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Technical Memorandum No. 86-68220-08-06

San Diego River Invertebrate Monitoring Program- Final Report

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

May 2008

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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San Diego River Invertebrate Monitoring Program- Final Report

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Abstract

Butterfly and aquatic invertebrate assemblages were studied at sites along the San Diego River from 2004 to 2007. Multivariate analysis indicated that environmental variables significantly associated with butterfly assemblages included riparian rank, soil moisture, air temperature, wind speed, nectar abundance, and forb & graminoid richness, while those associated with benthic invertebrates were stream velocity, depth, pH, water temperature, alkalinity, hardness, and bank height. Taxa richness was significantly correlated between the two taxonomic groups, suggesting that the quality of terrestrial and aquatic environments was linked. A multi-metric index was developed using environmental variables and taxa richness of the two groups. This analysis indicated that environmental quality (ranked from highest to lowest of the ten sites) was: MTP=JS=ABGC=MVP-Y>KSR=FVM>QCS=Estuary=PO=FSDRP. Sites MTP and JS were located in the Mission Trail Regional Park and may be regional reference sites. Some butterflies of conservation interest were encountered and these included Behr's Metalmark, Hermes Copper, Saltmarsh Skipper, and California Dogface. The lowest ranked site was at the First San Diego River Restoration Project (FSDRP), suggesting that restoration techniques should be modified if quality environments for invertebrates are desired. The ratio of butterfly and benthic metrics indicated that some sites had environments that were better for one or the other taxonomic groups. Water quality (dissolved oxygen) appeared to be impacted in some areas because of the presence of large amounts of the exotic plant *Ludwigia*. It appeared that historic gravel mining may have improved conditions for this plant, and lowered habitat values for invertebrates, through the creation of lotic habitat.

Introduction

The San Diego River, in southwest California, begins in the Peninsular Mountain Range and flows west through the city of San Diego to the Pacific Ocean. The Mission Valley Groundwater Basin underlies this east-west trending valley. The primary source of recharge for this basin is infiltration of stream flow from the San Diego River (California Department of Water Resources, 2003). This basin has potential for seasonal groundwater recharge and recovery of 1000 to 2000 acre-ft of water/year. Urban runoff water is a major pollutant which impacts the river and potentially may negatively affect the existing subterranean water sources which government entities are working to protect. Safeguarding of this resource will help avoid future water supply crises.

Protection of this groundwater basin is partially dependent upon the proper functioning of the river, and plans have been developed for rehabilitation of the San Diego River (Hosler, 2004). Wetland enhancement, water aeration, concrete removal, and floating islands are among the techniques suggested for use in improvement of the natural functioning of the river system. The urban portion of the San Diego River has a history of past wetland restoration activities and past efforts have included projects such as the city managed First San Diego River Restoration Project (FSDRP). Along with water supply resources, riparian areas are among the most important ecosystems in the arid western United States because of their high habitat value and biodiversity (Allan and

Flecker, 1993). Many of the "special animals" in the California Natural Diversity Database are associated with riparian areas (http://www.dfg.ca.gov/bdb/pdfs/SPAnimals.pdf) and rehabilitating riparian areas may be important to maintaining these resources.

River corridor restoration requires descriptions of degraded conditions and detection of deviations from desired conditions so that improvements can be monitored. Tools are needed to assess progress and to aid in adaptive management of restoration efforts. However, characterization of riparian systems may be problematic because communities are at the boundary between terrestrial and freshwater ecosystems. Large-scale theories of coupling between aquatic and terrestrial ecosystems involve exchanges of water (flooding and groundwater) and organic matter (autochthonous and allochthonous production). Difficulties in assessment are encountered because of the complexity of the environment at the interface of these different elements of the landscape and because of the potential interdependence of the ecosystems. Streams and adjacent riparian zones are intimately linked by the flow of resource subsidies between terrestrial and aquatic environments, suggesting that impacts to one environment may affect the other. Impacts to the stream-riparian boundary may change the flow of resource subsidies and perhaps alter community structure. It has been demonstrated that information on aquatic invertebrates and stream conditions allows for additional insight into riparian classifications (Kennedy et al., 2000). Absence of monitoring in one environment may impair the ability to quantify impacts in the adjacent environment. Theories regarding conditions at boundaries are understudied relative to river continuum and river mosaic concepts but boundary concepts are likely important in understanding lotic systems (Naiman and Decamps, 1997).

Literature related to terrestrial-aquatic linkages suggests the importance of the floodplain environment to aquatic organisms. Differences in riparian vegetation may affect distributions of riverine mollusks (Morris and Corkum, 1999) and impact inputs of terrestrial invertebrates to streams (Edwards and Huryn, 1996) and the fishes that feed upon them (Kawaguchi et al., 2003). England and Rosemond (2004) demonstrated that changes in riparian forest cover can alter stream food webs and Wooster and Debano (2006) showed that stream reaches that flowed through patches of woody riparian vegetation had higher numbers of aquatic macroinvertebrate taxa than those with no woody vegetation. Impacts to terrestrial environments from changes in the aquatic environment include those where flow regimes are altered resulting in different moisture and temperature regimes which negatively impact terrestrial arthropod communities (Wenninger and Fagan, 2000). Adult terrestrial forms of aquatic organisms may also impact pollination of terrestrial plants, as has been observed in the case of dragonfly predation on pollinators (Knight et al., 2005). Marczak and Richardson (2007) found instream environments to have positive effects on terrestrial arthropods, demonstrating that emergence of aquatic invertebrates subsidize spider populations. It has been suggested that in many cases subsidies, rather than moving from productive to less productive parts of the riverine environment, exist as alternating periods of productivity exchanges between habitats (Marczak and Richardson, 2007). Implicit in this argument is that high quality instream environments lead to high quality floodplain or riparian environments and visa versa.

It would seem that study of both aquatic and terrestrial indicators could be an important tool in demonstrating the success of restoration projects. A potentially important first step is to compare biodiversity and/or metrics of terrestrial and aquatic groups in riverine environments. The presence/absence of congruence between measurements of terrestrial and aquatic groups might suggest impact levels and be an important tool for monitoring restoration and identifying impacts or stressors. Positive patterns in both groups might imply an ideal state of restoration, while a lag in either group might indicate specific adaptive alternatives. Aquatic and terrestrial organism could respond in distinctly different ways to restoration projects and illustrate differences in colonization dynamics or broken linkages between communities. Study of both aquatic and terrestrial components would allow for integration of these important aspects of river restoration. Recent studies with multiassemblage assessments suggest that sensitivity of stressor identification should be improved when several taxonomic groups are used in evaluation (e.g., Carlisle et al., 2008).

Kremen et al. (1993) suggested that arthropods may be especially appropriate as ecological indicators because of their rapid response to environmental changes. These indicators may provide an accurate, low-cost method for environmental assessment and evaluation that is directly related to important resources. Some biota may be more appropriate as ecological indicators than others. Camargo and Jalon (1990) for example found that aquatic macroinvertebrates were especially useful communities for detecting environmental changes and for reflecting recovery from impacts to riverine environments.

Changes in aquatic macroinvertebrate assemblages may occur because of altered habitat, changes in sediment input, water quality, thermal regimes, and flow patterns (Ward, 1976; Armitage, 1984; Armitage et al., 1987). Aquatic invertebrates also play a role in transfer of energy to higher trophic levels. Benthic invertebrates are a major part of the food resource for fishes, and altered invertebrate communities may result in changes in condition of fish communities (e.g., Waters, 1982; Bowlby and Roff, 1986; Wilzbach et al., 1986). Further, many aquatic invertebrates have non-aquatic phases, leading to their importance to other predators, including birds (Paetzold et al. 2005, Sanzone et al. 2003).

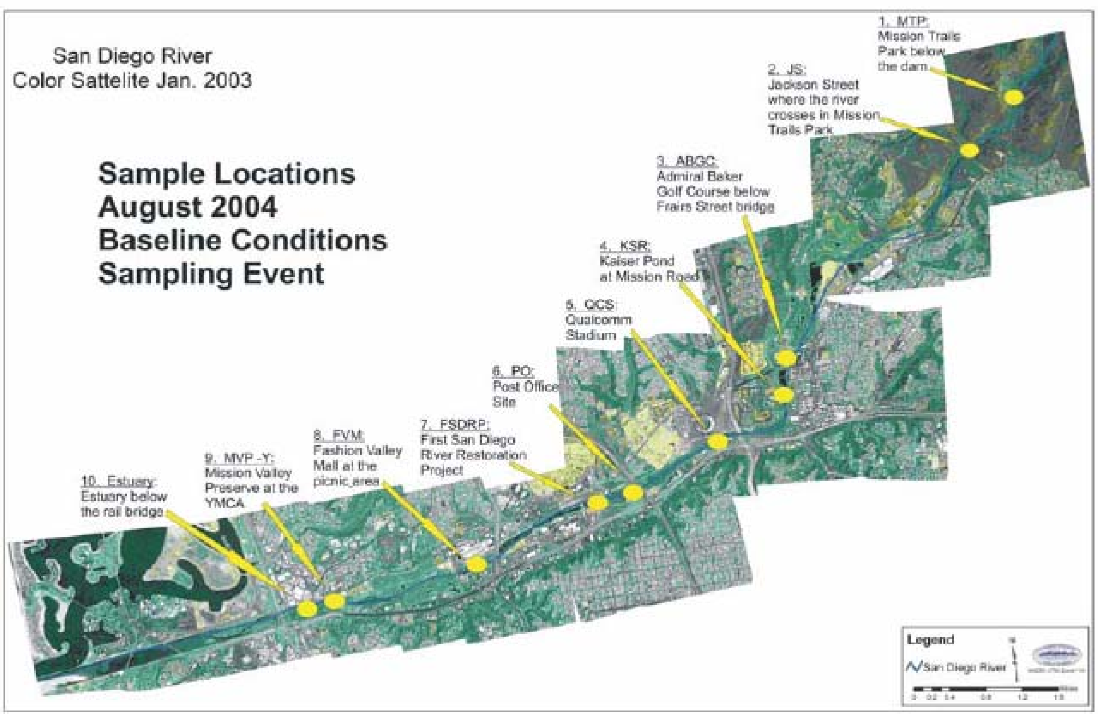
Riparian butterflies (Papilionoidea and Hesperioidea) may be appropriate indicators for monitoring the terrestrial portion of the stream environment. Butterflies have been used as indicators for landscape conservation (Brown Jr. and Freitas, 2000), logging impacts (Cleary, 2004), and as indicators of wetland types (Sawchick et al., 2005). Thomas (2005) concluded, after examination of butterfly life-history traits, relative sensitivity to climate change, and extinction rates, that butterflies could serve as indicator surrogates for other terrestrial insect groups. Butterflies are also phytophagous insects that play a role in transfer of plant energy to higher trophic levels (Tallamy, 2004). Butterfly assemblages can be threatened by exotic weed expansions (New and Sands, 2002) and butterfly assemblages appear to be effective indicators of riparian quality (Nelson, 2007).

With this in mind, both terrestrial (butterflies) and aquatic (benthic invertebrates) components of the San Diego River were sampled. Surveys of butterflies and benthic invertebrates were performed at ten different sites along the San Diego River from 2004 to 2007. This survey effort was intended to provide baseline information to monitor enhancement efforts along portions of the river through water management and habitat improvement. Multivariate analysis was used to aid in the design of metrics used to integrate aquatic and terrestrial components to rank sites and identify variables important in river restoration.

Methods

Sampling locations are presented in Figure 1. Sites were numbered sequentially starting in the Mission Trails Regional Park and proceeding downstream towards the estuary. The two furthest upstream sites (MTP and JS) were in the Mission Trails Regional Park, a relatively pristine area where exotic plants are managed, while downstream sites were exposed to increasing levels of urbanization and encroachment by exotic vegetation. Giant Reed (*Arundo donax*) dominates much of the plant cover, while Brazilian Pepper (*Schinus terebinifolia*) and some other broadleaf trees become common at more downstream locations (Burkhart and Kelly, 2005) such as the Estuary site (Figure 1) which is about 1.6 km (1 mile) from the Pacific Ocean. Castor Bean (*Ricinis communis*) was especially common at the QCS site next to Qualcomm stadium. Despite the presence of these exotics, native willow (*Salix* spp.) and cottonwood (*Populus fremontii*) were found at most sites and are structural dominants at the reclaimed FSDRP site.

Figure 1. Sampling areas along the San Diego River.



Aquatic macroinvertebrate sampling

Aquatic macroinvertebrates were sampled in April and August of 2005, 2006, and 2007. In 2004 only August samples were collected. A 3-minute kick method with a D-frame net (700-800 micron mesh) was used for sampling benthic invertebrates along a ca. 25-m wadeable portion of the streams. Sampling sites that were selected were characteristic of riverine habitat contained within the 2-ha butterfly sites. The net was placed on the stream bottom and upstream substrate disturbed by kicking or movement through the environment. As substrate was disturbed, the operator and net moved upstream for the required time. Samples collected from the net were preserved in 70% alcohol. In the laboratory, samples were washed in a 600-micron mesh sieve to remove alcohol, invertebrates were then picked from the substrate with the aid of an illuminated 10X magnifier, and then the entire sample was enumerated and identified to lowest practical taxon under a binocular dissecting scope.

Environmental variables

Dissolved oxygen, conductivity, pH, and temperature were measured with a portable meter. Water samples for alkalinity and hardness were analyzed with titration methods (Hach test kit).

Periphyton samples were collected from rocks or other solid, flat surfaces with a sampling device made from a modified 30-ml syringe with an inside diameter of 2.06 cm (Porter et al., 1993). Samples from three different substrates from the area where invertebrates were to be collected were composited into a single sample. The sample was then filtered onto glass-fiber filters. Ash-free-dry-mass was determined using standard methods (Eaton et al., 1995). Filters were dried for 48 h at 105^{o}C, dry weight determined on an analytical balance, filters ashed at 500^{o}C for 1 h, and the mass of the residue (ash weight) determined. Ash-free-dry-mass (g/m^2) was calculated by subtracting the ash weight from the dry weight of the sample and dividing by the periphyton sample area (9.99 cm^2).

Coarse-particulate-organic-matter (CPOM) was picked from the kick net samples during processing for benthic invertebrates. Material was dried (60^{o}C for 48 hrs) and weighed.

Size composition of the substrate was visually estimated at each site in the area where macroinvertebrates were collected. Categories were expressed as percent of bedrock, boulders, cobble, coarse gravel, fine gravel, and sand. Percentage categories were converted to a single substrate index (S.I.) value (e.g., Jowett and Richardson, 1990) using the formula S.I.=0.08*bedrock + 0.07*boulder + 0.06*cobble + 0.05*gravel + 0.04*fine gravel + 0.03*sand and fines. Wetted width of the river was measured using a range finder or meter tape and bank height was also estimated.

Water velocity at 10 cm above the substrate was measured at three discrete points in the area where invertebrates were collected. The average of these three measurements was used in analysis.

Habitat disturbance was estimated with Pfankuch's index (Pfankuch, 1975). This subjective, composite index involves scoring 15 stream channel variables along the upper bank, lower bank, and stream bottom. High scores represent unstable channels at the reach scale. This index has been found in independent studies (Townsend et al., 1997) to measure disturbance in streams.

Butterfly sampling

Individual butterflies were counted during timed searches to provide data on both species presence and an index of relative abundance. Sweep nets were used where required for verification or identification of species; however, most butterflies were identified by sight. One and a half person hours per day on two different days were spent sampling butterflies at each site. Three sessions (April, June, and August), corresponding to different species flight periods were sampled each year of the study, except for 2004 when only August samples were collected. Sampling was confined to ca. 2-ha areas at each site.

Nectar resources

The number of flowers or inflorescences considered nectar sources were estimated during butterfly surveys. Although not a direct measure of nectar, a linear relationship between amount of nectar and number of inflorescences has been found, and it has been suggested that the effort needed to quantify sugar production adds little additional information (Holl, 1995). Sampling took place within a 4-m radius circle at disjunct locations every 15 minutes during a survey. A running count of forb and graminoid diversity was taken within the same 4-m radius circle to estimate site plant richness.

Other environmental variables

A qualitative model developed to rapidly assess riparian systems (Stein et al., 2000) was used to evaluate the condition of riparian habitat. This model includes spatial and structural diversity, contiguity of habitats, invasive vegetation, hydrology, topographic complexity, characteristics of flood-prone areas, and biogeochemical processing. Wind speed, air-temperature, and relative humidity (RH) were also collected on each sampling occasion. Measurements of soil moisture took place at three locations across each plot. Light meters were used to measure lux levels in the plots and these measurements were compared to light levels in open areas and then used to calculate % shade.

Data analysis

We used constrained ordination (CANOCO 4.5) to examine gradients in benthic/butterfly assemblages (species and abundance) and to identify environmental variables most closely associated with species distributions in the ordination. Initial analyses of benthic or butterfly data using detrended correspondence analysis (DCA) revealed that the benthic data set had a relatively long gradient length (greater than 3), suggesting that analysis using unimodal models was appropriate. Therefore, canonical correspondence analysis (CCA) was used to explore relationships between assemblages (square-root transformed, infrequent species contributing < 1 individuals deleted) and environmental variables (ter Braak and Verdonschot, 1995). The butterfly data set had a relatively short gradient length (less than 3) as determined with DCA, suggesting that analysis using unimodal models was inappropriate. Therefore redundancy analysis (RDA) was used to examine the butterfly data set. Environmental variables were normalized, if needed, with arcsin-squareroot transformations for percent data and ln (X+1) for numeric data and examined for correlation with Pearson's correlation. Forward selection of environmental variables and Monte Carlo permutations were used to determine whether variables were significantly ($p \leq 0.05$) associated with invertebrate distributions.

The non-parametric Spearman rank correlation coefficient was used to evaluate the degree of correlation between annual (taxa were pooled from multiple sampling sessions for each year) benthic and butterfly richness and abundance. This technique operates on the ranks of data and is relatively insensitive to outliers and can also be used with very small sample sizes (Gauthier, 2001). Spearman was also used to examine correlations between some environmental variables and biotic measures.

A multi-metric index was designed to characterize the relative quality of San Diego River sites using variables identified from multivariate analyses and taxa richness of benthos and butterflies. This index was designed to integrate both riverine and riparian values into a single index. Percentiles were used to determine impairment levels where scores $\geq 75^{th}$ percentile were considered to have high values and $\leq 25^{th}$ percentile to have low values. Metrics were assigned an integer value of 1 (low), 3 (moderate), or 5 (high) for each of the parameters which were then summed to derive the San Diego River Index. ANOVA was used to test for location differences in metric values along the San Diego River. The ratio of the butterfly metric/benthic metric was used to determine whether there was congruence between terrestrial and aquatic group characteristics. Percentiles were used to determine whether sites had relatively high quality benthic characteristics ($\leq 25^{th}$ percentile) or relatively high quality terrestrial characteristics ($\geq 75^{th}$ percentile) as a method to establish which environment might be more in need of restoration.

Results and Discussion

Aquatic macroinvertebrates –Fifty-six taxa were found over the course of the study (Table 1). Canonical correspondence analysis of data from 2004 to 2007 suggested that velocity, pH, depth, temperature, alkalinity, hardness, and bank height were important parameters in structuring the benthic community (Figure 2). Eigen values for Axis I were 0.439 and for Axis II 0.364 with 17% of the species variance and 63% of species-environment relation explained in the first 2 axes.

Table 1. Taxa list of aquatic invertebrates found along the San Diego River.

EPHEMEROPTERA		
		Baetis sp.
		Caenis sp.
		Callibaetis sp.
		Fallceon quilleri
ODONATA		
	Aeshnidae	
	Calopterygidae	
	Coenagrionidae	
	Libellulidae	
TRICHOPTERA		
		Cheumatopsyche sp.
		Hydroptila sp.
		Oxyethira sp.
HEMIPTERA		
	Corixidae	
	Mesoveliidae	
	Veliidae	
COLEOPTERA		
		Enochrus sp.
DIPTERA		
		Bezzia/Palpomyia
		Dasyhelea sp.
		Probezzia sp.
	Orthocladiinae	
	Chironomini	
	Tanytarsini	
	Tanypodinae	
		Anopheles sp.
		Dixella sp.
	Ephydridae	
		Limnophora sp.
		Pericoma / Telmatoscopus
	Saldidae	
	Sciomyzidae	
		Simulium sp.
	Stratiomyidae	
	Tipulidae	
PORIFERA		
TURBELLARIA		
NEMATODA		
ANNELIDA		
	Lumbricidae	
	Lumbriculidae	
	Naididae	
	Tubificidae	
	Erpobdellidae	

	Glossiphoniidae	
BRANCHIOBDELLIDA		
CLADOCERA		
COPEPODA		
OSTRACODA		
AMPHIPODA		
		Corophium sp.
		Hyalella azteca
		Grandidierella sp.
THORACICA		
DECAPODA		
	Cambaridae	
		Palaemonetes sp.
MOLLUSCA		
	Ancylidae	
	Lymnaeidae	
	Physidae	
	Planorbidae	
		Corbicula sp.

Along Axis I (Figure 2), the upstream sites MTP, JS, and ABGC and the further downstream sites QCS and MVP-Y were located in the negative portion of the axis (especially in April) and were associated with higher velocities. Velocity sensitive blackflies (*Simulium*) were sometimes common at these sites (e.g., Figure 3) as were other taxa characteristic of higher velocity, shallow (lotic) sites. Collector-filterers such as the mayflies *Baetis* and *Fallceon quilleri* were found in this portion of the diagram (Figure 3). More lentic sites were found in the positive portion of Axis I and contained Odonates like Coenagrionidae and Libellulidae, along with shredders such as Chironomini (Figure 3). These sites were often deeper with steep banks (Figure 2). Alkalinity was often higher at these sites and was negatively correlated with DO (ρ=-0.6089, $P<0.0001$) indicating poor conditions for most aquatic invertebrates.

Stream velocities decreased in August (e.g., Figure 4) and temperatures increased (Figure 2) but the five lotic sites typically maintained some stream flow. However, at least some of the lotic sites became more similar to the lentic sites and were found to the right on Axis I in August (Figure 2).

The PO and Estuary sites appeared to contain unique benthic assemblages and were separate from other sites along Axis II (Figure 2). Estuary sites were influenced by salt water as indicated by the higher hardness values (e.g., Figure 2) and often contained *Corophium* and *Grandidierella*, brackish water amphipods. *Palaemonetes*, an estuarine shrimp, was also common at the Estuary site and was occasionally found at downstream sites such as FSDRP and FVM (Figure 3).

Figure 2. Canonical correspondence analysis of San Diego River benthic data showing the association of sites with environmental variables.

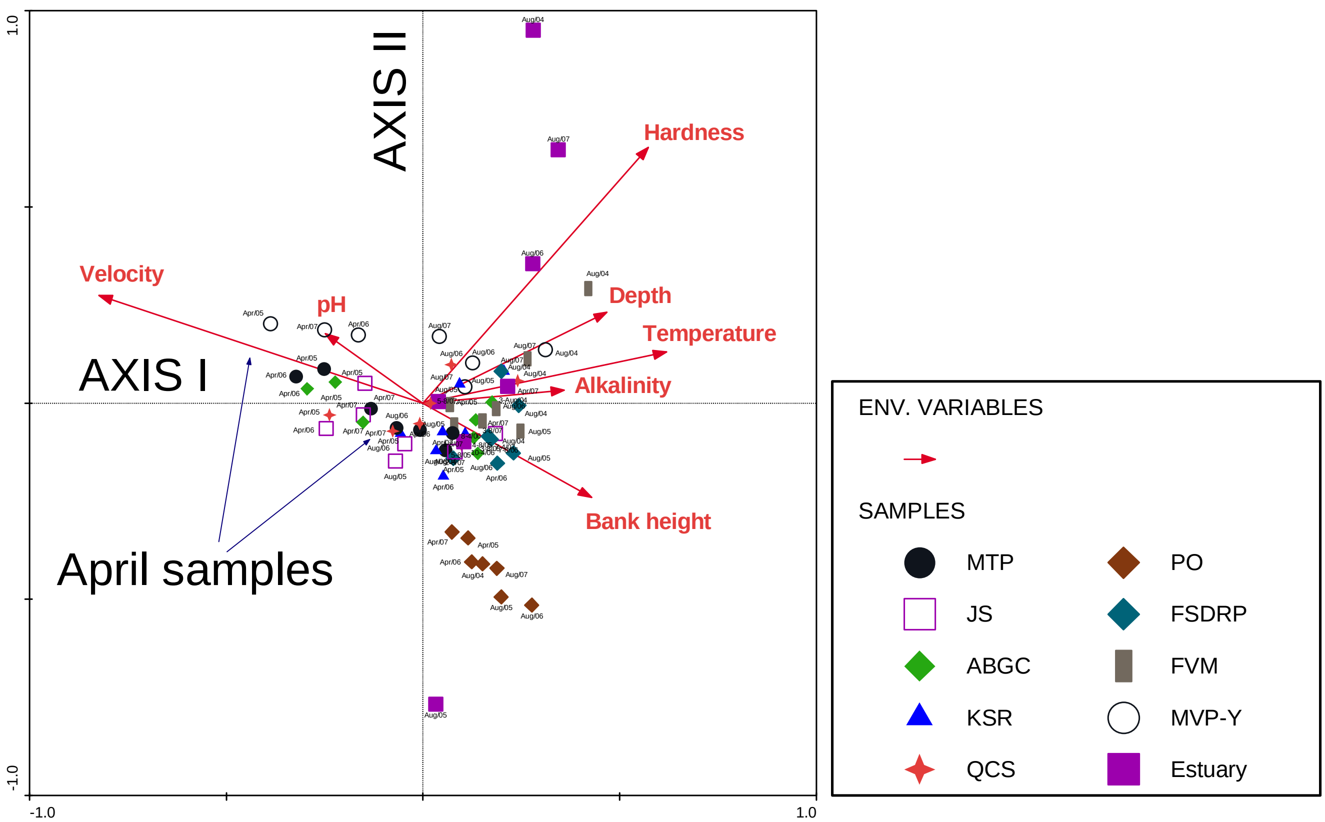


Figure 3. Canonical correspondence analysis of San Diego River benthic data showing the association of taxa with environmental variables. Only taxa with at least a 10% fit to the data are shown.

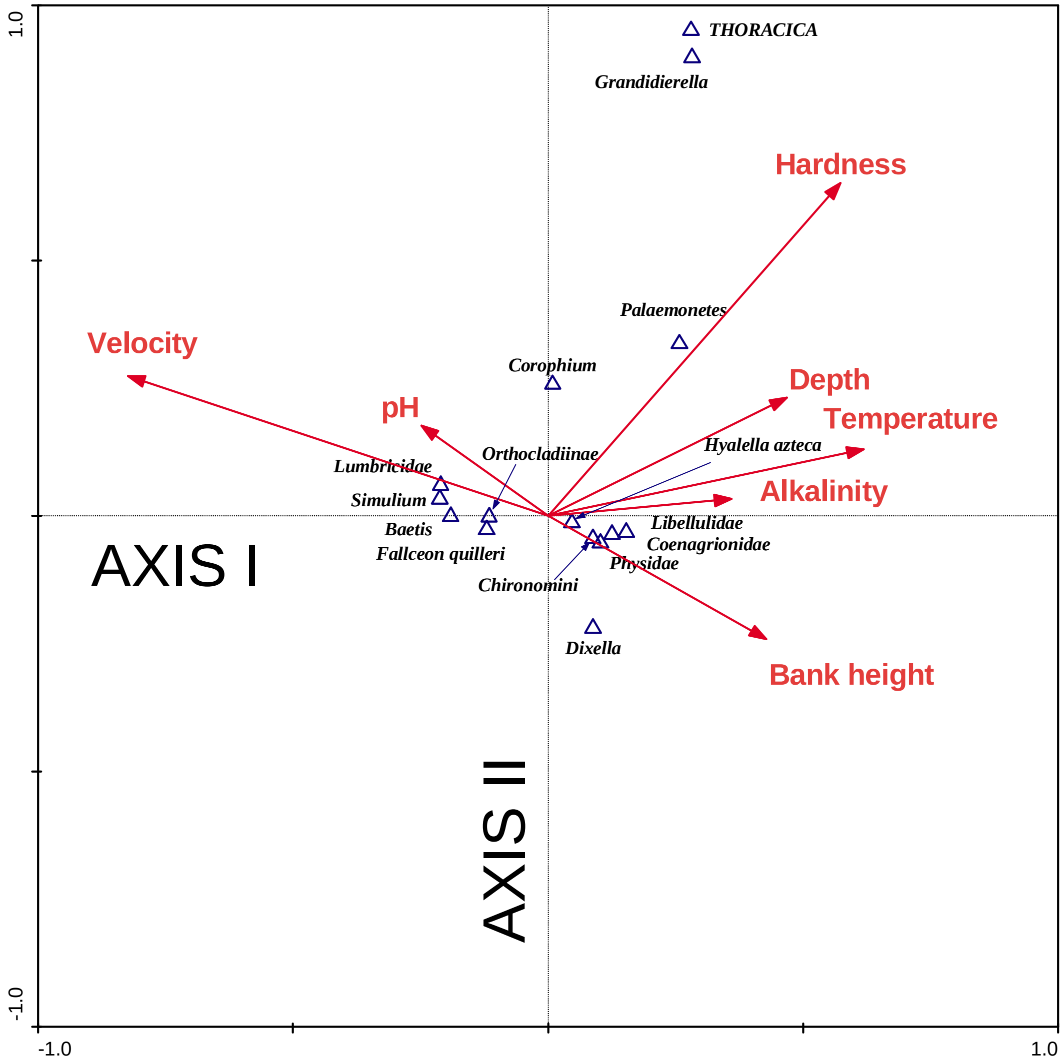
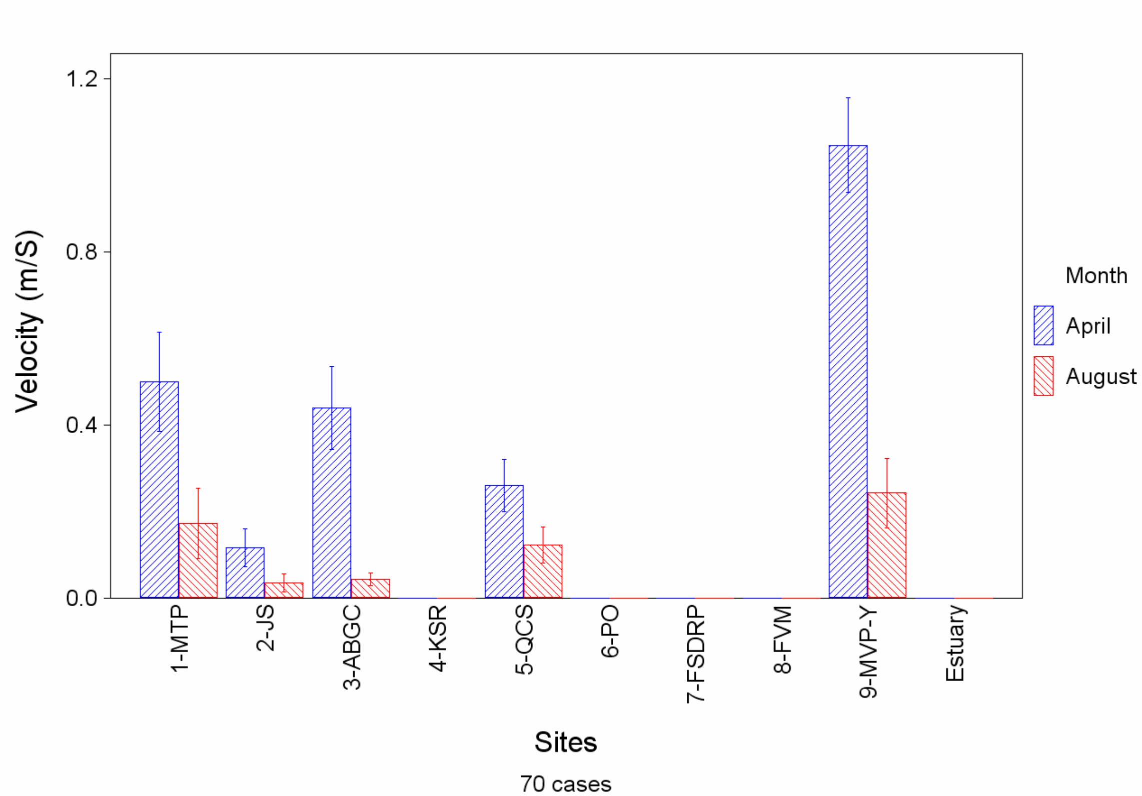
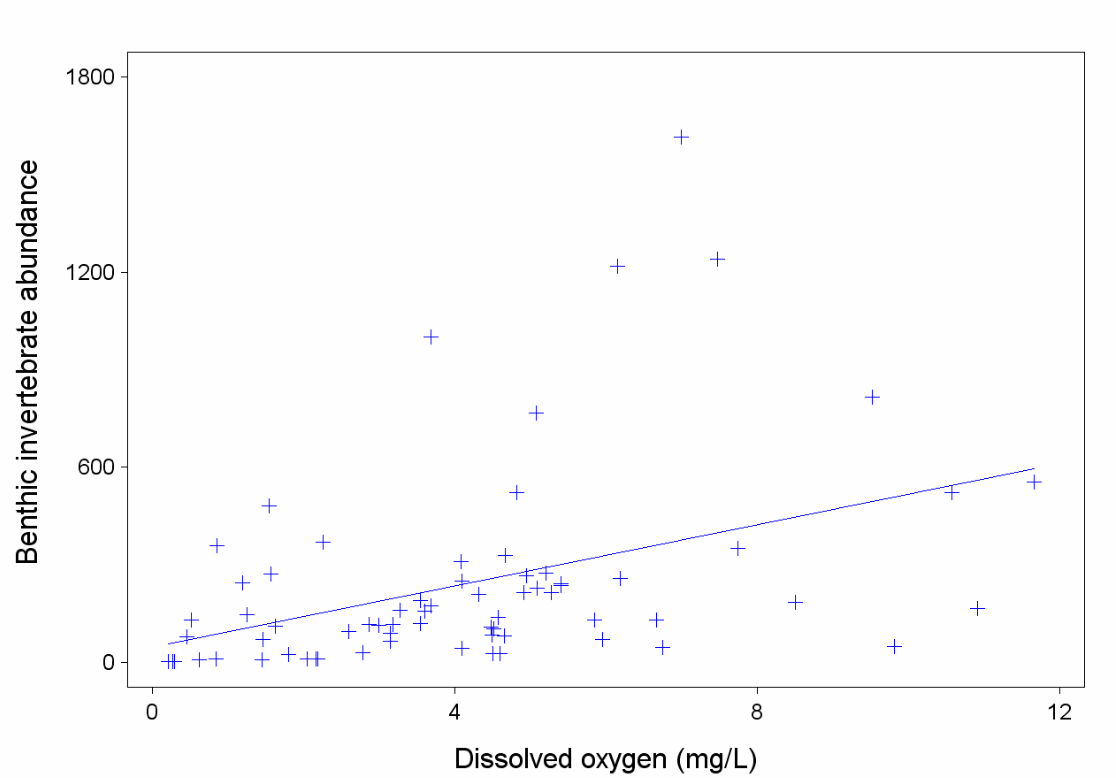


Figure 4. Mean velocities in April and August at sites along the San Diego River.



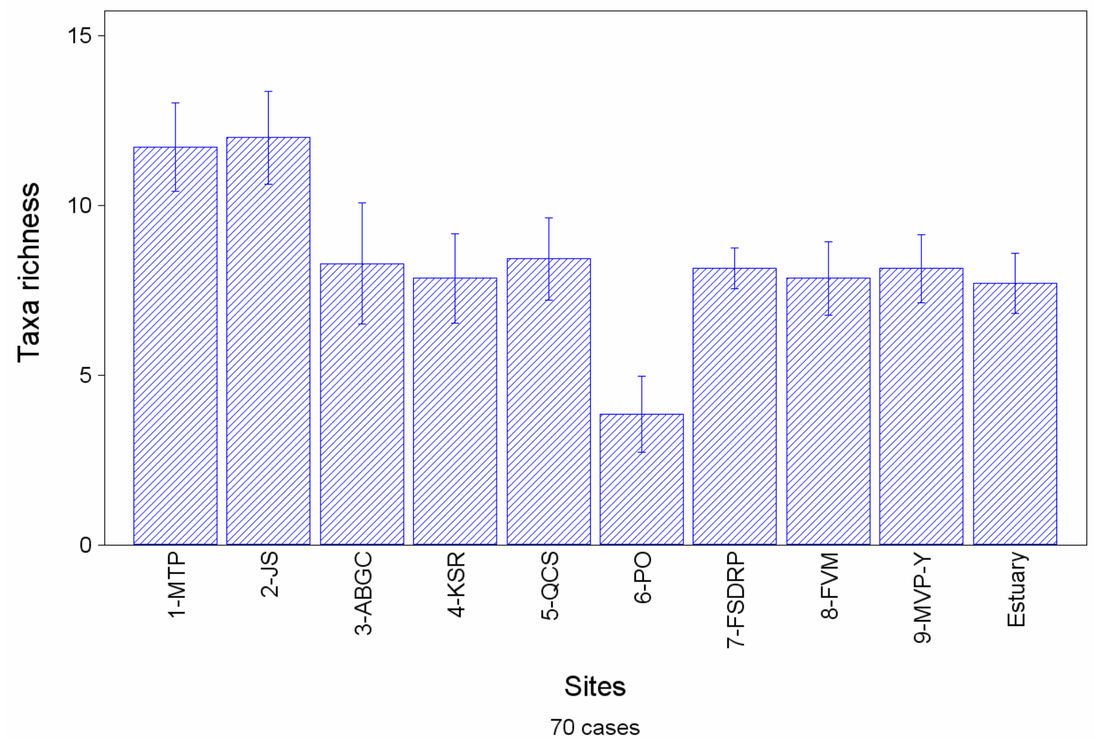
The PO site was in a very slow moving portion of the river and contained large amounts of emergent vegetation that likely created a high biochemical oxygen demand (BOD). Highest alkalinity values (mean=399 $\pm$ 43 mg/L) and lowest DO (mean=1.8 $\pm$ 0.8 mg/L) were encountered at this site. High alkalinity values can be indicative of organic matter decomposition under anaerobic conditions (Abril and Frankignoulle, 2001). This resulted in a depauperate invertebrate assemblage with low abundance. Dissolved oxygen is likely very important to producing large numbers of invertebrates and there was a significant correlation between DO and invertebrate abundance (ρ=0.5122, P<0.0001) in this study (Figure 5). Taxa richness was also lowest at the PO site (Figure 6). Unique to this site, however, was the limpet-like Ancylidae.

Figure 5. Correlation between dissolved oxygen and invertebrate abundance from all samples collected along the San Diego River.



Some sites that were lotic also had seasonally low dissolved oxygen concentrations. This occurred at ABGC and MVP-Y and seemed to be associated with the presence of large amounts of *Ludwigia* (an exotic invasive plant) just upstream of sampling points. ABGC, for example, had a dissolved oxygen reading of 5.09 mg/L in April 2006 which declined to 1.46 mg/L in August of 2006 when it was noted the pool above the sampling point was choked with *Ludwigia* and that there was a strong odor of hydrogen sulfide. Low dissolved oxygen may result from plant respiration at night along with increased BOD resulting from large amounts of biomass. *Ludwigia* forms extensive mats at the surface of the water and also restricts mixing from wind that would allow for diffusion of atmospheric oxygen. Miranda and Hodges (2000) reported that DO concentrations were inversely related to vegetation coverage (large amounts of *Ludwigia* were present in their study) with DO concentrations below 1 mg/L in dense vegetation.

Figure 6. Mean taxa richness from all benthic samples collected from the San Diego River.



Butterfly communities—There were 50 species of butterflies detected along the San Diego River over the course of the study (Table 2). Variables that were significant in the RDA model included riparian rank, soil moisture, temperature, wind speed, nectar amount, and forb & graminoid richness (Figure 7). Eigen values for Axis I were 0.233 and for Axis II 0.063 with 29.5% of the species variance and 66.5% of species-environment relation explained in the first 2 axes.

Table 2. Species list of butterflies found along the San Diego River.

Anise Swallowtail	*Papilio zelicaon*
Giant Swallowtail	*Papilio cresphontes*
Western Tiger Swallowtail	*Papilio rutulus*
Pale Swallowtail	*Papilio eurymedon*
Checkered White	*Pontia protodice*
Cabbage White	*Pieris rapae*
Sara Orangetip	*Anthocharis sara*
Orange Sulphur	*Colias eurytheme*
California Dogface	*Colias eurydice*
Cloudless Sulphur	*Phoebis sennae*
Sleepy Orange	*Eurema nicippe*

Dainty Sulphur	*Nathalis iole*
Hermes Copper	*Lycaena hermes*
Golden Hairstreak	*Habrodais grunus*
Sylvan Hairstreak	*Satyrium sylvinus*
Gray Hairstreak	*Strymon melinus*
Western Pygmy Blue	*Brephidium exile*
Marine Blue	*Leptotes marina*
Ceraunus Blue	*Hemiargus ceraunus*
Reakirt's Blue	*Hemiargus isola*
Spring Azure	*Celastrina ladon*
Western Tailed-Blue	*Everes amyntula*
Square-dotted Blue	*Euphilotes battoides*
Acmon Blue	*Plebejus acmon*
Fatal Metalmark	*Calephelis nemesis*
Behr's Metalmark	*Apodemia virgulti*
Gulf Fritillary	*Agraulis vanillae*
Variable Checkerspot	*Euphydryas chalcedona*
Mourning Cloak	*Nymphalis antiopa*
Painted Lady	*Vanessa cardui*
West Coast Lady	*Vanessa annabella*
Red Admiral	*Vanessa atalanta*
Common Buckeye	*Junonia coenia*
Lorquins Admiral	*Limenitis lorquini*
California Sister	*Adelpha bredowii*
Common Ringlet	*Coenonympha tullia*
Monarch	*Danaus plexippus*
Queen	*Danaus gilippus*
Northern Cloudywing	*Thorybes pylades*
Funeral Duskywing	*Erynnis funeralis*
Small Checkered-Skipper	*Pyrgus scriptura*
Common Checkered-Skipper	*Pyrgus communis*
Northern White-Skipper	*Heliopetes ericetorum*
Common Sootywing	*Pholisora catullus*
Fiery Skipper	*Hylephila phyleus*
Sachem	*Atalopedes campestris*
Woodland Skipper	*Ochlodes sylvanoides*
Umber Skipper	*Poanes melane*
Eufala Skipper	*Lerodea eufala*
Wandering Skipper	*Panoquina errans*

Butterfly assemblages were impacted by a cold and wet spring in 2006, conditions that apparently were widespread in California (University of California – Davis, 2006). Consistent with these regional impacts, no butterflies were detected in April of 2006 at some San Diego River sites. Variables associated to some degree with seasonal changes included soil moisture and air temperature and these were found along Axis I of the RDA (Figures 7 and 8). The presence of these variables along Axis I suggests seasonal differences were important in explaining butterfly assemblage distribution.

Figure 7. Redundancy analysis of San Diego River butterfly data showing the association of sites and environmental variables.

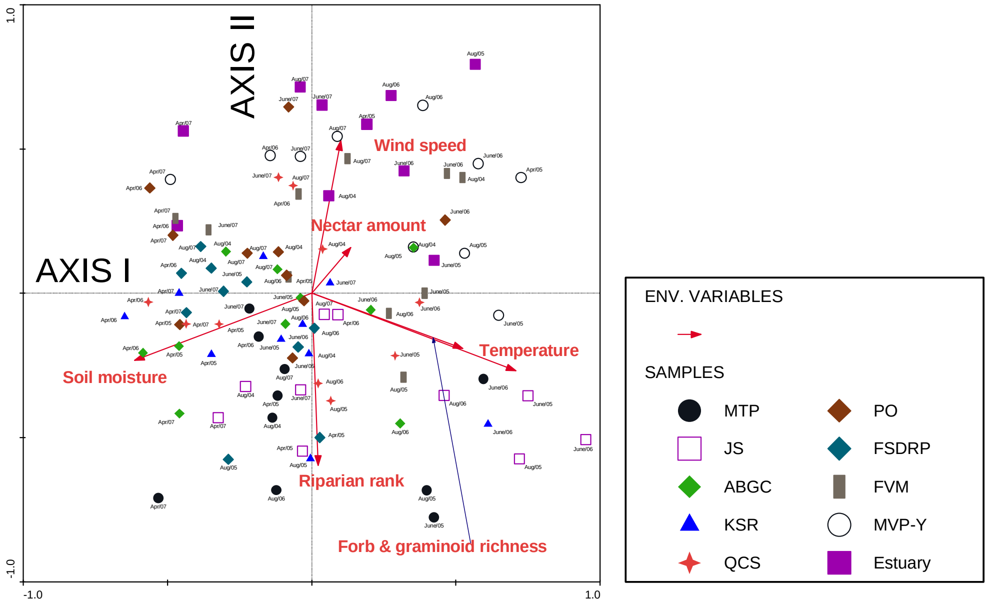
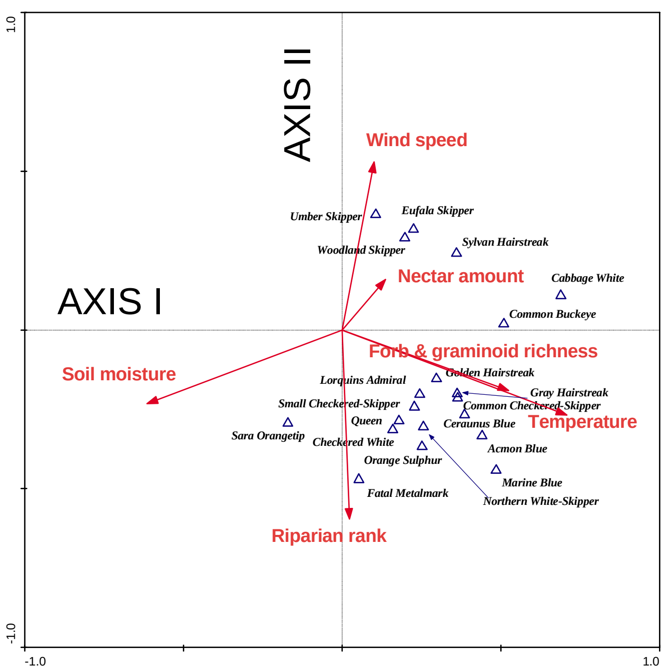


Figure 8. Redundancy analysis of San Diego River butterfly data showing the relationship between species and environmental variables. Only species with at least a 10% fit to the data are shown.



The furthest upstream sites at MTP and JS appeared to be high quality butterfly sites and were located in the negative portion along Axis II in Figure 7. A variety of butterfly species were found at these sites including the Fatal Metalmark and Queen (Figure 8) while Skippers of different sorts were common at downstream sites. Upstream sites had high riparian rankings and also had higher levels of forb & graminoid richness (Figure 9) than some other sites. Forb & graminoid richness was significantly correlated with both butterfly species richness (ρ=0.3460, P<0.0001) and butterfly abundance (ρ=0.5180, P<0.0001) when April of 2006 data were omitted from analysis. The furthest downstream sites also had high forb & graminoid richness. Wind speed was highest at the downstream sites and may have been related to the coastal environment with wind speeds highest near the ocean (Figure 10). While there were seasonal differences in soil moisture, moisture also tended to be lower at sites with high levels of forb & graminoid richness (compare Figure 9 and Figure 11). High soil moisture may result in overgrowth and decreased nectar and forb & graminoid diversity. Some of the increase in soil moisture may have been from irrigation in the urban environment.

One other major difference between the upstream and other sites is the lack of anthropogenic development along slopes adjacent to the riparian area at upstream sites. Urbanization may have impacted butterflies along the San Diego River with some becoming more common (e.g., Umber Skipper (*Poanes melane*), sixth most common butterfly in the present study) and others less so (Behr's Metalmark (*Apodemia virgulti*), 25^{th} most common butterfly). Wright (1930) reported in the 1930's that in San Diego County the Umber Skipper was undetected while Behr's Metalmark was common from sea level to mountain top. Presently the Behr's Metalmark is a target species for conservation in other parts of southern California (Martino et al., 2005) and is considered to be a sensitive species in decline. The caterpillar host plant of Behr's Metalmark is California buckwheat (*Eriogonum fasciculatum*) which has decreased in abundance because of invasive weeds and urbanization (Montalvo, 2000).

Figure 9. Forb & graminoid richness at sites along the San Diego River.

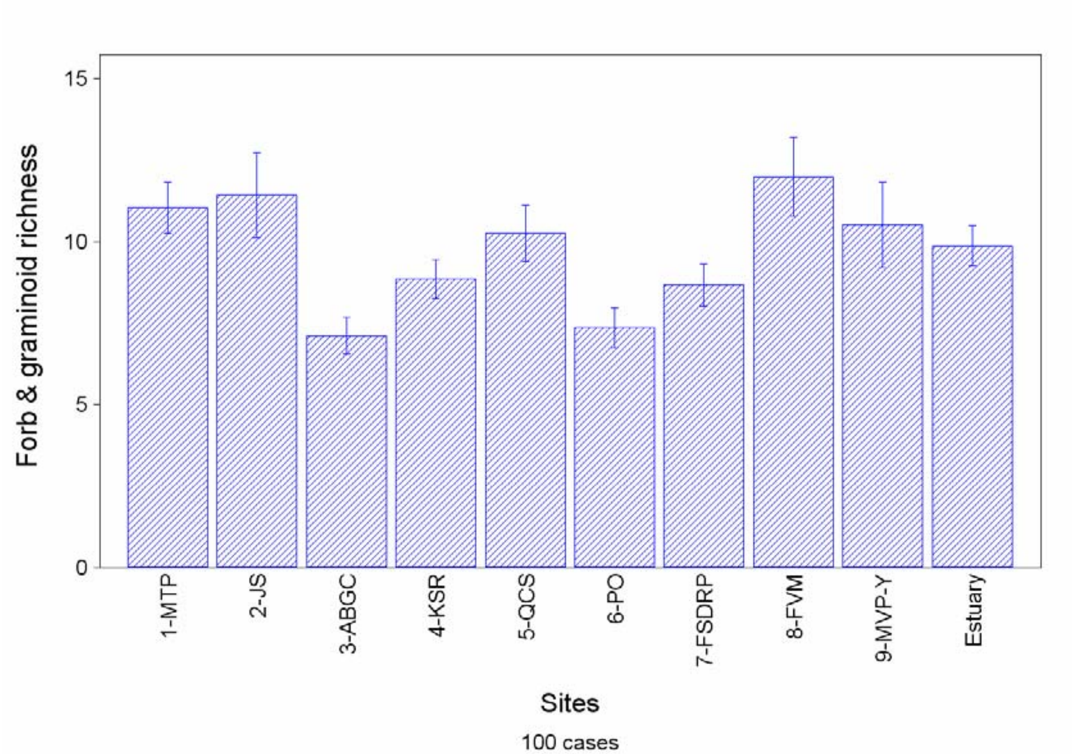


Figure 10. Mean wind speed at sites along the San Diego River.

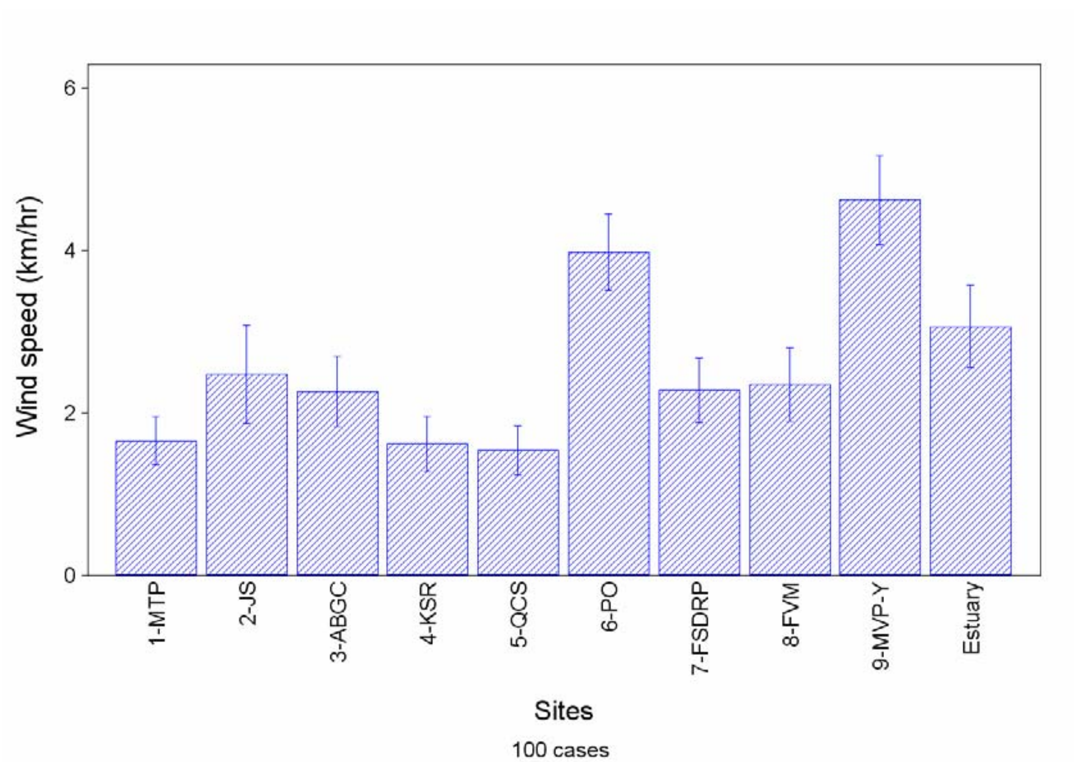
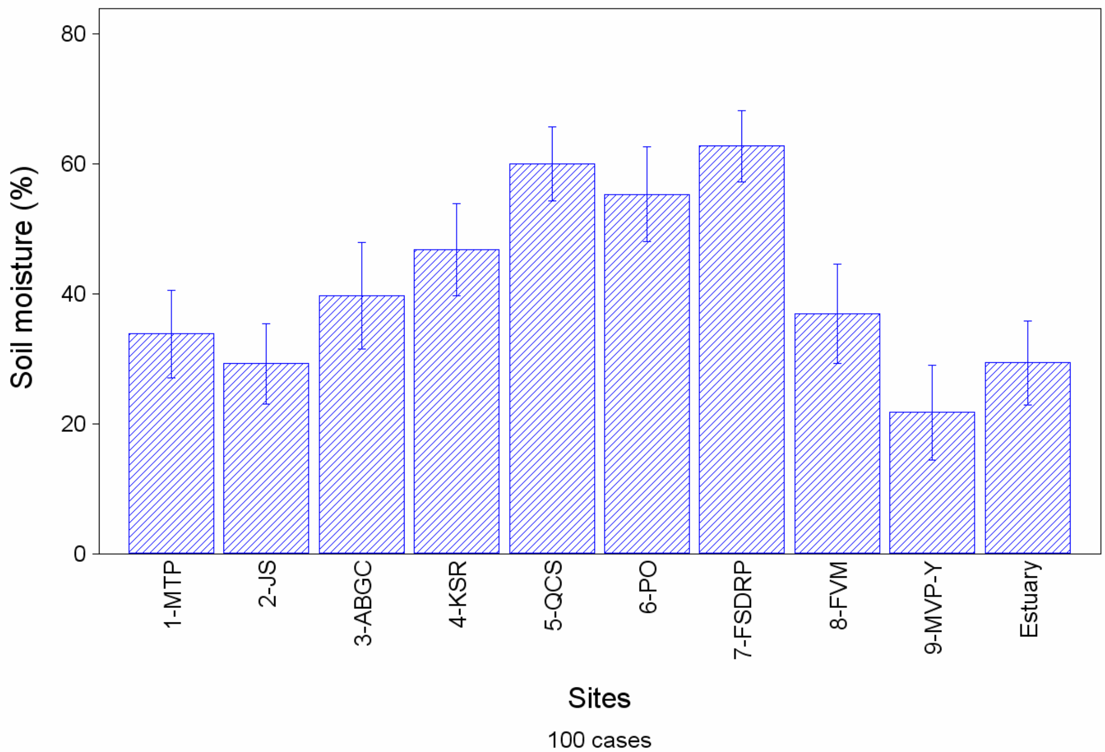


Figure 11. Mean % soil moisture at sites along the San Diego River.



Butterflies of special interest that were detected along the San Diego River included the Hermes copper butterfly (*Lycaena hermes*) which is considered to be at high risk of extinction in the wild and the Saltmarsh skipper (*Panoquina errans*) which is under threat from development. Behr's metalmark is also a butterfly that has been targeted by some California communities as a species of concern. Martino et al. (2005) also list the California dogface (*Colias eurydice*) and Lorquin's Admiral (*Limenitis lorquini*) as target species. The California dogface was only detected at Mission Trails Regional Park in 2006. This species is considered to be very rare or local throughout its range and is only found in California. Martino et al. (2005) suggest that Lorquin's Admiral is an indicator of riparian longitudinal connectivity. The presence of this *Salix* feeder at all of the sites along the San Diego River may indicate that upstream to downstream connectivity is not a large issue along this portion of the river.

Mean butterfly species richness was highest at the upstream sites MTP and JS and at the downstream site MVP-Y (Figure 12). These sites had higher forb & graminoid richness, along with lower soil moisture and higher amounts of nectar (Figure 13) in common with each other.

Figure 12. Mean butterfly species richness at sites along the San Diego River.

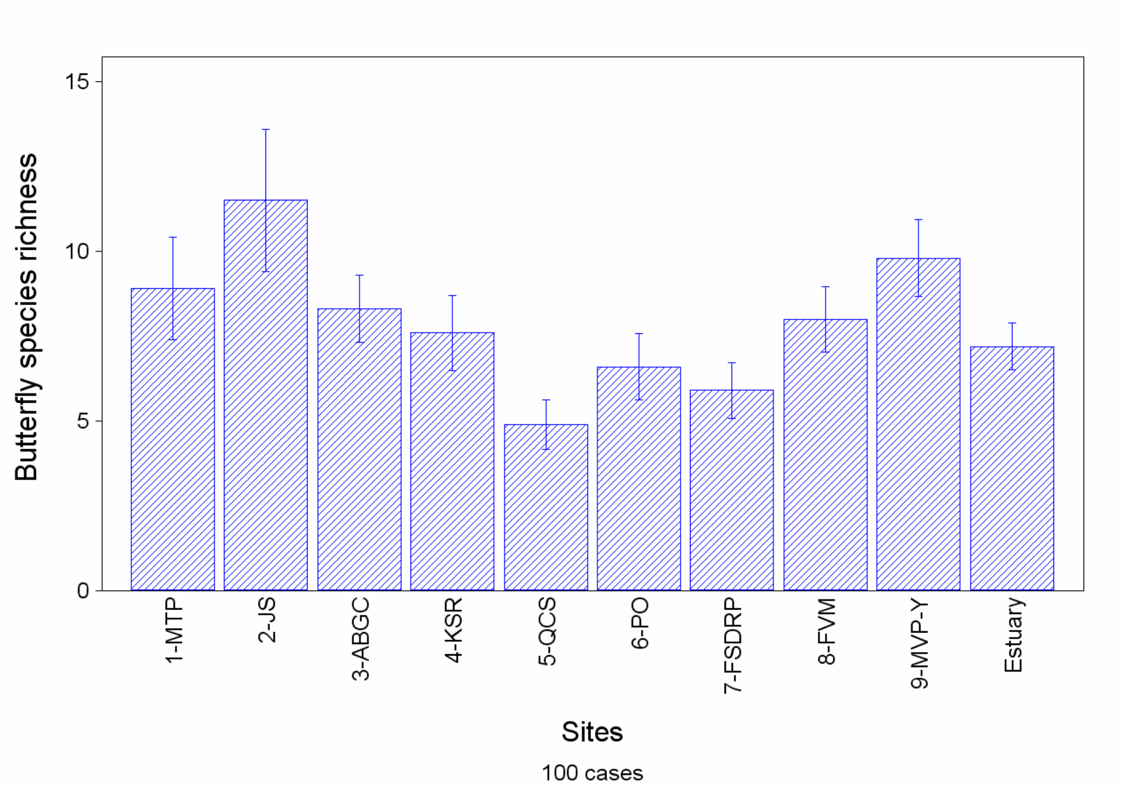
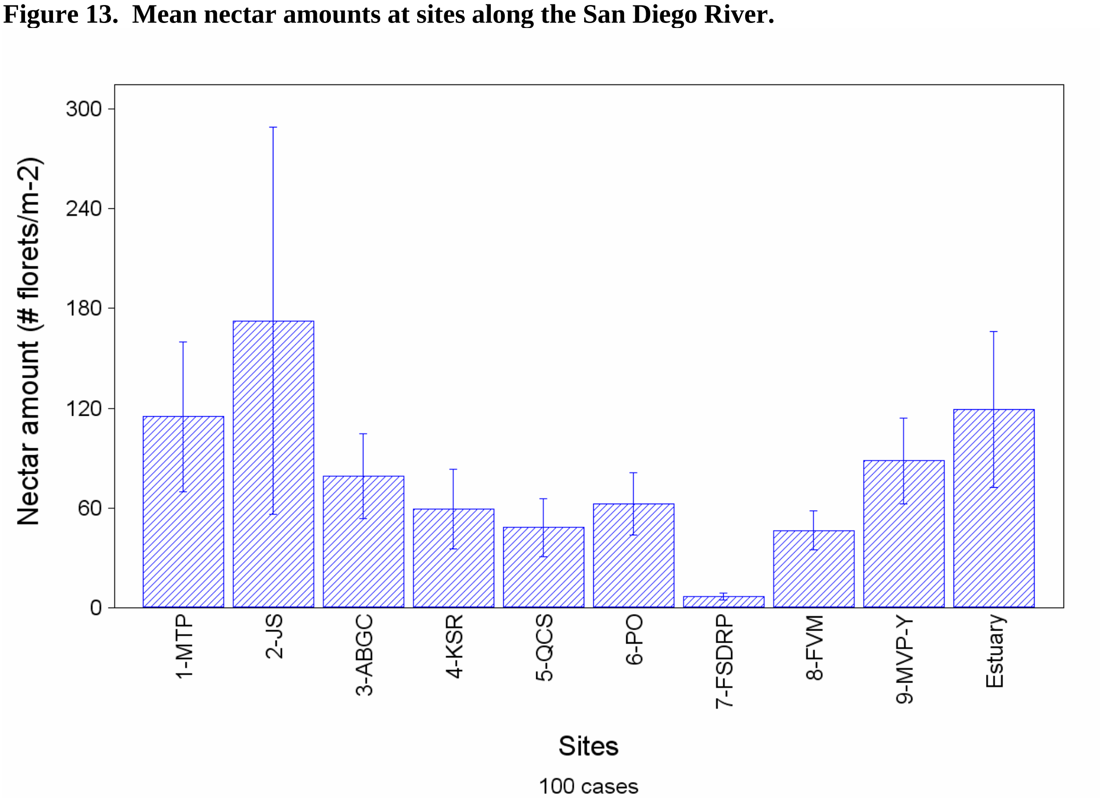


Figure 13. Mean nectar amounts at sites along the San Diego River.



Relationship between terrestrial and aquatic indicators—There was not a significant correlation ($P \geq 0.05$) between butterfly and benthos abundance. There was, however, a positive correlation between benthic taxa richness and butterfly species richness ($\rho=0.4210$, $P=0.0213$) (Figure 14). Consistent with this simple analysis, multivariate analysis also suggested relatively high quality benthos and butterflies at the two furthest upstream sites and indicated that the furthest downstream site (Estuary) contained benthic and butterfly assemblages that differed from other sites. The coastal environment apparently affected both the aquatic benthic community because of the effects of salinity on water quality and the terrestrial environment through coastal winds (and perhaps changes in terrestrial vegetation because of saline soils). Data also indicated that MVP-Y was a relatively high quality site for both benthos and butterflies. The benthic assemblage at this station was similar to the upstream MTP and JS sites while butterfly assemblages differed but had similar species richness. Also in common with aquatic and terrestrial faunal components was the recognition that many of the other sites were of lower quality.

A multi-metric index was developed using benthic and butterfly taxa richness along with environmental variables identified from multivariate analyses. Water quality parameters (alkalinity and hardness) and physical variables (depth, bank height, and velocity) were used as part of the benthic analysis. Significant multivariate variables that were omitted from the multi-metric index included temperature which appeared to represent seasonal differences and pH which is often closely related to alkalinity. Variables used from the butterfly multivariate analysis included forb & graminoid richness, nectar amount, riparian rank, and soil moisture. Wind speed and temperature were omitted from the multi-metric analysis because it appeared that wind speed represented longitudinal geographical differences while temperature was associated with seasonal differences. The multi-metric index was designed to reflect differences in environmental quality rather than seasonal or natural longitudinal alterations. Values derived from analysis of percentiles for the various metrics are presented in Table 3. In order to merge benthic and butterfly data sets for this analysis, only April and August sampling dates were used for metric analysis with ANOVA. Significant differences were detected in multi-metric values for the various locations ($F=18.4$, $P<0.0001$). Tukey's test indicated that MTP, JS, ABGC, and MVP-Y did not differ from each other and had the highest mean metric values (Figure 15). QCS, PO, FSDRP, and Estuary sites differed significantly from the four highest quality sites with FSDRP having the lowest mean score (Figure 15). Data from Figure 15 suggest that relative environmental quality, ranked from highest to lowest of the ten sites, was: MTP=JS=ABGC=MVP-Y>KSR=FVM>QCS=Estuary=PO =FSDRP.

Box plot data on the ratio of the butterfly/benthic metrics is presented in Figure 16. There were obvious differences in box plot patterns with data from QCS, PO, and FVM ranging beyond the middle 25^{th} to 75^{th} percentile of the data (Figure 16). QCS had a relatively higher quality aquatic environment, while PO and FVM had relatively higher quality terrestrial environments. Taken together Figures 15 and 16 allow for some diagnostic abilities, with MTP, JS, ABGC, and MVP-Y being high quality sites for both aquatic and terrestrial environments and FSDRP and the Estuary site being low quality sites for both environments. The Estuary site, however, may represent natural longitudinal change with environmental alterations caused by the marine influence. The KSR site appears to be of moderate quality for both aquatic and terrestrial environments.

These data suggest that the floodplain/riverine environment has been impacted in ways that are affecting both the terrestrial and aquatic biotic components. KSR, PO, and FSDRP appear to contain relatively low biological diversity and also are examples of sites that have been altered by historical sand and gravel mining activities. It has been reported that the San Diego River is one of the most heavily sand/gravel mined rivers in the nation (Minan, 2004). These large lentic sites cause obvious alterations to benthic community habitat. These slow moving areas appeared to create habitat that was highly suitable for *Ludwigia* which appeared to result in lower DO values in downstream areas. Biological consequences of instream gravel mining (e.g., Kondolf et al., 2002) include increased fine sediment load to downstream reaches where it is deposited and can have long term effects by decreasing habitat heterogeneity for aquatic organisms. Percentages of riffle areas are often decreased in rivers impacted by gravel mining (Brown et al., 1998) and this may be the case in the San Diego River. ABGC and MVP-Y were sites that were seasonally impacted by *Ludwigia* growth in gravel mined areas, but where the presence of lotic environments mitigated against the lower DO concentrations to some degree. Larger channel cross-sectional areas that result from gravel mining may decrease river-floodplain interactions (Brown et al., 1998), and also impact riparian biota, such as butterflies.

Figure 14. Relationship between annual butterfly species richness and benthic taxa richness.

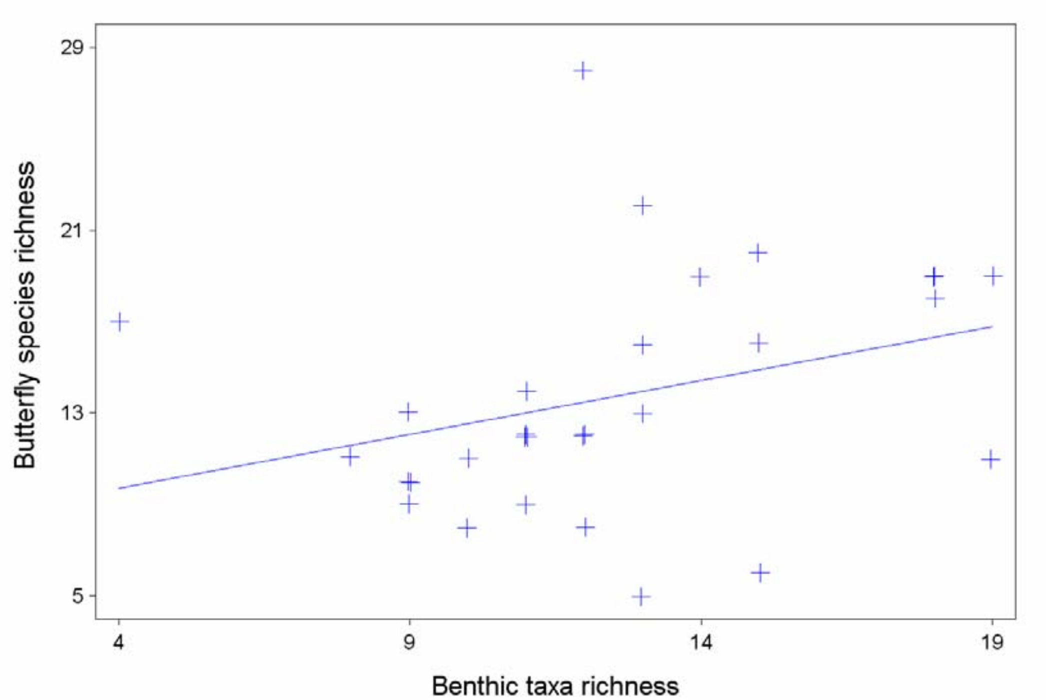


Table 3. Metric values derived from San Diego River data.

Metric	Response to degradation	Scoring Boundaries 1	3	5
Number of benthic taxa	Decline	≤6.0	6.1-10.9	≥11.0
Alkalinity (mg/L)	Increase	≥322	321-248	≤247
Depth (m)	Increase	≥.80	.79-.41	≤.40
Hardness (mg/L)	Increase	≥831	492-830	≤491
Bank height (m)	Increase	≥3.0	2.9-0.59	≤.58
Velocity (m/S)	Decline	0.0	0.1-0.17	≥0.18
Butterfly species richness	Decline	≤6.0	6.1-10.1	≥10.2
Forb & graminoid richness	Decline	≤7.35	7.36-11.90	≥12.00
Nectar amount (#/m^2)	Decline	≤10.35	10.36-93.77	≥93.78
Riparian rank	Decline	≤5.75	5.76-6.55	≥6.56
Soil moisture (%)	Increase	≥60.8	60.7-20.7	≤20.6

Figure 15. Mean multi-metric index values for sites along the San Diego River. Sites with the same letters are not significantly different.

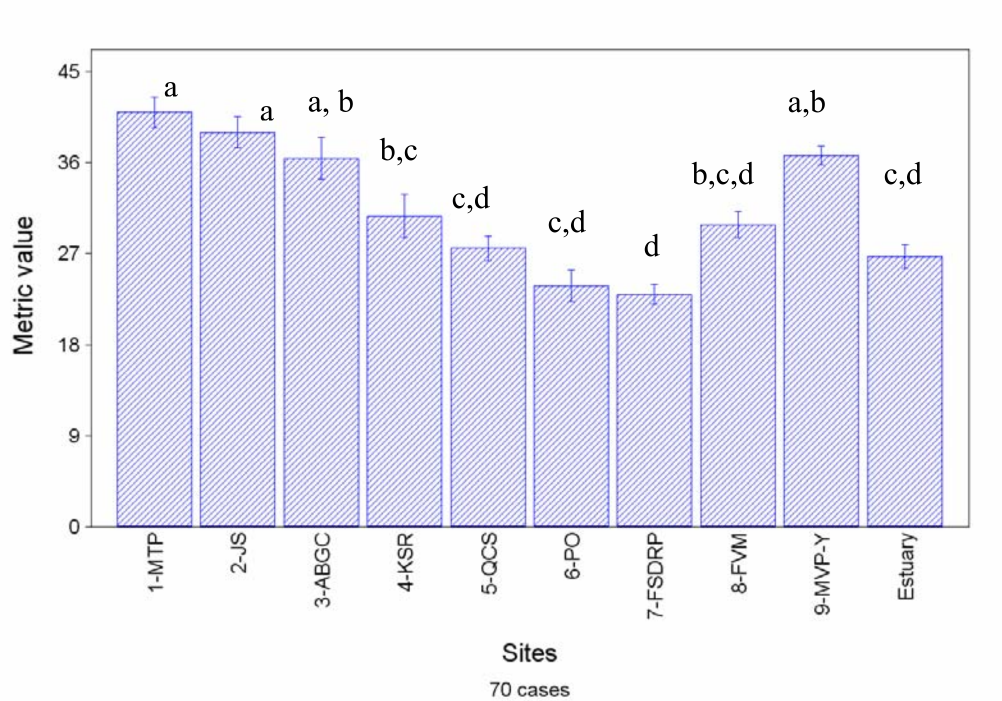
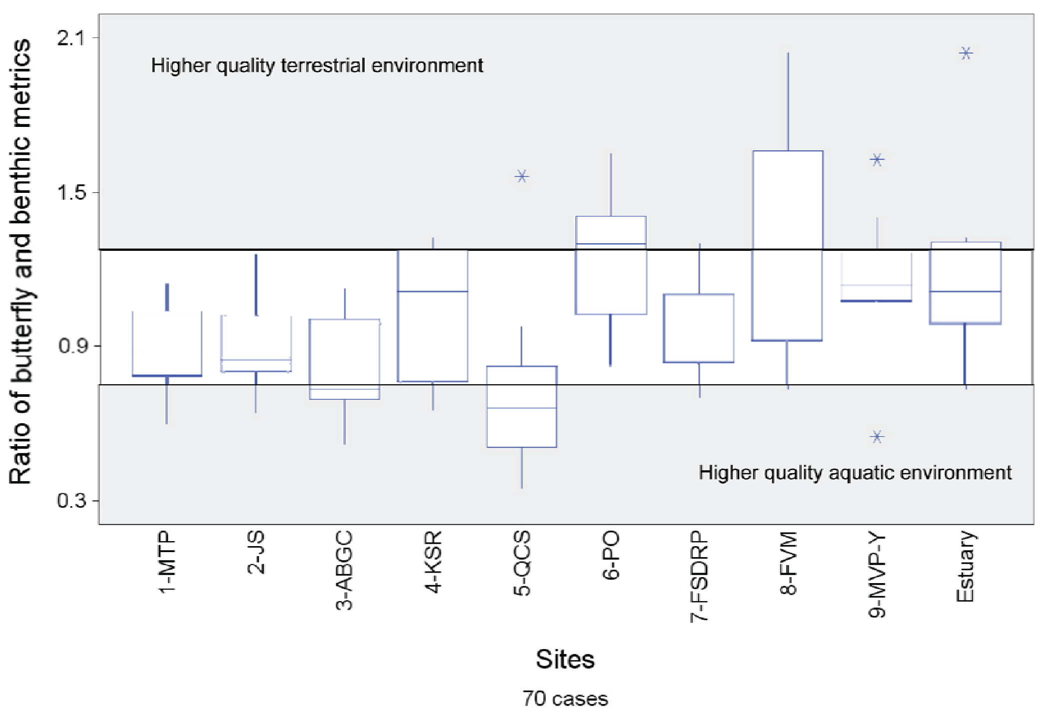


Figure 16. Box plots of metric ratios. High percentile values are in upper shaded area and low percentile values are in the lower shaded area.



Conclusions

The furthest upstream sites (MTP and JS) located in Mission Trails Regional Park tended to have high quality benthic and butterfly assemblages. Mission Trails Regional Park sites are located in a protected area that is managed by the city of San Diego and are probably the best examples of what might be attainable biologically in the area. However, development immediately adjacent to the riparian area through much of urban district may not allow for the presence of specific butterflies associated with upland areas that facultatively use riparian areas found in Mission Trails Regional Park. Despite this lack of upslope environment, MVP-Y had butterfly species richness values similar to the Mission Trails Regional Park sites. In common with the furthest upstream sites, this site tended to be more open, with a less confined floodplain where overbank flow occurred over a large portion of the floodplain during the study. It is likely that, historically, much of the river was similar to these sorts of sites and in the late 1700's the San Diego River was described as dry in many places, but also containing pools and streamlets in a mosaic of poplar, willow, and alder trees associated with a channel that shifted back and forth across the floodplain (Papageorge, 1971).

The largest differences in benthic samples were between lentic and lotic sites. Lentic sites, in large part, appeared to be those associated with gravel mining operations. In-river lentic sites also appeared to impact lotic sites when exotic emergent vegetation impacted water suitability by decreasing dissolved oxygen concentrations. Salinity also affected water quality. The estuary site and MVP-Y were likely influenced tidally and saline tolerant amphipods made up a portion of the assemblages found there.

These data suggest that restoration efforts that increase dissolved oxygen, such as water aeration and control of exotics like *Ludwigia*, may positively impact benthic aquatic invertebrates. Separating the river channel from gravel pits would also allow for areas of higher velocity and higher dissolved oxygen. Restoration designs that result in a mosaic of wooded and open areas along the river and increase the ability of flood flows to encroach upon the floodplain may allow for increased butterfly species richness. Activities that allow for shallow, wide banks with increased lateral connectivity between the river and the floodplain have resulted in increased richness and abundance of terrestrial plant species in other studies (e.g., Pedersen et al., 2006). The importance of increased forb & graminoid richness to butterflies has been demonstrated in the western USA (e.g., Nelson and Wydoski, 2008) and may be linked to floodplain/river connectivity (lack of steep banks) and destructive flooding which occurs with high flows and connectivity. An example of riparian restoration efforts that could have had much higher values for butterflies is that at FSDRP. This site contains high densities of native woody vegetation but lacks open areas that could increase forb richness and provide for nectar plants. While this site is apparently resistant to invasion from exotic weed species (Burkhart and Kelly, 2005) it also has very low value to butterflies and had the lowest mean multi-metric score of all of the sampled sites. The low metric values associated with this restoration site point to the importance of monitoring these projects. Without knowledge obtained from monitoring, other restoration projects might use FSDRP as the model for restoration efforts. This would likely result in decreased invertebrate diversity along the San Diego River.

It is possible that efforts aimed at increased invertebrate diversity and abundance may also increase natural treatment functions of the river. Increased dissolved oxygen would likely increase the breakdown rate of organic material associated with road run-off, while increasing floodplain interaction with the river channel would allow for increased treatment area via contact with soils and microbial agents. Floodplain aquifers have been demonstrated to be the site of enormous amounts of microbial production in some river ecosystems (Craft et al., 2002). Disconnection of rivers from floodplains can lead to large decreases in microbial activity in floodplain soils which could decrease microbial-mediated processes which, in turn, could result in water quality deterioration in adjacent groundwater (Kang and Stanley, 2005).

Results from this study suggest that efforts to restore areas along the San Diego River should incorporate both aquatic and terrestrial elements in design. Monitoring efforts, therefore, should incorporate both components of the biota. It appears that along the San Diego River that the quality of benthic and butterfly environments is largely correlated and that high quality aquatic and terrestrial environments are linked. Results provide guidance in future restoration attempts and suggest that specific steps should be taken to provide for planting of species beyond native woody vegetation and providing river channels that increase lotic environments and decrease the height of stream banks. In some cases metric ratios suggest that more restoration effort should be placed at either aquatic or terrestrial environments at a given site.

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PEER REVIEW DOCUMENTATION

PROJECT AND DOCUMENT INFORMATION

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Document Date May 2008 Date Transmitted to Client

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REVIEW REQUIREMENT

Part A: Document Does Not Require Peer Review

Explain

Part B: Document Requires Peer Review: SCOPE OF PEER REVIEW

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Peer Reviewer - I have reviewed the assigned Items/Section(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

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Team Member: [signature] Date: 5-5-08
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