Abbreviations and Acronyms

ABL	Aquatic Bioassessment Laboratory
Act	San Joaquin River Restoration Settlement Act
ADCP	Acoustic Doppler Current Profiler
ATR	Annual Technical Report
BMI	benthic macroinvertebrates
CDEC	California Data Exchange Center
cfs	cubic feet per second
DFG	California Department of Fish and Game
DWR	California Department of Water Resources
EMAP	Environmental Monitoring and Assessment Program
EPA	United States Environmental Protection Agency
FMWG	Fisheries Management Working Group
IBI	Index of Biotic Integrity
Restoration Area	San Joaquin River Restoration Area
RM	River Mile
SAFIT	Southwestern Association of Freshwater Invertebrate Taxonomists
SJRRP	San Joaquin River Restoration Program
STE	Standard Taxonomic Effort
SWAMP	Surface Water Ambient Monitoring Program
SWRCB	State Water Resources Control Board

1.0 Benthic Macroinvertebrate Bioassessment

1.1 Introduction / Background

Benthic macroinvertebrate (BMI) communities, the subject of this study, are both bioindicators of stream condition and a food resource for fish. The main purpose of assessing the biological condition of aquatic communities is to determine how well a water body supports aquatic life. Biological communities comprise the effects of different pollutant stressors such as increased temperature, toxic chemicals, excessive nutrients and sediment loading. The BMI within these communities respond to different types of human disturbance, physical changes in riparian vegetation and instream habitat heterogeneity. In addition, BMI are key food sources for the native and potentially reintroduced fish in the San Joaquin River.

In general, we anticipate that the San Joaquin River restoration flows will significantly improve physical habitat conditions and elicit changes in the abundance and diversity of BMIs. As portions of the river are restored and vegetated, BMIs can respond as a result of changes in stream condition because of alterations to water chemistry and physical habitat. Therefore, by collecting BMI and physical habitat data in different areas of the San Joaquin River, we can help assess water chemistry and identify habitat features responsible for the restoration of ecological integrity (Harrington 1999, Rehn and Ode 2005). Restoration Flows in the San Joaquin River could impact ecological integrity as a result of changes in habitat suitability.

This study provides information about the ecological integrity of the San Joaquin River system within the Restoration Area. The study directly addresses habitat objectives set forth in the San Joaquin River Restoration Program (SJRRP) Fisheries Management Plan and has been identified by the Fisheries Management Working Group (FMWG) as an on-going need for the SJRRP (SJRRP 2010). The main objective of this study requires that the ecological integrity of the Restoration Area be restored as a result of improved streamflow, water quality conditions and the biological condition of aquatic communities. Our original goal was to find if at least 50% of the total target river length was observed to be in *good condition* (benthic index of biotic integrity (B-IBI) = 61-80) or *very good condition* (B-IBI=81-100). In addition, none of the study sites should be in *very poor condition* (B-IBI=0-20). We hypothesized that the community composition of BMI will vary among individual survey sites and river reaches 1-5 because of changes in physical habitat and water chemistry.

1.2 Methods

1.2.1 Reconnaissance Surveys on Reaches 1 through 5 of the Restoration Area

Sampling locations were selected from a random set of 150 sites distributed throughout Reaches 1 through 5 that were generated each year with software developed by the Environmental Monitoring and Assessment Program (EMAP) of the United States Environmental Protection Agency (EPA). We surveyed the random set of locations to identify at least 30 sampling reaches (sites) on 2010, 2011 and 2012 which met a set of criteria including access conditions and wadeable depths, consistent with California's Surface Water Ambient Monitoring Program (SWAMP) Bioassessment Procedures (Figure 1). Each sampling reach had a length of 150m or 250m depending on whether the wetted width of the channel at the center of the reach was below or above 10m, respectively.

1.2.2 Physical Habitat at Sampling Reaches

The DWR and DFG staff characterized the physical habitat at 30 sites throughout the Restoration Area each year (Figure 2). At each site, the crew delineated 11 river transects and 10 inter-transects according to the Reachwide Benthos Procedure (Ode 2007). This procedure includes the measurement of ancillary water quality parameters and a general assessment of habitat complexity, riparian vegetation, bank stability and human influence. This multiyear study intends to capture temporal and spatial variation in physical habitat features during a minimum period of three years between the months of May and September from 2010 through 2012. The period between the months of May and September has been identified as the index period for SWAMP bioassessment in the Central Valley. This report includes new baseline information for 2011, the second year of surveys. We have successfully completed additional physical habitat surveys during the 2012 study period. The 2012 physical habitat results will be presented in conjunction with taxonomic results in the final report of this study.

1.2.3 Benthic Macroinvertebrate Collection and Analysis

The DWR and DFG staff collected benthic macroinvertebrate samples at the designated sampling locations during the SWAMP index period of late May through the end of September in 2010, 2011 and 2012 (Figure 2). This report includes a discussion of physical habitat and taxonomic results from the first two years of the study. Taxonomic analysis of 2012 samples is currently underway. Subsamples collected at each transect in a particular site were combined in a composite sample for each location. We included 10% duplicate samples each season to serve as controls for the sampling technique. The samples were delivered to the DFG's Aquatic Bioassessment Laboratory (ABL) at Rancho Cordova, CA. At the laboratory, ABL taxonomists performed quality control and quality assurance of the samples and logged in the sample information. Samples were identified according to the Standard Taxonomic Effort (STE) Level 2 of the Southwestern Association of Freshwater Invertebrate Taxonomists (SAFIT), using a fixed-count of organisms per sample. Level 2 entailed identification down to species for the more important indicator species and genus or higher taxonomic level for other species such as some nonarthropod invertebrates.

1.3 Results

1.3.1 Reconnaissance Surveys in Reaches 1 through 5 of the Restoration Area

We surveyed a total of 90 random sampling sites throughout the Restoration Area in 2010, 2011 and 2012 (Figure 1). All of the sites were visited before each survey to ensure that they met sampling criteria set forth by SWAMP. Physical habitat characterization and BMI sample collection occurred simultaneously at a rate of one sampling reach per work-day. All of the San Joaquin river reaches, except Reach 4A, were surveyed in the 2010 study. Reach 4A samples and the rest of the Restoration Area were represented in 2011. In 2012, groundwater management experts from the Flow Scheduling subgroup of the SJRRP determined that there would be no restoration flow releases below Sack Dam. Subsequently, Reach 4A remained dry and could not be included in the last year of bioassessment surveys. In addition, flows below Reach 4B were likely dominated by backwater effects because of water management and irrigation practices in the San Luis National Wildlife Refuge (NWR) and adjacent rangeland, respectively.

Agriculture was the dominant land use in the bioassessment study area in 2010 and 2011, although wildlife area land use remained dominant in reaches B2 and 5 (Table 1).

1.3.2 Physical Habitat at Sampling Reaches

Physical habitat features and ancillary *in situ* water quality measures have been recorded in association to BMI samples. Key physical habitat parameters describe different components of instream habitat complexity, river bed substrate, bank stability, riparian vegetation and human disturbance (Table 2). We compared water chemistry parameters to the water quality criteria set forth by the Fisheries Management Workgroup (SJRRP 2010, Exhibit B) to determine if water quality at the sites reflected unsuitable conditions for BMI and Chinook salmon.

Water temperatures during the 2011 index period exceeded most of the recommended thresholds for spring-run Chinook salmon adult holding. They also exceeded optimal and critical temperature thresholds for spring-run and fall-run Chinook salmon spawners, incubating eggs and emerging fry in all of the surveyed sites, except for two sites in Reach 1A. These two sites in Reach 1A had the lowest temperatures at 14.8°C and 15.32°C. Water temperatures at surveyed sites in 2011 would allow some level of in-river fry/juvenile survival within Reach 1A, but they increased to a lethal range in all of the downstream sites.

Salinity objectives were exceeded at some of the sampling sites. The maximum specific conductivity (838µS/cm) recorded reflects exceedances of salinity objectives for the irrigation (700µS/cm from April to August) season based on the State Water Resources Control Board (SWRCB) water quality standards. In 2011, two out of four sites surveyed in Reach 4B had specific conductivity values of 740.4µS/cm and 838µS/cm. Similarly, salinity measurements were highest at these two sites. For instance, we did not record salinity values above zero at any of the sites above Mendota Pool and Dam surveyed in

2010 and 2011. However, all of the sites below Mendota Pool and Dam had non-zero salinity measurements (range 0.11-0.43ppt).

Recorded pH values did not exceed the recommended criteria for freshwater and aquatic life protection (instantaneous maximum = 6.5-9 units) in most sites. However, at least three sampling sites had pH values below the lower level of the instantaneous maximum pH objective (<6.5). These slightly acidic sites were located in Reach 1A (RM=261, pH=6.16), Reach 1B (RM=232, pH=6.41) and Reach 3 (RM=200, pH=6.46). None of the sites surveyed in 2011 exceeded the upper threshold of the pH objective.

Most other water quality constituents did not exceed the recommended habitat objectives. The mean total dissolved solids concentration (0.169 mg/L) did not exceed the SJRRP objectives during the survey period. Also, dissolved oxygen measurements were above the water quality standards for the Restoration Area (>6.0mg/L) in all surveyed sites, with only one exception. One site in Reach 4B at RM 138 had an oxygen level of 5.97mg/L. This value falls slightly below the recommended threshold for salmonid migration, spawning and rearing within the Restoration Area during the period of 1 September through 30 November.

Bed substrate and bank stability showed marked transitions throughout the study area. Cobble substrate was only present in Reach 1A and 1B in 2010 and 2011. Coarse gravel substrate was absent below Reach 2A; fine gravel substrate was sparse or absent downstream of Reach 2A. Bedrock and boulder substrates were not represented in the 2010 evaluation, but were observed in the uppermost site in Reach 1A in 2011.Sand and fines were predominant throughout the study area in 2010 and 2011. Eroded and vulnerable sandy banks were predominant at all of the study sites in Reach 2A during 2011 surveys.

We recorded flow habitats at every sampling site. Flow habitats were quantified as fast water habitats (runs and riffles) or slow water habitats (pools and glides). Slow water habitats were predominant in the Restoration Area at sites surveyed in 2011, mainly throughout Reach 1A, most of Reach 2A, 2B, 3 and 4B.

1.3.3 Benthic Macroinvertebrate Collection and Analysis

We estimated the abundance of the most important indicator taxonomic levels of arthropod and nonarthropod invertebrates present in the sample (Tables 3 through 11). Abundance was determined by weighing the total number of organisms collected within each taxa by the number of samples collected within a particular reach of the Restoration Area. Our data shows that different BMI taxa showed restricted or unrestricted distribution throughout the study area. Their distinctive distribution patterns could be associated to their intrinsic tolerance for environmental degradation (Figure 3).

Tolerance for environmental degradation in the Restoration Area was quantified by weighted average tolerance values (Figure 3A) and estimated by the percentages of sensitivity indicator taxa present at surveyed sites (Figure 3B and 3C). Pairwise comparisons of weighted average tolerance values between reaches showed that, in 2010, only reach 4B had a significantly higher presence of tolerant taxa (ANOVA F=2.6, p=0.017). In 2011, reach 4A had a significantly higher presence of tolerant taxa than the adjacent reach 3 (ANOVA F=0.99, p=0.442). When considering the spatial distribution of sensitivity indicator taxa, we noticed a gradual loss of sensitive taxa as we moved to downstream reaches throughout the Restoration Area. Only reach 1A shows an increase in the mean percentage of sensitivity indicators (Ephemeroptera, Plecoptera and Trichoptera, EPT) between years; reaches 1B, 2A, 2B, 3, 4B and 5 showed a slight decrease in the mean percentage of EPT taxa. Further analysis of % EPT taxa collected within the Restoration Area at sites surveyed in 2010 and 2011 showed that, overall, significantly less sensitivity indicators were collected on the second year of this study (T-test T=4.02, df=4.02, p=0.000).

Coleopterans, commonly known as water beetles, were mostly confined to Reach 1 in 2010 and 2011 (Table 3). In 2010, coleopterans were found in reaches 1A and 1B; they did not occur anywhere else downstream, except for one observation in Reach 3. In 2011, *Microcylloepus*, the most sensitive of the elmidid coleopteran larvae collected that year, were still confined to Reach 1B. On the other hand, we observed coleopteran larvae (i.e., *Dubiraphia*), for the first time, as far downstream as Reach 4B. In addition, we observed adult coleopterans for the first time in 2011. These adults could be identified as hydrophilid coleopterans (i.e., *Ochthebius*) occurring in reaches 2B and 3.

A large diversity of Dipterans, commonly known as true flies, occurred throughout the study area. A few taxa within the Chironomidae family dominated Reaches 2A, 2B and 3 (Table 4).

Ephemeropterans, commonly known as mayflies, include a few sensitive families (Table 5). In general, Ephemeropterans are very important in aquatic environments because of their diversity and abundance. In 2010 and 2011, two of their families, Ephemerellidae and Leptohyphidae, occurred predominantly in Reach 1A. The family Ephemerellidae has the greatest sensitivity and was only present in Reach 1A in both years. Also, *Tricorythodes* larvae from the family Leptohyphidae were the dominant Ephemeroptera in Reach 1A and its abundance decreased sharply in downstream samples in both years. None of these sensitive larvae were recovered at reaches 4A, 4B or 5 during the first two years of this study.

Hemipterans, also known as the true bugs, are considered pollution tolerant and tend to prefer warm slow water with abundant vegetation (Table 6). In 2010, corixid larvae, from the order Hemiptera, were most abundant in Reach 5. In 2011, we found a slightly lower species richness of hemipterans; however, corixid hemipterans were relatively more abundant on the second year. Nevertheless, the change in total hemipteran abundance was minimal. Total hemipteran abundance observed in 2010 and 2011 was 20.5 and 23.2, respectively. This observation coincides with the highly tolerant nature of most hemipterans collected in this study.

Lepidopterans, also known as aquatic moths, have at least one family (Pyralidae) that can have successful aquatic stages. We observed *Petrophila* larvae, belonging to the aquatic pyralid moths, only at Reach 1A in the first two years of this study (Table 7). In 2011, *Petrophila* larvae were also observed in Reach 1B for the first time. Another order was collected in 2011 for the first time. Megalopterans (Table 8), represented by corydalid larvae, were only observed in Reach 3.

Benthic larvae belonging to the order Odonata occurred throughout the study area in both years (Table 9). However, we observed a higher diversity of odonatans in 2011, compared to the previous year. In addition, they were present in all reaches upstream of Reach 4A in 2011; however, they were not recovered downstream of Reach 4A.

Different trichopteran taxa, commonly known as caddisflies, occurred throughout the study area (Table 10). The overall estimated abundance of trichopterans in the Restoration Area increased from 2010 to 2011. Specifically, the estimated relative abundance of *Glossosoma* larvae in Reach 1A increased between the two years. Glossosomatid larvae and pupae with zero tolerance for environmental stress (TV=0) occurred only in Reach 1 on both years. Sensitive caddisflies, such as *Protoptila* larvae (TV=1) were observed only in Reach 1B. Less sensitive caddisflies (e.g., *Hydroptila*) were absent below Reach 2B; and those groups with the lowest tolerance values (TV) (i.e., greatest sensitivity) occurred mostly or only in sites within Reach 1A and 1B (e.g., *Neptopsyche*).

Most non-insects can tolerate water pollution and can live in mud or even low oxygen waters (Table 11). We observed that non-insect classes were widely represented throughout the study area, with few exceptions. In particular, Oligochaeta, also known as segmented aquatic worms, can be found in silty substrate and detritus. They were among the most abundant non-insect BMI detected in this study. We observed an overall reduction in the abundance of segmented aquatic worms during the second year of Interim Flows. This reduction in abundance was notable in reach 4B (68% reduction). We know that their abundance can indicate sedimentation, which may be supporting their persistence throughout reach 4B. Likewise, other non-insect classes, such as bivalves, appear to be more abundant in Reach 3. The introduced Asian clam (*Corbicula* sp.) was most abundant in Reach 3. This reach has also supported the gastropod species *Tryonia*; they have been present only in reach 3 in 2010 and 2011.

Taxonomic observations were used to estimate a number of metrics associated to the relative abundance of different groups, their feeding mechanisms, habits and diversity. We simplified the taxonomic data into indices of biotic integrity (IBI) that measure biological condition at each site (Table 12). High IBI scores reflect good ecological conditions while low IBI scores reflect poor ecological conditions. A previous study by Rehn and others (2008) was the first to set expectations for Central Valley BMI assemblages and has been used here as a general interpretive framework for benthic samples collected within the Restoration Area. We have measured and scored five metrics for inclusion in IBI estimations for the sampling reaches: collector richness, predator richness, percent EPT taxa, percent clinger taxa and the Shannon diversity measure. Our results show that most of the study sites were in poor condition in 2011 (36.7%) and at least one site exhibited very poor biological condition (3.3%). In 2010, the only two sites with good biological condition (6.67%) were located within Reach 1A and Reach 1B; In 2011, more sites exhibited good biological condition (26.67%) (Figure 4).

We explored the potential relationship between the calculated IBIs and four multimetric scores estimated from the physical habitat data (Figure 5): the riparian human disturbance index (W1_HALL) (Kaufmann et al. 1999), the mean mid-channel canopy density, riparian vegetation complexity and instream habitat heterogeneity. The W1_HALL is a proximity-weighted sum of all types of human disturbance metrics scored at each sampling site (Figure 2). Human disturbance indicators scored at each sampling site included the following: walls/rip-rap/dams, buildings, pavement/cleared lots, road/railroads, pipes, landfill/trash, park/lawns, row crops, pasture, range, logging operations, mining activity, vegetation management, bridges/abutments and orchards/vineyards. The mean mid-channel canopy density was calculated from the densitometer readings at the center of each transect at each sampling site. Riparian vegetation complexity averages the cover estimates for three vegetation layers (upper canopy, lower canopy and ground cover) for the whole reach. Finally, instream habitat heterogeneity combines the scores for different habitat features within the channel including: filamentous algae, aquatic macrophytes, emergent vegetation, boulders, woody debris, undercut banks, overhanging vegetation, live tree roots and artificial structures. Analyses of human disturbance of riparian habitat at sites surveyed in 2010 and 2011 show a significant association between the W1_HALL index and the benthic IBI within the study area (2010: $r=0.322$, $p<0.05$; 2011: $r=0.323$, $p<0.05$) (Figure 5A). In addition, riparian vegetation complexity had a positive linear association with the benthic IBI at sites surveyed in 2011 (Figure 5C).

1.4 Discussion

Interpretation:
The BMI bioassessment study used our ability to rank sampling sites relative to a set of biological expectations and applied it to the San Joaquin River restoration monitoring. The biological condition goal was to find that at least 50% of the total target river length, as represented by the area covered in this study, was in good condition (benthic index of biotic integrity (B-IBI) = 61-80) or very good condition (B-IBI=81-100). In addition, we did not anticipate to find that any of the study sites showed a “very poor condition” (B-IBI=0-20). We also hypothesized that the community composition of BMI would vary among individual sites and reaches 1-5 because of changes in physical habitat and water chemistry.

A preliminary analysis shows that we did not meet the original expectation of finding that about half of the surveyed area would be in a “good” or “very good” condition during the second year of surveys. Although one of the study sites was found to have a “very poor” biological condition, we found improvements in the benthic macroinvertebrate communities on the second year of this study. The proportion of sites in “good condition” almost quadrupled (2010 =6.67%; 2011=26.67%); moreover, sites with “good condition” occurred, for the first time, below reaches 1A and 1B. Specifically, three new sites showed “good condition” in reaches 2A and 3. These types of improvements in benthic assemblages and food availability for fish can be anticipated as we restore and maintain San Joaquin River connectivity and provide sufficient flows throughout the Restoration Area.

As expected, the community composition of BMI varied among individual sites and reaches, presumably because of changes in physical habitat and water chemistry during the second year of bioassessment surveys. The abundance and distribution of the taxa indicate a possible response to relative environmental degradation within the reaches. For instance, the predominance of tolerant species in Reach 4A relative to Reach 3 may reflect the nature of the BMI colonizing the recently re-watered Reach 4A. Early colonizers in the Reach 4A BMI community may have a greater tolerance to survive the hydrodynamics of the reach. On the other hand, the predominance of sensitive species in Reach 1A may be a response of the BMI community to increased flow releases to this reach. Future assessments can help determine if sensitivity improvements propagate to BMI communities downstream of Reach 1A.

The 2011 distribution of tolerance values (TV) of collected coleopterans suggests very good water quality with possible slight organic pollution in Reach 1B, good water quality with some organic pollution in reaches 2B and 3 and fair water quality with fairly significant organic pollution in Reach 4B (see Hilsenhoff, 1977, 1987).

The presence of chironomid dipterans with the highest tolerance value (TV=10) generally indicate very poor water quality or severe organic pollution at a site (Hilsenhoff, 1987). In 2011, these chironomids were most abundant in reaches 3, 4A and 4B.

In contrast to true flies, mayflies (Order Ephemeroptera) were observed again mostly in Reach 1A. Presumably, the more sensitive flies do not seem to have colonized and established themselves beyond reach 4A and other downstream reaches within the Restoration Area.

The Order Megaloptera, represented by corydalid larvae, was observed for the first time in Reach 3 during the second year of this study. Members of the family Corydalidae exhibit extreme sensitivity to environmental stress (TV=0). Therefore, the presence of corydalids in the Restoration Area suggests a positive effect of Interim Flows on the benthic environment.

Dragonflies and damselflies (Order Odonata) can be fairly tolerant to environmental degradation. Nevertheless, they did not seem to thrive downstream of Reach 4A.

An increased abundance of trichopterans may signal improved habitat conditions as a result of Interim Flows. The most sensitive Trichopterans seem to be restricted to the upper San Joaquin reaches, with very few exceptions.

Among non-insect benthic macroinvertebrates, oligochaetes and bivalves occurred prominently in river reaches were physical habitat appears to be consistent with their biological requirements. Oligochaetes were most abundant in reaches 4A and 4B. The observed reduction in oligochaete occurrence within Reach 4B during the second year of this study may represent a biological effect of increased sediment mobility because of 2011 Interim Flows routed through the San Luis National Wildlife Refuge area. On the other hand, bivalves, such as freshwater and brackish water clams of the genus *Corbicula* were most abundant in Reach 3. Sand-bedded Reach 3 receives brackish water intrusion from the Delta-Mendota Canal, which may promote *Corbicula* proliferation in this section of the Restoration Area.

Applicability:
Study results can be used to inform the SJRRP of potential biological and physical habitat degradation indicators within the Restoration Area. Besides answering questions about stream habitat condition and water quality, we are able to quantify food availability for reintroduced fish, as reflected by the relative abundance of BMI taxa throughout the Restoration Area in different years.

The present study addresses two main needs that have been identified during previous efforts: increase in biomonitoring scope and identification of local food resources. Recent studies in the San Joaquin Basin recommended additional biomonitoring at more sites over a longer period of time to fully understand the effects of water quality and habitat conditions in the composition of macroinvertebrate communities in the San Joaquin River watershed (e.g., Brown and May, 2004). Moreover, studies have shown that Chinook salmon tend to feed mainly on autochthonous organisms (e.g., Esteban and Marchetti, 2004), which highlights the need to identify local food sources in the Restoration Area, rather than extrapolating results from other locations. We know that salmonid diets are correlated with both benthic and drift invertebrate abundance (Esteban and Marchetti, 2004). By combining the results of the bioassessment study with other lines of evidence (e.g., drift surveys and stomach samples of rearing Fall-run Chinook salmon), the FMWG and other fisheries biologists could gain a better understanding of the prey base and abundance (food production) within the SJRRP Restoration Area.

Our findings about biological condition within different reaches in the Restoration Area provide baseline information on benthic richness; therefore, these data were incorporated in the set of environmental attributes of the Ecosystem Diagnosis and Treatment (EDT) framework developed for the SJRRP (SJRRP 2010, 2011). The EDT framework incorporates existing information about environmental attributes such as food resource availability and stream condition within discrete segments of the San Joaquin River. As a result, results of the present study informed modeling of fish-habitat relationships with EDT.

Limitations:
Multi-annual analyses of bioassessment results require a multivariate analysis to help identify both the most sensitive biological metrics and the most influential physical habitat and water chemistry stressors in the Restoration Area. Thus, we will be able to clarify the physical or chemical variables that have the greatest impacts on biological and ecological integrity, also reflected by changes in the multimetric IBI. We anticipate completing such analyses with the addition of a third set of annual taxonomic results for

field surveys performed on the 2012 season. This final analysis could help clarify the underlying associations between the benthic IBI and other multimetric ranking of physical habitat features.

1.5 Conclusions and Recommendations

Study results in this report show the baseline conditions of BMI in the San Joaquin River Restoration Area during 2010 and 2011. Ecological integrity of instream habitat in the Restoration Area was evaluated with a benthic macroinvertebrate assessment, using an approach described by the California's Surface Water Ambient Monitoring Program (SWAMP). This study provided information about species richness and benthic community composition, response to perturbation and tolerance/intolerance to environmental conditions in the Restoration Area. In addition, the study provided baseline parameters to evaluate the impact of restoration actions.

The study was designed as a 3-year effort to ensure that we gather enough data to provide spatial-temporal baseline information for BMI communities and understand their variability in the entire Restoration Area. All proposed field surveys have been completed; future analyses can potentially show if on-going restoration actions can improve the existing biological condition within the study area. Ongoing stream restoration actions in the Central Valley should consider the restoration of biological condition and food production as reflected by existing benthic macroinvertebrate communities.

1.6 References

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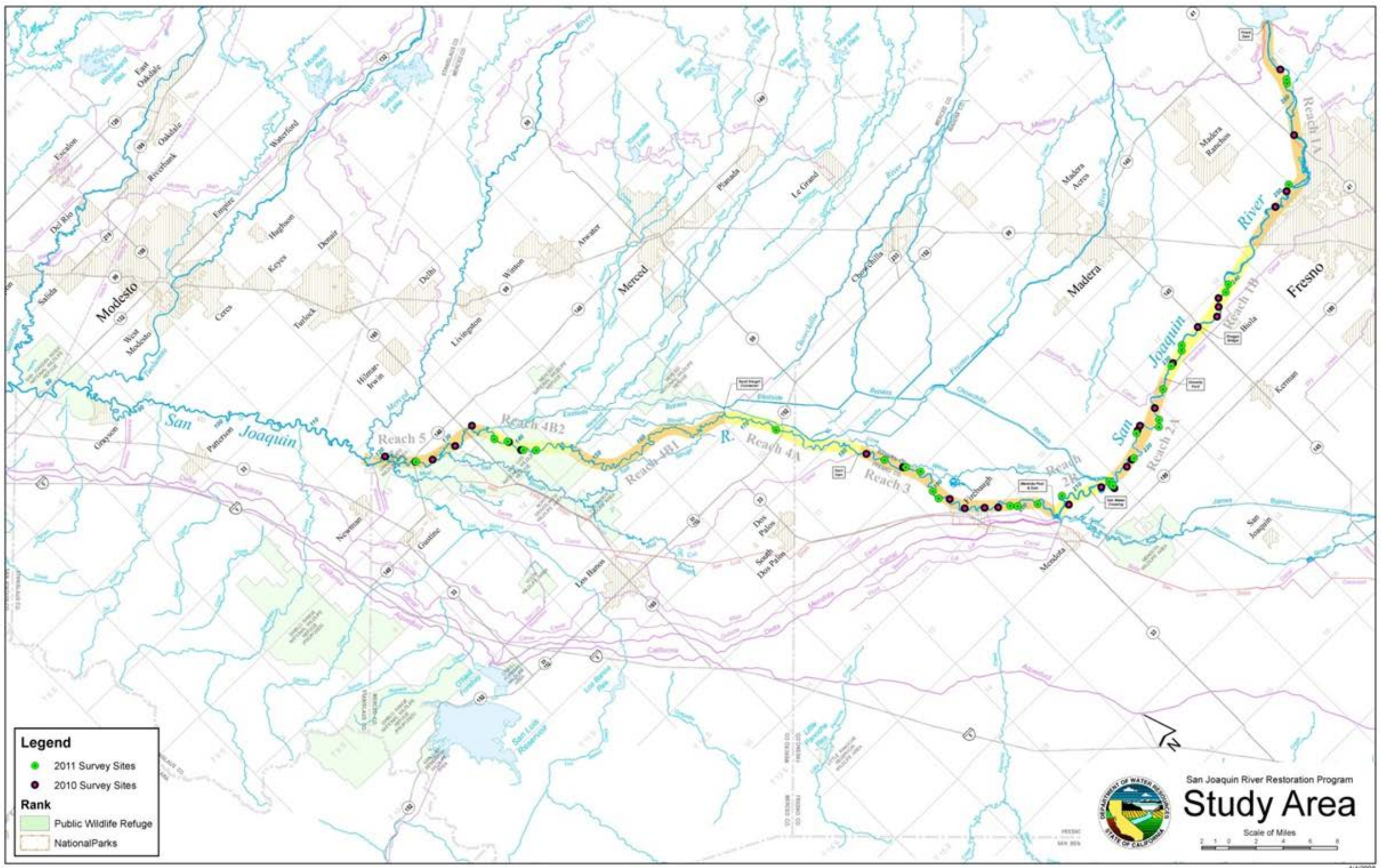


Figure 1.

Benthic Macroinvertebrate Bioassessment Sampling Sites within the San Joaquin River Restoration Area

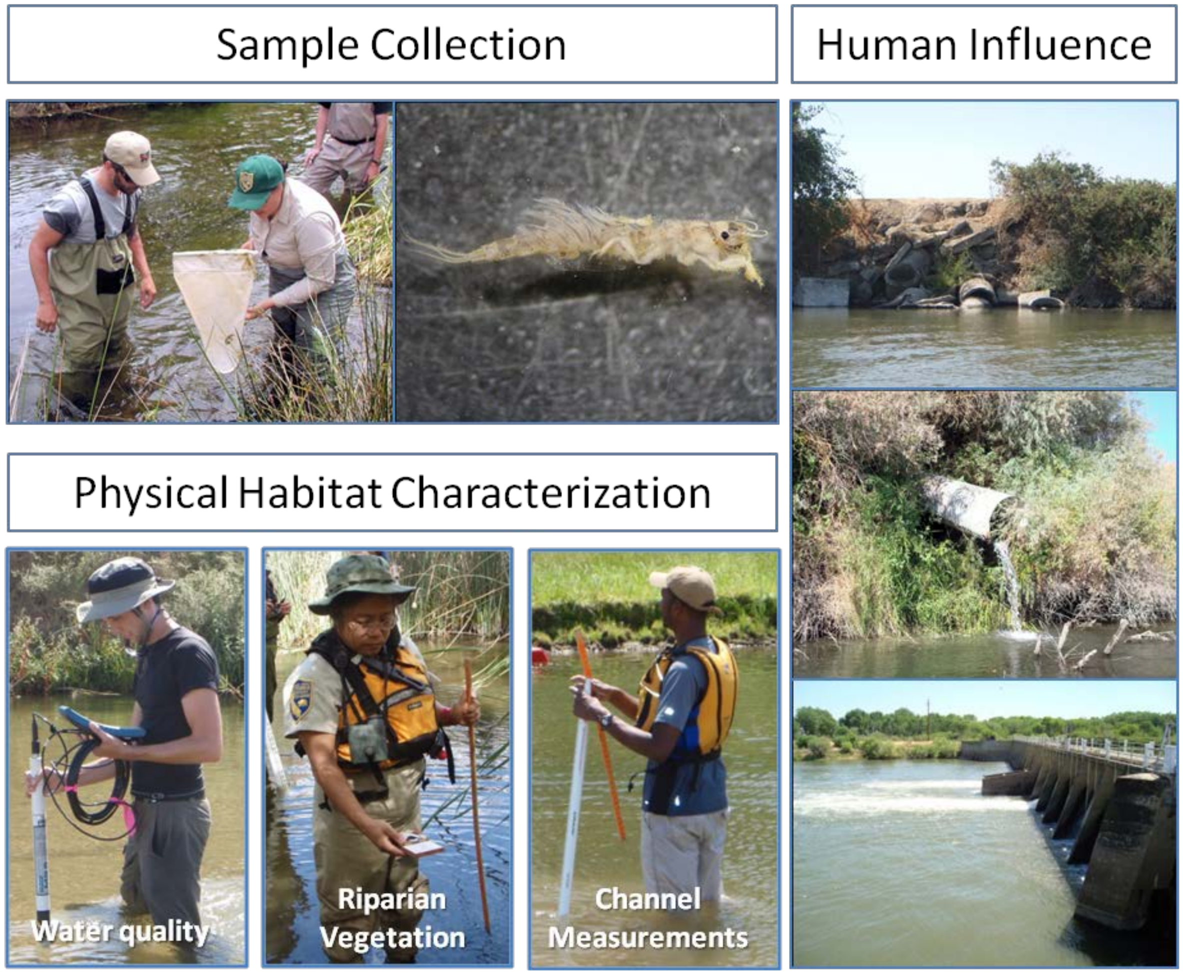


Figure 2. Physical Habitat Characterization and Benthic Macroinvertebrate Collection (2011)

Table 1. Land use predominance in the San Joaquin River Restoration Program benthic macroinvertebrate bioassessment study area (2010 and 2011)

Type of Land use	2010 Frequency of dominance; %(n)	2011 Frequency of dominance; %(n)
Agricultural land use	62.5(24)	76.67(30)
Wildlife Area/other land use	25(24)	23.33(30)
Urban/industrial land use	4.17(24)	0(30)
Rangeland land use	4.17(24)	0(30)

Table 2. Summary of physical and chemical variables associated with benthic samples collected in the San Joaquin River Restoration Area (Summer-Fall 2011)

Variable	Number of sites	Mean	Min	Max
width (m)	30	36.77	14.0	68.5
depth (cm)	30	50.59	12.59	87.91
specific conductivity (µS/cm)	28	236.2	17.3	838
salinity (ppt)	27	0.113	0	0.43
DO (mg/L)	27	8.2	5.97	12.1
pH	30	7.14	6.16	8.75
temperature (°C)	30	23.23	14.8	28.43
turbidity (NTU)	6	6.835	0	18.4
total dissolved solids (mg/L)	23	0.1691	0.0111	0.5355
% concrete	30	0.952	0	14.286
% bedrock	30	0.127	0	3.81
% boulder	30	0.159	0	4.76
% wood	30	1.304	0	5.714
% cobble	30	1.111	0	18.1
% gravel	30	12.147	0	56.19
% coarse gravel	30	9.963	0	46.67
% fine gravel	30	3.595	0	15.24
% hardpan	30	1.587	0	24.762
% sand	30	44.778	0.952	81.9
% fines	30	31.221	2.857	98.0952
% algae	30	0.349	0	8.57
mean embeddedness (quantitative = %)	4	29.56	0	44.42
qualitative embeddedness	3	52.98	21.9	100
riparian disturbance index (W1_HALL)	30	20.213	0	58.696
mean mid-channel canopy density	30	10.316	0	58.565
riparian vegetation complexity	30	1.4792	0.614	2.901
instream habitat diversity	30	5.665	0.3434	0.7778
stable bank frequency (%)	30	37.94	0	100
eroded bank frequency (%)	30	22.73	0	100
vulnerable bank frequency (%)	30	39.48	0	86.36
% fast-water habitat	30	28.25	0	88.85
% slow water habitat	30	70.033	11.5	100
% pool	30	43.978	1	91

Table 3. Abundance of Coleopterans in the San Joaquin River Restoration Area (2011)

Insecta: Coleoptera					`					**SJR Reach**							
										1A	1B	2A	2B	3	4A	4B	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit								
Arthropoda																	
	Hexapoda																
		Insecta															
			Coleoptera														
				Elmidae													
					Dubiraphia	Larvae	6	CG	CN							0.25	
					Microcylloepus	Larvae	4	CG	CN		0.8						
				Hydrophilidae													
					Ochthebius	Adults	5	SC	CN				0.25	0.111			

TV= tolerance value. This value refers to the relative tolerance of BMI to environmental disturbances, with a 0 value representing the most sensitive (intolerant) BMI and a 10 representing the most insensitive (tolerant) one.

FFG= Functional Feeding Groups. This column indicates how the BMIs obtain their food.
CG= Collector-Gatherers, CF= Collector-Filterers, P= Predators, PA=Parasites, SH= Shredders, C= Collectors, G= Scrapers or Grazers, PH= Macrophyte Piercers, OM= Organic Matter Detritivores

Habit= Mode of existence. This column refers to how the BMI utilizes the system.
CN= Clingers, SW= Swimmers, SP= Sprawlers, CB = Climbers, BU= Burrowers

Table 4. Abundance of Dipterans in the San Joaquin River Restoration Area (2011)

Insecta: Diptera												**SJR Reach**							
Phylum	Subphylum	Class	Order	Family	Subfamily	Tribe	FinalID	Life Stage	TV	FFG	Habit	1A	1B	2A	2B	3	4A	4B	5
Arthropoda																			
	Hexapoda																		
		Insecta																	
			Diptera																
				Ceratopogonidae				Larvae	6	P						0.111			
					Ceratopogoninae		*Bezzia/ Palpomyia*	Larvae	6	P	BU							0.25	
				Ceratopogonidae				Pupae	6	P	--					0.111		0.5	
					Dasyheleinae		*Dasyhelea*	Larvae	6	CG	SP			0.2				2.75	
					Ceratopogoninae		*Probezzia*	Larvae	6	P	BU						1		
				Chironomidae				Pupae	6	CG	BU	0.5		0.2		0.222		0.25	
					Chironominae														
						Chironomini		Larvae	6	CG	--					3.33		3	
						Chironomini		Pupae	6	CG	--			0.2	0.25	0.777			
							Chironomus	Larvae	10	CG	BU	0.75		0.2	0.25	3.556	2	2	
							Cladopelma	Larvae	9	CG	BU					0.111		9	
							Cladopelma	Pupae	9	CG	BU							1.75	
							Cryptochironomus	Larvae	8	P	SP	1.25	0.6		0.5	1.444		1.75	
							Cryptochironomus	Pupae	8	P	SP					0.111			
							Cryptotendipes	Larvae	6	CG	BU	0.25		0.2		0.444		0.25	
							Dicrotendipes	Larvae	8	CG	BU	3		0.2	0.25	5.778	3		
							Dicrotendipes	Pupae	8	CG	BU	0.25		0.4		0.222			
							Glyptotendipes	Larvae	10	CG	BU					0.333		45.75	7
							Harnischia	Larvae	6	CG	CN				1.5	0.556	2	0.25	
							Microchironomus	Larvae	6	CG	BU				0.25		1	1.5	
							Parachironomus	Larvae	10	P	SP					0.111	1		
							Paracladopelma	Larvae	7	CG	SP	0.25	0.2	0.2		4.889		0.25	
							Paracladopelma	Pupae	7	CG	SP					0.111			
							Phaenopsectra	Larvae	7	SC	CN	9.75				1.333			
							Polypedilum	Larvae	6	OM	CN	14.25	1.2	2.8	2.25	11.556	15	2.25	1
							Polypedilum	Pupae	6	OM	CN	1				0.888		0.5	
							Robackia demeijerei	Larvae	6	CG	BU		2.2	2.6	1.25	2.778		0.25	
							Robackia demeijerei	Pupae	6	CG	BU		0.4	2		0.111			
						Pseudochironomini	*Pseudochironomus*	Larvae	5	CG	BU	0.25							

Table 4. (Cont.) Abundance of Dipterans in the San Joaquin River Restoration Area (2011)

Insecta: Diptera												**SJR Reach**							
Phylum	Subphylum	Class	Order	Family	Subfamily	Tribe	FinalID	Life Stage	TV	FFG	Habit	1A	1B	2A	2B	3	4A	4B	5
Arthropoda	Hexapoda	Insecta	Diptera	Chironomidae	Chironominae	Tanytarsini										0.667			
							Cladotanytarsus	Larvae	7	CG	CB	4	37.8	1.2	38.75	4.222	19	1.5	
							Cladotanytarsus	Pupae	7	CG	CB	1.75	0.4	3.4	4.75	2.111		0.5	
							Micropsectra	Larvae	7	CG	CB	2.25							
							Paratanytarsus	Larvae	6	CF	CN	11.5				0.222			
							Paratanytarsus	Pupae	6	CF	CN	0.25	0.25						
							Rheotanytarsus	Larvae	6	CF	CN	27	0.2		0.25			0.25	
							Rheotanytarsus	Pupae	6	CF	CN	1		0.4	0.25				
							Stempellina	Larvae	2	CG	CB	1.5	0.2						
							Stempellina	Pupae	2	CG	CB		0.4	0.2	0.25				
							Stempellinella	Larvae	4	CF	SP	0.25							
						Tanytarsini		Larvae	6	CG	--	1.5	0.2			0.111			
						Tanytarsini		Pupae	6	CG	--	0.5	0.8	0.2	1.111			0.5	
							Tanytarsus	Larvae	6	CF	CN	29.5	5.6	1.2	3.5	0.111	1		
							Tanytarsus	Pupae	6	CF	CN	0.75	0.4	0.2	2.25	0.111			
					Diamesinae	Diamesini													
							Potthastia longimana group	Larvae	2	CG	SP	1.75							
					Orthocladiinae														
							Cricotopus	Larvae	7	CG	CN	0.75	0.2						
							Cricotopus	Larvae	7	CG	CN			0.2		0.111			
							Cricotopus	Pupae	7	CG	CN	2.25	1.2	0.4		4.667			
							Cricotopus bicinctus group	Larvae	7	CG	CN					6.111		1.25	2
							Nanocladius	Larvae	3	CG	SP	2.75	1.8	2	0	0.333	0	0.25	
							Nanocladius	Pupae	3	CG	SP	0.25		0.6					
					Orthocladiinae			Larvae	5	CG	BU	1	1		0.25	0.222			
					Orthocladiinae			Pupae	5	CG	BU	1.25				0.111			
							Orthocladius	Pupae	6	CG	SP	0.5							
							Orthocladius complex	Larvae	6	CG	--	14.5	3.6	0.6		0.222			
							Parakiefferiella	Larvae	4	CG	SP	8	3.4			0.111			
							Rheocricotopus	Pupae	6	OM	SP			0.4		0.667		0.25	
							Parakiefferiella	Pupae	4	CG	SP	0.75	0.8	0.4					
							Synorthocladius	Larvae	2	CG	--	3.5	0.8						
							Synorthocladius	Pupae	2	CG	--	3.75	1.2						
							Tvetenia	Pupae	5	CG	SP					0.111			
							Tvetenia discoloripes group	Larvae	5	CG	SP	0.25							
						Corynoneurini													
							Corynoneura	Larvae	7	CG	SP		0.2						
							Thienemanniella	Larvae	6	CG	SP	0.75	0.8			0.444			1
							Thienemanniella	Pupae	6	CG	SP					0.667			
					Tanypodinae			Larvae	7	P	BU		0.6						
					Tanypodinae			Pupae	7	P	BU	0.5	0.8			0.333			

Table 4. (Cont.) Abundance of Dipterans in the San Joaquin River Restoration Area (2011)

Insecta: Diptera												**SJR Reach**							
Phylum	Subphylum	Class	Order	Family	Subfamily	Tribe	FinalID	Life Stage	TV	FFG	Habit	1A	1B	2A	2B	3	4A	4B	5
Arthropoda	Hexapoda	Insecta	Diptera	Chironomidae	Tanypodinae	Pentaneurini													
							Ablabesmyia	Larvae	8	CG	SP	1.75	6.4	0.6	0.25	0.333			
							Ablabesmyia	Pupae	8	CG	SP		0.2						
							Meropelopia	Pupae	7	P	--			0.2	0.25				
							Pentaneura	Larvae	6	P	SP	2	0.8	2.2					
							Pentaneura	Pupae	6	P	SP	0.25				0.111			
							Thienemannimyia group	Larvae	6	P	SP	1	1.6	0.6	5.75	0.111			
						Procladiini													
							Procladius	Larvae	9	P	SP	1.5			0.75		3		
						Tanypodini													
							Tanypus	Larvae	10	P	SP						1	2.75	
				Empididae															
							Hemerodromia	Larvae	6	P	SP	0.25	0.8	0.2		0.556			
							Hemerodromia	Pupae	6	P	SP		1.8			0.111			
							Neoplasta	Larvae	6	P	SP	5.75							
				Psychodidae			*Psychoda*	Larvae	10	CG	BU							0.25	
				Simuliidae															
							Simulium	Larvae	6	CF	CN	0.25	0.2	0.2					
							Simulium	Pupae	6	CF	CN		0.2						

Table 5. Abundance of Ephemeropterans in the San Joaquin River Restoration Area (2011)

Insecta: Ephemeroptera										**SJR Reach**							
										1A	1B	2A	2B	3	4A	4B	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit								
Arthropoda																	
	Hexapoda																
		Insecta															
			Ephemeroptera														
				Baetidae													
					Acentrella	Larvae	4	CG	SW	12.75	5.8	0.2					
					Acentrella insignificans	Larvae	4	CG	SW		0.8						
					Acentrella turbida	Larvae	4	CG	SW	3.5	0.2						
				Baetidae		Larvae	4	CG	SW	1.75	4.6	0.2	0.5	0.111			
					Baetis	Larvae	5	CG	SW								
					Baetis tricaudatus	Larvae	6	CG	SW	1.25	3						
					Camelobaetidius warreni	Larvae	4	CG	SW		2.2	0.2		0.333			
					Centroptilum	Larvae	2	CG	SW	9.75	18.6	33.2	9	1.556			
					Fallceon	Larvae	4	CG	SW	1	11.2	0.8	0.25				
					Paracloeodes minutus	Larvae	4	CG	SW		0.2	0.6					
				Caenidae													
					Caenis latipennis	Larvae	7	CG	SP	0.5	0.4		1.25	1.111	1	0.75	
				Ephemerellidae													
					Serratella micheneri	Larvae	1	CG	CN	1.25							
				Heptageniidae		Larvae	4	SC	CN		0.2			0.111			
				Leptohyphidae													
					Tricorythodes	Larvae	4	CG	SP	9.75	5.25	0.6		0.556			

Table 6. Abundance of Hemipterans in the San Joaquin River Restoration Area (2011)

Insecta: Hemiptera										**SJR Reach**							
										1A	1B	2A	2B	3	4A	4B	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit								
Arthropoda																	
	Hexapoda																
		Insecta															
			Hemiptera														
				Corixidae		Larvae	8	P	SW	9.5		0		1.667		11	
					Trichocorixa calva	Adults	8	P	SW							1	

Table 7. Abundance of Lepidopterans in the San Joaquin River Restoration Area (2011)																
Insecta: Lepidoptera										**SJR Reach**						
										1A	1B	2A	2B	3	4B2	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit							
Arthropoda																
	Hexapoda															
		Insecta														
			Lepidoptera													
				Pyralidae												
					Petrophila	Larvae	5	SC	CB	0.5	0.2					

Table 8. Abundance of Megalopterans in the San Joaquin River Restoration Area (2011)

Insecta: Lepidoptera										**SJR Reach**						
										1A	1B	2A	2B	3	4B2	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit							
Arthropoda																
	Hexapoda															
		Insecta														
			Megaloptera													
				Corydalidae												
						Larvae	0	P	CN					0.111		

Table 9. Abundance of Odonatans in the San Joaquin River Restoration Area (2011)

Insecta:Odonata										**SJR Reach**							
										1A	1B	2A	2B	3	4A	4B	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit								
Arthropoda																	
	Hexapoda																
		Insecta															
			Odonata														
				Calopterygidae													
					Hetaerina americana	Larvae	6	P	CB					0.111			
				Coenagrionidae													
					Argia	Larvae	7	P	CB		0.6	0.2		0.111			
				Coenagrionidae		Larvae	9	P	CB	0.25				0.222			
				Gomphidae		Larvae	4	P	BU					0.111			
					Octogomphus specularis	Larvae	4	P	SP	0.75			0.25	1.333			
					Ophiogomphus	Larvae	4	P	BU				0.5	0.222			
					Progomphus borealis	Larvae	4	P	BU			0.4		0.111			
				Libellulidae		Larvae	9	P	SP	0.25	0.6		0.25				

Table 10. Abundance of Trichopterans in the San Joaquin River Restoration Area (2011)

Insecta:Trichoptera										**SJR Reach**							
										1A	1B	2A	2B	3	4A	4B	5
Phylum	Subphylum	Class	Order	Family	FinalID	Life Stage	TV	FFG	Habit								
Arthropoda																	
	Hexapoda																
		Insecta															
			Trichoptera														
				Glossosomatidae													
					Glossosoma	Larvae	1	SC	CN	1.25							
				Glossosomatidae		Larvae	0	SC	CN	1							
				Glossosomatidae		Pupae	0	SC	CN	1	1.6						
					Protoptila	Larvae	1	SC	CN		22.6						
				Hydropsychidae													
					Hydropsyche	Larvae	4	CF	CN	13.5	42.4	2.4		3.111			
				Hydropsychidae		Larvae	4	CF	CN					0.889		0.25	
				Hydropsychidae		Pupae	4	CF	CN			0.2					
				Hydroptilidae													
					Hydroptila	Larvae	6	PH	CN	103.75	75	22		1.111			
				Hydroptilidae		Pupae	4	PH	CB	23	4.4	0.4	0.25				
					Oxyethira	Pupae	3	PH	CB		0.4						
				Lepidostomatidae													
					Lepidostoma	Larvae	1	SH	CB	0.25							
				Leptoceridae		Larvae	4	OM	--		0.4			0.111		0.2	
				Leptoceridae		Pupae	4	OM	--		0.4						
					Nectopsyche	Larvae	3	OM	CN	17.25	10.4	4.4	1.25	0.556	1		
					Oecetis	Larvae	8	P	CN			0.2					

Table 11. Abundance of non-insect benthic macroinvertebrates in the San Joaquin River Restoration Area (2011)

Non-Insects								**SJR Reach**							
								1A	1B	2A	2B	3	4A	4B	5
Phylum	Subphylum	Class	Order	Family	FinalID	TV	FFG								
Arthropoda															
	Crustacea														
		Malacostraca													
			Amphipoda			4	CG		0.6						
				Corophiidae											
					Americorophium	4	CF					0.111			
					Americorophium spinicorne	4	CF					0.667			
				Gammaridae											
					Gammarus	6	CG					0.333			1
				Hyalellidae											
					Hyalella	8	CG	1	1	0.2		1.444		0.25	
			Decapoda												
				Palaemonidae		8	SH					0.111			4
			Isopoda			8	CG					0.111			
		Ostracoda				8	CG	9	0.6	0.4	0.5	28	1	0.75	
	Chelicerata														
		Arachnida													
			Trombidiformes			5	P							1	
				Hygrobatidae											
					Atractides	8	P		0.6						
					Hygrobates	8	P	3.75	8.8	7.2	0.25	2.111			
				Lebertiidae											
					Lebertia	8	P	23.75	32.8	15.8	10.75	2.667			
				Limnesiidae											
					Limnesia	5	P			0.2					
				Sperchontidae											
					Sperchon	8	P	4	1.6						
				Torrenticolidae											
					Torrenticola	5	P	0.25							
				Unionicolidae											
					Neumania	5	P					0.111	2		
Annelida															
	Clitellata														
		Hirudinea				10	P					0.222			
			Arhynchobdellida												
				Erpobdellidae											
					Mooreobdella microstoma	8	P		0.2						
			Rhynchobdellida												
				Glossiphoniidae											
					Helobdella	6	PA							3.25	

1

Table 11. (Cont.) Abundance of non-insect benthic macroinvertebrates in the San Joaquin River Restoration Area (2011)															
Non-Insects								**SJR Reach**							
								1A	1B	2A	2B	3	4A	4B	5
Phylum	Subphylum	Class	Order	Family	FinalID	TV	FFG								
Annelida															
		Oligochaeta				5	CG	99	5.6	0.4	4.25	23.444	146	128.5	1
Coelenterata															
		Hydrozoa													
			Hydroida												
				Hydridae											
					Hydra	5	P					0.111			
Mollusca															
		Bivalvia													
			Veneroida												
				Corbiculidae											
					Corbicula	8	CF	0.25	2.6	2	4.75	15.222	1	1	
				Sphaeriidae											
					Pisidium	8	CF	1							
Mollusca		Gastropoda													
			Basommatophora												
				Lymnaeidae											
					Lymnaea	7	SC							0.25	
				Lymnaeidae		6	SC	1.25	0.2						
				Physidae											
					Physa	8	SC	0.25	1.8	0.2		0.111		3.5	
				Planorbidae											
					Helisoma	6	SC	1							
					Menetus opercularis	6	SC			0.2		0.333			
			Hypsogastropoda												
				Cochliopidae											
					Tryonia	--	--					4.333			
Nemertea															
		Enopla													
			Hoplonemertea												
				Tetrastemmatidae											
					Prostoma	8	P	1	1.8		0.75	1.333			
Platyhelminthes															
		Turbellaria				4	P	0.5	0.2						

Table 12. Benthic Index of Biotic Integrity and component metrics for benthic macroinvertebrate sampling sites in the San Joaquin River Restoration Area (2011)

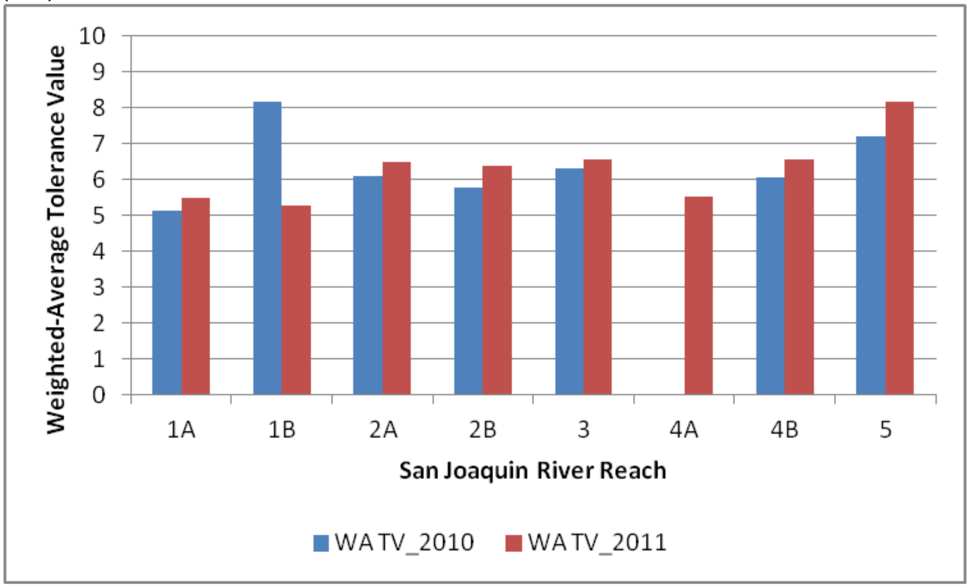
River Mile	Reach-ID	Collector richness	Predator richness	% EPT taxa	% Clinger taxa	Shannon diversity	Central Valley B-IBI (2011)	Biological condition
263	1A-124	13	6	18	40	2.14	56	Fair
261	1A-108	17	7.5	23	35.5	2.52	69	Good
251	1A-132	19	13	20	28	2.92	78	Good
239	1B-156	12	8	32	39	2.44	70	Good
238	1B-112	23	9	27	35	2.99	78	Good
232	1B-147	12	3	36	38	2.48	62	Good
231	1B-131	9	3	40	46	1.72	54	Fair
230	1B-136	3	4	27	43	1.75	38	Poor
228	2A-120	16	7	28	36	2.02	64	Good
225	2A-104	5	1	33	45	2.35	48	Fair
224	2A-159	7	2	18	25	2.03	32	Poor
222	2A-143	4	3	25	40	1.97	40	Poor
220	2A-115	8	3	23	25	2.16	42	Fair
216	2B-127	7	3.5	25	32.5	3.97	42	Fair
215	2B-152	5	4	20	12	0.84	24	Poor
208	2B-139	3	4	0	40	1.75	26	Poor
203	3-119	14	10	12	37	2.6	64	Good
201	3-135	11	7	5	15	2.53	46	Fair
200	3-162	12	4	13	29	2.24	48	Fair
192	3-107	7	6	14	44	2.36	48	Fair
191	3-151	9	3	17	36	2.58	68	Good
189	3-157	7	6	16	31	2.45	46	Fair
187	3-141	5	2	21	50	1.94	40	Poor
185	3-113	12.5	7.5	16	22.5	2.63	54	Fair
174	4A-149	8	5	12	31	1.15	30	Poor
143	4B-106	6	3	0	11	1.2	12	Very Poor
141	4B-122	7	5	6	25	1.15	24	Poor
140	4B-142	12	5	5	29	2.03	21	Poor
138	4B-126	9	2	14	9	1.59	28	Poor
126	5-130	5	0	0	50	1.77	26	Poor

EPT = Ephemeroptera, Plecoptera and Trichoptera

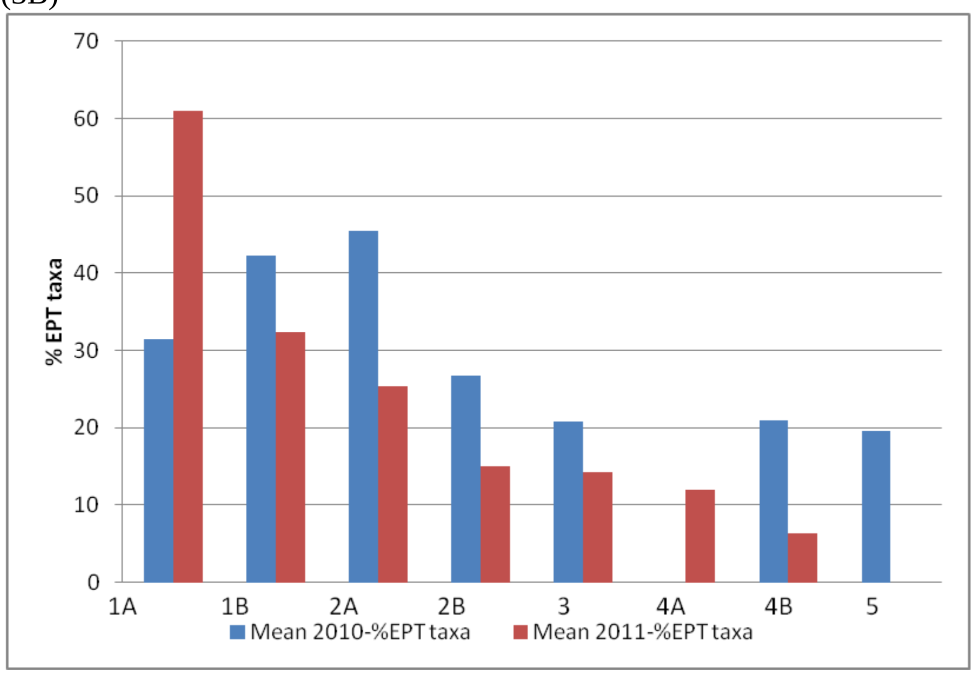
B-IBI = Benthic Index of Biotic Integrity

Figure 3. Tolerance Analysis of the San Joaquin River Restoration Area in 2010 and 2011: (A) weighted-average tolerance values by reach, (B) percentage of sensitivity indicators (Ephemeroptera, Plecoptera and Trichoptera) by reach and (C) by river mile.

(3A)



(3B)



(3C)

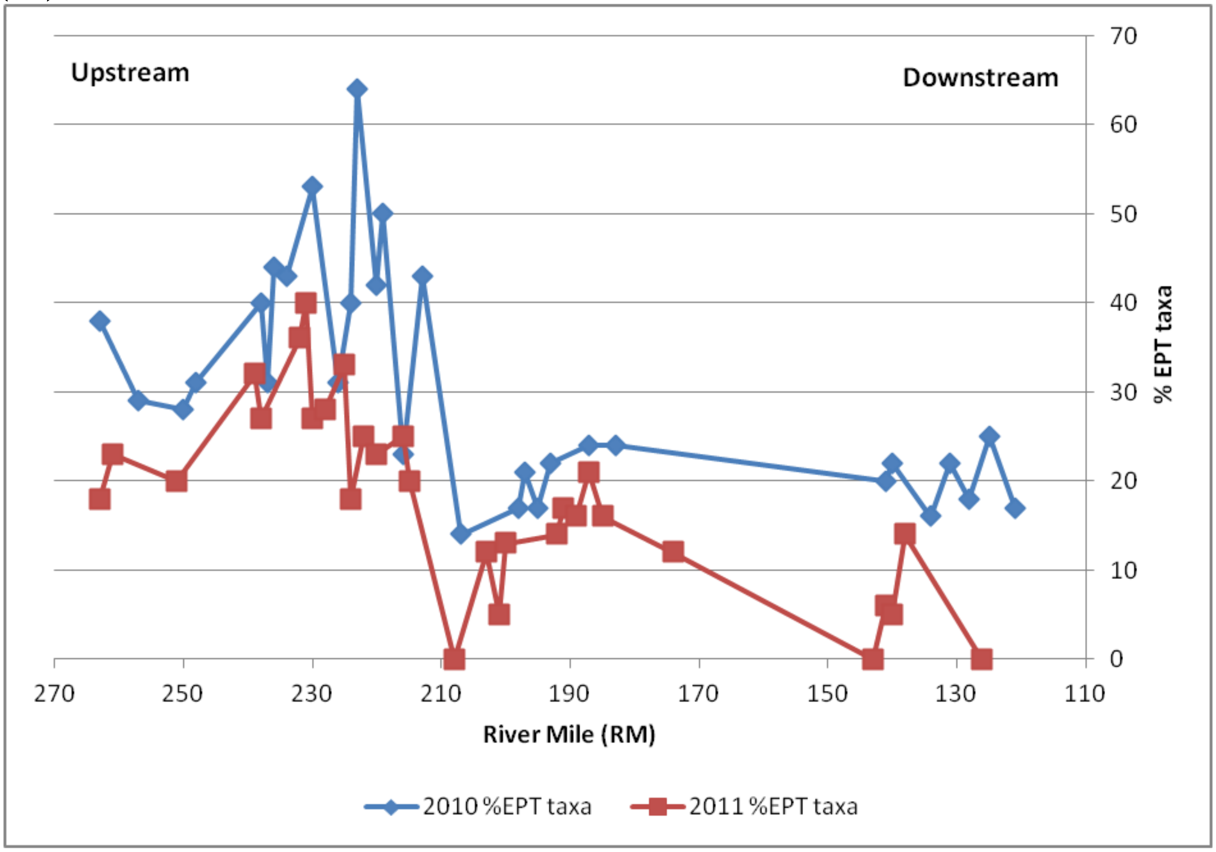
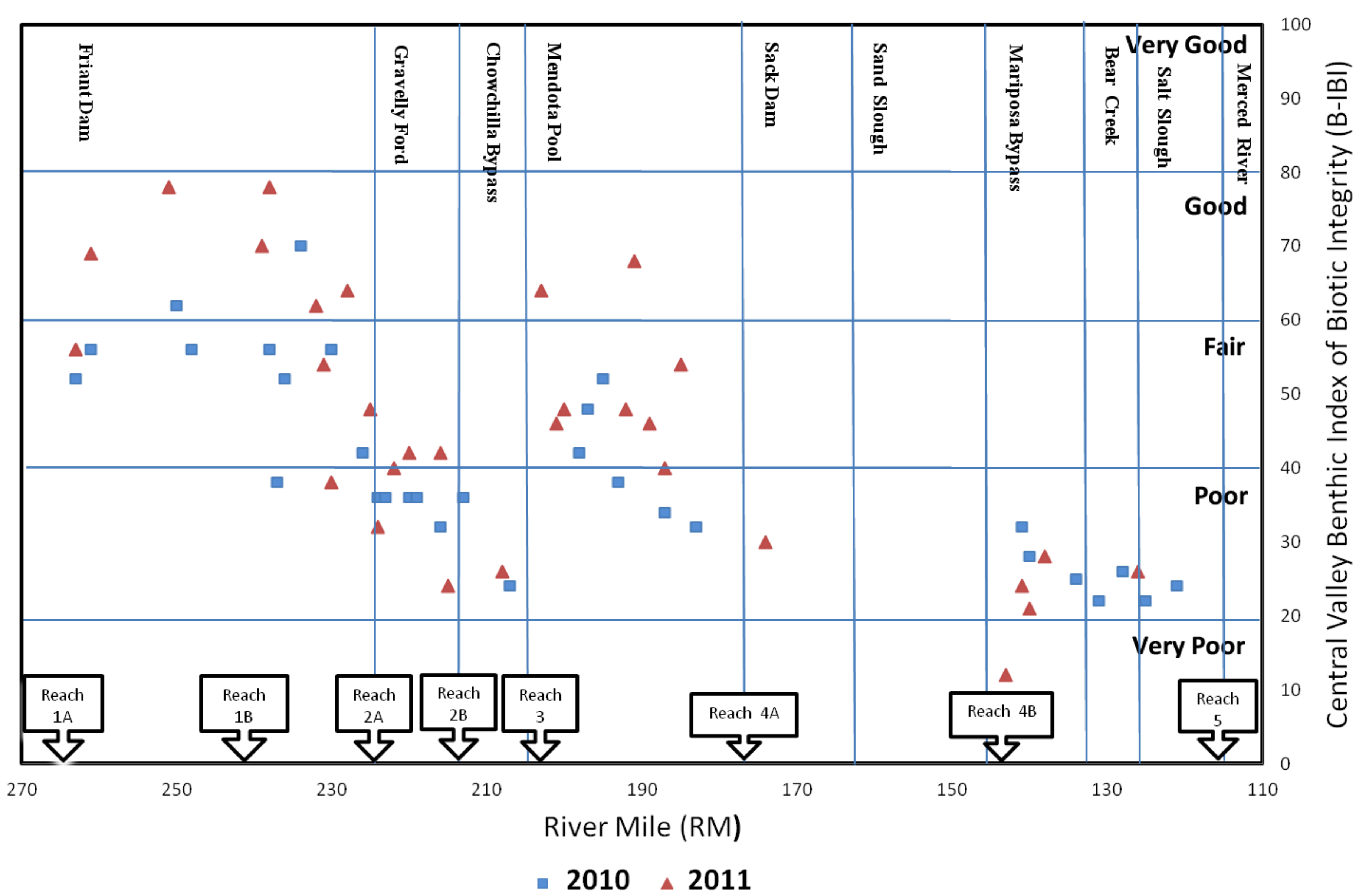

Upstream
Downstream
70
60
50
40
30
20
10
0
% EPT taxa
270
250
230
210
190
170
150
130
110
River Mile (RM)
2010 %EPT taxa
2011 %EPT taxa

Figure 4. Benthic Index of Biotic Integrity in the San Joaquin River Restoration Area



1

Figure 5. Linear association of the Central Valley benthic index of biotic integrity (B-IBI) with (a) riparian disturbance index (W1_HALL), (b) mid-channel canopy density, (c) riparian vegetation complexity and (d) instream habitat diversity.

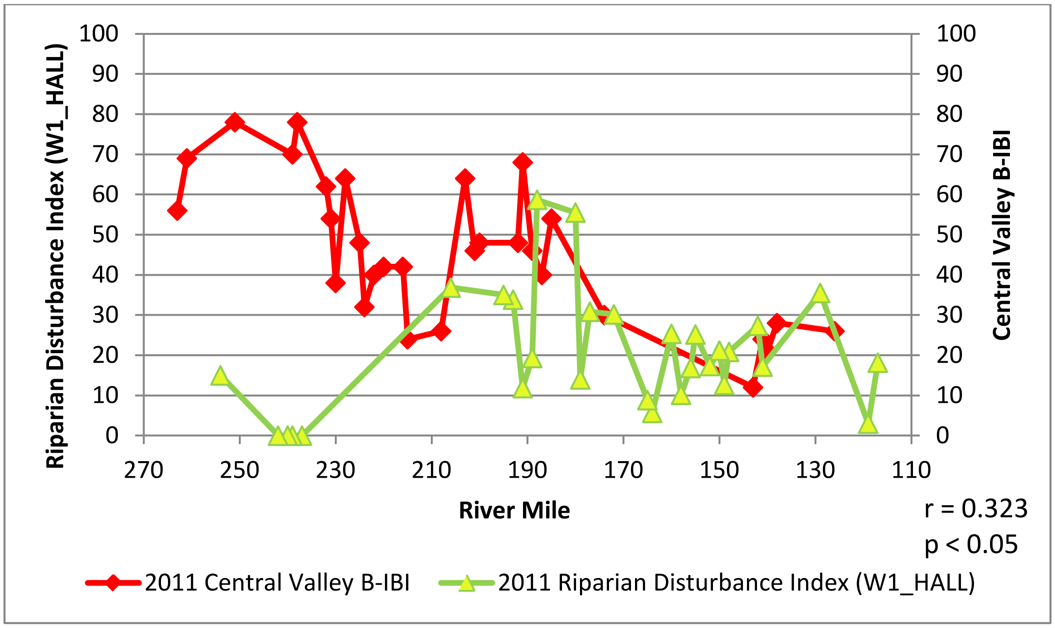


Figure 5A: Riparian Disturbance

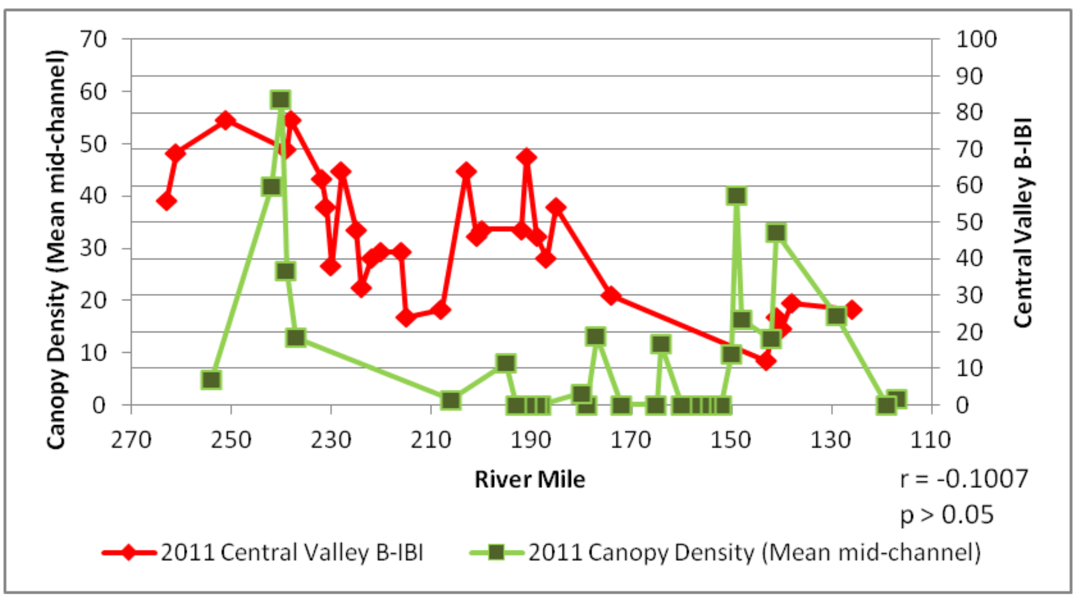


Figure 5B: Canopy Density

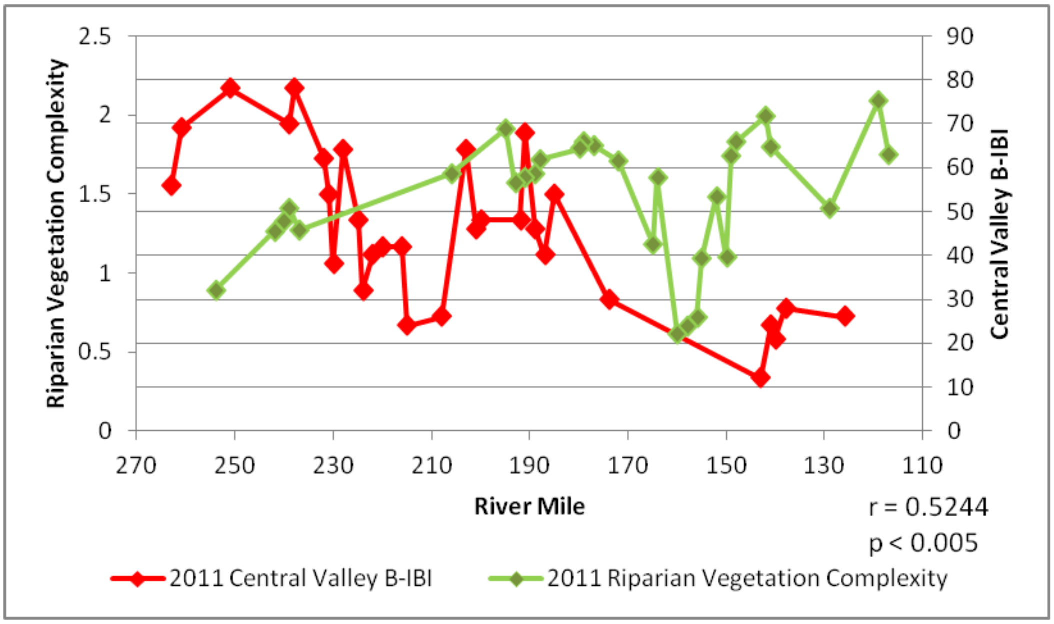


Figure 5C: Riparian Vegetation Complexity

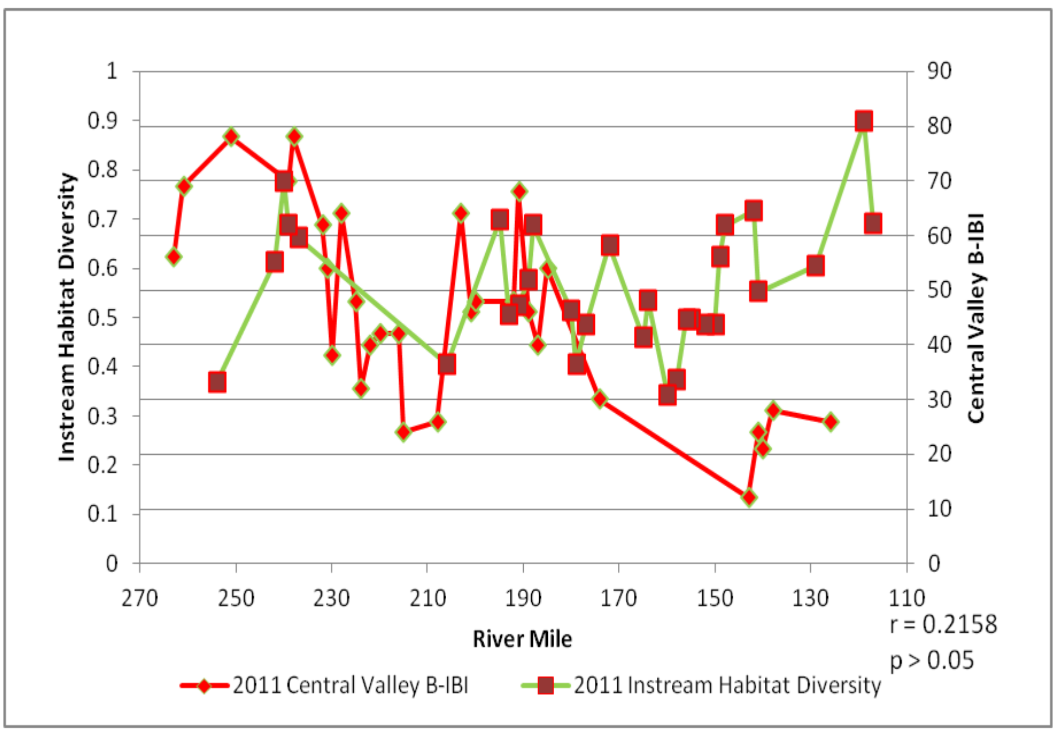


Figure 5D: Instream Habitat Diversity