chironomidae	Pseudochironomus	1	collector-gatherer
Diptera	Chironomidae	Smittia	1	collector-gatherer
Diptera	Chironomidae	Stenpellinella	1	unknown
Diptera	Chironomidae	Stilocladius	1	unknown
Diptera	Chironomidae	unidentifiable	2	--------------
Diptera	Simuliidae	Simulium	23	collector-filterer
Dorylaimida	Dorylaimidae	Dorylaimus	79	predator
Haplotaxida	Tubificidae	---------------	85	collector-gatherer
Hydracarina	Hydrachnidae	Hydrachna	2	predator
Hydroida	Hydridae	Hydra	2	predator
Limnophila	Physidae	Physella	55	collector-gatherer
Limnophila	Planorbidae	Gyraulus	4	collector-gatherer
Limnophila	Planorbidae	Helisoma	1	collector-gatherer
Podocopida	Candoniidae	Candona	4	collector-gatherer
Rhynchobdellida	Helobdella	Glossiphoniidae	2	predator

RDF2 Macroinvertebrate Identification for 08/12/03

Order	Family	Genus	Number	Functional Feeding Group
Anomopoda	Daphniidae	Daphnia	6	collector-gatherer
Coleoptera	Dytiscidae	Dytiscus	1	predator
Coleoptera	Dytiscidae	Oreodytes	18	predator
Coleoptera	Hydrophilidae	Berosus	9	predator
Diptera	Ceratopogonidae	Dasyhelea	3	collector-gatherer, scraper
Diptera	Ceratopogonidae	Mallocohelea	3	predator
Diptera	Chironomidae	Chironomus	6	collector-gatherer
Diptera	Chironomidae	Dicrotendipes	40	scraper, collector-gatherer
Diptera	Chironomidae	Eukiefferiella	10	collector-gatherer, scraper, predator
Diptera	Chironomidae	Lopescladius	8	collector-gatherer
Diptera	Chironomidae	unidentifiable	9	---------------
Dorylaimida	Dorylaimidae	Dorylaimus	169	predator
Ephemeroptera	Baetidae	Callibaetus	6	collector-gatherer
Eucopepoda	Centropagidae	Labronectum	16	collector-gatherer
Haplotaxida	Tubificidae	---------------	46	collector-gatherer
Hemiptera	Corixidae	unidentifiable	1	predator
Hydracarina	Eremaeidae	Hydrozetes	1	collector-gatherer
Limnophila	Physidae	Physella	150	collector-gatherer
Pharyngobdellida	Erpobdellidae	Erpobdella	3	predator
Podocopida	Candoniidae	Candona	107	collector-gatherer

SC1 Macroinvertebrate Identification for 03/06/04

Order	Family	Genus	Number	Functional Feeding Group
Diptera	Chironomidae	Chironomus	9	shredder, collector-gatherer
Diptera	Simuliidae	Simulium	1	collector-filterer
Haplotaxida	Tubificidae		30	collector-gatherer
Podocopida	Candoniidae	Candona	9	collector-gatherer

SC1 Macroinvertebrate Identification for 06/23/03

Order	Family	Genus		Functional Feeding Group
Diptera	Chironomidae	Chironomus	44	shredder, collector-gatherer
Diptera	Simuliidae	Simulium	26	collector-filterer
Dorylaimida	Dorylaimidae	Dorylaimus	2	Predator
Haplotaxida	Tubificidae		1260	collector-gatherer

SC2 Macroinvertebrate Identification for 03/06/04

Order	Family	Genus	Number	Functional Feeding Group
Diptera	Chironomidae	Chironomus	677	shredder, collector-gatherer
Diptera	Chironomidae	Eukiefferiella	170	collector-gatherer, scraper, predator
Diptera	Simuliidae	Simulium	275	collector-filterer
Limnophila	Physidae	Physella	1	collector-gatherer
Haplotaxida	Tubificidae		1579	collector-gatherer
Podocopida	Candoniidae	Candona	88	collector-gatherer

SC2 Macroinvertebrate Identification for 06/23/03

Order	Family	Genus	Number	Functional Feeding Group
Anomopoda	Daphniidae	Daphnia	8	collector-gatherer
Coleoptera	Hydrophilidae	Tropisternus	1	predator
Collembola	Hypogastruridae	Odontella	21	collector-gatherer
Diptera	Ceratopogonidae	Ceratopogon	12	predator, collector-gatherer
Diptera	Ceratopogonidae	Dasyhelea	5	scraper, collector-gatherer
Diptera	Ceratopogonidae	Mallocohelea	2	predator
Diptera	Ceratopogonidae	Sphaeromias	3	predator
Diptera	Chironomidae	Chironomus	75	collector-gatherer
Diptera	Chironomidae	Dicrotendipes	119	scraper, collector-gatherer
Diptera	Chironomidae	Endochironomus	3	shredder
Diptera	Chironomidae	Eukiefferiella	48	collector-gatherer, scraper, predator
Diptera	Chironomidae	Larsia	2	predator
Diptera	Chironomidae	Parachironomus	2	predator
Diptera	Chironomidae	Paramerina	60	unknown
Diptera	Chironomidae	Parorthocladius	3	collector-gatherer

Diptera	Chironomidae	Polypedilum	15	collector-gatherer, scraper, predator
Diptera	Chironomidae	Rheosmittia	1	unknown
Diptera	Chironomidae		16	
Diptera	Ephydridae	Hydrellia	6	shredder
Diptera	Psychodidae		4	
Diptera	Simuliidae	Simulium	118	collector-filterer
Dorylaimida	Dorylaimidae	Dorylaimus	154	predator
Eucopepoda	Dioptomidae		4	collector-gatherer
Haplotaxida	Tubificidae		1923	collector-gatherer
Hemiptera	Belostomatidae	Abedus herberti	2	predator
Odonata	Coenagrionidae	Coenagrion resolutum	18	predator
Pharyngobdellida	Erpobdellidae	Erpobdella punctata	16	predator
Podocopida	Candoniidae	Candona	78	collector-gatherer