AQUATIC RESOURCE PROGRAM REPORT

2. Aquatic resource survey for the upper Cosumnes and Mokelumne Rivers

This section has three parts:

2A. a survey of the aquatic invertebrates of the Cosumnes River.

2B. a report on the distribution and abundance of fishes in the Cosumnes River basin, relating these factors to land and water use.

2C. This is a report on food web studies in the upper basin to examine the impacts of invasive fishes. This part contains three sections (a) a description of stable isotope methods used in the study, (b) impact of the redeye bass invasion on the food webs, and (c) a description of how the structure of food webs changes within the river network.

After some early exploratory sampling trips into the Mokelumne watershed, we decided that additional data on the fishes and invertebrates of the river was not needed because of the detailed studies being conducted in relation to power plant relicensing on the river. The information is presented in the following multivolume report:

Garcia and Associates. 2000. *The distribution and abundance of the benthic macroinvertebrate fauna and fish populations in tributaries leading into and including the North Fork Mokelumne and mainsteam Mokelumne rivers: final report.* Prepared for Pacific Gas and Electric Company. Garcia and Associates, San Anselmo CA.

Only limited comparisons between the two watersheds are possible because they are so different in flow regimes and in their fish and invertebrate faunas. Essentially, the Mokelumne is a much larger system than the Cosumnes, originating at much higher elevations. The river is largely harnessed for production of power and water. Thus the North Fork Mokelumne, adjacent to the Cosumnes, now consists of stair-steps of power dams, with permanent cold-water streams in between each dam that have highly modified flow regimes. Most of the streams in the watershed are dominated by rainbow trout and brown trout. Native fishes (pikeminnow, hardhead, Sacramento sucker, speckled dace, riffle sculpin) appear in addition to trout below dams in the lower reaches above Camanche Reservoir and non-native fishes are relatively scarce. A curious exception is the presence of Lahontan speckled dace and redside shiner in some of the uppermost tributaries, apparently the result of bait-bucket introductions into alpine lakes.

2A. Aquatic Resource Survey of Upper Cosumnes and Mokelumne Rivers: Invertebrates

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Abstract

River ecosystems are influenced by processes operating and interacting on a variety of spatial scales. Quantifying the interplay of large and small-scale processes is central to both a basic ecological understanding of river ecosystems as well as the development of effective watershed management strategies. A key management goal for many western rivers restricted by large dams is to restore ecosytem function through restoration of the natural hydrograph. However, factors operating on small spatial scales may also compromise ecosystem function. In a watershed in the California Sierra Nevada without a major dam, we examined the influence of land use patterns, vegetation cover, water quality, native and introduced fishes and periphyton abundance on the distribution patterns of aquatic invertebrates. We found that patterns of invertebrate species richness, biomass and density were significantly influenced by water quality, surrounding land use and vegetation, and fish distributions, although the abundance of non-native fishes had no additional influence. Position in the watershed also had little influence on variation in several food web properties. Our data indicate that in this watershed, the influence of processes operating on larger spatial scales were of approximately the same magnitude as processes acting more locally. In particular, declines in water quality and decreased summer flows had the most significant negative effects on aquatic invertebrates. Our study highlights that even if high flows are maintained on western rivers, these systems are significantly at risk to reduced summer flows, altered water quality and nonnative species.

INTRODUCTION

The primary focus of river restoration in the watersheds of the western U.S. has been to recapture the natural variation in the hydrograph of these rivers that has been lost due to flow regulation by large dams (Mount 1995; Poff 1997; Poff et al. 1997; Fausch et al. 2002; Stanley and Doyle 2002). Among the many consequences of altered flows is the loss of seasonal flooding events that strongly influences sediment and nutrient transport (Power et al. 1996; Stanley and Doyle 2002) and also affects fish assemblages (Bain et al. 1988; Brown 2000; Moyle et al. *in press*) and aquatic invertebrates (Poff 1997; Stanley et al. 2002). Although restoring the natural hydrograph may be necessary for restoring ecosystem function and is a key management goal, it may not be sufficient if other processes including those with impacts on local sites are negatively affecting ecosystem function.

The Cosumnes watershed feeds the largest river in California that flows from the Sierra Nevada, and unlike many rivers in the western U.S., it has no major dams and consequently experiences much of the normal variation in flows driven by winter and spring precipitation and snowmelt. This watershed has become a focus of substantial conservation efforts, because it represents what is believed to the best example of a natural hydrograph for rivers of similar size in this region. The assumption is that the relatively unimpaired flow regime of the Cosumnes River with its highly variable hydrograph during the seasonal flood cycle should favor the maintenance of normal ecosystem function and including a healthy assemblage of native species. However, in common with many western watersheds, the Cosumnes River is dominated by rapidly changing land use as the result of logging, ranching and agriculture. These activities frequently result in changes in losses of surface and ground water, reductions in riparian vegetation, nutrient loading and alterations in other water quality characteristics that can substantially affect important faunal groups such as aquatic invertebrates. Even in watersheds without major dams, small diversions and groundwater pumping for agriculture and domestic use can drastically alter flow regimes by reducing important seasonal variation in hydrologic processes (Mount 1995) and can create serial discontinuities that disrupt the normally continuous stream habitat (Ward and Stanford 1983).

Addressing the effects of landuse on the abundance, diversity and biomass of invertebrate resources of the Cosumnes River is on of the two primary goals of this section. The other goal is to describe the spatially and temporally variable patterns aquatic invertebrate resources in the upper watershed of the Cosumnes River. We examine several factors that operate over a range of spatial scales that negatively influence this watershed despite this relatively natural flooding cycle. Specifically, we quantify processes operating on landscape scales at the level of entire watershed or sub-watersheds including land use and vegetation cover as well as processes acting more locally including water quality, abundances of native and introduced fishes and primary production and determine the effects of these processes on the diversity and abundance of aquatic invertebrates.

METHODS

Watershed Overview. The Cosumnes River watershed is an area of approximately 1600-km^2 on the west side of the central California Sierra Nevada (Figure 1). The elevation of this watershed ranges from essentially sea level where it meets the Mokelumne River just above its confluence with the Sacramento-San Joaquin Delta to an elevation of 2400 m at the headwaters in the El Dorado National Forest. Only 16% of the watershed lies above 1500 m, so most of the flow of the river is derived from rainfall rather than snow melt, which results in greater fluctuations in flows relative to most other rivers draining the Sierra Nevada. At the main gauging station at Michigan Bar (just below the confluence of the three main forks), flows range from no flow during dry years to a peak flow of 2,650-m^3/s during an exceptional event in 1997. The annual mean runoff at Michigan Bar is approximately 452 million m^3/yr with a peak in the average daily hydrograph typically occurring in February. While there are no large dams on the main stem or on the three major forks of the Cosumnes River, there are many large and small diversions that divert as much as 44 million m^3/yr (see Discussion).

Study Sites. In July and September of 2001, and July of 2002, a total of 14 sites were sampled throughout the Cosumnes watershed (Figure 1). We chose sites so as to represent the range of habitats present in the watershed, to cover equally the North, Middle and South forks of the river. Site accessibility was limited because much of the watershed is on private land. At each site, we sampled one riffle and one run to cover the minimum and maximum range of flows. We recorded the type of habitat along with relevant vegetation, benthic substrate characteristics. At each sample site, we measured maximum and mean depth of the water column and recorded stream velocity with a Marsh-McBirney Flowmate 2000. We also recorded conductivity, temperature, and dissolved oxygen with a YSI-85.

Invertebrate Sampling Methods. Aquatic insects were sampled at each site with a standard surber sampler. The surber samples were taken from downstream to upstream with each sample involving manipulating the substrate for at least one full minute by picking up rocks and moving gravel within the area delimited by the sampler. Larger rocks were rubbed on all sides of them in order to dislodge attached animals. Care was taken to make sure that all animals drifted into catch bucket of the surber sampler and did drift over or outside the sampler. Once the sample was taken, all the animals were rinsed into the catch bucket by rinsing the net with DI water or filtered river water. The contents of the catch bucket were then emptied into a labeled Ziploc bag. Larger animals, or animals that remained attached to the net were hand picked with forceps. Samples were preserved with 95% ethyl alcohol quickly after collection to minimize predation. All organisms were identified to the lowest practical level for counting (in most cases family or genus) and selected individuals were identified to genus or species where possible.

Vegetation and Landuse. We used land use information generated for a 500 meter radius around each sampling site with Geographic Information System (GIS) data sets using USGS land use / land cover data (1990), CALVEG Vegetation data, GAP Analysis Vegetation data and USGS Digital Line Graph (DLG) transportation linework. Each sampling site was mapped using a GPS unit or was screen digitized on a scanned 1:24,000 scale USGS quad (DRG) using ArcView3.2. The USGS data were classified LandSat TM imagery and were in raster format with a 30 meter cell size. The CALVEG data were from 1:250,000 scale vegetation maps from 1979 and 1981 and the GAP Analysis data were classified LandSat TM imagery (1990). The data were classified using WHR habitat types. The DLG road data were from the DLG-3 series at a 1:100,000 scale and were updated using transportation data maintained by CALTRANS in 1993. The rest of the GIS analysis was completed using a customized set of Arc Macro Language (AMLs) programs in ARC/INFO. The sampling points were individually buffered with a radius of 500 meters and the resulting buffer was used to clip the land use data, the CALVEG vegetation data and the roads data. The number of cells of each land use type within the 500 meter buffer was stored in an ASCII file and later transferred to an Excel spreadsheet. The cell counts were converted to areas, therefore, the areas produced by this analysis may be greater or less them the area of the 500 m radius of the circle because of the conversion between vector and raster data. The CALVEG vegetation data, the GAP Analysis vegetation data and the roads data were both vector data sets so there was no problem with conversion.

From the land use data (Figure 2), we used 14 categories that were represented at our study sites: annual grassland, grassland/herbaceous, shrub lands, deciduous forest, evergreen forest, mixed forest, low intensity residential, orchards and vineyards, pasture and grain fields, transitional areas, roads, jurisdictional dams, non-jurisdictional dams, and elevation (Table 2). We used the jurisdictional dams data set and the water rights data set maintained by the State Water Resources Control Board to calculate the numbers of dams and potential diversions upstream of each sample site. Both of these data sets were completed since 1990 and have not been updated since. We calculated the upstream drainage area of each sample site from a 30 meter Digital Elevation Model (USGS DEM) and determined the number of dams falling into each area. From the vegetation cover data (Figure 3), we used 10 categories that were represented at our study sites: Ponderosa pine, Jeffrey pine, Sierra mixed-conifer, blue oak-digger pine, montane hardwood-conifer, chemise-redshank chaparral, blue oak woodland, montane hardwood, annual grassland, and cropland (Table 3).

Native and Nonnative Fishes. Fish sampling data as part of a collaborative study of the Cosumnes watershed (Moyle et al. *in press*). At each site, 100-200 m of stream was sampled for fish using the most effective technique or combination of techniques. For 40 of the 44 sites, electrofishing was the principal technique applied, using a Smith-Root Type 12 Backpack electrofisher. Each site was subjected to a single pass with the electrofisher and the fish were captured by two people using dip nets. In areas with wide, shallow, sandy-bottomed pools, electrofishing was supplemented by sampling with a 10 x 1.3 m bag seine (8 mm mesh). For both techniques, fish were kept alive in buckets until they were measured (standard length) and returned alive to the water. Pools too large and deep to electrofish or seine were surveyed using mask and snorkel by one or two observers and all fish were counted and lengths estimated. Snorkeling surveys were useful mainly for determining the presence of large individuals of some species and for determining the presence of rare species not captured by other techniques. All study sites were sampled once during the 2000 and 2001 season, but not at all sites in 2002, so our analyses of fish effects only included 2001 dates. Prior survey data showed that fish populations changed little among surveys in the same season (Moyle et al. *in press*), so we use the summer 2001 fish data for both our July and September 2001 invertebrate data.

Of the 25 fishes found throughout the Cosumnes River watershed (Moyle et al. *in press*), we conducted our analyses with the 10 species that were present present at our study sites including five native fishes: California roach (*Lavinia symmetricus*), Sacramento pikeminnow (*Ptychocheilus grandis*), Sacramento sucker (*Catostomus occidentalis*), Pacific lamprey (*Lampetra tridentate*), rainbow trout (*Oncorhynchus mykiss*), and five introduced fishes: brown trout (*Salmo trutta*), green sunfish (*Lepomis cyanellus*), redear sunfish (*Lepomis microlophus*), redeye bass (*Micropterus coosae*), smallmouth bass (*Micropterus dolomieui*) (Moyle 2002) (Table 4). We used the total number of fishes per site, the total number of species (species richness), and the number of invasive species as predictor variables for our analyses.

Water quality. Data for water quality were available for sites throughout the watershed, including stream reaches that included most of our sampling sites (R. Dahlgren, University of California, Davis, unpublished data). The variables included Na, NH_4, K, Mg, Ca, Si, Cl, NO_3, PO_4, SO_4, HCO_3, pH, conductivity, dissolved oxygen, turbidity, total dissolved solids, total nitrogen, total phosphorous, chlorophyll a, pheophytin a, dissolved oxygen, and dissolved organic carbon and physical characteristics of the stream channel including temperature, depth, and flow velocity (Table 4). For dates in 2001, we had data for all 23 variables, however, we did not have these available for 2002, so we used 15 variables that were available for all sites available for all three dates (July 2001, Sept. 2001, July 2002). Water samples were collected biweekly during this period. During the low flow summer period, data show little variation among dates, so we used data collected closest to the invert sampling dates. All samples were stored at 3 deg C and filtered to 0.2 um prior to analysis and major anions and cations were measured using Dionex ion chromatography (see Holloway and Dahlgren 2001 for details).

Trophic Interactions. To better understand the relationship between invertebrate abundance and periphyton abundance, we sampled periphyton in 2001 and 2002. At each of three sites in 2001 and seven sites in 2002, we placed three stratified random transects to represent the range of periphyton cover. Along each transect, we collected the nearest cobble from five randomly chosen points and, with the cobble above the water line, scrapped all the material from a 0.01 x 0.01 m area with a single edge razor blade. This material was bagged and returned to the lab for processing. In 2001, we separated sand, invertebrates and other visible material from the periphyton and dried and weighed the remaining biomass. In 2002, we calculated a dry weight for total biomass and then ashed samples in a muffle furnace to determine inorganic and organic portions. We also examined watershed position by on several foodweb metrics by assigning the study sites to one of four positions (from higher to lower elevation) in the watershed. We then tested for differences among watershed positions using site-specific ratios of the biomass for three separate contrasts using ANOVA: 1) herbivores to periphyton, 2) primary predators to herbivores, and 3) secondary predators to primary predators.

Statistical Methods. In order to understand the influence of environmental variation on broad spatial scales involving a large number of variables, we used canonical correspondence analysis (CCA), a direct gradient method that permits assessing the strength of environmental variables on species values for numerous sites where both are measured (ter Braak and Verdonschot 1995). CCA performs relatively well with multiple collinear environmental variables, skewed species distributions, and noise in species distributions (Palmer 1993). For stream invertebrates, we used on of three levels of classification: 1) invertebrate families (see Table 1), 2) invertebrate orders, or 3) functional groups (following Merritt and Cummings 1996). For each of the three levels of invertebrate classification, we ran CCA separately for each of the three categories of environmental data: 1) land use (14 variables), 2) vegetation (10 variables), 3) fish distribution (10 taxa), and 4) water quality (15 variables). Although significance tests do not depend on parametric assumptions, we log transformed data for species abundances and environmental parameters prior to analysis on a priori grounds (see Palmer 1993). For the trophic linkage data, we ran both parametric (Pearson) and non-parametric (Spearman) correlation analyses (SAS ver 8.0, SAS Institute, Carey, NC) using summary data for invertebrates (mean abundance per site, mean biomass per site, species richness per site) and for fishes (total abundance per site, species richness per site, total abundance of nonnative species per site). Data for fishes for 2002 were the same as those used for 2001. With a smaller subset of sites, we ran correlation analyses with summary data for invertebrates and with periphyton (total biomass sampled per site). We also ran several analyses both with and without one study site DCLA (Deer Creek) because of the extreme values at this one site and concern about its statistical influence. See Discussion for explanation of results from this site.

RESULTS

Landuse. We found that land use explained a significant proportion of the variation in invertebrate abundance. At the invertebrate family level, CCA axes 1-3 explained 37.3% of the variation in invertebrate abundance with the eigenvalue for all three axes being significant (p<0.01) (Table 6). Low intensity residential and deciduous forests have the largest canonical coefficients for the first axis. As in other analyses below, we removed on site Deer Creek (DCLA) from the analyses because of its extreme values in water quality and invertebrate abundances (see Discussion and Figure 7). When we did so, the fit declined to 33.9%. At the invertebrate order level, CCA axes 1-3 explained 63.2 % of the variation overall with the eigenvalue for all three axes being significant (p<0.01). Removing Deer Creek had little effect on this result. Here both low intensity residential, transitional areas and dams have the largest negative canonical coefficients on the first CCA axis mixed forest having the largest positive values (Figure 4). At the level of invertebrate functional groups, CCA explained less of the variation and the eigenvalues for axes 2 and 3 were not statistically significant.

Vegetation. The results from vegetation show a modest association between these variables and invertebrate distribution patterns. For analysis at the level of invertebrate families, we found approximately 35.6% of the variance was explained by CCA axes 1-3 with statistically significant eigenvalues (p<0.01) (Table 6). When Deer Creek was removed, the fit declined to 31.7%. The factors with the highest canonical coefficients were Ponderosa pine and blue oak woodland. At the level of invertebrate orders, CCA explained 64.9% of the variation, which was also significant (p<0.01). Removing Deer Creek had little effect on this result. Here blue oak woodland and blue oak-digger pine had the largest canonical coefficients. At the level of invertebrate functional groups, CCA explained less of the variation and produced nonsignificant eigenvalues.

Native and Nonnative Fishes. The results from the fish abundance analysis also explain a significant, but somewhat smaller, proportion of the variation in invertebrate abundance. When we ran the CCA analysis with the ten fish taxa present at our sites, we found a poor fit with nonsignificant eigenvalues for CCA axes at all levels for invertebrates (family, order, functional group). When we conducted the analyses after removing piscivorous fishes (pikeminnows and both bass species) and found the model produced a better fit (with fewer variables). At the level of invertebrate families, fishes explained 43.2% of the variation with statistically significant eigenvalues ($p<0.01$) (Table 6). The fishes that had the largest canonical coefficients were rainbow trout and green sunfish. This fit actually improved to 47.0% when we removed the Deer Creek sites. With Deer Creek removed, California roach also had a high canonical coefficient on the first CCA axis. At the level of invertebrate orders, the reduced fish matrix (without piscivores) produced nonsignificant values that were only marginally significant ($p=0.03$) when Deer Creek was removed from the analysis. With Deer Creek removed, non-piscivore fishes explained 63.2% of the variation and the fishes that had the largest canonical coefficients were roach and green sunfish and redear sunfish (Figure 5). All analyses involving invertebrate functional groups produced nonsignificant eigenvalues.

Water Quality. The influence of water quality at the level of invertebrate families explained a total of 40.3% of the total variance with CCA axes 1-3, which declined to 36.2% with Deer Creek removed. Both of these produced eigenvalues that were statistically significant ($p<0.01$) (Table 6). The results from the water quality and physical parameters also showed the most influence at the level of invertebrate orders. For invertebrate orders, the CCA explained 63.2% of the variation with statistically significant eigenvalues ($P<0.01$). Here, removing Deer Creek had a much larger effect on exploratory correlation analyses where some strong correlations were eliminated entirely by removing the three outliers that constituted the three Deer Creek points (see below). The same variables generally had the largest canonical coefficients regardless of the inclusion of Deer Creek. Turbidity, temperature, total nitrogen, total phosphorous and DOC had the largest canonical coefficients (Figure 6).

Trophic Interactions. We found strong correlations for fish abundance with mean invertebrate abundance (Pearson r=0.58, $p<0.002$) and biomass (Pearson r=0.56, $p<0.003$) and for fish species richness with invertebrate abundance (r=0.53, $p<0.007$) and biomass (Pearson r=0.54, $p<0.005$). Invertebrate species richness and fish invader abundance were not significantly correlated with any other variables. When the highly eutrophic Deer Creek site was removed, from all three time periods, however, all of the significant correlations become nonsignificant.

We found no significant relationship between any measures of invertebrate abundance and periphyton abundance. We also ran this analysis with invertebrate functional groups including shredders and scrapers and found no significant relationship. Unfortunately, we did not collect periphyton data from the eutrophic Deer Creek site, where a clear positive relationship was evident. Finally, we examined the relationship between invertebrate functional groups such as filter feeders and chlorophyll a and pheophytin a and found no significant associations ($p>0.05$). Finally, we found that position in the watershed did not significantly influence variation in food web properties. There was no significant differences among the four watershed position in the ratio of consumers to periphyton biomass, primary predators to herbivores, or secondary predators to primary predators ($p>0.05$ for all contrasts).

DISCUSSION

Despite the lack of dams and the unhindered seasonal high flows that regularly occur in the Cosumnes River watershed, our data demonstrate that several processes acting at different spatial scales are negatively affecting the abundance and diversity of aquatic invertebrates in this watershed. We also document that processes acting on watershed or sub-watershed scales are having impacts of approximately the magnitude as processes acting locally at individual sites. For most categories of variables examined, the first three CCA axes explained more than 50% of the variation in the distribution of aquatic invertebrates. Among the most important were land use variables and water quality parameters where more than 60% of the variation among sites was explained. The landuse variables that dominated the CCA analysis included low intensity residential development, jurisdictional dams and transitional areas. While the mechanisms behind these changes in landuse are varied, the influence of small dams and diversions can likely be attributed to reduced flows during low flow periods in the summer and early fall.

The issue of water diversion has substantial consequence for the Cosumnes watershed. Although no large dams exist on the main stem or major forks of the Cosumnes River, and winter flows are likely similar to historic levels, there many diversions large and small in the watershed. The diversion on Camp Creek sends over 28.3 million m^3/yr across the basin to Sly Park Reservoir on Sly Park Creek where it is pumped into the adjacent American River watershed. Two other large diversions (Crawford Ditch and Plymouth Ditch) remove over 8.6 million m^3/yr and an additional 135 smaller diversions remove up to 6.9 million m^3/yr (see Moyle et al. *in press*). The biggest impact of all this diverted water is the reduction of flows during the summer period when flows are naturally low. Our data show that water diversions can have important influences, not by reducing variation in flow, but by reducing summer flows and increasing the period during which reaches may be dry. These affects are likely compounded in the lower parts of the watershed by additional losses due to groundwater pumping. It is important to note that our sampling greatly underestimates the effect of reduced summer flows, because we did not include sites that had become totally dry and had no invertebrates because of their statistical influence. Our data are consistent with other studies that have shown similar influences of intermittent flows on invertebrates (Del Rosario and Resh 2000).

Water quality also contributed substantially to the patterns observed in this study. In general, temperature and turbidity together with dissolved oxygen, total nitrogen and phosphorous were among the best predictors of invertebrate diversity and abundance. Changing land use practices that reduce riparian vegetation or increase terrigenous inputs contribute to changes in water quality parameters that can have strong, negative impacts on aquatic invertebrates. This was most apparent for the relatively extreme water quality values found at highly eutrophied sites such as Deer Creek (DCLA in Figure 1). In particular, data from this site reflected the results of high organic loading associated with inputs from agricultural retention ponds. This resulted in high levels of nitrogen and phosphorous, conductivity, cations, turbidity, DOC, and associated water quality variables. The values for this site in water quality were substantially different than all other sites (Figure 7). Consequently this heavily impacted site also showed the most dramatic divergences in abundances and diversity of invertebrates.

Other factors such as the abundance of native fishes had somewhat less influence on the patterns of invertebrate abundances (Table 6). The effects were significant in most cases, however, we found little evidence that invasive fish species exerted any additional influence above that of native fishes. The numbers of introduced fishes had little influence on the patterns of invertebrate abundance. Although certain introduced fishes in the Cosumnes watershed, such as the redeye bass, have already resulted in significant changes in the distribution of native fishes (Moyle et al. *in press*), the replacement of native fishes by introduced species does not seem to be strongly reflected in the abundance and distribution of aquatic invertebrates. Ours is among the first studies to address the impact of introduced fishes on aquatic invertebrates in watershed in this region.

Our conclusions must be tempered by the limitations of our data and analyses. First, our data for individual sites is also limited by variables that we were not able to quantify. Our efforts to characterize a given sampling site included first order measures of flow velocity, depth, substrate, and related characteristics that captured the most important overall features of the sampling site, while ignoring variation in these parameters on finer scales. Our sampling also involved pooling samples across habitats for final analysis, which would average over many important differences within a site. The tradeoff of sacrificing within site variation was the ability to devote more sampling resources to differences among sites. The patterns we have demonstrated are also specific to the habitats and depths we sampled as well as the sampling gear. We were restricted to the depths equal to or less than the height of the surber sampler, though we note that this depth included most of the reaches that were available for sampling during our mid and late-summer sampling. Of course at some sites there deeper pools that we were not able to sample with our gear, so our conclusions do not apply to organisms in these deeper habitats. Also, we did not adequately sample some invertebrate groups that typically occupy rocky benches, woody debris, and other habitat types that could not be effectively sampled with our methods.

There are dependencies in our predictor variables that are unavoidable in this type of analysis. Changes in land use may obviously affect the other biological and physical features that we have treated as independent variables in this study such as water quality and fish abundance. The link between fishes and land use in this watershed has been investigated in detail by Moyle et al. (*in press*). They found comparatively weak linkages between fishes and land use, so we feel confident in ignoring some of the potential interactions between these factors. We tested the association of land use variables and water quality using CCA and found little evidence for a strong overall association between these two. Based on these results, we feel justified in independently testing the variable categories in our analysis. Of course land use and associated activities on some level do contribute to water quality. However in this watershed, water quality is also being heavily influenced by processes operating on local scales. With these limitations noted, the value of our approach was to simultaneously examine the influence of several important categories of variable that can simultaneously influence aquatic invertebrate abundances on a variety of spatial scales across an entire watershed. Furthermore, our data also provide a link between human activities across an entire watershed and the consequences of these activities for aquatic invertebrate assemblages.

We can draw some conclusions from the data presented here that are relevant for future management of the Cosumnes watershed. Much has been stated about the importance of maintaining and restoring the natural flow regimes to river ecosystems (Mount 1995; Poff 1997; Poff et al. 1997; Fausch et al. 2002; Stanley and Doyle 2002). The Cosumnes River is viewed locally as a model watershed, because the lack of a major dam means that the watershed still experiences high winter flows that were present historically. Rivers in this region with more natural flow regimes, for example, typically have more native fishes (Marchetti and Moyle 2001). However, reduced summer flows caused by diversions and ground water pumping are likely contributing to intermittent dry periods in reaches that were once continually flowing and lengthening dry periods in reaches that historically did dry out. Given the status of the Cosumnes River as one of the few watersheds in the Sierra Nevada range without a major dam, our data do define the baseline for restoration needed by federal and state agencies working to manage this and similar watersheds in the region (Ward et al. 2001).

In summary, our data suggest that although restoring the natural flooding events in a given watershed is a necessary step in restoring the function of river ecosystems, this may not be not necessarily be sufficient to guarantee a healthy and functioning river. Changes in land use, water quality and the invasion of introduced fishes on smaller scales can substantially compromise river systems such as the Cosumnes River that has managed to maintain most of the original hydrograph. Therefore, in addition to restoring the historical hydrographs, we must be diligent in minimizing additional human impacts in river ecosystems.

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Table 1. Invertebrate taxa from of the upper watershed of the Cosumnes River during summer monitoring from 2000-2002.

Invertebrate Family	Biomass Range (mg)	Invertebrate Family	Biomass Range (mg)
Elmidae(A)	0-46.02	Leptoceridae	0-24.77
Elmidae(L)	0-89.07	Limnephilidae	0-100.94
Histeridae(A)	0-6.07	Odocentridae	0-96.71
Dryopidae(A)	0-9.24	Philopotamidae	0-20.01
Dysticidae(A)	0-1.00	Phryganeidae	0-0.78
Psephenidae	0-105.1	Polycentropodidae	0-10.90
Ptilodaclitidae(L)	0-0.18	Psychomyiidae	0-1.91
Ceratopogonidae(L)	0-23.56	Rhyacophilidae	0-6.31
Chironomidae	0-212.01	Sericostomatidae	0-3.44
Dixidae(L)	0-0.02	Hydrobiidae	0-431.16
Empididae(L)	0-3.80	Lymnaeidae	0-124.80
Simuliidae(L)	0-194.87	Physidae	0-54.15
Stratiomyiidae(L)	0-123.77	Planorbidae	0-245.70
Tipulidae(L)	0-39.19	Corbiculidae	0-134.40
Ameletidae	0-49.57	Gammaridae	0-10.40
Baetidae	0-60.32	Cyprididae	0-2.98
Ceanidae	0-0.35	Turbellaria*	0-61.29
Ephemerellidae	0-23.99	Acari*	0-19.26
Heptageniidae	0-64.63		
Leptophlebiidae	0-4.32		
Tricorythidae	0-118.23		
Veliidae(L)	0-1.51		
Pyralidae(L)	0-31.42		
Tortricidae(L)	0-4.10		
Corydalidae	0-0.12		
Sialidae	0-3.79		
Gomphidae	0-19.07		
Libellulidae	0-4.11		
Calopterygidae	0-1.25		
Coenagrionidae	0-50.97		
Chloroperlidae	0-32.06		
Nemouridae	0-4.39		
Perlidae	0-180.22		
Perlodidae	0-49.49		
Pteronarcydae	0-7.74		
Brachycentridae	0-296.77		
Glossosomatidae	0-46.33		
Helicopsychidae	0-420.20		
Hydropsychidae	0-244.45		
Hydroptilidae	0-11.15		
Lepidostamidae	0-53.90		

Table 2. Landuse categories used in the CCA analysis with approximate range of cover (sq. meters) across all sampling sites.

Landuse	Range
Annual Grassland	0-682851
Blue Oak	0-763145
Mixed Conifer-Fir	0-781393
Mixed Conifer-Pine	0-781393
Deciduous Forest	0-234000
Evergreen Forest	0-1341900
Grasslands-Herbaceous	0-598500
Low Intensity Residential	0-94500
Mixed Forest	0-80100
Orchards-Vineyards-Other	0-219600
Pasture-Hay	0-156600
Shrub land	12600-192600
Transitional Areas	0-138600
Roads	1022-5363
Nonjurisdictional Dams	0-405
Jurisdictional Dams	0-18
Elevation	62-5034

Table 3. Vegetation categories used in CCA analysis with approximate range of cover (sq. meters) across all sampling sites.

Vegetation	Range
Ponderosa Pine	0-781392
Jeffrey Pine	0-260814
Sierran Mixed Conifer	0-639785
Blue Oak-Digger Pine	0-552420
Montane Hardwood-Conifer	0-701511
Chemise-Redshank-Chaparral	0-47906
Blue Oak Woodland	0-96582
Annual Grassland	0-405369
Cropland	0-282746
Irrigated Row/Field Crops	0-498647
Urban	0-480149

Table 4. Data for fish taxa (from Moyle et al. *in press*) used in the CCA analysis showing range of abundances and summary variables across all sampling sites and dates. Each of the summary categories are based on totals per site per sampling date basis: total species abundance= abundance of all fish species; total species richness= number of species; invasive species abundance= abundance of introduced fishes only; invasive species richness=number of introduced species only.

Taxa	**Range**
Rainbow Trout	0-63
Brown Trout	0-10
Sacramento Sucker	0-14
Pikeminnow	0-164
Redeye Bass	0-151
California Roach	0-95
Pacific Lamprey	0-3
Green Sunfish	0-15
Redear Sunfish	0-26
Smallmouth Bass	0-3
Total Species Abundance	39-185
Total Species Richness	2-5
Invasive Species Abundance	0-180
Invasive Species Richness	0-3

Table 5. Water quality parameters used in CCA analysis showing the units for each parameter and the range of values across all sampling sites and dates.

Parameter	Units	Range
TDS	g/l	0.02-0.52
NO_3	mM	0-849
SO_4	mM	2.7-913
HCO_3	mM	324-4235
Cl	uM	9.1-2194
Si	uM	227-372
Na	uM	89.6-6020
K	uM	10-225
Mg	uM	31-762
Ca	uM	81-1470
Turbidity	NTU	0.02-1.50
Total Nitrogen	ppm	0.05-13.80
Total Phosphorus	ppb	0-2713
Chlorophyll a	ppb	0.20-6.78
Pheophytin a	ppb	0.09-21.35
Dissolved Organic Carbon	ppm	0.18-21.35
Water Depth	cm	20-100
Water Flow	m/sec	0.02-0.62
Temperature	^{0}C	13.4-29.9
Dissolved Oxygen	mg/L	6.54-10.69
Specific Conductivity	us	29.9-896

Table 6. Results of CCA analysis showing the influence of variables on the biomass of invertebrate taxa at different grouping levels (invertebrate levels) in terms of the percent variation, the eigenvalue, and significance level of the eigenvalue.

Variable	Invertebrate Level	% Variance	Eigenvalue	p value
Vegetation Cover	Families	37.3	0.405	0.01
Vegetation Cover	Functional Groups	58.7	0.014	0.02
Vegetation Cover	Order	63.2	0.219	0.01
Land Use	Families	35.6	0.391	0.01
Land Use	Functional Groups	48.4	0.012	0.05
Land Use	Order	64.9	0.112	0.01
Water Quality	Families	40.3	0.425	0.01
Water Quality	Functional Groups	55.5	0.015	0.03
Water Quality	Order	63.2	0.224	0.01
Fish Abundance	Families	43.2	0.382	0.01
Fish Abundance	Functional Groups	47.2	0.014	NS
Fish Abundance	Order	52.8	0.168	NS

Figure 1. Map of upper watershed of the Cosumnes River. Site abbreviations are as follows: Camp Creek at North-South Rd. (CCNS), North Fork Cosumnes at N-S Rd. (NFNS), Dogtown Creek at N-S Rd. (DTNS), Middle Fork Cosumnes at N-S Rd. (MFNS), North Fork Cosumnes at E16 (NF16), Middle Fork Cosumnes at E16 (MF16), South Fork Cosumnes at E16 (SF16), Cosumnes at Hwy 49 (CS49), Cosumnes at Latrobe Rd. (CSLA), and Deer Creek at Latrobe Rd. (CDLA).

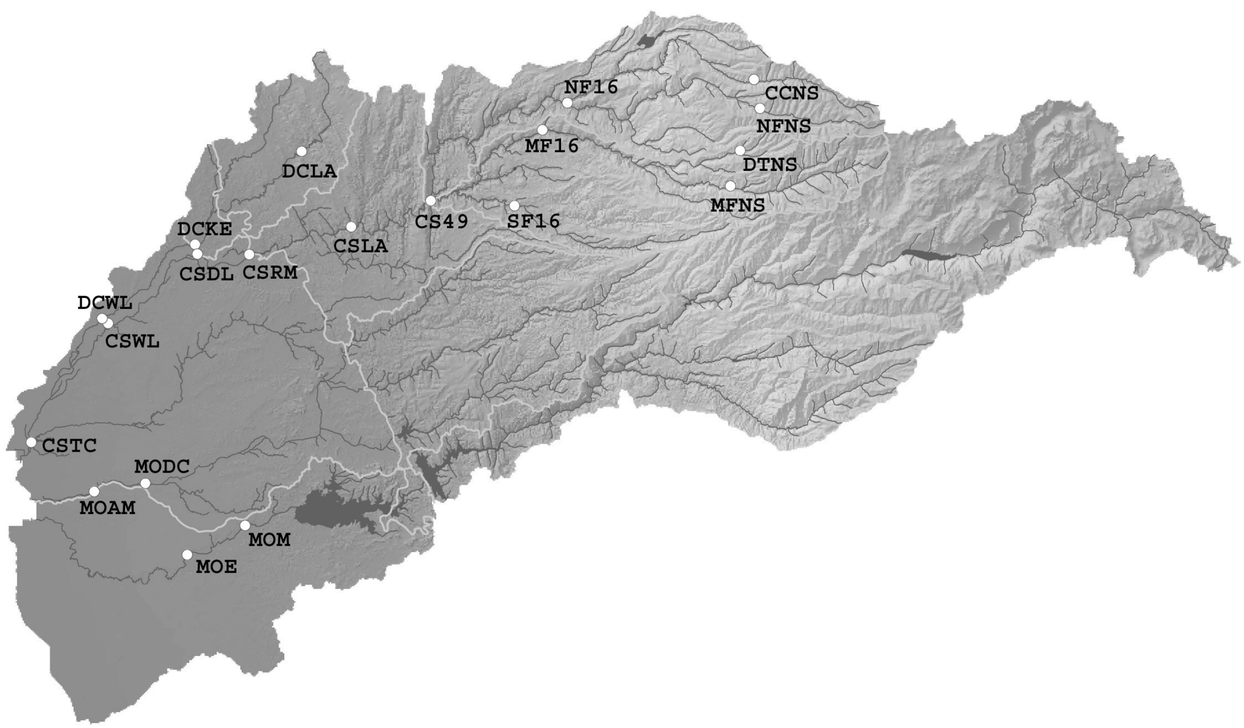

Figure 2. Landuse types for the upper watershed of the Cosumnes River. Land use types found within a 500 m radius of the study site were used in subsequent analyses.

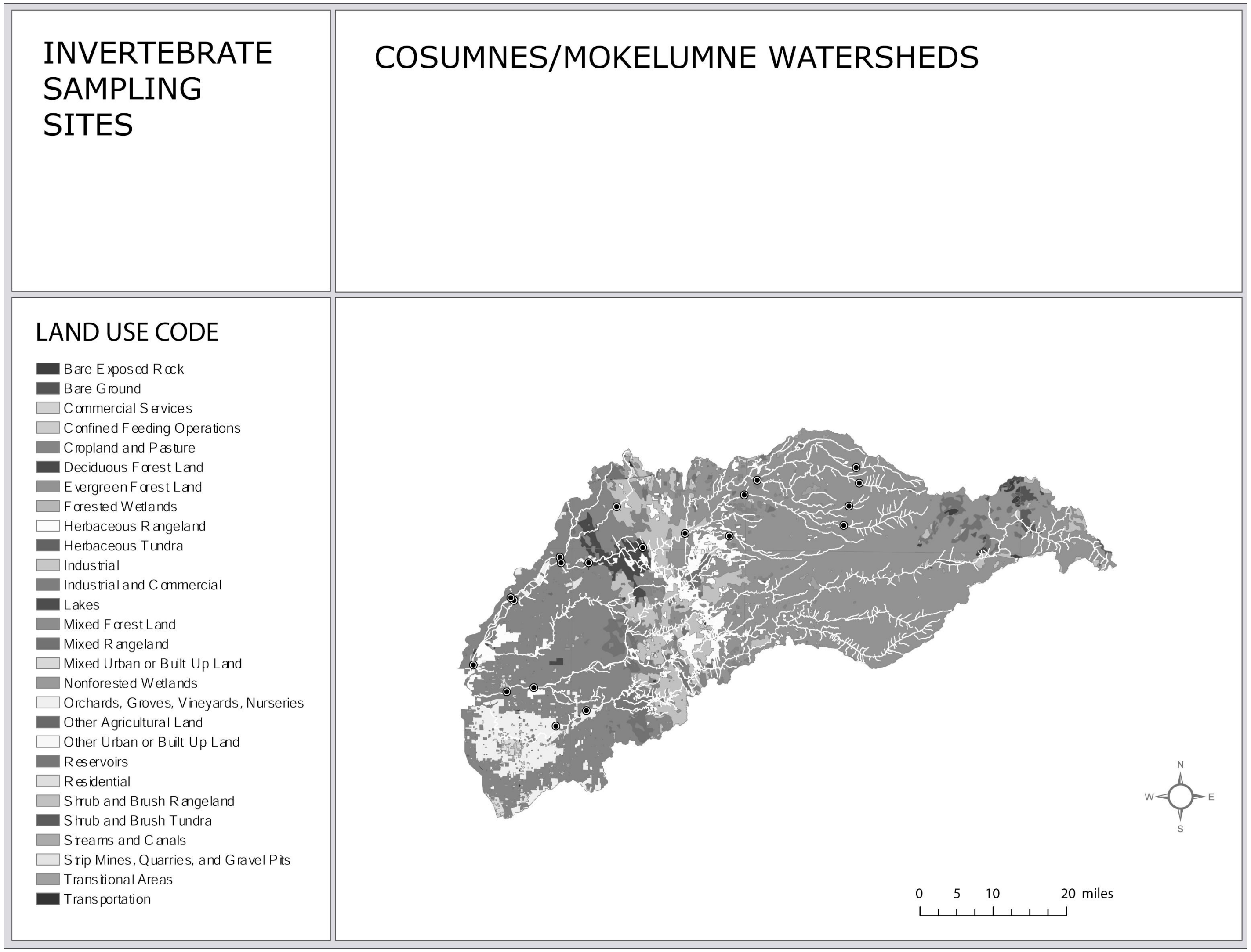

Figure 3. Vegetation types for the upper watershed of the Cosumnes River. Vegetation types found within a 500 m radius of the study site were used in subsequent analyses.

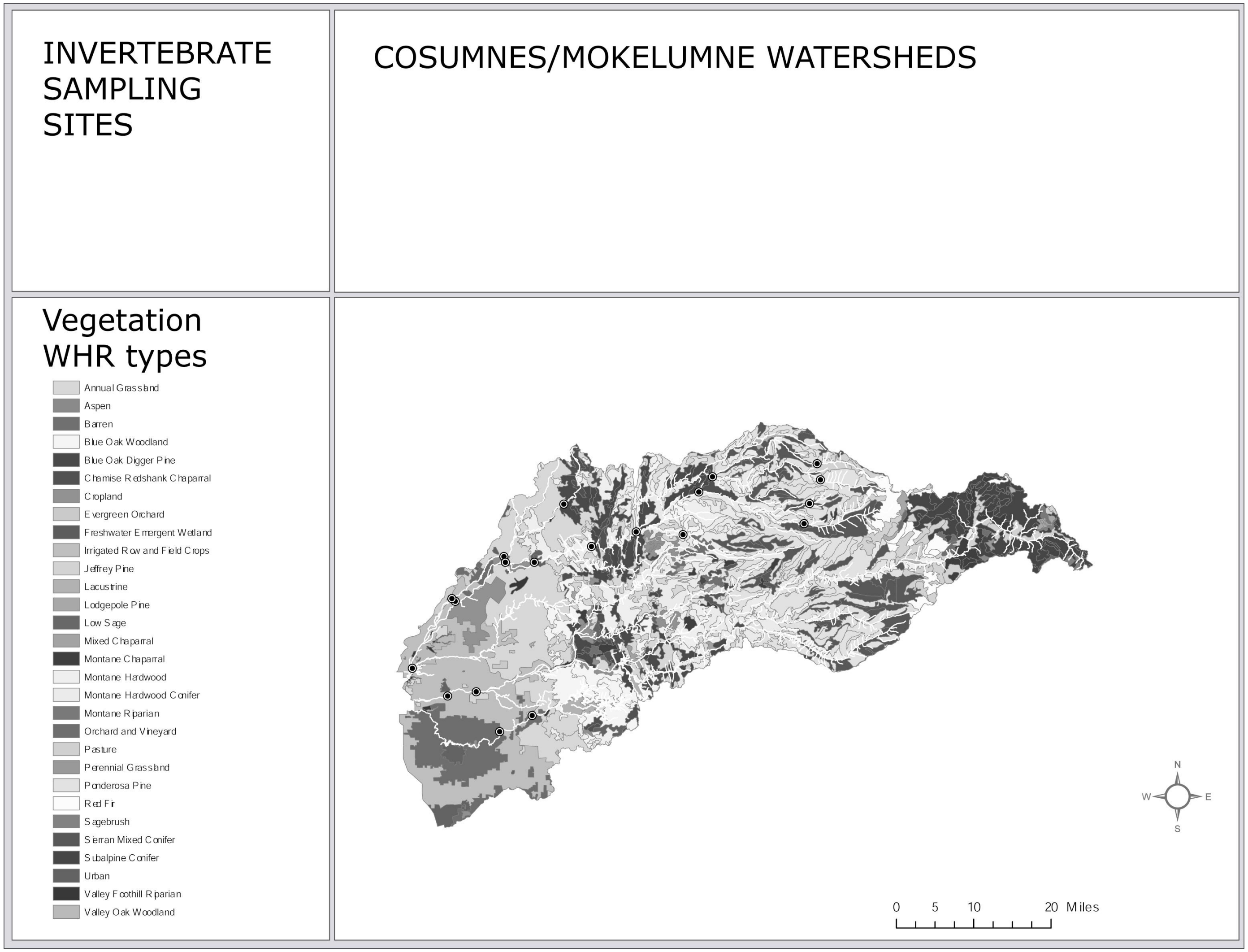

Figure 4. Plot of CCA canonical coefficients for landuse analysis showing the relative importance of these variables: AG=annual grassland, DF=deciduous forest, EF=evergreen forest, GR=grasslands-herbaceous, LI=low intensity residential, MF=mixed forest, OR=orchards-vineyards, PH=pasture-hay, SL=shrub lands, TA=transitional areas, RD=roads, NJ=nonjurisdictional dams, JD=jurisdictional dams, EL=elevation

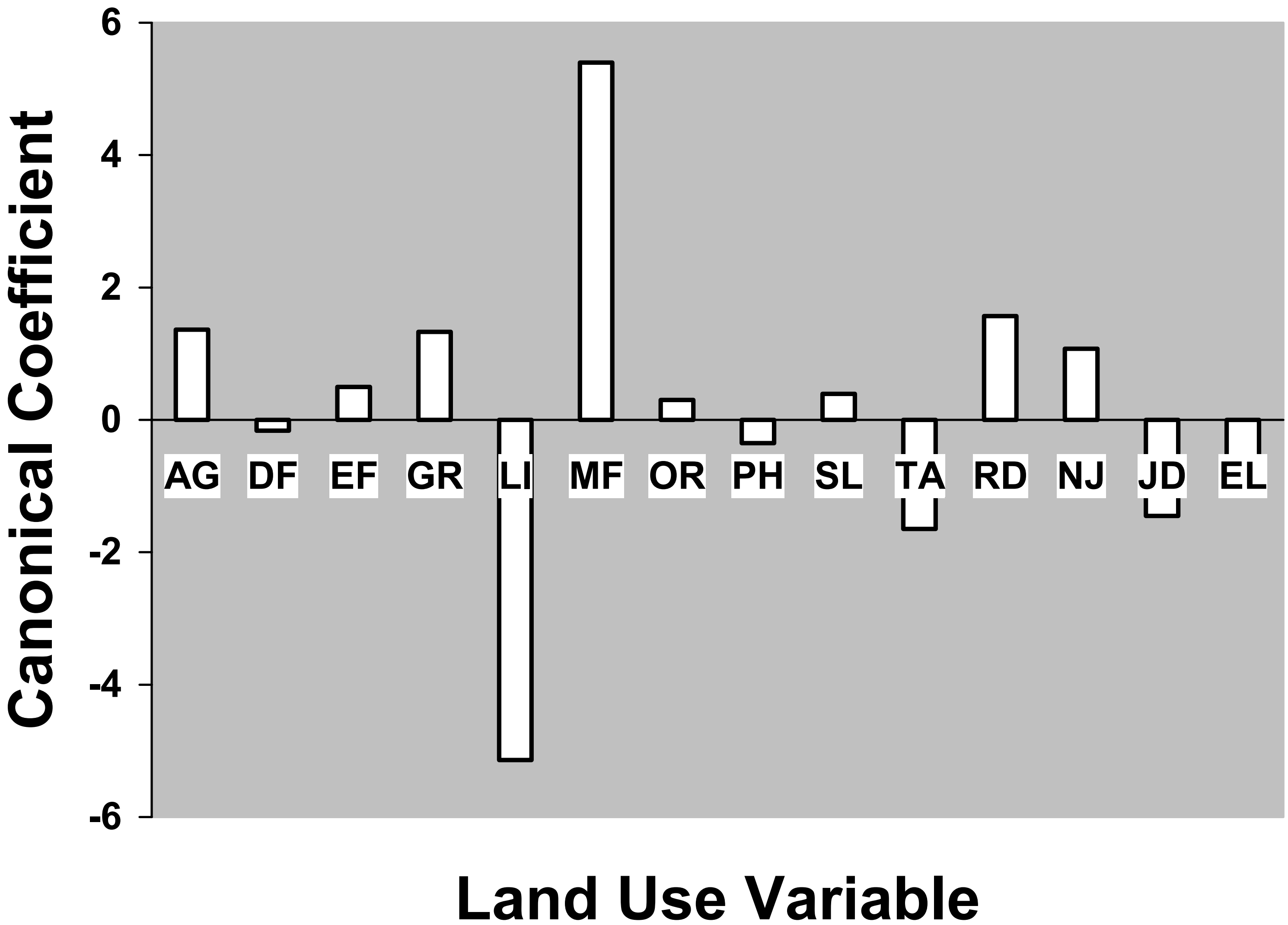

Figure 5. Plot of CCA canonical coefficients for non-piscivorous fish taxa showing relative importance of these variables: RBT=rainbow trout, BNT=brown trout, SKS=Sacramento sucker, RCH=California roach, PLR=Pacific lamprey, GSF=green sunfish, RSF=red sunfish

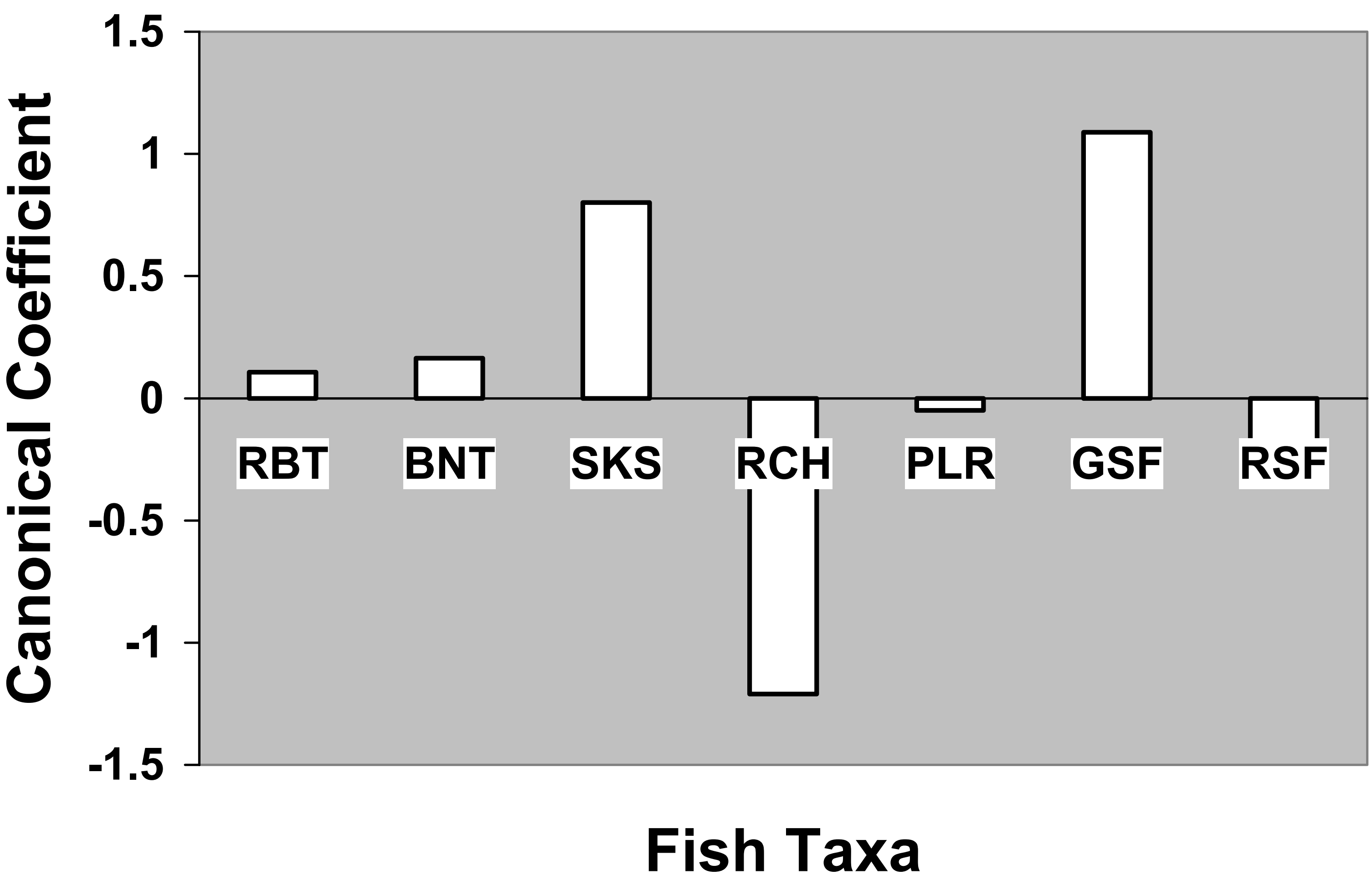

Figure 6. Plot of CCA canonical coefficients for water quality variables showing relative importance of these variables: TR=turbidity, TN=total nitrogen, TP=total phosphate, CH=chlorophyll a, PH=pheophytin, DC=dissolved organic carbon, DP=depth, FL=flow, TM=temperature, DO=dissolved oxygen, SC=specific conductivity

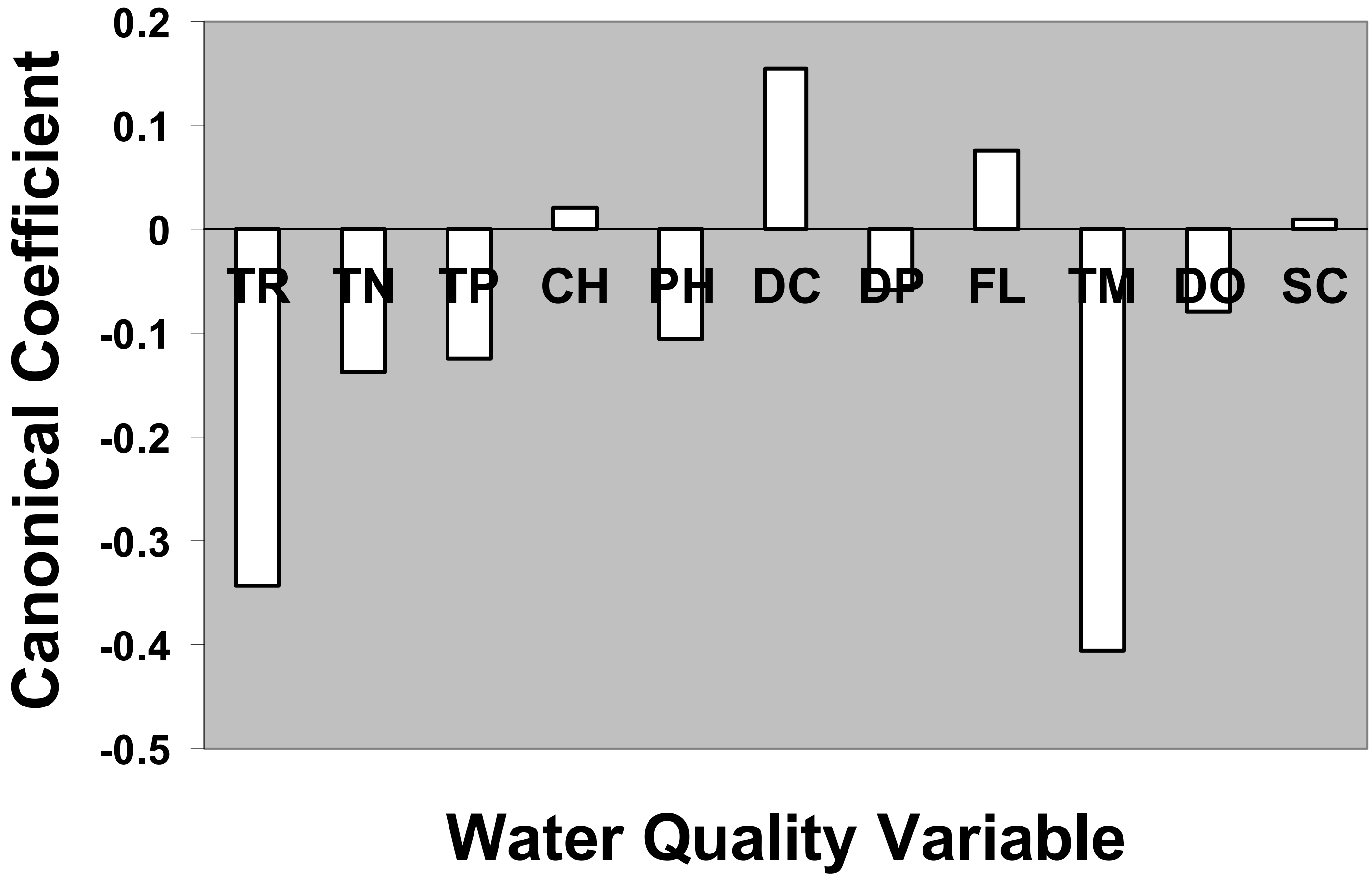

Figure 7. Figure 7. Comparison of Deer Creek (DCLA) with other sites (see site locations in Figure 1) for several water quality variables measured in 2001: KuM=potassium (µM), CauM=calcium (µM), Mg=magnesium (µM), NO3=nitrate (mM), SO4=sulfate (mM), Cl=chloride (µM), TP=total phosphate (ppb), HCO3mM=carbonate (mM), NauM=sodium